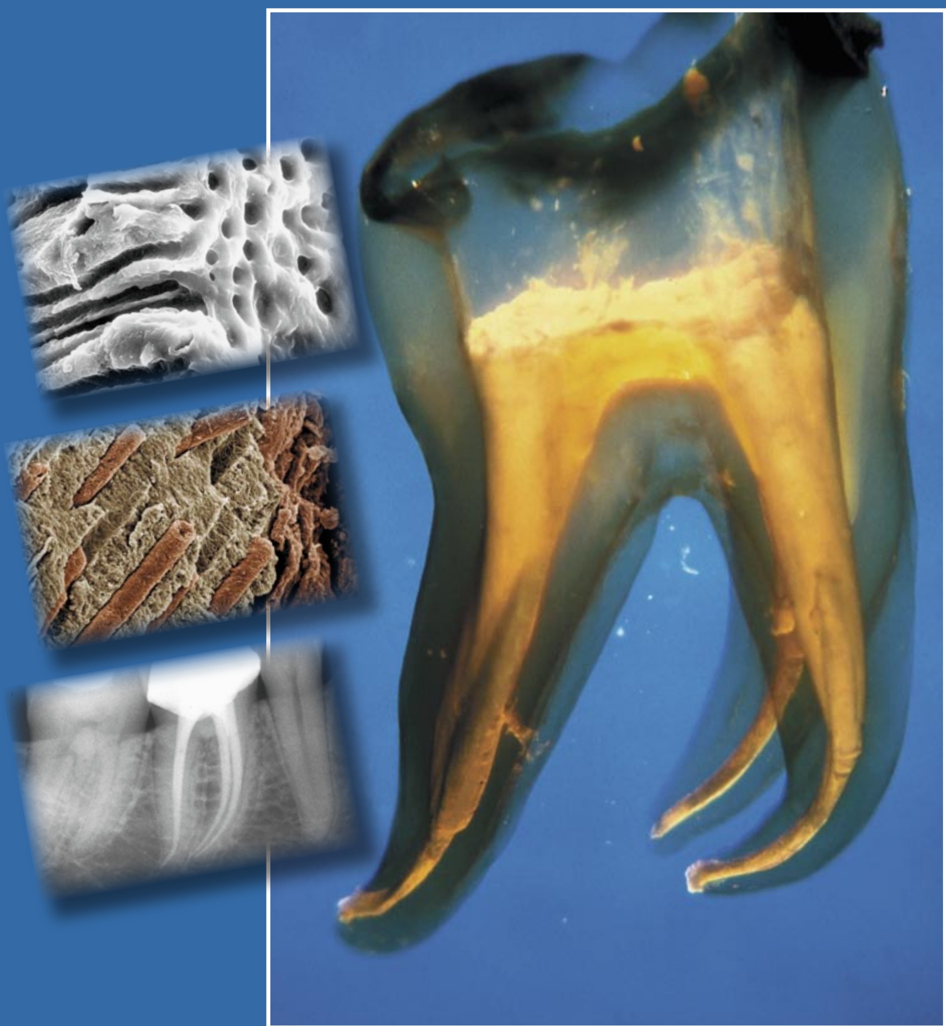
ARNALDO CASTELLUCCI MD, DDS

ENDODONTICS

VOLUME II



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Endodontic Instruments

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BRIEF HISTORY

The manufacture of the first instruments for endodontic use dates to 1875. These early instruments, which were made by hand from thin steel wires, performed more or less the function of modern barbed broaches.

In accordance with the lack of sophistication of the time, more importance was given to obturation of the canal space than to cleaning of the root canal system.[2]

With the advent of dental radiology, local anesthesia, and advances in bacteriology at the turn of the last century, a new era opened in endodontic therapy.

In 1932, G. V. Skillen[43] stated that it was necessary to curette the canal walls to remove the pulp debris. He believed that all residual tissue became degenerative and would lead to failure of canal therapy.

Skillen and his contemporaries were occupied in establishing standards for the methods of root canal cleaning, which at the time were not standardized.

Grove[23] designed "standardized instruments and gold cones". His intent was to prepare the radicular canal space according to precise norms of shape, size, and conicity.

Jasper[27] developed silver cones corresponding to the sizes of the files that were in use at that time.

In 1955, Ingle[24] was the first to express finally the need for standardization of canal instruments, which he advocated again in 1958 at the Second International Conference of Endodontics[26] in Philadelphia.

In 1961, Ingle[25] established a basic, standardized shape for endodontic instruments and a standardized endodontic technique using newly-designed obturation instruments and materials. He substituted stainless steel for carbon steel and introduced color-coded instruments that were smaller (06 and 08) and larger (110-150) than those in use at the time.

In 1965, the American Association of Endodontists adopted the terminology and nomenclature of the proposed standardized system,[1] and in June 1976 the Council on Dental Materials and Devices[12] of the American Dental Association approved the specification # 28, which established the classification norms, requisite physical properties, and procedures for investigation, sampling tests, and preparation for the distribution of root canal files and reamers.[19]

The system of standardization and agreements among the various manufacturers to observe them is therefore a fairly recent development.

STANDARDIZATION OF ENDODONTIC INSTRUMENTS

Before the standardization proposed by Ingle and the agreements among the various manufacturers, each company produced its own instruments without adhering to any pre-established criteria. The numbering of instruments from 1 to 6 was purely arbitrary, there was no uniformity governing the progression from one size to the next, and the instruments of one manufacturer rarely matched similar instruments of another maker (Tab. I).

The standardized norms provided a numbering system that indicated to hundredths of a millimeter the diameter of the tip of the instrument at the first rake angle. This diameter is termed "D_1". The diameter at the end of the cutting edge is termed "D_{16}". In all instruments, the difference of the diameters D_1 and D_{16} is always a constant 0.32 mm. This confers a consistent taper to instruments of whatever size (taper .02: the increment in diameter is 0.02 mm x each millimeter of length).

Table I

Approximate correspondence between conventional and standardized instruments

Conventional instruments	*Standardized instruments*
0	10
1	15
2	20
3	25
4	30 / 35
5	40 / 45
6	50 / 55
7	60
8	70
9	80
10	90
11	100

The correspondence of the data presented in this table are approximate, as at the time there was no A.D.A. specification dictating the morphological characteristics of the instruments; thus, files and reamers differed slightly, depending on the manufacturer (from Ingle J.I.: Transactions of the Second International Conference on Endodontics, Philadelphia, University of Pennsylvania, 1958).

The D_1/D_{16} distance is also constant (16 mm), so that the working portion of the instruments is always the same, despite the variability of the lengths of the available instruments: short (21 mm) for the molars of patients with small mouths, standard (25 mm), and long (31 mm) for the canines and any particularly long roots.

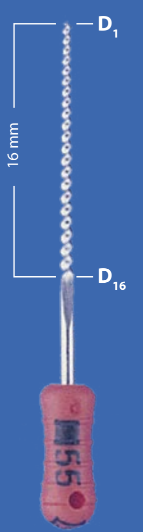
What accounts for the differences in the three lengths is the distance between the most coronal cutting flute and the handle, which represents the shaft, or non-working portion of the instrument.

In this author's opinion, it would be logical that 31 mm instruments have a proportionally longer working portion instead of a longer shaft, since they serve to cleanse a longer root canal or a longer intra canal surface.

The colors have also been standardized. They are repeated every six instruments, with the exception of the first three of the series. In accordance with this standardization, therefore, the increase in D_1 from one instrument to another is 0.02, 0.05, or 0.1 mm. From # 06 to # 10, each instrument increases by 0.02 mm; from # 10 to # 60, by 0.05 mm; and from # 60 to # 140, by 0.1 mm (Fig. 13.1).

The obturating materials were also standardized, so that the manufacturers produce gutta-percha cones and paper points whose size and taper correspond to those of the instruments.

At the 1989 Congress of the American Association of Endodontists, Schilder[38] proposed a new criterion



UNIFORM CALIBRATION

mm in D_1	0.06	0.08	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
mm in D_{16}	0.38	0.40	0.42	0.47	0.52	0.57	0.62	0.67	0.72	0.77	0.82
mm in D_1	0.55	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	
mm in D_{16}	0.87	0.92	1.02	1.12	1.22	1.32	1.42	1.52	1.62	1.72	

The number of the instrument is indicated by D_1 in hundredths of millimeters. D_{16} is always 0.32 mm greater than D_1. This assures constant taper among all the instruments.

Fig. 13.1. Instrumental diameters according to the standardized norms.

of standardization for the instruments: rather than increase by a fixed measurement (0.05 mm), he suggested they increase by a fixed percentage (29.17%) from one number to the next (Fig. 13.2). This new criterion is based on the observation that 5 hundredths of a millimeter represents a significant increase of 50% when passing from a # 10 to a # 15 or of 33% when passing from a # 15 to a # 20. In contrast, the increment is minimal or very small between a # 40 and # 45 (13%) or between a # 50 and a # 55 (10%) (Tab. II). For this reason, during the preparation of a canal one sometimes encounters difficulty in passing from a # 15 file to a # 20, while some sizes, such as # 45 or # 55, are so superfluous that they are frequently skipped. Therefore, the new standard called Profile 29 supplies a greater number of instruments in the more useful sizes (i.e., smaller calibers) and a smaller number in the less useful sizes (i.e., larger calibers), with a more gradual increase of size (Fig. 13.3).

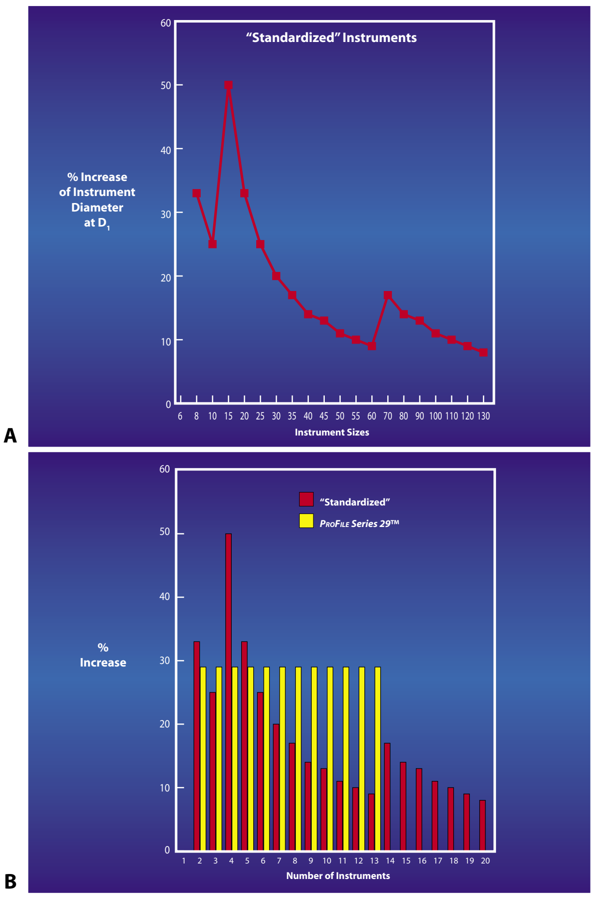


Fig. 13.2. **A**, **B**. Graphic representation of the chaotic percent incremental changes at D1 with instruments manufactured according to the current ISO specifications, compared to the constant incremental changes of Profile 29 (Courtesy of Dentsply Tulsa, Tulsa Oklahoma, USA).

Table II

Percent incremental changes among ISO instruments

Instrument #	*% Increase*
06	
08	33%
10	25%
15	50%
20	33%
25	25%
30	20%
35	17%
40	14%
45	13%
50	11%
55	10%
60	9%
70	17%
80	14%
90	13%
100	11%
110	10%
120	9%
130	8%
140	8%

In summary, the great clinical advantages that are mathematically associated with the size progression of Profile 29 are:[39]

– a smaller number of instruments in progressing from smaller sizes to larger ones (13 instead of 21)
– better distribution of instruments in the useful range, with more instruments at the beginning of the series and fewer at the end. In fact, using a percentage increase of 29.17% (K=29.17%), the 11 instruments presently available according to ISO norms between # 10 and # 60 are replaced by 8 instruments. If one considers all the instruments between 06 and 140, when K=29.17% the same range of increment in size is covered by 13 instruments rather than 21, as in the ISO standardization.

The new series is numbered 00, 0, then 1 to 11. A convenient reference for the clinician used for years to the ISO norms has been that # 1 corresponds exactly to # 10 of the old system. The new # 8 corresponds exactly to the old # 60.

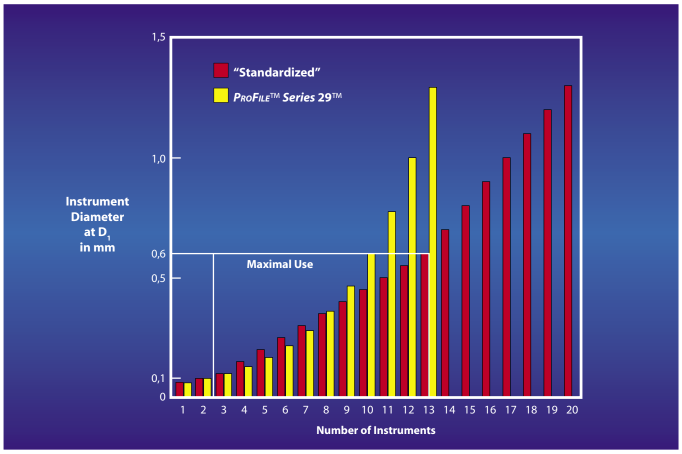


Fig. 13.3. The instruments are automatically better spaced within the useful range, with more instruments at the beginning of the series and fewer at the end (Courtesy of Dentsply Tulsa, Tulsa Oklahoma, USA).

Furthermore, if one compares the present D_1 measurements of the ISO 10-60 instruments with the same instruments of the new series, one immediately notes that the difference between the first two new instruments is 29% rather than 50%, as it is between ISO # 10 and ISO # 15 (Fig. 13.4). The difference between the second and third of the new series is again 29% rather than 33.33%, as it is between ISO # 15 and ISO # 20.

The parabolic nature (Fig. 13.5) of the increase in size in the new series is such that the first five instruments used in succession are all thinner in D_1 than the first five instruments of the present ISO system (Tab. III).

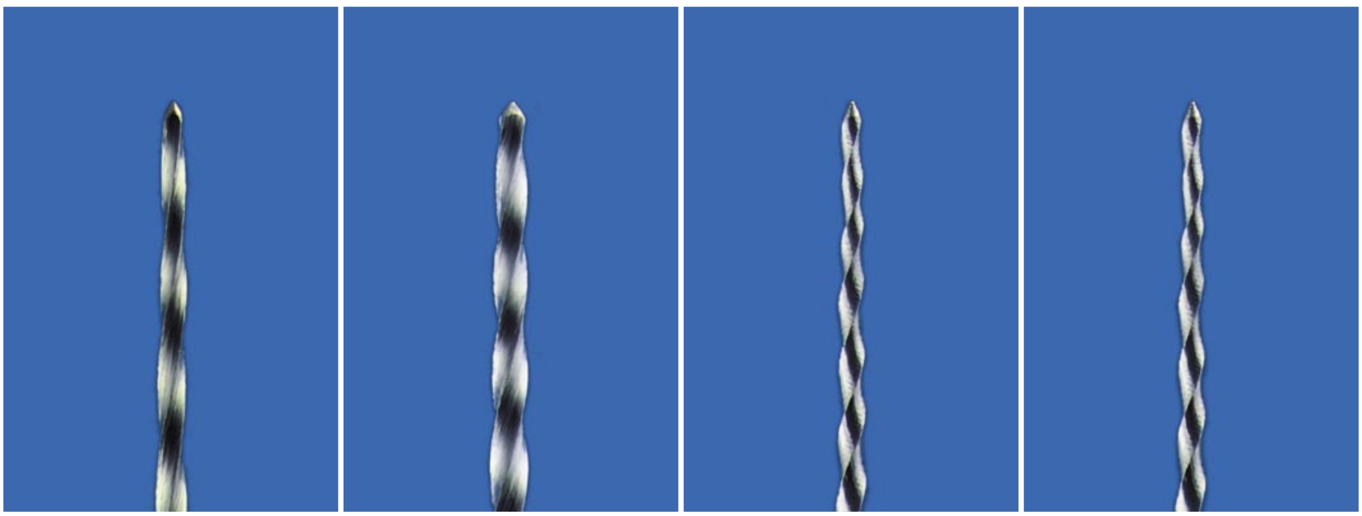
In this example, only with the sixth instrument is D_1 in the new series equal to the diameter of the sixth instrument of the ISO system (35 file), though in reality it is just slightly larger (Fig. 13.6).

Finally, only two instruments take the dentist to D_1=0.60 in the new system (# 7 and # 8), instead of the five instruments in the ISO system which were required to pass from a # 35 to # 60.

Table III

Diameter in D_1 of new instruments in thousandths of millimeters

Instrument #	*Ø - D_1*
00	0.060
0	0.077
1	0.100
2	0.129
3	0.167
4	0.216
5	0.279
6	0.360
7	0.465
8	0.600
9	0.775
10	1.000
11	1.293



A **B** **C** **D**

Fig. 13.4. **A.** # 10 file (Maillefer) (x64). **B.** # 15 file (Maillefer) (x64). **C.** # 1 file (Profile) (x64). **D.** # 2 file (Profile) (x64).

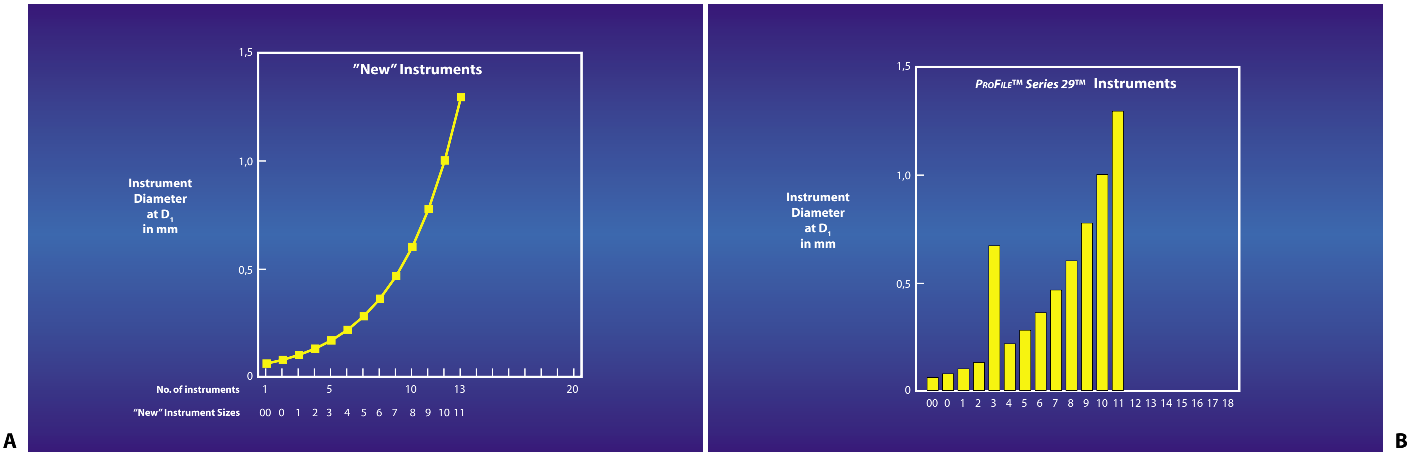


Fig. 13.5. **A**, **B**. Automatic parabolic nature of increases in size at D_1 once a constant percent has been chosen for defining D_1 increments (Courtesy of Dentsply Tulsa, Tulsa Oklahoma, USA).

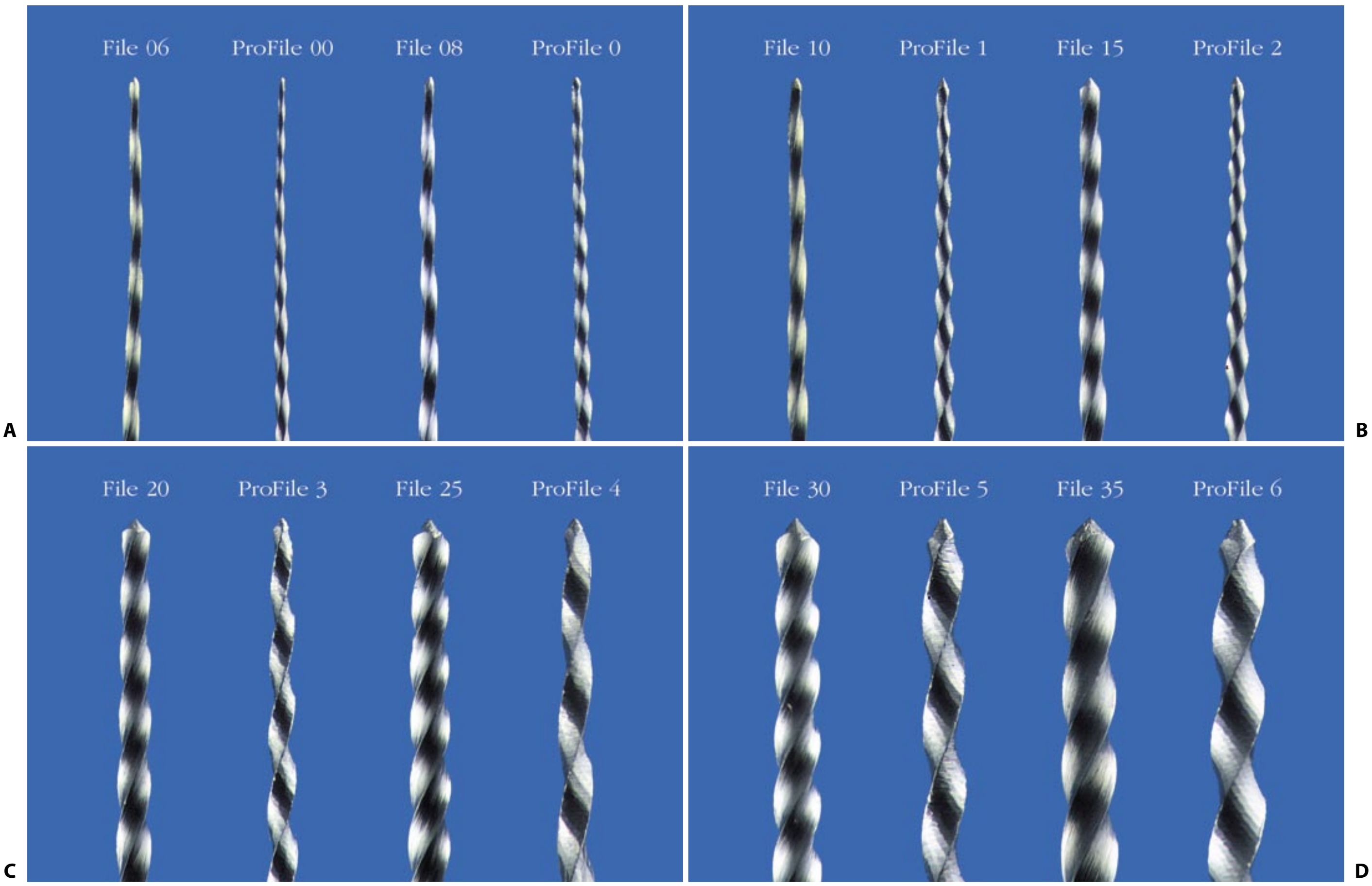
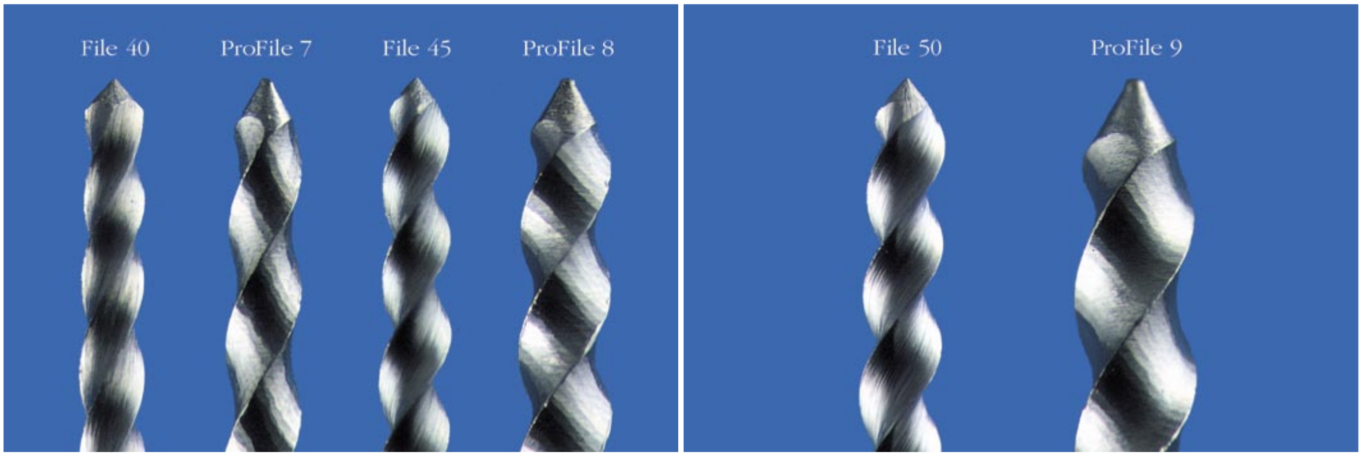


Fig. 13.6. **A**, **B**. Instruments standardized according to the ISO norms (Maillefer) compared with the new instruments (Profile) (x32). **C**, **D**. Note the different increment in size between the old and new standardizations (continued).



E F

Fig. 13.6. (Continued) **E**, **F**. Note that the ISO instruments are about the same caliber as compared to the new ones for the first three numbers (06, 08, and 10; 00, 0, and 1), larger in the next four (15, 20, 25, and 30; 2, 3, 4, and 5), about the same caliber in the next one (35; 6), and thinner in all the subsequent numbers (40, 45, 50, etc.; 7, 8, 9, etc.)

Regarding the material of which the instruments are made, carbon steel was widely used years ago. This is a mixture of pure iron or ferrite (93.31%) and iron carbide or cementite (6.69%). Today, stainless steel, a mixture of pure iron (74%), chromium (18%), which prevents corrosion, and nickel (8%), which confers elasticity to the alloy, is preferred.

The characteristics of carbon steel instruments (Fig. 13.7) are:[13]

– rigidity increases with increased size
– the larger instruments are less resistant than smaller ones to breakage by bending or twisting
– the instruments are easily corroded[18] (Fig. 13.8)
– low cost.

The characteristics of stainless steel instruments (Fig. 13.9) are:[14,19]

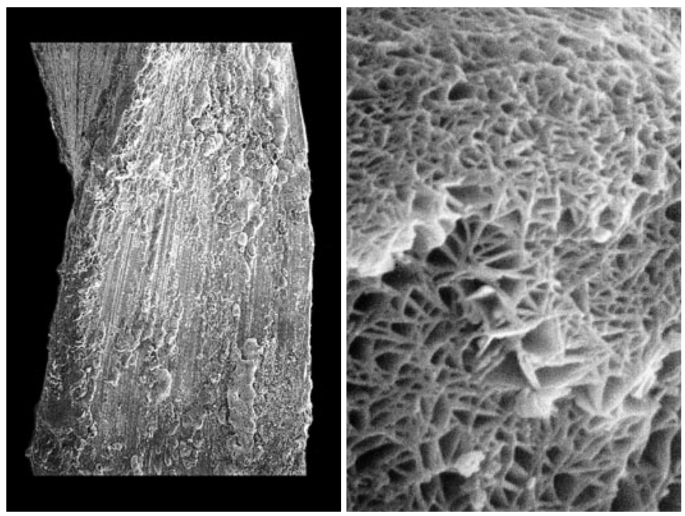
– greater flexibility than their carbon steel counterparts, which can be measured in one size instrument
– greater resistance to fracturing by twisting
– reamers are more resistant to fracturing by twisting than files.

The clinical use of stainless steel instruments therefore has more advantages over the use of carbon steel.

Today, nickel-titanium instruments are also available commercially. This is a new alloy that confers even greater flexibility to the instruments (which therefore are much more resistant to fracturing) and better capacity of shaping curved canals. The characteri-

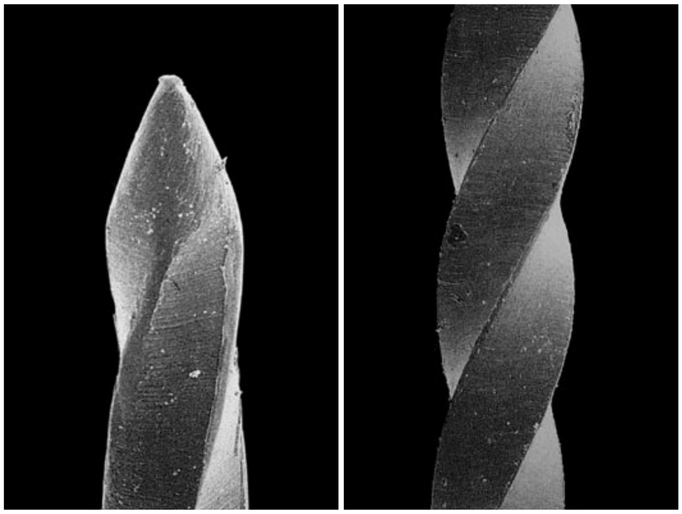
A B

Fig. 13.7. **A**. # 3 carbon steel file photographed by scanning electron microscopy (conventional, non-standardized instrument) (x30). **B**. The tip of the same instrument seen at higher magnification (x180).



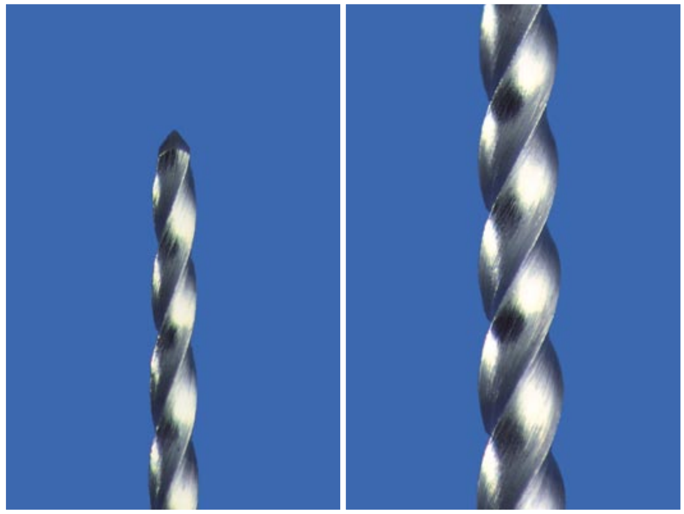
A B

Fig. 13.8. **A**. Conventional # 7 carbon steel reamer photographed by S.E.M. Macroscopically, the part in question appeared rusty (x60). **B**. The same area seen at higher magnification (x10,000).



A B

Fig. 13.9. **A.** Stainless steel # 25 file (FKG) viewed by S.E.M. (x60). **B.** The body of the same file (x60).



A B

Fig. 13.10. **A.** The tip of a # 20 file (Dentsply, Maillefer) viewed under a stereomicroscope (x64). **B.** Photograph of the body of the same file (x64).

stics of NiTi alloy for endodontic use have been extensively described in Chapter 18; here however, it is necessary to emphasize that, because of their extreme flexibility, the instruments in Nickel Titanium cannot be obtained by twisting, but only by micromachining, irrespective of the blade and cross-section design.

HAND INSTRUMENTS WITH A CONVENTIONAL .02 TAPER

1. Files

Files are the instruments most used for cleaning and shaping the root canal system. Traditionally they are manufactured from stainless steel in the form of a filament with a round cross-section and an ISO .02 Taper. They are firstly precision ground in such a way as to have a quadrangular cross-section and then twisted clock wise to achieve the definitive form.[10,11,29] The number of spirals per mm (pitch) for stainless steel files can very slightly depend on the manufacturers but is always more (generally double) than that of the reamers; their blades are furthermore positioned perpendicular to the long axis of the instrument giving files a particularly efficient cutting action during filing (Fig 13.10).[10,11,29] The first files to be marketed were the K-Files; following this, to improve the characteristics, many other instruments were introduced which can be differentiated from the traditional Files by the manufacturing alloy used (NiTi instead of stainless steel), by the design of the cross-section and the tip, by the type of handle and length of shaft. To optimize the cutting capability of the K-Files it is necessary to place the File in the canal in contact with the dentine walls and use a push and pull motion that should not range over more than 2 to 3 mm distance. When the canal is elliptical in cross-section or even circular and larger than the File width, it is obvious that the instrument cannot be in contact with the whole circumference and over the whole length at the same time. Therefore, the instrument has to be reinserted more often and placed against the various parts of the canal circumference carrying out a so called "circumferential filing" of the walls. In alternative to the filing movement the K-Files can be used by rotating them in the canal in a clockwise direction (watch-winding according to Ruddle) or by using Roane's balanced forces technique: a 90° clock-wise rotation (engaging) during insertion, followed by a 360° counter-clockwise rotation (cutting) keeping the instrument at the same depth, and the final 90° clock-wise rotation during removal of the instrument (disengaging).[10,11,29]

1.a K-Files

The K-Files, (the letter K derived from Kerr who were the first to market them) are probably the most used endodontic instruments. Marketed, with the minimum of variation, by all the endodontic manufacturing companies, K-Files are made by twisting a steel wire with a square cross-section. In cross-section a K-File has a robust quadrangular design which increases its resistance to torsion and flexion making it particularly useful in the initial negotiation of the canal; the four points of contact by the blades against the canal walls improve the tactile perception of the operator, making the K-File the ideal instrument for exploring (scouting) endodontic anatomy. The tip of the K-File is cutting and has an aggressive transition angle with the first spiral capable of causing ledging especially when using the less flexible instruments in curved canals. The K-Files produce large amounts of dentinal debris, which can block the spirals of the files making them less efficient at cutting and the push and pull action can push debris apically, causing a plug and blocking the foramen. To prevent this inconvenience, the file should principally work on withdrawal, the debris must be frequently rinsed away and their use must be alternated with frequent and abundant irrigation. The filing movement of the K-Files inside the canal must be quite gentle to prevent the instrument from being a plunger of dentin mud.[31] The K-Files are available in ISO diameters from .06 to .140 mm and lengths from 21, 25, 28, 30 and 31 mm (depending on the manufacturer).

1.b K-Flex

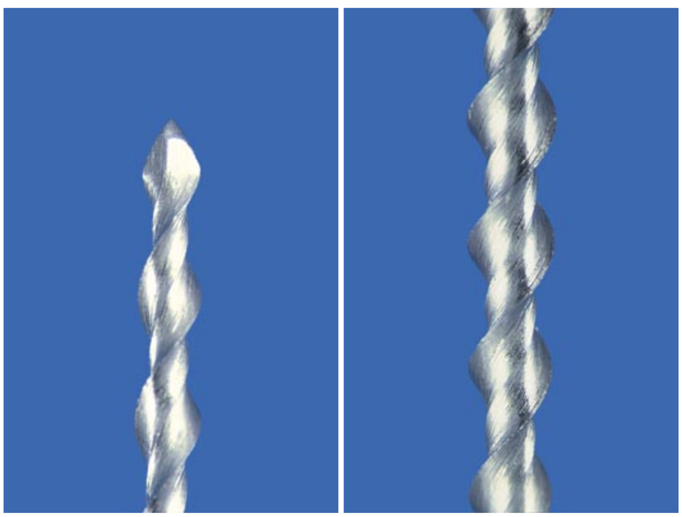
The K-Flex file (*www.kerrdental.com*) represents the first attempt to make a "hybrid" instrument, able to integrate the force and versatility of a K-File with the cutting aggression of a Hedstroem file. The K-Flex has a romboidal cross-section, which increases the flexibility of the larger diameters, alternating depths of spirals capable of removing more debris and a reduction of 37,5% of the cross section area. It is only available in stainless steel with the same diameters and lengths as K-Files[10,11,21] (Fig 13.11).

1.c K-FlexoFiles

The K-Flexofiles (*www.dentsply-maillefer.com*) are files in steel obtained by twisting a wire with a triangular cross-section and is available from a diameter of 15 (Fig. 13.12). Compared to the classic K-Files, the K-FlexoFiles differ regarding the tip and cross-section. The FlexoFiles tip is rounded and has a transitional angle that is blunted making this instrument safer during the shaping of curved canals and particularly suited for the balanced force technique.[20,32,33]

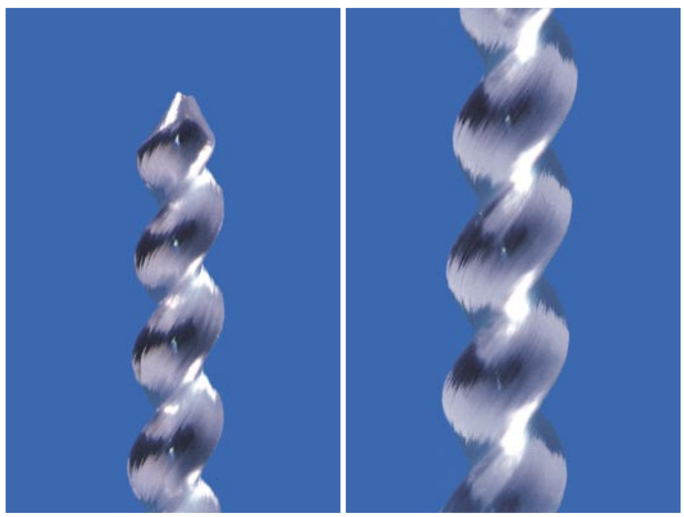
The triangular section is less bulky than K-Files, increasing the flexibility of the FlexoFiles, while the three angles of contact that the blades have with the dentinal walls reduce the friction and favour penetration in an apical direction. Furthermore, the increased space for the removal of debris (due to the triangular design in cross-section) explains why there is less tendency with respect to K-Files to build dentin mud and to cause dangerous apical plugging with debris.[31,42]

The FlexoFiles are only available in ISO diameters of 0.15 to 0.40 mm and lengths 21, 25 and 31 mm. Practically identical to the FlexoFiles are the Flexicut Files (*www.antaeos.de*). They are available in the same diameters and lengths as the FlexoFiles.



A B

Fig. 13.11. **A.** Tip of a # 70 K-Flex (Kerr) (x25). **B.** Photograph of the body of the same instrument (x25).



A B

Fig. 13.12. **A.** Tip of a # 40 K-Flexofile (Dentsply Maillefer) (x64). **B.** Photograph of the body of the same instrument (x64).

1.d K-FlexoFiles Golden Mediums

The K-FlexoFiles Golden Mediums (*www.dentsply-maillefer.com*) are identical to the K-FlexoFiles except that the diameters have intermediate values compared to those of the ISO standard.

The K-FlexoFiles Golden Mediums infact are only available in ISO diameters 12, 17, 22, 27, 32 and 37; the lengths remain those of the classic Maillefer 21, 25 and 31 mm. Their use is recommended for long and calcified or curved canals where the passage from a 10 file to a 15 file or from a 15 to a 20 may be difficult; the use of intermediate diameters enable the operator to reach the working length earlier and with less risk of complications.

1.e Unifile

The Unifile (*www.dentsply-maillefer.com*) has a cross-section in the shape of an S obtained by machining a double helix on the long axis of a round wire.[10,11] The structure of the spirals show that Unifiles are not obtained by torsion but by micromachining like the Hedstroem files; the depth of the spirals is however less than that of the H-File with consequently higher strength. The Unifiles are available in the ISO diameters from 15 to 80 and with lengths 21, 25 and 31 mm. There is also a rotary version in stainless steel, available though only with lengths 21 and 25 mm (Fig 13.13).

1f. S-File

The S-File (*www.sdidirecta.com*) is obtained by micromachining a nickel titanium wire with ISO .02 taper having a S configuration in cross-section similar to a Unifile that however differs, due to a constant angle of the spirals throughout its working length and a spiral depth which increases from the tip to the handle.[10,11] Apart from the manual version, available in the ISO diameters from 15 to 80 and lengths 21, 25 and 28 mm, there is also a rotary version only available in lengths 21 and 25 mm (Fig. 13.14).

1g. Flex-R

The Flex-R file (*www.dentnetkorea.com*), designed by Roane,[34] was developed by Moyco Union Broach®. It is characterized by a tip design that is completely modified.

According to Roane the tendency by conventional files to cause transportation of canals, ledges and perforations depends on their lack of flexibility, their cutting tip and their use with unbalanced forces.[40] Removing a section of the tip and eliminating all the cutting angles, it was possible to reduce the angle of the tip from 75° to 35° creating a type of collar that guides the penetration of the file. Furthermore the spirals of the Flex-R files are obtained by micromachining and not by torsion and varies in depth according to the size of the instrument: less depth in the smaller

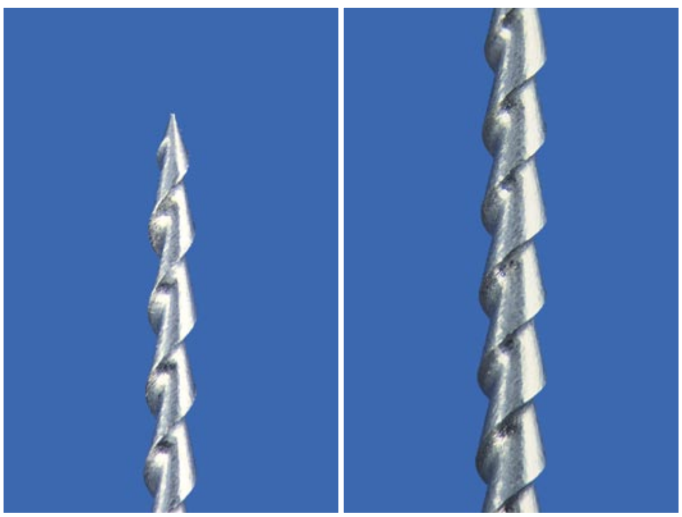


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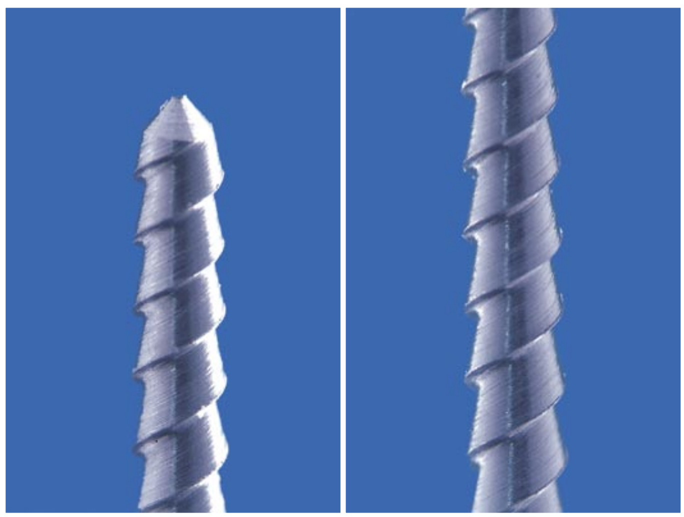
Fig. 13.13. Unifile # 5 (Ransom-Randolph). **A.** Tip (x25). **B.** Body (x25).



A B

Fig. 13.14. S-File # 40. **A.** Tip (x64). **B.** Body (x64).

sizes to give more strength and more depth in the bigger sizes to give more flexibility (Fig 13.15).

1.h Nitiflex

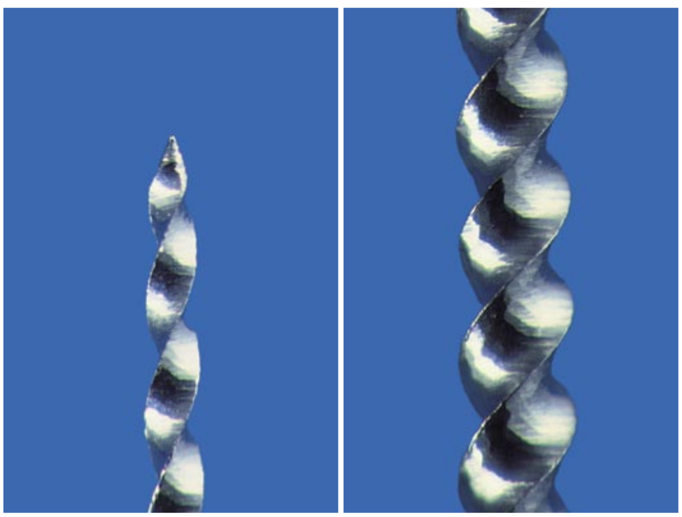
The Nitiflex (*www.dentsply-maillefer.com*) are files in nickel titanium with a rounded non-cutting tip, obtained by micromachining a round wire. The Nitiflex are available in ISO diameters 15 to 60 and lengths of 21 and 25 mm. They have a cross-section design that varies progressively with the size of the instruments with the aim of maintaining constant flexibility and torsional strength. Infact the Niti with the smaller size are more fragile, have a core design that is triangular with convex sides to increase the mass of metal and thus the torsional strength while the bigger sizes are more robust but more rigid and have a triangular design with concave sides to increase flexibility[21] (Fig. 13.16).

1.k ProFile Series 29.02 Hand Files

The ProFile Series 29.02 Hand Files (*www.tulsadental.com*) are files manufactured by micromachining a steel or nickel titanium wire with .02 taper and is characterized by a tip with a rounded transition angle that reduces the risk of creating ledges in curved canals.[20] The ProFile Series 29 does not follow the standardization of the ISO diameters, but those of the ProFile 29 devised by Schilder in 1989: their diameter at the tip does not increase in a linear and fixed way but by 29.17%, enabling the operator to have more instruments in the range of maximum utility, (from size 10 to size 40). Even the numbering of the ProFiles 29 does not follow the standard ISO system: infact they are numbered from 2 (with a tip diameter of 0.129 mm) to number 11 (with tip diameter 1.293 mm). Furthermore there are ProFile 29 Hand files in steel number 00, 0 and 1 corresponding respectively to ISO files 06, 08 and 10. It is important to emphasize once again that the term ProFile 29 does not refer to a type of instrument but to a type of standardization that can be applied to all the instruments: infact there are ProFile 29 reamers and ProFile 29 Hedstroem etc.[10,11,21]

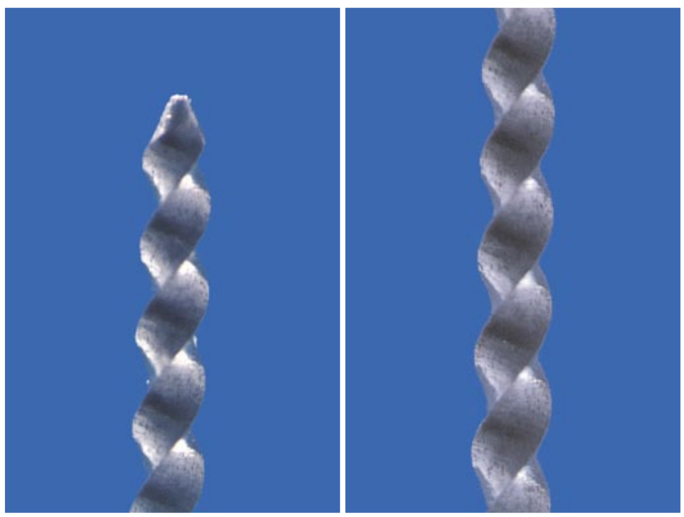
1.j C+Files

The C+Files (*www.dentsply-maillefer.com*) are files devised to facilitate the location of the canal orifices and the initial exploration of calcified canals. Available in ISO diameters 8, 10 and 15 with lengths of 18, 21 and 25 mm, the C+Files show a characteristic resistance to deformation, derived from the robust quadrangular cross-section, which allows the operator to exert 143% more pressure during insertion into a canal than would deform a K-File of corresponding size. The C+Files have depth gauge black markings along their shaft, which indicate 18, 19, 20, 22 and 24 mm from the tip, aiding the positioning of the silicone stop



A **B**

Fig. 13.15. **A.** Tip of a # 25 Flex-R (Union-Broach) (x64). **B.** Photograph of the body of the same instrument (x64).



A **B**

Fig. 13.16. **A.** Tip of a # 30 Nitiflex (Dentsply-Maillefer) (x64). **B.** Photograph of the body of the same instrument (x64).

and allowing an accurate check of the insertion depth of the instrument. Ultimately the pyramidal tip of the C+Files favours the penetration in calcified canals, while their metallic surface has been subjected to an electropolishing process, which makes them particularly smooth, thereby reducing the friction against the canal walls and the accumulation of debris in the spaces between the blades.

1.i Ergoflex

The Ergoflex K-Files (*www.fkg.ch*) are files obtained by microgrinding that are characterized by a particular flexibility, depending on the depth of the blades, by the blunted tips for security and an ergonomic handle that prevents undesired intra-canal rotation of the instruments. Available in steel and nickel titanium with ISO diameters from 8 to 70 and lengths 21 and 25 mm, the Ergoflex K-Files are particularly efficient in cutting by filing but must not be rotated in the canal as they do not have a high torsional strength (Fig. 13.17).

1.l Triple-Flex

The Triple-Flex file (*www.kerrdental.com*) is obtained by twisting a steel wire with a triangular cross-section, has a cutting tip and is characterized by high flexibility, torsional strength and debris removal capability. The Triple-Flex file is available in ISO diameters from 08 to 80 and lengths of 21, 25 and 30 mm (Fig. 13.18).

1.m Ultrasonic Files

The ultrasonic files (*www.satelec.com*) are practically K-Files without handles, which can be mounted using appropriate inserts on the ultrasonic handpiece. They are available for various ultrasonic units namely Satelec, Spartan and EMS. Until a few years ago they were recommended for root canal shaping, currently they are used to passively activate the irrigating solution before canal obturation. The use of the ultrasonic files for canal shaping is not recommended due to their tendency to make ledges in the canal walls and their structural fragility.

1.n Senseus Files

The SenseusTM, (*www.dentsply-maillefer.com*) are instruments in stainless steel characterized by a large and ergonomic silicone handle that gives the operator an increased tactile feedback and increased working comfort (Fig. 13.19). The Senseus line consists of 4 instrument categories (Fig. 13.20): FlexoFiles, FlexoReamers, Hedstroem and ProFinders. All the Senseus have calibration rings along the shank (Fig. 13.21), which are radiographically visible and ve-

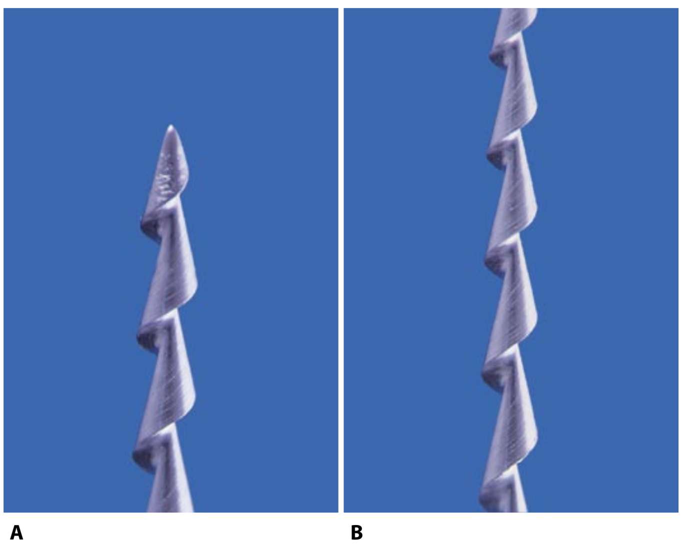


Fig. 13.17. **A.** Tip of a # 40 Ergoflex (FKG) (x64). **B.** Photograph of the body of the same instrument (x64).

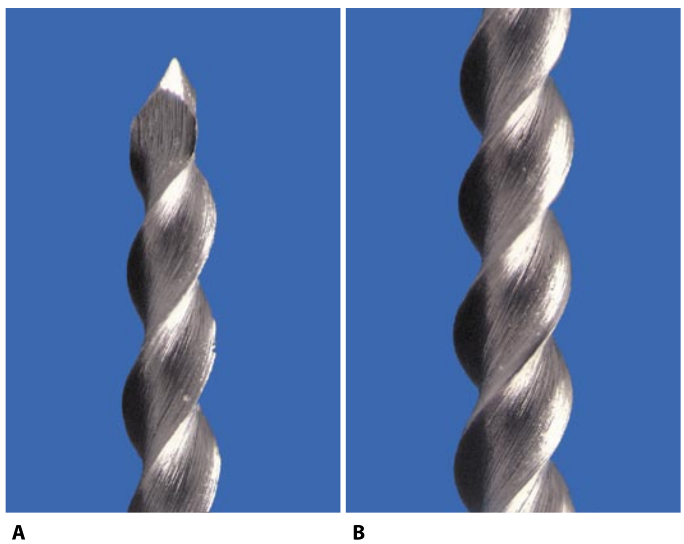


Fig. 13.18. **A.** Tip of a # 50 Triple-Flex (Kerrdental) (x64). **B.** Photograph of the body of the same instrument (x64).

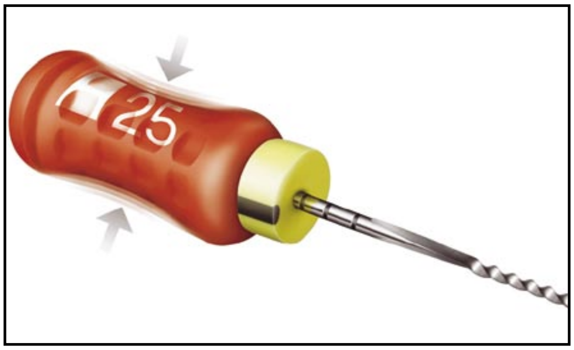


Fig. 13.19. The extra-large silicone handle gives the operator greater working comfort, improved torque and force transmission, improved tactile feedback (Courtesy of Dentsply Maillefer, Ballaigues, Switzerland).

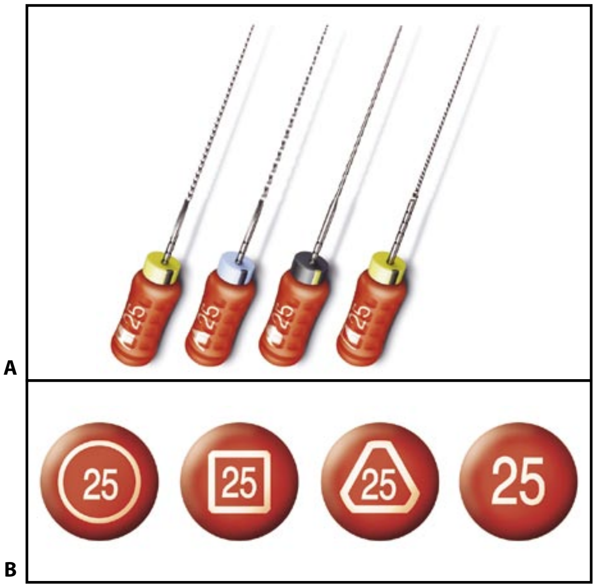


Fig. 13.20. **A**. The Senseus range. Left to right: FlexoFile, FlexoReamer, Hedstroem, ProFinder. **B**. For instrument identification, the print on top and side of the handle indicates instrument type and ISO size (Courtesy of Dentsply Maillefer, Ballaigues, Switzerland).

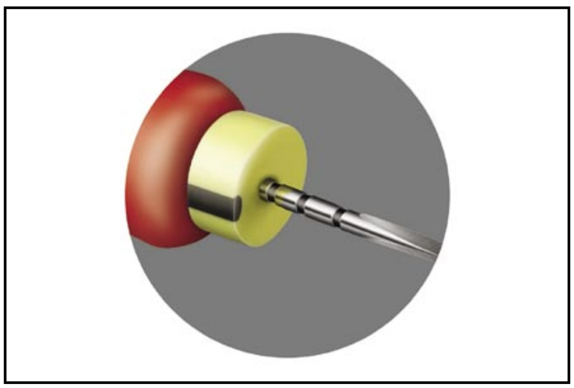


Fig. 13.21. X-Ray visible calibration rings help improve clinical performance during endodontic procedures (Courtesy of Dentsply Maillefer, Ballaigues, Switzerland).

ry useful for checking every level of canal penetration of the instruments.

The Senseus Profinders are instruments obtained by torsion of a steel wire with quadrangular cross-section (Fig. 13.22). They are for initial canal negotiation and have a decreasing taper of the blade from the tip (where it is about .02) to the shank (where it is about .01). The decreasing taper of the Senseus ProFinder and their bevelled tip of 65° favours the negotiation of narrow and calcified canals without, however, reducing the deformation strength even when subjected to relatively high pressure or torsion. The Senseus ProFinder are available in three ISO diameters (0.10 mm, 0.13 mm and 0.17 mm) and with lengths of 21 and 25 mm.

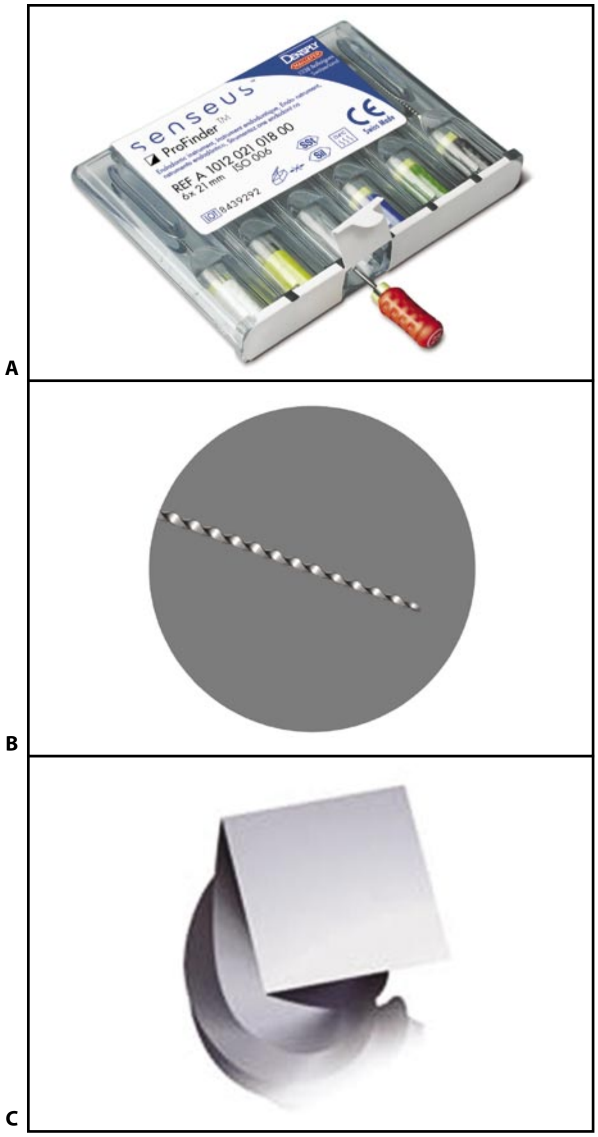


Fig. 13.22. **A**-**C**. Senseus Profinder (Courtesy of Dentsply Maillefer, Ballaigues, Switzerland).

The Senseus FlexoFiles, with the exception of the grip, have the same characteristics as the Standard FlexoFiles and like these are obtained by torsion of a steel wire with a triangular cross-section. They have a bevelled Batt type tip of 55° and are available in 3 lengths (21, 25 and 31 mm) and with ISO diameters from 06 to 140 (Fig. 13.23).

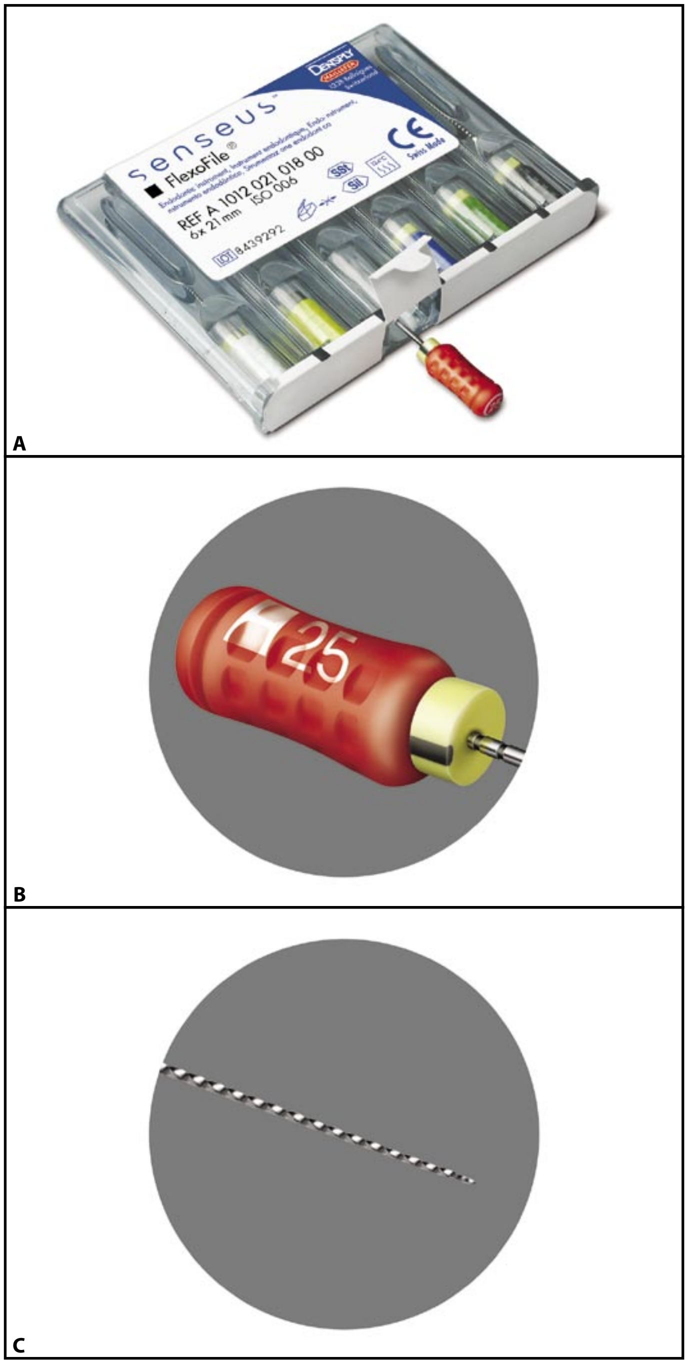


Fig. 13.23. **A-C**. Senseus FlexoFile (Courtesy of Dentsply Maillefer, Ballaigues, Switzerland).

The Senseus FlexoReamers have the same characteristics as the Standard FlexoReamers, just like these they are obtained by torsion of a triangular steel wire, they have a bevelled Batt type tip of 55° and are available in three lengths, (21, 25 and 31 mm) and with ISO diameters from 06 to 140 (Fig. 13.24).

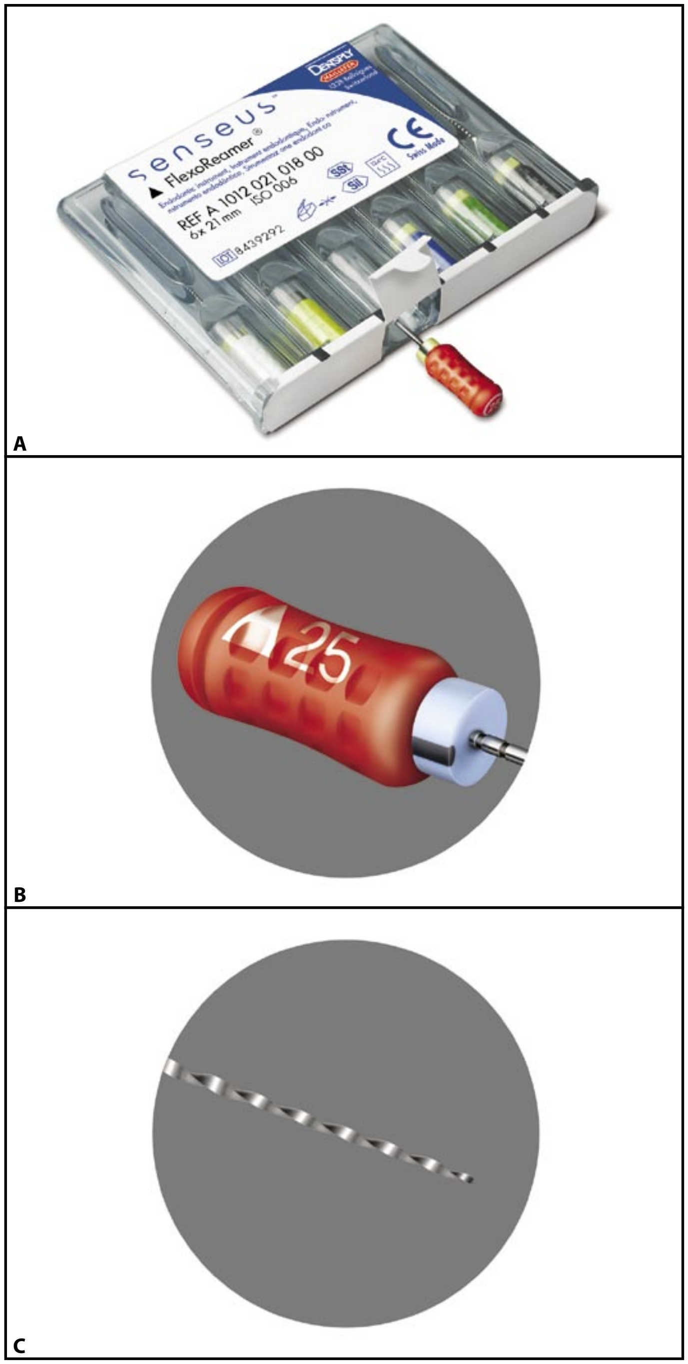


Fig. 13.24. **A-C**. Senseus FlexoReamer, (Courtesy of Dentsply Maillefer, Ballaigues, Switzerland).

The Senseus Hedstroem have blades that are identical to the corrisponding Maillefer Hedstroem Files with a round cross-section obtained by microgrinding and a cutting tip angle at 65°. Like the Standard Hedstroem Files, the Senseus Hedstroem are available in three lengths (21, 25 and 31 mm) and have ISO diameters from 06 to 140 (Fig. 13.25).

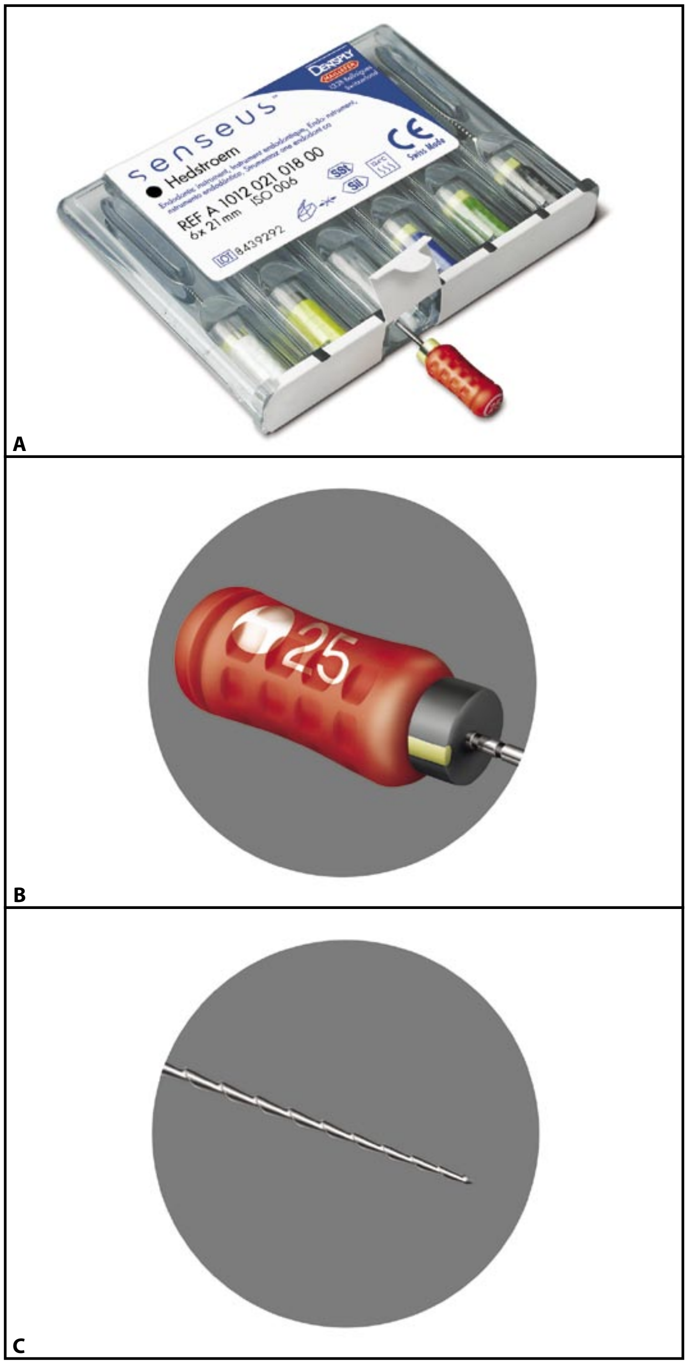


Fig. 13.25. **A**-**C**. Senseus Hedstroem (Courtesy of Dentsply Maillefer, Ballaigues, Switzerland).

2. Reamers

Reamers are generally obtained by twisting a steel wire with a triangular or quadrangular cross-section. Compared to K-Files the reamers have less spirals per mm (about half) and a more acute blade cutting angle against the dentine[10,11,29] (Fig. 13.26). The main consequence of the different blade angle of the reamers as regards the K-Files is their poor efficiency at cutting with a push and pull movement (filing); to be used correctly the reamers should be rotated in the canal so that the blades have a 90° angle contact with the dentine.[31] The correct action of these instruments is passive insertion to a depth permitted by the canal diameter and a quarter clock-wise rotation with simultaneous extraction of a few millimeters. The cutting action takes place during the withdrawal phase. This movement is repeated a number of times without ever forcing the instruments during their insertion but engaging the dentine during rotation and removal from the canal. A rotation exceeding half a turn is not advisable as it could cause engagement and fracture inside the canal.

To be certain of imparting the correct movement to the instrument one need only remember not to remove one's fingers from the handle of the instrument as would be necessary to rotate it 360° or more (Fig 13.27). The necessity for rotation in the canal contra-indicates the use of reamers for initial exploration (fracture risk) and in the preparation of curved canals (risk of lacerating the apical foramen).[20]

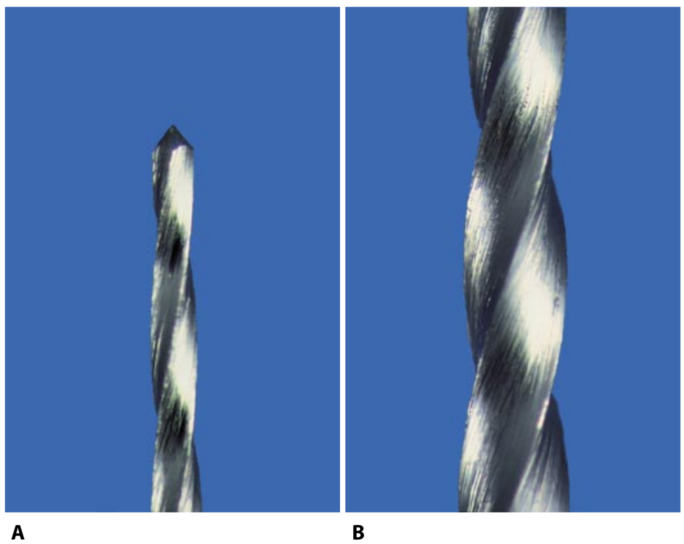
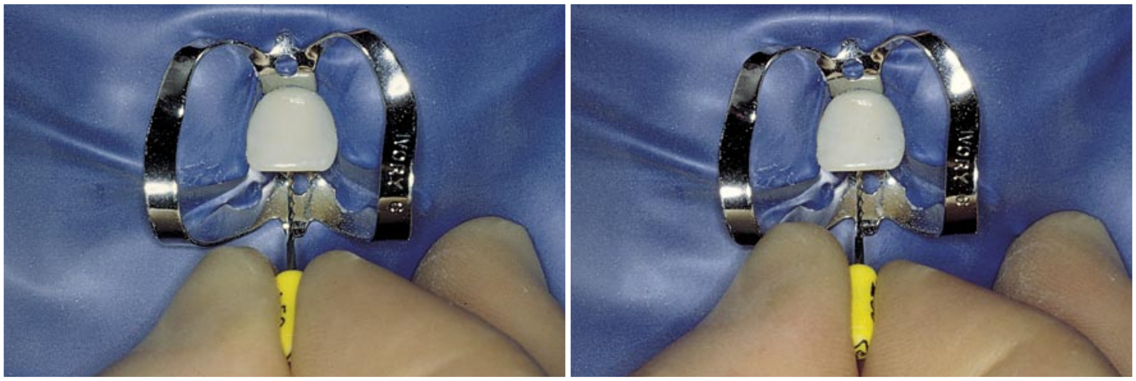


Fig. 13.26. **A**. The tip of a # 20 reamer (Dentsply Maillefer) (x64). **B**. Photograph of the body of the same reamer (x64).



A B

Fig. 13.27. **A**, **B**. Without lifting the fingertips from the handle, the instrument is rotated 90°-180°.

The Reamers, due to the reduced number of spirals and the large spaces between the blades, do not tend to accumulate debris but on the contrary, represent an optimum solution for removing the smear layer produced by the files.

Finally it should be noted that nickel titanium Reamers are also available and obviously are manufactured by micromachining.

2.a K-Reamers

The K-Reamers (*www.dentsply-maillefer.com*) are traditional reamers, only available in steel with ISO diameters from 08 to 140 and lengths 21, 25, 28 and 31 mm.

Their cross-section is quadrangular up to size 40 and triangular from size 45 to 140.

2.b K-Flexoreamers

The K-Flexoreamers (*www.dentsply-maillefer.com*) are reamers obtained by twisting a steel wire with a triangular cross-section having a pitch (number of spirals) and helical angle (cutting angles of the blades) analogous to the classic Reamers.

The triangular cross-section even in the smaller diameters gives the Flexoreamers an increased flexibility compared to the traditional reamers, while the rounded tip (identical to the Flexofiles) reduces the risk of ledging or apical transportation when preparing curved canals.[30,32]

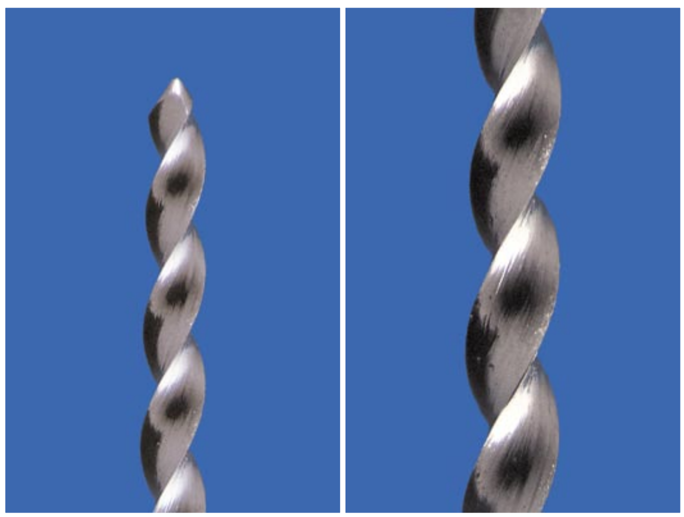
The Flexoreamers are only available in ISO diameters from 15 to 40 and lengths 21, 25 and 31 mm (Fig. 13.28).

2.c K-Flexoreamer Golden Mediums

The K-Flexoreamer Golden Mediums (*www.dentsply-maillefer.com*) are identical to the Flexoreamers except that the tip diameters have intermediate values compared to the ISO ones. The K-Flexoreamer Golden Mediums are infact available in ISO diameters 12, 17, 22, 27, 32 and 37. They are indicated for use in long and calcified canals or with curves where a more gradual increase in instrument diameter could be particularly useful.

2.d Farside

The Farside (*www.dentsply-maillefer.com*) are reamers in steel with a quadrangular cross-section parti-



A B

Fig. 13.28. **A**. Tip of a # 40 Flexoreamer (Dentsply Maillefer) (x64). **B**. Photograph of the body of the same instrument (x64).

cularly useful for the initial penetration of calcified canals or in the presence of coronal interferences. They are available in ISO diameters 06, 08, 10 and 15 with lengths from 15 to 18 mm, characterized by a particularly short shaft that increases the resistance against deformation during the initial exploration.

2.e Deepstar

The Deepstar (*www.dentsply-maillefer.com*) are reamers with a quadrangular cross-section identical to Farside as regards length and blade design, with the difference that the Deepstar are only available is ISO diameters 20 to 60. The Deepstar are indicated in retreatments to accelerate the removal of old obturating materials; their short shaft and square section allow the application of considerable pressure during insertion without deformation, while the ample space between the blades favours the elimination of debris (Fig. 13.29).

2.f ProFile Series 29.02 Reamers

The ProFile Series 29 Reamers (*www.tulsadental.com*) are obtained by microgrinding a round steel or NiTi wire. Like all the ProFile 29 instruments, this reamer follows the ProFile diameter standardization with a fixed percentage increase of 29.17%. The ProFile Series 29 Reamers are available in diameters from 2 to 9 (steel) and 2 to 11 (Nickel-Titanium).

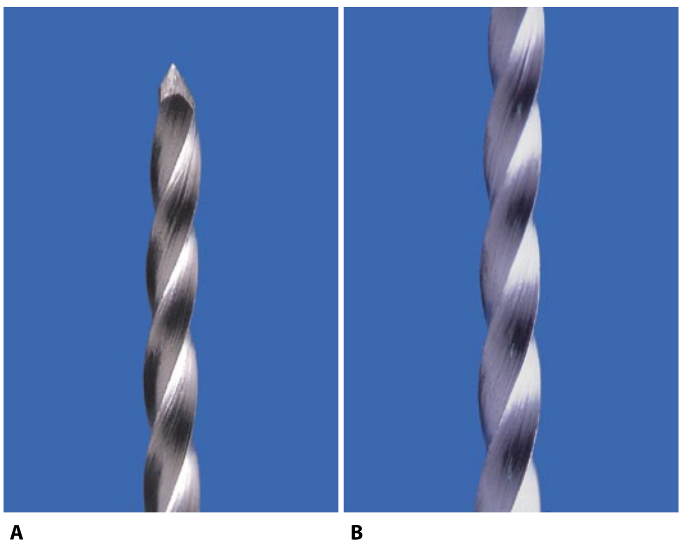
3. Hedstroem files

The Hedstroem Files or H Files are obtained by microgrinding a conical steel or NiTi wire with a round cross-section (Fig 13.30). The cutting angle of the blades (helical angle) against the dentine is, for the Hedstroem, close to 90° making this instrument particularly aggressive when using the push and pull (filing) action.[10,11,29]

The design of the blades is however also responsable for the structural weakness of the Hedstroem files, when used in a rotational manner. This is due to the fact that the deep grinding of the surface has reduced the central mass of metal which determines the torsional strength of the instument. The efficient cutting action of the H-Files seems to be superior of that of K-Files and this explains the popularity of this instrument especially for circumferential filing of canals with oval or eliptical cross-section. The Hedstroem files are distributed by most manufacturers of endodontic instruments with diameters and lengths provided by the ISO standard.

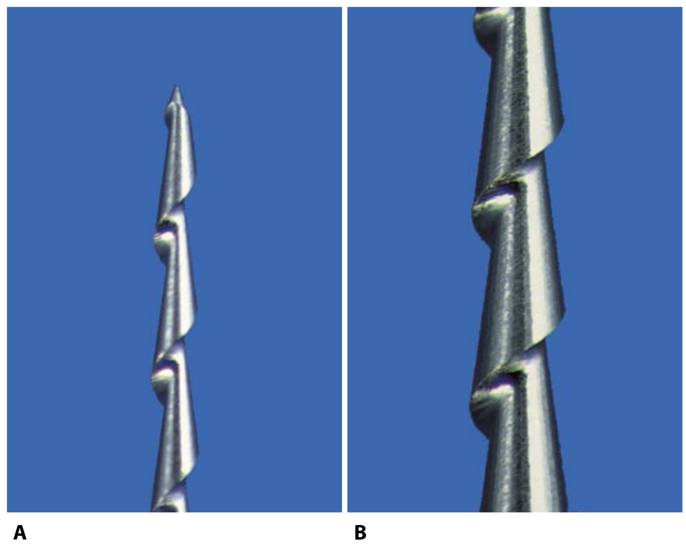
3.a Profile Series 29.02 Hedstroem

The Profile Series 29.02 Hedstroem (*www.tulsadental.com*) are obtained by machining a blank wire with round cross-section in steel or NiTi. Like all the instruments of Profile Series 29, these H-Files follow the standardization of the Profile diameters with increments



A **B**

Fig. 13.29. **A.** Tip of a # 40 Deepstar (Dentsply Maillefer) (x64). **B.** Photograph of the body of the same instrument (x64).



A **B**

Fig. 13.30. A # 20 Hedstroem file (Dentsply Maillefer). **A**. Tip (x64). **B**. Body (x64).

fixed at 29.17%. The Profile Series 29 Hedstroem are available with diameters from 2 to 9 (steel) and 2 to 11 (Nichel-Titanium).

3.b Ergoflex H-Files

The Ergofles H-Files (or Flextroem) (*www.fkg.ch*) are Hedstroem files that are characterized by a particular flexibility that depends on the depth of the machining of the shaft, the rounded tip for safety and an ergonomic grip that prevents undesired rotation of the instrument inside the canal. Available in steel and NiTi, in ISO diameters of 8 to 50 with lengths 21 to 25; the Ergoflex prove to be very efficient when cutting by filing but must not be rotated in the canal because they are not very resistant to rotational loading (Fig 13.31).

3.c Micro-Debriders

The Micro-Debriders (*www.dentsply-maillefer.com*) are Hedstroem Files with a taper of .02 characterized by a short shaft bent at and angle of 200° and a long grip in plastic (Fig. 13.32). It is ideal for working under the microscope without interference of the fingers in the operative field. They can also be useful for teeth with difficult access such as some upper and lower molars or in patients with limited opening. The Micro-Debriders are to be used only with a circumferential filing movement and are availabe in ISO diameters 20 and 30. The MC Instruments (*www.vdw-dental.com*) are almost identical to the Micro-Debriders but are available in diameters 08 to 30.

4. Barbed broach

The Barbed Broaches are for removing the pulpal tissue en masse from the inside of the root canal. They are machined from a conical blank filament in steel creating numerous hooks as part of a blade which is at 45° along the shaft and rotated on itself (Fig. 13.33). In this way the flutes cut and raise a proper spiral of broaches along its length which, created at the expense of the instruments original diameter, are the points of weakness.

The Broaches have an elevated capability of engaging the pulp tissue (Fig. 14.4) and at the same time of fracturing (Fig. 13.34). If the instrument engages

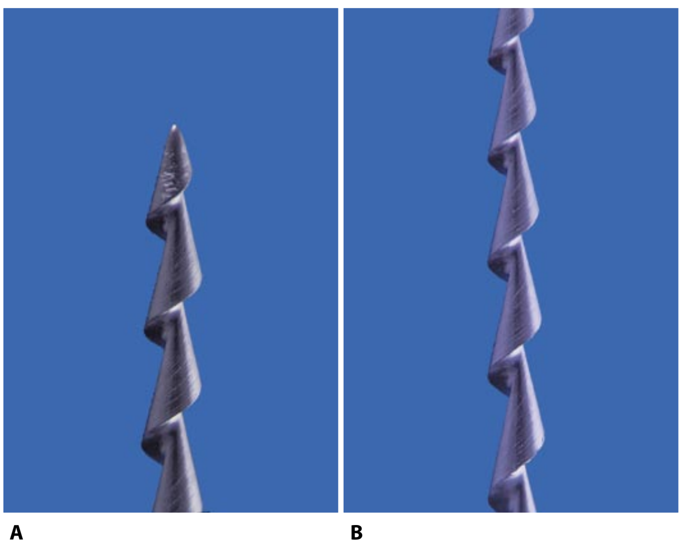


Fig. 13.31. A # 20 Ergoflex H file (FKG). **A.** Tip (x64). **B.** Body (x64).

Fig. 13.32. Micro-Debriders (Dentsply Maillefer).

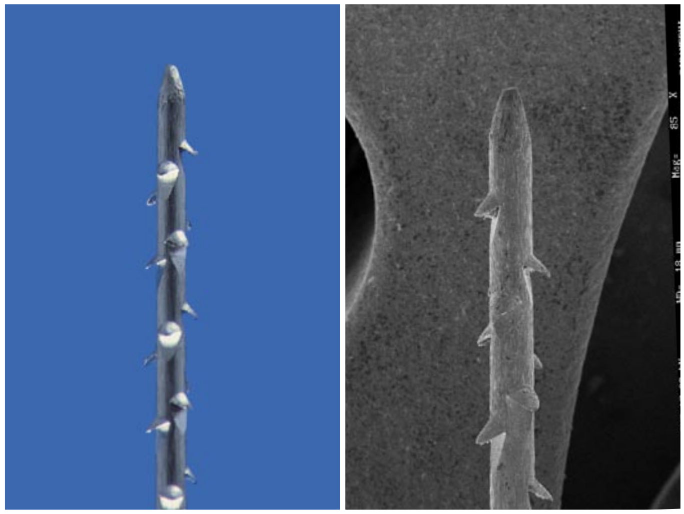
the canal wall and is rotated in an attempt to hook the pulp as a rule fracture occurs.

Excessively deep placement of the instrument can cause the hooks to bend in towards the shaft of the instrument. On withdrawl the broaches engage the dentine and bend outwards in which case fracture usually occurs of the instrument.

For this reason Barbed Broaches are considered disposable to be used only once and should be used with the utmost caution and where there is a true indication: large and straight canals. They must not be placed deeper that two thirds of the canal length and rotated 180° and extracted without dentinal wall contact.

There are different sizes: fine to extra large, from 21 to 28 mm in length and it is best to have a large assortment in the practice. Depending on the case, the most suitable size broach should be selected: too small will end up tearing and mashing the pulp without hooking it while one which is too large will engage the dentinal wall with a risk of fracturing.

The broach can be used to remove food residue or cotton pellets placed as provisional medication.



A B

Fig. 13.33. **A**. Coarse barbed broach (x25). **B**. The same instrument viewed by S.E.M. (x50).

A B C D

Fig. 13.34. **A**. Preoperative radiograph of the lower left second molar: a broken instrument is in the apical one third of the mesial root. **B**. A fragment of a barbed broach has been removed. **C**. Intraoperative radiograph to check that the fragment has been completely removed. **D**. 15 month recall.

HAND INSTRUMENTS WITH GREATER TAPER

1. Profiles .04 hand files

Profiles .04 Hand Files[11,28] (*www.tulsadental.com*) are NiTi hand instruments obtained by machining; available in ISO diameters from 15 to 80, the Profile .04 Hand Files have a taper that is twice that of traditional hand files with a diameter that increases from the tip to the handle by 0.04 mm per mm of length. The design of the blades and tip of the hand Profiles is identical to the rotary Profile; the blades infact are flat radial lands type and the tip is rounded and non cutting. The correct method of using the ProFiles manually is rotation in the canal with light pressure without forcing the instrument. Complete rotation of 360° or more is permissible but it is also possible to use the balanced force technique. The Profile Hand instruments can be used as finishing instruments in complex cases where the use of rotary instruments could be hazardous (confluent canals, sharp apical curvatures) or also as the only instrument for root canal shaping.

2. Hand GT Files

The Hand GT Files[6,7] (*www.dentsply-maillefer.com*) devised by Dr. L.S. Buchanan, are instruments in NiTi with greater taper obtained by machining (Fig. 13.35); contrary to the Rotary GT Files and Profiles which have radial lands type blades, the Hand GT Files have sharpened blades (Fig. 13.36) which are machined in an counter-clockwise direction with a pitch (number of spirals per mm) and helical angle (blade inclination) that is variable from the tip towards the handle. In particular, the number of spirals are higher and the cutting angle wider near the apical part of the instrument, while coronally the spiral number is reduced and the angle becomes narrower. Clinically the apical part functions like a K-File with good torsional strength and tactile perception of the canal, while the coronal part functions like a reamer reducing the tendency to screw in and favouring the elimination of debris. The Hand GT Files also have the blade direction counter-clockwise, that is opposite to other hand instruments and therefore to be able to cut they must be rotated in a counter-clockwise direction. It is possible to use the Hand GT Files with the watch winding movement but in the opposite direction or using the balanced force technique inverted, while their filing efficiency is modest (push and pull). The GT Hand Files consist of four instuments with a fixed diameter at the tip of 0,20 mm, a maximum diameter of the blades of

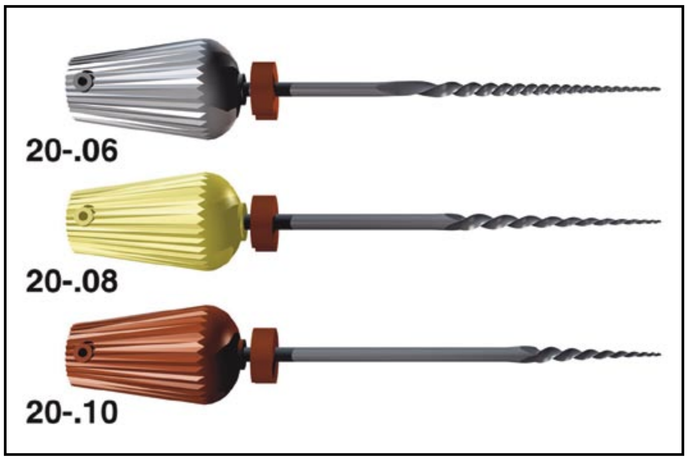
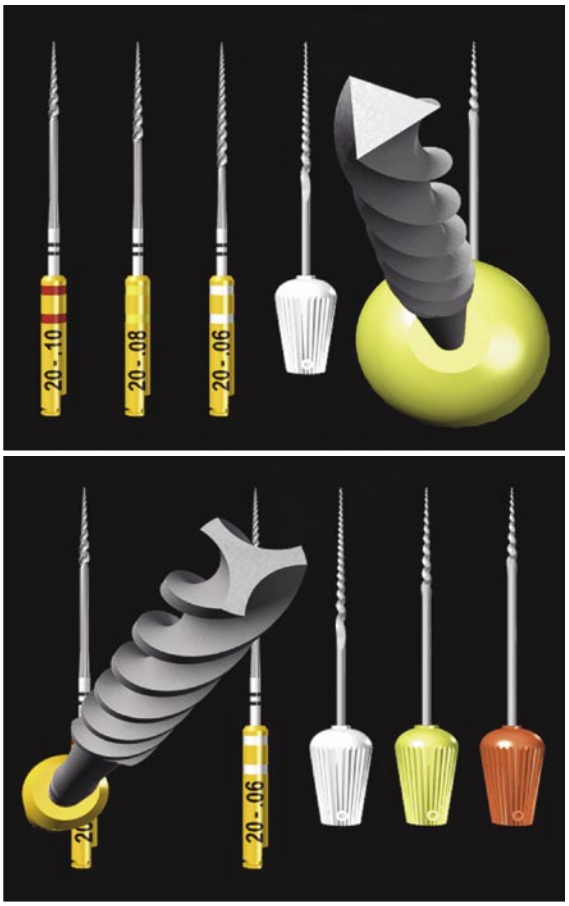


Fig. 13.35. The hand GT files (Courtesy of Dr. L.S. Buchanan).

A



B

Fig. 13.36. **A**. Hand GT files have a triangular cross section. **B**. Rotary GT files have radial lands type blades (Courtesy of Dr. L.S. Buchanan).

1.00 mm and a taper respectively of .06, .08, .10 and .12; as a consequence of this characteristic, the length of the cutting part of the GT Files reduces from 13.5 mm for the .06 taper to 6.7 mm for the .12 taper.[6,7] The GT Hand Files have a non-cutting tip, ergonomic pear shaped handle with a diameter of 6 mm and depth gages that is dark markings placed along the shank at 18, 19, 20, 22 and 24 mm from the tip, that facilitates the positioning of the silicone stop and allows accurate control of the insertion depth of the instrument. The colours of the handle (white for GT .06, yellow for GT .08, red for GT .10 and blue for GT .12) do not follow the ISO system but are for indicating the progression of the taper of the instruments. The GT Hand Files can be used on their own as the only instruments for shaping or sequentially with hybrid instrumentation together with hand instruments or following rotary instruments such as GT Rotary Files, Profiles or the ProTapers.[11] They are particularly useful to bypass the ledges and in the presence of canals with a severe apical curvature due to the possibility of precurvature with the appropriate instruments such as the Endobender (*www.sybronendo.com*) (Fig. 13.37).

A

B

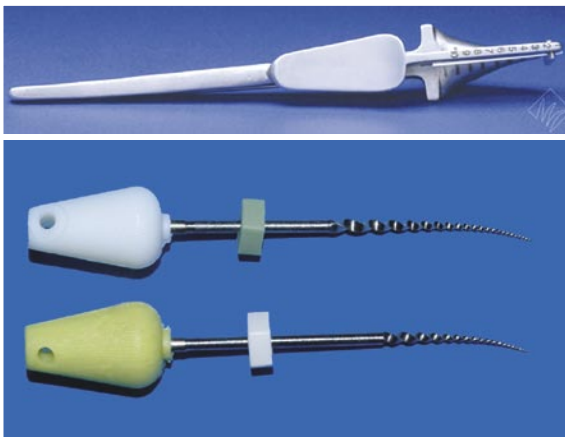


Fig. 13.37. **A.** The Endobender from SybronEndo, specifically designed by Dr. S.L. Buchanan to precurve both stainless steel and NiTi instruments. **B.** Hand GT files after being precurved with the Endobender.

3. Micro-Openers

Micro-Openers (*www.dentsply-maillefer.com*) are K-Files with a greater taper characterized by a shank that is bent at an angle of about 200° and a long handle in plastic (Fig. 13.38). Ideal for using under the microscope, they prevent interference in the operative field by the fingers. The Micro-Openers can be useful in teeth with difficult access such as some maxillary and mandibular molars or in patients with limited opening of the mouth. The Micro-Opener series comprises three instruments with a tip diameter respectively of 0.10, 0.15 and 0.10 mm and a taper respectively of .04, .04 and .06.

Fig. 13.38. Micro-Openers (Dentsply Maillefer).

STEEL ROTARY INSTRUMENTS

1. Gates-Glidden drills

The Gates-Glidden drills are steel instruments for the contra angled handpiece characterized by a long shank and an eliptical extremity which is flame shaped with a "guiding" non cutting tip (Fig. 13.39). The Gates-Glidden drills are available in six sizes and marked with circular notches on the part that attaches to the contra angled handpiece; the Gates # 1 has one notch, the # 2 has two notches and so on. The calibration of the Gates Burs is measured at the widest part of their eliptical portion; the # 1 has a maximum diameter of 0.50 mm, which increases 0.20 mm for each successive size, until # 6 which has a maximum diameter of 1.50 mm.[29] The length of the cutting part increases progressively with the calibre, although always remaining less than 50% than that of the Largo drills. The Gates drills are available in a short version with an overall length of 28 mm, with a shank length plus active part of 15 mm, and a long version with an overall length of 32 mm, with a shank length plus active part of 19 mm. The Gates-Glidden drills are designed with the weakest point at the start of the shank, so that they are easier to remove in case they fracture inside the root canal (Fig. 13.40); it is very important to remember that the Gates # 1 and # 2 are very fragile and can fracture at the level of the tip, especially if the recommended rotational speed of 800 rpm is exceeded and if they are subjected to bending stress. The blades of the Gates-Glidden drills do not have angles but flat cutting planes to reduce the aggressiveness and the tendency to screw in; they could be considered as the first example of the "radial lands" type of blades.

The Gates drills must be used passively on withdrawal from the canal with a brush like circumferential movement and their use must always be preceeded by preflaring of the canal using hand instruments. An active use of the Gates Glidden drills (Fig. 13.41) is not recommended because they can lead to the formation of ledges and dangerous structural weakening that in the curved and thin canals can cause stripping. Used correctly, the Gates drills infact represent an important aid for the endodontist, especially for eliminating coronal interferences and in the preparation of the coronal one third of the canal.

A B

Fig. 13.39. **A**. 1-6 Gates-Glidden drills (Maillefer). **B**. G-G no. 3 (x25).

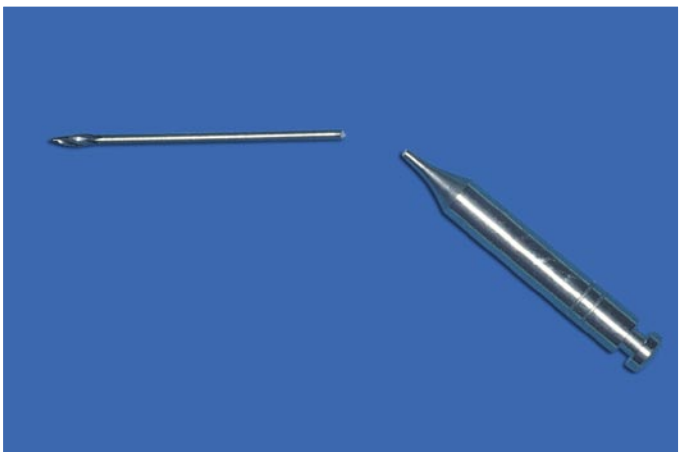


Fig. 13.40. Fracture of Gates-Glidden drills always occurs at the base of the shaft.

Fig. 13.41. Obturation of the distal canal demonstrates incorrect use of the Gates-Glidden drill, which has left its impression on the middle one third of the root canal.

2. Largo drills

The Largo drills or Peeso Reamers are steel instruments for the contra angled handpiece similar to the Gates-Glidden drills, from which they differ in that the blades are spread over a wider surface and the shape that is cylindrical (Fig. 13.42). The design of the blade (radial lands type) and the non cutting tip is infact identical to that of the Gates drills. The # 1 Largo Bur has a maximum diameter of 0.70 mm that increases by 0.20 mm for each successive size until finally reaching Largo # 6 that has a maximum diameter of 1.70 mm. Due to the extension of the active part, the Largo drills have a very aggressive cutting action and can easily cause root stripping if not used carefully.[20] Their initial use as suggested by some authors for opening the canal orifice is particularly dangerous, even if the instrument has a so called "non working tip". Trying to open a canal orifice with the smallest of these instuments is the same as introducing a rotary instrument with a calibre 70 into a canal into which a .08 file enters with difficulty!

On the contrary, the Largo drills are very useful in the preparation of the dowel space (post space) in canals already enlarged or in retreatments to speed up the removal of the obturation material.

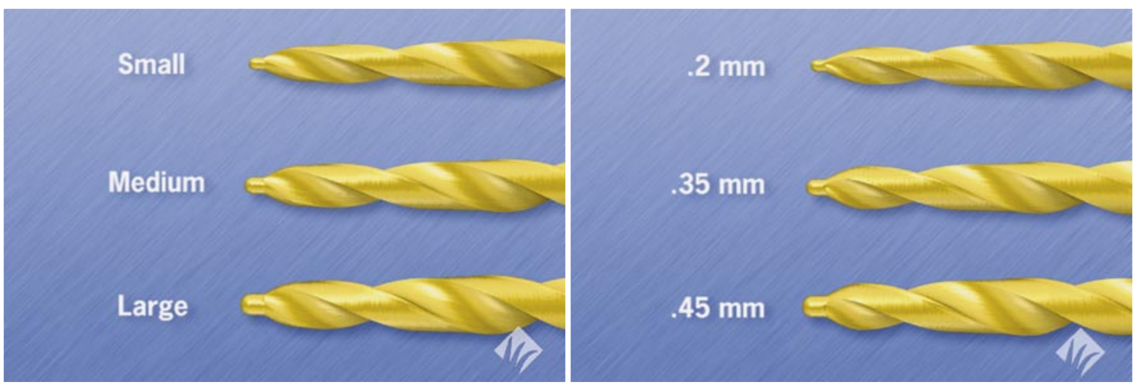
3. LA Axxess burs

The LA Axxess Burs (Line-Angle Axxess) (*www.sybronendo.com*) (Fig. 13.43) are steel burs for the low speed handpiece designed by Dr. L.S. Buchanan specifically for the elimination of interferences in the pulp chamber and coronal one third of the canal. The LA Axxess are available in 3 diameters: small with a minimum diameter of 0.20 mm, medium with minimum diameter of 0.35 mm and large with a minimum diameter of 0.45 mm (Fig. 13.44). The LA Axxess have a

Fig. 13.42. 1-6 Largo or Peeso reamers (Texceed).

Fig. 13.43. The LA Axxess endodontic bur kit (Courtesy of Dr. L.S. Buchanan).

A



B

Fig. 13.44. **A**, **B**. The pilot tip of the LA Axxess is available in three diameters (Courtesy of Dr. L.S. Buchanan).

rounded guiding tip (Fig. 13.45) and a 12 mm length of flutes (Fig. 13.46) of which the first 3 mm has a parabolic increase (Fig. 13.47), while the remaining 9 mm is characterized by a .06 taper (Fig. 13.48). The particular design of this bur favours the penetration of the coronal one third of the canal while the blade with its double cutting spiral (Fig. 13.49) rapidly removes the pulp chamber and coronal interferences. The recommended rotational speed for LA Axxess is about 5,000 rpm. Like the Gates and Largo drills, the LA Axxess must also be used with care, by pre-enlarging the canal with less aggressive endodontic instruments.

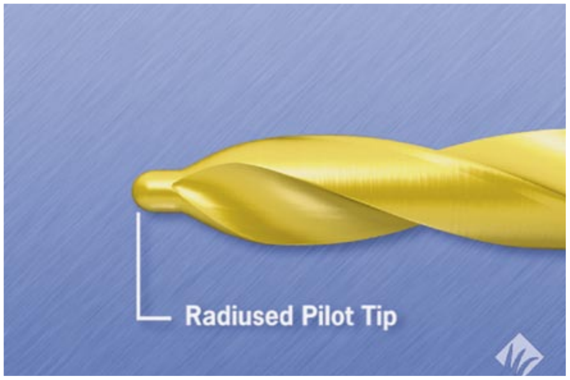


Fig. 13.45. The radiused pilot tip at high magnification (Courtesy of Dr. L.S. Buchanan).

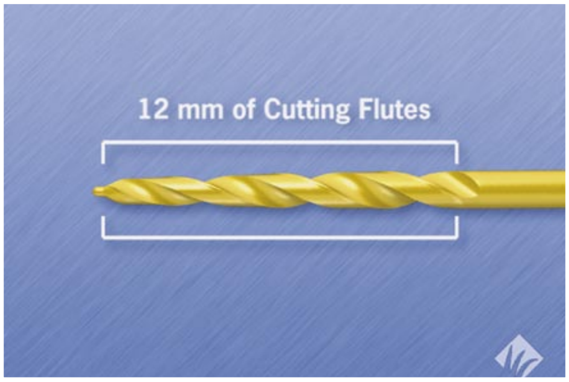


Fig. 13.46. The LA Axxess burs have a full 12 mm length of flutes (Courtesy of Dr. L.S. Buchanan).

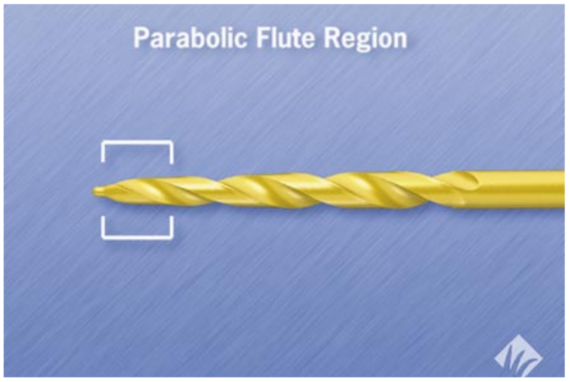


Fig. 13.47. In the alpha-flute region behind the non-cutting pilot tip are 3 mm's of very sharp parabolic flutes that cut an ideal funnel shape that guide files, without impediment, into the canal beyond the bur's apical extent of cutting (Courtesy of Dr. L.S. Buchanan).

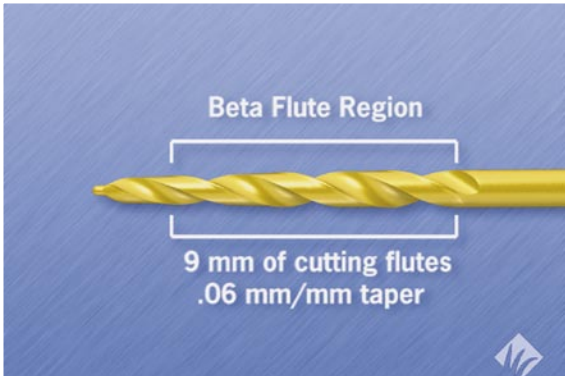


Fig. 13.48. The beta-flute region consists of 9 mm's of cutting flutes with a .06 taper (Courtesy of Dr. L.S. Buchanan).

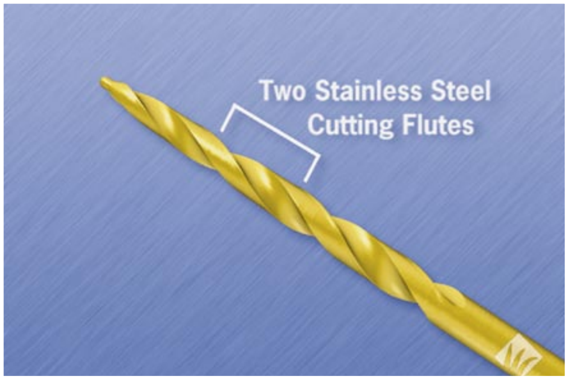


Fig. 13.49. The LA Axxess have two stainless steel cutting flutes, to rapidly remove all the coronal interferences and obtain a straight-line access (Courtesy of Dr. L.S. Buchanan).

4. Endo-Eze A.E.T. files

The Endo-Eze A.E.T. Files (Anatonical Endodontic Technology)[15] (*www.endoeze.com*) consist of two types of instruments, the Shaping Files and the Apical Files, both in steel and designed by F. Riitano. The Shaping Files are 4 rotary instruments to be used in an appropriate contra angled handpiece having alternate clockwise/counter-clockwise movement of 30°. The Shaping Files are available in 4 lengths (19, 23, 27 and 30 mm) and are: Shaping 1 with tip diameter of 0.10 mm and .025 taper, Shaping 2 with tip diameter of 0.13 mm and .045 taper, Shaping 3 with tip diameter 0.13 mm and .06 taper and Shaper C with tip diameter 0.25 mm and taper .035.[15] The Shaping Files have blades that cut even with a lateral brushing movement and are particularly indicated for the cleaning of canals with an irregular anatomy such as canals with an eliptical cross-section, C-Shaped etc. (Fig. 13.50 A). The Apical Files are hand instruments in steel characterized by a working part with limited length to allow a better tactile perception during the apical shaping. The Apical Files are available in lengths of 19, 23, 27 and 30 mm and ISO diameters of 15 to 50 (Fig. 13.50 B-C). The taper of the working part is .02 up to diameter 25 and then increases to .025.[15]

MECHANICAL INSTRUMENTS IN NICKEL TITANIUM

1. ProFiles

The ProFiles (*www.dentsply-maillefer.com*) are rotary instruments in nickel titanium introduced by Dr. W. Ben Johnson in 1994;[28] about 10 years after they were first marketed, the ProFiles, excluding some minor changes such as colour standardization and nickel plating of the handles, have the same characteristics as the original ones, and they remain amongst the most popular NiTi instruments.

ProFiles are obtained by micromachining three parallell furrows on a nickel titanium wire; the surfaces of the wire between the furrows are not sharpened so that in cross-section the instrument has a design defined as a “triple U” with blades characterized by flat cutting surfaces called “radial lands” (Fig. 13.51).[28] The main consequence of this particular blade design is a reduction of the central “core” of resistance of the instrument with a resulting structural fragility to torsional stress conditions, such as during the shaping of long and calcified canals or as a result of the applica-

Fig. 13.50. **A.** The A.E.T. Shaping files are particularly indicated for the cleaning of canals with an irregular anatomy such as canals with an eliptical cross-section (Courtesy of Ultradent). **B, C.** The apical files are available in length of 19, 23, 27, and 30 mm (Courtesy of Ultradent).

tion of excessive force.[10,11] To avoid this inconvenience the ProFiles manufacturing companies (Maillefer and TulsaDental) have worked on three fronts:

– Production of instruments with a greater taper able to increase the total metal mass in cross-section and therefore able to increase torsion resistance.
– Introduction of Endodontic handpieces with torque control, able to prevent using instruments with an excess of manual pressure.
– A sequence of instrument use which allows reduction of the contact surface and therefore the friction of the blades with the dentinal walls.

The "triple U" design of the ProFile with the correlated reduction of the metallic mass however, also has a positive effect represented by an increase in flexibility which is particularly useful in the presence of flexional stress.

The "radial lands" blades of the ProFiles are not efficient in lateral cutting; infact ProFiles cut perimetrically at 360° on all the walls until they have imprinted their shape in the canal, after which their action decreases rapidly. The low cutting capacity and their flexibility make the ProFiles particularly useful in the shaping of curved canals, reducing the risk of apical tears and transportation; vice versa in the removal of coronal interferences and in the creation of the glide path for the finishing instruments, ProFiles are less secure and less efficient than the sharper instruments such as the ProTaper.

The rotary ProFiles are now available in .02, .04 and .06 taper, and in the ISO diameters from 15 to 45 (.02 taper) and from 15 to 80 (.04 and .06 taper) and in 21, 25 and 30 mm lengths. ProFiles all present a working surface of 16 mm and a round non cutting tip (Fig. 13.52); furthermore along the shaft there are "depth gages" that are dark grooves placed at 18, 19, 20, 22 and 24 mm from the tip, that facilitate the positioning of the silicone stop and allow an accurate control of the depth of instrument placement. The handle of the ProFile in nickel plated and has a small ISO standard coloured rings which are useful to identify both the diameter and the taper (one small ring for the .02 series, two small rings for the .04 series, and three small rings for the .06 series) (Fig. 13.53).

ProFiles can be used on their own or in hybrid sequences to finish off the canals prepared with more resistant instruments such as the ProTaper. In the "pure" instrument sequences ProFiles are used in a crown-down based on reductions of taper and/or of diameter. The recommended rotational speed is about 250-300 rpm; the torque of the microhandpiece should be set at low values for the ProFiles of .02 and .04 and on medium values for those with .06 taper.[10,11,28]

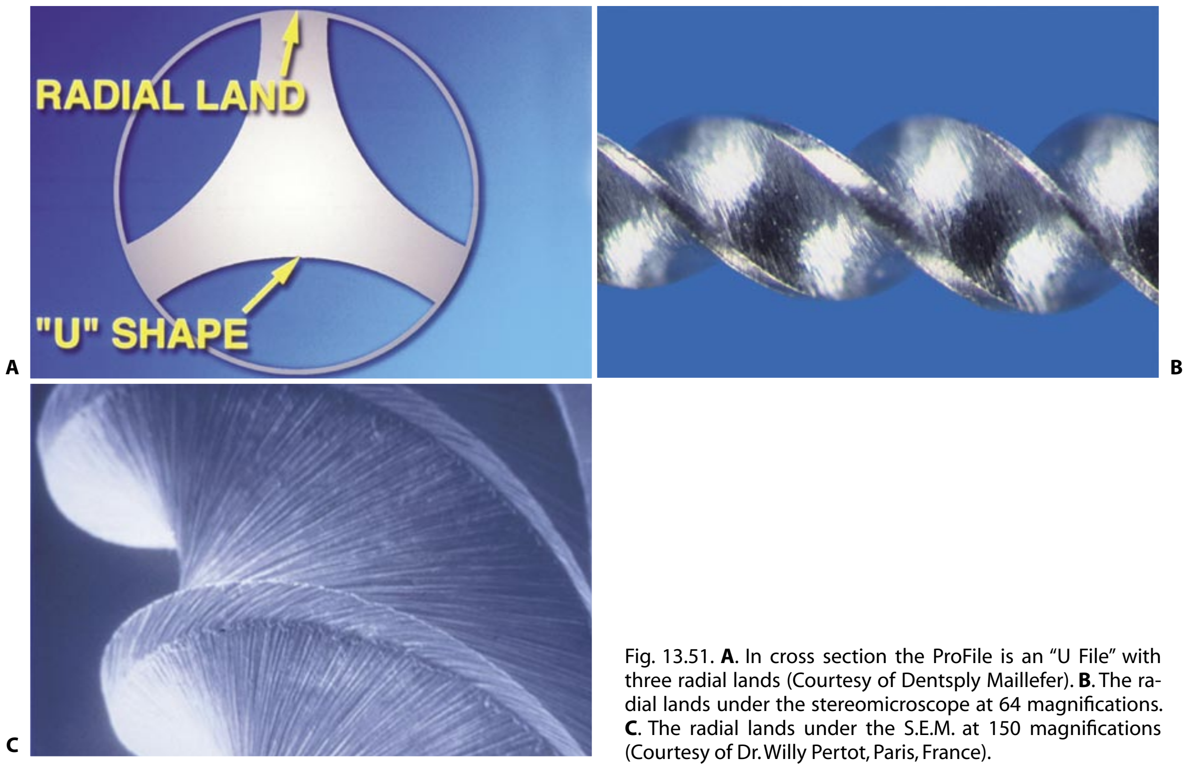


Fig. 13.51. **A**. In cross section the ProFile is an "U File" with three radial lands (Courtesy of Dentsply Maillefer). **B**. The radial lands under the stereomicroscope at 64 magnifications. **C**. The radial lands under the S.E.M. at 150 magnifications (Courtesy of Dr. Willy Pertot, Paris, France).

Fig. 13.52. All ProFiles have a round non-cutting tip, with a smooth transition angle, where the tip meets the flat radial lands.

A

B

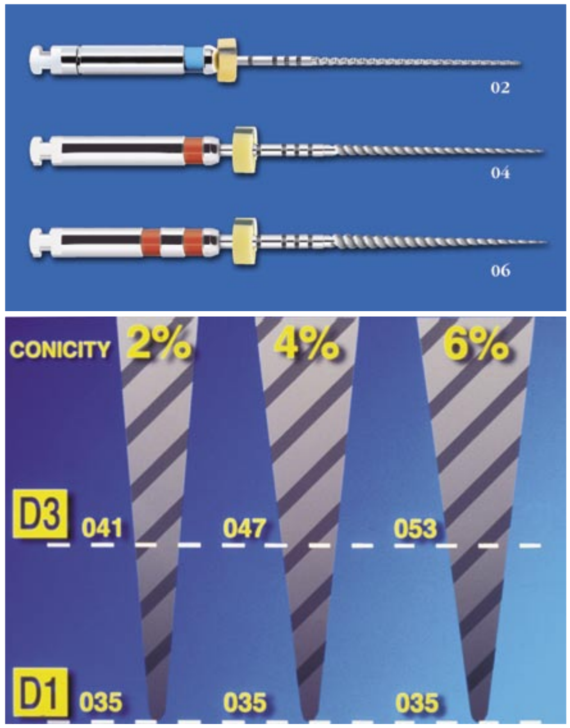
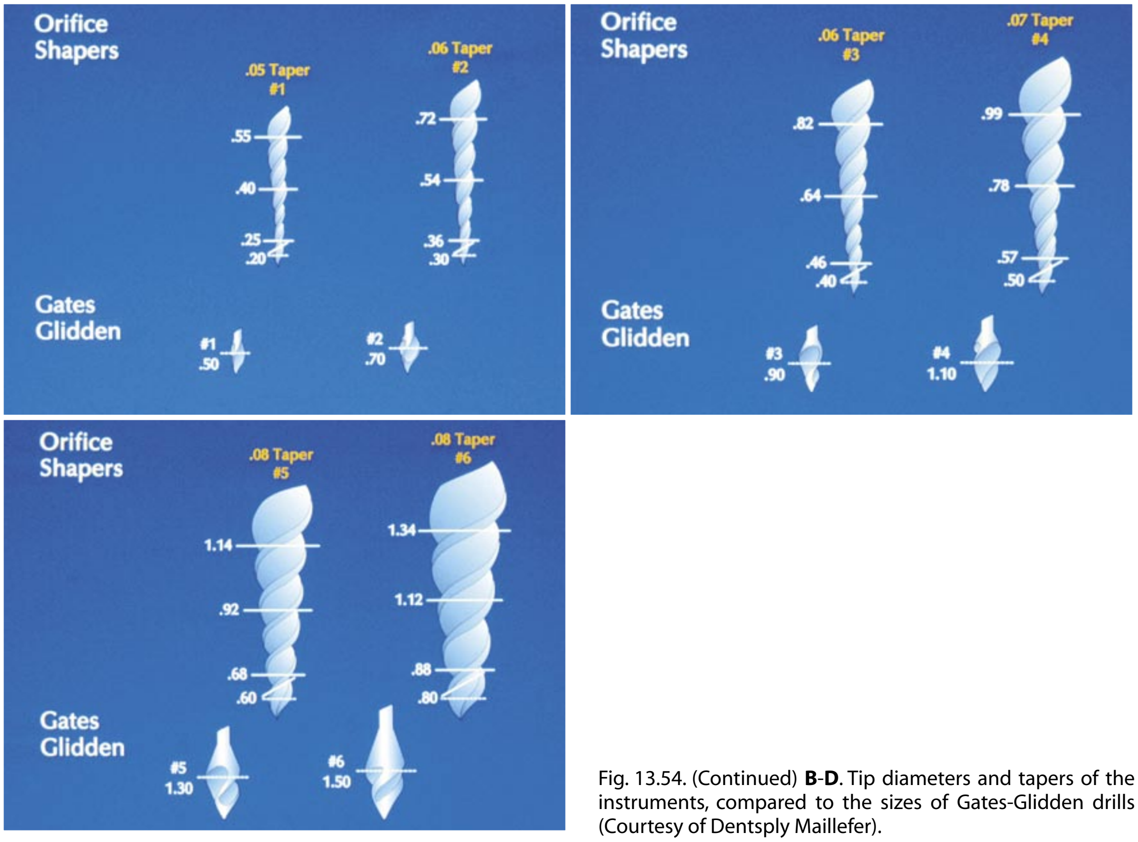


Fig. 13.53. **A**, **B**. ProFile instruments are available with .02, .04 and .06 taper (Courtesy of Dentsply Maillefer).

2. ProFile Orifice Shapers

The ProFile Orifice Shapers (*www.dentsply-maillefer.com*) are a series of 6 instruments devised for the elimination of coronal interferences and for flaring the coronal one third of the canal (Fig. 13.54 A). They are characterized by blades and a tip that are identical to that of the ProFiles, a total length of 19 mm and an active part that is 10 mm long.[10,11,28] The diameter at the tip and the taper of the 6 ProFile Orifice Shapers are respectively 20-.05, 30-.06, 40-.06, 50-.07, 60-.07 and 80.08 (Figs. 13.54 B-D). The ProFile Orifice Shapers can be used at the initial phases of the ProFile instrument sequences; for the elimination of coronal interferences they are less efficient than other similar instruments such as the Gates-Glidden drills or the SX ProTapers.

Fig. 13.54. **A**. Orifice Shapers have three rings in their shank. (continued)



B C D

Fig. 13.54. (Continued) **B**-**D**. Tip diameters and tapers of the instruments, compared to the sizes of Gates-Glidden drills (Courtesy of Dentsply Maillefer).

3. Quantec

The Quantec (*www.sybronendo.com*) devised by John McSpadden are available in 2 series of instruments (Fig. 13.55) with a cutting tip (Quantec SC) and with a non cutting tip (Quantec LX).[10,11] The Quantec SC has a facetted cutting tip without a transition angle and with a 60° tip angle, while the external tip diameter is smaller than the working surface, favouring the progression in curved canals with a minimum risk of canal transportation. The LX Quantec instead present a blunt pointed tip at 60°, which is non cutting, and has an external diameter that is always inferior to that of the working surfaces (Fig. 13.56). McSpadden advises the use of the SC Quantec in canals that are narrow, calcified, and that have accentuated curvatures, while the SX Quantec are to be prefered for the treatment of canals with wider curves and severe apical curvatures.[10,11] Both LX and LC Quantec are at present available with a standard handle (not all the tapers) and with a short handle similar to the Axxess type.

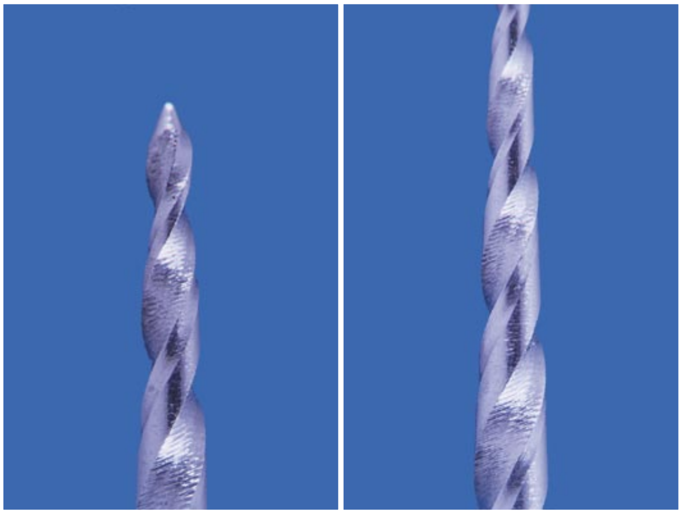
The LX Quantec consist of:

- four 17 mm long instruments with a 0.25 mm tip diameter and a taper of .06, .08, .10 and .12 which are ideal for removal of coronal interferences;
- seven instruments for canal preparation; these are 21 or 25 mm long with a 0.25 mm tip diameter and tapers of .03, .04, .05, .06, .08, .10 and .12;
- ten instruments for apical finishing, which are 21 or 25 mm long having a taper of .02 and ISO diameters from 15 to 60.

The SC Quantec consist of:

- two 17mm long instruments with a 0,25 mm tip diameter to eliminated coronal interferences;

Fig. 13.55. The Quantec instruments.



A B

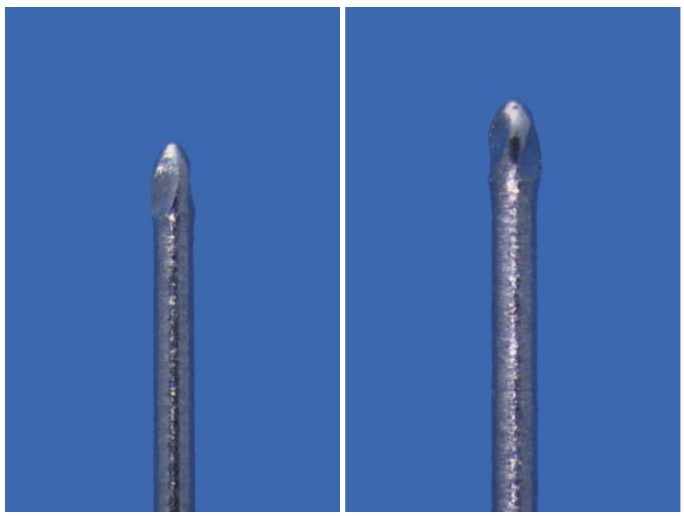
Fig. 13.56. Quantec LX 25.08 (SybronEndo). **A.** Tip (x64). **B.** Body (x64).

– four instruments for canal preparations which are 21 or 25 mm long with a 0.25 tip diameter and a taper of .03, .04, .05, .06;
– ten instruments for apical finishing which are 21 or 25 mm long having a taper of .02 and an ISO diameter from 15 to 60.

The angle of impact of the Quantec blades is slightly positive, to optimize the cutting action and the removal of debris by the radial tiers (radial lands) that substitute the cutting angles. The cutting radial tiers are asymetric ensuring an efficient and homogenous cutting pressure on all the canal surfaces during the continuous 360° rotation; furthermore they are behind with respect to the contact surface thereby obtaining a reduction in the friction which develops during the rotation.[10,11] The radial tiers also add support mass behind the cutting edge preventing the formation of microfractures and flexion or the reversal of the blade angles. Machined grooves on the surface of the Quantec facititate the removal of debris; its width becomes progressively more copious in the distal direction with respect to the blades, preventing compression of the dental mud towards the apex. Quantec instruments must be used in a progressive order even if simplified operative sequences which require a limited number of instruments are foreseen.[10,11]

4. LightSpeed

The instrumentation system LightSpeed (*www.septodont.co.uk*) introduced by Dr. S. Senia,[36,37] includes 20 instruments in nickel titanium very similar to the Gates Glidden drills with a long shaft and a working part in the shape of a very short flame. The elevated number of instruments depends on the progression of the diameters, measured at the widest point on the working part which includes, apart from the classic ISO diameters from 20 to 100, intermediate sizes such as 22.5, 27.5, 32.5, and 37.5 etc.[36,37] The long and thin shaft ensures that the LightSpeed has an elevated flexibility but at the same time it diminishes torque stress resistance; for this reason LightSpeed instruments are made with a point of separation at 18 mm from the tip, in order to facilitate their removal incase of endocanal fracture. The length of the working part varies according to the calibre from 0.25 to 1.75 mm (Fig. 13.57); the blades present characteristic radial cutting tiers and the tip is rounded and non cutting. LightSpeed instruments available in the 21, 25 and 31 mm lengths, must be used from the smallest to the largest in a stepback sequence with a typical pecking movement (advancement in the apical direction followed by a light withdrawal.[36,37] The stepback sequence begins after having manually pre-enlarged the canal up to K-File 15 then after having determined the diameter of the apical preparation which should correspond to the diameter of the LightSpeed (defined MAR that is Master Apical Rotary) which is able to reach working length in 12 pecks, that is repeating the pecking movement 12 times.[36,37] At this point the sequence continues inserting the successive instruments in stepback with 4 to 8 pecks each until the canal is



A B

Fig. 13.57. The tips of the LightSpeed at 64 magnifications. **A.** LightSpeed # 20. **B.** LightSpeed # 25 (continued).

enlarged up to a larger diameter of at least 0.25 mm with respect to the MAR. The suggested rotation speed for the LightSpeed instruments is between 1,200 and 2,000 rpm.[36,37]

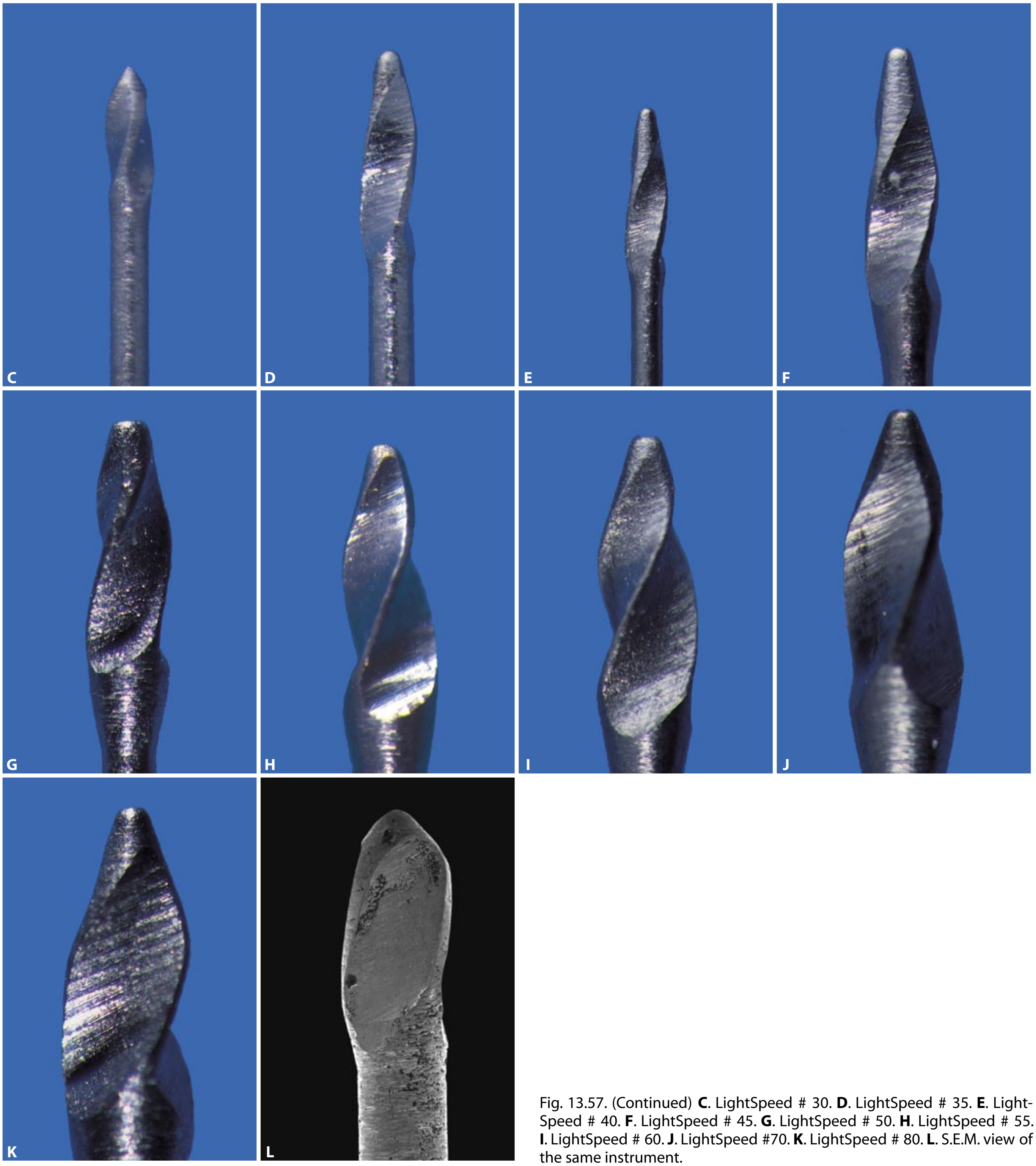


Fig. 13.57. (Continued) **C**. LightSpeed # 30. **D**. LightSpeed # 35. **E**. LightSpeed # 40. **F**. LightSpeed # 45. **G**. LightSpeed # 50. **H**. LightSpeed # 55. **I**. LightSpeed # 60. **J**. LightSpeed #70. **K**. LightSpeed # 80. **L**. S.E.M. view of the same instrument.

5. Rotary GT Files

The Rotary GT Files (*www.dentsply-maillefer.com*) are instruments in Nickel Titanium devised by Dr. S. Buchanan on the basis of the Hand GT Files design and belong to the GT System (Fig. 13.58).[6,7] Like the hand instruments, the Rotary GT Files present a non cutting tip, a prefixed tip diameter and a prefixed maximum flute diameter (MFD), multiple tapers and a blade length inversely proportional to the taper. Rotary and Hand GT Files however, also present substantial differences, the most evident of which being the blade direction which is clockwise in the Rotary GT and counter-clockwise in the Hand GT; furthermore, the Rotary GT blades are classical "radial lands" (Fig. 13.59) without the sharp cutting angles found in the Hand GT Files (Fig. 13.36).[6,7] The clockwise direction of the blades and the radial cutting planes are fundamental because they make it possible to use the Rotary GT in continual clockwise rotation without screw in. Like the ProFiles, the Rotary GT Files are hardly efficient in lateral cutting and they tend to imprint their shape into the canal; on the basis of the last GT brought to the working length, the operator can predetermine the final diameter and tapers of the preparation and choose the corresponding papaer points (Fig. 13.60), gutta-percha cones (Fig. 13.61) or Thermafil obturators (Fig. 13.62).

Fig. 13.58. The GT System: GT Obturator, GT paper point, GT gutta-percha cone, GT Rotary File, and GT hand file. They all have the same tip diameter and the same taper: 20.08 (Courtesy of Dr. L.S. Buchanan).

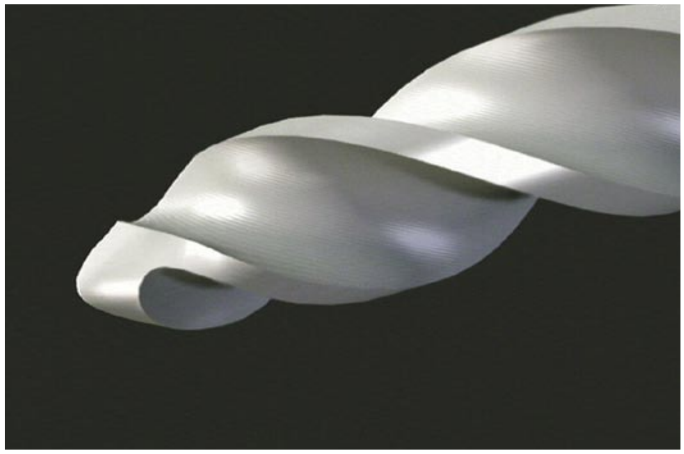


Fig. 13.59. Like ProFiles, GT rotary files have a non-cutting tip and radial lands (Courtesy of Dr. L.S. Buchanan).

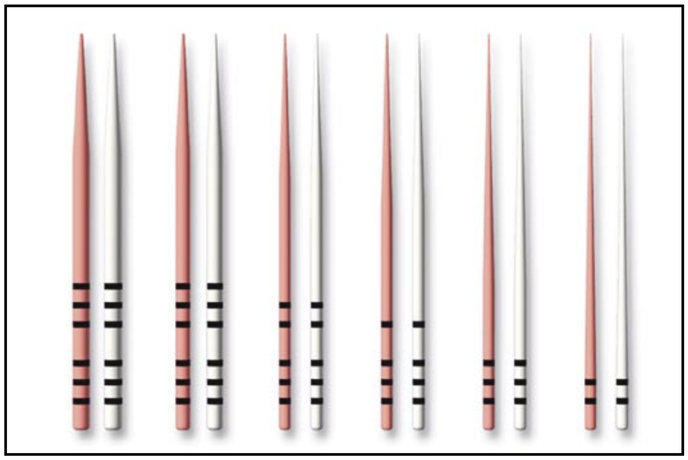


Fig. 13.60. Gutta-percha cones and the corresponding paper points with the same taper (Courtesy of Dr. L.S. Buchanan).

Fig. 13.61. Gutta-percha cones by Analytic (SybronEndo) and by Tulsa Dental (Dentsply Tulsa Dental) (Courtesy of Dr. L.S. Buchanan).

A B C

Fig. 13.62. **A**-**C**. GT Rotary Files and the corresponding GT Obturators (Courtesy of Dr. L.S. Buchanan).

Rotary GT Files are at present available in 4 principal series, each one of which comprises 4 instruments:[6,7]

– GT 20 Series comprises 4 instruments with a 0.20 mm tip diameter and tapers of .04, .06, .08 and .10 (Fig. 13.63);
– GT 30 Series comprises 4 instruments with a 0.30 mm tip diameter and tapers of .04. .06, .08 and .10 (Fig. 13.64);
– GT 40 Series comprises 4 instruments with a 0.40 mm tip diameter and tapers of .04, .06, .08 and .10 (Fig. 13.65);
– GT Accessory comprises 3 instruments with a taper of .12 and a tip diameter respectively of 0.50, 0.70 and 0.90 mm (Fig. 13.66).

The maximum blade diameter is 1.00 mm for all GT's 20 and 30 Series and for GT 40 Series with of .04, .06 and .08 taper, is 1.25 mm for GT 40 Serie with .10 taper and is 1.5 mm for GT Accessory with .12 taper.

The GT File and product identification is very simple (Fig. 13.67).

The blade length varies according to the tip diameter, to the maximum diameter and according to the taper. To calculate it the following formula must be used:

$$\textit{Blade length} = \frac{\textit{Maximum diameter} - \textit{Tip diameter}}{\textit{Taper}}$$

For example, a GT 30 Series with a taper of .10 will have a blade length of:

$$L = \frac{125 - 30}{10} = 09.5\ mm$$

The Rotary GT Files are generally used in a crown-down sequence progressively reducing their taper and/or their diameter. The choice of the instrument series to be used will be made on the basis of the initial examination (thin, medium and wide canals) and then confirmed by the apical gauging results (see Chapter 20).[6,7] The recommended rotational speed is about 250 to 300 rpm; the torque of the micromotor should be set on low values for GT's with a taper of .04, on medium values for those with a taper of .06 and medium/high values for GT's with a higher taper.

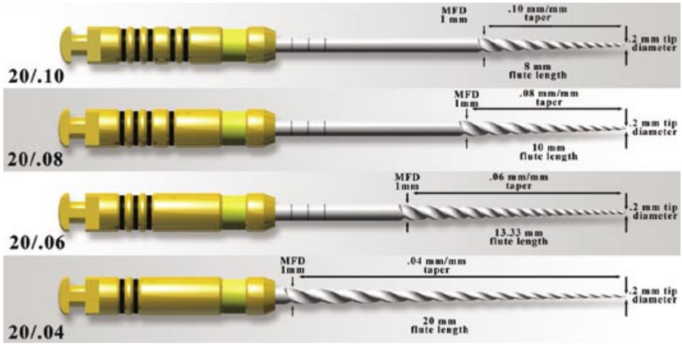


Fig. 13.63. GT Rotary Files Series 20 (Courtesy of Dr. L.S. Buchanan).

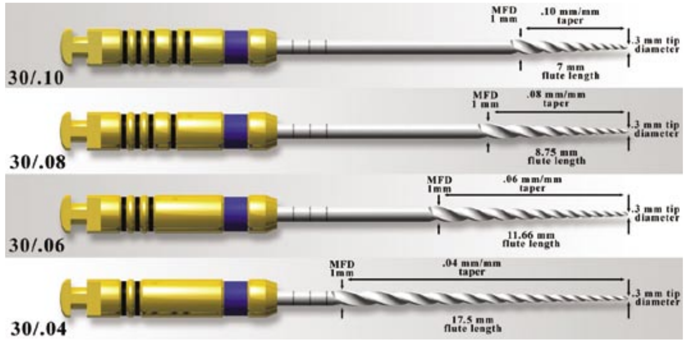


Fig. 13.64. GT Rotary Files Series 30 (Courtesy of Dr. L.S. Buchanan).

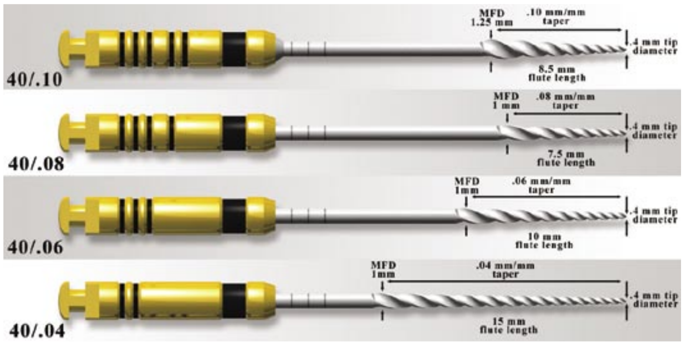


Fig. 13.65. GT Rotary Files Series 40 (Courtesy of Dr. L.S. Buchanan).

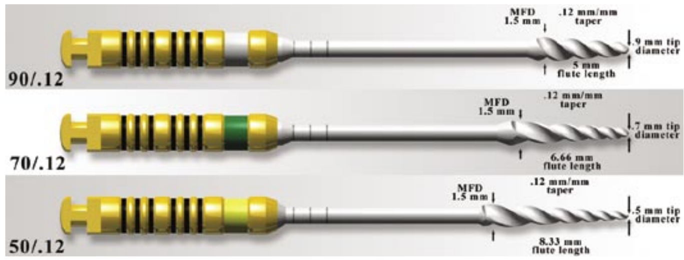


Fig. 13.66. GT Accessory (Courtesy of Dr. L.S. Buchanan).

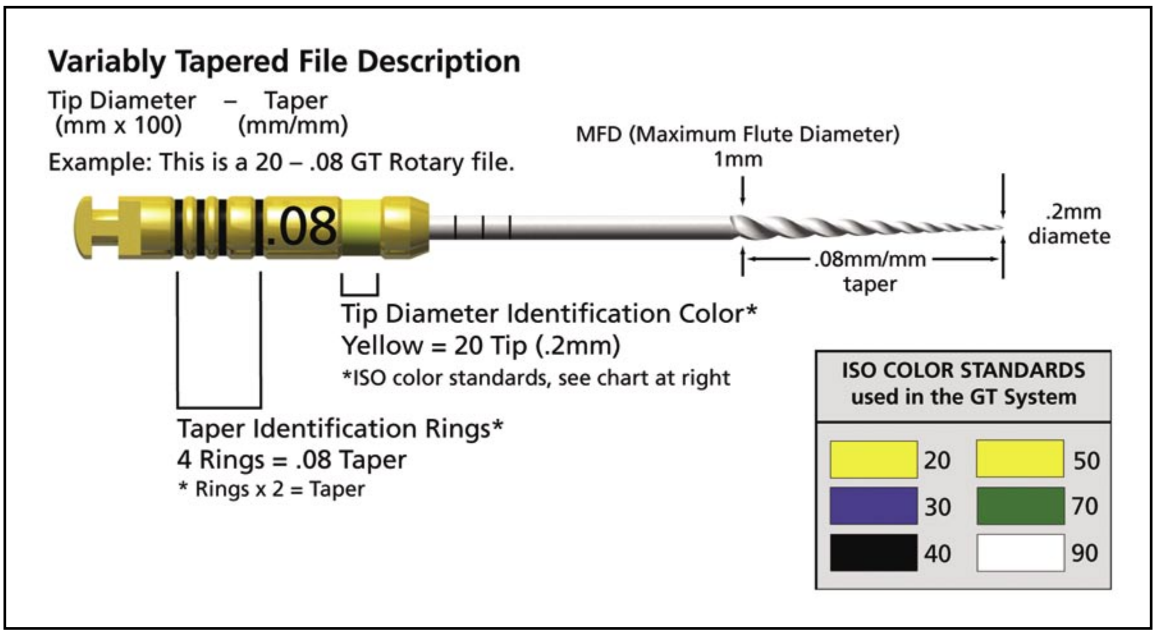


Fig. 13.67. GT identification system (Courtesy of Dr. L.S. Buchanan).

6. Hero

6.a Hero 642

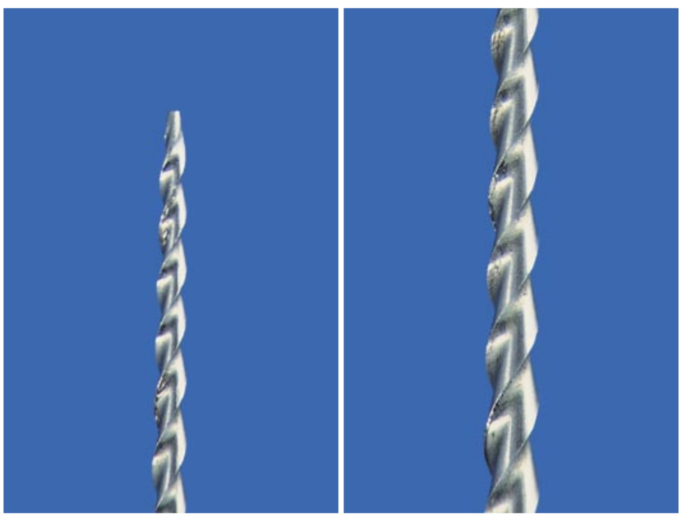
Hero 642's (*www.micro-mega.com*) are mechanical instruments derived from the Helifiles available in three tapers: .02 (diameters from 20 to 45 and lengths of 21, 25, and 29 mm), .04 (diameters of 20, 25, and 30 and lengths of 21, 25, and 29 mm) and .06 (diameters of 20, 25, and 30 and lengths of 21 mm). The Hero 642's (Fig. 13.68) are characterised by:[22,41,44]

- a triple helix cross-section with three positive rake angles; there are no radial cutting tiers as in the ProFile and Quantec instruments, but there are cutting angles as in the ISO instruments even though they have a different inclination;
- a higher " residual core" inside the blades which increases the resistance to torsional loads diminishing the risk of fracture;
- a progressive sequence of the blades to reduce the tendency to screw in;
- three tapers which permit the reduction of the contact surfaces between the blades and the canal walls;
- a tip that remains centred in the canal and which does not normally come into contact with the canal walls.

For the Hero 642 the manufacturers recommend three different sequences for use according to the degree of case difficulty, evaluated on the basis of the angle of curvature of the canal. Generally Hero are used in a crown down sequence based on the reduction of the taper (6-4-2) and/or of the diameters. The recommended rotational speed is 300 to 600 rpm.[3,22,41,44]

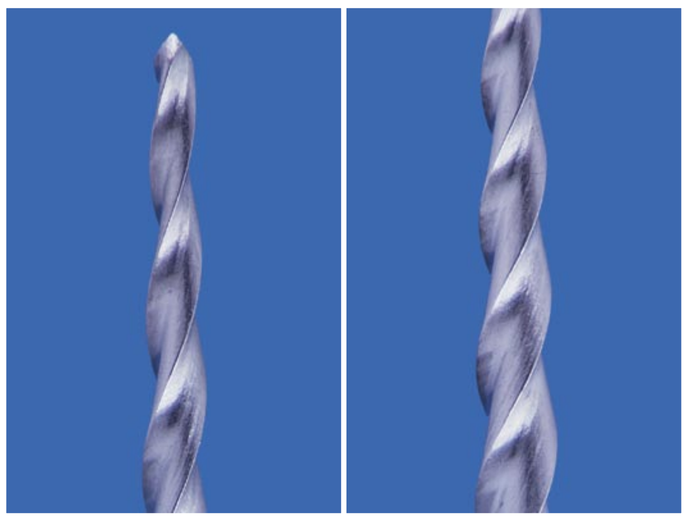
6.b Hero Shaper

The Hero Shaper (*www.micro-mega.com*) are instruments which are derived directly from the 642 Hero's and they have the same triple helix cross-section, with positive rake angles (Fig. 13.69).[3,8] However, the Hero Shaper differs from the 642 Hero in that the rake angle (helical angle) of the blades is variable and increases from the tip towards the handle, in that the pitch (distance between two spirals) increases with the taper of the instruments, in that the shorter handle allows an easier access to the posterior teeth and in that the tip is completely inactive and self guiding.[3,8] These changes in the geometry of the Hero Shaper reduce the risk of instrument screw in, increases the flexibility and optimizes the removal of the debris.[8] The Hero Shaper series comprises three instruments with a taper of .06 (20, 25 and 30) and three instruments with a taper of .04 (20, 25 and 30), available in lengths 21, 25 and 29 mm. The Hero Shaper provides for three operative sequences for easy, medium and difficult canals; all the sequences are crown down type and characterised by few steps and a limited number of instruments. The recommended rotational speed is between 300 and 600 rpm.[3,8]



A **B**

Fig. 13.68. Hero 642 # 30 (Micro-Mega). **A.** Tip (x25). **B.** Body (x25).



A **B**

Fig. 13.69. Hero Shaper # 30.06 (Micro-Mega). **A.** Tip (x25). **B.** Body (x25).

6.c Endoflare

Endoflares[8,9] (*www.micro-mega.com*) are instruments designated for the enlargement of the coronal one third of the canal (Fig. 13.70). They have a tip diameter of 0.25 mm and .12 taper. The Endoflare have the same tip characteristics, helical angle, pitch and cross-section as the Hero Shaper and like the latter are used at a speed between 300 and 600 rpm.[8,9] The Endoflare are instruments that are resistant and useful for the elimination of coronal interferences; their use is complementary to the Hero Shaper or the Hero 642 in as much as they simplify their use and reduce the risk of fracture in the canals.

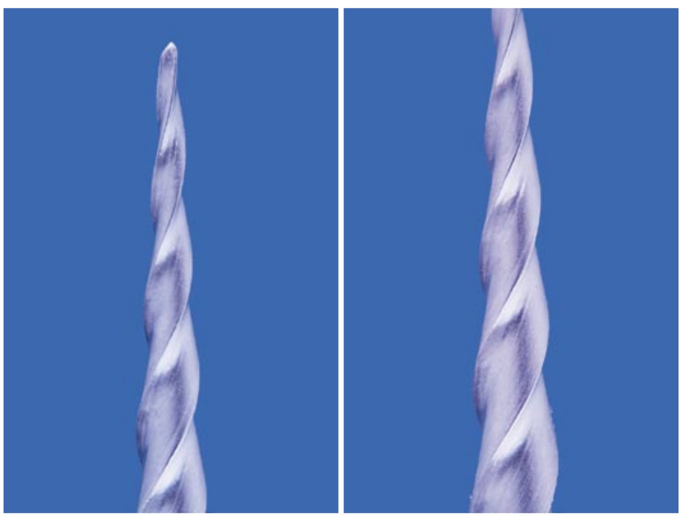
6.d Hero Apical

The Hero Apical (*www.micro-mega.com*) are instruments for the enlargement of the apical one third in canals where it is desired to obtain diameters and tapers greater than that offered by the Hero Shaper or the Hero 642.[8,9] The series comprises two instruments both with tip diameter of 0.30 mm with a taper of .06 and .08 respectively. The Hero Apical have the same characteristics regarding tip, helical angle, pitch and cross-section as the Hero Shaper and like these must be used at a rotational speed of between 300 and 600 rpm.[8,9] Due to their increased taper they have a certain structural rigidity (especially the .08 instrument) and therefore must be used with care in curved canals.

7. Sybron Endo K3

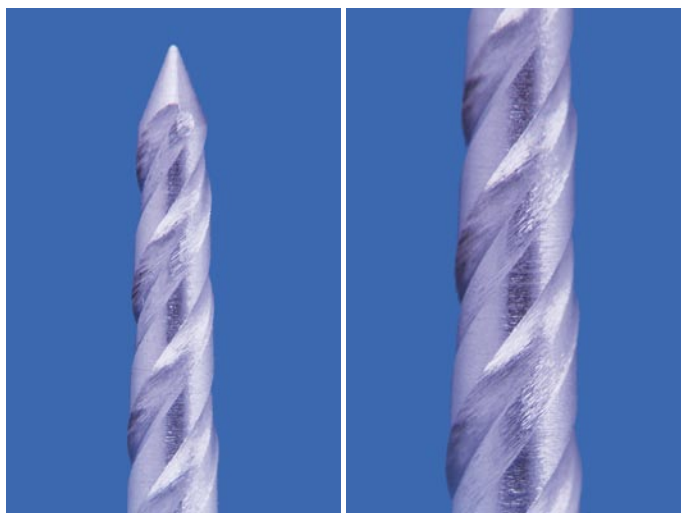
The K3's[4,45] (*www.sybonendo.com*) are hand instruments in nickel titanium available in lengths of 21, 25 and 30 mm and with a taper of .02 (ISO diameter from 15 to 45), .04 (ISO diameter from 15 to 60), and .06 (ISO diameter 15 to 60) (Fig. 13.71). The set is completed by two orifice openers with a taper of .08 and .10. From a structural point of view the K3 has a cross-section of 3 radial tiers (radial lands), the first of which lends support to the blade and guarantees an increased resistance to torsional stress of the periferal zone, the second which is retracted reduces the friction against the canal walls and the third stabilizes the instrument and keeps it centred inside the canal avoiding eccessive load (Fig. 13.72).[4,45] The K3 also have a slightly positive cutting angle, a non working tip, a variable helical angle, a variable pitch with less blades on the coronal part to prevent the screw in effect and a diameter of the core that reduces in the coronal direction so as to keep the flexibility of the instrument constant all along its length.[4,45]

The handle of the K3 is the Axxess type (like the Quantec), however shorter to facilitate access of the posterior teeth (see Chapter 21). If the K3 are furthermore used in the appropriate contra-angled handpiece with a microhead, it is possible to reduce the access space of the instrument to 5 mm. The sequence of using the K3 is crown-down based on decreasing diameter, taper or on alternate decreasing of diameter and taper.[4,45] In all cases the use of the K3 must be



A B

Fig. 13.70. Endoflare # 25.12. **A.** Tip (x25). **B.** Body (x25).



A B

Fig. 13.71. K3 # 60.06 (SybronEndo). **A.** Tip (x25). **B.** Body (x25).

A

B

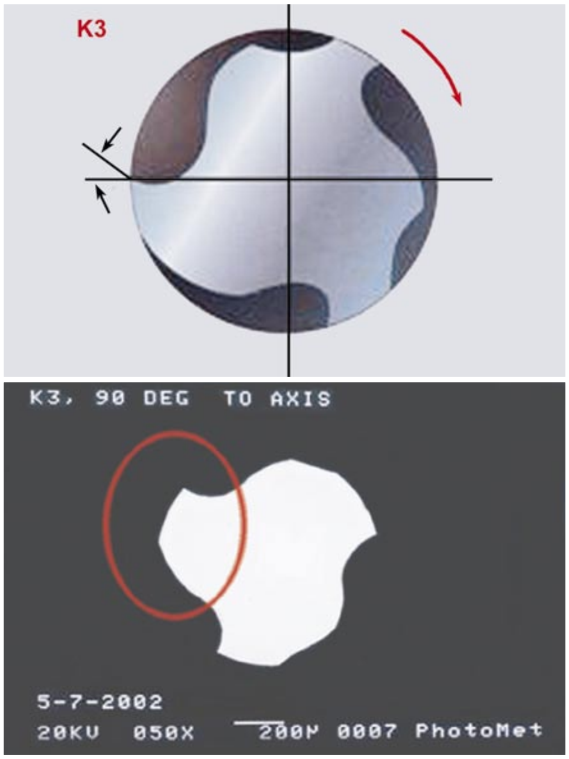


Fig. 13.72. **A.** Cross section of the K3. **B.** The radial lands keeps the instrument centered inside the root canal.

preceeded by exploring and preflaring with hand instruments up to file size 15. The crown-down sequence must be recapitulated without force until a 25 or 30 .06 can be brought to working length. With the K3 it is recommended to use an endodontic motor with automatic torque control and autoreverse.[4,45]

8. ProTapers

The ProTaper System[5,35] (*www.dentsply-maillefer.com*) is made up of 6 instruments that are divided into 2 groups of 3 instruments each: Shapers with the marking SX, S1 and S2 and Finishers with the marking F1, F2 and F3 (Fig. 13.73). The Shapers are instruments for eliminating coronal interferences and to create a smooth pathway for the Finishing instruments while the Finishers are meant for the finalizing of the shape created by the Shapers and for giving a definitive taper and diameter to the canal.[5,36] The important structural characteristics of the ProTapers are:[5,36]

– robust triangular cross-section with convex sides to increase the metal mass of the central core resistance of the instruments (Fig. 13.74);
– cutting blades with cutting angles (there are no radial lands);
– variable helical angle to reduce screw in risk;
– variable pitch (distance between spirals) to reduce the risk of screw in and aid the removal of debris (Fig. 13.75);
– multiple increase in tapers towards the handle of the shapers (so as to increase the flexibility in the apical third) and decrease towards the handle in the Finishers (so as to enlarge the apical preparation without making the coronal third of the instrument too rigid).

The characteristics of these instruments can be summarized as follows:[5,35]

– the ProTaper SX have a total length of 19 mm with a blade length of 16 mm. The diameter at the tip is 0.19 mm, while the taper at D_1 is .035 increasing

Fig. 13.73. The ProTaper NiTi rotary set of files is comprised of just three shaping and three finishing instruments (Courtesy of Dentsply Maillefer).

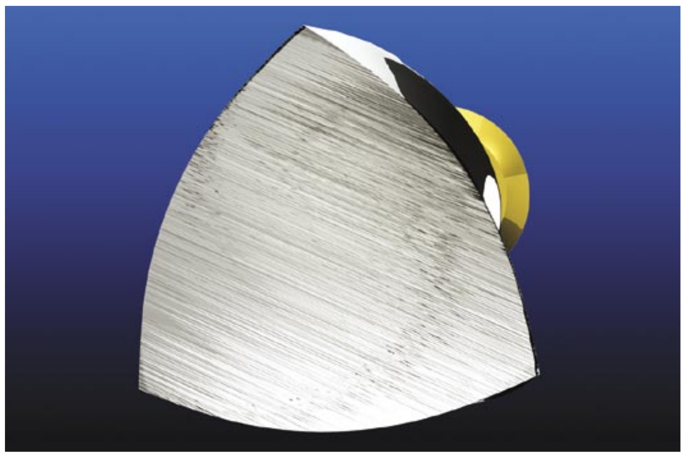


Fig. 13.74. The ProTaper instruments have a convex triangular cross-section, which improves cutting efficiency while maximizing core strength (Courtesy of Dentsply Maillefer).

at D_9 to .19. After which decreases to .02 from D_{10} up to D_{14} and it has no taper at D_{15} and D_{16} (Fig. 13.76);

- the ProTaper S1 is available in lengths of 21 and 25 mm, with a tip diameter of 0.17 mm and a blade of 16 mm. The taper of the S1 is .02 at D_1, .04 at D_4, .08 at D_8 and .11 at D_{15} (Figs. 13.77A);
- the ProTaper S2 is available in lengths of 21 and 25 mm with a diameter at the tip of 0.20 mm and a blade of 16 mm. The taper of S2 is .04 at D_1, .06 from D_5 up to D_9, and .115 at D_{15} (Fig. 13.77 B);
- the ProTaper Finisher F1 is available in lenghts of 21 and 25 mm with a tip diameter of 0.20 mm and a blade of 16 mm. The taper of the F20 is .07 at D_1-D_3 which then reduces to .055 at D_5-D_{15} (Figs. 13.78 A);
- the ProTaper Finisher F2 is available in lengths of 21 and 25 mm with a tip diameter of 0.25 mm and a blade of 16 mm. The taper of the F25 is .08 at D_1-D_3 which then decreases to .06 at D_5 and then to .055 at D_6-D_{15} (Fig. 13.78 B);
- the ProTaper Finisher F3 is available in lengths of 21 and 25 mm with a tip diameter of 0.30 mm and

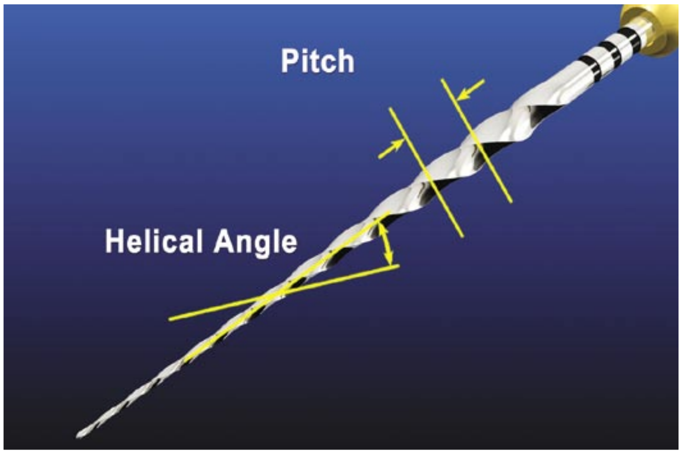


Fig. 13.75. ProTaper files perform smoothly, efficient, and safely as a result of their progressively tapered design and continuously changing pitch and helical angle (Courtesy of Dentsply Maillefer).

ProTaper Shaping SX

∇ Taper		Ø Diameters	
0		0	19
1	.035	1	22.5
2	.045	2	27
3	.055	3	32.5
4	.065	4	39
5	.085	5	47.5
6	.110	6	58.5
7	.145	7	73
8	.170	8	90
9	.190	9	109
10	.02	10	111
11	.02	11	113
12	.02	12	115
13	.02	13	117
14	.02	14	119

Fig. 13.76. Shaper X has nine incrisingly larger tapers ranging from 3.5% to 19%, and is used in a brushing motion to cut dentin, between D_6 and D_9, on the outstroke (Courtesy of Dentsply Maillefer).

ProTaper Shaping S1

∇ Taper (12)		Ø Diameters	
0		0	17
1	.02	1	19
2	.03	2	22
3	.04	3	26
4	.045	4	30.5
5	.05	5	35.5
6	.06	6	41.5
7	.07	7	48.5
8	.08	8	56.5
9	.09	9	65.5
10	.10	10	75.5
11	.10	11	85.5
12	.105	12	96
13	.105	13	107.5
14	.11	14	118.5

Fig. 13.77. **A.** S1 and S2 each have progressively larger tapers over the length of their blades, allowing each instrument to perform its own crown-down work (Courtesy of Dentsply Maillefer).

ProTaper Shaping S2

∇ Taper (9)		Ø Diameters	
0		0	20
1	.04	1	24
2	.045	2	28.5
3	.05	3	33.5
4	.055	4	39
5	.06	5	45
6	.06	6	51
7	.06	7	57
8	.06	8	63
9	.06	9	69
10	.07	10	76
11	.09	11	85
12	.105	12	95.5
13	.115	13	107
14	.115	14	118.5

Fig. 13.77. **B.** S1 and S2 each have progressively larger tapers over the length of their blades, allowing each instrument to perform its own crown-down work (Courtesy of Dentsply Maillefer).

ProTaper Finishing F1

∇ Taper (2)		Ø Diameters	
0		0	20
1	.07	1	27
2	.07	2	34
3	.07	3	41
4	.055	4	46.5
5	.055	5	52
6	.055	6	57.5
7	.055	7	63
8	.055	8	68.5
9	.055	9	74
10	.055	10	79.5
11	.055	11	85
12	.055	12	90.5
13	.055	13	96
14	.055	14	101.5
15	.055	15	107
16	.055	16	112.5

Fig. 13.78. **A**. The finishing files have variable D_0 diameters and tapers, and blend the deep shape into the middle one third of the canal (Courtesy of Dentsply Maillefer).

ProTaper Finishing F2

∇ Taper (3)		Ø Diameters	
0		0	25
1	.08	1	33
2	.08	2	41
3	.08	3	49
4	.06	4	55
5	.06	5	61
6	.055	6	66.5
7	.055	7	72
8	.055	8	77.5
9	.055	9	83
10	.055	10	88.5
11	.055	11	94
12	.055	12	99.5
13	.055	13	105
14	.055	14	110.5
15	.055	15	116
16	.055	16	121.5

Fig. 13.78. **B**. The finishing files have variable D_0 diameters and tapers, and blend the deep shape into the middle one third of the canal (Courtesy of Dentsply Maillefer).

a blade of 16 mm. The taper of F30 is .09 at D_1-D_3 which then decreases to .07 at D_4-D_5 and then to .05 at D_6-D_{15} (Fig. 13.78 C).

The ProTapers must be used, without ever being forced into the canal, in increasing order from the

ProTaper Finishing F3

∇ Taper (3)		Ø Diameters	
0		0	30
1	.09	1	39
2	.09	2	48
3	.09	3	57
4	.07	4	64
5	.07	5	71
6	.05	6	76
7	.05	7	81
8	.05	8	86
9	.05	9	91
10	.05	10	96
11	.05	11	101
12	.05	12	106
13	.05	13	111
14	.05	14	116
15	.05	15	121
16	.05	16	126

Fig. 13.78. **C**. The finishing files have variable D_0 diameters and tapers, and blend the deep shape into the middle one third of the canal (Courtesy of Dentsply Maillefer).

smallest to the largest after having explored and pre-enlarged the canal at least to number 20 K File (see Chapter 19). The ProTapers have a lateral cutting action and therefore can be used with a brushing action which is very useful for removing coronal interferences.[5,35] This type of movement must be restricted to the ProTaper Shapers, while the Finishers with their greater taper and diameter must be used with a rapid insersion and withdrawal without excessive pressure. The recommended rotational speed for all the ProTapers is 250-300 rpm. In the canals that are extremely curved it is possible to use the ProTapers by hand after attaching, to the handle, a special plastic insert that changes it to a hand instrument (Fig. 13.79).[5,35] Lastly it should be remembered that it is preferable as with all NiTi Rotary instruments, to use the ProTapers in an endodontic handpiece with torque control and autoreverse.

9. FlexMaster

The FlexMasters[16,42] (*www.vdw-dental.com*) are instruments available with tapers .02, .04 and .06 in lengths 21 and 25 mm. The series also includes an instrument with a tip diameter of 0.22 mm, .11 taper and overall length of 19 mm (blade length 9 mm) for flaring the coronal one third of the canal. The FlexMaster has a triangular cross-section with convex angles, cutting blades and a tip very similar to that of the ProTaper, however, it differs by the multiple taper, helical angle and pitch.[16,42] To simplify the use of the FlexMaster one can use the appropriate endobox which has the possible sequence of use, easy, medium, difficult canals, marked. All the sequences provide for the use of a limited number of instruments, from 3 to 5 to be used in a crown-down sequence based on reduction of diameter and/or taper.[16,42]

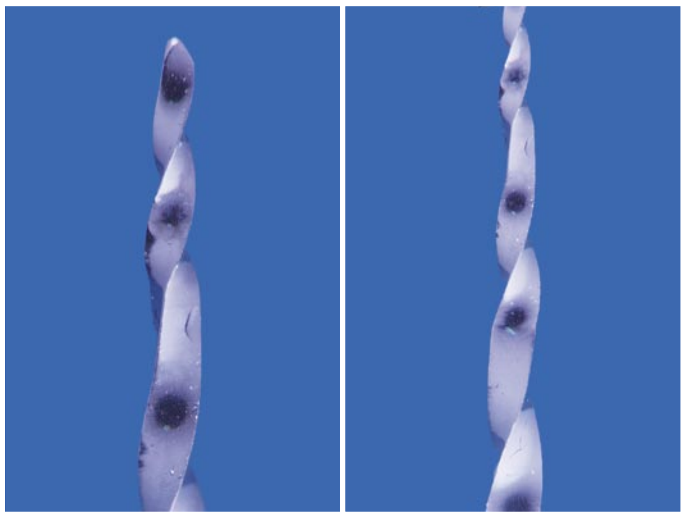
10. RaCe

The RaCe[17] (Reamers with Alternating Cutting Edges) (*www.fkg.ch*) are chacterised by a triangular cross-section, cutting blades, non working tip and alternating cutting angles that reduce the risk of screw in, canal blockage and reduces the working torque of the instruments (Fig. 13.80).[17] The RaCe instruments are subjected to an electro-chemical processing of the blade that serves to increase the resistance against torsional stress and fatigue. The RaCe are available in the following tapers and lengths:

– RaCe .06 taper # 20, 25 and 30 with overall length of 19 mm and blade length of 10 mm;
– RaCe .06 taper # 20, 25 and 30 with overall length of 25 mm and blade length of 16 mm;
– RaCe .04 taper # 25, 30 and 35 with overall length of 25 mm and blade length of 16 mm;
– RaCe .02 Taper from # 15 to # 60 with overall length of 25 mm and blade length of 16 mm.

The RaCe series also includes for flaring the coronal third of the canal, the Pre-RaCe, availabe in ISO diameters 40 with .10 and .06 taper, ISO 35 with .08 taper and ISO 30 with .06 taper. The Pre-RaCe has an overall length of 19 mm with a blade length of 10 mm. All the instruments of the RaCe series have a particular rubber stop divided into 8 petals, defined as Safety Memo Disk (SMD)[17] that represents the recommended method by the manufacturer to keep a controlled check of instrument fatigue. After using each instrument a number of petals proportional to the radius of the canal curvature (which is evaluated by placing a SMD transparent gage over the diagnostic radiograph) are removed, in this way the operator is aware of how much fatigue stress each RaCe instrument has been subjected to and therefore whether to continue to use it or discard it.[17] The RaCe can be used either in the crown-down or step back sequence; the recommended rotational speed is 600 rpm, while the use of torque control for this instrument would not be fundamental, considering its low tendency to screw in.

Fig. 13.79. Using the special plastic insert it is possible to convert the hand Rotary ProTaper into hand instruments (Courtesy of Dentsply Maillefer).



A B

Fig. 13.80. Race # 30.06 (FKG). **A.** Tip (x25). **B.** Body (x25).

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14

Cleaning and Shaping the Root Canal System

Elio Berutti, Arnaldo Castellucci

According to an old and famous endodontic axiom, what is removed from the root canal is more important than what is placed inside.[156]

Without minimizing the importance of the obturation phase, it is nonetheless true that the phase of preparing or emptying the root canal is undoubtedly the most important, the most complex, and the most delicate.

It is difficult to imagine how one can completely obturate a canal that has not been adequately cleaned and disinfected. On the other hand, minor deficiencies in the filling of a root canal that has been totally debrided and disinfected can be biologically tolerated, as well as they can be contributing causes of periapical inflammation in a root canal that remains infected.[156] Therefore, the dentist should direct as much attention and time as possible to thorough preparation of the canal. Good preparation facilitates the subsequent phase of obturation.

Schilder correctly states that even a dentist who is not conversant with his obturation technique can easily obturate a root canal with warm gutta-percha as long as the root canal has been cleaned and shaped *lege artis*.[155]

On the other hand, haphazard preparation of a root canal that does not respect the endodontic anatomy will negate any attempts to obtain a perfect obturation of the entire root canal system.

Over the years, canal preparation has been described by a variety of names, including "enlargement", "mechanical preparation", and "instrumentation".

These descriptions are not precise, because the root canals are not simply "enlarged" or "instrumented;" nor is the ultimate goal of "preparation" to reproduce in the canal the shape of the instrument being used. In modern Endodontics, which emphasizes the related biological and anatomical problems, "cleaning" and "shaping" are more correct terms.[150]

Schilder introduced these terms to the endodontic vocabulary in 1974. Since then, they have been universally used to indicate the principal goals of canal preparation.

When "preparing" a root canal system, it is in fact cleaned of all inorganic debris, organic substrates and microorganisms, and it is shaped to facilitate the placement of a permanent three-dimensional filling.

The two procedures of cleaning and shaping are intimately related, both conceptually and mechanically-temporally. When one of the two is performed well, the other will also be correctly performed: shaping facilitates cleaning!

In preparing the root canals, one must assure that no trace of organic or inorganic material, which could contribute to the growth of bacteria or generate products of tissue decomposition, is left in the root canal system, and that any microorganisms that might be present are removed or destroyed. At the same time, one must plan and prepare within each root canal the cavity form or shape that is appropriate for the simplest and most effective three-dimensional obturation:[152] shaping facilitates obturation! If the root canal is shaped well, every clinician could compact the gutta-percha in root canals in three dimensions.[7,148]

It is important to appreciate that *files* produce shape, but it is essential to understand that *irrigants* clean a root canal system.[144]

Since shaping facilitates cleaning and cleaning is completed *after* a complete shaping is achieved, (shaping allows a deeper and more apical penetration of the irrigating solutions, and a deeper and more complete dissolution of the existing organic material), today it is preferred to speak in terms of "*shaping*" first and "*cleaning*" later. Furthermore, taking into consideration the results obtained with the new NiTi instruments, which allow to ideally shape relatively easy root canals sometimes in just a few minutes, while the cleaning of the same system needs much more time, today is considered more appropriate to speak in terms of "shaping and cleaning", since in chronological order the root canal system is first shaped and then later becomes adequately cleaned, if irrigation protocols are followed. Nevertheless, for practical reasons, in our chapter we will keep the old sequence, describing the cleaning principles first and the shaping objectives later.

A controversial issue in endodontics is: is it possible to thoroughly clean the root canal system? Some dentists think it is impossible and in order to be as close as possible to the ideal result, it is necessary to enlarge the root canal with large size instruments, as a deepper cleaning is only obtainable with bigger enlargement. Many dentists, on the other hand, correctly believe that it is possible to clean into all aspects the root canal anatomy.[192] This obviously not just with files, which can only take care of the negotiable part, but mainly with irrigants, which can take care of the unnegotiable and inaccessible aspects of the root canal system: isthmus, resorptions, lateral canals, bifidities, finns etc. As already stated, one concept must be absolutely clear: files shape and irrigants clean, and this is demonstrated by many accredited studies.[23-25,48,66,94,108,142,192] Now, the question is the following: how do we know when a root canal is totally cleaned? The answer is: when there is sufficient shape to fit at least an .08 or .10 taper gutta-percha cone (fine-medium or medium of the nonstandardized serie).[7,114,191] If there is room for such a tapered cone, we also have room for an effective volume of irrigant that, with sufficient time, can penetrate and clean every aspect of the complex anatomy of the root canal system.[108,139]

CLEANING

The purpose of cleaning is to remove all intracanal material, whether of pulpal origin, vital or necrotic, or microorganisms, from the root canal system.

The removal of vital pulp tissue

In sufficiently wide and straight canals, broaches are recommended to withdrawn the pulp tissue all in one piece.

Barbed broaches are produced from a slightly conical, round metallic filament, which is notched in such a manner as to create a "multiple barb" (Fig. 14.1). It is a very delicate instrument that fractures easily. It is not designed to work on canal walls nor, far less, to engage them, but rather only to hook and twist the pulp filament around itself so that as to extract the pulp from the root canal.

Used properly and safely, therefore, the instrument should never come into contact with the canal walls.

It cannot be used indiscriminately in any situation. First, the correct size must be chosen. Furthermore, it must be wide enough to engage the pulp effectively, but not so wide as to touch the canal walls.

Once it has hooked the pulp filament around itself for two-thirds of its length, the apical third of the pulp will usually become dislodged easily and sectioned without having to thread the instrument to the apex (Fig. 14.2).

One may draw three conclusions from the above statements:

– the broach must never be used in narrow or calcified canals
– it must never be introduced into curved canals or into curved portions of straight canals
– it is useless, as well as dangerous, to introduce it to the apex.

It may be used confidently in the upper central incisors, in canines known to have a single canal, in up-

Fig. 14.1. Barbed broach.

per second premolars with a single canal, in the palatal roots of the upper molars, and in the distal roots of the lower molars. It is always introduced as far as two-thirds of its length.

If one suspects or knows with certainty that a root has two canals, a broach must not be used. This applies in the lower incisors, in canines with two canals, in the upper and lower first premolars, in upper second premolars with two canals, in the mesial roots of the lower molars, and in the buccal roots of the upper molars.

The correct technique for the use of the broach (with the rubber dam in place, of course) requires that an adequate access cavity be prepared and irrigated with sodium hypochlorite. Inadequate irrigation or poor control of bleeding may cause discoloration of the tooth within a few hours (Fig. 14.3). The broach is introduced for two-thirds of the length of the root canal. The instrument is rotated at least 180°, and it is then extracted (Fig. 14.4).

Another technique for the use of the broach is that proposed by Riitano,[138] who suggests that two broaches be introduced in the coronal two-thirds of the canal and rotated around each other.

The removal of necrotic pulp tissue and microorganisms

Pulp tissue that is necrotic or in an advanced state of degeneration cannot be removed with a broach. This is obviously even truer where microorganisms are concerned.

The removal of this material is achieved by the use of irrigating solutions and the mechanical action of the endodontic instruments.

Irrigating solutions

As already suggested with regard to access cavities and pretreatment, the root canal instruments must never be used in dry canals, but rather should always be completely immersed in irrigating solutions that completely fill the root canal and pulp chamber.

Over the years, many substances have been tried: sulfuric acid,[38] a mixture of sodium and potassium,[158] sodium dioxide,[93] sodium methylate,[101] papaine,[195] a solution of sodium hypochlorite and sodium chloride,[189] hydrochloric acid, sodium hydroxide, potassium hydro-

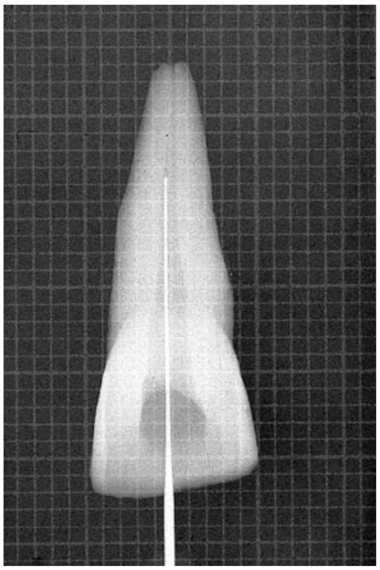


Fig. 14.2. The barbed broach must be introduced for about two-thirds the length of the root canal without coming into contact with the dentinal walls.

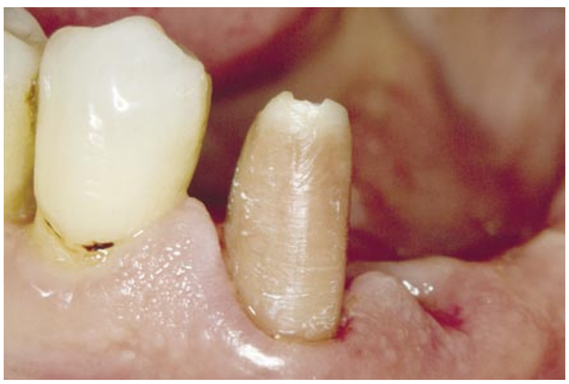


Fig. 14.3. The presence of two narrow root canals in this lower premolar of an elderly patient was a contraindication to the use of a barbed broach by the previous dentist. Failing to remove the pulp tissue, he only caused considerable hemorrhage, poor control of which caused readily apparent discoloration in the course of only 24 hours.

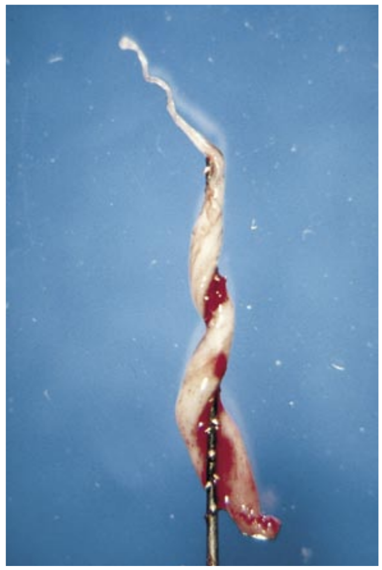


Fig. 14.4. The barbed broach, which was introduced for two-thirds the length of the canal and rotated 720°, has hooked the pulp filament, which was sectioned at its point of entry in the root canal.

xide, citric acid,[188] urea peroxide (Gly-Oxide),[30,175] aminoquinaldinium diacetate (Salvizol),[87] sodium lauryl sulfate,[100] dodecyldiaminoethylglycine (TEGO),[81] ethylenediaminetetraacetic acid (EDTA),[112,124,158] a combination of urea peroxide and EDTA (RC Prep),[176] chlorhexidine gluconate,[49,126] solutions of chlorhexidine digluconate, dodecyldiaminoethylglycine and sodium fluoride (Red Tubulicid), solutions of chlorhexidine digluconate and dodecyldiaminoethylglycine (Blue Tubulicid),[28,29,186] and solutions of orthophosphoric acid, citric acid, and a cationic surfactant (Canal-Clean).[139]

Irrigating solutions for endodontic use must meet precise requirements:

a) they must be able to digest proteins and dissolve necrotic tissue
b) they must have a low surface tension to reach the apical delta and all the areas that cannot be reached by the instruments
c) they must have germicidal and antibacterial properties
d) they must be non-toxic and non-irritating to the periapical tissues
e) they must keep the dentinal debris in suspension
f) they must lubricate the canal instruments
g) they must prevent discoloration of the tooth; indeed, they should bleach the tooth
h) they must be relatively harmless to the patient and dentist
i) they must be readily available and inexpensive.

Sodium hypochlorite (NaClO) is the irrigating solution most used today. More than the others, it meets the requirements listed above.

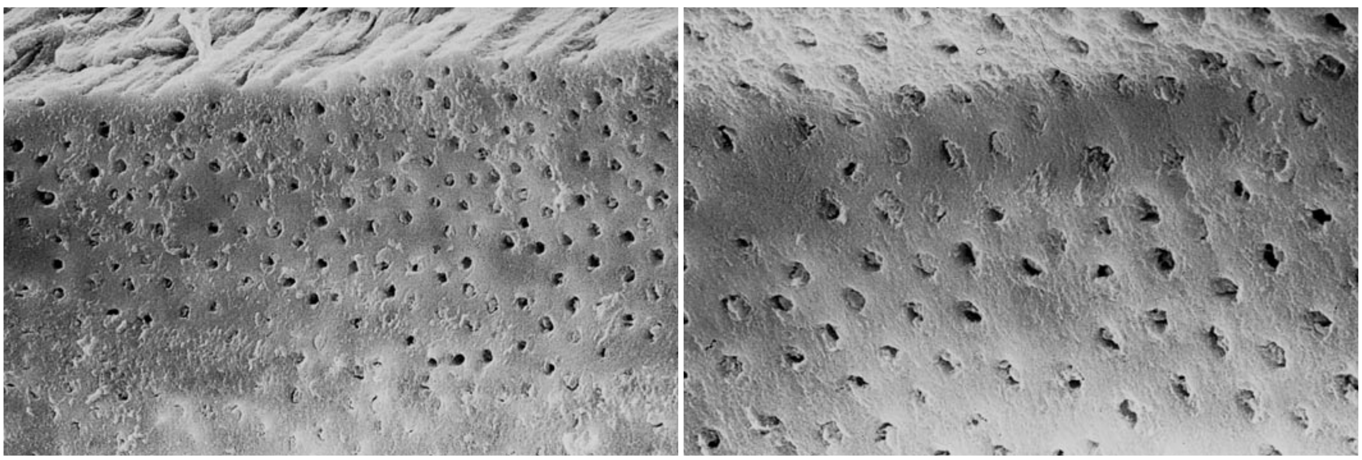
In 1915, Dakin[47] reported the use of 0.5% sodium hypochlorite for the irrigation of wounds sustained by soldiers in the First World War. Taylor[179] and Austin[20] tested the solvent activity of Dakin's solution in vitro and in vivo in non-vital tissues. In 1936, Walker[189] found that a solution of 3% sodium hypochlorite and sodium chloride was a good solvent for organic substances. He was the first to recommend its clinical use as a root canal irrigant. In 1941, Grossman and Meiman[72] demonstrated in vitro the solvent activity of this solution on pulp that had just been extracted. In the same year, Grossman recommended irrigation with alternating solutions of NaClO and 3% hydrogen peroxide.[68] Finally, in 1954, Lewis[102] suggested Clorox (5.25% commercial bleach) as a source of sodium hypochlorite for endodontic use.

a) Solvent action

The ability of sodium hypochlorite to dissolve organic substances and thus to dissolve pulp fragments and debris (Fig. 14.5) is well known and easily documented. One need only to place a broach with a freshly extirpated pulp in a dappen dish filled with sodium hypochlorite solution and observe the digestion of the pulp tissue within a few minutes. The pulp filament detaches from the broach and is transformed into a suspension of small particles (Fig. 14.6).

Sodium hypochlorite effects its solvent activity on necrotic tissues and tissue fragments that have lost their blood supply; it is ineffective on vital tissues

A



B

Fig. 14.5. A cleaned and shaped lower premolar viewed by scanning electron microscopy. Saline solution was used for irrigation. **A**. The surface of the root canal appears smooth, without organic debris, which has been removed by the mechanical action of the instruments. However, lacking the digestive activity of sodium hypochlorite, the remains of odontoblastic processes are still present and visible within the dentinal tubules (x1,000). **B**. At higher magnification, the organic material within the dentinal tubules is even more appreciable (x2,000).

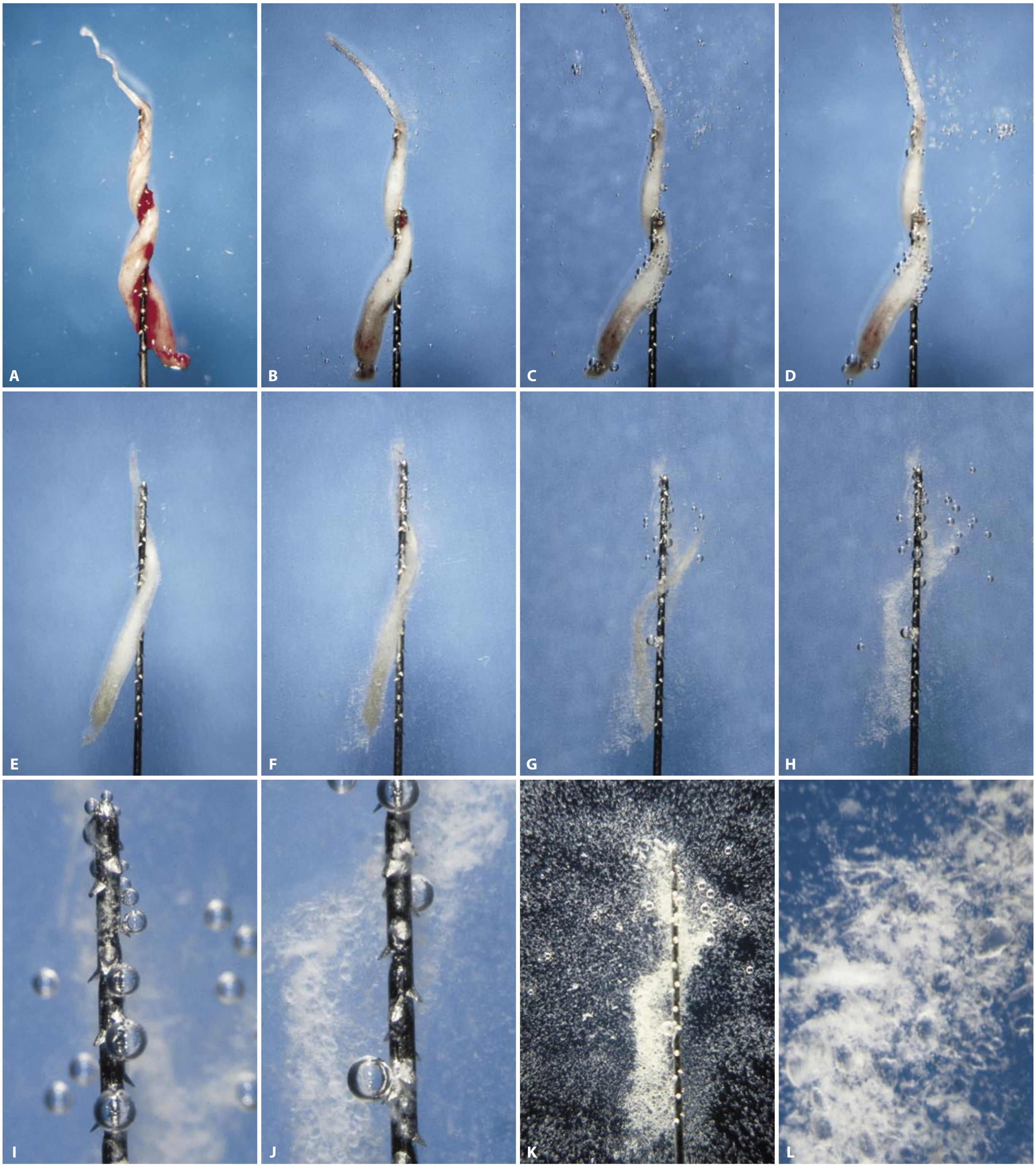


Fig. 14.6. The recently-extracted pulp filament has been immersed in a dappen dish containing 5% sodium hypochlorite at 50°C. The photographs were taken at 1-2 minute intervals. **A-H.** The organic material is digested before one's eyes, and it deposits on the bottom of the glass in the form of small particles. **I**. Detail of the tip of the barbed broach. **J**. Detail of the body of the barbed broach: the pulp is no longer wrapped around the instrument. It has deposited on the bottom. **K**. Lateral illumination gives a better view of the pulp debris in suspension. **L**. Detail of pulp debris photographed on the bottom of the glass.

with an intact blood supply: as a matter of fact, when antibiotics were not available yet, lavaging large flesh wounds with "Dakin's solution" saved many lives that may have been otherwise lost to gangrenous infection.

In the literature there is some disagreement regarding the solvent action of sodium hypochlorite on the vital pulp tissue.

Grey[67] has demonstrated the digestive action of sodium hypochlorite in the lateral canals of necrotic teeth (Fig. 16.7). In this experiment, tissues contained in the lateral canals of vital teeth appeared almost intact and undigested.

Using scanning electron microscopy, McComb and Smith[112] arrived at the same conclusion. Bashford[12] has hypothesized that "the local action of hypochlorite on vital tissue is kept under control for a certain period of time by the efficient blood circulation, which both provides protein-containing fluid and removes and neutralizes the hypochlorite".

The findings of Grey's research seem to confirm the opinion of many previous investigators, such as McComb et al.,[113] who felt that sodium hypochlorite had little or no effect on vital tissues when used in controlled clinical situations. Examination of the accessory canals containing pulp deemed vital suggests that some degree of tissue digestion occurs, especially in the portion of the accessory canal adjacent to the principal root canal, but this seems to be due to the digestive action of the hypochlorite on the portion of the tissues that has deteriorated in the interval of time between the two appointments. The limited activity of sodium hypochlorite on tissues still perfused with blood also seems to confirm the clinical impression that during the obturation phase with warm gutta-percha, it is easy to accomplish filling of the lateral canals of necrotic teeth, whose content has been digested, rather than of vital teeth, which still contain a vital pulp stump.

In another study using a radiopaque irrigating solution, the solution was identified only in the accessory canals of roots with necrotic pulp.[146]

Newer studies that have appeared subsequently[141] seem to dispute Grey's conclusions, as they attribute a solvent action to hypochlorite even on vital, well-perfused tissues. Rosenfeld et al.[141] measuring the pulpal level, indicate a strong solvent action of full-strength Clorox on vital noninstrumented teeth. The limited solvent effect in the apical region was attributed to the barrier of the apical plug of dentin filings, narrow lumen, and the fibrous nature of the apical pulp tissue. According to these authors, the major barrier to be overcome in the clinical use of this popular irrigant is its ability to penetrate confined areas. Therefore, the conclusions we can deduce from this important article are that if the canal has been sufficiently enlarged (which means it holds an adequate quantity of fresh irrigating solution) and if we give to the irrigant an adequate amount of time, it can exert a digestive effect even on vital, young, healthy human pulp tissue, like the one of the accessory canals.

On the other hand, another more recent study by Klinghofer[94] has confirmed that NaClO can penetrate lateral canals and bifidities, and this was done in vivo, using a radiopaque irrigant (Hypaque). Scarfe et al.,[147] in agreement with the findings of Klinghofer, alternating a water-soluble radiopaque contrast solution to the use of NaClO while preparing root canals in vivo, demonstrated that as NaClO dissolved organic materials, the radiopaque solution progressively penetrated into all aspects of the root canal system. Radiopaque contrast solutions provide visual evidence that irrigating solutions can dynamically circulate along the pathways of the pulp.[108]

Histologically, Grey[67] demonstrated that a 5.25% solution of NaClO routinely dissolved organic tissue and cleaned both large and extremely fine ramifications. These results have been later confirmed in a SEM study by Daughenbaugh.[48] He performed canal preparation procedures in vivo on teeth that were subsequently extracted for prosthetic reasons. He demonstrated that a 5.25% solution of NaClO is able to penetrate, dissolve, and flush out organic tissue and related debris from inaccessible aspects of the root canal system where files cannot reach.

This solvent effect, like any other chemical reaction, is increased by heat. Several articles have shown that warming NaClO to approximately 60°C (140°F), significantly increases the rate and effectiveness of tissue dissolution.[24,44,57,124] Clinically, a 60°C warm-water bath is prepared by placing a beaker of water on a hot plate. Preloaded syringes of NaClO may be warmed by placing them into this warm-water bath (Fig. 14.7 A). Recently new technologies have been developed to warm up the preloaded syringes (Fig. 14.7 B) or other even more sophisticated that deliver various types of "on-line" irrigants from in-office air-pressurized bottles (Fig. 14.7 C) (Vista Dental Products, Racine, WI). In this method of irrigation, clinicians can select among several pre-heated solutions with a push of a button.[144] They can also choose among a variety of needles of different gauge and different shapes, to achieve deeper and safer placement. Certain cannel dispense irri-

Fig. 14.7. **A**. A small "mug warmer" is an optimal heat source to keep the irrigating solutions at the desired temperature. **B**. Vista Dental produces this syringe warmer. **C**. The Endo Irrigator (Vista Dental) allows the clinician to switch from one pre-heated solution to the other just with a push of a button.

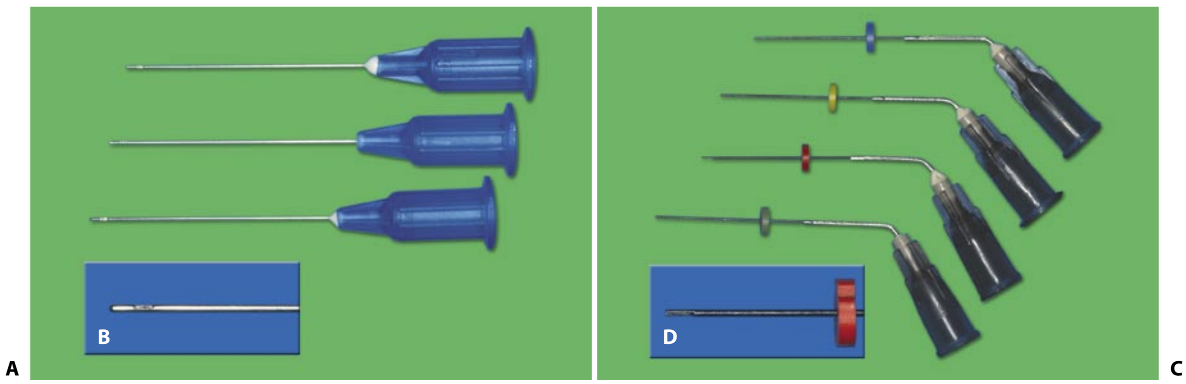


Fig. 14.8. **A**. Maxiprobe needles with the safe lateral opening. **B**. The tip at higher magnification (Dentsply Maillefer). **C**. Very narrow and flexible needles made in nickel titanium, to carry the irrigants deeper in the canal. **D**. The tip at higher magnification (Vista Dental).

gant through a closed ended side port delivery system (Figs. 14.8 A, B), and some others are very narrow and flexible, made in nickel titanium (Figs. 14.8 C, D).

The activity of hypochlorite seems to be slower on necrotic pulp tissue fixed by parachlorophenol or formaldehyde.[180]

One must keep this in mind when cleaning root canals that have been pretreated with medications containing these substances.

b) Low surface tension

Another important conclusion can be drawn from Grey, Klinghofer, Scarfe, Daughenbaugh, Yana, and Machtou, studies: because sodium hypochlorite has a low surface tension, it can reach areas beyond the reach of instruments (Fig. 14.9), lateral canals (Fig. 14.10), resorptions (Fig. 14.11), depressions and anfractuosities of the endodontic space, including the

A

B

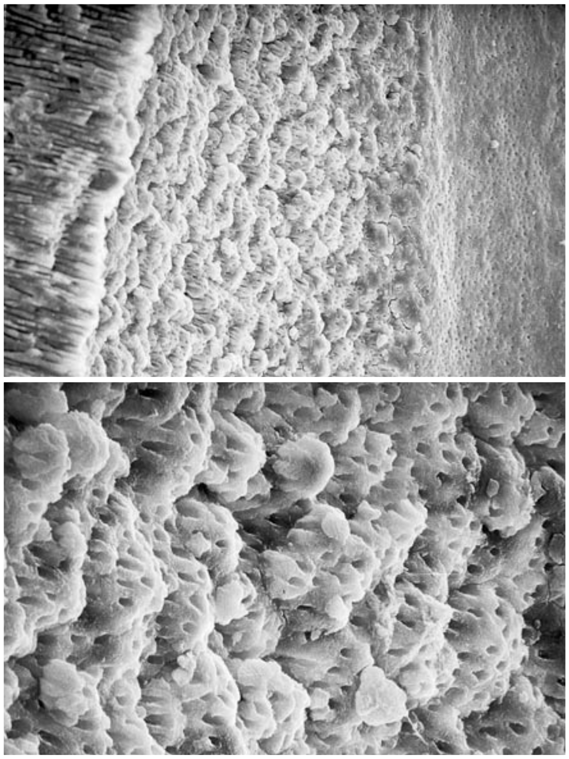


Fig. 14.9. Palatal root of an upper first molar which has been cleaned, shaped, and irrigated with 5% sodium hypochlorite, dried with paper points, and then longitudinally fractured and examined by S.E.M. **A**. On the right, the zone of the root canal where the instruments have worked is visible. This is smooth, free of debris, with patent dentinal tubules, not blocked. In the center, the canal wall presents calcospherites of predentin; therefore, in this zone only irrigating solutions, not instruments, have worked. On the left, one recognizes the split surface of the root, with the dentinal tubules in longitudinal section. Coronal third (x300). **B**. Detail of the central zone of the preceding figure. One better appreciates the calcospherites, the mineralization front of the predentin (x1,000).

Fig. 14.10. A lateral canal in the apical third of the distal wall of the distal root of a lower first molar, viewed by S.E.M. To that extent to which it can be explored, the canal appears to be completely free of organic material (x1,000).

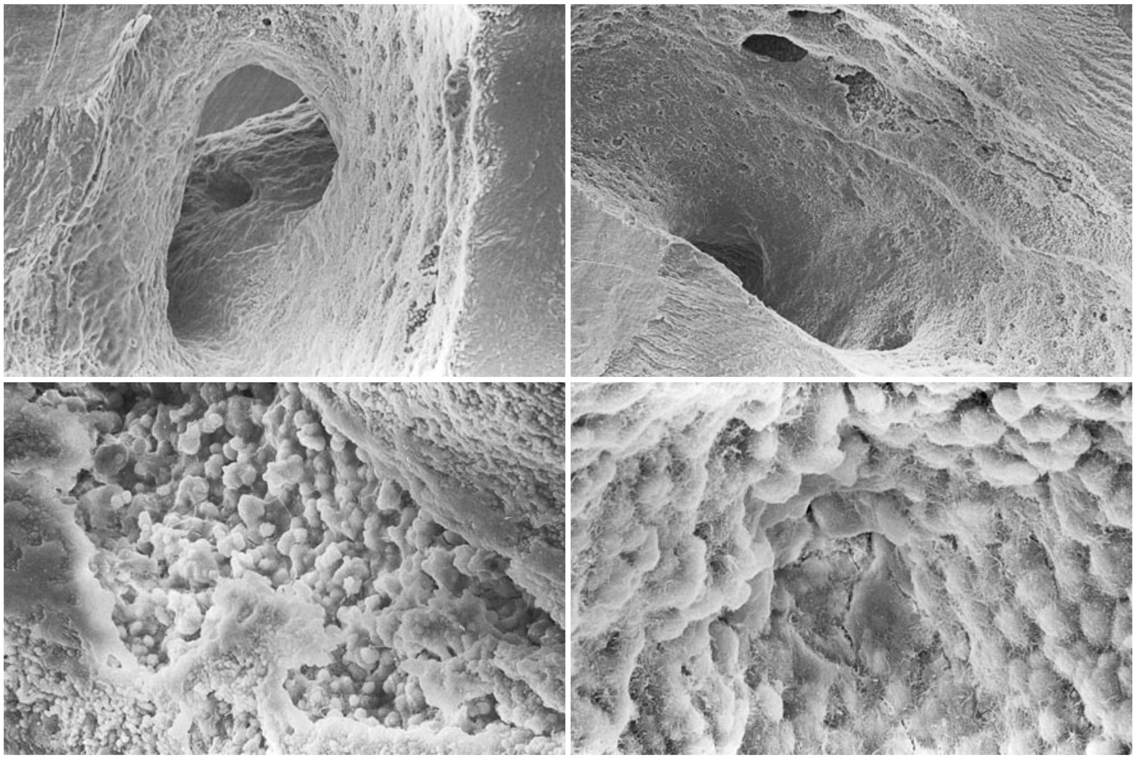
Fig. 14.11. S.E.M. photomicrograph of the palatal canal of an upper first molar. The lacuna visible on the dentinal wall represents a small area of internal resorption. For obvious reasons, the instruments were not able to work on the walls of this defect, which nonetheless appears to be free of organic material, owing to the solvent activity of sodium hypochlorite.

apical delta (Fig. 14.12). Hypochlorite exerts its activity on predentin and then on the contents of its tubules[141] (Fig. 14.13). The clinical significance of this is evident if one considers that in infected teeth most bacteria are limited to the predentin and adjacent dentin.[21]

Because of its low surface tension, it is not necessary to generate great force to inject sodium hypochlorite into the root canal to make it reach the proximity of the apex. Hypochlorite passively reaches deeply into the canal, with the help of the endodontic instruments. Indeed, its presence has been demonstrated for the entire depth corresponding to the working length of the instruments.[146] When an instrument is placed into a relatively small canal, the file tends to displace the irrigant. When the instrument is withdrawn, the irrigant usually flows back into the space previously occupied by the file. This phenomenon must be appreciated to integrate the most efficacious irrigation methods clinically.[144]

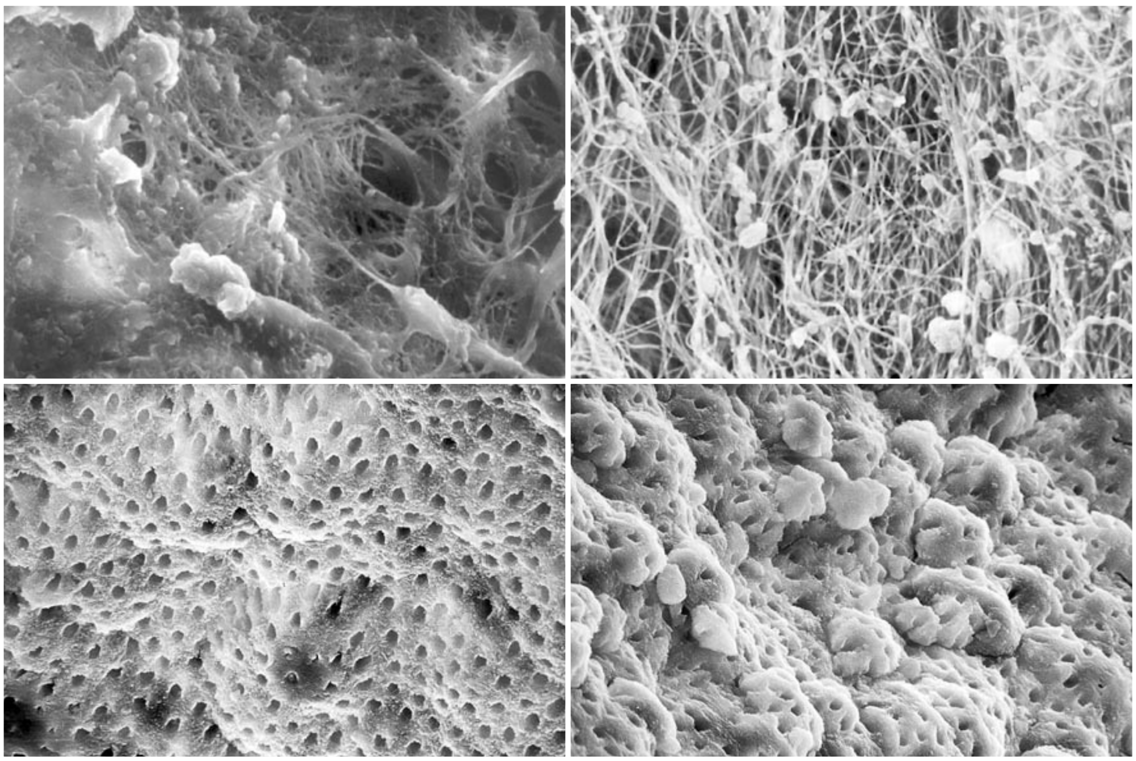
Several investigators[2] have proposed adding a biocompatible surfactant (polysorbate[156]) to sodium hypochlorite, so as to lower its surface tension and improve its ability to penetrate the principal canal, lateral canals, and tubules of dentin and predentin. The addition of surfactant would lower the surface tension by 15-20%.

Other authors[45] suggest using ethyl alcohol as a surfactant because of its ready availability. A 30% dilution of hypochlorite in alcohol has been shown to be most effective, though it has some disadvantages. The solution must be fresh, as it is labile. After 15 minutes, hypochlorite combines with ethanol to produce chloroform. Since it is particularly irritating to the pe-



A B C D

Fig. 14.12. **A**. S.E.M. photomicrograph of an apical delta. 5% sodium hypochlorite seems to have digested the organic material (x120). **B**. The same area of the previous photograph as seen with different angulation (x72). **C-D**. Details of the preceding figure. The depressions in this canal have not been shaped by instruments, but have been cleaned by sodium hypochlorite (x500, x1,000)



A B C D

Fig. 14.13. S.E.M. photomicrograph of a lower incisor (**A**) and upper central incisor (**B**) which have not been treated endodontically. The connective web of predentin is visible. **C**. Distal root of a lower second molar. Coronal third: the wavy appearance of the canal wall is clear proof that the instruments were not effective in this tract. Notwithstanding that, no trace of organic material is visible, owing to the digestive action of sodium hypochlorite (x1,000). **D**. Palatal root of an upper first molar. Middle third: calcospherites, the mineralization front of predentin, indicate that in this case as well the wall was not shaped. The lack of organic material, nonetheless, indicates that cleaning has occurred, owing to the digestive action of sodium hypochlorite (x1,000).

riapex, this solution becomes noxious once the canal has been sufficiently enlarged. It is therefore indicated only in the early phases of the treatment of particularly narrow root canals.

Nonetheless, in these author's opinion, the low surface tension of sodium hypochlorite alone is more than enough to assure optimal results.

c) Germicidal and antibacterial properties

The germicidal and antibacterial properties of sodium hypochlorite have been known for some time[42] and demonstrated by many investigators.[35,36,53,166] When in contact with water, NaClO produces hypochlorous acid and sodium hydroxide. Then hypochlorous acid produces hydrochloric acid and oxygen. The free chlorine has germicidal properties when it combines with protoplasmatic constituents, like proteins.[132]

A 5.25% solution of sodium hypochlorite has been shown to be potently bactericidal against Gram-positive and Gram-negative bacteria, spore-producing microorganisms, and is also effective against virus. Recent in vitro studies have also demonstrated the germicidal effect of 5.25% sodium hypochlorite against some obligate anaerobes commonly found in infected root canals (Bacteroides melaninogenicus, Bacteroides fragilis, Clostridium perfringens, and Peptostreptococcus anaerobius).[123]

Zehnder et al.[202] have recently demonstrated the killing efficacy of low concentrations of NaClO against *Enterococcus faecalis*, a facultatively anaerobic gram-positive coccus which exibits a high level of resistance to a wide range of antimicrobial agents and which is among the few facultative bacteria associated with persistent apical periodontists.[167]

Sodium hypochlorite is particularly indicated for the sterilization of gutta-percha cones,[162,174] which obviously cannot be heat-sterilized. Immersion of gutta-percha cones in hypochlorite for about one minute is sufficient to sterilize them completely (and also to neutralize the spores of Bacillus subtilis, which are particularly resistant), without altering their physico-chemical structure.[162]

Recent studies have reported that both hypochlorite's capacity to dissolve protein substances[44] and its germicidal properties[51] increase significantly at higher temperatures.

On the other hand, the bactericidal effect is not influenced by the different amounts of concentrations: several studies reported that NaClO has the same antibacterial action at concentration of 5,25% and of 0,5%.[36,46]

We should also remember that hypochlorite reacts with organic debris in the root canal and in that way facilitates cleaning; however, this reaction inactivates the hypochlorite and reduces its antibacterial capacity. This represents one more reason to apply frequently fresh hypochlorite solution into the root canal.[36]

d) Toxicity

Regarding the toxicity of sodium hypochlorite to periapical tissues, it is obvious that its use must be limited to within the root canal and every precaution must be taken to avoid its extrusion beyond the apical foramen.[32] In addition to using a rubber dam, which is taken for granted, one must check carefully the working length of the instruments, irrigate the root canal always very gently, use small needles that never engage the root canal, and visually check any irrigating solution that refluxes from the access cavity while being introduced into the root canal.

This problem is more readily appreciated in a necrotic tooth with a lesion than in a vital tooth, in which the adjacent healthy tissue would contribute to confining the solutions within the root canal[146] and hamper its extrusion.[187]

The fact that sodium hypochlorite dissolves necrotic tissues, while having little effect on adjacent viable tissue,[157] the description in the literature of a case of inadvertent injection of the inferior alveolar nerve with a cartridge of 5.25% sodium hypochlorite which resolved with *restitutio ad integrum* within two weeks,[80] the reported low toxicity of sodium hypochlorite inadvertently sprayed in the eye,[39,84] and the complete and relatively rapid resolution of symptoms after 0.5 ml of 5.25% sodium hypochlorite was inadvertently forced beyond the apex[16,17,145] do not negate the cytotoxicity of the irrigating solution. If forced beyond the apex, sodium hypochlorite can cause inflammation, possibly very severe, and damage (paresthesia), possibly permanent,[135] on account of its characteristics as a strongly "hypertonic", caustic, and irritating-agent[16,141,169] whose action is not limited to necrotic tissue only. Sodium hypochlorite is cytotoxic to all cells, with the exception of highly keratinized epithelium.[128] It should therefore be used with great care in Endodontics.[82] The hand that holds the irrigating syringe is always kept in motion when dispensing irrigant to prevent the needle from inadvertently wedging in the canal. Slowly injecting irrigant in combination with continuous movement will virtually eliminate NaClO accidents.[144]

Finally, a case of allergy to sodium hypochlorite has recently been reported.[6,90] Although very rare, its occurrence obviously demands the use of an alternate endodontic irrigant, such as bis-dequalinium acetate (Solvidont),[172] a quaternary ammonium with many properties similar or even better than sodium hypochlorite, such as its bactericidal effect,[171,173] its detergent action,[88,89] and lower toxicity.[170,172]

e) Preventing blockage

The function of hypochlorite within the root canal is not only the chemical one discussed above; it also performs a very important physical-mechanical role. It keeps the dentinal debris in suspension, preventing blockage of the apical portion of the canal. The use of endodontic instruments within the root canal generates a large amount of dentinal filings, which the dentist must keep under control by carefully, continuously refreshing the solution within the pulp chamber and the root canal (Fig. 14.14). The root canal must be "irrigated," not "injected", and the fluid must be changed when one has finished working with each instrument.

The irrigations must be frequent and delicate, and the goal should be not just to "sprinkle" the walls of the canal with the irrigating solution, but to dilute the suspension of dentinal debris as much as possible, as it tends to settle principally in the apical zone, risking blockage.

It also appears obvious that the concept – to which many authors subscribe – of enlarging the canal until white dentin shavings are no longer seen on the spirals of the instruments just extracted from the canal is wrong. Rather, the dentinal filings should not come away with the endodontic instrument, but should remain suspended in the irrigating solution. If they are removed with the instrument, the irrigation is either insufficient or completely non-existent.

Endodontic instrumentation without the help of an irrigant is also extremely dangerous. In addition to leading easily to canal blockage by dentin mud, it can lead to fracture of the instrument as a result of the greater force required for its use, the lack of lubrication, and possible engagement of the instrument in the dry canal.[187]

To facilitate the mechanical removal of dentin shavings with sodium hypochlorite, many authors[69,110,152,160,177] suggest alternating with 3% hydrogen peroxide.

The generation of oxygen by the chemical reaction between hydrogen peroxide and sodium hypochlorite within the root canal produces an effervescence that contributes (in the lower teeth and in upper zones only after having changed the position of the patient in the chair) to the dentin mud being churned upwards, towards the access cavity, where it is mechanically removed.

Two other potential advantages of the alternating use of 3% hydrogen peroxide and sodium hypochlorite are:

– an increase of the permeability of the dentinal tubules,[110] with consequently greater penetration of the

A B

Fig. 14.14. **A.** The irrigating solution present in the pulp chamber appears turbid after an instrument has worked in the root canal. This is caused by the suspension of dentin mud. **B.** The irrigating solution has been rejuvenated between the use of one endodontic instrument and the next, to prevent the suspension of dentin mud from becoming too concentrated, which would increase the risk of blocking the canal.

intracanal medications into the dentinal tubules and better adaptation of the canal obturation material to the walls
– greater antimicrobial activity, resulting from the action of the oxygen generated on anaerobic bacteria.[70,190]

Nonetheless, other authors do not share the belief in the need to alternate 3% hydrogen peroxide with sodium hypochlorite. In the view of some, their alternating use would be superfluous; others believe it would even be negative. The former have found no difference in the capacity to remove debris between the alternating use of NaClO and hydrogen peroxide and the use of NaClO alone.[3,31,178] The latter have observed that hydrogen peroxide reduces the capacity of NaClO to digest protein substances.[112,180] Furthermore, the liberation of small gas bubbles could act as a barrier to fresh solution reaching the deepest portions of the canal,[144,163] and the oxygen liberated by the chemical reaction of the two agents would produce periapical pain.[83]

Cases of accidental injection of hydrogen peroxide into the periapical tissues have been reported in the literature.[26,129]

These resolved with *restitutio ad integrum*. The removal of dentinal debris by mechanical means, more than by effervescence, could be facilitated by positioning the syringe needle as close as possible to the apical third of the canal[3] or near the apex,[26] without engaging it, so as not to force fluid through the apical foramen.[74]

More recently several authors suggest alternating NaClO with a chelating agent, which, beside having an effervescence similar to hydrogen peroxide, dissolves the smear layer left on the canal walls during instrumentation.[15]

f) Lubricating action

As already suggested, sodium hypochlorite provides lubrication for the use of endodontic instruments. It favors the introduction of instruments even in narrow, tortuous canals, facilitating their work within the canal, limiting their engagement with the walls and finally reducing the risk of fracture.

g) Bleaching action

Sodium hypochlorite also satisfies the need to use an irrigating solution that prevents discoloration of the tooth and may help to bleach them. In fact, 5.25% sodium hypochlorite is prepared and sold commercially as a bleaching agent; it is none other than household bleach.

The bleaching activity, which is described by Luebke[104] as very effective and by Schilder[149] as passive and esthetic, is attributed to its oxidizing activity, which has been reported by Coolidge.[43]

It is an everyday experience that at the end of the cleaning and shaping procedure the tooth appears whiter than the adjacent teeth (Fig. 14.15); this is particularly true in the anterior teeth. The plaster-white appearance, however, is reversible. It recedes within a few hours, and therefore neither the dentist nor the patient should be concerned.

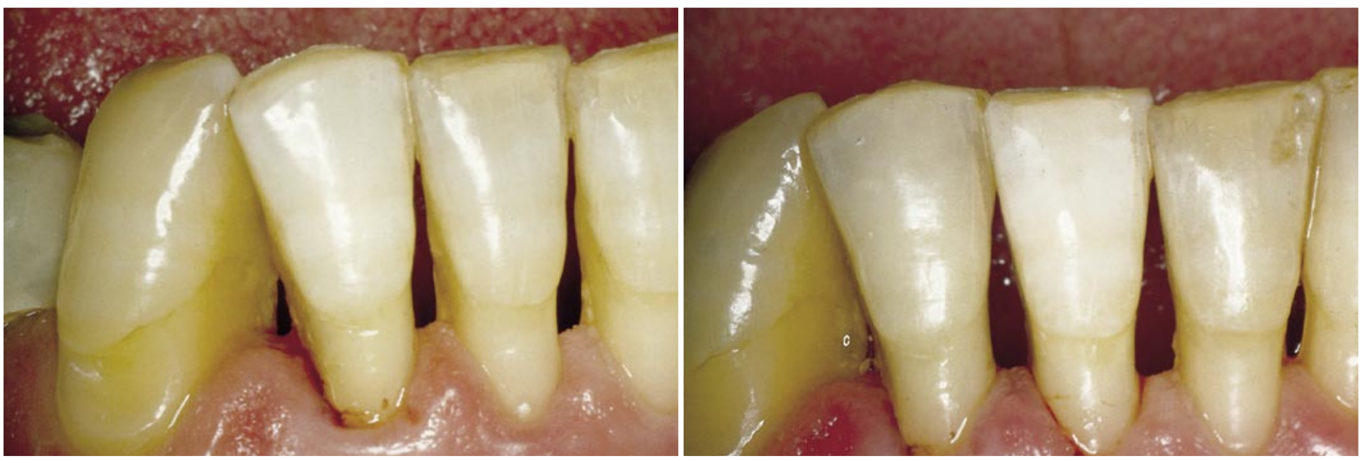
A  B

Fig. 14.15. **A**. Cleaning and shaping of the lower right lateral incisor have just been concluded. Note that the crown is whiter than the adjacent teeth. **B**. Twenty-four hours later, cleaning and shaping of the central incisor have been completed. It now appears whiter, while the lateral incisor has already returned to its natural color.

h) Harmlessness

As already stated, hypochlorite is cytotoxic if forced beyond the apex.

On the other hand, it is not harmful to healthy, vital tissues, especially if they are keratinized. Its use therefore may be considered relatively innocuous, both for the patient and for the dentist. If a small amount passes into the patient's mouth because the rubber dam is not sealing well, it suffices to rinse the patient's mouth with a syringe of the unit, while the assistant aspirates, to completely eliminate the discomfort produced by the unpleasant taste. Likewise, it is to be considered innocuous if the dentist inadvertently touches it.

i) Cost

Commercially-available bleach (Clorox) is 5.25% sodium hypochlorite. Commercially household bleaching agents cannot and should not be used as endodontic irrigant like we used to do in the past and many endodontists still do. Recent studies[57] have shown that the concentration of available chlorine and the pH are not stable, therefore the efficacy as antiseptic and solvent agent decreases with time: less available chlorine means less effectiveness in dissolving tissue. Furthermore, the utilization of household bleach in Italy is illegal (D.L. 29-05-91 #178), since disinfecting solutions used for human beings are considered "medicines" and must first be registered by the Department of Health, Education and Welfare. For this reason, the suggested irrigating solution specifically made for endodontic purposes and duly registered is Niclor 5 (Ogna Laboratori Farmaceutici, Milano, Italy). As a matter of fact, Niclor 5 is 5% NaClO which recent studies[57] demonstrated to have stable pH and above all a stable concentration of available chlorine, particularly if the open bottle is stored at low temperature (4°C or 38°F), and protected from light and air.

A much-discussed and much-disputed subject in Endodontics is the ideal dilution of sodium hypochlorite for intracanal use.

Unfortunately, irrigating solutions that are strong enough to be effective bactericides are also toxic to healthy tissues.[169] On the other hand, this bactericidal action is a necessary property of solutions used to treat teeth with necrotic pulp, in which a greater tendency to the extrusion of fluids beyond the apex has been noted.[146]

In teeth with vital pulp in which the required antibacterial properties are minimal and even very dilute solutions can be used, the problem does not exist.[90] On the other hand, the most important characteristic of the irrigating solution is its solvent action on organic material, and this action decreases as the dilution increases. Therefore, the vast majority of authors[1,20,53,64,71,74-76,110,141,197] favors the use of 5.25% sodium hypochlorite, since they believe that its toxicity (measured as incidence of post-operative pain) is the same as that of physiologic solution if used as a canal irrigant. Furthermore, at this concentration it is much more effective as a solvent of necrotic tissues as compared to more dilute concentrations: dilution reduces the ability to digest necrotic tissues[74] (until one reaches little difference between 1% and 0.5% NaClO, both judged by some authors[185] to be completely ineffective), reduces the detergent capacity and the ability to remove debris,[11,110,177] and even reduces the antibacterial properties.[109]

Other authors[96,119,120,122,168,169] favor the use of hypochlorite at low concentrations, between 0.5% and 1%, given its cytotoxicity and irritant effect on the periapex.

Yet others suggest the use of hypochlorite diluted to 2.5-3%.[66,97,130,140,153,180,185,191]

In our opinion, the ideal concentration is 5.25%, since at this concentration hypochlorite meets all the requirements of an ideal irrigating solution, and when used cautiously in the canal it does not cause damage to the periapex. Furthermore, it is easily available (Niclor 5 Ogna, Italy) and doesn't need any further manipulation.

Chelating agents

The use of chelating solutions in endodontic procedures is suggested by the capacity of these substances to combine chemically with the Ca^{+2} ion and thus, possibly, soften the dentin. The substance most commonly used for this purpose is ethylenediaminetetraacetic acid (EDTA), which, on combining with Ca^{+2} ions causes the hydroxyapatite crystals to transform into the calcium salt of ethylenediaminetetraacetate.

EDTA was introduced in Endodontics for the first time by Nygaard-Ostby[124] in 1957 to facilitate the preparation of the root canals, particularly in the case of narrow, calcified canals.

Stewart et al.[176] have found that, in combination with urea peroxide, EDTA very effectively removes debris within the canal, owing to its bubbling action, and improves the cutting capacity of canal instruments.

Chelating agents are used in endodontics for several purposes, like lubrication, emulsification, and flotation.[144] They are available in either a viscous suspension or an aqueous solution.

RC Prep (Premier Dental Products, King of Prussia, PA) is a viscous chelator, and its main ingredients are EDTA, urea peroxide, and propylene glycol.

Lubrication. Glycol is the lubricant that facilitates the movement of instruments in narrow and calcified canals. The lubricant encourages the file to slip and slide by intracanal calcifications and obstacles, like pulp stones or sheaths of fibrotic tissue.[144]

Emulsification. The use of a viscous chelator is particularly indicated in the initial negotiation of vital cases, as it advantageously promotes the emulsification of organic tissue and facilitates the negotiation of the root canal. Collagen is a major constituent of vital pulp tissue and can be inadvertently packed into a glue-like mass that contributes to iatrogenic blockages.[144] In vital cases, attempting to negotiate any portion of a canal with a # 10 file without the aid of a chelator can be very risky. When the instrument is withdrawn, the vital tissue tends to collapse and readhere to itself. The next larger instrument is not able to pierce through the pulp tissue to progress in an apical direction, and pushes the glue-like mass, blocking the canal. A chelator discourages this tissue phenomenon and accelerates emulsification by leaving a favorable pilot hole that facilitates the introduction of the sequentially larger instrument.[144]

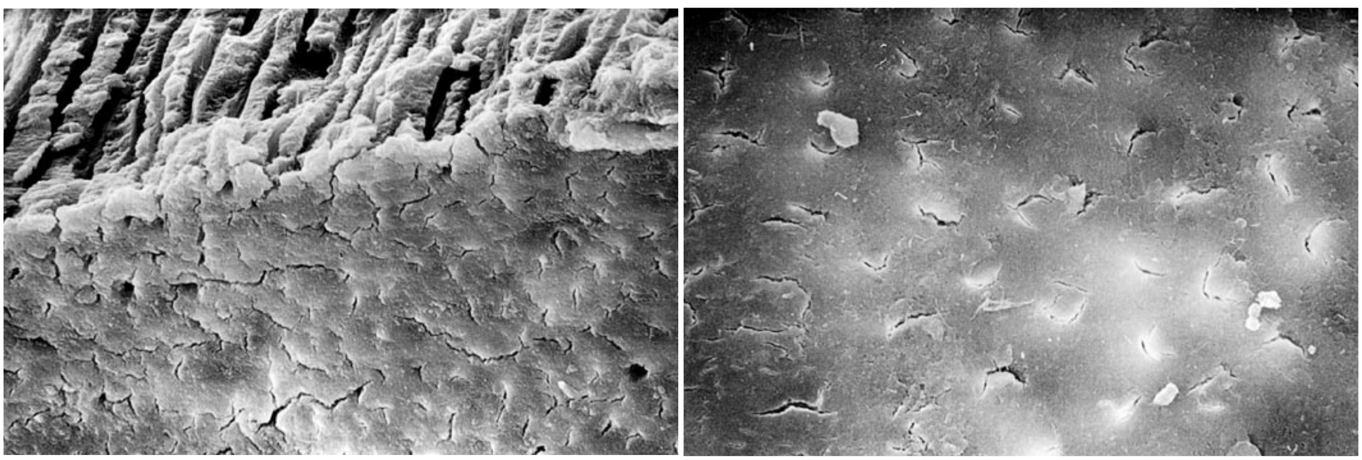
Flotation. A viscous chelator is best used for holding debris in liquid suspension. RC Prep encourages the flotation of pulpal remnants and dentinal muds thereby reducing the probability of canal blockage. Irrigation with NaClO after using RC Prep causes significant effervescence, creating an elevator action to evacuate debris that was dislodged from the root canal system.[144]

An aqueous solution of chelating agent (like EDTA 10% and EDTA 17%, Ogna Laboratori Farmaceutici, Milano, Italy; EDTA 17% Roth International, Chicago, IL) is indicated for finishing the preparation, to remove the smear layer formed on the walls of the canal by the cutting action of instruments.

Many authors[22,60,62,63,112] recommend the use of a chelating agent to remove the layer of dentin mud ("smear layer") that remains smeared on the internal surface of the canal after the endodontic instruments have completed their action (Fig. 14.16). This layer, which occludes the dentinal tubules and therefore reduces their permeability, is most often constituted of inorganic material and therefore cannot be digested by sodium hypochlorite.[63,109,112]

Instead, it can be removed by a chelating agent such as EDTA, used as an irrigating solution together with NaClO. Among the other advantages, this type of irrigation allows filling of a greater number of lateral canals,[61] opens the dentinal tubules, and provides a cleaner surface against which gutta-percha and sealer will adapt.[92]

This substance can be confidently used in narrow, tortuous canals only after they have been completely negotiated. At this point, the chelating agent facilitates the action of the instrument in the removal of dentin around itself. Its use is to be discouraged, however, in the case of canals that are unnegotiable be-



A B

Fig. 14.16. A cleaned and shaped upper central incisor. **A.** The root canal appears to be free of debris, but the dentinal tubules are completely obstructed by dentin mud. Middle third of the root, near the surface of the split, which can be seen at upper left (x1,400). **B.** A nearby zone photographed at higher magnification. The dentinal tubules appear like fissures, because of the presence of a thick smear layer that covers the entire root canal surface (x2,400).

cause of the presence of calcifications or obstacles of whatever type. In fact, when one is making a path in dentin softened by the chelator, it is difficult to know whether one is advancing into the original root canal or whether a new canal is being "made", that is a false canal. The activity of the chelating agent is also inhibited by the presence of sodium hypochlorite. One must keep this in mind when using it within the canal and not forget that the final irrigation must be made with sodium hypochlorite to neutralize the acid.[64,139,197]

The dentin mud or "smear layer"

It is a well known fact that, the main cause of pulpal and periapical pathology, are bacteria. The success of endodontic therapy, that enables one to save the tooth, depends on the dentist's ability to clean and disinfect the root canal system three dimensionally, and then completely fill and seal the space (Fig. 14.17).[148,150]

As has been stated previously, it is important to remember that one cannot clean with endodontic instruments during the shaping process.[14] The shaping process opens the root canal system for the irrigants and allows successive three dimensional obturation, but the true agents of cleaning are the irrigants (Fig. 14.18). Thus one shapes to clean: the instruments shape, the irrigants clean. From this viewpoint the shaping must be seen as a means to obtain the right result which depends on:

1) correct shaping with respect to the original anatomy
2) correct choice and use of irrigants
3) sufficient irrigation action time
4) three-dimensional obturation.

We saw previously how NaClO is an effective solvent of vital and nonvital pulp tissue and therefore it is this sodium hypochlorite which is truly responsible for the deep down cleaning out of the root canal system.[3,141] It being the ideal irrigant, it cannot be considered "complete", and this because it is not able to remove the smear layer produced during the instrumentation.[188]

McComb and Smith were among the first researchers to describe the smear layer.[112]

The smear layer is a consequence of the action of the endodontic instruments which cut the dentin. The debris that is formed is smeared and compacted against the canal surfaces during the movement of the endodontic instruments.

The smear layer can be separated into two distinct components:

– a thin layer that forms a mat over the canal walls with a thickness of 1-2 microns[109] (Fig. 14.19 A)
– a part that is much more aggressive and penetrates the dentinal tubules forming plugs about 40 microns deep[109] (Figs. 14.19 B, C).

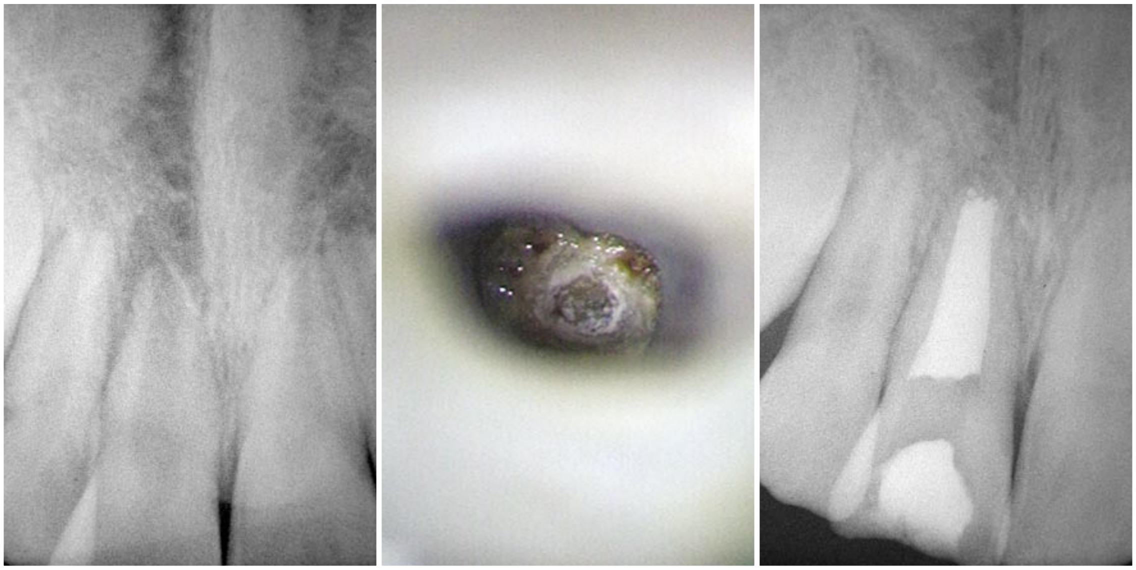
A B C

Fig. 14.17. **A**. The upper left central incisor did not respond normally to vital pulp tests. On the mesial aspect of the root an angular bony lesion is evident. One can suspect the presence of a lateral canal, responsible for the lesion. **B**. The postoperative radiograph shows the complete obturation of the system, previously cleaned by the irrigants. **C**. Four month recall: the bony defect is completely healed.

The smear layer therefore is only present on the surfaces of the canal where the endodontic instrument has been in working contact and not in other areas.[63]

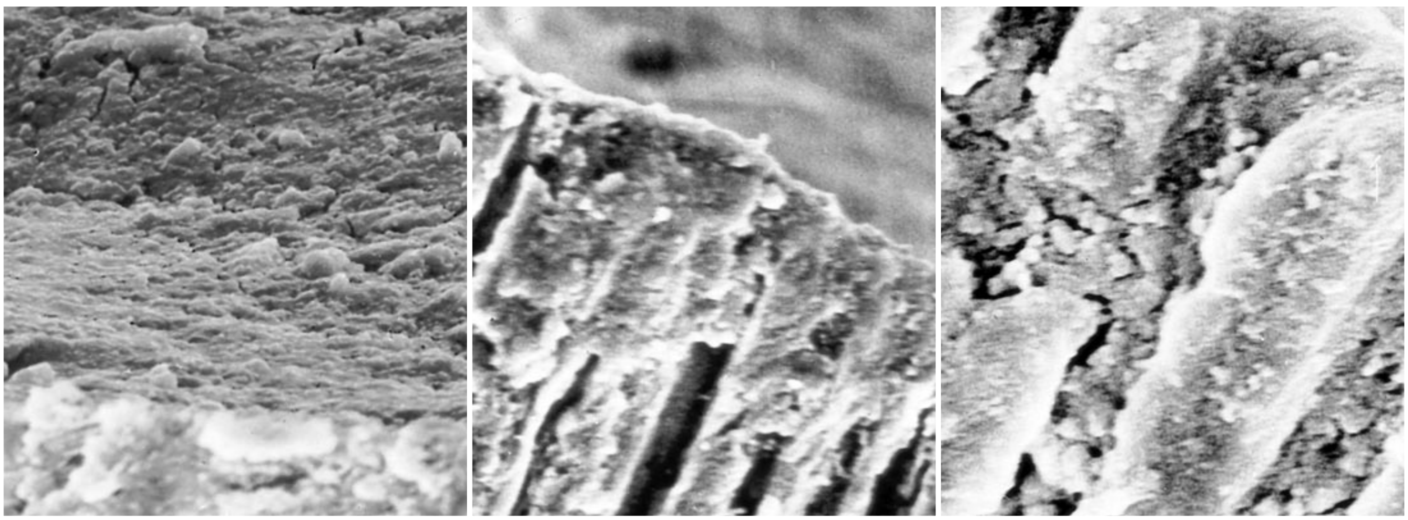
It consists of small inorganic particles of calcified tissue,[63,64,112,117] and organic material (vital residual or necrotic pulpal tissue, odontoblastic processes, bacteria, hematic cells).[64,112,118] Up to a few years ago the clinical implications of the smear layer were not clearly known.[64,161]

We know that the debris plugs obstruct the dentinal tubules and reduce the permeability of the dentin,[50] more so it was hypothesized that, by forming a barrier prevented the penetration of bacteria into the tubules. This is only partially true: in fact following this it was shown that the smear layer only slows the passage of microorganisms in the dentinal tubules but does not block the tubules themselves.[196] Furthermore the



A B C

Fig. 14.18. **A**. The upper right central incisor was traumatized when the root was not completely formed: the tooth needs apexification. No endodontic instrument was used, but just irrigating solutions: NaClO 5%, EDTA 10%. Then calcium hydroxide was used. **B**. Four months later the apical barrier is checked under the operating microscope (x25). **C**. The root canal has been obturated.



A B C

Fig. 14.19. **A**. Middle one third of a root canal after mechanical instrumentation. The canal surface appears to be completely smeared with dentin mud (x1,000). **B**. The photograph shows the deep penetration in the dentinal tubules of the smear layer produced by mechanical instrumentation (x3,000). **C**. Same area at higher magnification (x6,000).

smear layer does not permit the penetration of medication or obturation material into the tubules.

The removal of the smear layer, on the other hand, improves the contact between the obturation material and the canal walls and therefore the seal.[18,59,86,92,193] Palaris et al.[125] have in fact demonstrated that the endodontic cement deeply penetrates the tubules with gutta-percha projections only in those teeth in which the smear layer has been removed.

Kouvas et al.[95] have demonstrated that in the absence of the smear layer the endodontic cement tested by them (Sealapex, Roth 811 and CRCS) penetrates the dentinal tubules to a depth of 35-80 microns inclusive.

As will be explained in more detail later (Chapter 23), it is certain that notwithstanding our efforts it is never possible to completely remove the contents of the root canal system: pulpal residue, bacteria, toxins.[112]

More so with the aim of inactivating the bacteria and the pulpal residue that has evaded the instrumentation as well as cleaning, we must make use of a three-dimensional obturation. This has the function of isolating, between the gutta-percha and canal walls, those micro-organisms, that have evaded the cleaning, by eliminating their biological living space.[116,134] Therefore we conclude that by really and truly obtaining a three-dimensional obturation that intimately penetrates the insides of the dentinal tubules, represents the second and ultimate cleaning phase which is only achievable by elimination of the smear layer.

We must therefore prevent its formation to allow the irrigants to complete their three-dimensional action.

Baumgartner and Cuenin[14] have demonstrated that the removal of the smear layer allows the sodium hypochlorite to penetrate the dentinal tubules as well as those areas that are rendered inaccessible by the smear layer and therefore protected from the irrigant action. It was also shown[52] that the presence of the smear layer reduces the permeability of the dentin by 25% to 49%.

At this point, if we consider that persistent endodontic infection could be determined by the presence of bacteria that have invaded the dentinal tubules, obviously then the removal of the smear layer is of fundamental importance.

Literature review

As the smear layer is mainly composed of inorganic material, the ideal solution for removing it would be a weak acid (citric acid, phosphoric acid, tannic acid) or chelating agents (EDTA, REDTA).[193]

Brannstrom and Johnson[27] found that cavities treated with a 0.2 solution of benzalkonium chloride and EDTA were cleaned in an acceptable way. The surface of the smear layer was completely removed however, the plugs of debris inside the tubules remained.

Goldman et al.[64] and Yamada et al.[197] showed that at the end of instrumentation, a final rinse with 17% EDTA followed by rinse with NaClO is able to completely remove the smear layer: the EDTA and NaClO remove both the inorganic and organic components of the smear layer.

Baumgartner et al.[13] have further shown how during instrumentation citric acid used on its own, or in combination with NaClO was more effective than NaClO on its own for removing the smear layer. In a successive study[15] the same author showed that the alternative use, during instrumentation, of 5,25% NaClO and 15% EDTA was able to completely remove the pulpal remnants and smear layer from those surfaces instrumented, leaving the surface smooth and the dentinal tubules opened, while those surfaces not instrumented were devoid of pulpal residue and predentine.

Garberoglio and Becce[58] showed that a 3% EDTA solution is as effective as 17% phosphoric acid or citric acid in removing the smear layer. More so the canal surfaces treated with 3% EDTA did not show a marked demineralization of dentin and tubules as was instead visible on the canal surfaces treated with 17% phosphoric or citric acid (Fig. 14.20). Having a surface not excessively demineralized is an advantage for the successive obturation phase: the aggressive demineralizing liquids create a crazed surface, with a consequently notable increase in surface area. This obviously causes an increase in the surface in contact between dentin and gutta-percha and further the excessively demineralized rough surface makes it difficult to have an intimate contact between the dentin and the obturating material.

The removal of the smear layer without excessive acid attack on the dentinal surface leaves a smooth surface ready for intimate adhesion of the gutta-percha and endodontic sealer.

More recently, Liolios et al.[103] have shown that a final irrigation at the end of instrumentation with 15% EDTA is as effective in removing the smear layer as is 3% EDTA, while 50% citric acid did not have satisfying results with incomplete removal of the smear layer.

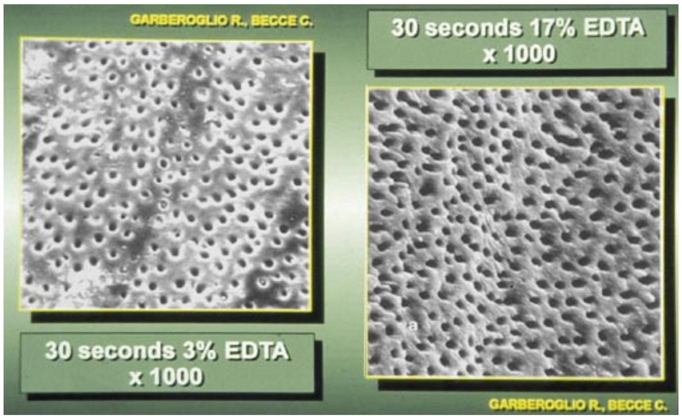


Fig. 14.20. 17% EDTA and 3% EDTA are both effective in removing the smear layer and no significant difference was found between them. **A**. After a final flush for 30 seconds with 3% EDTA, the middle portion of the root canal appears clean, without smear layer. Dentinal tubules are open to the canal surface. Note the complete smear layer removal inside the dentinal tubules (x1,000). **B**. A final flush for 30 seconds with 17% EDTA rendered canal walls free of organic and inorganic debris. In the middle portion of the root canal, the dentinal tubules are exposed and enlarged. Note the complete soft tissue removal inside the dentinal tubules (x1,000) (Courtesy of Prof. Riccardo Garberoglio and Carlo Becce [57]).

Use of chelating agents

From this brief review of the literature we can deduce that irrigants for removing the smear layer can be used:

a) during instrumentation
b) at the end of instrumentation.

As stated earlier, the objective of endodontic therapy is symbolized by the complete elimination of the canal system through cleaning and three-dimentional obturation.[148,150] It was also noted that the continued presence of bacteria can influence the success of the treatment.[73]

In the light of the above observations it becomes imperative to implement a strategy which enables the NaClO to act on the insides of the dentinal tubules.[14]

One must therefore:[23]

1) use operative techniques and instruments that only create a small amount of smear layer
2) use the appropriate irrigants
3) during the shaping, hinder the formation of the smear layer, to allow the NaClO to be effective throughout the canal system and dentinal tubules
4) aid the penetration of NaClO into the dentinal tubules
5) allow enough time for the irrigants (NaClO- EDTA) to complete their action.

Presently EDTA seems to be the most effective product for removing the smear layer:[14,15,28,58,64,103,193,197]

a) to enable NaClO to carry out its function in depth it is useful to counter the smear layer formation using EDTA even during the canal shaping [13,14,23,25]
b) only in this way can NaClO penetrate the dentinal tubules in those areas where otherwise the smear layer would make it impossible[14]
c) EDTA alternated with NaClO prevents the smear layer from becoming organized and with its more aggressive portion forming plugs that penetrate and occlude the dentinal tubules.[14,26]

As well as efficiently removing the smear layer and preventing its formation, the alternate use of EDTA and NaClO during canal preparation was shown to be more effective as a bactericidal than the use of only NaClO.[36]

Another addition would be to raise the temperature. As we saw previously, if one raises the temperature of the NaClO the solvent action is potentiated.[44,180]

Berutti and Marini[24] have shown that elevating the temperature of NaClO to 50°C had a notable reduction in the formation of the smear layer at the middle third level of the canal while in the apical third it appears less well organized and consisting of small particles (Fig. 14.21). The NaClO heated to 50°C is not however sufficient to break the links between the collagen chains. The authors affirm that the ability of the NaClO heated to 50°C to reduce the deposition of the smear layer on the canal walls can be attributed to the kinetic increase in the chemical reaction.[24]

The ultrastructural difference between the middle third and the apical third smear layer confirms the difficulty of achieving optimal irrigation in the apical third. It is therefore important to utilize a strategy that

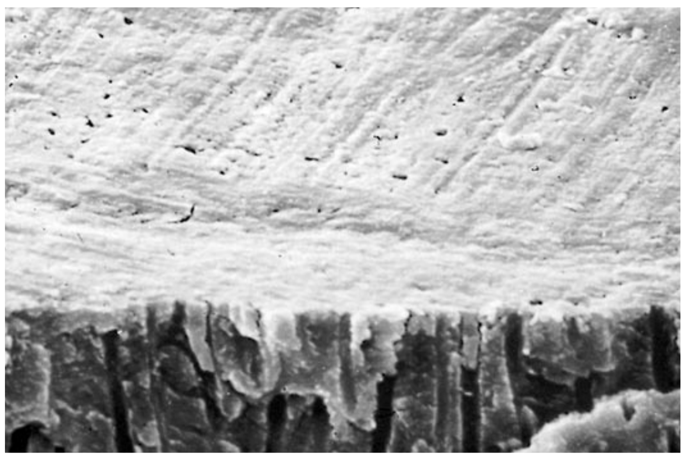


Fig. 14.21. Middle one third of a root canal after mechanical instrumentation and irrigation with 5% NaClO heated at 50°C. The canal wall is covered by a thin layer of dentin mud, and some dentinal tubules are partially open (x1,000).

favours adequate penetration of the irrigating liquid to this depth. A technique of corona-apical instrumentation by which the coronal and middle third are prepared before the apical third definitely aids the deeper penetration of the irrigant. The early coronal enlargement, apart from eliminating the interferences favouring passive progress of the file to the apical third, it allows a larger reserve of irrigant that can act on this final portion of the canal system.[143]

Berutti et al.[25] have also demonstrated that the association of 10% EDTA with a surface-active agent (Triton X-100, Sigma Chemical Co.) and 5% NaClO carries out an optimum disinfection of the dentinal tubules.

The operative sequence provides for the use of EDTA to remove the smear layer produced by the endodontic instruments, followed by a surface active agent that prepares the surface by lowering the surface tension. At this point NaClO penetration into the depths of the dentinal tubules will be enhanced, due to “capillary action” and “fluid dynamics”[25] (Fig. 14.22).

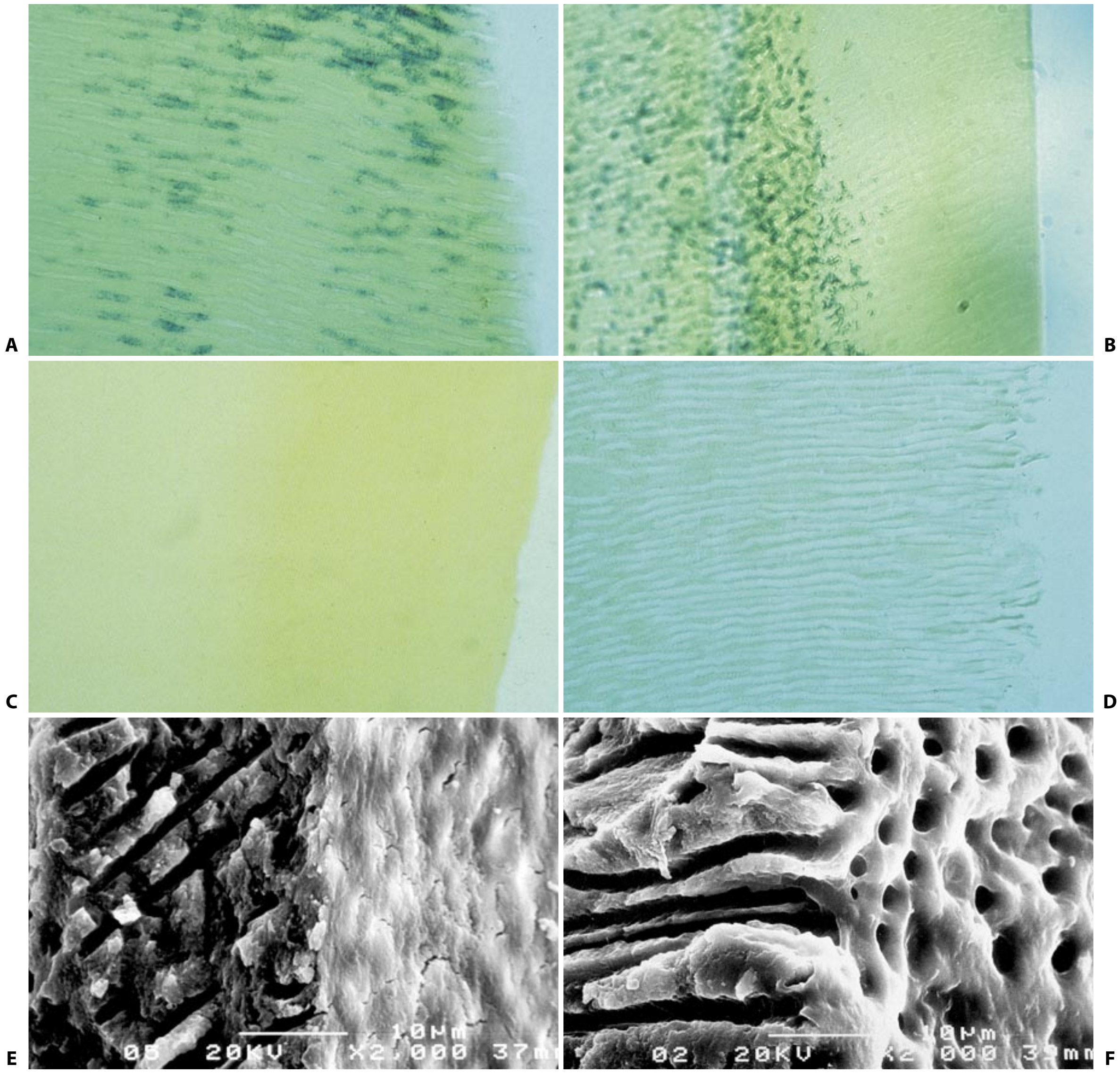


Fig. 14.22. **A**. Histological section of the middle one third of a root canal after mechanical instrumentation with NiTi files and irrigation with 5% NaClO, final rinse with 10% EDTA for 3 minutes, neutralization with 5% NaClO. Dentinal tubules are still infected (Brown and Brenn, x400). **B**. Histological section of the middle one third of a root canal after mechanical instrumentation with NiTi files and alternate irrigation with 5% NaClO, 10% EDTA and surfactant (Triton x100). The area facing the root canal if free of bacteria. Deeper inside there is still some area of tubular infection (Brown and Brenn, x250). **C**. Histological section of the middle one third of a root canal after mechanical instrumentation with NiTi files and alternate irrigation with 5% NaClO, 10% EDTA and surfactant (Triton x100). The dentinal tubules are completely free of bacteria (Brown and Brenn, x250). **D**. Same specimen at higher magnification (x400). **E**. S.E.M. photomicrograph of the middle one third of a root canal after mechanical instrumentation with NiTi files and irrigation with just 5% NaClO. An homogeneous layer of smeared dentin mud is evident (x2,000). **F**. S.E.M. photomicrograph of the middle one third of a root canal after mechanical instrumentation with NiTi files and alternate irrigation with 5% NaClO, 10% EDTA . Note the complete absence of smear layer (x2,000).

The authors have thus shown that the elimination of the smear layer by the EDTA during the instrumentation phase is indispensable to enable the NaClO to penetrate into the depths of the dentinal tubules. A high concentration of EDTA (10%) is necessary because the acid is partially diluted by the NaClO already in the canal.[25] The addition of a surface-active agent (Triton, X-100, Sigma Chemical Co) lowers the surface tension, enhancing the NaClO action in the deeper areas.

The operative sequence used by the authors was the following: instrumentation, 10% EDTA, after 15 seconds Triton, followed immediately by 5% NaClO.

The results showed an average penetration of 130 microns by the irrigants into the dentinal tubules.[25]

In successive checks the authors found approximately analogous results without the use of surface tension activator, alternating simply and randomly with NaClO and EDTA.

The "time" factor

The final condition which has to be respected and probably the most important is the time factor. We have to allow enough time for the irrigants to complete their action (Fig. 14.23).

Nowdays the new technology (Rotary NiTi Instruments) enables canal preparation, even difficult ones, to be completed in very little time with excellent results. This however contrasts with the principal objective of therapy, namely the complete elimination of the contents of the root canal system, achieved by the action of irrigants; this elimination could not be achieved in the brief time that the rotary instruments have performed the shaping.

One should bear in mind that the rotary instruments during their shaping action, not only do not clean the canal, in fact by creating a smear layer hinder the action of the irrigants in the deeper parts.

What is the time required for the irrigants to complete their action?

Nakamura et al.[121] evaluated the in vitro solvent action of three concentrations of NaClO (2%, 5%, 10%) at 37°C on bovine collagen (tendons, dental pulp, gingiva).

The 2% NaClO dissolved 33% of the bovine collagen after 10 seconds and 52% after 10 minutes.

The 5% NaClO dissolved 47% of the bovine collagen after 10 seconds and 61% after 10 minutes.

The 10% NaClO dissolved 78% of the bovine collagen after 10 seconds and 80% after 10 minutes.

Andersen et al.[8] evaluated the in vitro solvent action of 2% NaClO at 37°C on human pulp: the 2% NaClO dissolved 15% of the human pulp after 15 minutes, 50% after 1 hour, and 100% after 2 hours.

To reduce the long time one can intervene in the following way:
– the temperature
– renew the irrigants
– movement of irrigant in the canal.

We have already previously seen the numerous advantages derived from the use of heated NaClO (50°C).[24,44,49,180]

We constantly renew the irrigant, so that the solution in the canal is always at its maximum functional capacity.[23] This principle is valid for all chemical reagents. This way we can remove the degradation pro-

A  B

Fig. 14.23. **A**. Preoperative radiograph of the lower right first premolar: the tooth needs a root canal treatment. **B**. Postoperative radiograph. The irrigating solutions need time to completely perform their activity. Only then the treatment, shaping, cleaning, and obturation, will really be three-dimensional.

ducts of the pulp and allow the fresh irrigants to penetrate deeper, enabling direct contact with the pulp tissue and any incidental bacteria present.[23]

Continuing with this point of view, it is determinant with regards to the final result, to move the irrigants within the canal system. Agitating the irrigants means pushing it into all the cavities, dentinal tubules, changing it constantly (the irrigant that contacts the pulpal tissue and bacterial is always fresh and not saturated) makes use of fluid dynamics that mechanically wash and cleanse the canal walls.[23]

Ultrasonics and microbrushes

A method of potentiating the action of irrigants is by using ultrasonics to activate them.

Ultrasonics in endodontics were introduced by Richman in 1956 for the preparation of the access cavity and for preparation, as well as, obturation of the canals.[137]

Twenty years later Martin[111] described the in vitro disinfectant action of ultrasonics, demonstrating that the combined use of ultrasonics and sodium hypochlorite could be more effective than either one on its own.

The ultrasonics used in endodontics are acoustic vibrations with frequencies around 25,000 cycles/sec. From the energy source (electromagnetic or piezo-electric) the ultrasonic waves are transferred via a transducer to a liquid in which well known physical phenomena occur. One of these is “acoustic stream” and is connected to the rapid movement of fluid particles in a vortex around the object that vibrates.[4]

Another phenomenon caused by the ultrasonic vibration is cavitation, which is the formation of micro-bubbles that gradually increase in diameter until they collapse provoking very effective small implosions, that produce an irregular agitation of the liquid. Both of these effects are indicated[4,111] as the principal reason why the debris are removed from the dentinal walls. It should also be remembered that ultrasonics raise the temperature of the liquid that surrounds the vibrating object.[44]

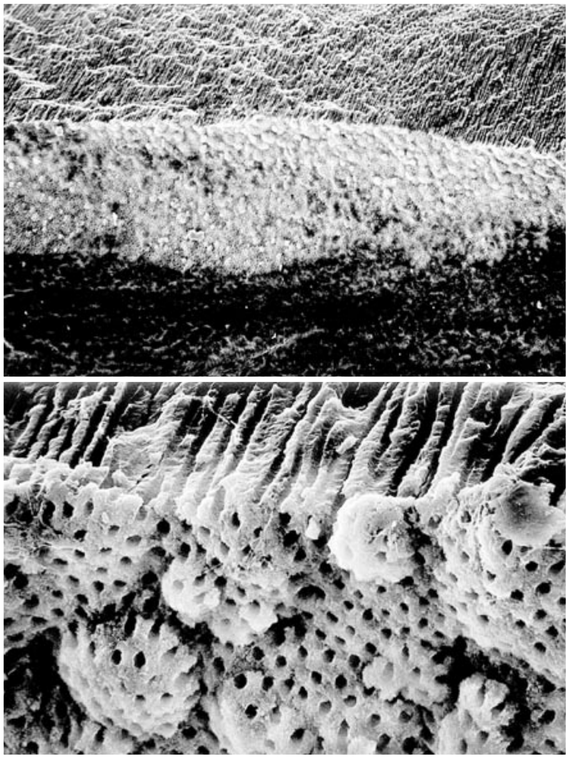
After an initial enthusiasm for ultrasonics used for shaping root canals, it was noted that dentin removal only occurred in those areas where the activated part of the instrument was in close contact with the canal wall. This is demonstrated by the finding of calcospherites near the area smoothed by the action of the instruments, in accordance with what Mader [109] described (Fig. 14.24).

On the other hand, the ultrasonics in combination with NaClO has been shown to be extremely effective[40,54] in the removal of organic substrate even in the areas where the instruments were unable to have contact with the canal walls such as cavities, depressions, internal resorption, apical deltas and lateral canals.

This particularly efficient cleaning of the root canal system is due to the “combined” action of the ultrasonic and sodium hypochlorite and not just the cavitation of the ultrasonic on its own.[133,136]

In conclusion, on the one hand ultrasonics as an instrument for shaping canals has been abandoned because of lack of predictability and efficiency with respect to traditional methods,[105,131] on the other hand it is currently considered useful for activating the irrigating solutions in the canals that have been correctly prepared.[9,24,44,65,85,144] In fact, once the taper of the canal has been developed in accordance with the primary mechanical objective of the shaping (as is subsequently described in detail), the root canals become optimum candidates for ultrasonic activation of the irrigants. The passive activation of the file implies

A



B

Fig. 14.24. **A.** Middle one third of the distal root of a second lower molar, irrigated with NaClO, EDTA, and final rinse combined with ultrasonics. The area on the bottom has been prepared by the files, while in the upper area (near the fracture zone) the calcospherites of predentin are evident, to confirm that the instruments did not make contact with the dentinal walls (x110). **B.** At 1,000 magnifications it is evident that there is no organic material in the areas which have been cleaned but not shaped.

that the instrument does not touch the canal surface to make the maximum use of the physical phenomena previously described: acoustic stream, cavitation, increase in temperature. In 1992 Archer et al.[9] demonstrated that the use of a file activated by ultrasonics and passively introduced into the canal for 3 minutes after hand instrumentation results in a significant increase in the degree of detersion of the canal system, as opposed to canal instrumentation on its own.

In 1999 Jensen et al.[85] showed that one can obtain the same results with sonic energy.

Putting to use all this information, we can quantify that the time necessary for the cleaning of a root canal is about 30 minutes. Naturally this is an average time. Some variables have to be taken into consideration. In fact, in accordance with that described by Gordon et al.,[66] canal systems that have isthmi or ramifications require more time for their complete emptying by the NaClO.

The irrigant in these cases carries out its action on an extremely small surface area of the tissue (isthmus connecting the mesial canals of lower or upper molars) which is at the same time very deep.

Another variable not to ignore is the condition of the tissue in the canal system: we know in fact that while fresh tissue dissolves rapidly, necrotic tissue needs more time and fixed tissue requires even more than the latter, to dissolve.[1] At this point one can ask oneself whether an intracanal medication to be used between appointments would be capable of completing the cleaning of the root canal system.

Yang et al.[199] recently showed that both $Ca(OH)_2$ and NaClO left in the canals for a period of 1-7 days was not able to significantly improve the cleaning of the root canal system.

Recently researchers have been experimenting with new irrigants in an alternative to NaClO and EDTA.

In 1996 Hata et al.[78] suggested the use of Oxidative Potential Water as a canal irrigant. This is a substance extensively used domestically and in the bee culture in Japan due to its bactericidal properties and low toxicity. It proved to be as efficient at removing smear layer as both 15% and 17% EDTA.[78,79]

A new irrigant called MTAD[183] has recently been proposed. The solution contains:

– Tetracycline (Doxicycline, Sigma-Aldrich Co., St. Louis MO)
– Acid (Citric Acid, Sigma-Aldrich)
– Detergent (Tween 80, Sigma-Aldrich).

Tetracycline is a wide spectrum antibiotic, well researched and used in dentistry, especially in periodontology. According to the authors Tetracycline is

A

B

C

D

Fig. 14.25. **A**. A prototype tapered endodontic microbrush. **B**. A close-up view of a microbrush demonstrates the braided wires used to secure the bristles and their configuration. **C**. Four variably tapered-rotary driven microbrushes. **D**. Four variably tapered-ultrasonically driven microbrushes (courtesy of Dr. Clifford J. Ruddle).

absorbed and then gradually released by the mineralized tissues of the teeth (dentin and cementum). Furthermore it carries out a chelating action contributing to the removal of the smear layer.

The latter action is primarily carried out by the citric acid, which freeing the dentinal tubules of the smear plugs, favours the entrance of the antibiotic molecules into the dentinal tubules. Ultimately the detergent has the function of reducing the surface tension and increasing the penetration ability of the irrigant into the tubules.

Following the original work, that proposed MTAD, further publications by the same group of researchers reported various properties found in the irrigant:

- completely removes the smear layer without significantly altering the dentinal structure[182]
- solubilizes the organic components of the pulp residues and inorganic components of the dentin[19]
- it is an efficacious antibacterial, even against E. faecalis[164,165,184]
- it is less toxic than eugenol, calcium hydroxide paste and other substances commonly used in dentistry[203]
- it does not alter the physical properties of dentin[106]
- conditions the dentinal surface predisposing it for the successive adhesive phase[107]
- reduces the coronal leakage of the teeth obturated with gutta percha.[127]

Currently we can however confirm that NaClO and EDTA still remain the irrigants of choice for cleaning the root canal system.

Recent technological progress has brought about the creation of "microbrushes" (Fig. 14.25) with bristles attached to braided wires or flexible, plastic cores. The brushes can be activated using rotary or ultrasonic handpieces.[91,144]

Currently, these microbrushes are the subject of evaluation to determine which method of activation, which irrigant solution and what operative sequence produces clean canals, with open tubules, in the most predictable, most rapid and most efficient manner. Regardless of rotary versus ultrasonic activation, these microbrushes can optimally finish the preparation and should be used for a minute in the presence of 17% EDTA to completely clean the root canal system.[144]

Their bristles in fact deform on the inside of the anatomic irregularities, shifting the debris into the solution for removal out of the canal in a coronal direction.

Operative technique

After opening the pulp chamber and having removed, if present, the pulp in the chamber, the cavity is cleaned by irrigating with NaClO. If a pulpal hemorrhage is present, using a high concentration (90 volumes) of H_2O_2 may be able to arrest it, followed by copious rinsing with physiological saline solution to neutralize it.

At this point the pulp chamber is filled with a chelating agent in gel or paste form. A precurved file is delicately introduced into the canal and this in turn carries with it the chelating agent due to the surface tension phenomenon. The chelating agent on the other hand aids the passage of the instrument by allowing it to slide and find a way between any calcifications or tufts of fibrous tissue present. In the narrow canals it is extremely important to initially use the chelating agent, as this suspension emulsifies the tissues, softens the dentin, reduces the risk of blockages and maintains the tissue residue in suspension, enabling it to be aspirated from the canal.[144]

We should remember as well that with vital teeth the use of a chelating gel prevents the precocious formation of collagen plugs, that can occur after introduction of the first instrument in the pulp tissue, compromising the final result right from the start. The collagen is in fact the main constituent of the vital pulp tissue and could be inadvertently compacted into a sticky mass that could irremediably block the root canal.

After the initial manual phase, the rotary instruments (Gates Glidden burs or NiTi rotary instruments) are used. These produce a large amount of debris, which has to be removed with abundant NaClO irrigation. The contact between hypochlorite and the gel chelating agent causes the formation of rising oxygen that kills the anaerobic bacteria and with the effervescence that occurs aids the removal of dentin filings.[144] The debris therefore remains in suspension avoiding the formation of excessive smear layer and consequently dentin plugs.

The irrigants must be renewed constantly after the use of every rotary instrument and the pulp chamber space performs the function of an irrigant reservoir.[98]

As soon as the instrumentation allows, the irrigant must be introduced directly into the canal.

Normally, 5 ml syringes are used with a fine needle of either 25 or 28 gauge. The needle should be precurved to aid its passage into the canal and should reach the maximum working depth without any obstruction from the canal walls. As was mentioned previously, the irrigation must be carried out without excessive pressure and with continuous movement of the needle up and down, to reduce to a minimum the risk of pressure extrusion of irrigant. The excess irrigant is contemporaneously and constantly aspirated.

Schilder[150] recommended that the minimum volume of irrigant be 1 or 2 ml each time.

To improve the efficiency of irrigation at the apical level, Buchanan[33] suggested using the patency file, (thin file to control the patency of the canal) before each irrigation, with the aim of preventing possible organization of the debris, which under irrigant pressure can become compacted and form dentin plugs.

As regards the chelating agents in acqueous solution, this being represented by EDTA of varying concentrations (10% EDTA and 17% EDTA Ogna Laboratori Farmaceutici, Milan, Italy; 17% EDTA Roth International, Chicago IL).

We have previously seen the innumerable advantages that one has if NaClO and EDTA are alternated.[13-15,23,25,26] The chelator removes the smear layer gradually as it is formed by the instruments, allowing the hypochlorite to penetrate into the dentinal tubules that have remained open. The recommended concentration is 10% and the correct use consists of alternate rinsing with 5% NaClO heated to 50°C.[23-25]

The irrigation with each solution must be copious to eliminate as much as possible of the preceding irrigant. This is important especially when NaClO substitutes EDTA as the former neutralizes the latter. The endodontic instruments therefore carry out their function in a bath of either NaClO or EDTA.

The irrigation with one or the other solution must be carried out after every two or three hand instruments and after every one or maximum two rotary instruments.

At the end of the shaping, one can conclude the cleaning with ultrasonics which with a passive file in the canal potentiates the action of firstly EDTA and then NaClO. The thin K files (# 15) are attached to a special ultrasonic handpiece.

The K file must be precurved until it is completely passive inside the canal, without touching the walls and should reach 2 mm short of the canal terminus.

After having placed the K file in the canal filled with irrigant, the ultrasonic instrument is activated and without carrying out any movement, the file is kept activated for the following time: one minute with 10% EDTA to remove all traces of smear layer and then for 3 minutes with 5% NaClO at 50°C to improve the completion of the cleaning and to neutralize the acid.

The vibration power must be very low, usually 20-25% of the total power of the ultrasonic source.

We have seen, that to aid the disinfection of the inside of the dentinal tubules one can use a surface active agent before the NaClO.[25,55] After the irrigation of the canal with the surface active agent, it is best to wait a few seconds, without using any instrumentation that can create smear layer and follow immediately with a NaClO irrigation.

This is to avoid that the surface active agent, by lowering the surface tension, causes a profound penetration of the smear layer, created by the instruments during their working action with this irrigant in the canal, into the dentinal tubules.[5] The use of a surface active agent is indicated when we suspect a deep tubular infection, as in the case of a tooth with a necrotic pulp and with the pulp chamber communicating with the oral cavity or in retreatment, after the canal has already been prepared.

Summary of procedure

Initial manual preparation (vital pulp)
chelating gel

Rotary instruments (Gates-Glidden or NiTi)
5% NaClO 50°C
10% EDTA
(alternate and renew every 1-2 instruments)

Final rinse with ultrasonics
1 minute 10% EDTA
3 minutes 5% NaClO 50°C

It should be remembered that the final rinse should be with NaClO.

As was stated previously, the cleaning procedure should not only last the time it takes to shape the canals as, especially with new NiTi rotary instruments with greater taper, the instrumentation time has been notably reduced. This is normally insufficient to achieve a complete cleansing of the canal system.

The key to success is determined by:
a) correct shaping
b) sufficient time for the irrigants to carry out their bactericidal action and the dissolution of the pulpal tissue.

We saw previously how we could quantify 30 minutes as the time that is necessary for NaClO to carry out its action, provided it is used in a 5% concentration heated to 50°C and constantly renewed.

Finally, it should be remembered that necrotic tissue requires more time than vital tissue to be dissolved and that tissue fixed with mummification substances (devitalizing substances, endodontic cements containing paraformaldehyde) require even more.[1]

The treatment time for a multi rooted tooth will automatically increase, in that step by step as one goes on to prepare a new canal, one continues to renew the irrigant solution in the previously prepared canals, so that they are cleaned for even more time.

SHAPING

On account of the activity of the irrigating solutions and endodontic instruments, the fragments of pulp tissue, the microorganisms and their toxins, and all the infected material that may be contained within are removed from the root canal system during the cleaning procedure. Simultaneously, the instruments give the canal such a shape that the space obtained within may then be easily filled three-dimensionally.

The shape to be given to the root canal depends on the obturation technique that will be used subsequently, exactly as in restorative dentistry a second-class cavity of a molar would be prepared in a different way, depending on whether it must then be restored with an amalgam restoration or with an inlay.

In the same way that G.V. Black[27] at the beginning of the last century described the principles that regulate the preparation of the various cavities in restorative dentistry, Schilder[150] has listed the "mechanical" and "biological" objectives of shaping of the root canal to receive the warm gutta-percha obturation.

Mechanical objectives

1) ***A continuously tapering preparation***. The canal must be uniformly and progressively conical or in the shape of a truncated cone, without ledges on its walls, with the thinnest section of the cone positioned apically and the widest coronally (Fig. 14.26). At obturation, the vertical forces applied to the gutta-percha cone can thus be translated into lateral forces directed toward the walls along the entire dentin/gutta-percha interface. This will assure homogeneous distribution of as thin a layer as possible of sealer,[99] as well as filling of any lateral

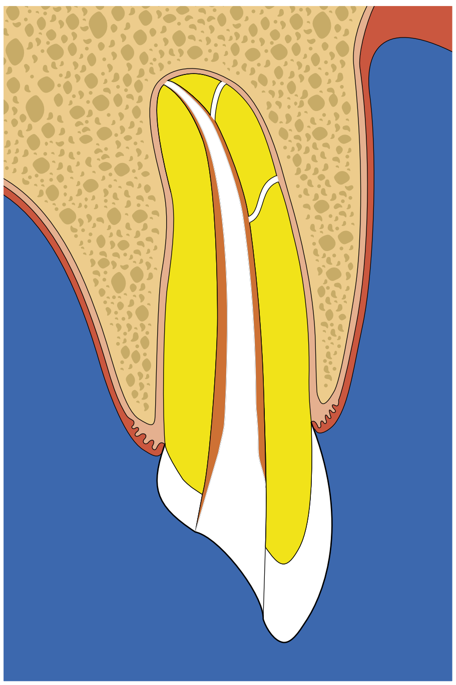


Fig. 14.26. During the shaping of the root canal, the dentin must be removed (red in the drawing) in such a way that the final shape of the preparation is a truncated cone, with continuous tapering and without ledges.

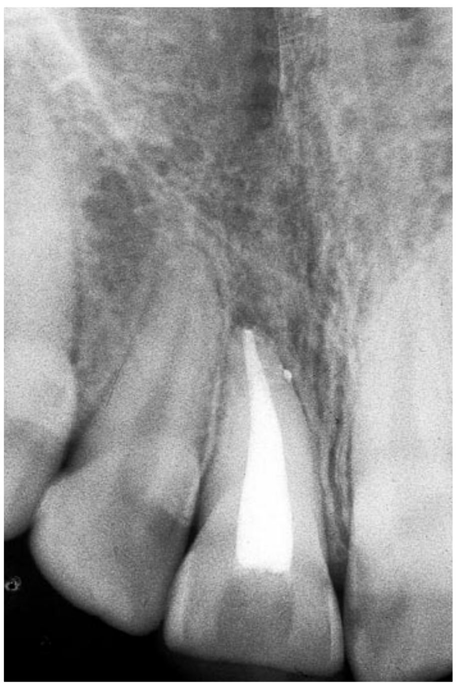


Fig. 14.27. Upper left central incisor with a lateral canal facing mesially in the apical third of the root, automatically filled during the obturation phase with warm gutta-percha.

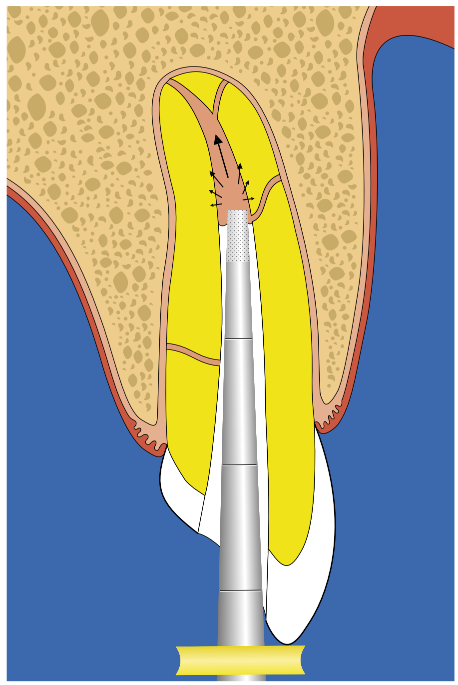


Fig. 14.28. The vertical push applied to the obturation material is translated laterally, causing filling of any lateral canals that may be present.

canals (Fig. 14.27). This will occur according to the common laws of physics,[154] more precisely in accordance with Pascal's Law:[37] in the absence of forces due to volume, the pressure that is exerted on a point of the surface that limits a fluid is transmitted unaltered to all the other points of this surface perpendicularly to the surface itself (Fig. 14.28).

A tapering conical shape does not mean a circular section, which, even if it were desirable, is never achieved in practice without destroying the tooth, especially in the most coronal portion of the root canal. Ovoid or flattened roots must not be weakened in the central or cervical zone while preparing the canal in a round shape.[151]

The truncated cone shape, in contrast, can be achieved in a way that respects the original anatomy and therefore can also exist in canals with elliptical, laminar, and ribbon shaped sections, among others. One should imagine a funnel of plastic material in one's hands and compress it from one or more sides. Its section will become elliptical, ribbon shaped, or however one desires, but its shape, in any section passing through its major axis, will remain conical.

The truncated cone shape permits more thorough cleaning, better contact between the endodontic instruments and dentinal walls, better removal of all the pulp debris, and better penetration of the irrigating solutions. It therefore increases the probability of obturating the important lateral canals.[151] This occurs on account of the greater possibility of sodium hypochlorite digesting their contents and also to the shortening of their length, which occurs simultaneously with the preparation of the main canal.

Making an analogy between restorative dentistry and endodontics, the widening that is given to the canal preparation can be compared to the "convenience form" of the cavity preparation.[83] The "convenience form" permits better access for the instruments to remove the caries and perform a proper restoration. The conicity of the canal accomplishes a similar function: it allows the endodontic instruments to reach the critical area of the apical third to perform an adequate preparation and obturation.[7,150,189]

2) ***Cross-sectional diameter diminish in a corono-apical direction.*** (Fig. 14.29). It would be wrong to create a sort of apical "collar", whose transverse diameters remain equal for several millimeters, as

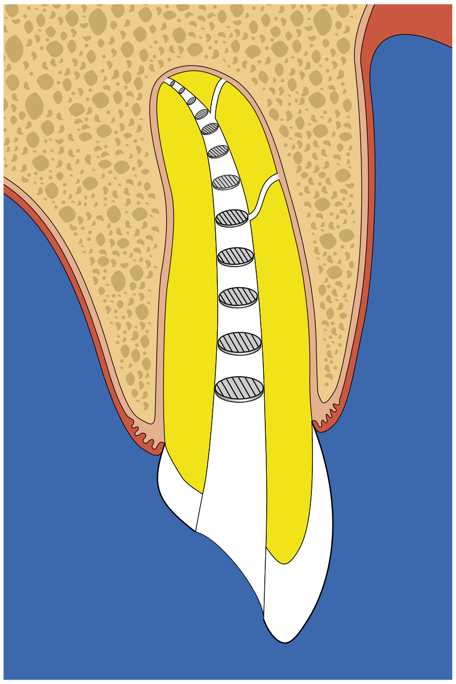
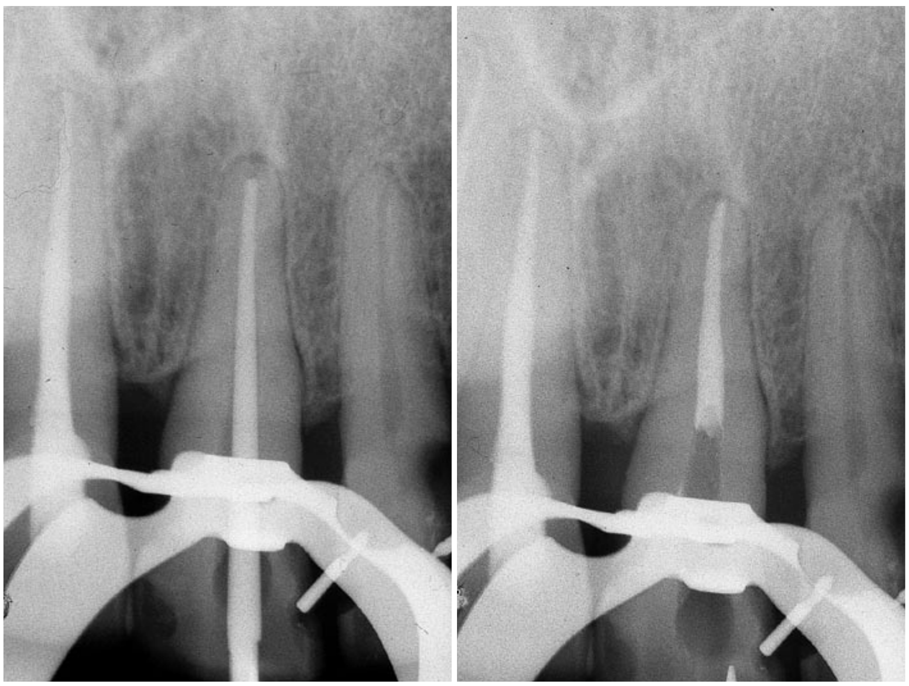


Fig. 14.29. The transverse diameters of the tapering cone preparation diminish in a corono-apical direction.



A B

Fig. 14.30. **A.** The gutta-percha cone to obturate the root canal must be slightly shorter than the canal preparation. **B.** During compaction, the cone will move apically, and its tip will be engaged through zones of progressively decreasing diameters. This forces the cone to deform, and this deformation assures a tight apical seal and a good control of the material.

one does in the silver cone preparation. In our case, there are no two equal diameters in the entire length of the root canal. Rather, they diminish in a corono-apical direction, which is logical if the canal has been given a tapering conical shape.

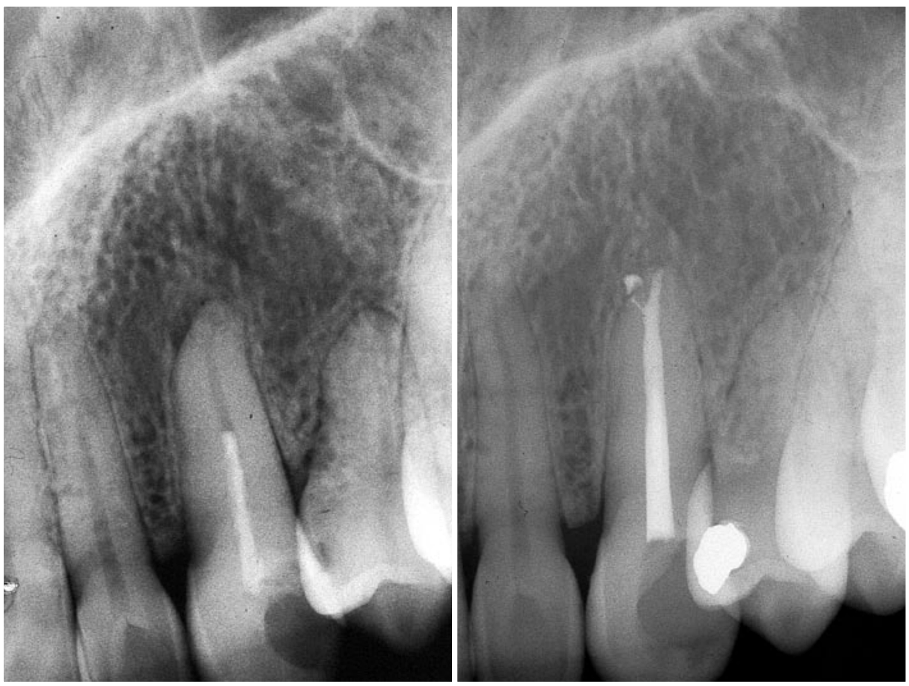
The concept of cross-sectional diameters has an important practical implication which becomes evident on obturation of the canal. The gutta-percha cone will be chosen, measured, and positioned slightly shorter than the performed canal preparation (Fig. 14.30 A). The diameter of the tip of the gutta-percha cone is therefore greater than the diameter of the more apical small portion of root canal. When the gutta-percha cone is heated and compacted, thanks to a vertical push it moves apically and fills those empty apical portions (Fig. 14.30 B). To do this, it must deform to pass through progressively smaller sections. This deformation assures better adaptation of the gutta-percha, which thus assumes the shape of the canal, a better seal of the obturation, and better apical control of the material. Because of their conicity, the walls of the preparation limit the progression of the cone within the canal and cause them to achieve extremely precise fillings, without uncontrolled overfillings. The continuous taper creates a resistance form to hold gutta-percha within the canal and eliminate the potential for packing overextensions.[150]

The only two exceptions to this second mechanical objective are lateral canals and large internal resorptions.

With rare exceptions, the lateral canals have not been instrumented and have no conicity; thus, "apical" control of the obturation material is impossible in them. This explains the presence of typical "puffs" of sealer at their ends (Fig. 14.31).

Internal resorptions also cannot be subject to the rule of cross-sectional diameters, because this would mean excessively weakening the tooth or even destroying it. Nonetheless, anatomical conditions permitting, the pluggers should almost "show themselves" at the beginning of the portion of the canal situated apically to the resorption when filling with Schilder's technique. In at least this part of the canal the rule of cross-sectional diameters should be observed to prevent all the forces of condensation from arraying only within the zone of resorption, which would preclude good compaction also at the apex (see Chapter 30).

Finally, during obturation, the tapering shape that the



A B

Fig. 14.31. **A.** Preoperative radiograph of an upper left canine. The slight radiolucency on the external side of the apical curve may indicate the presence of a small lateral canal. **B.** Recall radiograph 30 months later. Note, in addition to the disappearance of the small lesion, filling of the lateral canal, which has led to the extrusion of a small amount of endodontic sealer. In contrast, no material has issued from the apical foramen, thanks to good apical control of the obturation, which was guaranteed by the conically shaped canal preparation.

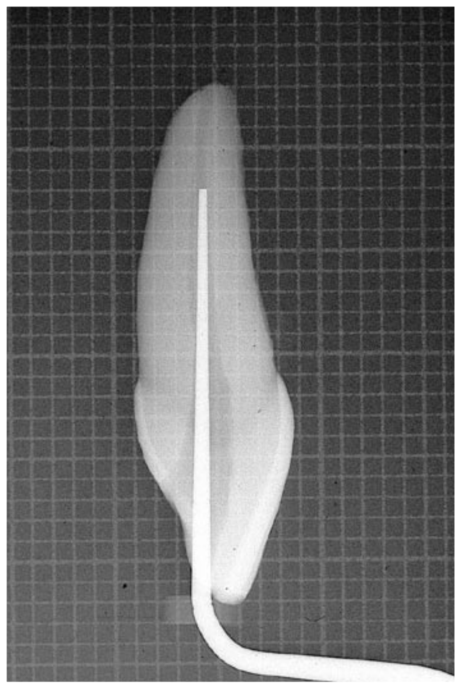


Fig. 14.32. The conically shaped canal preparation must permit the introduction as apically as possible of materials and, especially, of instruments necessary for three-dimensional obturation of the root canal system.

body of the canal also assumes with this type of preparation will permit the introduction of instruments required for the compaction of warm gutta-percha as apically as possible (Fig. 14.32), without producing obstacles or lateral interference. The latter are extremely dangerous, because not only do they hinder good compaction of the apical gutta-percha, they also represent a high risk of root fracture.

3) ***The conicity must exist in multiple planes and must give a sense of "flow."***
The tapering conical preparation must not exist on only two planes, but on all planes of the space. The root canal must be conical both in a mesio-distal plane (the sides of the tapering conical form will be one mesial and one distal) and in a bucco-lingual plane (the sides of the tapering conical form will be one buccal and one lingual or palatal: obviously, the first form can be appreciated on the radiograph, while the second one only on the extracted tooth). In other words, one must respect and support the curves of a root canal that may be directed not only mesially or distally (the only ones appreciable radiographically), but also buccally or lingually. One must not reproduce the shape of the endodontic instruments in the canals that one is preparing. The enlargement must respect the original anatomy of the root canal (Fig. 14.33). If one takes an extracted tooth, prepares it, obturates it, and then radiographs it in different projections, one should be able to see the curves and the taper in all the views.
The gutta-percha must seem to "flow" within the root canals. This concept of "flow" must characterize the entire process of canal preparation.
In a postoperative radiograph, the course of the root canals should resemble that of a river seen from the altitude of an airplane; it should not have the appearance of a man-made canal. The postoperative radiographs should remind one of branching trees, not telegraph poles (Fig. 14.34).

4) ***The apical foramen should not be transported***, but should be preserved in its original position and shape.
Respect for the apical curvature of the canal also implies respect for the foramen which remains in its original position and shape. Excessive or improper instrumentation may cause transportation of the apical foramen from the original position and a modification of its original shape by two mechanisms.
EXTERNAL TRANSPORTATION. This consists of transporting the apical foramen onto the external surface of the root, either by the formation of an elliptical, teardrop foramen or by direct perforation.
   a) A teardrop foramen is obtained when one uses straight, non-precurved instruments in curved

A B

Fig. 14.33. **A**. Postoperative radiograph of the upper central incisors: the shaping totally respects the endodontic anatomy. The left lateral incisor, in contrast, had been treated previously, without taking into consideration the anatomy of the endodontium, so as to reproduce the shape of the instruments within the root canal. **B**. Recall radiograph 18 months later.

A B

Fig. 14.34. **A**. Preoperative radiograph of the upper left central and lateral incisors. The necrotic central incisor must be treated, and the lateral, which has already been treated with iodoformic paste, must be retreated. Note the typical "pole" appearance of the preparation of the lateral incisor, which lacks conicity and has a deformed, over-instrumented foramen. **B**. Recall radiograph 18 months later. Note the sinuosity of the canal obturation of the central incisor, prepared in respect of the endodontic anatomy.

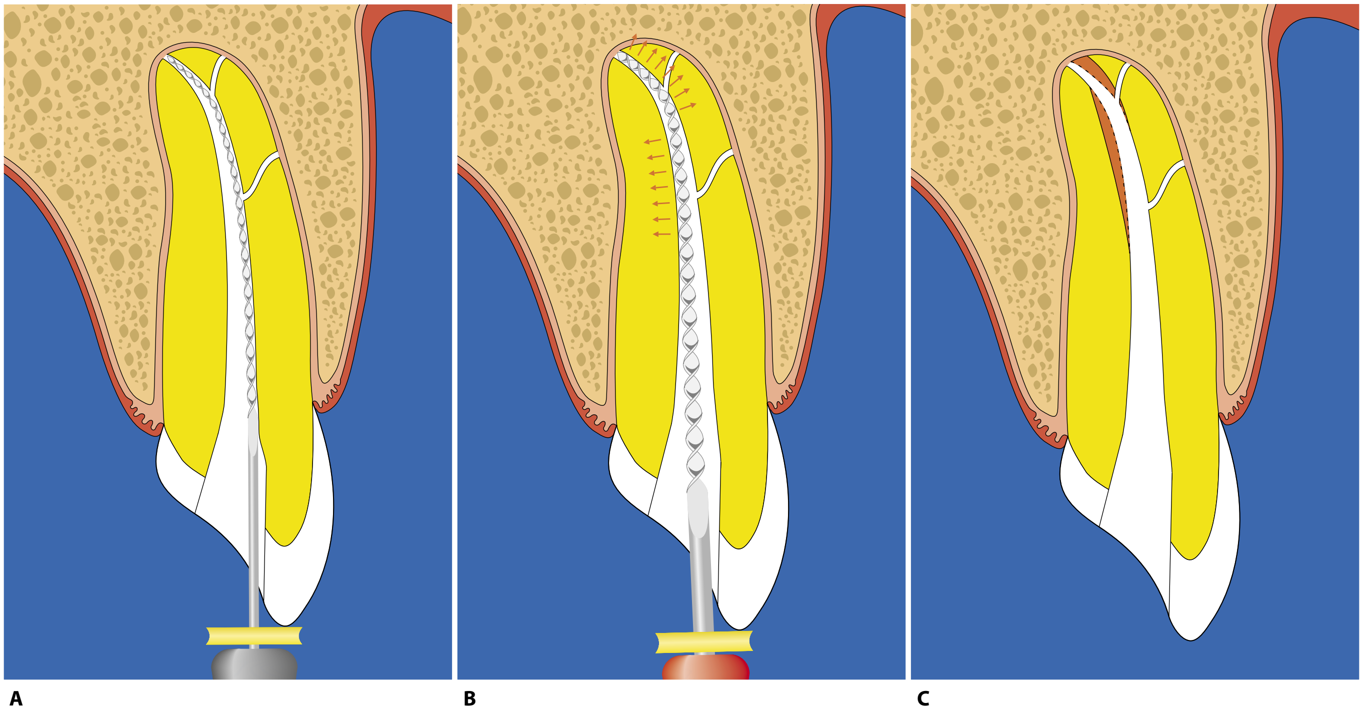


Fig. 14.35. **A**. A small, straight file introduced into a curved canal deforms and follows the canal curvature. **B**. The elastic memory, which is always greater in instruments of increasing size, tends to cause the instruments to straighten and make them work particularly in the zones indicated by the arrows. **C**. This involves greater removal of dentin from the external zone of the curve in the apical one third and from the internal zone of the curve in the middle one third (red in the illustration).

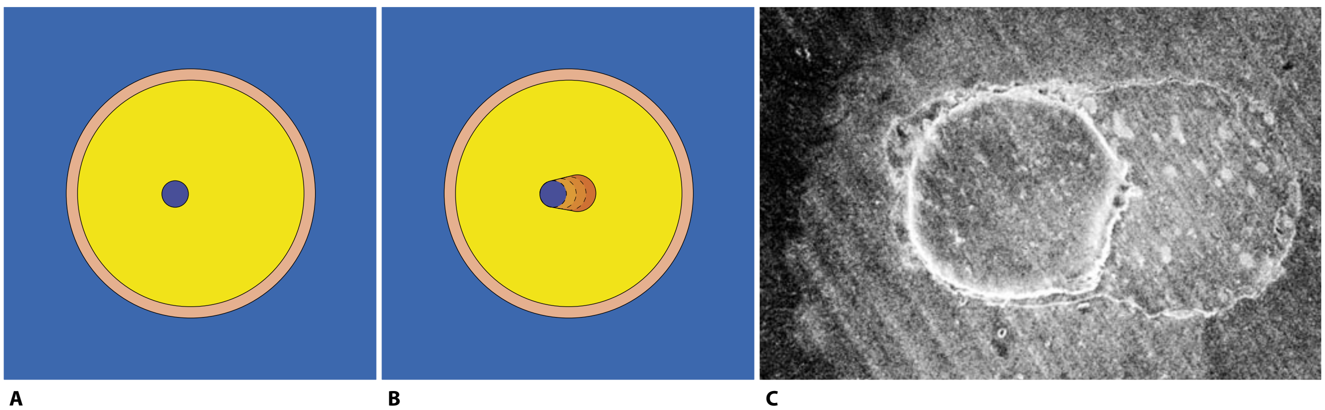


Fig. 14.36. **A**. Schematic representation of a cross section of the root at the level of the apical foramen before cleaning and shaping with straight, non-precurved instruments. The apical foramen is light blue. **B**. Appearance of a teardrop foramen. The original foramen is light blue, the dentine removed by a non-precurved instrument, increasing in size, is red. **C**. Palatal root of an upper first molar extracted following endodontic therapy for periodontal reasons. The root has been sectioned transversally at the apical foramen and then examined by S.E.M. Transport of the foramen, partially obturated with gutta-percha (left) and with sealer (right), is evident (x50).

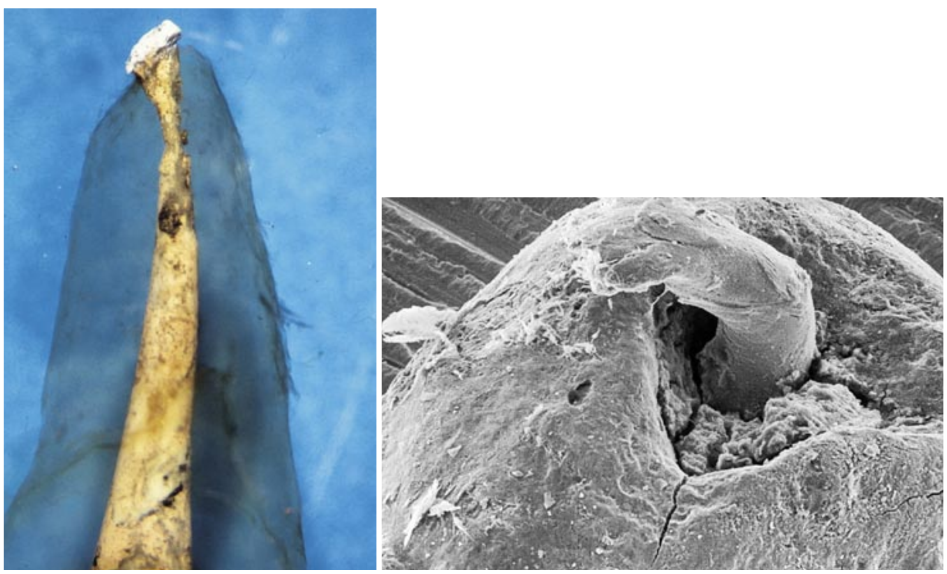
canals. All the instruments are flexible and elastic. As one gradually passes from small instruments to larger ones, the instruments' flexibility decreases, while their elastic memory increases. Thus, the instruments can be bent, but they have an increasing tendency to return to their original, straight shape.

When a small, straight instrument is introduced into a curved canal, the instrument tends to follow the curvature of the canal, thanks to its flexibility (Fig. 14.35 A); however, because of its elastic memory, it tends to return to its original straight shape. That is, it has a tendency to straighten out as one works (Fig. 14.35 B). Its action is therefore exerted only at the points of the root canal where they make contact, rather than on the entire canal circumference. This means that the external side of the curve close to the apex and the internal side of the curve in the intermediate portion of the canal are instrumented excessively (Fig. 14.35 C).

Because of their flexibility, as one gradually passes to instruments of greater size, they continue to follow the curvature of the canal, but because of their increasing rigidity and elastic memory, they tend to work increasingly more on the external side of the curve in the apical third and on the internal side in the middle third. At the apex, the result of such instrumentation is eccentric enlargement of the apical foramen, which assumes an elliptical or teardrop shape (Fig. 14.36).

The narrow part corresponds to the original foramen, while the wider portion is where the larger instruments have performed their work. In the middle third, the thinning of the dentin can be so marked as to lead to perforation or "stripping" (see "anticurvature filing method"). The clinical consequences of the teardrop foramen depend either on the periodontal damage that has been caused by the instruments (thus, during the preparation of the canal, one will continue to have a certain amount of bleeding, the tooth will then always be painful, the canal will be moist and full of exudate, and the apparently inexplicable situation will be resistant to the various and repeated medications), or from the irregular shape that has been given to the apical foramen. The foramen will be so difficult to seal and will be the cause of the "inexplicable" gross extrusion of obturation material, which in these cases includes not only sealer, but also gutta-percha. Not only is the foramen elliptical (much more difficult to seal), but most of all, the root canal has the shape of an hourglass in the last millimeters (Fig. 14.37 A): the smallest diameter is not at the foramen any more, but rather some millimeters more coronally, and then becomes wider apically. Apical control of the obturating material is not possible (Fig. 14.37 B).

b) Direct perforation occurs when straight, large size instruments are used in curved canals. The instruments are forced into the canal and screwed into the dentin in the attempt to cause the instrument to emerge radiographically "at the apex" (Fig. 14.38). Similar errors are often committed in the upper lateral incisor, because its palatally-oriented apical curvature is not radiographically appreciable, in the mesiobuccal roots of the upper molars and in the mesial roots of the lower molars (Fig. 14.39), but such mistakes can occur in any root with a marked curvature. To avoid this adverse outcome, one should always begin the instrumentation with



A B

Fig. 14.37. **A**. The transparent tooth is showing the hourglass shape of the apical one third, due to the tear drop foramen. **B**. S.E.M. photograph of a tear drop foramen with extrusion of obturating material (x65).

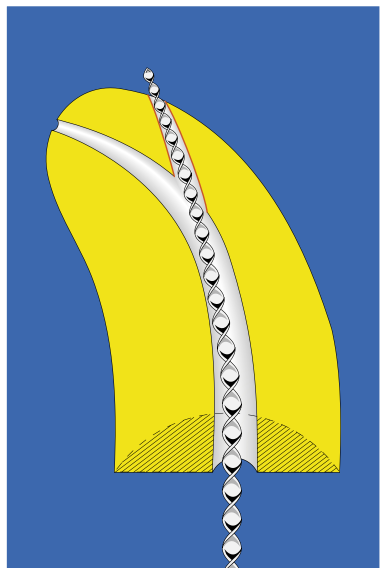


Fig. 14.38. Schematic representation of a direct perforation. The straight, large size instrument has been forced within a curved canal, until it appeared radiographically "at the apex".

small, pre-curved files. The instrument should adapt itself to the anatomy of the canal, which must be respected as much as possible, especially in the most delicate zone, the apical one third.

INTERNAL TRANSPORTATION. This consists of the transportation of the apical foramen within the root canal and can be performed a) within the original canal or b) within the dentinal walls.

a) Transportation within the original canal. This occurs when one is working intentionally or inadvertently "short" without being concerned with keeping patent the most apical portion of the canal. In this segment, collagenous tissue, debris and dentin mud accumulate easily, blocking the canal as far as the apical foramen, which is thus occluded (Fig. 14.40). Leaving pulp remnants or necrotic debris in the avascular root canal system is one of the major factors in persistent attachment apparatus disease. Every dentist who has worked short has experienced the frustration of apical "blockage", ending up even shorter than was intended. Working arbitrarily short of the real terminus of the canal (the foramen!) based on statistical averages, encourages the accumulation and retention of debris and dentin mud, which may result in apical blocks that predispose the patient to the next type of transportation: ledges, false paths and perforations.[140]

b) Transportation within the dentinal walls. In certain situations, the instrumentation may terminate 2-3 or more millimeters short of the apex, after having begun the canal instrumentation at 0.5 mm from the apex and having created an internal transportation by blockage of the canal with dentin mud. In the attempt to re-establish the lost path, one tries to advance in the canal with the last instrument used, screwing it into the dentin in the conviction that one is removing the dentin mud from the apex. In fact, one is creating a new path in the "wrong" direction; one is making a "false canal" (Fig. 14.41).
If one is even more zealous, one can proceed in the wrong way until one reaches the periodontium, creating a perforation (Fig. 14.42).
If the most apical portion of the canal is obstructed, the proper method for re-establishing the apical patency consists of using generous sodium hypochlorite irrigations and trying to re-negotiate the canal with the first instrument that was used, namely, the first, small, precurved file. The use of chelating agents is contraindicated, because in this situation they predispose to the creation of a false canal and perforation.

5) ***The apical foramen must be kept as small as practical***, in order to obtain a better seal and to prevent extrusion of the gutta-percha filling.[150] This does not mean that the apical foramen must remain as small as possible: if one advances to a # 10 file with difficulty, it should not be left thus. The apical foramen must be cleansed and then enlarged, but to a size that is convenient for the dentist, which allows him to obturate easily.
On the other hand, it is useless and dangerous to enlarge a foramen excessively, because this would be obtained at the cost of periodontal damage, with

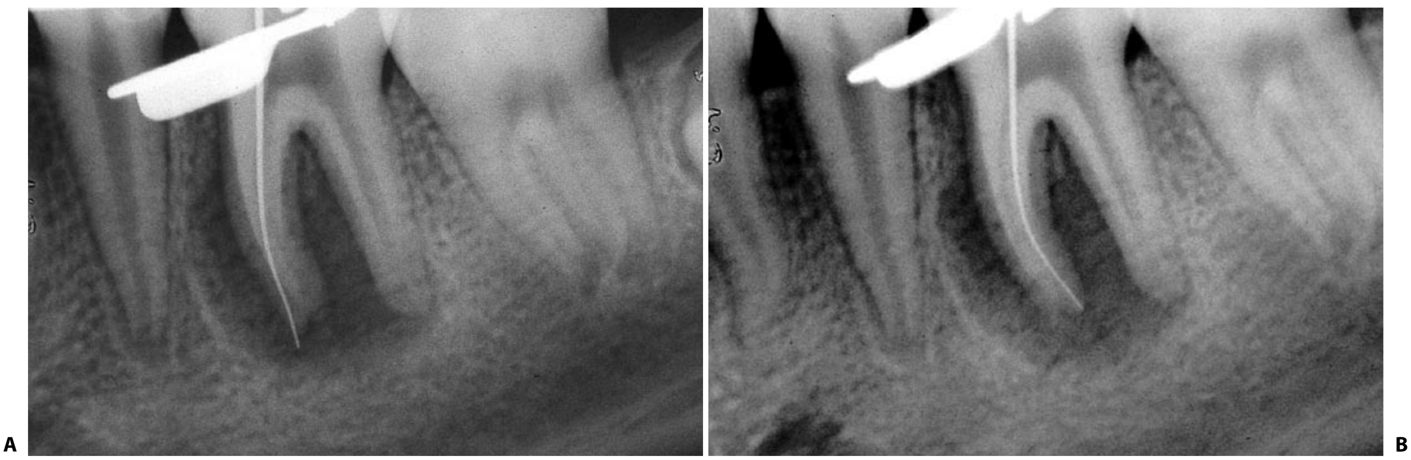
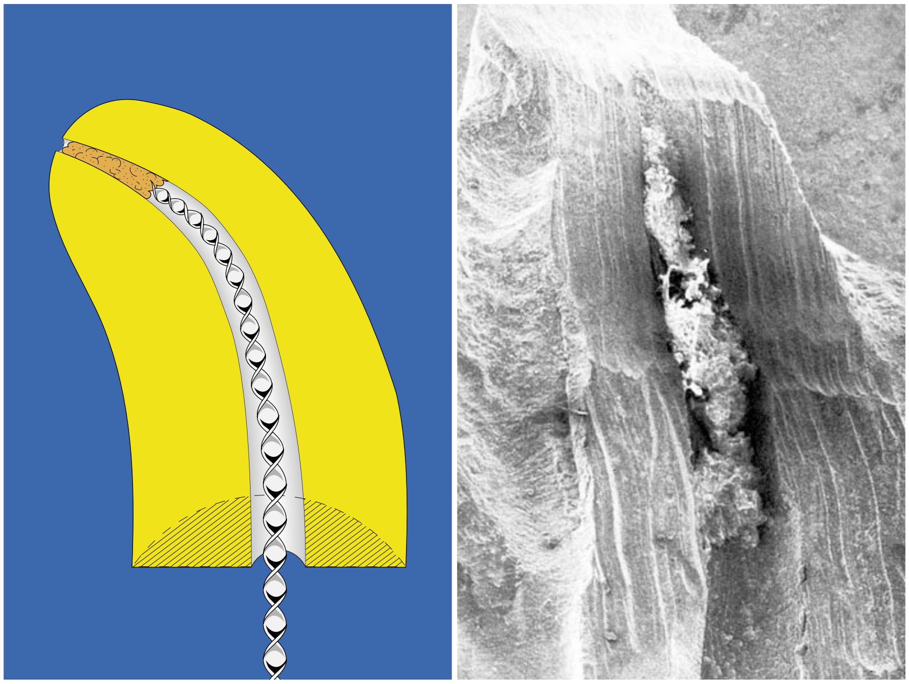
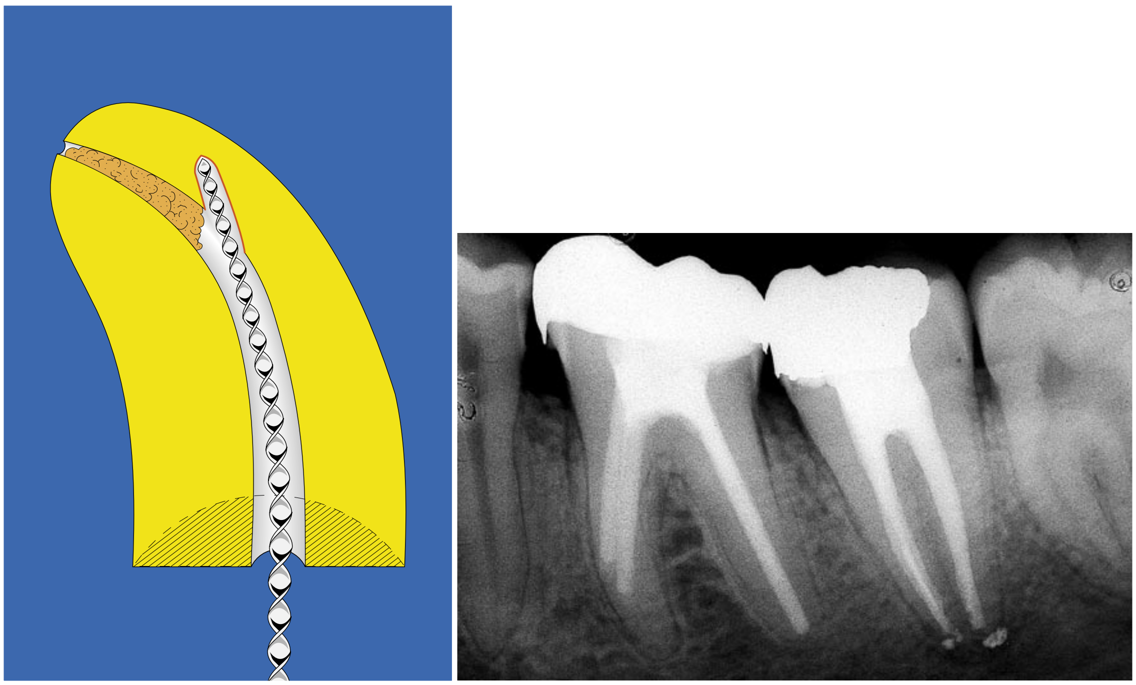


Fig. 14.39. **A.** Direct perforation of the mesial root of a lower left first molar. **B.** Compare the course of the instrument in the other canal of the same root.



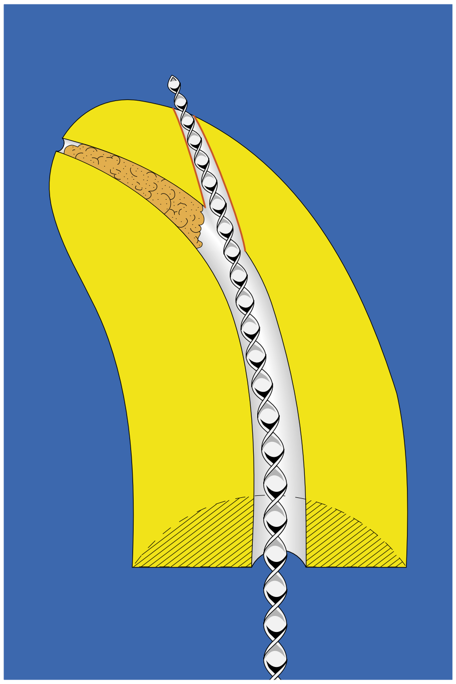
A B

Fig. 14.40. **A**. Schematic representation of an internal transportation. The last millimeters of the root canal are blocked by dentin mud. **B**. Root apex sectioned longitudinally. The dentin shavings that block the final portion of the root canal are evident (x22).



A B

Fig. 14.41. **A**. Schematic representation of a false canal (ledge). In the attempt to re-open the original canal, which was blocked by dentin mud, the instrument is actually opening an artificial canal. **B**. The lower left first molar of this patient had been treated years before by forcing straight, non-precurved instruments into the three canals. Note the false canals in the mesial root. The tooth was vital, and one may deduce that the apices of the two mesial canals were blocked with sterile dentin mud, so that no lesion had developed previously. The second molar, in contrast, has been treated without transportation of the apical foramina, respecting the endodontic anatomy.



A

B

Fig. 14.42. **A**. Schematic representation of a direct perforation. In the attempt to introduce the instruments to the apex, a ledge was initially created, which was then deepened until the periodontal ligament was encountered. **B**. In the distal canal of the lower left molar, an internal transportation has occurred, while in the mesial canals the result of the direct perforation is evident.

consequent greater difficulty in obtaining a good seal, and less apical control of the obturation: a bigger foramen means a bigger area to seal,[201] more difficulty in developing the taper, and more difficulty in preventing overextensions.[200]

The apical foramen of a narrow canal will therefore have to be enlarged to at least the size that corresponds to a # 20 ISO file or to a # 3-4 Profile (Fig. 14.43), while the apical foramen of an already-wide canal will just have to be cleaned, without any enlargement: it should remain the same original shape and size (Fig. 14.44). In conclusion, foramina already bigger than a # 20 file only need to be cleaned and don't need to be shaped or enlarged at all.

Fig. 14.43. The apical foramina of these upper left molars have been enlarged to receive a # 20 K-type file.

Fig. 14.44. The apical foramen of this upper left central incisor has been just cleaned with irrigating solutions, without any enlargement.

In this way, in a narrow canal, one will have a foramen wide enough to allow the introduction of a gutta-percha cone, while in a wide canal one will still have good apical control of the obturation.
The basic principle which stipulates that the apical foramen must be maintained as small as practical does not place any maximal limit on its dimensions, since these are strictly correlated with the clinical situation. Apical foramina which are already large (e.g., in the permanent teeth of young patients or in teeth with partially-resorbed roots) must also always remain small for greater practicality. The excessive removal of dentin is therefore contraindicated.[151]

Biological objectives

Since lesions of endodontic origin are caused by the presence of infected material within the root canal system, the earlier it is removed the sooner the healing process will begin.

The extraction of a tooth with periradicular pathology leads to a successful outcome and healing of the lesion by the simple fact that, together with the tooth, the infected contents of its canal system have also been extracted (see Fig. 18.4).

The same degree of healing may be obtained by accurately removing the pulp debris and microorganisms, naturally without extracting the tooth.

This is obtained during the very important phase of cleaning and shaping, which has to be performed with respect to the above-mentioned mechanical objectives and the following biological objectives:[150]

1) ***Limit the instrumentation to within the root canal***. The endodontic instruments must not be introduced beyond the foramen, so as to avoid damaging the periodontium and important nearby structures (e.g., maxillary sinus, nasal floor, and mandibular canal). To prevent such injury, it is necessary to accurately check the working length of the instruments by using electronic apex locators, paper points, by radiographic means and to pay attention to correct positioning of the rubber stops of the various instruments.
An exception to this rule is the use of the "patency files". Patency is an extremely important concept in endodontics and can make the difference between success and failure. To successfully complete the rational of endodontics, foraminal patency is essential.[192] Diligently and carefully confirming patency throughout the cleaning and shaping process ensures preservation of the apical anatomy and produces a cleaned, patent foramen ready to be obturated. The clinician should estabilish patency by intentionally and passively inserting the tip of the # 10 file to (and then 1 mm through) the foramen. Estabilishing and maintaining patency are nonharmful biologic events, considering the blood supply and immune capabilities present in the periradicular tissues.[144]
The other situation in which one may go slightly beyond the foramen with an instrument is when trying to establish an endodontic drainage for an acute alveolar abscess. In all other cases, there is no need to touch the lesions with instruments nor, much less, to inject caustic medications with the goal of "treating the lesion". It has been known for some time and amply demonstrated that asymptomatic endodontic lesions are always sterile. It is therefore not the lesion that must be "treated", but rather the root canal system. The lesion is where germs die, not where they survive.
If, during the phase of canal measurement, a small instrument is inadvertently introduced beyond the apical foramen to a depth of a few fractions of a millimeter, no serious damage will result. However, injury will occur if the entire biomechanical instrumentation has been performed with an incorrect measurement of the working length. In this case, the patient will continue to feel pain, and the canal will be filled with exudate or blood (see Fig. 5.71).
2) ***Don't force necrotic material beyond the foramen***. Careful use of the instruments within the root canal, in such a way that they are made to work only on withdrawal and do not exert a piston-like action, will avoid pushing infected material beyond the apex.
On the other hand, inadequate instrumentation with the consequent introduction of necrotic and infected material of pulpal origin into the periapical tissues can have outcomes ranging from simple periodontitis to an acute alveolar abscess.
Today, however, many endodontists perform complete treatment of necrotic teeth in a single visit, with a very low, if not negligible, incidence of flares.
This confirms the fact that if one performs the shaping procedure with care, there is no danger of pushing infected material beyond the apex. If this does happens inadvertently it can readily be controlled by the body which can activate its defense mechanisms beyond the apical foramen as long as

the amount of infected material is minimal. In contrast, it can do nothing against microorganisms that remain within the root canal. For this reason, instrumentation which, for fear of pushing infected material beyond the apex, does not completely cleanse the root canal system, is more dangerous than pre-planned instrumentation whose goal is to remove as early and as completely as possible all the infected intracanal contents, even with the remote risk of pushing something out.

3) ***Scrupulously remove all tissue debris***. If the etiology of the lesion happens to be endodontic, the importance of total removal of all tissue debris to prevent this debris from acting as a substrate for bacterial growth is clear. This removal is performed with the use of endodontic instruments, but, try as the dentist may to perform proper instrumentation, there will always be some areas in which contact between the endodontic instruments and the dentinal walls does not occur, even in the simplest, straightest, round canals. In these zones, the complete removal of tissue debris is assured by the digestive activity of 5% sodium hypochlorite heated at 50°C, which always accompanies the work of instruments within the root canal. Sodium hypochlorite digests anything organic that may be present within the canal, including predentin, thus eliminating any material that may favor bacterial growth.
Observation by S.E.M. would demonstrate non-instrumented walls that are free of organic material (Fig. 14.9).
One should not forget that while endodontic instruments shape, the irrigating solutions clean.

4) ***Complete the cleaning and shaping of individual canals in a single visit.***
When treating a root canal, it must be completely cleaned and shaped, so that it is ready to receive the obturation, even if this is planned for a subsequent appointment. The concept of using potent medications to sterilize non-instrumented – hence full of bacteria – canals is mistaken. The bacteria should not be killed in the root canal, but rather simply removed. The use of medications is therefore futile and discouraged, inasmuch as they can act as periapical irritants. What has been removed from the canal can no longer cause any problems, but what has been left in the canal should be of concern.
The approach of one who attempts to sterilize a canal with medications only is therefore mistaken, just as it is wrong to carry out the cleaning and shaping of the same canal in multiple visits. This concept applies not only to singlerooted teeth, in which it may seem logical to prepare the canal completely in a single visit, but also to multirooted teeth, whose several canals must be individually and completely prepared. The time required to prepare three or four canals correctly, dealing with them one at a time, is certainly equal to, if not less than, the time required to prepare them simultaneously.
Each canal has its own length, its own reference point for the rubber stop, its own curvature, its own orientation of the apical foramen, and it requires a particular angulation of the radiographic cone. It is therefore mistaken to introduce three of four endodontic instruments simultaneously into one molar with the goal of saving time and radiographs. Each canal requires its own series of instruments and the dentist's attention for its preparation. One can concentrate fully when preparing one canal at a time, while it is difficult to keep in mind the various difficulties that the various canals may present simultaneously. When dealing with multirooted teeth, it is good to clean and shape each root canal separately and completely before continuing to the next one, since the single mechanical procedure is directly related to the specific shape of each canal.
Thus, it is a mistake to jump from one canal to another with the same instruments, and it is likewise a mistake to prepare simultaneously the three or four canals of one molar. However, one is equally mistaken to prepare them in a stepwise fashion: one visit for the working length, another to prepare them to a certain size, and yet another to complete the preparation. The canals should always be prepared individually and completely. If the time available does not permit complete cleaning and shaping of all the root canals of a multirooted tooth, one should clean and shape some of them in one visit and postpone the preparation of the others to a subsequent visit.
This concept applies to both vital and non vital teeth.
Vital tooth: once pulpotomy has been performed, if there is insufficient time to prepare all the canals, one should prepare one canal, dry it, and close the access cavity with Cresatin and Cavit.
At the subsequent appointment, the anesthesia is repeated, the rubber dam is re-positioned, and another canal is prepared. The Cresatin and Cavit

are then re-administered. At the third appointment, one repeats the same treatment in the third canal.

Asymptomatic pulpless tooth with penetrating caries and open pulp chamber: one performs the cleaning and shaping of one canal, after which one can perform a closed treatment in this single canal, sealing the medication at its opening, or one can leave the tooth completely open. At the successive appointment, another canal is prepared, and so on. The pulp chamber can be sealed with the temporary cement only after all the canals have been completely cleaned and shaped.

Asymptomatic pulpless tooth with closed pulp chamber or retreatment: one completely prepares one canal without the use of anesthesia, and one performs the closed treatment in the usual manner. At the subsequent appointment, one prepares another canal, re-medicates it, and so on.

It is obvious, however, that complete preparation of all the canals of the multirooted tooth in the same visit is much less procedural and brings about a significant saving of time and materials. Therefore, a single, long appointment is preferable to many very brief ones.

In conclusion, this biological objective can be summarized as follows: never introduce a file into a root canal if you are not 100% sure that that specific canal will be completely cleaned and shaped and then ready for packing at the end of the same appointment.

5) ***During the enlargement of the canals, create a space sufficient to contain any exudate that may form***.

In the past, the space obtained by enlarging a canal served to introduce medications that could thus carry out their pharmacological function. Modern practice, in contrast, tends to leave this space as empty as possible, so it can contain an exudate that might accumulate as a result of the dentist's nonetheless delicate and careful instrumentation.

Therefore, if the canal is empty, and, especially, if the apical foramen has remained "patent", the exudate can spill into the canal before accumulating in the space of the periodontal ligament, stretch its fibers, and give rise to periodontitis.

Today, therefore, less and less importance is given to canal medications that can also act as irritants. Rather, contemporary practice calls for leaving the canals empty, for the above reasons. The medication is placed in the chamber in the form of a cotton pellet barely moistened by the vapors of the medication (which is usually very volatile, given its low surface tension) without putting pastes or medicated paper points in the canals. For the most part, canal medications are irritants,[146] so that their placement in the canal rather than in the chamber may provoke apical infiltration of the medication itself, which can cause further formation of exudate in the space of the periodontal ligament, leading to periodontitis and discomfort for the patient.

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15

Schilder's Technique for Shaping the Root Canal System

ARNALDO CASTELLUCCI

INTRODUCTION

In these last years many changes have taken place in general endodontics and particularly, in the field of canal preparation: rotary instruments in nickel titanium have become progressively more utilized in the same way as crown-down shaping of the root canal system has been universally accepted.

Nevertheless, given the limits of rotary instruments, as will be discussed in detail later, and therefore the need to resort to classical manual preparation with stainless steel instruments, as well as the historical importance of the preparation technique described in the distant 1974 by Prof. Herbert Schilder, the author has therefore deemed it appropriate to keep this chapter.

On the other hand, as will be seen in the course of this chapter, many of the concepts of the so-called "crown-down" are also inherent to the Schilder technique. What is hidden in the various recapitulation phases of "preparation of the body of the canal", in which the instruments progressively advance further apically, other than a "crown-down" concept?

There are three distinct phases in the preparation of the root canal:
1) negotiation of the root canal and determination of the instruments' working length
2) maintenance of the patency of the apical foramen
3) enlargement of the body of the canal.

Files are used for the first two phases, reamers for the third. These instruments must be new, sterile, and re-sterilized whenever the need arises.

All instruments must be within reach of the dentist and must be kept sterile throughout the entire procedure (Fig. 15.1).

Furthermore, they must be precurved and equipped with rubber stops.

Fig. 15.1. **A.** The series of instruments are placed in a sterilizer bag and sterilized (continued).

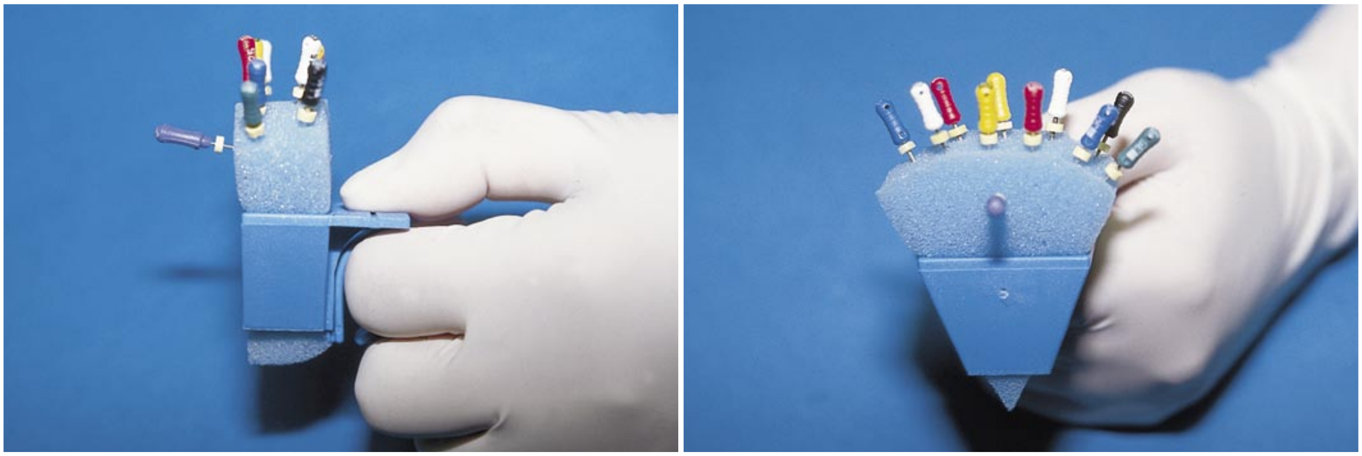
PRECURVATURE

All the instruments must be precurved.[39,69] The amount of precurvature depends on the radiographic appearance of the degree of curvature of the root. It must always be done, even when dealing with roots that are, to all appearances, straight.

A precurved file makes its way more easily among the obstacles and calcifications that the instrument may encounter during early probing of the canal. Precurvature prevents the instrument from making ledges or false canals.

Precurved files also allow preservation of and respect for the apical curvatures, thus preventing transportation of the foramen.

The ideal instrument for precurving endodontic instruments in a predictable and repeatable way without minimally changing the blades is represented by the Endobender. We are referring to an instrument simi-



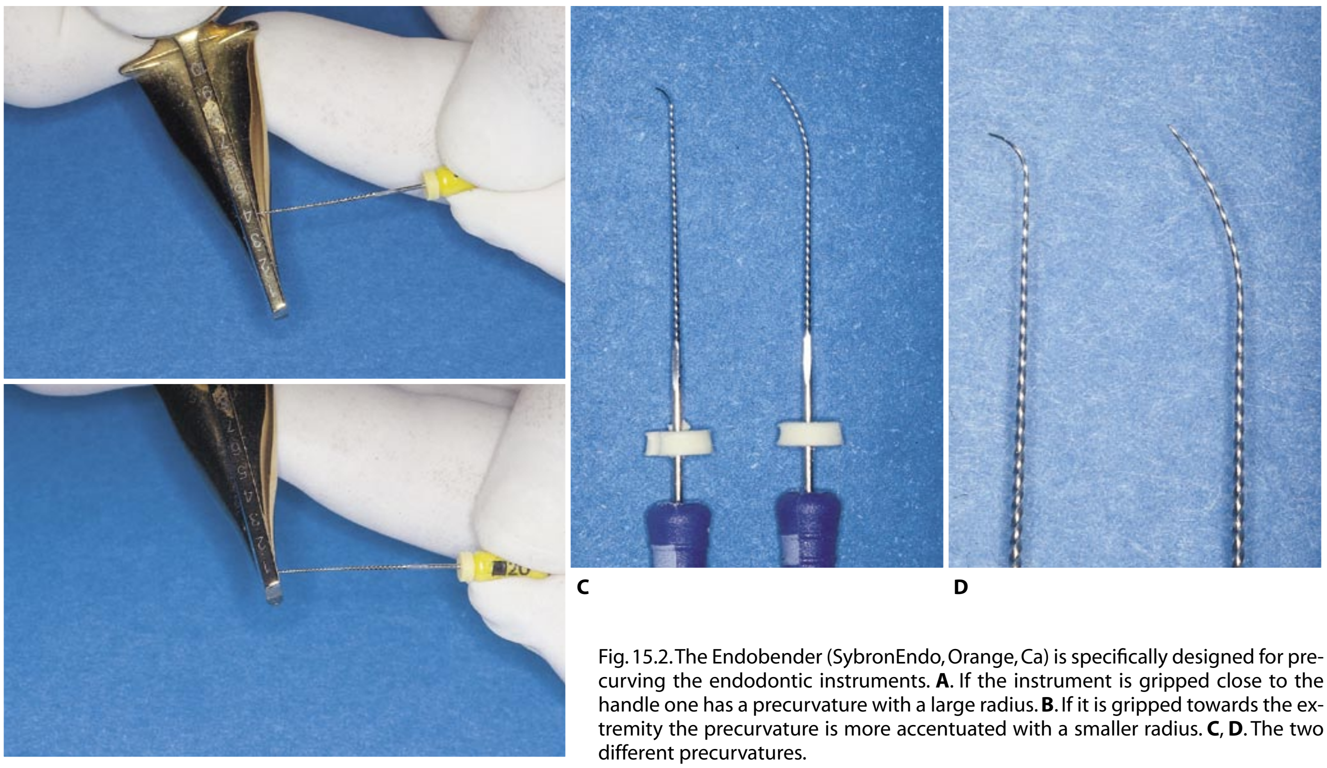
B C

Fig. 15.1. (continued) **B**, **C**. The instruments are kept by the assistant in the appropriate Endoring disposable sponge.

lar to an orthodontic pliers, which bends and therefore precurves the instruments in a different way depending on the curve radius at the point where the file is placed. (Fig. 15.2) and it must coincide with the curve of the root canal: therefore it will be all the more accentuated, the shorter the curve radius of the root. In any case the file must be precurved in a gentle and gradual way and must not be bent.

The reamers must also be precurved to make them more effective. When rotated in the canal after being slightly precurved, they describe in space a figure (the "envelop of motion" described by Herbert Schilder[69]) with a cutting surface superior to the original one of the straight instrument[47] (Fig. 15.3 A).

A non-precurved reamer introduced into a curved canal will follow the canal curvature. However, because it cannot rotate on its own axis, it reproduces in space the curve that it has adopted, producing an "hour-



A B C D

Fig. 15.2. The Endobender (SybronEndo, Orange, Ca) is specifically designed for precurving the endodontic instruments. **A**. If the instrument is gripped close to the handle one has a precurvature with a large radius. **B**. If it is gripped towards the extremity the precurvature is more accentuated with a smaller radius. **C**, **D**. The two different precurvatures.

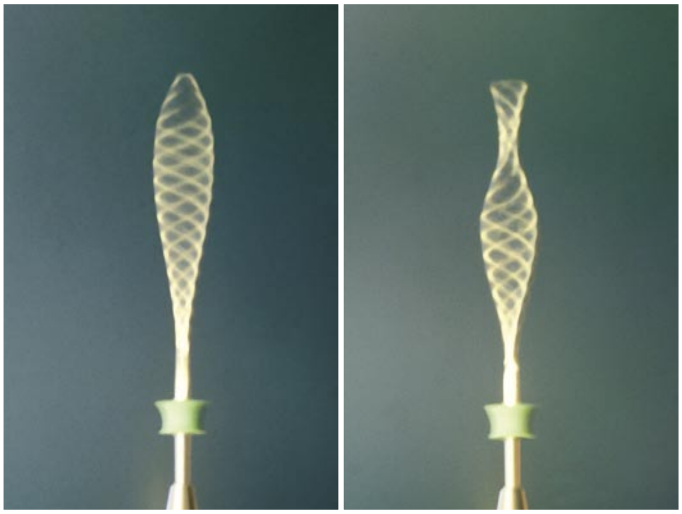


Fig. 15.3. **A.** The cutting surface of the "envelop of motion" obtained by rotating a reamer is larger than that of the original, straight instrument (adapted from Lavagnoli). **B.** Introduced into a curved canal, a non-pre-curved reamer reproduces in space an hourglass-shaped figure when rotated. This can cause tearing of the apical foramen and ledges (adapted from Lavagnoli).

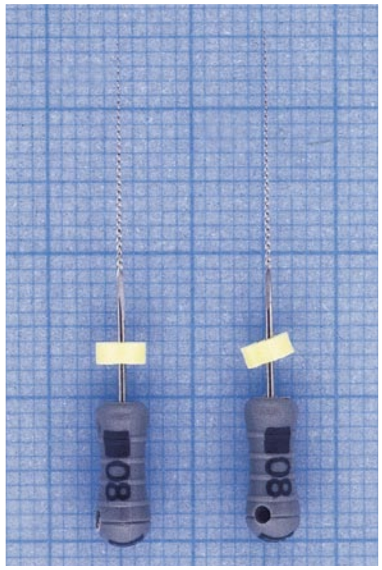


Fig. 15.4. The rubber stop must be perpendicularly positioned to the instrument's long axis and must not be inclined; otherwise, it will not be possible to have good control of the working length.

glass" effect in the canal, which increases the chance of lacerating the apex or creating ledges (Fig. 15.3 B).

The precurvature of reamers must be gradual and distributed over the entire working portion of the instrument. It must diminish slightly as one advances to larger-size instruments.

RUBBER STOPS

All instruments must be equipped with rubber stops, which are used to regulate their working length.

The stops must be easily applied and, if the need arises, easily movable. Most important, they must be secure enough on the instrument shaft that the same working length can be maintained consistently throughout the entire process of cleaning and shaping.

The stop must be seated 90° to the long axis of the instrument; it should not be tilted (Fig. 15.4). If the stop is positioned obliquely, the instrument's working length can vary by as much as 2 mm.

Finally the stops must be directional, that is they must be made in such a way as to have the possibility of being oriented in the direction of the precurvature. This is so that one always knows, while the instrument is inserted inside the canal, towards which side the precurvature faces in order to be able to direct it in the desired direction.

NEGOTIATION OF THE ROOT CANAL AND DETERMINATION OF THE INSTRUMENT'S WORKING LENGTH

Negotiation of the root canal

This is the most delicate phase of canal preparation. It can sometimes require a good deal of time and patience.

The canal must be generously irrigated with sodium hypochlorite, and the precurved instrument must be almost passively introduced into the root canal without forcing or pushing it. The first instrument to enter the root canal should be a file, which will never fracture if used correctly. As stated previously, this instrument requires a simple back-and-forth motion with no rotatory component. Even if it gets stuck in the canal, the vertical movement will never cause it to fracture, since even the smallest file is highly resistant to traction.

In contrast, the reamer must be rotated to effect its action. If it is tightly wedged in the canal, the rotational movement can cause it to fracture, as it has little resistance to rotation.

For safety reasons, the first instruments to be placed in a canal should be those that do not need to be rotated; in other words, they should be files, which are resistant to traction, and not reamers, which are susceptible to fracture by rotation.

The first instrument should always be very small (e.g., # 08 or # 10, even if the canal is wider), since it functions as a feeler that relays information about any obstacles that may be present within the canal lumen. In performing its tactile function, this first instrument must act as an extension of the dentist's finger, and it must go around and bypass obstacles without attacking them directly.

If one senses an obstacle, one should not force the instrument in the root canal in an attempt to overcome it; on the contrary, one must extract it from the root canal, give it a greater degree of precurvature at its tip, and repeat the probing. In doing so, one must consider that the canal must be patent at some point, and thorough probing of this canal depends on the dentist's patience and competence.

Often an obstacle in the final millimeters of the canal is interpreted as a "calcified canal". As has been previously stated, diseases of the pulp progress in the corona apical direction. This means that the pulp gets infected, it becomes inflamed, it calcifies and dies in the same direction. In other words it cannot happen that the canal is pervious except for the last millimeter. Therefore the obstacle that sometimes appears present in the most apical portion of the canal is not indicative of a calcification of the entire canal lumen, but rather by a sudden and accentuated curvature in the same canal. The probing must therefore be carried out with numerous attempts, precurving the file tip each time in a more accentuated way, until we literally (without the minimum effort on our part) "fall" into the canal which was just waiting to be probed.

Forcing the small instrument into the root canal in an attempt to reach the apex can cause various errors, such as bending and fracture of the instrument, mobilization of calcifications from the canal walls that could fall into the canal and obstruct it; and the creation of ledges, false canals, or perforations, all of which would inevitably lead to failure of therapy.

The instrument must be used with great care, and its use should be accompanied by generous irrigations. It should be substituted whenever its original shape appears altered, and it should be re-precurved if it is removed from the root canal in an attempt to reach the apex.

Once the instrument has progressed apically to the depth indicated by the preoperative radiograph and the electronic apex locator has indicated that our evaluation is correct, the rubber stop should be positioned against the reference point of one's choice, which should be stable and readily identifiable. The first intraoperative radiograph is then obtained to confirm the working length. As will be explained in detail later, the apex locators do not substitute radiographic examinations.

The instrument, which has most likely been introduced into the canal with difficulty and patience, must not be moved until its position has been radiographically verified. If extracted, one might not be able to reintroduce it to the same point because of debris that may have detached from the narrow wall and blocked the canal. On the other hand, beginning to move it with a back-and-forth motion could create ledges (if the instrument is too short) or damage to the periapical tissues (if the initial assessment was incorrect and the instrument is in fact too long and protrudes beyond the apex).

Once the working length has been verified, the instrument is made to work within the canal using small back-and-forth movements with excursions that do not exceed 2 mm. The instrument is withdrawn from the canal only after it has created enough space around itself, so that it is "loose" within the canal and free to move unimpeded. This indicates that the root canal has been enlarged sufficiently and is ready to receive a file of the next larger size.

Determining the working length

A much-discussed topic, which perhaps will always be disputed, is where to end the preparation – and thus, the obturation – of the root canal; in other words, what point to choose to determine the instruments' working length.

Many schools maintain that instrumentation and root canal obturation must stop at the cementodentinal junction, near which the apical constriction is maximal (Fig. 15.5). At this point, the pulp tissue ends, and the endodontium yields to the periodontium. The canal walls are no longer formed of dentin, but cementum.

Theoretically, this view is more than correct, since the apical constriction ensures a good stopping point for preparation and canal obturation, which must maximally respect the periodontium and periapical tissues.

In practice, however, the facts are quite different. As Coolidge[19] maintained as long ago as 1929, the site of the cementodentinal junction is so variable that trying to use it as a landmark during pulp removal and canal obturation is of little help. This junction often has

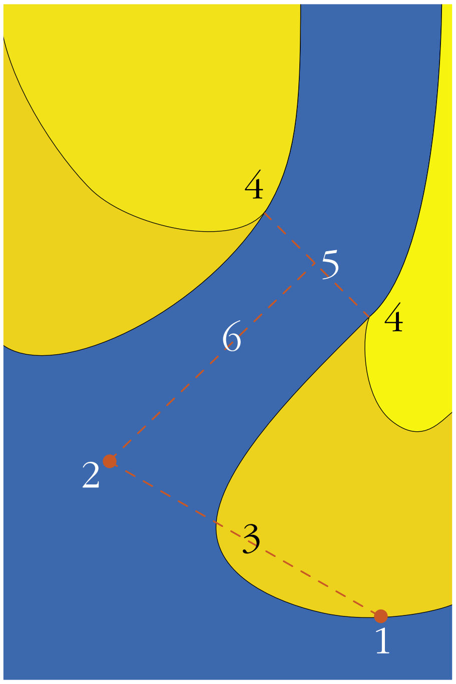


Fig. 15.5. Schematic representation of the root apex, according to Kuttler. **1**. Anatomic apex, geometric apex, or vertex of the root. **2**. Center of the foramen. **3**. Distance between the vertex and the center of the foramen. **4**. Cementodentinal junction. **5**. Canal diameter at the level of the cementodentinal junction. **6**. Distance between the center of the foramen and the apical constriction (adapted from Kuttler).

indistinct borders, and it may be found at different levels within the root canal (Fig. 15.6). Still according to Coolidge, "the dividing line between the pulp and the periodontal tissue is not a fixed point to be used as a guide in operating. Not only the dentinocemental junction is a dividing line imaginary, but the conception also is erroneous and may be misleading. It would be more accurate to speak of this area as the area of the *apical foramen* and disregard the variable position of the junction between cementum and dentin".

At its point of entry in the root canal, the pulp tissue has the same characteristics both just before and just after it crosses the foramen: a wide band of blood vessels, nerves, and connective tissue. Thus, it is impossible to establish at what point or at what line the pulp tissue ends and the periodontal tissue commences (Fig. 15.7). The conclusion of Coolidge article is that "it would seem that the success of a root canal filling does not depend on the removal of the pulp to any definitive point, but it should be amputated close to the *apical foramen*".

In an article that appeared a few months later, Groove[35] claimed that "after eruption, the radicular apex is entirely formed by cementoblasts, and thus the end of the root is entirely formed of cementum. The pulp does not extend into the zone composed of cementum. If the pulp were present in this portion of the canal, dentin would form instead of cementum. The pulp therefore ends at the cementodentinal junction and must be removed up to this point ....".

Thus, according to Groove, pulp fragments must not be left in the root canal, nor should portions of the root canal be left untreated. Rather, the canal preparation must terminate at the cementodentinal junction without going beyond it.

Groove had no doubt about the presence of the cementodentinal junction. Nor did he doubt that the demarcation line is irregular. However, there is no reason to believe that such irregularity exists along the entire circumference of the canal. "Since the formation of dentin precedes that of cementum, it is obvious that there must be a definite demarcation line between the two tissues". "The presence of irregularity of the junction does not mean that it is not practical or that it is impossible to obturate at the cementodentinal junction". Therefore, to avoid imprecision, a very precise point must be chosen that prevents not only overfilling but also underfilling; according to Groove, the only sure point is the cementodentinal junction.

In an article that appeared immediately afterward, the same year, the same journal and the same title, Orban[55] concurred with Coolidge and criticized Groove, stating that from a practical point of view "it is utterly impossible to use the cementodentinal junction as a landmark in root canal work". When it is used, it is by chance most of the time.

One must keep in mind that, practically speaking, identification by tactile means of the cementodentinal junction as the site of maximal apical constriction may often be misleading.[16] Some authors, however, maintain the contrary.[71]

In a recently published article, Ricucci and Langeland[62] actually state that seeing that the anatomical location of the apical constriction cannot be clinically determined with accuracy and that it has been recorded as far as 3.8 mm from the anatomical apex, that one should mainly rely on tactile sensation to determine its location and not on the use of apex locators!

According to the author, the above is as much as can approximately be confirmed! To stop at "the constriction" using tactile sensation is as good as stopping as far as the instruments can go, because we are simply not able to make them proceed further apically. The author warns the reader to be aware of the danger of similar articles found in the literature. Articles such as this encourage one to work in an approximate way and consequently the long-term results are completely unpredictable.

The "constriction" encountered by the instruments can infact be due to a calcification or a narrowing of the canal space which can be close to or far from the real endodontic terminus (Figs. 15.8, 15.9), therefore the tactile sensation used to determine the working length can definitely be considered unreliable.[56] On the other hand, it is well known that at the origin of all endodontic failures there is a short preparation and therefore a short obturation.[85] Therefore, the arbitrary rule that canal preparation should terminate 1 or more millimeters short, is unacceptable in modern endodontics because it increases the likelihood of failure![8,53]

The patient's response to pain may be equally misleading. Some dentists believe that once the preparation of the canal has been concluded and once the anesthesia has passed, or if the pulp is necrotic, the patient can feel the instrument when it reaches the apical foramen and comes into contact with the surrounding vital tissues. In fact, the sensation of pain by the patient in the former situation could be due to the pressure of the instrument in the canal, even if the apical foramen has not been reached. In the latter case, the painful response could be elicited by contact with inflamed but vital pulp tissue still present within the apical third of a canal that otherwise appears necrotic.

Some other times, in an unanesthetized patient with a necrotic pulp, the first pain sensation may occur when the instrument is already several millimeters beyond the apical foramen!

Skillen[73] emphasizes that it is histologically impossible to define a clear line of demarcation between the pulp and the periodontal membrane. It is therefore impossible, even histologically, to find the point within the canal at which the pulp tissue ends and the periodontium begins.

In conclusion, even if it would be desirable, it is unfortunately not possible to terminate the canal preparation and obturation at the cementodentinal junction, for both histologic reasons (i.e., the irregularity and inconsistency of the cementodentinal junction and the lack of differentiation of the pulp neurovascular bundle before and after its entry in the apical foramen) and clinical reasons (i.e., the impossibility of identifying and locating the cementodentinal junction, the unreliability of tactile sensation in identifying the point of maximal apical constriction, and the unreliability of pain sensation in the patient).

Other investigators make use of mathematical formulae and statistics to locate the junction, but even these methods cannot be considered rigorous, since they must obviously be considered approximate and arbitrary.

When Kuttler[45] states that the "mean" thickness of the apical cementum is 0.5 mm and that the canal obtu-

Fig. 15.6. The cementum may rise within the canal, so that, even histologically, the cementodentinal junction is not easy to locate.

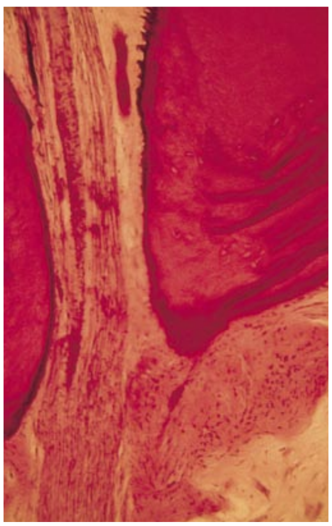


Fig. 15.7. The pulp tissue, apart from the odontoblasts, has the same characteristics both before and after having crossed the foramen.

Fig. 15.8. In this case, the apical constriction does not correspond to the cementodentinal junction, but is more coronal, where the canal walls almost contact each other.

Fig. 15.9. In this case, the apical constriction corresponds to a calcification situated coronally to the cementodentinal junction.

ration must therefore end 0.5 mm from the foramen, he concedes in other words that if one follows this reasoning, one sometimes surpasses the junction and the point of ideal stopping, and falls short other times.

According to Stein and Corcoran,[76] Kuttler studied the *average* distance between the major and minor diameters of the apical foramina in 268 teeth. He found the *average* distance to be 0.507 mm in patients 18 to 25 years old and 0.784 mm in patient more than 55 years old.

Green[34] claims that the point of maximal apical constriction is, on *average*, 0.75 mm from the foramen.

In a recent article, Rosenberg[64] said that the distance to be subtracted from the radiographic apex is based on studies where the *average* distance of the apical foramen from the radiographic apex has been measured. Then an *average* length discrepancy with a standard deviation is determined. The problem with this approximation technique is that the teeth we treat are not *average*, but very *unique*.

Another consideration that can be done is the following: if one doesn't go to the foramen and decides to stay 0.5 or 1 or more millimeters from the canal terminus, how does he/she know that he/she is exactly at 0.5, or 1 or more millimeters from the canal terminus? In this world, to know the distance from one point to another we need to measure from that place to the other!

According to Pecchioni,[59] when one considers the mean thickness of the cementum and of the periodontal ligament, it is preferable that canal preparation and obturation halt 0.5-1 mm from the radiographic apex so that one can be certain of working up to the endodontic apex, namely the cementodentinal junction.

We can conclude that the recommended distance that one must keep away from the apical foramen varies according to the different schools of thought.

Other authors feel that canal preparation and obturation should be performed slightly short of the apical foramen for yet another reason: the lack of correspondence between the radiographic apex and the anatomic apex.

However, because there is much confusion regarding the terminology, some clarification is in order.

Anatomic apex[1] refers to the tip or end of the root of a tooth as determined morphologically, or in other words, refers to the vertex of the root and is also called geometric apex.

Radiographic apex[1] refers to the tip or end of the root of a tooth as seen on a radiograph, in other words is the anatomic apex as seen on the radiograph.

Apical foramen[1] refers to the opening of the root canal on the external surface of the root and not necessarily coincide with the anatomic apex, depending on the apical curvature of the canal inside the root.

Since the cementodentinal junction cannot be chosen as the terminal point of canal preparation and obturation, because it is not possible to determine its location either clinically or histologically; given that the distance by which one falls short is a rather arbitrary and subjective choice (0.5-0.75-1 up to 3 mm, depending on the author the dentist decides to follow), it is necessary to establish another landmark for the determination of the instruments' working length.

Schilder[70] states that canal preparation and obturation must be performed to the "radiographic terminus of the canal", meaning the point at which the canal radiographically encounters the outline of the root. This derives from the following considerations:

- its determination is not arbitrary or subjective, nor is it dictated by statistics
- clinically, it is easily identifiable by the dentist, even of different schools, by simply examining a properly-performed intraoperative radiograph
- in 50% of cases,[14,34] the canal ends at the anatomic or geometric apex or vertex of the root, and is thus identifiable radiographically. In these cases, using the radiographic terminus of the canal therefore entails neither overinstrumentation nor overfilling
- if the emergence from the canal is not at the geometric apex of the root, but in a lateral position, it will always be identifiable radiographically if situated mesially or distally, as often happens[18,48,82] (about 40%)
- if, instead, the foramen is displaced buccally or lingually, it obviously will not be radiographically identifiable. In these cases, instrumentation at the radiographic terminus of the canal will entail overinstrumentation by several fractions of a millimeter, since there is a certain distance – which cannot be radiographically evaluated – between the vertex of the root and the apical foramen. This distance, measured by Dummer[24] on the external surface of the root in a group of 270 teeth including incisors, canines, and premolars, both maxillary and mandibular, turned out to be, on average, 0.38 mm (Fig. 15.10).

A recent study by Olson et al.[53] on 305 anterior and posterior root canals has further demonstrated that the apical foramen can be accurately located by a good radiographic study alone (paralleling technique) in a good 82% of cases. The canals in which it was not

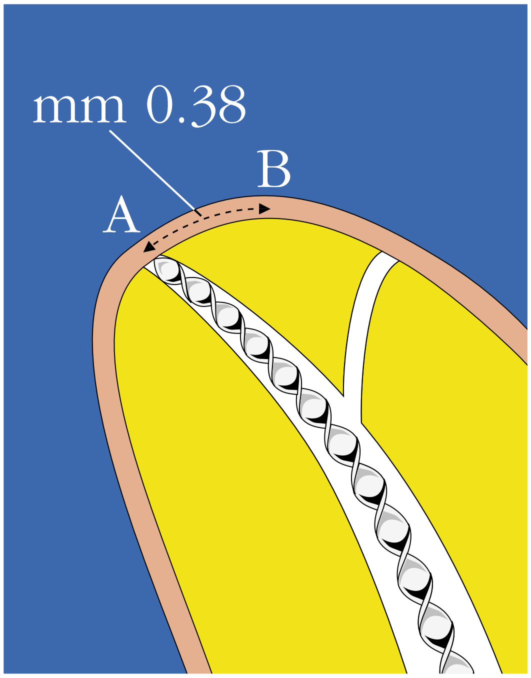
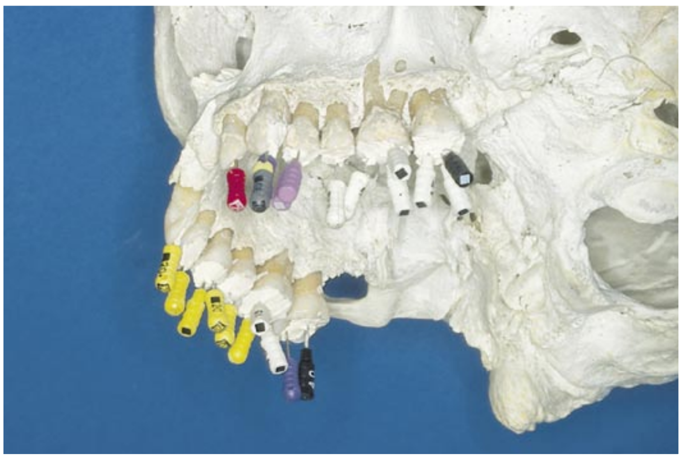


Fig. 15.10. The mean distance between the apical foramen and the anatomic apex (always radiographically visible) is 0.38 mm in Dummer's study. A: apical foramen; B: Anatomic apex; A-B: foramen-anatomic apex distance measured on the external surface of the root.

possible to locate the apical foramen exactly by radiography were in the upper canines in 50%, the upper molars in 25%, and the upper central incisors in 23%.

A study by this author[18] on 227 teeth with a total of 342 canals led to even more reassuring conclusions. The study was carried out on teeth which had been extracted from dried maxillae and mandibles:π the access cavity was made, a root canal file was placed into each root canal until the tip could be seen under the microscope to be flush with the root surface at the apical foramen (Fig. 15.11 C), then the file was luted into position with acrylic resin and then each tooth was reintroduced into its respective alveolus for radiographic evaluation (Figs. 15.11 A, B). The results of the investigation are shown in Fig. 15.12. In categories A and B, the radiographic position of each file was flush with the external root surface at the apical foramen and could be seen accurately on the radiograph. In category A the file appeared to exit at the radiographic apex, while in category B the files appeared to exit elsewhere along the root surface (mesial or distal). In category C the file appeared short of the root surface on the radiograph. It demonstrated that



A

B

C

Fig. 15.11. **A**, **B**. In this skull and in these mandibles the teeth were extracted. Access cavities were prepared and instruments positioned exactly at the apical foramen, checked with a 64x stereo microscope (**C**). They were then fixed in this position and the teeth reinserted in their respective alveoli. Radiographs using the paralleling technique were taken.

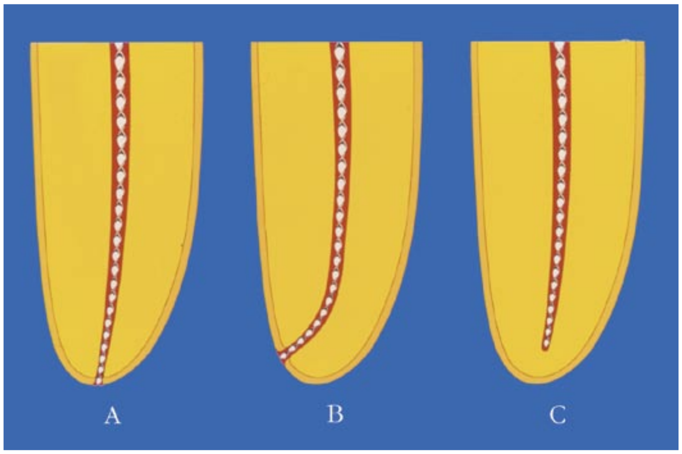


Fig. 15.12. The radiographic appearance that the instruments have could be
***A**: if the foramen is at the anatomic apex and therefore at the radiographic apex, which means that the canal was straight;
***B**: if the foramen opens mesially or distally, because the canal curved in that direction;
***C**: if the foramen opens buccally or palatally/lingually, because the canal curved in that direction. Since the instruments were positioned flush at the foramen under magnification, they could not be beyond the apex.

in 48% of cases the apical foramen is at the anatomic apex (and therefore localizable radiographically), while in 40.9% of cases the emergence of the canal is mesial or distal (and therefore still radiographically identifiable). In only 11.1% of cases was the foramen on the buccal or lingual surface of the root (and therefore not radiographically visible) (Tab. I).

We can therefore come to these important conclusions:

1) in 88,9% of the cases it is possible to accurately determine the location of the apical foramen by the use of a radiograph
2) if one wants to consider the choice of the radiographic terminus of the canal to be approximate (given that this sometimes involves preparation and obturation slightly beyond the foramen), it cannot be considered any more approximate than the choice of staying 0.5 mm, 0.75 mm, 1 mm or even more[62] short of the radiographic apex.

The result of this choice often leads to inadequate treatment of a considerably wider portion of the canal and blockage of the apical foramen. On the other hand, this choice does not prevent overinstrumentation and consequent overfilling in those unusual cases in which the opening of the apical foramen is many millimeters from the anatomic apex (Fig. 15.13).

In this author's opinion, therefore, the technique that adopts the radiographic terminus of the canal as a landmark by which to determine the instruments' working length is to be preferred, even though this sometimes leads to an obturation that spills beyond the foramen by several fractions of a millimeter, which is the exception and not the rule. A small excess of obturation material in a three-dimensionally filled root canal is irrelevant and well tolerated by the organism,

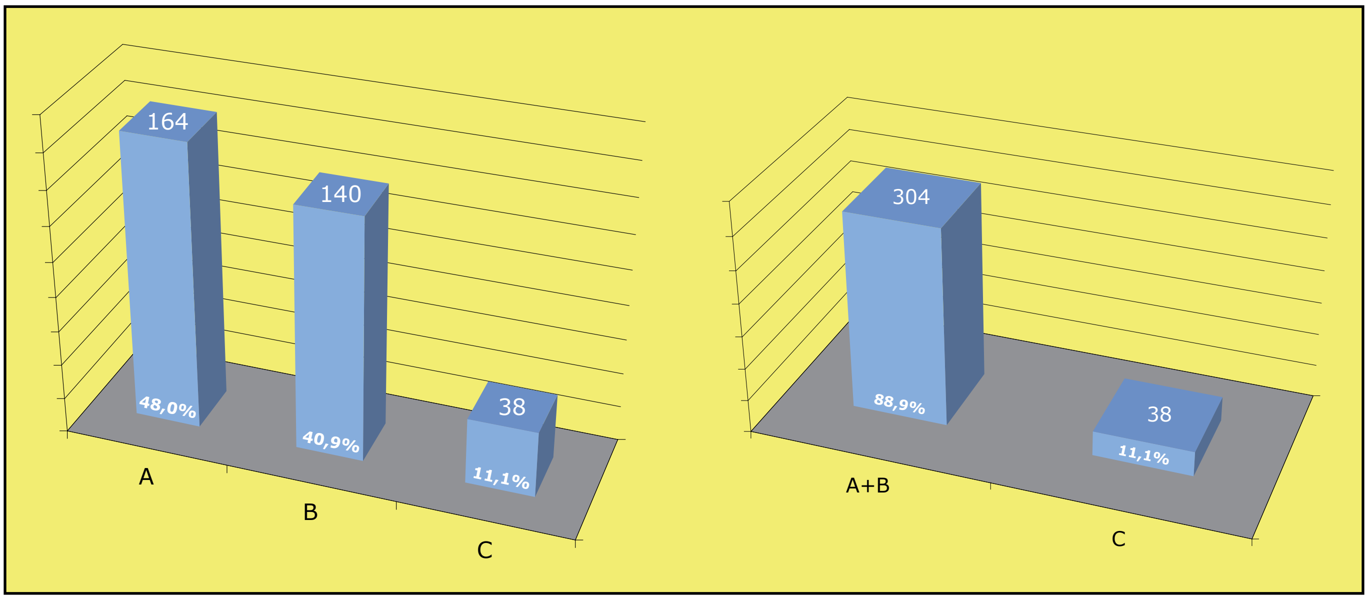


Table I. Research shows that in 88.9% of cases the apical foramen is radiographically verifiable and only in 11.1% is it necessary to remain "radiographically short", and use the "electronic apex" as reference point for the working length.

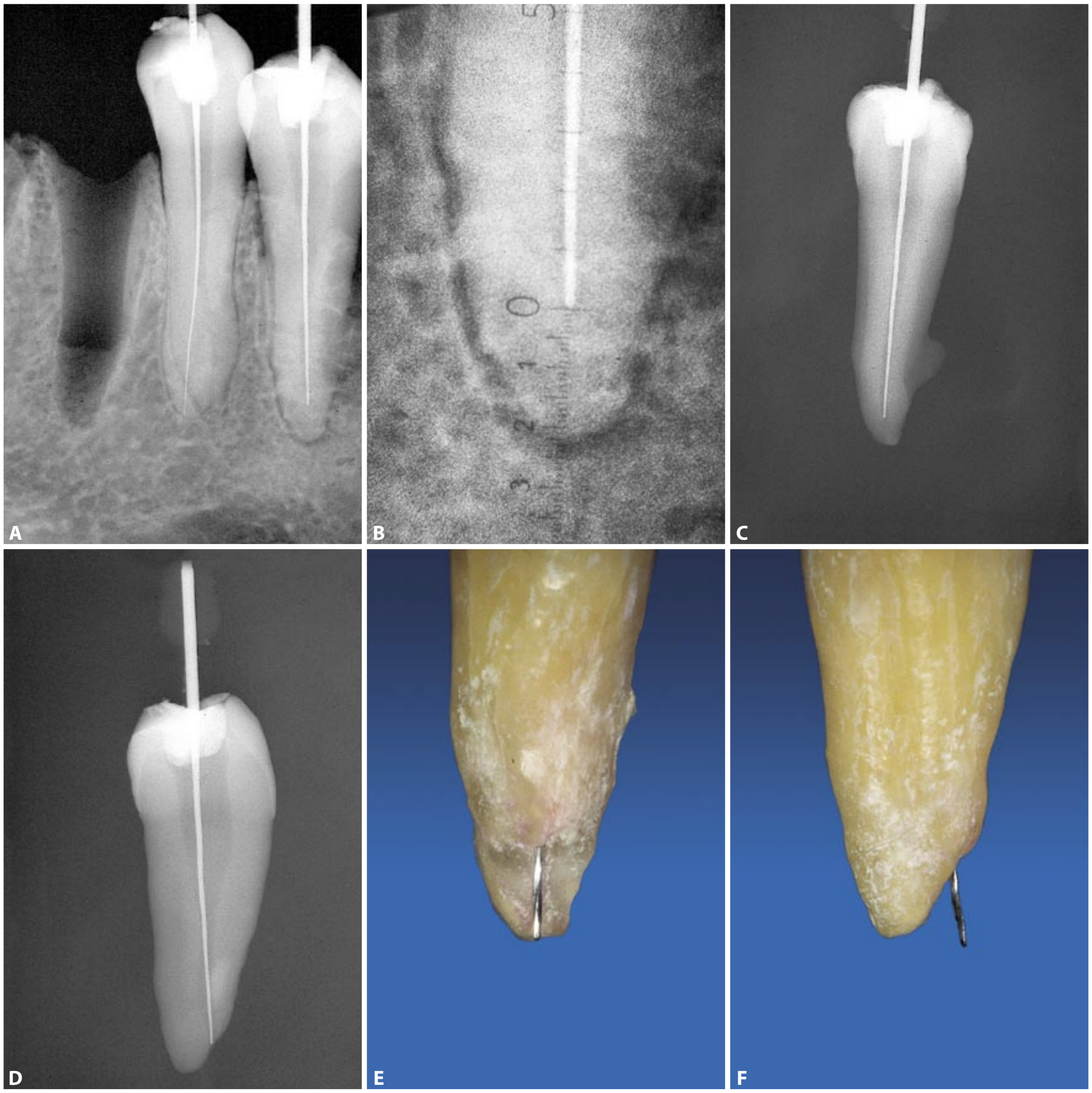


Fig. 15.13. **A**. One of the research mandibles. In the first lower left premolar the instrument is at the exact radiographic terminus of one of the two canals, while in the second premolar it is visibly short. **B**. The measurement on the radiograph with a millimeter rule shows it to be 2 mm short of the radiographic apex. **C**. The extracted tooth radiographed outside of the alveolus. **D**. The tooth radiographed in a mesio-distal projection. The instrument is at the foramen, but it opens buccally on the root surface and would not be identifiable with a normal radiographic projection. **E**, **F**. Note how much the file would need to extrude from the apex to be at the radiographic apex. What would it mean in a case like this to remain 0.5 mm short of the radiographic apex?

as demonstrated by studies performed by numerous investigators.[4,23,27,67,74,75]

Even in these last cases (the 11.1% cases of the previous study), nevertheless, "long" preparations and obturations are not carried out, because the electronic apex locators inform us of the true position of the apical foramen and therefore on the correct working length. So we can without doubt say that the reference point of the apical depth or our preparation and obturation is represented by "electronic apex", which coincides in about 90% of the cases, with the radiographic terminus of the canal.

Furthermore seeing that the reason for endodontic failures is due to bacteria that have been left in a portion of the canal that is incompletely cleaned and unsealed, seeing that the canal ends at the apical foramen, seeing that the foramen can open on any side of the root apex, what sense is there in taking as the reference point of the working length, a point chosen at random which is more or less far from the radiographic apex that could have nothing to do with the true end of the canal (Fig. 15.14)?

How can someone explain that staying short in vital cases, the pulp stump in contact with the obtu-

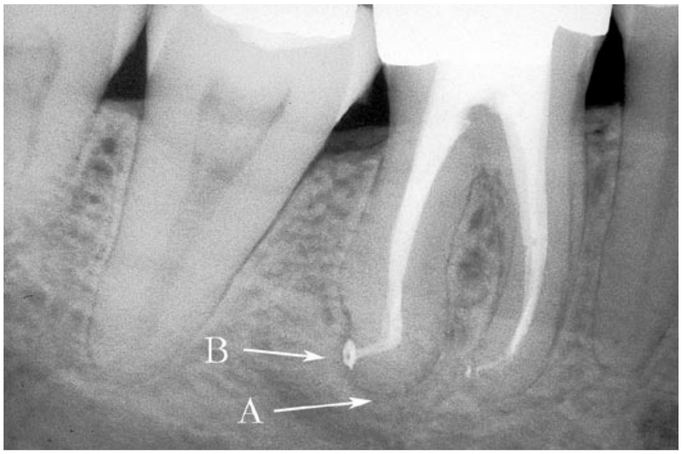


Fig. 15.14. The radiograph illustrates very well how absurd it would be to use the radiographic apex (A) as a reference point, especially when this has nothing to do with the real site of the apical foramen (B), the real root canal terminus and the real terminus of our preparation and obturation. In this case the treatment was carried out at the radiographic terminus of the canal but at the same time at least 3 mm from the radiographic apex.......!

rating material remains vital forever and never inflamed, while the same material if extruded through the foramen is the cause of inflammation, of a foreign body reaction and ultimately of the endodontic failure? Even Groove,[35] who was in favor of the cemento-dentinal junction, at the beginning of the last century said: "I question very much the successful application of the method, suggesting leaving 2 or 3 mm of the pulp end; for atrophy is very likely to follow for reasons already given, and the resultant products of putrefaction find entrance by way of the open foramen to the periapicale tissue, producing infection. I can see no justification for purposely leaving pulp tissue since there is no reasonable assurance of successful results."

The only justification the present author can see is that staying short makes everybody's' life a lot easier, since all the difficulties in Endodontics exist in the last 1 or 2 mm!

Finally, wanting to list the various methods of calculating working length at our disposal, we cannot not take into consideration that method which may seem to be the most empirical but which is certainly the most reliable of those so far mentioned, certainly the easiest to put into practice and which is represented by the constant drying point of the canal, measurable as the most extreme dry point of the paper point. If some doubts exist with the proceeding methods (radiography, apex locator, tactile sensitivity) the one on which we can certainly rely, is the drying point of the canal measured on the paper point.[64]

The day an instrument that is capable of clinically identifying the cementodentinal junction and thus of informing one where to terminate the preparation and canal obturation becomes available, there will be no further reason to discuss whether it is better to stay one or more millimeters short or risk sometimes being few fractions of a millimeter long. However, everyone would agree in selecting it as a stopping point of the treatment, given that the maximal apical constriction is present at this point. The endodontium ends there, while beyond it lies the periodontium. One could thus always be certain of clinical and biological success. That day, however, is still far away.

Electronic apex locators

Currently the use of the electronic apex locator represents a very valid method of measuring the working length for our instruments which, as has just been mentioned, take the *electronic apex* as their reference point.

These instruments are based on the principle that the electrical resistance between one electrode in the root canal and another applied to the oral mucosa registered consistent values. This was demonstrated in studies by Suzuki[79] in 1942, but had already been suggested by Custer[20] in 1918.

Sunada[78] was the first to take advantage of this principle to measure the length of root canals. He established an electric circuit between the oral mucosa and the periodontal ligament, and with the help of an ohmmeter found that the resistance of this circuit was consistent. He concluded that when an endodontic instrument was inserted in the canal and the ohmmeter registered 40 mA, the instrument tip was exactly in contact with the periodontal ligament at the apical foramen of the root canal.

Recently, a variety of electronic apparatuses have been placed on the market with the aim of measuring the root canals by applying the findings of Suzuki and Sunada.

Cash[13] has reported favorable results with the use of the Endometer. Inoue[40] has obtained identical results with the Sono-explorer. Before isolating the tooth with the rubber dam, both these instruments must be calibrated by inserting the file connected at the insertion into the gingivalal sulcus of the patient's tooth.

The principle on which these instruments are based dictates that the tissue resistance of the periodontal membrane that surrounds the tooth is constant and is therefore the same at the gingival sulcus and at the apical foramen.

In the case of the Endometer, the apex is localized by reading a graduated scale, while the Sono-explorer registers the potential difference of the dental tissues, and transforms it into sounds that are interpreted by the user.[10]

More recently, new devices such as the Neosono D (Fig. 15.15) and Analytic Technology's Apex Finder (Fig. 15.16) have been introduced. Because they do not require individual calibration in the gingival sulcus of each patient, they are easier and faster to use. A digital scale is used in these instruments to inform the user that the foramen has been reached.

All the instruments mentioned above belong to the old generation of electronic apex locators and their use has both advantages and disadvantages.

Advantages

These are the only instruments capable of locating the apical foramen and that don't take the radiographic apex into consideration.[41] They are, above all, useful in those situations where radiography cannot aid us, as in the case of hidden apices and other anatomical structures (impacted teeth, adjacent roots, etc) (Figs. 15.17, 15.18), pregnant women, uncoopera-

Fig. 15.15. Neosono-D electronic apex locator (Amadent).

Fig. 15.16. Apex-Finder electronic apex locator (Analytic Technology).

A B C

Fig. 15.17. The electronic apex locator was shown to be particularly useful in this case, since the unerupted canine was superimposed on the apex of the lateral incisor. **A.** Preoperative radiograph. **B.** Intraoperative radiograph to check the site of the apical foramen indicated by the electronic locator. **C.** Postoperative radiograph. In the meantime, the central incisor has also been treated.

tive patients, patients suffering from Parkinson's disease (Fig. 15.19) or the handicapped in general, patients that have a sensitive gag reflex and all the situations where it is impossible to obtain a radiograph.[5,80]

These electronic apex locators can also be useful in diagnosing perforations. When the instrument comes in contact with the periodontal ligament through a perforation, it registers the same electrical resistance that it would at the apical foramen. This is particularly useful in buccal or lingual perforations, which are impossible to identify radiographically.[33,41,51,52,80]

It may also be useful in diagnosing the convergence of two canals into a single canal and thus a single foramen. The file is placed in a canal down to the apex and the instrument is connected to another file that has been introduced in the other canal. The contact between the two instruments is detected by the apex locator, and the diagnosis of confluence is easily made.[80]

Lastly, but certainly not of lesser importance, the apex locators result in a notable reduction of exposure to X-rays.

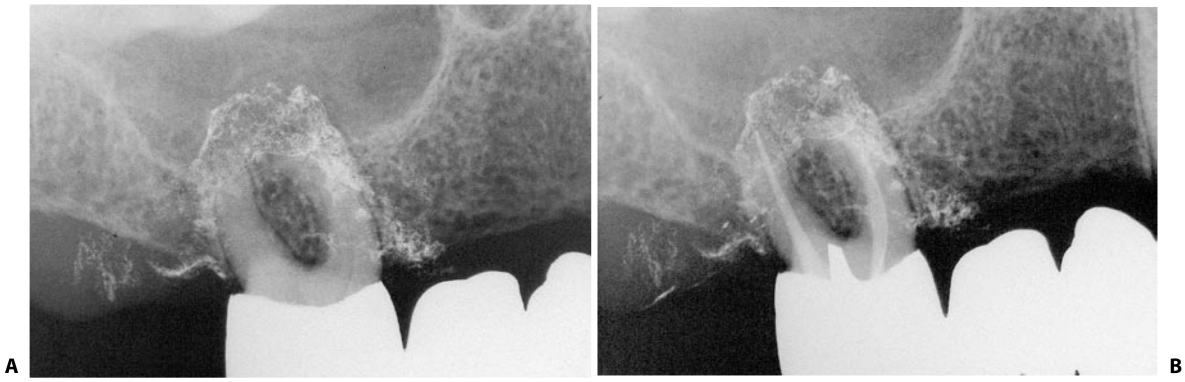


Fig. 15.18. **A.** The palatal root of this upper right first molar was removed for periodontal reasons before the endodontic therapy was performed. Now, the metallic filings remaining in the thickness of the flap conceals the apex of the mesiobuccal root. **B.** The endodontic therapy has been completed with the help of the electronic apex locator.

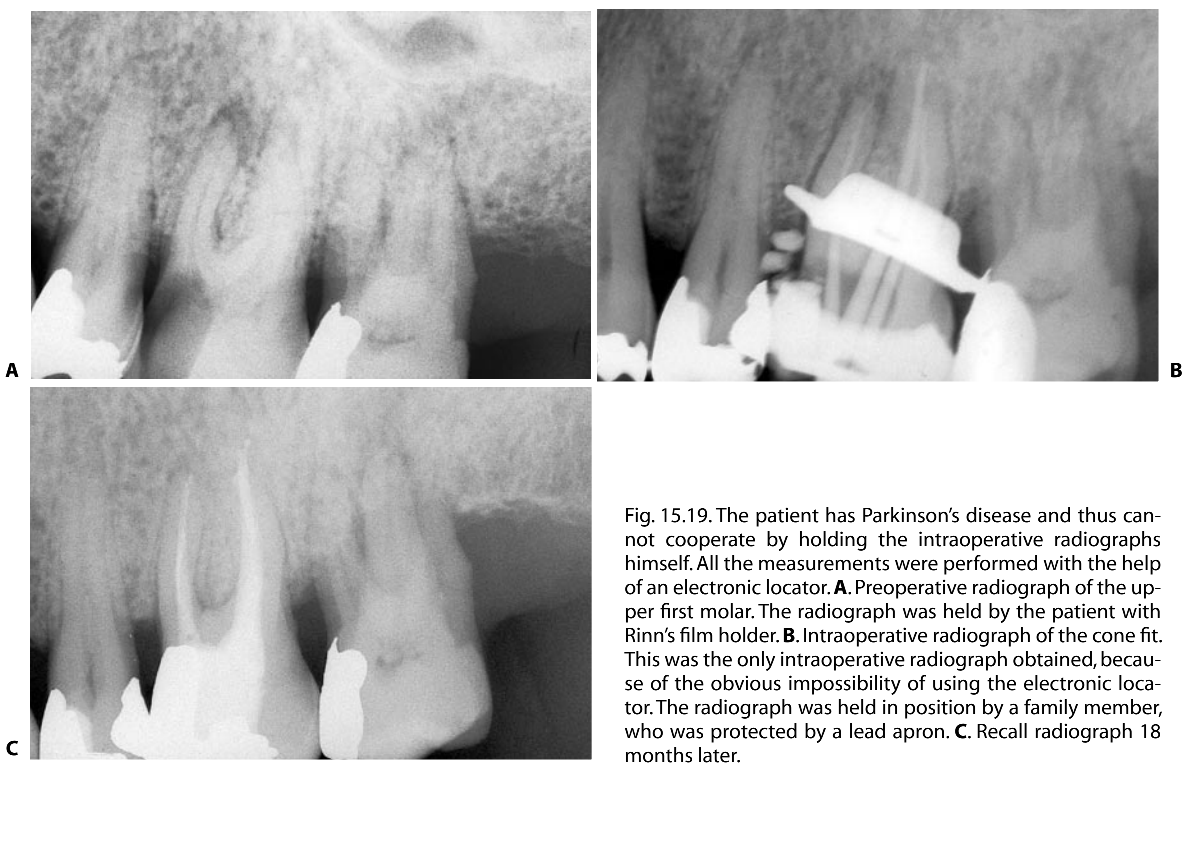


Fig. 15.19. The patient has Parkinson's disease and thus cannot cooperate by holding the intraoperative radiographs himself. All the measurements were performed with the help of an electronic locator. **A.** Preoperative radiograph of the upper first molar. The radiograph was held by the patient with Rinn's film holder. **B.** Intraoperative radiograph of the cone fit. This was the only intraoperative radiograph obtained, because of the obvious impossibility of using the electronic locator. The radiograph was held in position by a family member, who was protected by a lead apron. **C.** Recall radiograph 18 months later.

Disadvantages

It is necessary to keep in mind that the accuracy of these instruments' measurements is about 80-90%. There is therefore always a certain percentage of error.[3,7,9,36,60,77]

The measurements are particularly unreliable in teeth with an immature apex with either vital[80] or necrotic pulp,[38] or in teeth with a periapical radiolucency.[10,77] The same is true in case of large radicular cysts.[12]

Furthermore for the correct use of these old generation apex locators, the canal must be free of pulp tissue, exudate, pus, blood, electrolytes, and sodium hypochlorite; in other words, any substance that can act as a conductor.[80]

If these rules are not observed, false readings will occur, just as there are inaccurate responses if the file comes into contact with another metal, including gold, amalgam, or the metal of a silver cone or another instrument present in another canal of the same tooth.

From all of this we can understand that in the past these instruments were not successful since, to be able to use them it was absolutely necessary to have a dry and empty canal, when perhaps it wasn't yet ready to receive a # 10 file!

With the exception of special cases, however, these devices could be helpful in confirming radiographic data, but only after the canal has been enlarged to a certain size, irrigated, and dried:[77] the pulp debris had to be removed,[3] neither bleeding[31] nor the presence of exudate was permitted,[77] sodium hypochlorite had to be aspirated,[2,21,54] and possibly replaced by an electrolyte-free solution such as hydrogen peroxide,[31] or, even better, the canal had to be dry,[5,37,77] otherwise the measurements were inaccurate.

New generation electronic apex locators

The applications and possible uses of electronic apex locators have evolved significantly in recent years as new, completely revolutionary instruments have become available to the dental profession. Their use is not influenced by the contraindications and disadvantages that are true limitations to the use of the instruments previously discussed.

The first new instruments available have been the Apit/Endex and Root ZX locators, which are respectively produced by the Japanese manufacturers Osada Electronics and J. Morita Co. They have overcome almost totally all the disadvantages previously discussed. Recently others have appeared on the market and nowadays there is a truly wide range of the latest generation locators available (Fig. 15.20).

Fig. 15.20. Some of the various new generation apex locators. One notes: ProPex (Dentsply Maillefer); Apit (Osada - In U.S.A. marketed as Endex); Justy II (Yoshida Toei); Diagnostic (Sybron Endo).

These instruments make use of a different principle and are not at all affected by the contents of the root canal, whether blood, vital or necrotic pulp,[50] pus, RC Prep,[72] or (most of all) sodium hypochlorite.[30] In other words, the instruments can perform accurately even in moist conditions and in the presence of mineral salts; moreover, they may be used with small size files immersed in sodium hypochlorite and in contact with organic fluids. It is thus possible to obtain an accurate measurement of the working length from the first probing of the root canal.[17]

The instruments yield inaccurate responses only if the shaft of the file used for the measurement comes into contact with the metal of a coronal restoration or if there is a previous obturation within the canal that impedes contact of the endodontic file with the surrounding dentin. The reading is inaccurate also if the file used is of a too small size compared to the size of the apical foramen or if the conductive liquid is in contact with the metallic restoration: in the first situation an accurate reading can be obtained using an endodontic instrument of a proper size, while in the second case the length of the root canal can be accurately measured by simply removing the electrolyte from the access cavity with a suction tip and, if necessary, from the root canal with a paper point (Tab. II).

Table II

Causes of incorrect measurement by the apex locator

1) Incorrect use of the rubber dam: the dam does not completely isolate and there is salivary contamination.
2) Presence of hypochlorite in pulp chamber (especially in multirooted teeth)
3) Contact between the instrument and a metallic restoration[72]
4) Contact between the hypochlorite of the chamber and a metallic restoration
5) Instrument diameter too thin compared to the diameter of the apical foramen (the digital scale oscillates frenetically between the zero value and beyond the apex value)[49]
6) The canal still contains traces of the old canal obturation
7) The file has entered into a lateral canal
8) The file has entered into a perforation

The physical principle on which their function is based differs from that of the above instruments, inasmuch as they do not give the impedance measurement value for the periodontium and the measuring needle, but rather the *difference* in the impedance responses for two different frequencies (1 kHz and 5 kHz) in the Apit/Endex ("the relative values of frequency response method"[86]), and the ratio in the impedance for two different frequencies (400 Hz and 8 kHz) in the Root ZX ("the ratio method"[42]) at differing points in the root canal.

This ratio gives a very precise value, that represents the position of the electrode inside the canal independently of the type of electrolyte contained in it.[44] This value diminishes as the file nears the foramen, until it becomes zero upon reaching it. This principle therefore not being influenced by the canal contents, reduces to a minimum the error caused by the conditions of the self same canal and of the measuring instrument.

Once the Apit/Endex is turned on and contact between the file clip and labial clip is established, the latter is attached to the patient's lip and the file is introduced into the middle third of the canal. The clip is then connected to the file, and the indicator needle moves toward the green zone (Fig. 15.21 A), while an intermittent acoustic signal is emitted. When the "Reset" button is pressed, the instrument is calibrated, the indicator needle returns to the starting point, and the acoustic signal ceases. When the endodontic file is advanced toward the apical third, the needle moves into the green zone again, and the acoustic signal is once again emitted intermittently. When the apical foramen is reached, the sound becomes steady, and the needle is positioned on the red marking designated "APEX" (Fig. 15.21 B).

If the endodontic instrument overshoots the foramen, the needle passes to the yellow zone of the scale, while the acoustic signal remains steady (Fig. 15.21 C).

A recent study has shown that the instrument is 96.5% accurate with a clinically acceptable default margin of error that is less than 0.5 mm.[28]

Because the Apit/Endex cannot be accurately calibrated when the inside of the root canal is dry, it is unable to make an accurate measurement of a dry root canal.[30,32,43]

The Root ZX is based on a slightly different method (the "ratio method"[42]) and the measurement is even easier to make, since:
– the instrument needs no calibration and no reset
– it is accurate even in dry canals
– the root canal cleaning and shaping can easily be

performed while the length of the root canal is simultaneously monitored

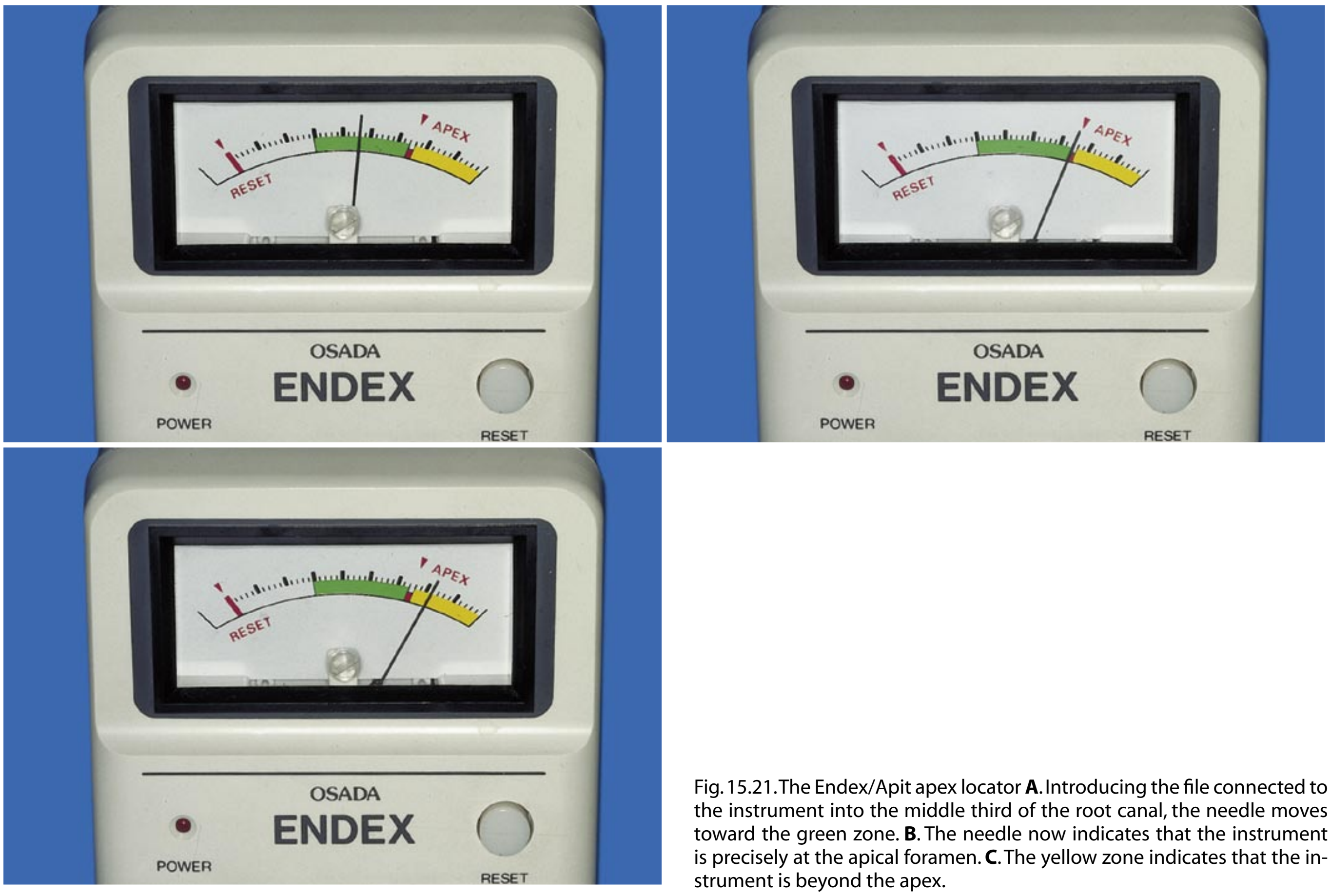
– it works on replaceable long lasting batteries and therefore does not have to be continuously recharged.[41]

Once the device has been activated, the clip is applied to the patient's lip, and the other is connected to the instrument introduced within the root canal.

An acoustic signal, as well as the digital scale at the zero value while the "Apex" sign is flashing, inform the dentist that the apical foramen has been reached (Fig. 15.22). After about ten minutes, the instrument automatically turns itself off.

Recent studies[58,81] have shown that the Root ZX gives readings that are 100% accurate with a clinically acceptable margin of error ±0,5mm: the average distance of the file tip from the apical foramen was 0,2 mm. The same authors,[81] have also emphasized the fact that the Root ZX can be used with confidence to localize the apical foramen, not the apical constriction, referred to by other authors,[25] and thus it is obvious if we take into account the physical principle of which it is based and on the role the instrument has in diagnosing the site of the radicular perforation. Therefore contrary to what its manufacturers say, the Root ZX must not be utilized to determine the site of the point that is 0,5mm from the foramen, but to locate the actual foramen, that is reached when the digital scale is on the "Apex" sign and when the wording flashes.[57] Only then, if desired, one can measure 0.5 mm from the foramen.

In conclusion as has already been emphasized, even if today one cannot imagine an endodontic practice that doesn't use one of the apex locators, and if determining the working length without the use of a locator has been compared to piloting an airplane without a radar, nevertheless, not even these latest generation of electronic apical locators can be considered radiographic substitute[66] since radiographs provide the operator with other information that the electronic measuring equipment is unable to provide: canal width, degree and direction of curve, position of the foramen, dentine thickness, relationship between canals which might be in the same root. Furthermore

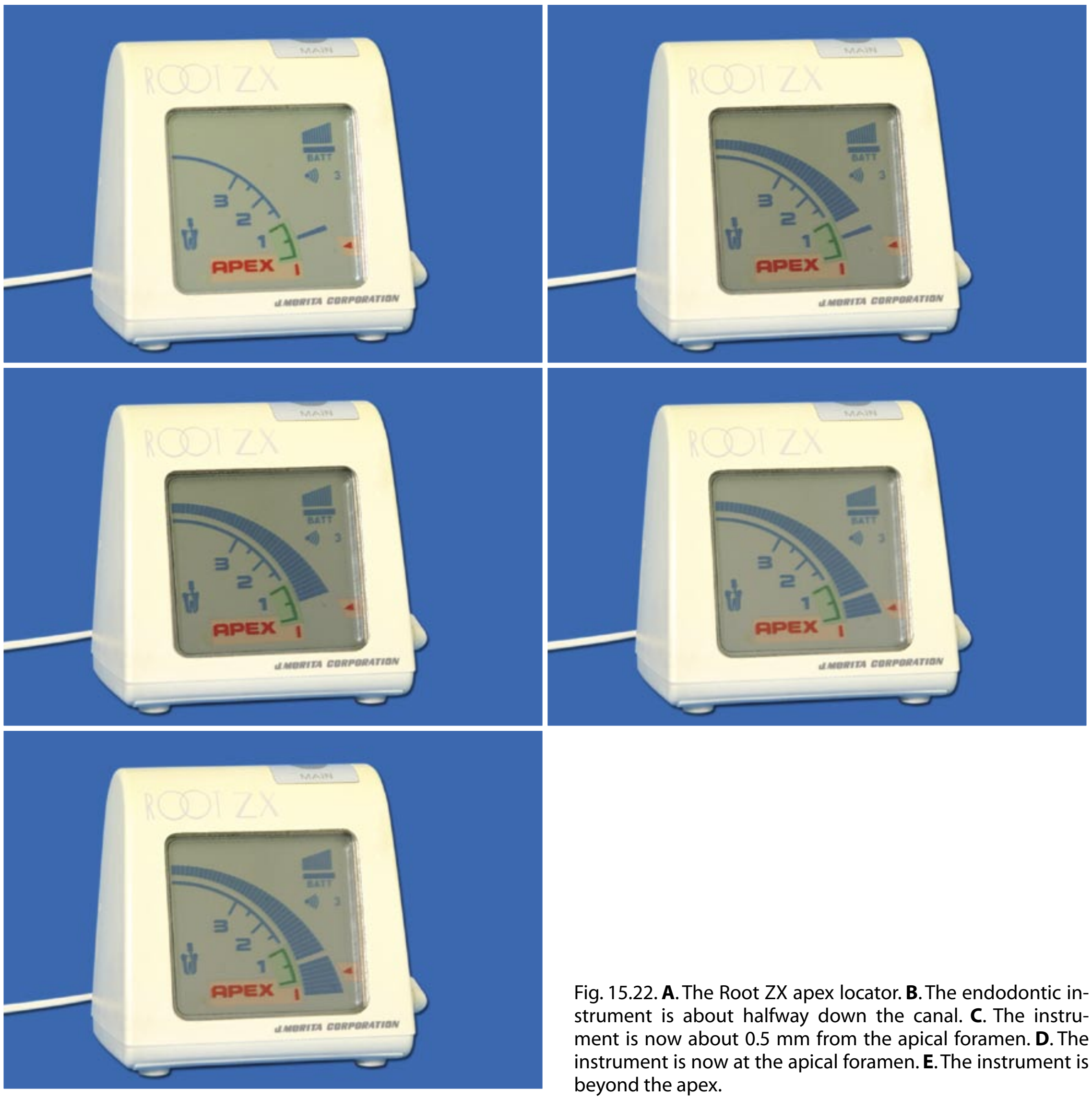


A B C

Fig. 15.21. The Endex/Apit apex locator **A.** Introducing the file connected to the instrument into the middle third of the root canal, the needle moves toward the green zone. **B.** The needle now indicates that the instrument is precisely at the apical foramen. **C.** The yellow zone indicates that the instrument is beyond the apex.

these instruments are able not only to inform the operator about the location of the foramen, but they can also reveal the opening of any other foramen, such as that of a lateral canal (Fig. 15.23) or that of a perforation (Fig. 15.24).

If once the radiograph has been taken, a variance occurs between the radiographic image which shows a “short” file with respect to the radiographic terminus of the canal and the apex locator which has just indicated that we have reached the foramen, then one must consider the locator reading as valid[61] since evidently the foramen is in an area (buccal or lingual/palatal) not radiographically identifiable (Fig 15.25). Our therapy will therefore be based on a measurement carried out by an electronic apex locator (it will be at the Electronic Apex and not just 0.5 mm from the radiographic apex!) and we shall know from the beginning that in the post operative radiograph the canal obturation will appear “short”, but it will instead be accurate, at the apical foramen. Not taking the radiograph as some do, believing blindly in an electronic instrument, our “short” obturation will be a post operative surprise and we shall never know whether or not we are truly short.



A B C D E

Fig. 15.22. **A.** The Root ZX apex locator. **B.** The endodontic instrument is about halfway down the canal. **C.** The instrument is now about 0.5 mm from the apical foramen. **D.** The instrument is now at the apical foramen. **E.** The instrument is beyond the apex.

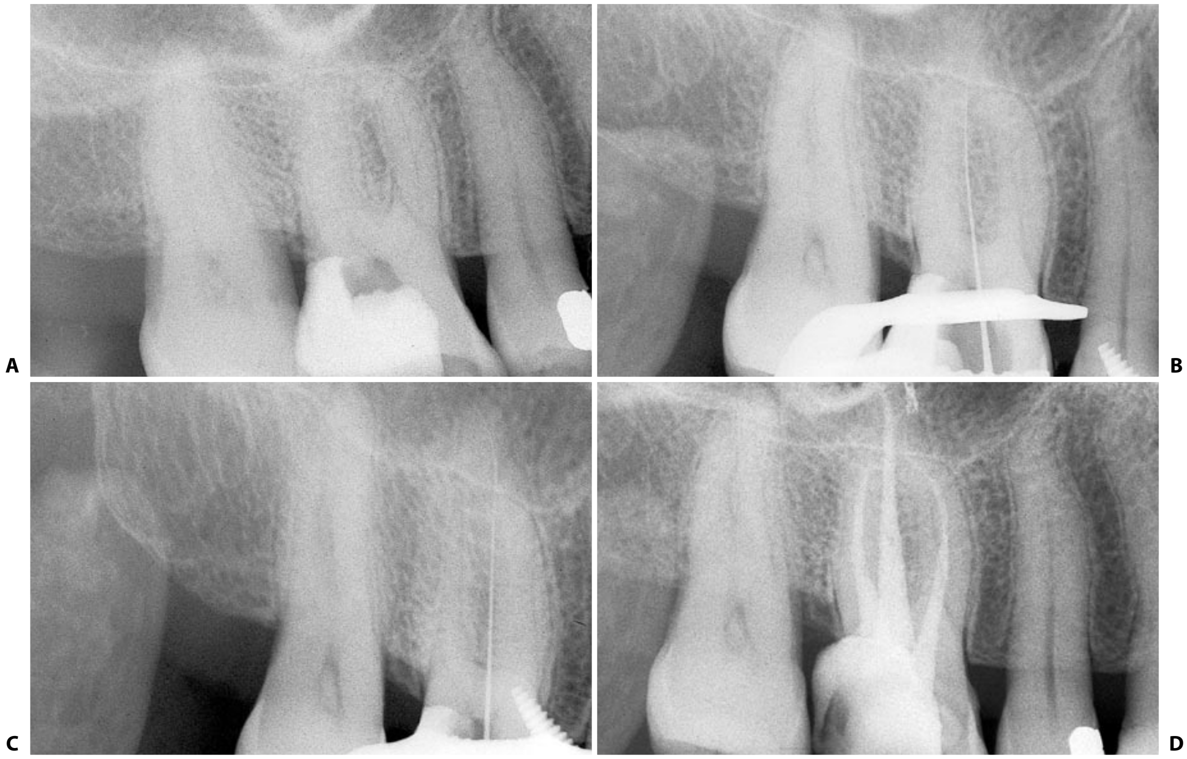


Fig. 15.23. **A**. Preoperative radiograph of the upper right first molar. **B**. The electronic apex locator indicates that the instrument is at the foramen and the X-ray shows that the foramen belongs to a lateral canal. **C**. The file has been withdrawn and reintroduced more apically: the electronic apex locator indicates that a new foramen has been reached and the X-ray shows the file at the apical foramen. **D**. The postoperative radiograph shows that both canals have been three-dimensionally obturated. **E**. Three year recall.

Fig. 15.24. The apex locator indicated that the instrument has reached the apex however, the radiograph shows that it has entered a perforation!

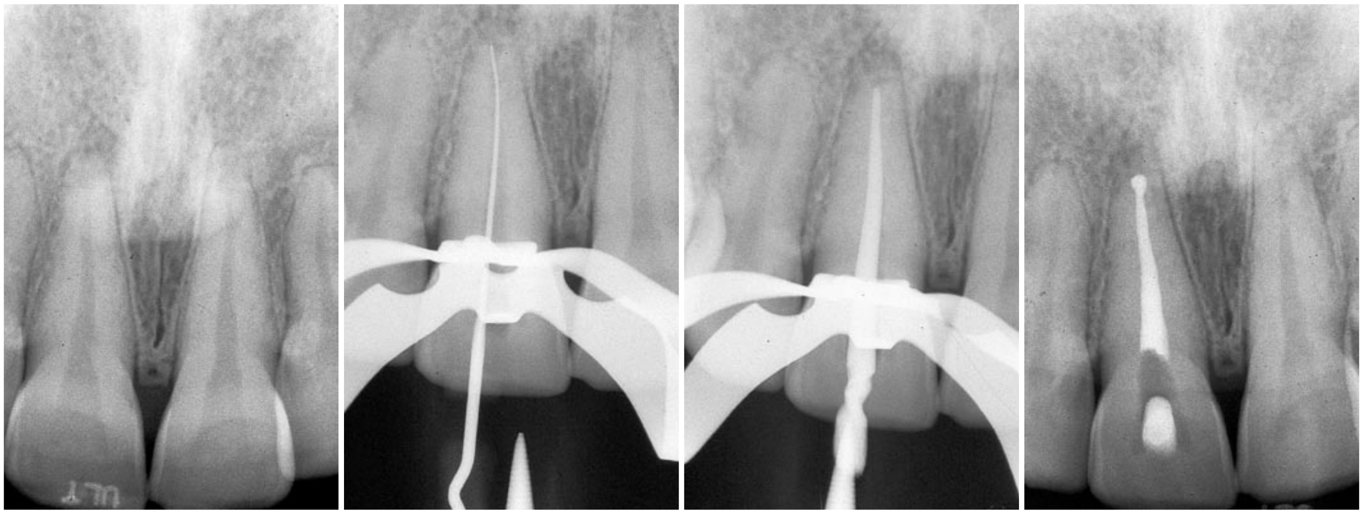


Fig. 15.25. **A.** Preoperative radiograph of the upper right central incisor with necrotic pulp. **B.** The apex locator indicated that the instrument is at the apex, but the radiograph shows that it is short. In these cases the locator is always correct! The foramen is buccal or palatal and cannot be identified radiographically. These cases then are treated up to the electronic apex. **C.** Cone fit. **D.** Post operative radiograph. The small enlargement visible at the extremity of the obturating material is nothing more than the classic puff of sealer extruded from the apex. Note its position with respect to the radiographic apex.

MAINTAINING THE PATENCY OF THE APICAL FORAMEN

In this phase, the files are introduced as far as the apex in such a way as to clean the foramen, enlarge it to a practical, convenient size, and prevent it from being obstructed by dentin mud.

When the first instrument has been removed and the canal copiously irrigated, the same working length is transferred to the next instrument of bigger size, which is then introduced into the root canal.

This file also (e.g. a # 10) must be precurved and passively introduced into the root canal. Force must not be applied to make the instrument descend, since the canal should already have been enlarged by the preceding instrument.

This very important principle must never be forgotten. Respecting it will prevent many errors. The instruments do not work for themselves, but for those to be used after them; in other words, each instrument prepares and enlarges the canal in such a way that the canal can easily receive the next instrument of bigger size.

If the # 10 file does not descend to the same working length, it must not be forced, screwed, or pushed into the canal. It must be replaced by the next file of smaller size, so that the path can be better prepared.

The second file must also be used with small, back-and-forth movements with excursions of about 0.5-2 mm, and the user's hand must rest securely on the neighboring teeth (Fig. 15.26).

Once this instrument is also loose in the root canal, it is withdrawn. The canal is irrigated, and one passes to the next instrument of bigger size, which in this case would be a # 15 file.

This must also be precurved, introduced into the root canal with the precurvature facing the canal's curve, and it must be able to descend passively.

Obviously, with this instrument as with that which follows, the stop must be placed at the same working

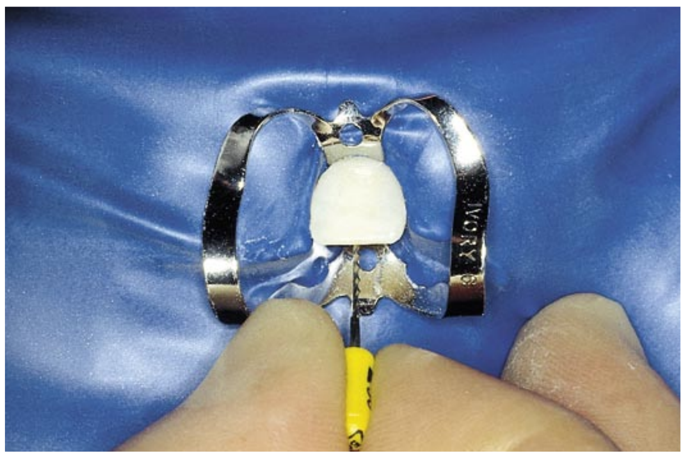


Fig. 15.26. While the thumb and index finger hold the instrument handle, the middle finger searches for a good support point on the crowns of the neighboring teeth.

length: all the files used up to this point (in this example, from # 08 to # 20) descend as far as the radiographic terminus of the canal with the aim of cleaning, enlarging, and, especially, maintaining the patency of the apical foramen (Fig. 15.27).

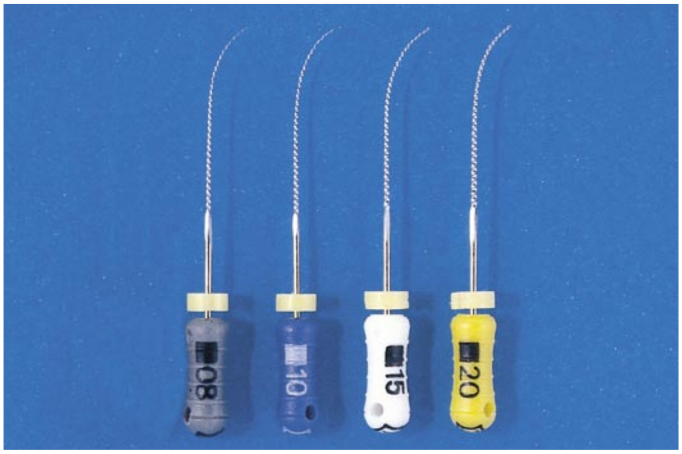


Fig. 15.27. The files used in the phase of apical patency all have the same working length and the same precurvature.

The foramen must remain patent. It must not be obstructed by dentin mud, and the dentist should *theoretically* be able to introduce a small instrument beyond the foramen at any point in the cleaning and shaping procedure.

Using small files that are fine and flexible all the way to the radiographic terminus of the canal facilitates the elimination of the pulp residues, various irritating substances and dentin mud. Maintaining the terminus of the canal patent avoids blockages, ledges and perforations.[68]

Taking into consideration the rich collateral blood supply and the elevated healing potential of the attachment apparatus, it is illogical to think that extending a small file passively and accurately beyond the apex will compromise the final result or cause an irreversible condition for the patient.[66]

The patency of the foramen will permit the accumulation of any exudate (which may form in the apical tissues in spite of careful shaping) within the canal rather than among the fibers of the periodontal ligament. This prevents the development of periodontitis postoperatively.

Once the file that one has chosen to be the last to penetrate to the apex has been introduced (a # 20 file if the canal is fairly narrow, a K-type file of bigger size if the canal is wider, as described with respect to the fifth mechanical objective of shaping), it is necessary to verify the instrument's working length electronically and, if necessary, also radiographically before moving it within the canal. The more curved the canal and the more it has been enlarged by the instruments, the more important this second confirmation, since the canal length is altered by shaping.

This occurs because in working within a curved canal, the curve is smoothed, reducing the length.[11,83] The first instrument used will follow the curve of the canal perfectly and will describe an arc of a certain length (Fig. 15.28). The last instrument, in contrast, which finds the canal enlarged and the curved smoothed, runs in a shorter path that corresponds to the chord subtended to the arc of the preceding circle: since the chord is shorter than the arc of the circle that subtends it, the working length of the last instrument at the apex must be slightly changed. The more curved a canal, the more it is necessary to make small modifications of the working length as one advances to instruments of bigger size.[11]

If this adjustment is not made, the last instrument at the apex will appear to be beyond the foramen on radiographic examination (Fig. 15.29).

For this reason, even though the instruments are all

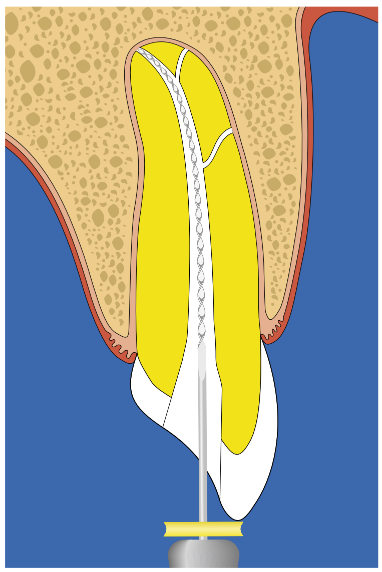


Fig. 15.28. A # 08 file introduced in a narrow, curved canal describes an arc of a circle of a certain length.

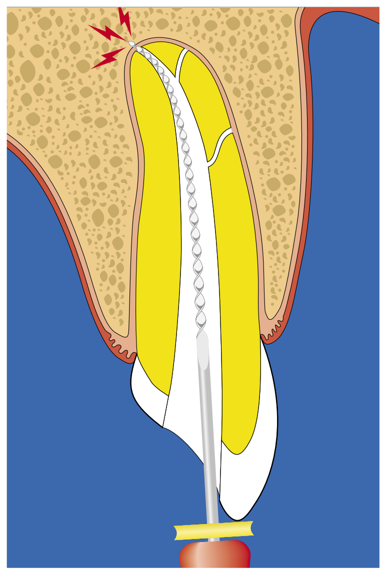


Fig. 15.29. The # 25 file, introduced to the same working length in the same canal after it has been enlarged, is longer, since it does not follow the same arc of the circle as the # 08 file, but the chord subtended to it.

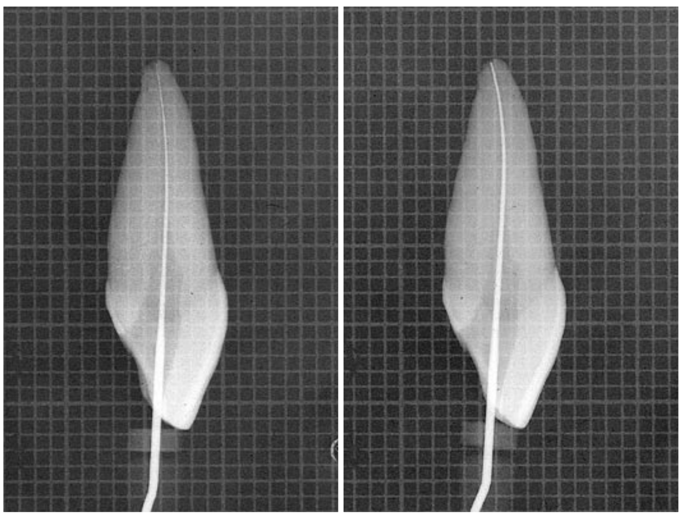
pre measured to the same working length using a millimeter gauge, one must take this progressive shortening into account. The working length does not necessarily remain the same, but can vary, as discussed above.

A recent study by Farber and Bernstein[26] has shown that the mean shortening of a canal during instrumentation is 0.4 mm.

Marini et al.[48] have recently confirmed these findings, demonstrating that in the mesial roots of the lower molars variations of the working length are pertinent in the coronal tract of the canal exclusively. In practice, they cannot be calculated pre-operatively, but must be entrusted to the individual sensitivity of the dentist.

After having examined the second intraoperative radiograph and checked the working length of that which we believe to be the last instrument to the foramen, one uses the instrument within the canal, thus ending the second phase of shaping (Fig. 15.30).

To clean and predictably seal the foramen, the size of the file used at the end of cleaning and shaping should be at least a # 20 or # 25, but not more, unless one is dealing with an already wider foramen. There is no advantage to creating a wider foramen unless the canal is too small to predictably compact gutta-percha and sealer.[85] As has already been thoroughly explained in Chapter 14, the foramen must be clean but not enlarged. If the diameter of the foramen is increased from a # 20 to a # 40 file making it double, the area of the foramen (to be sealed) has increased four times, since the area of a circle is = πr^2, which means that the area of the circle increases with the square of the radius. To enlarge the foramen more than it is necessary can only increase the risk of transporting the foramen itself[85] and also increases the potential for overfilling and microleakage around the margin.[87,88] The final goal of cleaning and shaping is to create a continuously tapering conical form from the access cavity to the radiographic terminus of the canal, keeping the foramen in the same position and size.



A B

Fig. 15.30. Radiographs to check the working length of the files. **A**. The first instrument at the radiographic terminus of the canal, to determine the working length. **B**. The last instrument at the radiographic terminus, to ascertain whether the working length is still correct (23 mm).

ENLARGEMENT OF THE BODY OF THE CANAL

In this phase of canal preparation, the reamers are used in such a way as to cause the canal to assume the shape of a continuously tapered cone (first mechanical objective of shaping). The canal will already have been enlarged, albeit minimally, by the files that were used in the preceding phase. One may therefore begin to introduce reamers of a certain size that will tolerate careful clockwise rotation, without the risk of breakage.

The first reamer to be introduced should be the same size as the last file used previously (which is considered the "last instrument at the apex"). More than for enlargement of the canal, it is used to remove the dentin shavings that may have been left on the canal walls by the preceding files. Since the reamers' cutting edges are quite distantly spaced, they can collect more dentin mud than a file.

This first reamer, (# 20 for instance, if the last instrument at the apex was a # 20 file), has the same working length as the preceding file, but is not made to work to the radiographic terminus, but rather slightly shorter to avoid unwanted flaring of the apical foramen due to the "hourglass effect" that occurs when the reamer rotates within the root canal (Fig. 15.3).

This first instrument, like the others that follow in this phase of enlargement of the body, is passively introduced into the canal and rotated about a quarter turn as it is simultaneously withdrawn from the canal. The reamer must never be screwed or forced into the canal, must not be made to work inwardly, and must never reproduce its shape on the canal walls. On the contrary, like all instruments used in Endodontics, it must be used on withdrawal. That the cutting blades may exert their action on the dentin walls, it is necessary to rotate the reamer roughly 90 degrees while it is partially withdrawn from the root canal. This motion is repeated several times, after which one irrigates and advances to the next reamer, a # 25 in our example. This instrument is introduced into the root canal until it makes contact with the walls, which occurs a certain distance from the apical foramen. Without forcing the instrument, it also is rotated about a quarter turn. It is then withdrawn coronally several millimeters, and this movement is repeated several times. At this point, one must not concern oneself with the working length of the reamer, but simply introduce the instrument into the root canal and let it work at the depth to which it has passively descended. Let the instruments work where the canal will accept them!

One irrigates again and advances to the reamer of next bigger size, in this case a # 30.

Like all the reamers that follow (# 35, # 40, # 50, and # 60), this one also must be passively introduced until it makes contact with the walls and then rotated by about a quarter turn as it is simultaneously withdrawn (Fig. 15.31).

If one now examines the different working lengths of the various reamers used up to this point, as reflected by the rubber stops that have been positioned at the point of maximal passive introduction, one notes that each successive instrument has entered about 3 mm less than that of the preceding size (Fig. 15.32). In practice, this means that the taper that has been imparted to the canal is minimal and that the walls of the cone that has been developed within are still too parallel. If the preparation were halted at this point, one would find that the canal was not a truncated cone but a cylinder with many small ledges, each at a different

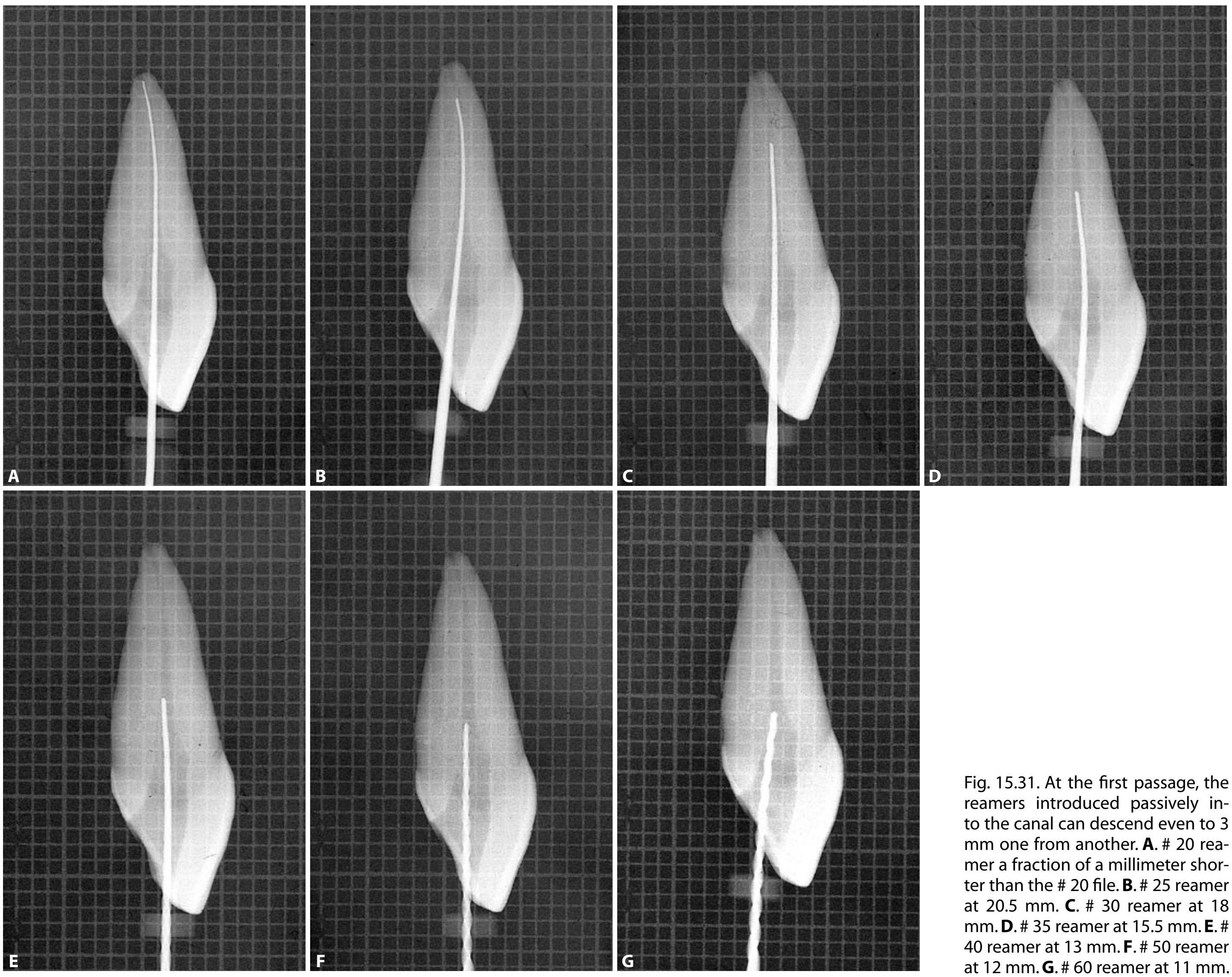


Fig. 15.31. At the first passage, the reamers introduced passively into the canal can descend even to 3 mm one from another. **A**. # 20 reamer a fraction of a millimeter shorter than the # 20 file. **B**. # 25 reamer at 20.5 mm. **C**. # 30 reamer at 18 mm. **D**. # 35 reamer at 15.5 mm. **E**. # 40 reamer at 13 mm. **F**. # 50 reamer at 12 mm. **G**. # 60 reamer at 11 mm.

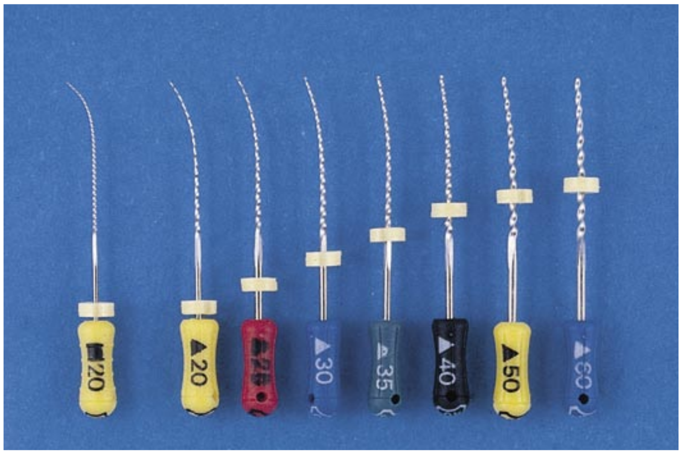


Fig. 15.32. The stops of the various reamers testify that the instruments have been used to work passively at about 3 mm distance from one another.

depth corresponding to the different depths of work of the reamers used.

To eliminate these imperfections, to prepare the canal more conically, so that the taper is uniform and without ledges, the entire series of reamers must be introduced again in the root canal in a procedure that Schilder calls *recapitulation*.[68]

During this second passage (1^{st} recapitulation), the instruments passively descend to positions more apical than they had descended before, because each instrument encounters a canal that has been enlarged by the instruments that have been used after it at the first passage.

This contributes to giving greater taper to the canal and to smoothing the ledges that may have been left behind earlier.

After having introduced the last instrument to the radiographic terminus to re-check the apical patency, one recapitulates the various reamers, introducing them again into the canal without ever forcing them, advancing them until they passively touch the canal walls. They are rotated about a quarter turn and simultaneously withdrawn partially from the root canal.

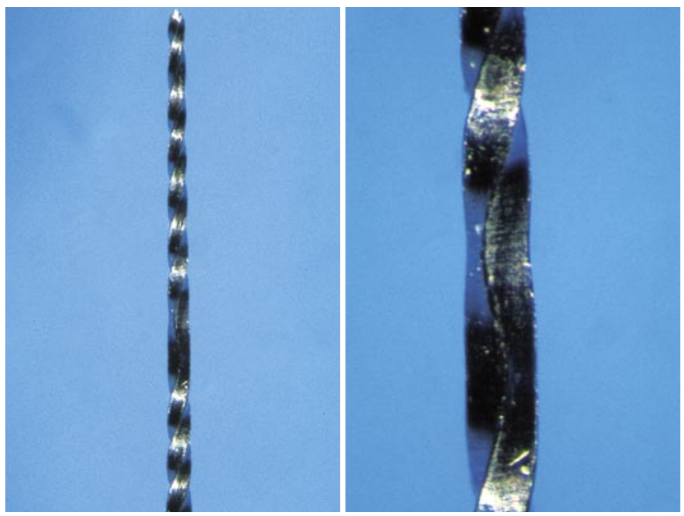
If the instruments encounter resistance to rotation, one may be tempted to rotate the instruments more than 90 degrees, rotating it several times around its own axis and screwing the instrument into the canal to overcome the resistance. This is an error that must absolutely be avoided, since it can lead to the formation of ledges, false canals, deformation of the blades (Fig. 15.33), or even instrument fracture in the canal.

One must instead remind oneself not to rotate the instrument more than 90 degrees. To do this, it suffices never to detach the fingers from the instrument handle. It will not be possible to rotate the instrument more than 90 or at most 180 degrees, and one will never perform a complete 360 degrees rotation or more, as this requires detaching the fingers from the instrument handle so that it can be re-grasped and rotated further.

Returning to the example (one should keep in mind that it is only illustrative, referring to a narrow root canal of average difficulty), after having used a # 60 reamer to a depth of about 3-4 mm within the canal, one advances to the first and only rotating instrument used in the technique described by Schilder, the Gates-Glidden drill (Fig. 15.34). This drill is used at this point to flare the more coronal portion of the canal into which a large reamer could enter only a few millimeters and to blend the root canal gradually with the access cavity.[69]

The Gates-Glidden drill can be used within the canal only after it has been sufficiently enlarged by the hand instruments, so that the canal can easily receive the drill. It must not be introduced into a canal that is still narrow, since this would incur the risk of instrument fracture and the formation of ledges and false canals.

The drill must be passively introduced into the coronal third of the canal and must be applied carefully on withdrawal with its equator, without ever simultaneously making contact with the entire circumference of the canal. If this did happen, the drill would impress its shape on the canal walls, giving them a typical funnel-shaped appearance (Fig. 15.35).



A B

Fig. 15.33. **A.** The instrument has been rotated in the canal while the tip was engaged: the cutting edges have opened. **B.** Detail of the preceding figure at higher magnification.

The drill must rather be free to move within the canal. One must make certain that it makes contact successively with the various portions of the canal circumference, always on withdrawal. The drill must be used with a "brushing" motion in apical-coronal direction.

Gates-Glidden drills are available in various sizes. The dentist must choose the appropriate size for the existing situation.

Returning to the example, one would use the # 2 drill or the size required to blend the coronal third of the canal with the access cavity.

The Gates-Glidden drill produces a large amount of dentin mud, so that it must always be used with the pulp chamber completed flooded with irrigating solution, and the canal must always be generously irrigated after its use.

The drill is very fragile and very frequently fractures, especially if it is applied too energetically to a canal wall and causing the shaft to bend while it is working. Fractures occur at the base of the long shaft, never at the head. It is therefore a simple matter to remove the fractured portion from the canal with the cotton pliers. The breakage of the Gates drill must not be considered an accident, but on the contrary; it is the test that the drill is being used in the correct way, leaning against the canal walls with a brushing motion.

After using the first Gates-Glidden drill, the canal is ready for the second recapitulation with the reamers.

Once the second recapitulation has been completed, the coronal third of the canal will be sufficiently wide to receive a Gates-Glidden drill of larger size than the one used before (a # 3 in the example).

If one again examines the working lengths of the successive reamers after the first recapitulation, one notes that the rubber stops have been displaced about 2 mm. This means that each instrument:

a) has descended more apically, smoothing any ledge that may have been left
b) has worked about 2 mm shorter than each preceding instrument of smaller size (Fig. 15.36).

At last, if one checks the different working length after the second recapitulation, one notes that the rubber stops of the successive instruments are displaced about 0.5-1 mm from one to the next (Fig. 15.37). At this point, if the last instrument taken to the radiographic terminus of the canal confirms the size of the foramen (gauging), since the instrument with the larger size is still about 0.5 mm shorter and the subsequent ones are shortened by the same amount in an homogenous manner (tuning), it means that the canal can be considered cleaned and shaped, and the taper of the canal is optimal. In other words, the canal is in the shape of a continuously tapered conical form without ledges, the walls are smooth, and the apical foramen has not only been respected and minimally enlarged, it is patent and unobstructed by dentin mud.

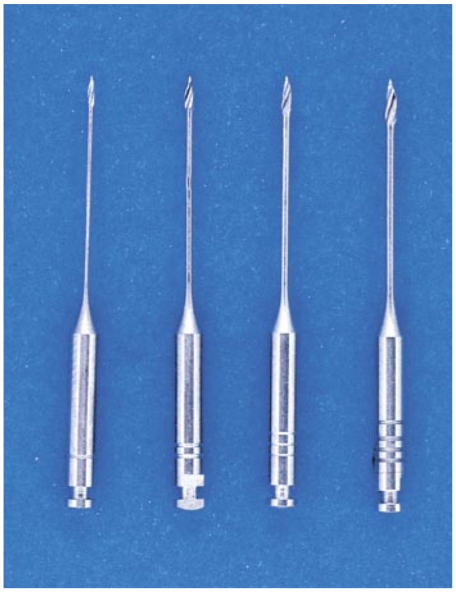


Fig. 15.34. Gates-Glidden drills, to be used after the reamers.

Fig. 15.35. The wrong use of Gates-Glidden drills causes a typical funnel-shaped appearance of the canal and pointless weakening of the root. Note the impression left in the distal canal of this lower left second molar.

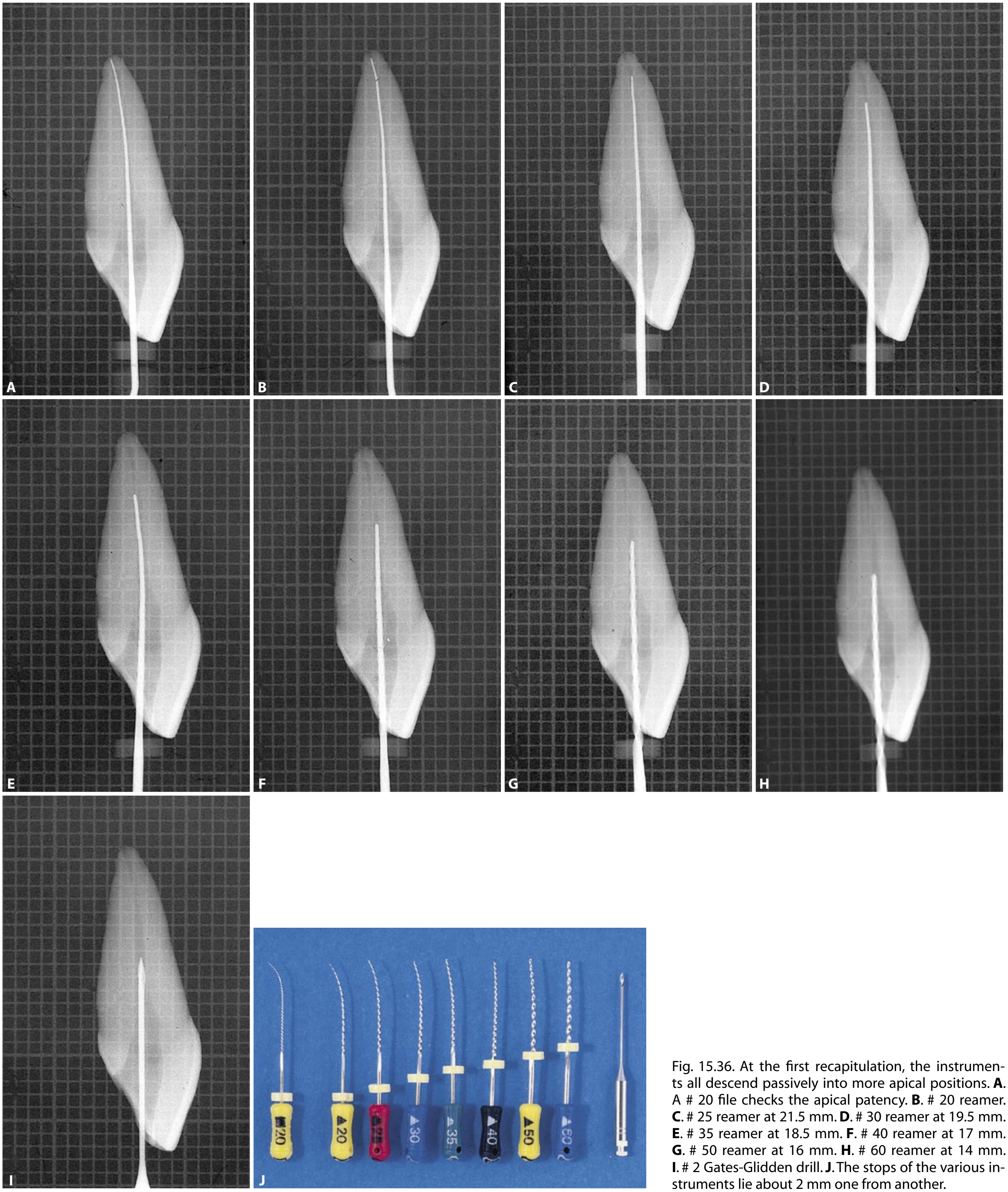


Fig. 15.36. At the first recapitulation, the instruments all descend passively into more apical positions. **A**. A # 20 file checks the apical patency. **B**. # 20 reamer. **C**. # 25 reamer at 21.5 mm. **D**. # 30 reamer at 19.5 mm. **E**. # 35 reamer at 18.5 mm. **F**. # 40 reamer at 17 mm. **G**. # 50 reamer at 16 mm. **H**. # 60 reamer at 14 mm. **I**. # 2 Gates-Glidden drill. **J**. The stops of the various instruments lie about 2 mm one from another.

In practice, nonetheless, when one enlarges the body of the canal by recapitulating the reamers several times, rather than moving the rubber stops after each passage, it is advisable to distance the various stops about 0.5-1 mm from each other from the beginning and recapitulate the various instruments until the entire series passively descends to the point that has been designated by the rubber stop.

In other words, using a series of standardized instruments, if one wants to be certain that the canal is cleaned and shaped optimally, one must make certain that the instruments successively descend about 0.5-1 mm less. To further simplify matters, provided that one has a careful and trained eye, we can place all the instruments at the same working length and then visually check that the stops distance themselves from the reference point by increments of 0.5 mm from each other.

Naturally, before each recapitulation and whenever the need arises, one must re-introduce the last instrument (patency file) to the radiographic terminus to ascertain that the foramen is still patent. After each instrument is used, it is further necessary to irrigate the canal copiously to remove the dentin mud.

If, partway through the recapitulation, one senses a ledge or an obstacle that impedes the proper use of the other reamers, one must stop and begin a new recapitulation, always beginning with the patency file.

The number of recapitulations that one may perform within a root canal naturally depends on the anatomy but more particularly the dentin thickness. Each recapitulation leads to the removal of more dentin, due to the greater apical depth of work of instruments of increasingly bigger size. This naturally must be taken into consideration when dealing with the canals of particularly thin roots, if one wishes to avoid perforation, stripping, or needless radicular weakening, which could lead to vertical root fracture.

Once the preparation has been completed and the last rinse with EDTA has been carried out, one rinses with sodium hypochlorite to neutralize the acid and the canals are then dried.

The purpose of drying is to remove all the moisture not only in the canal but also inside the dentinal tubules. In order to achieve this result, it is not sufficient to only utilize paper points. A rinse with pure alcohol is carried out so as to dilute the watery content of the hypochlorite after which one dries in the traditional manner with paper points (these too must be paced according to the working length) (Fig 14.38). Then one directs a very weak stream of air inside the canal with the special syringe, which has a fine needle, mounted on the Stropko Irrigator (Fig 15.39). Only in this way can we be certain of having removed the moisture from the dentinal tubules, which are then ready to receive the obturating material.

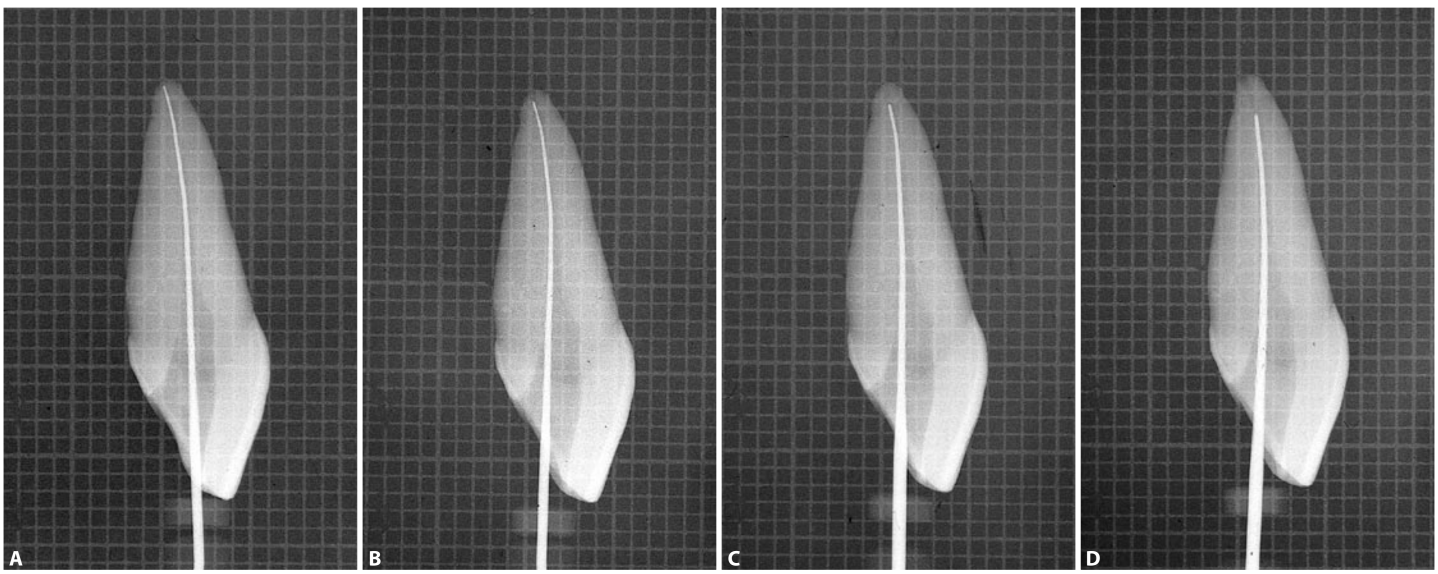


Fig. 15.37. **A**-**D**. During the second recapitulation, the instruments descend spontaneously to about 0.5-1 mm from one another (continued).

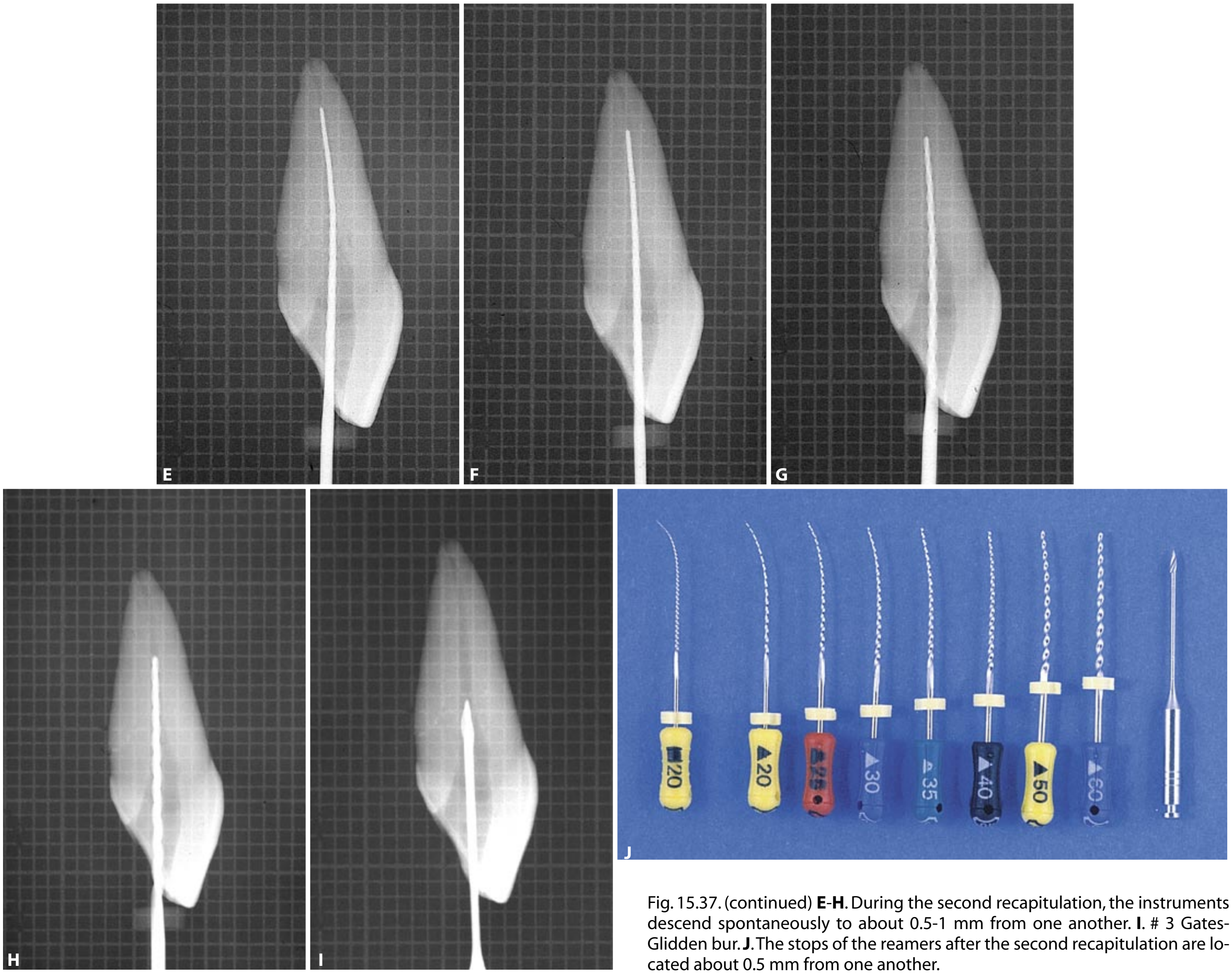


Fig. 15.37. (continued) **E**-**H**. During the second recapitulation, the instruments descend spontaneously to about 0.5-1 mm from one another. **I**. # 3 Gates-Glidden bur. **J**. The stops of the reamers after the second recapitulation are located about 0.5 mm from one another.

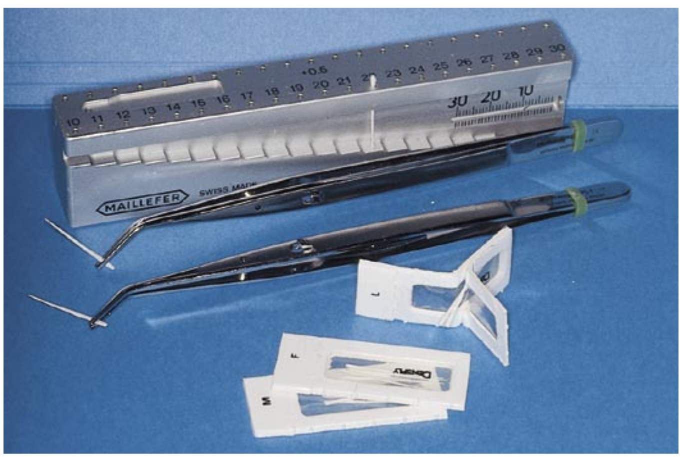
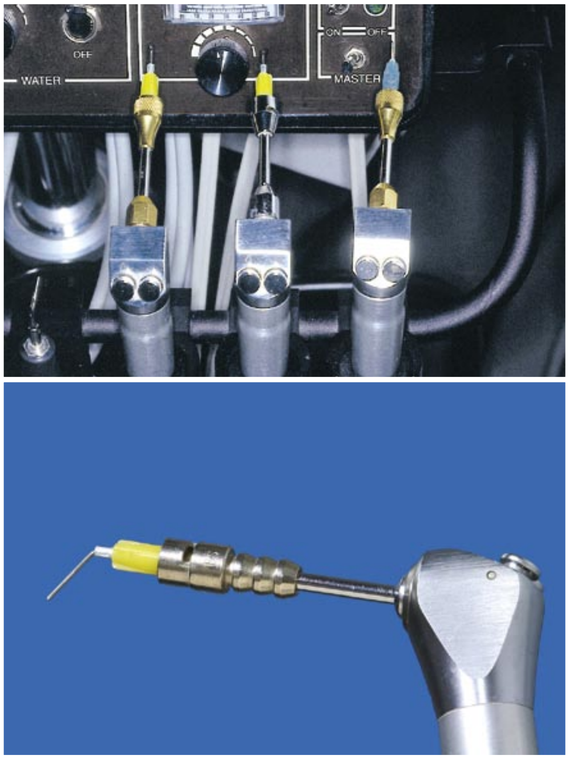


Fig. 15.38. The paper points are measured by the assistant with a tweezers at the exact working length.



A

B

Fig. 15.39. **A.** The Spartan cart equipped with three syringes all with a Stropko irrigator. The first is connected to air at maximum pressure, the second to air and water, and the third only air at the minimum pressure. This is the syringe that is used to dry the root canal. **B.** Magnified view of the Stropko irrigator.

RADIOGRAPHIC EVALUATIONS

It is clear that proper, accurate cleaning and shaping require several radiographic evaluations, which are essential if one wants to "see", even if in only two dimensions, what one is doing.

In no other branch of Dentistry does the dentist work as "blindfolded" as in Endodontics. The prosthodontist can see the margins of the prosthetic preparation, the restorative dentist can check the cavity for amalgam or inlay, and the periodontist can see the flap that he/she has raised and the operative field. The endodontist works, so to speak, in the dark. Every once in a while, a "flash" is required to illuminate what he is doing. Such "flashes" are the X-rays.

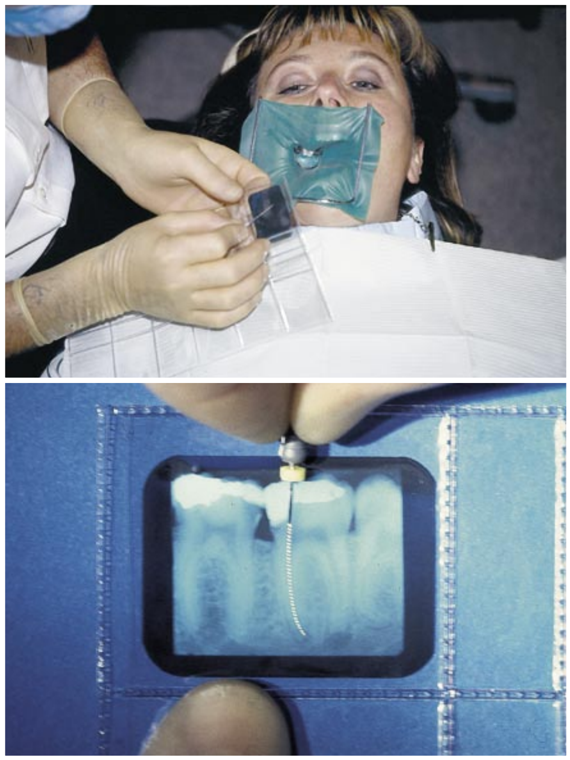
The need to limit the patient's radiation exposure should not serve as an excuse to provide mediocre endodontic therapies. The damage that results from improper endodontic treatment is much greater than that which may arise from one or two extra intraoral radiographs.

In a recent article on the risks associated with the use of X-rays in Endodontics, Danforth and Torabinejad[22] have shown that using 70 kVp, a good 10,900 endodontic surveys are needed to produce cataract changes and that one radiograph carries the same risks of dying of leukemia as dying from cancer from smoking 0.8 cigarettes a day, or from an auto accident when driving 3.0 km.

Intraoperative radiographs required to prepare the canal properly are therefore the following:

– A radiograph of the first instrument at the radiographic terminus of the canal. This is very important, because the first instrument is the key, as the accuracy of all subsequent work depends on it, since the working length of all the other instruments depends on this measurement. Canal reaming should not begin until one has seen the first instrument arrive exactly at the desired point. Obviously, it is essential to have a satisfactory preoperative radiograph, according to the long cone and paralleling technique.[24]

  In practice, to have an idea of how far the instrument will have to enter the canal, one can align the instrument with its radiographic image and shorten by one millimeter (Fig. 15.40). Because the radiographic image magnifies the actual dimensions of the tooth, a reduction of the length of the ra-



A

B

Fig. 15.40. **A, B.** To have an approximate idea of the future working length, one may compare the first file with a properly-performed radiograph and shorten the stop by about one millimeter (given that the radiograph always gives a slightly enlarged image (See Chapter 5).

diographic image by one millimeter is a reasonable estimate of the maximal working length of the file, without any risk of overinstrumentation.[46]

– A radiograph of the last instrument at the radiographic terminus of the canal (the patency file). As was mentioned before, this radiograph can be substituted by the use of an electronic apex locator. In the absence of a reliable apex locator this radiograph is required to check that the working length of the instrument has not changed. This could have happened because one has blocked the apex and one is thus short, because the rubber stops were not secure and have slipped on the file's shaft, or because the canal was particularly curved and in smoothing its curvature its length shortened. In the last cases, one is long.

The importance of this new radiographic verification lies in the fact that the reamers' working length in the phase of enlargement of the body of the canal is based on the last instrument at the radiographic terminus. Furthermore, that instrument is essential in the next phase of canal obturation, to check the length of the gutta-percha cone and its tip diameter (see Chapter 24): it infact corresponds to the diameter of the apical foramen.

As already suggested with regard to the electronic apex measuring devices, this second radiographic information could be substituted with an electronic measurement. One must also keep in mind that the information one obtains from the second intraoperative radiograph refers to more than just the working length. For example, in the mesial roots of the lower molars and in the mesiobuccal roots of the upper molars, one can check the thickness of the dentin still present around the instrument and thus avoid stripping.

CLEANING AND SHAPING OF CONFLUENT ROOT CANALS

Cleaning and shaping of two canals in the same root which merge to a common foramen require particular precautions to prevent tearing of the apical foramen or pointless weakening of the root, including stripping.[6,15]

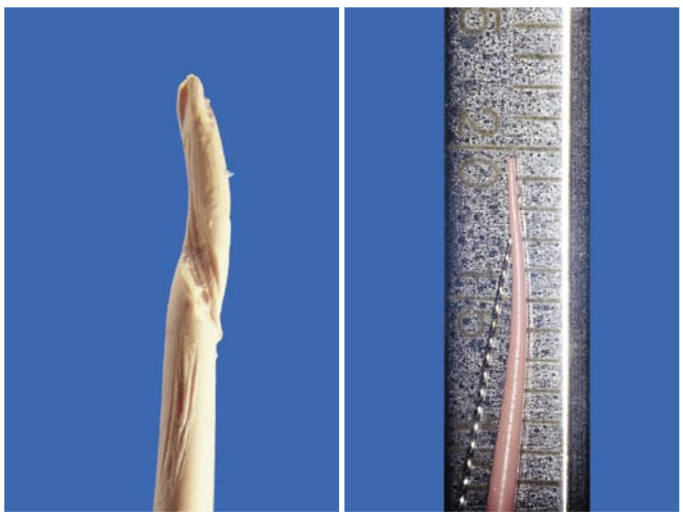
Once the confluence has been detected by the impression that a small file (# 08 or # 10) leaves on a gutta-percha cone inserted in the canal that has just been prepared (Fig. 15.41 A), one can determine the point of the confluence (distance from the apical foramen) and, consequently, regulate the working length of the instruments in the second canal, as well as the flare to be given to it (Fig. 15.41 B).

It is useless to reach the same foramen arising from a different canal and thus from a different direction, because this risks tearing the foramen and breaking the file.

It is equally useless to enlarge the apical portion of the canal common to the two canals of the same root: the conical form that one develops in the second canal that has been diagnosed to be confluent with the first will therefore begin from the confluence itself rather than from the apical foramen.[15]

The mesial root of a lower molar will serve as an example to illustrate the operative sequence:

– one first cleans and shapes the mesiolingual canal, which has a more rectilinear course. It is more difficult to cause stripping in this canal, since it is more centered with respect to the root
– when the mesiobuccal canal is ready to receive a small size instrument to determine the working length, one introduces first a gutta-percha cone in the mesiolingual canal already prepared and then the file (for instance a # 10 file) in the mesiobuccal canal to measure
– the file is worked with short back-and-forth movements. In the meantime, one checks whether the cone present in the other canal is being displaced
– the file is withdrawn from the mesiobuccal canal
– the gutta-percha cone is withdrawn from the me-



A B

Fig. 15.41. **A.** Typical imprint left by a fine instrument on a gutta-percha cone previously placed in confluent canals of the same root. **B.** This is an information not only about the confluence but also at what distance from the common foramen the canals meet, in this case 3.5 mm. The working length of the confluent canal should be calculated considering the point of confluence as the apical foramen.

siolingual canal and carefully examined, preferably with a magnifying lens, to search for any grooves, scratches, tunnels, or folds left by the file
– once the presence of the confluence and its distance from the apical foramen have been confirmed, one commences the cleaning and shaping of the mesiobuccal canal, taking as the working length the point of confluence. The preparation of this canal is therefore shorter and less marked than the canal already prepared.

The same sequence is indicated in the mesiobuccal root of the upper molars, in which, once the confluence of the two canals to a single foramen has been diagnosed, it is extremely important to perform a moderate enlargement of the mesiopalatal canal, given the natural buccopalatal thinning of the root that is very often present, and thus an accompanying high risk of stripping.

TEN RULES TO FOLLOW

1) Do not begin endodontic therapy unless a recent and up-to-date preoperative radiograph is available.
2) The instruments must always be precurved and equipped with a directional rubber stop.
3) Do not begin to work to the foramen, without first having radiographically ascertained the position of the instrument in the canal.
4) The endodontic instrument does not work for itself, but prepares the canal for the following instrument.
5) All endodontic instruments work on withdrawal, arriving where the canal will accept them: "Take what the canal will give you!"[65]
6) In multirooted teeth, one always performs the cleaning and shaping of one canal at a time, always starting from the easiest.
7) Each root canal deserves a series of new instruments.
8) The instruments' working length must always be checked electronically first and then radiographically: never take an X-ray without consulting a reliable electronic apex locator.
9) It is advisable not to trust one's tactile sense.
10) Never progress to the next step unless the preceding step has been completed.

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16

A Contemporary Approach to Cleaning and Shaping of the Root Canal System Emphatizing "Early Coronal Enlargement"

Michael J. Scianamblo

INTRODUCTION

The earliest references to root canal preparation and obturation can be traced to Edward Maynard (1838) who was both a physician and a dentist. Maynard described a technique for pulp extirpation, preparation and obturation. Maynard created barbed broaches, by notching the untempered steel used in making watch springs. He also fashioned reamers by filing piano wire into three and four-cornered metal blanks and then twisting it. This method is not dissimilar to the techniques currently employed in the manufacture of modern endodontic instruments.

Only rudimentary discussions of root canal procedures occurred until Hess[21] published a compendium of the anatomy of root canals of teeth, which demonstrated the complexity of that anatomy. Hess concluded from those studies that root canal systems could not be adequately cleaned or adequately obturated. That assumption in conjunction with the focal infection theory presented by Hunter[23] and confirmed by Rosenow[43] severely undermined the development of endodontics until well after the discovery of penicillin by Sir Alexander Fleming[15] and commercially available antibiotic preparations.

Stewart[54] discussed the importance of irrigation with sodium hypochlorite during root canal preparation, also designated as chemo-mechanical preparation. The canal was enlarged initially by manipulating the largest reamer that could reach the apical region, which was followed by manipulating a file of the same size. Reamers and files of increasing size were carried to the apex, alternately, until the canal was debrided and enlarged. This technique came to be known as serial filing.

Schilder[50] was the first clinician to provide a detailed discussion of root canal preparation. Schilder referred to this procedure as cleaning and shaping and outlined specific design objectives, which included the most significant principle of cleaning and shaping, namely, the continuously tapering shape. Schilder was also the first clinician to discuss step-back preparations of the root canal system and recapitulation. Although numerous other authors have contributed greatly to the body of knowledge regarding root canal preparation, the criteria and objectives that were originally described by Schilder remain essentially unaltered. The techni-que that was described by Schilder entailed serial instrumentation with progressively larger instruments working from the apical extent of the root canal coronally in a step-back fashion. Files were used alternately with reamers. Gates-Glidden drills were used to enlarge the coronal portion of the preparation. The use of the smaller preceding instruments to reestablish patency or recapitulation was also described.

Coffae and Brilliant[10] corroborated the work of Schilder. They demonstrated that a tapering preparation was more efficacious in the removal of debris from the confines of the root canal system than parallel preparations. They also demonstrated that the use of files serially, and in a step-back modality, was more effective in producing the tapering shape, than serial filing alone.

Weine et al.[56] used clear acrylic blocks to evaluate the effectiveness of various instrumentation techniques. Their conclusions were somewhat disconcerting. They demonstrated that the utilization of standard instruments in either a reaming, a filing, or a reaming and filing modality, produced preparations that were irregular in shape. Furthermore, these preparations were not continuously tapering, with the narrowest part, at a point coronal to the root apex. This point was designated as the elbow of the preparation. The preparation developed at the apex of the root was found to be considerably eccentric in shape, and was reminiscent of a teardrop. The apical preparation was designed as an apical zip. These characteristics were felt to result from the elastic memory of instruments and a predilection to straighten as they are manipulated around curves. To alleviate this problem, Weine suggested removing the flutes from the outer surface of a pre-curved file, and the use of instruments in intermediate sizes, which are not commercially available.

To minimize the problems described by Weine, Abou Rass et al.[1] engaged in a discussion of anti-curvature filing. This method advocated the removal of conspicuous amounts of tooth structure from the outer walls of the curve of a root canal system. This, of course, provided a safer approach to the root apex, in addition to protecting the furcation of multi-rooted teeth.

Marshall and Pappin[32] advocated an innovative approach to root canal preparation described as a crown-down technique. This method addresses the canal by expanding the preparation coronally before an attempt is made to reach the apex. Pre-curvature of instruments was found to be unnecessary, however, the apical zip as described by Weine, could still be detected.

A somewhat abstruse, but compelling, article on instrumentation was published by Roane et al.[42] Roane described a technique for root canal preparation called "balanced force". The technique is a variation of reaming, but purportedly maintains the contour of the canal and does not transport, or zip the apical foramen. Theoretically, the restoring force or elastic memory of the file described by Weine, can be overcome when it is pit against dentinal resistance. The technique is carried out by rotating a file in a clockwise direction, while forcibly engaging the flutes of the instrument. This is followed by a counter-clockwise rotation, while simultaneously applying forcible apical pressure. The counter-clockwise rotation cuts the dentin via shear force or the balanced force. This procedure is continued with each file apically until forcible resistance is met, at which time the next largest instrument is employed. The precurvature of instruments was not found to be necessary and the technique was not recommended for root canal systems with significant curvature. Some preliminary investigations by the author indicate that, although the technique is an efficient method of enlargement, there is a predisposition to fractured instruments, intracanal obstructions, ledging and transportation when this technique is used injudiciously.

Dedeus[12] has also described a method that is reminiscent of balanced force, but is distinct, utilizing oscillatory movement. A file is carried down the canal by turning the instrument clock-wise, and then counter-clockwise 180 degrees repeatedly until forcibly resistance is meet. The instrument is then continuously exchanged for the next largest instrument until the preparation of the desired diameter is achieved. Multiple repetitions of the instrument sequence and recapitulation, is obviously necessary. The method is extremely safe and efficient and renders very round preparations.

In addition to the above, the advent of Nickel-Titanium rotary instrumentation has given clinicians, yet, another tool in developing clean, continuously tapering preparations that duplicate the original canal anatomy. These instruments, however, cannot substitute for a thorough knowledge of root canal anatomy and mastery of the skills necessary to prepare canals manually.

Finally, the author[51] has described a technique that is an extrapolation or maritage of step-back filing and crown-down methodology. The technique incorporates the use of hand instrumentation and rotary instruments. The combination of these techniques can provide continuously tapering shapes safely and efficiently. This technique will be described in greater detail, following a discussion of the requirements for an ideal root canal preparation.

REQUIREMENTS

In a previous discussion,[52] it was established that endodontic success is dependent on two fundamental criteria, the complete removal of the contents of the root canal system and the complete elimination or obturation of that system.

To fulfill these criteria, a set of requirements for an ideal root canal preparation must be delineated. These requirements should not be dissimilar to those for any tooth cavity preparation. Some of these are embodied in the requirements for an ideal cavity preparation delineated by G.V. Black,[7] which include: an outline form, a convenience form, debridement, a retention form, a resistance form, finishing, and lavage.

The following are a list of requirements for an ideal root preparation:

1. *Complete access*. The preparation should allow unobstructed visibility of the pulp chamber and convenient access to the root canal system at every level.
2. *A continuously tapering shape*. This aids in the removal of debris, facilitates finishing and irrigation and prevents the displacement of filling material or provides retention for that material.
3. *Maintenance of the original anatomy*. The outline of the cavity preparation is dictated by the anatomical outline of each tooth. Thus, the orifice, the pathway of the canal and the apical foramen remain in their original spatial location during and after preparation.
4. *Conservation of tooth structure*. The conservation of tooth structure provides resistance to fracture and decreases the incidence of perforation. Furthermore, if the integrity of the apex is maintained and the apical foramen is kept small, transportation of the apex is eliminated and the opportunity to seal the apex is enhanced.

1. Complete access

This requirement should be obvious, and yet, is frequently overlooked. Complete access should provide unobstructed visibility to the pulp chamber revealing the shape of the systems and the configuration of the orifices. A common cause of endodontic failure is the omission of a complete system during cleaning and shaping. This is undoubtedly the result of inadequate access. In addition, fractures, resorptions, and anatomic anomalies can hinder the endodontic prognosis unless they are identified.

Unobstructed access to the root canal system provides freedom during cleaning and shaping, facilitates the removal of debris and provides an opportunity to compact material into the prepared system three-dimensionally. Manipulation of endodontic instruments is impossible when the instrument shanks are encroaching on tight unyielding access cavities that bind the instrument coronally. The access cavity must be adequately flared to eliminate impedance of the working instrument may enhance the usefulness of the instrument apically.

2. The cavity is continuously tapering

This requirement is probably the most important requirement of endodontic cavity preparation and it serves a number of functions. As we discussed, it provides convenient use of instruments, aids in the removal of debris, facilitates finishing and irrigation and prevents the displacement of filling material during compaction (Fig. 16.1).

The convenience of instrumentation that is being referred to, results from the elimination of restrictive dentin that takes place during access and enlargement of the root canal system. The control and effectiveness of a root canal instrument is hindered by the bending moment created by the curvature or the arc of the canal and by the elastic memory, or restoring force, of the instrument itself. Reducing the degree of curvature of the canal or reducing the arc length can reduce the bending moment generated by the canal. Both can be accomplished by enlargement of the endodontic cavity and specifically by creating a continuously tapering shape.

Fig. 16.1. An endodontically treated upper central incisor depicting one of the essential requirements of the root canal preparation, the continuously tapering shape. Note the filling material obturating a fine loop in the middle third of the root canal system (Scianamblo 1992).

A continuously tapering shape also enhances facilitation of debridement, finishing and irrigation. Providing a clear access to the various reaches of the preparation, promotes the uncovering and removal of debris, and permits the flow of irrigating solution to the recesses of the apical third of the root canal preparation including anatomical complexities such as fins, cul-de-sacs, loops and secondary and tertiary canals. These advantages are minimized in preparations with more parallel shapes.

Finally, a continuously tapering shape provides retention of the filling materials and prevents apical displacement. Just as important, perhaps, this shape permits deformation of gutta-percha during vertical condensation providing an opportunity to seal the system in the densest manner possible. Further, unimpeded access of the condensers to the gutta-percha eliminates the risks of root fracture attendant with techniques that advocate the contact of filling instruments such as spreaders with dentin.

3. Maintenance of the original anatomy

Although this objective seems somewhat straight forward, it is the objective that is the most difficult to accomplish and the objective that is most often neglected. There are several explanations for these deficiencies. The primary reason is that information regarding the configuration of the root canal system is garnered primarily from radiographs. Unfortunately, radiographs are two-dimensional representations of three-dimensional objects. Therefore, even a well-angled series of periapical radiographs is inadequate in defining the true anatomy of that system. The advent of the use of the operating microscope has profoundly influenced our technical ability to visualize root canal anatomy. However, the clinician must rely heavily on his knowledge and clinical experience, and on his tactile sensations as he manipulates endodontic instruments within the system. As this information, knowledge and skill is applied, a cavity preparation is rendered that hopefully fits the criteria for the ideal preparation. By necessity, the final result is an artistic rendition or conceptualization of that preparation. Indeed, on occasion, even the most skillful clinician is humbled by this exercise (Fig. 16.2).

Maintenance of the original anatomy, while still providing access for the endodontic cavity preparation and obturation of the system is most often accomplished by the removal of significant amounts of tooth structure from the upper and middle portions of the system at the expense of the outer walls of curvature. This provides better access to the more complex anatomy apically. During this process, straightening the coronal third and parts of the middle third of the canal is often required (Fig. 16.3).

Fig. 16.2. An endodontically treated upper first bicuspid with three primary canals. Note the preparation design, which depicts and demonstrates two of the essential requirements for an ideal cavity preparation, a continuously tapering shape and the maintenance of the original anatomy. The incidence of three primary canals in the upper first bicuspid is approximately 7% (Scianamblo 1992).

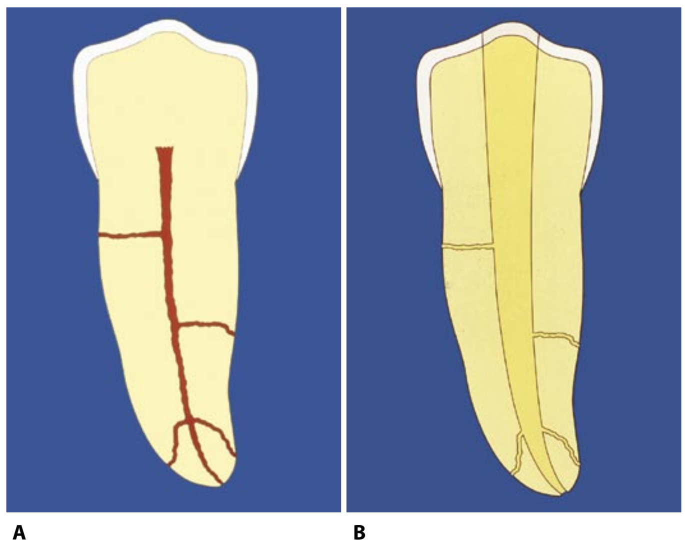


Fig. 16.3. **A**, **B**. Graphic illustrations depicting a lower bicuspid before and after cleansing and shaping. Complete cleansing and shaping is accomplished by the removal of significant amounts of coronal tooth structure at the expense of the outer walls of curvature and by straightening the coronal third and parts of the middle third of the canal. This provides better access to the more complex anatomy apically. This process help eliminate the effects of the elastic memory of the instrument and the bending moment of the curve of the canal and helps expansion of areas that might be inaccessible otherwise. It will also allow the delicate opening and cleansing of the foramen itself (Scianamblo 1992).

This helps eliminate the effects of the elastic memory of the instrument and the bending moment of the curve of the canal and helps expansion of areas that might be inaccessible otherwise. It will also allow the delicate opening and cleaning of the foramen itself.

Cleaning and enlarging the foramen is the most important process of the preparation. Indelicate cleaning and enlarging of this area will quickly lead to transportation of the foramen. This is usually seen as a teardrop shape or zip or manifest as a frank perforation. It is this procedural error that is directly responsible for a large portion of endodontic failure.

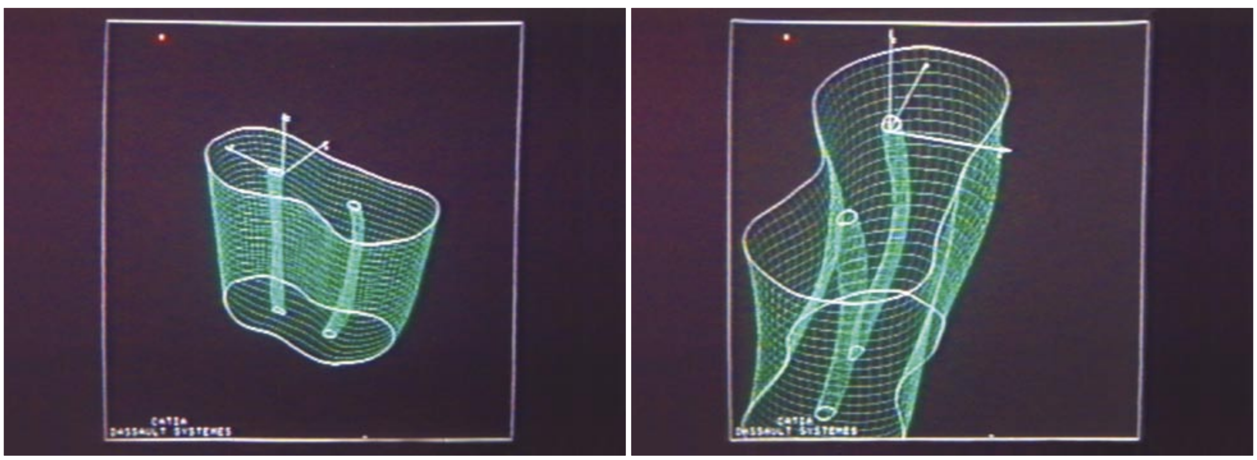
While cleansing and shaping the apical foramen, small pre-curved files should be employed. These files are rarely larger than size 20 or 25. The larger sizes should only be used in the very last stages of preparation. The apex is left totally patent without attempting to create apical stops or intentionally ledging the preparation. This process will not only maintain the integrity of the apex but will insure that the filling material reaches the apex. This feature may also allow exudates that have accumulated in the periapical area to drain.

4. Conservation of tooth structure

This requirement is rarely mentioned but is critical to the success of any endodontic procedure. Omission of this requirement predisposes teeth to a variety of procedural errors such as perforation and transportation and encourages the opportunity for root fracture. Maintenance of the integrity of the apex may also facilitate filling.

Although adequate amounts of coronal tooth structure must be removed to provide access to the middle and apical thirds of the preparation, this tooth structure should be removed judiciously. Generally, a larger bulk of dentin exists in the upper and on the outer portions of roots. Thus, the removal of larger amounts of tooth structure coronally and peripherally is encouraged. Maintenance of the furcation area of teeth is critical. Therefore, emphasis should be also be removal of tooth at the expense of the outer walls is positively important curves. When this process is cared out carefully, a preparation can be created that provides almost unlimited access to all areas of the root canal system eliminating the opportunity for the procedural errors removal of tooth structure and root fracture (Figs. 16.4 A, B).

Root fracture, when removal of tooth structure is sustained, there is usually a discovery several months or several years after initial endodontic treatment. These fractures may have been present prior to treatment, but are usually the result of failure of the root to withstand masticatory stress after treatment or as a direct result of excessive condensation pressure during compaction of filling materials. These fractures will occur in the weakest part of the root and often correspond to areas of the preparation where over enlargement has occurred. It is not surprising, therefore, to find many fractures emanating from the furcation areas of teeth where excessive thinning has



A B

Fig. 16.4. **A**, **B**. Computer graphic schematics of the mesial root lower human adult molar demonstrating the close proximity of root canal systems to the furcation areas. Note that the bulk of tooth structure exists on the outer walls of the curve and on the periphery of the root. These findings have significant implications during endodontic cavity preparation (Berutti, 1992).

occurred or opposite posts that have been placed indiscriminately.

Finally, conservation of tooth structure should not only lead to the maintenance of the integrity of the root complex but should enhance filling. When the apical foramen is kept small, the extrusion of sealer is minimized. Further, a foramen that corresponds to a 20 or 25 file will completely impede the flow of warmed gutta-percha during compaction (Fig. 16.5).

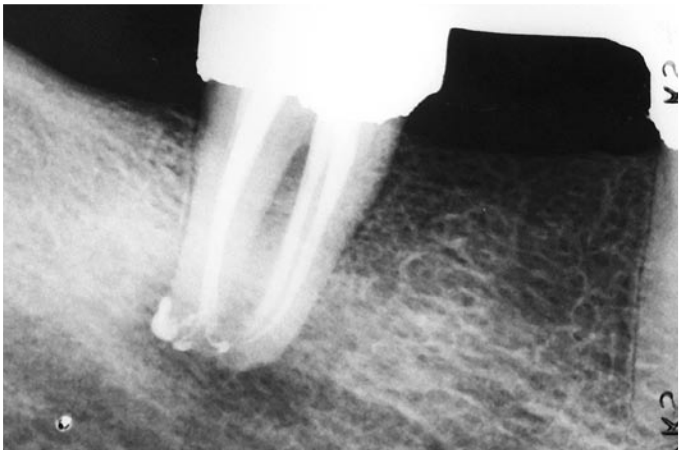


Fig. 16.5. An endodontically treated lower second molar displaying multiple portals of exit. When the apical foramen is kept small, obturation of fine ramifications is maximized and the extrusion of sealer is minimized. Further, a foramen that is as small or smaller than a 20 or 25 file will completely impede the flow of warmed gutta-percha during compaction (Scianamblo 1992).

INSTRUMENTS & MATERIALS

Instruments

The creation of an endodontic cavity preparation that is functional and predictable in design is an artistic rendering that requires a thorough knowledge of available armamentarium. This armamentarium includes a combination of hand and engine driven instruments.

Hand instruments are all manufactured from metal wire of varying sizes. The metallurgical properties of these wires have been engineered to produce a wide range of physical properties. These wires are then ground or cut to produce specific shapes and styles. They have been designated either R-type, K-type or H-type instruments according their varying characteristics.

R-type instruments are historically the oldest hand instruments. They were the first instruments to appear, introduced by Maynard (1838) and fashioned from piano wire. The most typical R-type instrument used today is the barbed broach. It is manufactured from soft iron wire that is tapered and notched to form barbs or rasps along its surface. These instruments are generally used in the gross removal of pulpal tissue or debris from the root canal system. Another R-type File is a rat-tail file, which is also of historical interest but seldom used today.

In the early part of the twentieth century, the Kerr Manufacturing Company developed the K-type instrument. K-type instruments that remain in current usage are reamers and K-files. They are available in either carbon steel, stainless steel and, more recently, nickel-titanium. Round wire of varying diameters is ground into three or four-sided pyramidal blanks and then rotated or twisted into the appropriate shapes. These shapes are strictly controlled by the American National Standards Institute (ANSI) and the International Standards Organization (ISO). The manufacturing process for reamers and files is identical, however, files have a greater number of cutting flutes per unit length than reamers. Reamers and files are used to clean and shape the root canal system. Reamers are used in a rotational direction only, whereas files can be used in a rotational or push-pull fashion. Files made from three-sided or triangular blanks have smaller cross sectional areas. Thus, these instruments are more flexible and less likely to fracture. They also display larger clearance angles and are more efficient during debridement. Triangular Files are, therefore, generally considered more desirable.

H-type files are manufactured by grinding flutes into tapered round metal blanks to form a series of intersecting cones. Cutting occurs in the pull direction only. Hedstrom files are extremely efficient cutting instruments. All hand instruments are available in 21, 25 or 31 mm lengths.

Newer designs have also been studied. Schäfer[46] compared traditional instruments with square and triangular cross-sections (K-type) and instruments with round cross-sections (H-type) to experimental instruments with rhomboidal cross-sections. The experimental instruments cut more efficiently than any of the traditional instruments used in either a push-pull (linear) or rotary modality. He also compared instruments with 16, 24 or 32 cutting flutes along the instruments working surface. Instruments with 24 cutting flutes were the most efficient.

The most commonly used engine driven instruments for endodontic cavity preparations are G-type reamers or Gates Glidden drills. They are extremely efficient and safe. The G-type drills are available in carbon or stainless steel. It has a short flame-shaped head attached to a long shank. The flutes of the head are spiraled with a wide rake-angle. The tip usually has a non-cutting surface to prevent perforation. The instrument is used as a side-cutting instrument only, and is relatively rigid; therefore it can only be used in a straight line.

The G-type drill is available in 14, 18 and 25 mm lengths measured from the tip to the shank where it inserts into a standard slow-speed handpiece. They are available in varying diameters of 0.30 mm to 1.5 mm from sizes 1 through 6 respectively.

Walia[55] first discussed the use of nickel-titanium rotary instruments in endodontics. Although he is credited with the introduction of this material in dentistry, alloys of nickel-titanium and its various usages have been discussed for several decades. The instruments can be found in a myriad of shapes and sizes. They are all cut from round nickel-titanium blanks. In cross-section the earliest instruments had two cutting surfaces (McSpadden,[33]) with radial lands providing the instrument with a so-called counter-balancing characteristic. This system, also known as the Quantec System, is still available and features a multiplicity of instruments with various tip sizes and tapers. Subsequent instruments had three or more cutting surfaces. The design of these instruments is credited to Arpaio,[3] Heath[19] and Buchanan.[8] All of these instruments, however, were designed with constant or uniform helix angles with a right-hand or threading helix, which is problematic. Constant helix angles with right-handed cut and a right-hand helix cause the instruments to thread into the canal like a screw. As the instrument twists in the canal it becomes bound precipitating spontaneous breakage. The addition of radial lands did mitigate the threading problem. However, the instruments become less efficient cutting devices. In addition, an increase in torque is required to drive the instrument, causing fatigue and premature breakage. A new design eliminating the radial lands and altering the helix angles has been introduced by the Brasseler and is called the RaCe System. Maillefer[30] in cooperation with Tulsa Dental products also introduced an instrument with a progressive taper along the working surface called the Protaper. Breakage may still occur with these instruments due to the fact that they still display right handed-helix with a right-handed cut, which bind in the canal.

Until recently, the work of Mizarhi et al.[36] Hülsmann el al.[22] and others indicated that the most effective methods of endodontic cavity preparation were accomplished by hand instrumentation. However, the advent of super-elastic nickel-titanium rotary instruments has altered our perspective. Super-elastic instruments, such as these, can be carried around curves without exceeding their bending or tortional moments of failure. Stainless steel instruments, of course, are highly predisposed to both, bending and tortional failure. Several investigators, including Glosson et al.,[17] Esposito et al.,[14] Schafer and Florek[46] and others, have suggested that nickel-titanium rotary instruments were superior to hand instrumentation, in maintaining the original anatomy. However, Schafer and Zapke,[49] Ahlquist et al.,[2] and Schafer and Schlingermann[48] found that canals prepared manually were cleaner than those prepared using rotary Ni-Ti instruments. Indeed, Peters et al.[40] demonstrated that the rotary nickel-titanium systems that they studied left 35% of the canal surface area unchanged.

In addition, Schafer[46] found that instruments with triangular and square cross-sections left all curved canals poorly cleaned and shaped, whereby tooth structure was removed almost exclusively from the outer-wall of the curve. It is the observation of many clinicians, as well as the author, that the greatest failing these instruments is the continued predisposition to tortional failure and breakage, the findings, of which, have been verified by Kum et al.,[28] Calberson et al.,[9] Schafer and Florek[47] and others.

The endorsement of the safety and efficiency of all of these instruments is probably over-stated, particularly by the manufacturers. Further, some researchers indicate that the effectiveness of any one instrument, over another, is not statistically significant (Kum et al.,[28] Peters et al.[40] and Ahlquist et al.[2] Notwithstanding the criticisms above, most clinicians find that nickel-titanium instrument systems facilitate their treatment. In addition, rotary instrumentation facilitates the coronal removal of debris, which is desirable. And although nickel-titanium instruments do break, the use of torque controlled hand pieces can, to some extent, control the tortional limits placed of the instruments. In addition, the use of the instruments at slower speeds or speeds in the range of 150 rpms seem to reduce fatigue.[13] In addition, instruments with low or negative rake angles are safer, but less efficient than instruments with neutral or positive rake angles. And tapers of 0.4 mm or less are safer than larger tapers, but are less efficient. Finally, fatigue and intimate failure can be mitigated by frequent instrument replacement and moderate usage.[16]

Thus far, all of the instruments that have been discussed have a right-handed helix and right-handed cut. Unfortunately, all instruments with this design are pre-disposed to binding or "taper-lock" and failure.

The newest approach to root canal preparation is found in the use of instruments that display a left-handed or reverse helix with a right-handed cut. These instruments are unusual in that they are the first instruments that will cut while rotating in a clock-wise direction, but do not thread or bind in the canal space. The instruments feature a sharp (positive) rake angle without radial lands. They also center extremely well as the result of the compensating forces produced by the reverse helix, when pitted against right-hand cut/rotation. For further safety, they also feature tip sizes and tapers that increase egually as a function of the area of a circle. This distribution is derived, by dividing the total surface area of the preparation by the number of desired instruments.

Remembering the formula for the area of a circle is $A = \pi r^2$, this distribution is exponential as opposed the conventional instruments that increase in size linearly. They can be used sequentially or alternatively with convention instruments having right-handed helix and right-handed cut. They are currently being manufactured under the name CPT or Critical Path Technology.

Current research does not completely endorse hand instrumentation or rotary instrumentation exclusively.

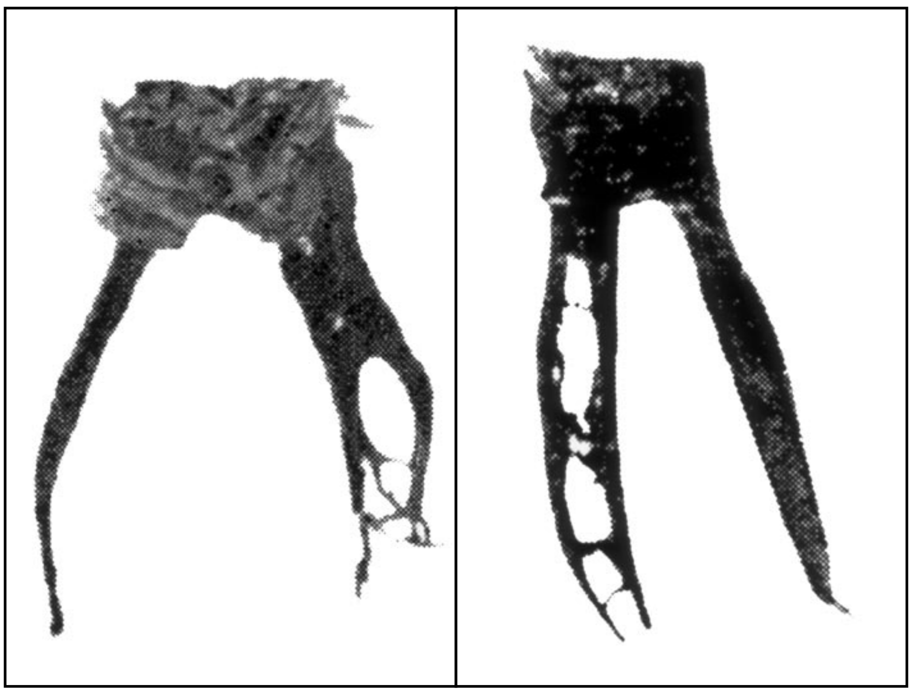
Endodontic preparations, however, will be done using both hand instruments and rotary instruments due to the facility and safety of these instruments, when used in combination, regardless of their shortcomings.

Thus, all of these systems require further evaluation and modification.

Irrigating agents

The complexity of the root canal system was delineated by Hess,[21] Okumura,[38] Pucci,[41] and others, while endodontics was in its infancy. Regrettably, many of these early observers concluded, that the root canal system was so complex it could not be adequately cleaned or obturated (Figs. 16.6 A, B).

As stated earlier, these conclusions, in conjunction with the focal infection theory, accounted for the



A B

Fig. 16.6. **A**, **B**. Vulcanite perfusions of the root canal systems of lower adult human molars demonstrating the anastomoses, fins, cul-de-sacs, and secondary and tertiary ramifications common to the human dentition. It was recognition of these complexities that hindered the advancement of clinical endodontics in the early 1900's (Hess, 1916).

wholesale extraction of pulpitic and necrotic dentition in the early 1900's. It was also the impetus for the rapid development of prosthetic dentistry during that time.

Although complete debridement of the root canal system was deemed impossible, it was believed that these systems could be sterilized using a broad range of sterilizing or pharmacological agents. These agents included bases, acids, aldehydes, phenols, antibiotics and steroids.

Subsequent research, including that by Grey,[18] Ruddle,[45] Klinghofer[25] and others has demonstrated that the root canal system can be thoroughly debrided and cleaned safely, using nothing more than a dilute solution of sodium hypochlorite, and the proper enlargement or shaping of the root canal system itself (Figs. 16.7 A-F).

To this extent, it is now recommended that all root canals be irrigated with copious amounts of sodium hypochlorite in at least a 2.5% solution. In addition, this solution should remain in the system throughout the cleansing and shaping procedure and be replenished

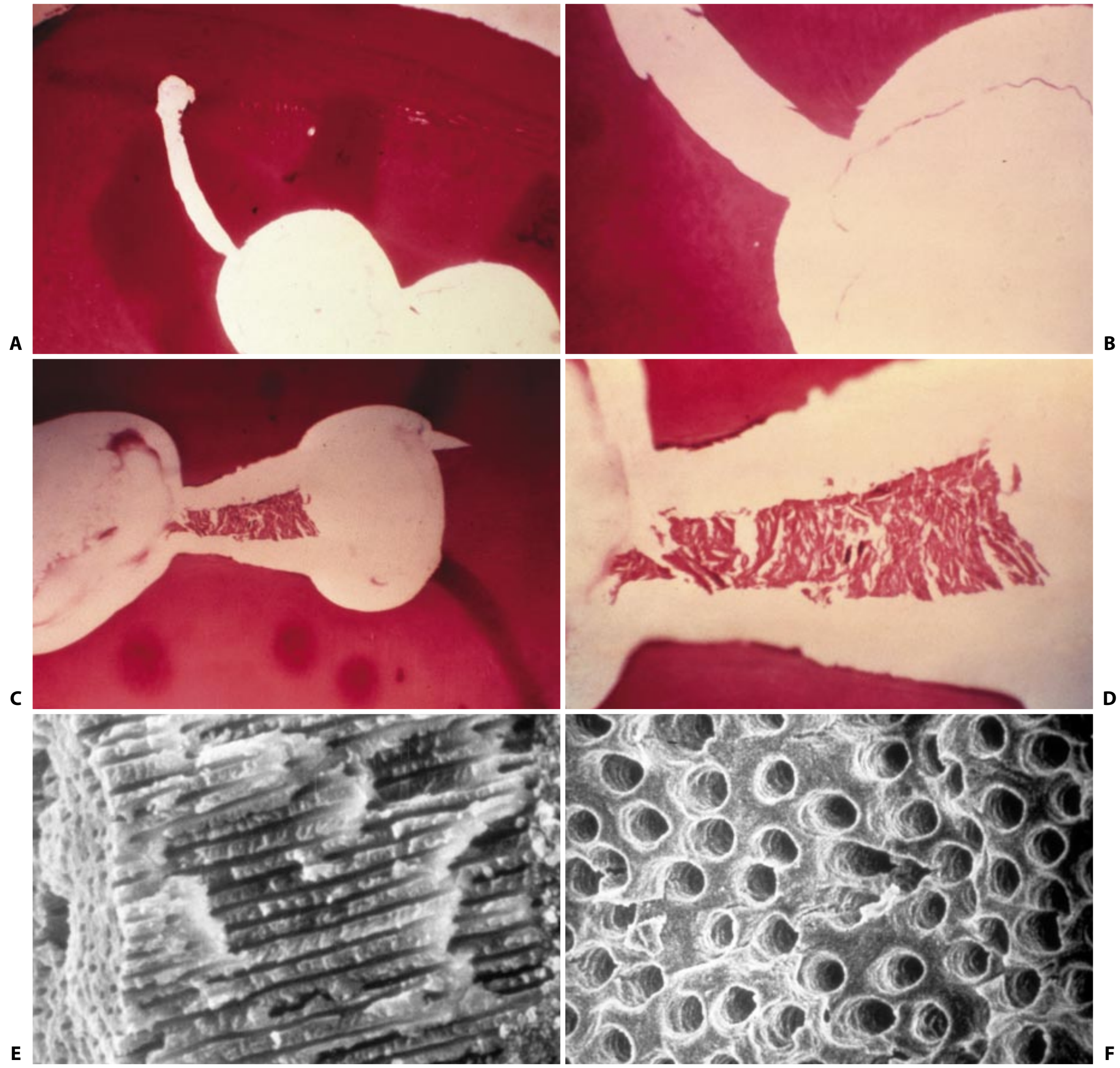


Fig. 16.7. **A**, **B**. Hemotoxylin and eosin sections of an upper first bicuspid cleansed and shaped using 2.5% sodium hypochlorite as an irrigant. The primary canal and a significant lateral canal have been totally cleansed demonstrating the efficacy of sodium hypochlorite as an irrigan (Grey 1970). **C**, **D**. Hemotoxylin and eosin sections of an upper bicuspid cleansed and shaped using normal saline as an irrigant. A large amount of undigested debris remains in the isthmus area between the two primary canals (Grey 1970). **E**, **F**. Scanning electron micrographs (sectionl and plane views) of dentinal tubules exposed following endodontic instrumentation using 2.5% sodium hypochlorite alone as an irrigant (Ruddle, 1976).

frequently. Thus, a reservoir of irrigant should be maintained at all times during the root canal preparation.

This reservoir can be accomplished with the help of pre-endodontic restorations or banding, if necessary.

Numerous other irrigating solutions have also been suggested for use. These include saline, hydrogen peroxide, and a variety of acids, bases and other reagents. However, Baumgartner and Mader[5] and others have demonstrated that nothing is more effective than sodium hypochlorite in at least a 2.5% solution either alone or in combination with other media.

Lubricating and chelating agents

The most common agents advocated for these purposes are ethylenediaminetetracetate or EDTA, EDTA and Cetrimide or EDTAC, urea peroxide, EDTA and urea peroxide or RC-Prep, urea peroxide in an anhydrous glycerin base or Gly-oxide. These substances have been advocated to aid in the cleansing and enlargement of canals, particularly those that are sclerosed or calcified.

Nygaard-Ostby[37] was the first to demonstrate that EDTA was an effective chelating agent forming a soluble calcium- chelate when exposed to dentin. He also investigated Cetrimide, a quaternary ammonium bromide, which theoretically acts to reduce surface tension and increases penetrability, when combined with EDTA. Yamada et al.[57] have also demonstrated that EDTA acts to remove the deposits, or the smear layer, that is left after dentinal surfaces are ground or planed. Most recently, Stewart[54] demonstrated that RC-Prep with 15% carbamide in combination with sodium hypochlorite was the most effective method of removing the smear layer. Koskinen et al.,[27] however, demonstrated that most these materials are ineffective in digesting the organic component of dentin or pulp tissue and Michelich et al.[35] have demonstrated that the smear layer inhibits the percolation of bacteria and inhibits leakage after obturation. It has also been observed by Patterson[39] that these materials have an extended half-life and that they continue to react with dentin after filling has taken place. Clinicians have also observed that the root canal system is predisposed to ledge formation, transportation, and perforation when EDTA is employed. In light of this information, the use of EDTA is considered to be controversial.

In addition, materials containing glycerol or glycerin can quickly form emulsions during root canal preparation. These emulsions can obstruct the secondary anatomy, i.e., lateral or accessory canals that the operator is attempting to address. Therefore, the use of this material may be contraindicated.

Intracanal medicaments

As was previously discussed, intracanal medicaments were an outgrowth of numerous misconceptions that existed during the inception of endodontic therapy. Specifically, it was assumed that root canal systems were so complex that they could not be cleaned or filled. Thus, a pharmacological approach to endodontics was undertaken in an attempt to sterilize or fix the organic component of the root canal system that, as it was assumed, could not be removed.

Research now exists demonstrating that the endodontic cavity can be completely cleaned and sealed. Thus, the use of intracanal medicaments are deemed to be unnecessary. In addition, many of these reagents are toxic, as well as allergenic. In the event that an interim appointment is required, leaving some residual sodium hypochlorite in the root canal space appears to be quite safe and may also serve as an effective anti-microbial agent.

In a preliminary study, Barkhordar et al.[4] demonstrated that the use of the antibiotic doxycycline hydrochloride (DH) in at least a 100 mg/ml solution in combination with sodium hypochlorite was not only a potent anti-microbial agent, but was an extremely effective irrigating medium. It was found to be more effective than sodium hypochlorite in combination with EDTA and capable of completely eradicating the smear layer. As was previously discussed, however, removal of the smear layer may not be beneficial. Thus, until further studies can be conducted, the use of sodium hypochlorite alone, without intracanal medication is the treatment of choice.

CONCEPTS

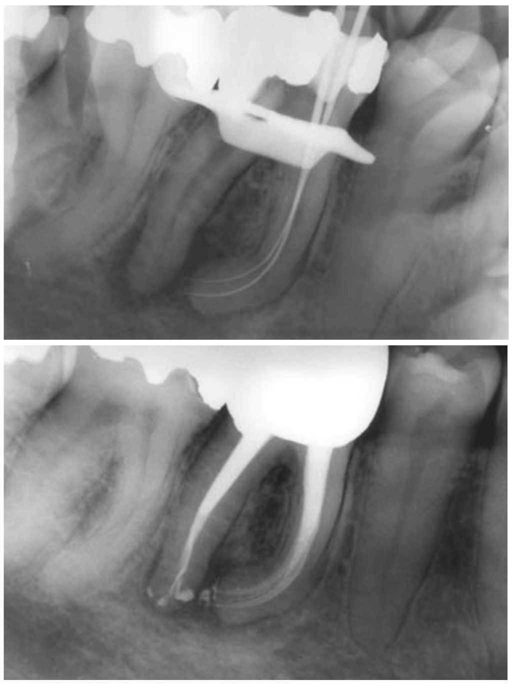
Broaching - Gross removal of debris

Broaching is extremely beneficial to endodontic cavity preparation. It eliminates the bulk of the debris that is present prior to the use of more refined root canal instruments and, in turn, helps prevent the obstruction of the apex. It also creates space providing a pathway for the irrigating solution apically.

Broaches are barbed instruments that are created by notching malleable round metal blanks. These instruments are, therefore, fragile and predisposed to fatigue and fracture. Thus, a large selection of broaches should be available and the instruments should be used passively. Generally, the smallest broach is chosen that can fit within the confines of the canal without binding. The instrument is inserted, impaling the pulp. The instrument is then turned slightly to engage the tissue and gently removed from the canal. The instrument may be curved to conform to the shape of the root canal space. It should never be inserted forcibly. Broaches should be discarded after each use.

Working length instrumentation to the radiographic terminus and patency

The working length, or the final terminus of instrumentation, has been the topic of considerable controversy in endodontic practice. This controversy has no doubt resulted from the fact that the anatomic terminus of a root canal is quite variable. Furthermore, that anatomical end point cannot be predictably located using electronic apex locators or radiographs.



A

B

Fig. 16.8. **A**, **B**. A lower first molar prepared and filled with warm gutta-percha to the radiographic terminus. Note that the instruments often pass slightly beyond this terminus encroaching of the periodontal ligament, thus, addressing the entire root canal system. Note that numerous secondary and tertiary canals have been obturated (Scianamblo 1992).

The first intensive discussion of this problem was provided by Kuttler[29] in a paper entitled "A microscopic investigation of root apices".

Kuttler's original work was published in Spanish and was later translated into English as well as several other languages. Although this paper was well written and very influential, many of his conclusions have been misconstrued. Kuttler indicated that the anatomic terminus, or the geometric terminus as he called it, did corresponded to the radiographic apex, but could be as far away as 1-2 mm. It was determined, however, that the average distance from the anatomic terminus to the radiographic apex, was 0.5 mm.

Unfortunately, what Kuttler designated as an "average distance" has been misinterpreted by many as the "actual distance" of the anatomical terminus to the radiographic apex. Ignoring the fact that the anatomic terminus and the radiographic apex may be almost identical. This work, of course, has been corroborated by many other insvestigators.

Thus, for decades many clinicians have worked within this rigid parameter; when, in fact, a working length that is 0.5 mm short of the radiographic apex may not correspond to the true location of the anatomical terminus of the majority of the teeth they have treated. In addition, working short of the true anatomic terminus is a predisposing factor to unclean, unfilled canals, ledging, perforations, and most commonly, obstructions with dentinal shavings.

Clinicians who have been plagued with these difficulties often assume that instrumentation and subsequent filling to the anatomic terminus is, in many cases, unattainable. Thus, they often become complacent about the final location of the last instrument and the filling material itself. This single misunderstanding has probably done more to render endodontic therapy inadequate, or at best mediocre, frequently predisposing to failure.

A more critical approach, and the one endorsed by most contemporary clinicians, is carrying the endodontic preparation to the radiographic terminus (Figs. 16.8 A,B). It is assumed in this approach that instruments will often encroach on the periodontal ligament.

This is the only approach, however, that insures that the entire root canal system has been fully addressed.

Furthermore, it is the only approach that insures endodontic success and eliminates the complications and frustrations associated with working short of the anatomic terminus.

Precurvature of instruments

Within nature, matter takes on a myriad of configurations. In addition, no object is completely uniform and, in particular, uniformly straight. This cannot be truer than in the case of a root canal system. All root canal systems are curved, many of which display such complex bends as to be almost indescribable. This observation has special consequence when one attempts to clean and enlarge these complex spaces.

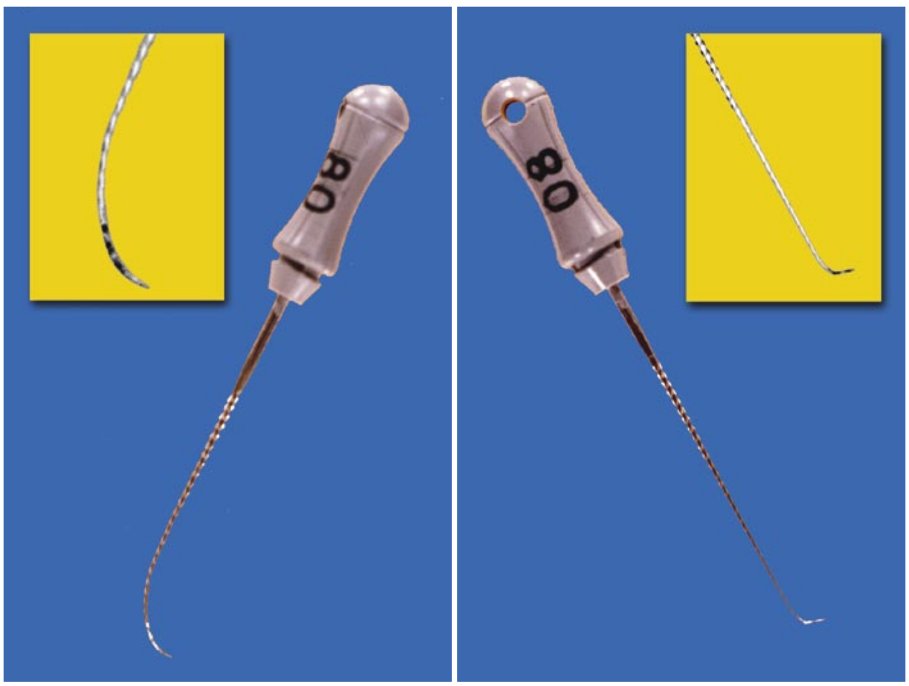
To maintain the curvature of the root canal system and to capture the tortuosity of that anatomy in all dimensions, the clinician must adapt instruments that not only duplicate the original anatomy of the system but also address the directional shifts that occur as the instrument is manipulated during use.

This requires a though knowledge of root canal anatomy and a thorough evaluation of radiographic and clinical data that has been collected prior to treatment. After the pathway of the primary canal has been determined, an attempt to mimic that pathway or curvature is made by shaping or adapting the root canal instrument (Figs. 16.9 A, B). The shapes that are created in these instruments, however, must be exaggerated to compensate for the elastic memory of the instrument.

It must be remembered that root canal instruments are manufactured from straight metal blanks that are either cut or wrought by twisting. The instruments that are rendered are not only straight but are often resistant to bending and will resume their original shape very quickly when they are engaged during the instrumentation process. The concept of elastic memory can only be over come by over bending the instrument while it is being prepared for use. The degree and extent of over bending that is applied depends on the curvature of the canal and the flexibility of that instrument. This is an artist's tool, and the use of this tool cannot always be taught. Thus, significant experience is often required to master this concept.

It must also be remembered that canals curve in three dimensions. Thus, the final shape of the instrument may be extremely complex. It must mimic the shape of the canal in three-dimensions while compensating for the elastic memory by exaggerating the curvature. In addition, when the precurved instrument is placed in a canal and worked, the shape of that instrument is altered very quickly. Thus, the instrument must be removed from the canal repeatedly and recurved during use.

Finally, as the preparation of the primary canal continues, the degree of curvature of the canal and the



A B

Fig. 16.9. **A**, **B**. Size 08 files that have been pre-curved in preparation for instrumentation. File A demonstrates a smooth curve and is typical of an initial file prepared for a curved canal. File B demonstrates an abrupt curve that may be used to explore and probe calcified or obstructed canals (Scianamblo 1992).

tortuosity of the pathway is reduced. Thus, the length of the canal as well as the length of the instrument must also be reduced.

As a general rule, all hand instruments are precurved before they are placed in a canal.

There are few exceptions. One notable exception, however, is the use of these instruments in a balanced-force modality. These concepts will be discussed later in the text.

Recapitulation

The term recapitulation was introduced by Schilder[46] and describes an essential concept in the cleansing and shaping procedure. It refers to the sequential re-entry or recapture of that portion of the root canal system that has been previously enlarged during preparation. This is accomplished using instruments that were previously introduced and are smaller in size than the instrument currently employed. This re-entry or recapitulation frees the root canal system of the dentinal shavings that accumulate apically as a working instrument is employed. It will also insure the continuously tapering shape that is an ultimate objective in endodontic cavity preparation.

This concept is one that should be universally shared regardless of the methodology that is used during preparation.

The sequence and frequency with which each instrument is used in this manner is dependent of the complexity of the anatomy of each root canal system. Only continuous and painstaking utilization of this concept will lead to the desired result. This will be described in greater detail.

Reaming

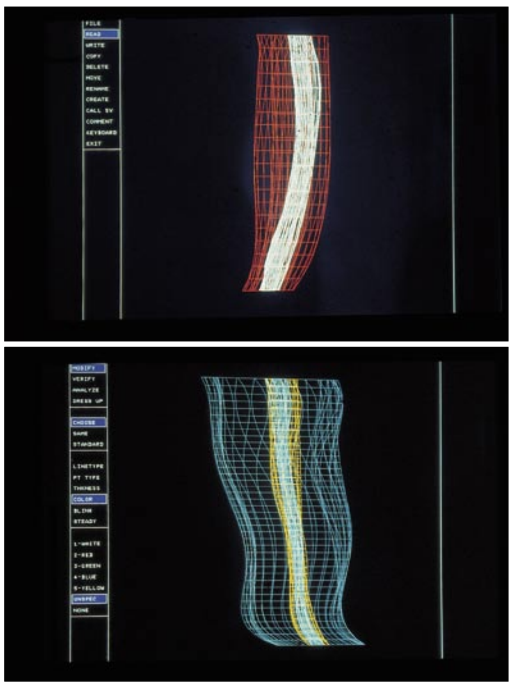
Reaming is an efficient method of enlargement and debridement of the endodontic cavity preparation. As previously mentioned by Berutti[6] and others, however, endodontic instruments used in a reaming modality, rapidly transport the endodontic cavity preparation toward the inner wall of the curve of the root canal system.

Thus, reaming alone is contraindicated. When reaming is used alternately in conjunction with filing, as described by Schilder, a more ideal shape may be created (Figs 16.10 A, B).

Filing

Although filing is an indispensable methodology in endodontic cavity preparation, there are few discussions or descriptions of the actual technique of filing itself. Ingle[23] discussed manipulation of files in the pattern of a Maltese cross, while other descriptions are more simplistic.

The objective of any filing technique should include a purposeful motion that cleans and enlarges the endodontic cavity space harmlessly, while maintaining the natural pathway of the space. This exercise should be comparable to fine sculpture, where small amounts of material are removed incrementally until the desired result is achieved. This, then, would dictate that the motions of the instrument should be harmonious push-pull strokes with relatively short, i.e., amplitudes in the realm of 1-3 millimeters. An attempt should be made to engage all the walls of the canal circumferentially. However, tooth structure should be removed preferentially from the outer wall of the curve of the root canal system to gain the straightest possible ac-



A

B

Fig. 16.10. **A**, **B**. Computer graphic schematics of the mesial roots of a lower human adult molar demonstrating the endodontic cavity preparations after enlargement using reaming and filing motions. As depicted in this schematics, when instruments are manipulated in a reaming motion, tooth structure is removed at the expense of the inner wall and when instruments are manipulated in a filing motion, tooth structure is removed from both the inner and outer wall. It has been concluded from this study, that instrumentation conducted in a filing motion not only maintains the original anatomy of the root canal system, but is protective in nature (Berutti, 1992).

cess to the foramen. The plane or the long axis of the stroke is altered continuously throughout the procedure and is determined by the operator as he attempts to fulfill the requirements of an ideal model.

Step-back

The size and sequence of these instruments is also critical to the shape of the sculpture being undertaken. As discussed previously, Schilder[50] and Coffae and Brilliant[10] discovered that instruments used sequentially from smallest to largest, in a step-back modality, produced shapes that conformed to the natural path-way of the canal while creating a continuously tapering shape which is essential to an ideal endodontic cavity preparation. Thus, the smallest instrument that can effectively penetrate and enlarge the canal, without forcible pressure is selected, followed by progressively larger and larger instruments. These instruments are stepped out of the canal as they increase in size. This technique is compared to serial filing or reaming, where all the instruments are carried to the same depth of the endodontic cavity preparation creating a taper that corresponds more closely to the taper of the instrument itself.

Step-back methodology has been the core of most instrumentation techniques for decades and will probably remain an integral part of most modern procedures.

Crown-down

This innovative method of endodontic cavity preparation was originally described by Riitano[42] in 1976 and later by Marshall and Pappin[32] and advocates the enlargement of the root canal system from the crown of the tooth to the apex. This method is, of course, an antithetical approach when compared to many of the techniques previously described. Previously, many clinicians assumed that obstruction of the endodontic cavity preparation was unavoidable unless the apical extent of the canal was captured prior to canal enlargement. This technique dismissed that concept and careful scrutiny indicates that it has several merits. The most significant advantage might be the elimination of the bulk of the restrictive tooth structure as well as the contents of the root canal system prior to negotiation of the apex. If this were possible, the foramen could be cleaned and enlarged, almost effortlessly, with little risk of transportation or obstruction. The technique that was described advocates forcible entry with hand instruments that have not been precurved. This, however, may lead to abrupt transportation of the foramen as well as the original canal. An extrapolation of this concept, however, may lead to a technique that is workable and extremely efficient. The description of the technique for endodontic cavity preparation in this chapter will employ a portion of this philosophy in combination with other methodology to form a new and more effectively approach.

Balanced force

This method of instrumentation was described by Roane.[43] As previously stated, the method is a variation of reaming. Like reaming, it is an efficient method of enlargement and debridement. Also like reaming, transportation of the endodontic cavity preparation, particularly in the apical one-third is a common finding, although to a less appreciable extent. Thus, the use of balanced force alone is contraindicated. When, balanced force is used in conjunction with filing, however, some may find that it is a useful adjunct during endodontic cavity preparation.

The use of the technique requires a pilot hole and previous coronal enlargement. Files with a parabolic or round tip may be useful. However, traditional K-type files may also be used. Enlargement is carried out by rotating the file in a clockwise direction with light inward pressure using a three-quarter revolution or less. The instrument is then rotated in a counterclockwise direction with moderate to heavy inward pressure past 120 degrees until the shear force or balance force, as it is called, cuts the dentin that has been engaged. This procedure is then followed by the passive removal of the dentin chips using the file in a light reaming motion to engage the material.

This procedure may be continued apically until forcible resistance is met at which time the next largest instrument is employed. The precurvature of instruments is not found to be necessary. When this method is employed with pre-enlargement of the upper one-third or two thirds of the endodontic preparation, it may be employed to gain rapid enlargement of the canal itself prior to final shaping. Again, the method should not be employed in the extreme apical extent of the endodontic cavity preparation to avoid transportation of the apex.

Method of DeDeus

This may be deemed to be an obscure method; however, most clinician probably employee some variation of the technique. The method was described to the author by the late Quintiliano DeDeus, a reknowned endodontist from Brazil, while taking a walk in San Francisco one evening in the fall of 1990. To my knowledge, a description of the method has yet to be published. The method employs the use of a precurved file used in a rocking or oscillatory manner. As the instrument is manipulated, it is moved apically through the length of the canal until it meets resistance. The instrument is, then, turned slightly counter-clockwise to retrieve or unlock it. It is then turned lightly in a clockwise direction to capture debris. This instrument is followed by larger and larger instruments used progressively deeper and deeper in the canal. This sequence of instruments is repeated until the desired diameter, and shape, of the preparation is complete. It is an extremely safe and effective method of enlargement, however, painstaking. The shapes can be narrower than in other techniques, but follows the path of the root canal well.

Blending

Blending, as described by the author,[51] is the clinician's final attempt to blend or marry the various aspects of the enlargement procedure to create the ideal shape of an endodontic cavity preparation. The instruments employed are usually files used in a rasping and push-pull motion. The instruments are precurved to correspond to the natural curvature of the endodontic cavity space and applied to the outer wall of each arch to insure a smooth transition from one plane of the endodontic cavity space to the next. The finished preparation should then provide unimpeded exit and entry of instruments and materials, with effortless access of the apex.

Signature

This defines the artistic result that the clinician renders on completion of the endodontic cavity preparation. It is the culmination of his attempt to enlarge the endodontic cavity space harmlessly, albeit, with adequate access to completely clean and obturate that space. The ideal preparation is continuously tapering smallest apically and duplicates the natural configuration of the canal and the root complex. It bears the attributes of a fine sculpture or carving and is unique, i.e., each clinician will incorporate small nuances to the preparation that are solely attributable to his artistic ability and workmanship. This is termed the signature of the preparation. Talented clinicians can often identify their work, or so called signature, merely by glancing at a radiograph shown to them at random.

TECHNIQUE

As previously mentioned, the requirements for endodontic cavity preparation are:
1. complete access
2. continuously tapering shape
3. maintenance of the original anatomy
4. conservation of tooth structure.

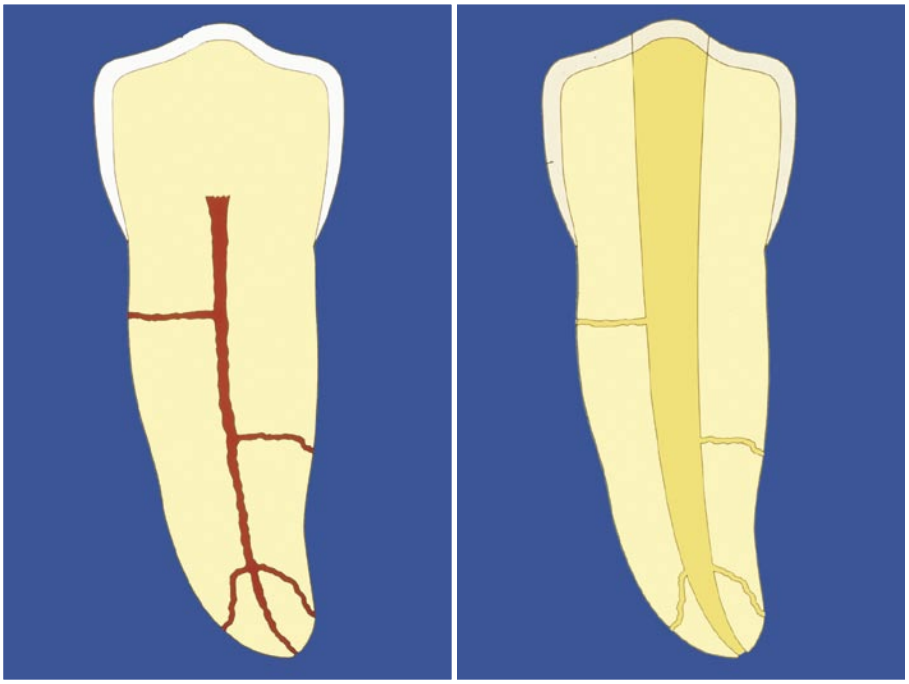
These requirements will enable us to fulfill the criteria for endodontic success, i.e., complete removal of the contents of the root canal system and the complete elimination or obturation of that system (Figs. 16.11 A, B).

Numerous clinicians have described preparation of the root canal space, each of whom have a distinct formula and style. These formulas, however, are often inadequate or inefficient, leaving the student or the clinician ill adept and frustrated. As was mentioned in the introduction, ideal preparations are attainable, regardless of the complexity the root canal anatomy.

Strategy

The strategy that is forthcoming may appear to be a significant departure from the techniques described heretofore. Close evaluation will reveal, however, that this strategy is an extrapolation of many concepts previously described as well as several new ones. This methodology is versatile, efficient and effective. The technique can be divided into six phases:
1. initial access and gross debridement
2. preliminary enlargement
3. establishment of patency
4. enlargement
5. blending
6. finishing and apical refinement.

The various phases are comparable to those followed by artists of fine sculpture. Our work during cavity preparation is, in fact, a sophisticated form of



A B

Fig. 16.11. **A**. A lower bicuspid tooth model demonstrating a root canal system with one primary canal and multiple portals of exit. Note that the root canal system becomes more complicated as the system progresses apically. Also note that the system curves as it courses apically. (Ruddle and Scianamblo 1992). **B**. The lower bicuspid tooth model demonstrating the root canal system following cleaning and shaping. The four requirements for cleaning and shaping should be depicted: 1. complete access, 2. a continuously tapering shape, 3. maintenance of the original anatomy, and 4. conservation of tooth structure (Ruddle and Scianamblo 1992).

sculpture that requires special armamentarium, knowledge, and skill. The use of the armamentaria and knowledge may be assimilated very quickly. However, as in all objects of art, the skill in performing an ideal endodontic cavity preparation may take longer to develop. Indeed, mastery of any art may take place over a lifetime.

For the purposes of our discussion, the root canal system will be divided into three segments: the coronal, middle, and apical thirds. One of our chief objectives, of course, is to develop a continuously tapering shape, which would make the junctions of these segments indistinguishable. Therefore, these junctions should be viewed only as references points without clear demarcation. (Fig. 16.12).

An access cavity is created to provide unobstructed visibility and unimpeded flow of instruments to the endodontic cavity preparation. The working instruments should never bind or impinge on the perimeter of the access cavity. These cavities, therefore, are generous in size and are divergent occlusally. After an initial access cavity has been developed, working instruments may be introduced and preliminary enlargement can begin. As preparation continues, changes may occur in

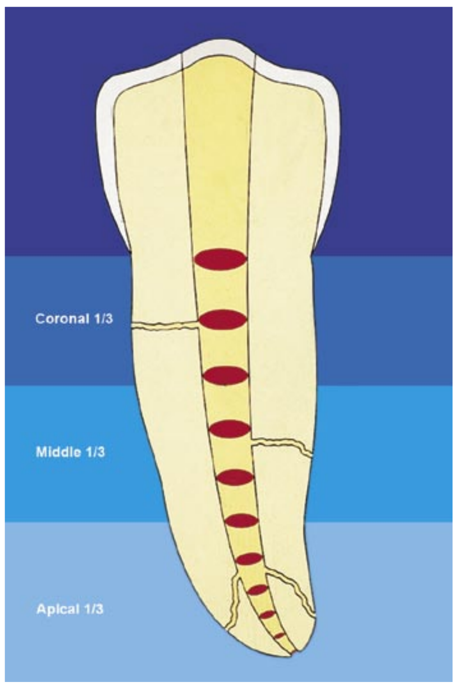


Fig. 16.12. The root canal system is divided into three segments the coronal, middle and apical thirds. Various phases of the endodontic cavity preparation will be confined to one or more of these segments and the outline of the preparation defined by the concentric circles above. Frequent reference will be made to these segments individually (Ruddie and Scianamblo 1992).

the long axis of the working instrument in relation to the access cavity and the instruments may, again, impinge on the perimeter of the access. Thus, the access cavity may evolve to accommodate these changes and the final access preparation may require further enlargement. The first phase of preparation, however, is an opening that will adequately accommodate the initial instruments without impingement or restriction and is termed initial access (Figs. 16.13 A-D).

With the exception, perhaps, of crown-down methodology, a paragon of clinical endodontic practice, heretofore, has been the establishment and maintenance of a working length from the commencement of treatment through to the final stages of the endodontic cavity preparation. This concept, however, is often unworkable, particularly in curved or obstructed canals. In fact, in these instances, any attempt to reach the apical foramen or establishment of a working length is deleterious. It can also be argued, that even in instances where the apex is easily negotiable, there is a greater benefit in gross debridement and removal of coronal tooth structure prior to negotiation of the apex. This concept is termed preliminary enlargement and will be a pivotal aspect of the technique that will now be described. Maintaining patency and avoiding obstructions of the endodontic cavity preparation is obviously of the utmost importance. However, there is grave risk of obstructing the canal early on, by an over zealous attempt to find the apex quickly, without attention to the complexities of the root canal system. Careful and judicious debridement and enlargement of the coronal and middle portion of the canal, prior to engagement of the apical segment, has numerous advantages. Some of these advantages are freedom and control of instrument cycles, coronal evacuation of contents of the canal, maintenance of a large reser-

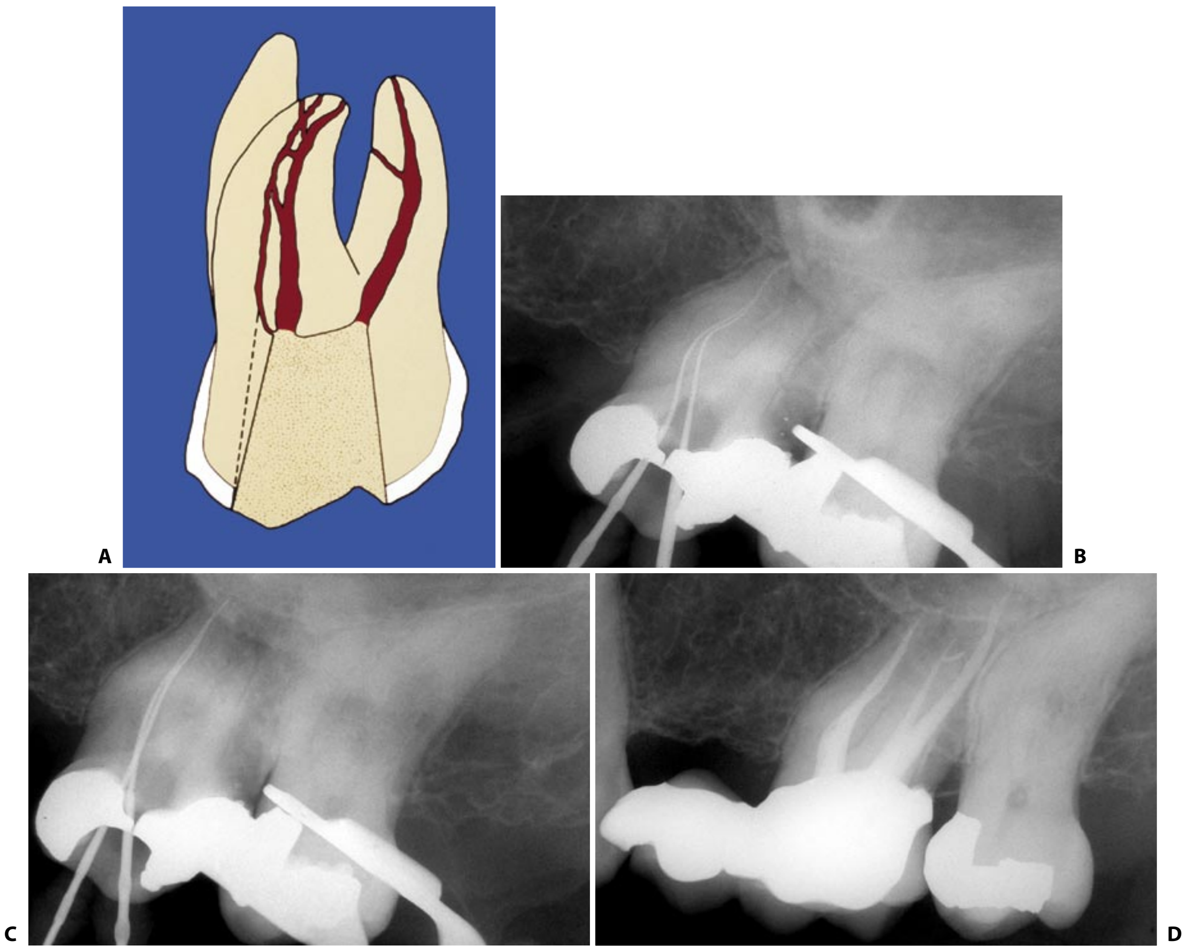


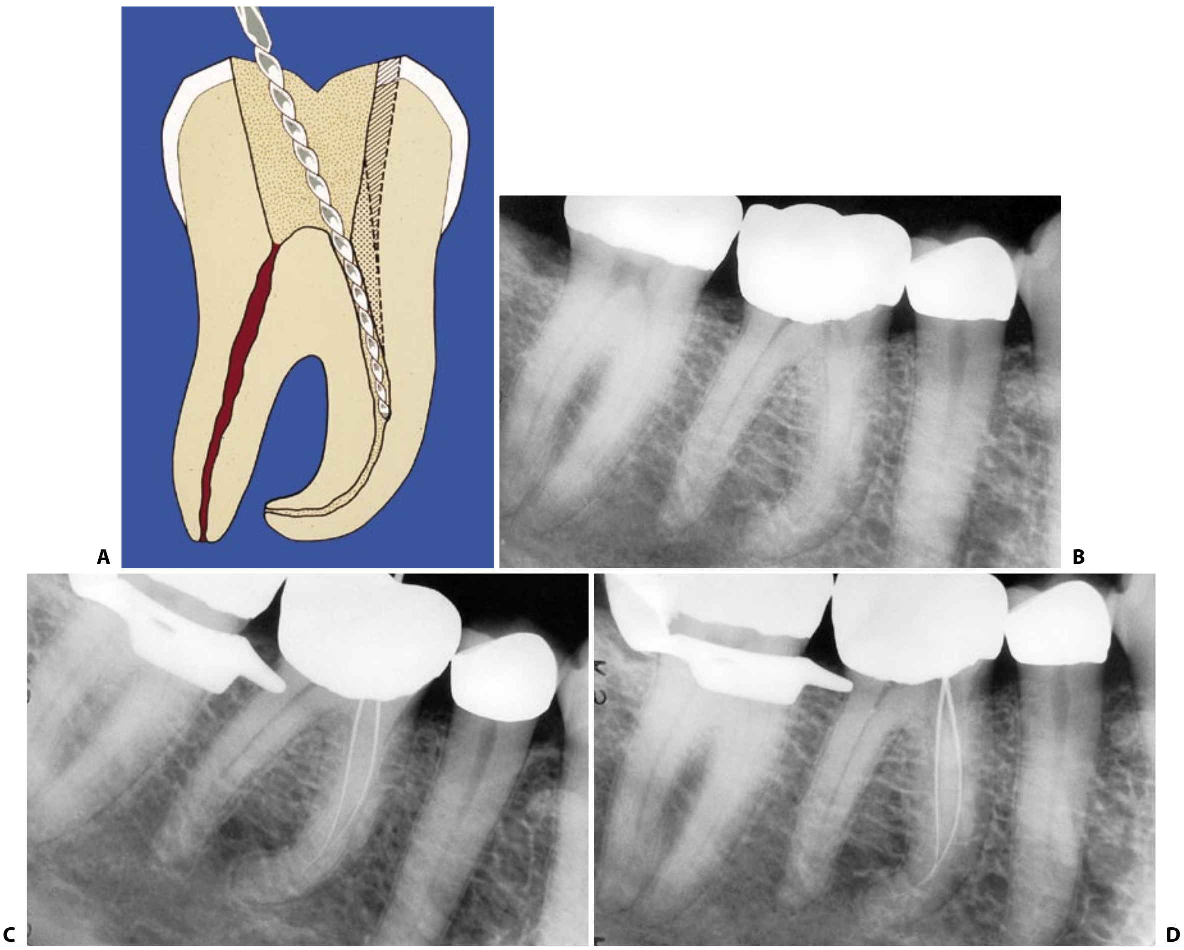
Fig. 16.13. **A**. A graphic illustration demonstrating the access cavity of an upper molar and the outline of the "triangle of dentin". Sequential removal or larger and larger triangles of dentin from the outer walls of the cavity preparation accommodates instruments of increasing diameter (Ruddle and Scianamblo 1992). **B**-**D**. A clinical case demonstrating easy accommodation of # 20 K-files at the apices of a severely dilacerated root followed by similar expansion of the outer walls (Scianamblo 1992).

voir for irrigant, clear visibility, and safe access to the foramen (Figs. 16.14 A-E).

Safe access to the foramen with instruments that arrive passively is of critical importance. The tip of instruments that has been passed forcibly into the apex undergoes substantial deflection and predisposes the preparation to the apical zip that has been previously mentioned.

Preliminary enlargement of the coronal and middle portion of the root canal system can take place utilizing a variety of instruments and procedures. No attempt is made during this phase of treatment to develop a finished preparation. Every attempt is made to begin to develop the continuously tapering shape that has been described previously. During this phase of procedure, the walls of the preparation will often demonstrate a roughened appearance, and can manifest undulations created by the rough work of hand instruments or rotary instruments such as G-type drills. Thus, this phase of treatment is often called the rough-in. This will be discussed in greater detail below.

Establishment of patency can now follow the negotiation of the apical third. As previously discussed,



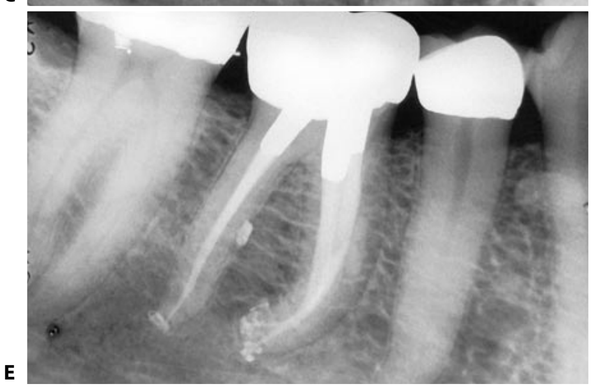


Fig. 16.14. **A**. A graphic illustration demonstrating the access cavity of a lower molar and the outline of the "triangles of dentin". As tooth structure is removed coronally and laterally, at the expense of the outer walls, the instruments are permitted greater and greater freedom until the apex is negotiated (Ruddle and Scianamblo 1992). **B**-**E**. In the clinical case, multiple lateral and accessory canals have been obturated in spite of the marked dilacerations and minimal size of the apical foramina. The final instrument to the radiographic terminus of each system was a # 15 file (Scianamblo. 1992).

the establishment and maintenance of patency can effectively eliminate obstructions, ledges and perforations, and provide a pathway for drainage. Exudates frequently accumulate in the periapical tissues of endodontically involved teeth. An open apex allows this material to escape into endodontic cavity space helping to eliminate infection and providing relief to the patient.

Following preliminary enlargement and establishment of patency, continued enlargement brings the final contour closer and closer to its ideal configuration or shape. A variety of techniques may be employed here. Regardless of the technique chosen, however, this phase of treatment should begin to join the locus of the apical foramen with the access cavity via a smooth tapering conduit. A final blending phase, which employs the use of planning instruments serially to remove any irregularities or undulations, can then be undertaken. Hedstrom files are well suited for this procedure. This is the phase that provides the smooth gradual tapering contour necessary for complete cleansing and obturation. It is also that phase in which the clinician may lend artistic value to the carving and is connoted by his individual signature.

The final phase of preparation is dedicated to finishing or polishing the walls and refining the apex. This phase is saved for last, because it is perhaps, the most critical phases of treatment. It can only be accomplished after restrictive tooth structure has been removed. Only fine files are used to smooth the walls and to gently enlarge the apical foramen. Generally, only K-type files are employed. Although larger sizes are used to refine and smooth the upper parts of the preparation, only the smallest sizes are used to enlarge the apical foramen. These instruments must be manipulated delicately to avoid over enlargement or transportation of the apex. The final phase is termed finishing and apical refinement and immediately precedes compaction (Figs. 16.15 A, B)

A

B

Fig. 16.15. **A**, **B**. Two maxillary first bicuspids demonstrating the complexities of the endodontic cavity space and the necessity of three-dimensional cleaning, shaping and obturation (Scianamblo, 1992).

Initial access and gross debridement

As previously mentioned, the access cavity is created to provide visibility and unimpeded flow of instruments to the confines of the root canal system. Access is initiated with high speed round burs, preferably number 1 or 2. An opening is made through the enamel and dentin penetrating the roof of the pulp chamber. No attention is given to the occlusal anatomy or previous restorations. Instead, the objective is to extend the opening to include the entire pulp chamber, obliterating the pulp horns and providing a slight divergence occlusally. Generally, greater advantage can be gained by removing tooth structure on the pull stroke, using the outer perimeter of the roof of the chamber and the pulp horns as a guide (Fig. 16.16). The walls of the access cavity can then be straightened and smoothed using tapered diamond burs again creating a slight divergence occlusally and attempting to define the initial outline of the finished preparation (Fig. 16.17).

The chamber is then irrigated. Irrigation is conducted using high volume syringes containing at least a 2.5% solution of sodium hypochlorite. The irrigating solution is expelled from the syringe into the canal using gentle pressure while being suctioned away simultaneously. The needle of the syringe should never be inserted forcibly or locked in the canal (Fig. 16.18). Gross debridement may then be carried out using barbed broaches. A wide selection of broaches should be available to provide an instrument that will impale and bind the bulk of the pulpal mass without binding on the walls of the canal appreciably. The broaches should be precurved to conform to the architecture of each canal and then gently manipulated apically, until the instrument meets resistance. The instrument is then turned slightly to engage the pulp and withdrawn carefully.

After the pulp has been removed, the chamber is again irrigated with sodium hypochlorite and the irrigant is allowed to pool in the chamber forming a reservoir. This reservoir of irrigant is maintained throughout endodontic cavity preparation and acts to provide continuous floatation of debris (Fig. 16.19). The use of pre-endodontic restorations and bands are encouraged to establish and maintain the reservoir of irrigant. Sodium hypochlorite in at least a 2.5% solution alone has been demonstrated to be the most efficacious irrigating medium available. It acts, not only as an irrigant, but also as a potent antiseptic, an oxidizing agent and a lubricant. The irrigating solution should be exchanged repeatedly. No other procedure is more important to endodontic cavity preparation than copious and thorough irrigation. It is this procedure that provides the digestion and removal of organic debris within the secondary ramifications and permits the flow of filling material to these areas (Figs. 16.20 A-C).

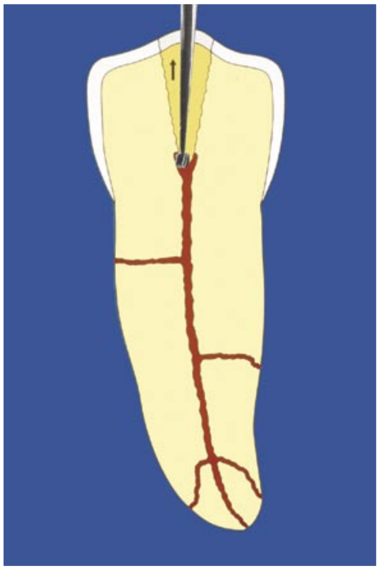


Fig. 16.16. Initial access is made with high speed round burs, preferably numbers 1, 2 or 4. An opening is made through the enamel, dentin, and the roof of the pulp chamber. Generally, a greater advantage can be gained by removing tooth structure on the pull stroke, using the outer perimeter of the roof of the chamber and the pulp horns as a guide (Scianamblo 2004).

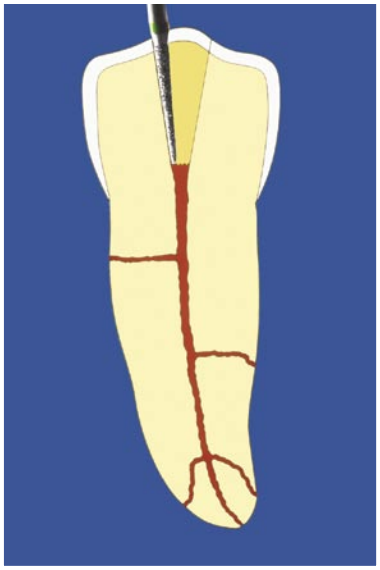


Fig. 16.17. The walls of the access cavity are smoothed and straightened with a tapered diamond bur creating a slight divergence occlusally and attempting to define the initial outline of the finished preparation (Scianamblo 2004).

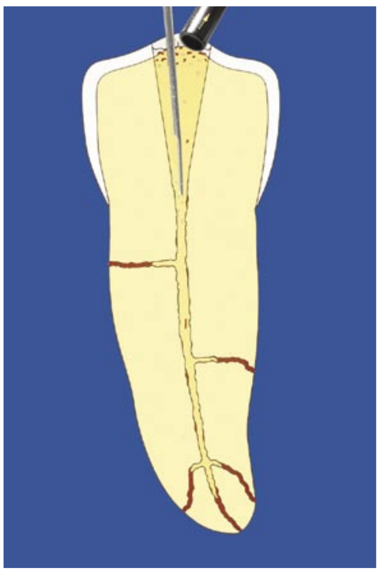


Fig. 16.18. Irrigation is conducted using high volume syringes containing at least a 2.5% solution of sodium hypochlorite. The irrigating solution is expelled from the syringe into the canal using gentle pressure while being suctioned away simultaneously. The needle of the syringe should never be inserted forcibly or locked in the canal (Scianamblo 2004).

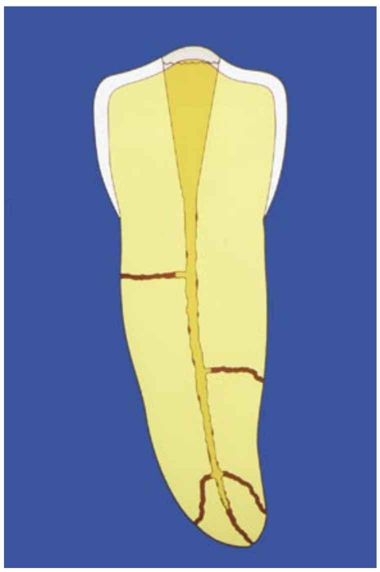
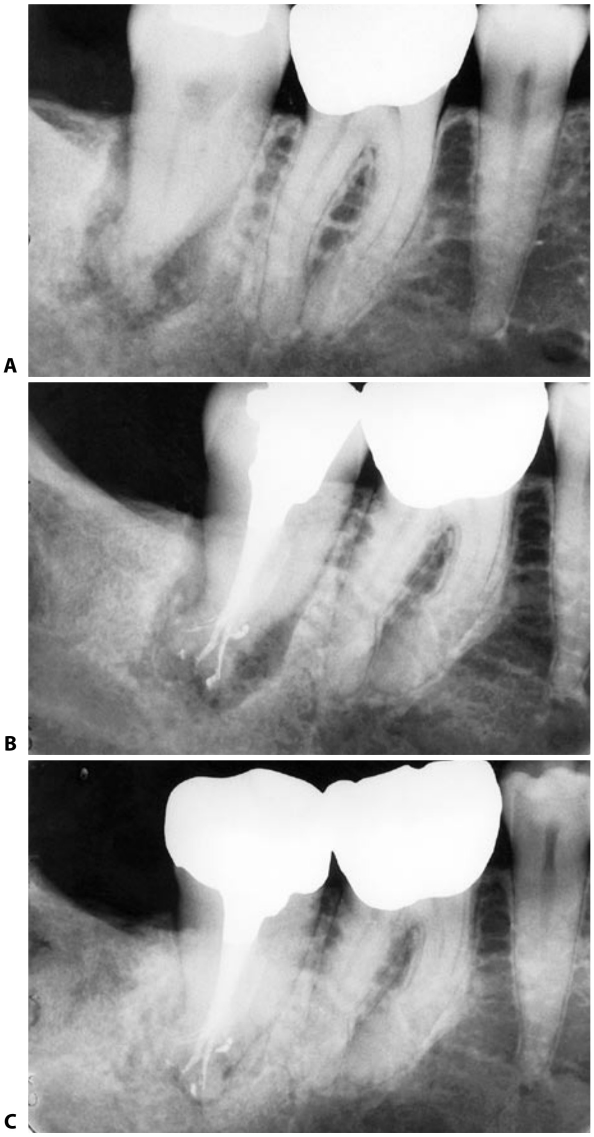


Fig. 16.19. After the pulp has been removed the chamber is again irrigated with sodium hypochlorite and the irrigant is allowed to pool in the chamber forming a reservoir. This reservoir of irrigant is maintained throughout the cleansing and shaping procedure and acts to provide continuous floatation of debris (Scianamblo 2004).



Figs. 16.20. **A-C.** An endodontically treated lower second molar demonstrating multiple secondary ramifications that have been cleaned via sodium hypochlorite irrigation. The postoperative radiograph was taken after one year on a recall appointment (Scianamblo 2004).

Preliminary enlargement

An initial file may now be passed into the root canal system. The first instrument is not a working instrument, but a guide file that is used to explore the configuration of that system. The smallest instrument that can be accommodated by the system, without resistance, is now chosen. In many cases this file is very fine and may correspond to only a size 06 or 08. The instrument is precurved to mimic the pathway of the original canal and is gently manipulated in a watch winding motion as the system is being explored. The direction, angulations, and configuration of each curve should be carefully evaluated and recorded. A search for ramifications that cannot be detected by the radiographs should also be undertaken, and anatomic variations such as fins and cul-de-sacs should be noted.

If an obstruction is encountered, or if it is found that the apex is not easily negotiated, the initial file should be removed and the preliminary enlargement has begun.

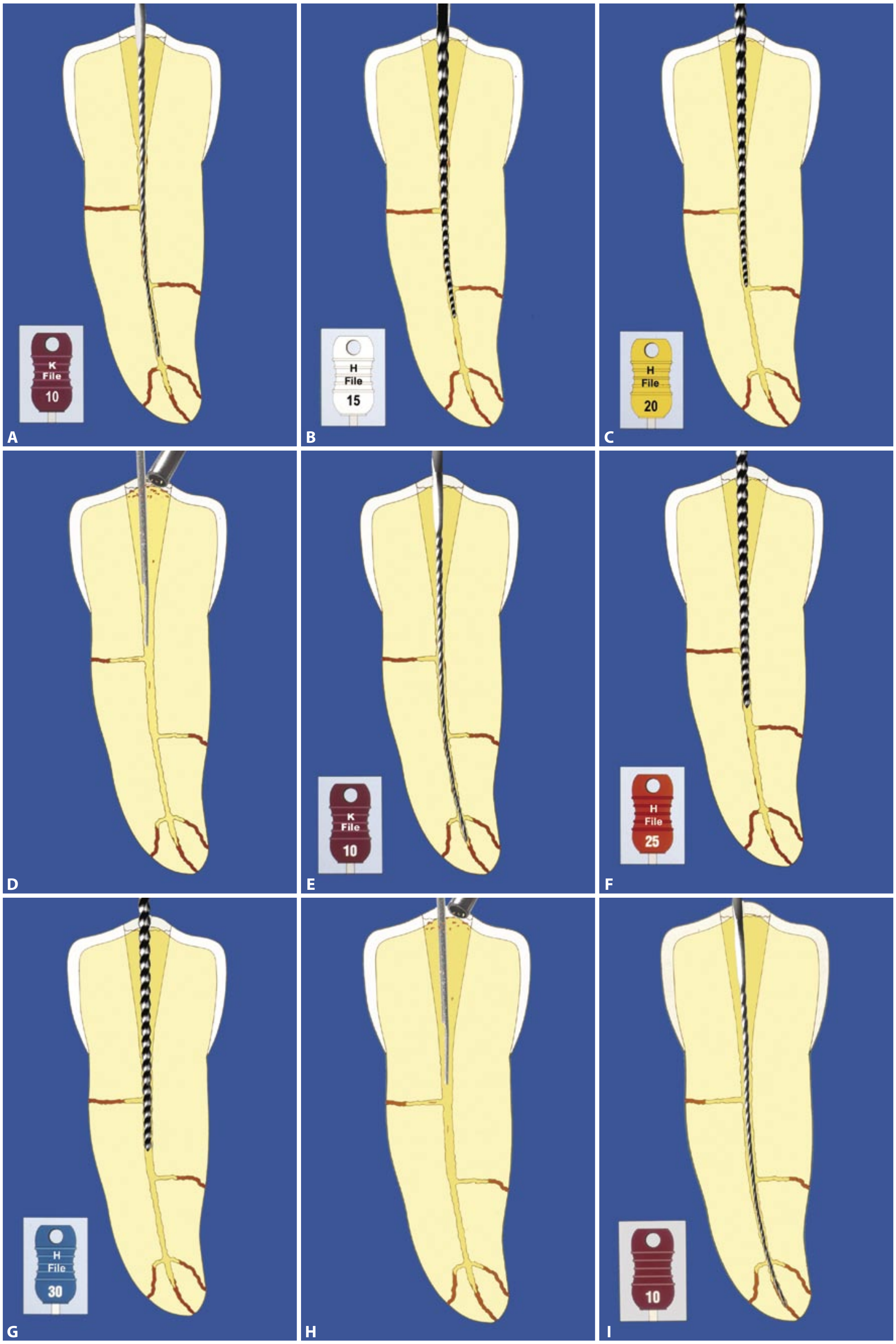
Even in instances where the initial file is easily accommodated, the preliminary enlargement will facilitate endodontic cavity preparation and is almost always undertaken. The attributes of the preliminary enlargement have been described above, the most important of which is to provide the freedom and control of instrument cycles and safe access to the apical region. As we have discussed, techniques that encourage forcible entry to the apex early in the preparation procedure, commonly result in obstructions and transportation, or more deleterious alterations such as ledges and perforations.

The preliminary enlargement begins by enlarging only the coronal third and middle third of the root canal system. A variety of techniques and instruments may be chosen. One of the most expedient methods that have been enlisted is rapid enlargement of the upper portion of the system using K-type or H-type files in a step-back modality until Gates Glidden drills can be accommodated. No attempt is made to carry instruments to the apex at this time. The instruments are simply delivered to the body of the system until they meet slight resistance and then worked in a filing motion enlarging the space coronal to point of initial resistance. An attempt is made, however, to begin to develop the continuously tapering shape that is required in the final preparation. In addition, the most direct access to the apex must be outlined.

Thus, emphasis is placed on removal of material from the outer wall of curvature or anti-curvature filing. Since tooth structure in the upper and outer portion of the curve of the root canal system is generally thicker, material can be removed from this area safely.

The sequence of instruments employed in this first phase of preparation would typically be 06, 08, or 10 files for the initial penetration; followed by copious irrigation; recapitulation with 06 or 08 and continued enlargement with10 through 30 or 35 files; irrigation; and recapitulation with 10 file (Figs. 16.21 A-I).

Gates Glidden drills can now be introduced. Utilization of these instruments can be safe and very



Figs. 16.21. **A-I**. Preliminary enlargement begins by enlarging only the coronal and middle third of the root canal system. No attempt is made to carry instruments to the apex during this phase of the procedure. The instruments are simply delivered to the body of the system until they meet slight resistance and then worked in a filing motion enlarging the space coronal to point of initial resistance. Every attempt is made, however, to begin to develop the continuously tapering shape. The sequence of instruments employed in this first phase of preparation would typically include: 10 through 30 K-files, accompanied by copious irrigation and recapitulation with a10-K file (Scianamblo 2004).

effective. The use of G-type drills without a pilot preparation similar to the one just described, however, can be extremely deleterious. As has been previously discussed, the G-type drill usually has a non-cutting tip to prevent perforation. The use of this instrument without preliminary enlargement, however, often results in ledging. Because these instruments are not flexible, they should only be used in a straight line. The instrument is carried to the body of the system using a push-pull motion and allowed to work apically until it meets with resistance. The smallest drill that engages tooth structure is chosen as the initial drill and is followed by the next largest size. The drills should be used sequentially and in a step-back modality and the cutting emphasis is on the outer walls of curvature. The sequence, as well as the frequency with which each drill is used, can vary with the complexity of anatomy of each system.

This phase of preparation would typically include 1, 2, 3, 4, 5, or 6 G-type drills, followed by copious irrigation and recapitulation with the initial file (Figs. 16.22 A-F).

An alternative to the use of the Gates Glidden drills during preliminary enlargement is the use of nickel-titanium rotary instruments. Although there is a multiplicity of choices, instruments that are designed for this purpose, and which are completely safe, are the instruments of Critical Path Technology.

These instruments display a reserve helix and broad progressive flute pitchmaking them ideal for pre-en-

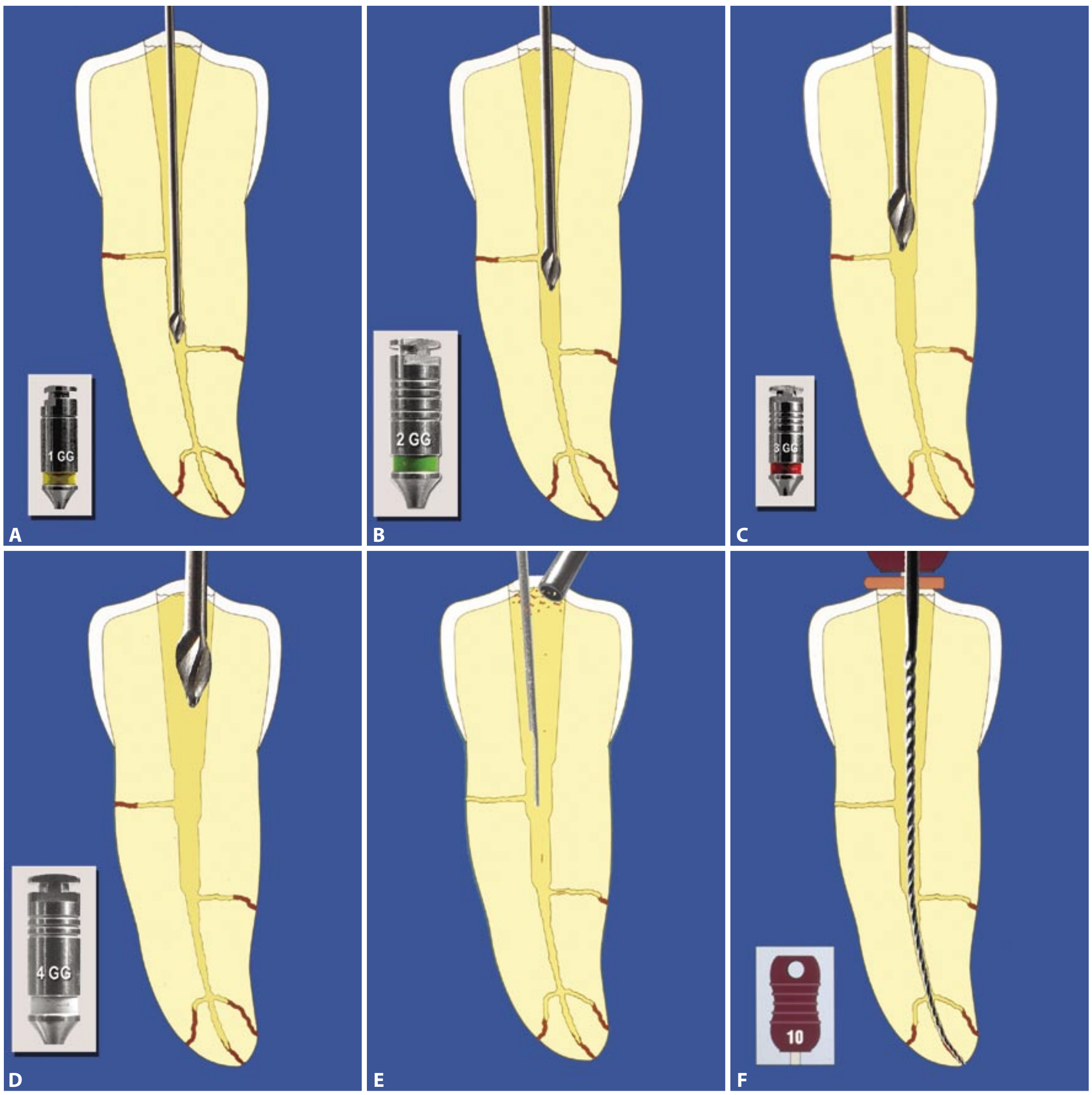


Fig. 16.22 **A**-**F**. Gates Glidden drills can now be introduced safely and effectively following the pilot preparation created with files coronally. This instrument should only be used in a straight line with emphasis on the outer walls of curve. The instrument is carried to the body of the system using a push-pull motion and allowed to work apically until it meets with resistance. The smallest drill that engages tooth structure is chosen as the initial drill and is followed by the next largest size. The drills should be used sequentially and in a step-back modality. This phase of preparation would typically include: 1, 2, 3, 4, 5, or 6 G-type drills accompanied by copious irrigation and recapitulation a 10 K-file (Scianamblo 2004).

largement. There are six instruments in the sequence, The most useful instruments are the 16/.05, 18/.06, 20/.08 and 22/.10 taper (Figs. 16.23 A-D). Utilization of instrument sequences of variable or progressive tapers may also be useful since they do not have the same predisposition to bind in the canal. One example of this instrument is the Protaper, which is also marketed by Tulsa Dental Products and by the Maillefer Company. The instruments that are the most useful for preliminary enlargement are the SX (19 tip with 3.5%-20% taper), S1 (17 tip with 2.0%-11.0% taper), and S2 (20 tip with 4.0%-11.5% taper). These instruments are also deemed to be more efficient cutting instruments since they do not have radial lands. These instruments should be used progressively from smallest to largest in a step-back modality until a pilot preparation is firmly established. Because these instruments are super flexible, they may be carried around curves; however, negotiation of severe curves should be avoided.

Following preliminary enlargement of the upper portion of the system, access to the apical third, or the foramen, is usually unimpeded. If the smallest instruments still cannot penetrate the apex freely, the instrumentation sequence outlines above must be repeated. This is particularly common in systems with more complex anatomy, such as those with marked constrictions, dilacerations or complex bends. Further expansion of the coronal and middle thirds, including expansion of the upper part of the apical third may be required. This completes the preliminary enlargement.

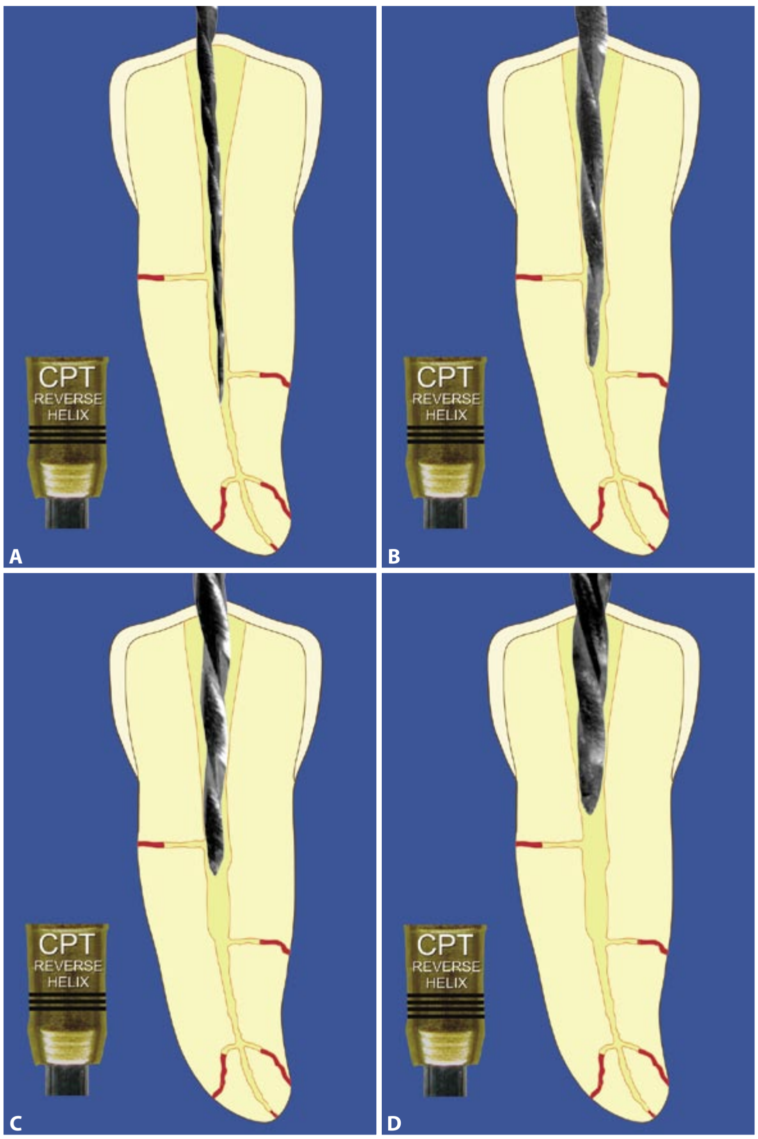


Fig. 16.23 **A-D**. An alternative to the use of the Gates Glidden drills during preliminary enlargement is the use of nickel-titanium rotary instruments. Although there are a multiplicity of choices, instruments that are designed for this purpose, and which are completely safe, are the instruments of Critical Path Technology. These instruments display a reverve helix and progressive flute pitch making them ideal for pre-enlargement. There are six instruments in the sequence. The most useful instruments are the 16/.05, 18/.06, 20/.08 and 22/.10 taper (Scianamblo, 2005).

Establishment of patency

The preliminary enlargement may now permit unimpeded access to the apical third with negotiation of the apical foramen. Patency should be established and checked using only passive strokes with the smallest and most delicate instruments. These instruments will often require significant precurvature to negotiate the foramen and the complex bends that often occur in this region. Again, in many cases, these instruments correspond to only the smallest sizes, 06, 08 or 10. There is no attempt to enlarge the apical foramen at this time (Fig. 16.24).

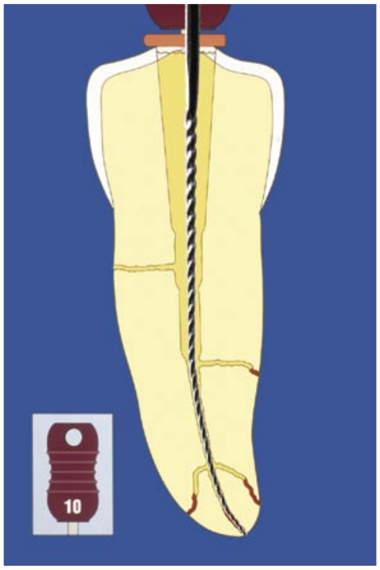


Fig. 16.24. The preliminary enlargement will now permit unimpeded access to the apical third and the foramen can be negotiated. Patency should be established and checked using only passive strokes with the smallest and most delicate instruments. These instruments will often require significant precurvature to negotiate the foramen and the complex bends of this region. Again, these instruments may correspond to only the smallest sizes 06, 08 or 10. No attempt is made to enlarge the foramen at this time (Scianamblo 2001).

Enlargement

Enlargements of the apical third of the canal and continued enlargement of the middle and coronal thirds can now ensue, establishing the rough configuration and shape of the endodontic preparation. The work will take place primarily in the middle and apical thirds since the coronal third has already been expanded via the pre-enlargement step. The enlargement procedure is usually the phase that requires the most time, since the most dramatic curvatures of a root complex, or the greater curvature, usually occur in the middle and apical thirds. There are a myriad of techniques that may be employed in this phase. Consideration, however, should be given to two specialized instrumentation procedures. These procedures are designed for rapid removal of tooth structure, while keeping the preparation well centered. The procedures are:

1. balanced force methodology or a combination of DeDeus and balanced force methodology
2. crown-down methodology using Nickel-Titanium rotary instruments.

When balanced force methodology is employed, a pilot opening is always required. This can be accomplished via the pre-enlargement procedure already discussed. Only K-files are recommended for this procedure. They are utilized in sequence from the smallest instruments, usually 25, 30 or 35 to the largest instrument, usually 60, 70 or 80. A balanced forced technique or a combination of balanced force and DeDeus technique is used for each instrument carrying them to the apical extent of the preparation until resistance is meet. As the instruments increase in size, they are stepped out of the preparation to continue to develop the continuously tapering shape that is required. The apical 1-2 mm of the preparation should be avoided to eliminate the possibility of transportation.

In balanced force or DeDeus methodology, the elastic memory or restoring force of the instrument, is pitted against dentinal resistence. The restoring force of the instrument, then, becomes a useful tool and should be preserved. Pre-curvature of instruments, therefore, is not always necessary or recommended. Naturally, copious irrigation and recapitulation should be included during this phase of treatment (Figs. 16.25 A-G).

Nickel-Titanium rotary instrumentation may also be employed during the enlargement phase. As previously mentioned, many of these instruments must be used with caution, since they are predisposed to spontaneous fracture, and cannot be retrieved or bypassed easily. Safe use of these instruments requires a pre-enlargement phase similar to the one already described. Utilization of handpieces that control speed and torque are also helpful. When these instruments are used, they are usually used in sequence from largest to smallest, i.e., in a crown-down fashion. Generally, the sequence must be repeated at least twice, because these instruments do not display the sharpness of stainless steel, and because many of these instruments display thick radial lands and negative rake angles. Examples of these are the

Profile and Profile GT instruments by Tulsa Dental Products. Newer instruments with sharp leading edges and neutral or positive rake angles may be preferable, especially those with safety nuances such as a reverse helix. Examples of these instruments are those of the CPI series or Critical Path Technology.

Again, the engagement phase should not begin until a pilot open or preparation is established also known as pre-enlargement. Further, due to the predisposition of nickel-titanium instruments to fail, and the safety of hand instruments, addition enlargement should be considered using hand instrument in a balanced force and/or oscillatory movement, before the use of rotary instruments. When the profile sequence of instruments is chosen, they are used in a crown-down methodology from size 40/.06 to 20/.06 or 25/.06. An alternative instrument is the Profile GT or instrument of Greater Taper. This is particularly useful in anterior teeth and bicuspid teeth with reasonably large and/or straight roots. The sizes of the instruments vary from 20/0.06 to 50/0.12 and again are used in a crown-down modality. Although rotary instrument of other designs and tapers are available, they may be too narrow or too predisposed to fracture to be considered useful. Most of the instruments that are currently available have a parabolic tip to keep the instrument well centered minimizing ledging and perforations (Figs. 16.26 A-L).

To further minimize instrument failure, these instruments should be used in pecking or push-pull motion. Furthermore, working the instrument in a static or stationary position will create eccentricities in

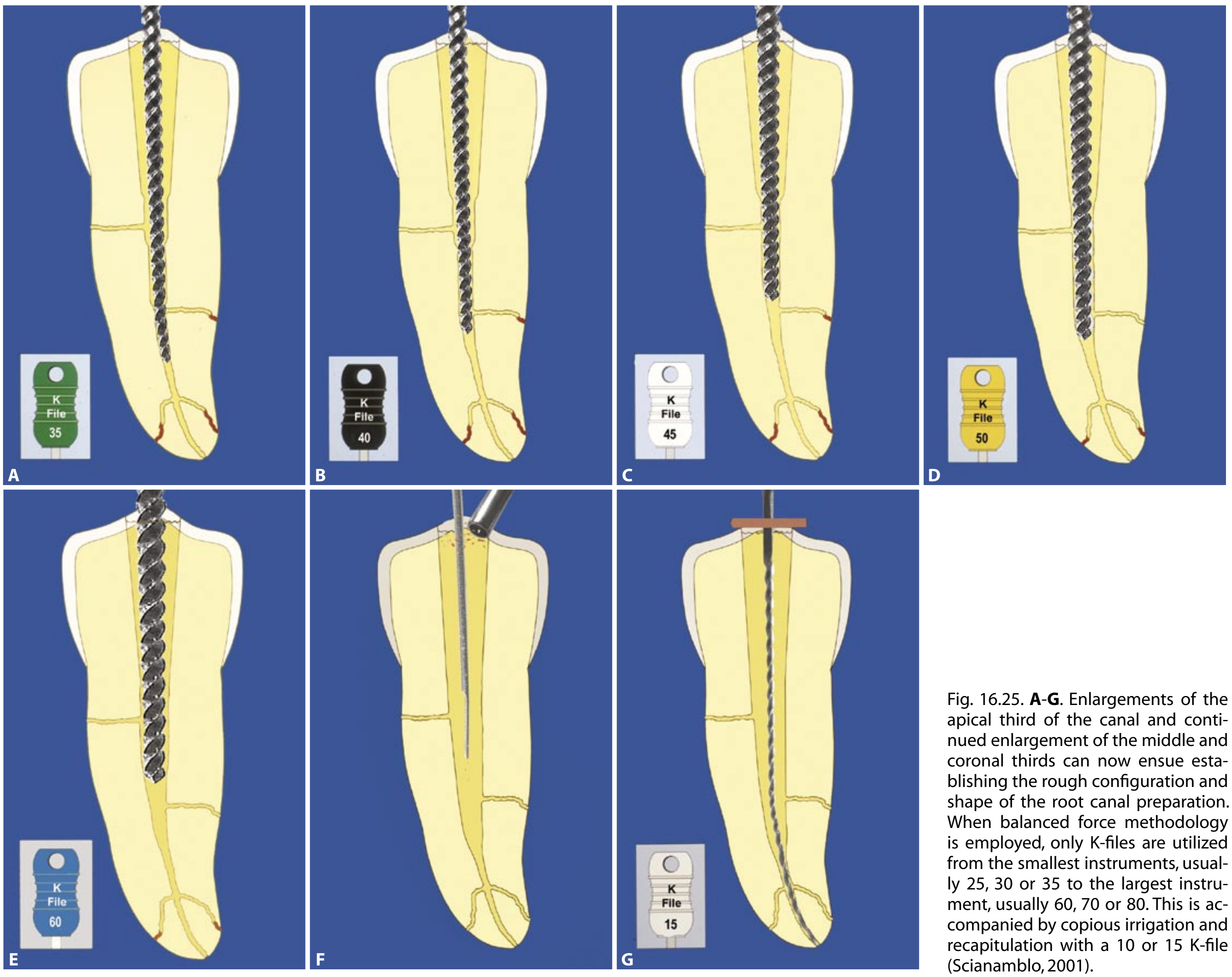


Fig. 16.25. **A**-**G**. Enlargements of the apical third of the canal and continued enlargement of the middle and coronal thirds can now ensue establishing the rough configuration and shape of the root canal preparation. When balanced force methodology is employed, only K-files are utilized from the smallest instruments, usually 25, 30 or 35 to the largest instrument, usually 60, 70 or 80. This is accompanied by copious irrigation and recapitulation with a 10 or 15 K-file (Scianamblo, 2001).

the preparation rapidly. Again, care should be taken to avoid the apical 1-2 mm to prevent transportation of the foramen. The instruments, therefore should be allowed to revolve while penetrating the canal until they meet resistance and then withdrawn. As previously mentioned, the use of speed and torque controlled handpieces is also recommended. Further, the instruments should be inspected frequently to identify tortional fatigue and/or failure. Moderate usage and frequent disposal is mandatory.

The expansion and basic design of the preparation is now complete. However, the walls must still be smoothed and evened, and the final contoured must be inscribed.

Blending

During this phase of preparation, effort is directed toward development and perfection of the continuously tapering shape. This shape occurs via a marriage of the apical, middle, and coronal thirds of the preparation, which have been expanded via the pre-enlargement and enlargements phases. This is called blending. This can be a laborious portion of the preparation, if preliminary enlargement or enlargement is inadequate. Judicious employment of the techniques described in those sections, simplify this procedure greatly.

The continuously tapering shape is paramount to endodontic success; thus, it must be executed with precision. A variety of instruments and techniques may be utilized for this procedure. It is the clinician's personal preference that often defines the final contour and so called signature of the preparation. It has been the experience of the author that filing in a step back modality is ideally suited for this phase of the procedure. Great control over the direction and flow of the instruments can be achieved, leading to perfectly tapered preparations. Regardless of the methodology that is chosen, emphasis is placed on direct access to the apex with the removal of material from the outer walls of curvature or anti-curvature filing. This part of the preparation is often accomplished with Hedstrom files; K-files, however, may be used.

Files are passed into the apical third of the preparation, but coronal to the apical foramen. Beginning with the smallest file that meets resistance, the files are used in a push-pull fashion. As the instruments increase in size, they are stepped-back to engender the tapering shape. The sequence of instruments may be large or small in number, depending on the complexity of the anatomy of the system. In severely dilacerated systems or systems with complex bends, large sequences of instruments, and multiple repetitions may be required. Precurvature of instruments is of particular importance during this phase of preparation. The bulk of tooth structure continues to be removed via the outer walls of curvature. The long axis of the stroke of the file is continuously altered to develop the final shape or character of the preparation.

This phase of preparation would typically include 25, 30, 35 40, 50 or 60 file. Larger canals may require

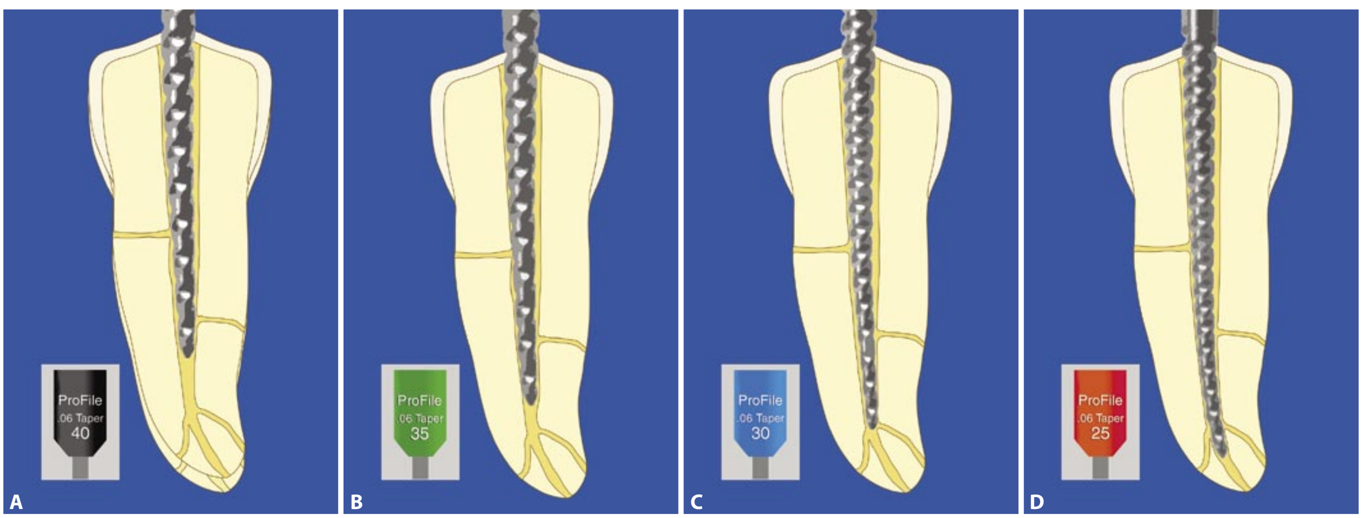


Fig. 16.26. **A**-**D**. Nickel-Titanium rotary instrumentation may also be employed during the enlargement phase (Continued).

even larger instruments. Copious irrigation and recapitulation with 15 or 20 K-files is required. If the clinician is not satisfied with the contour, the sequence can be repeated. Alternating a sequence of even numbered files with odd number files can also be useful (Figs. 16.27 A-H).

The preparation is now essentially complete with the exception of the apical finishing and refinement.

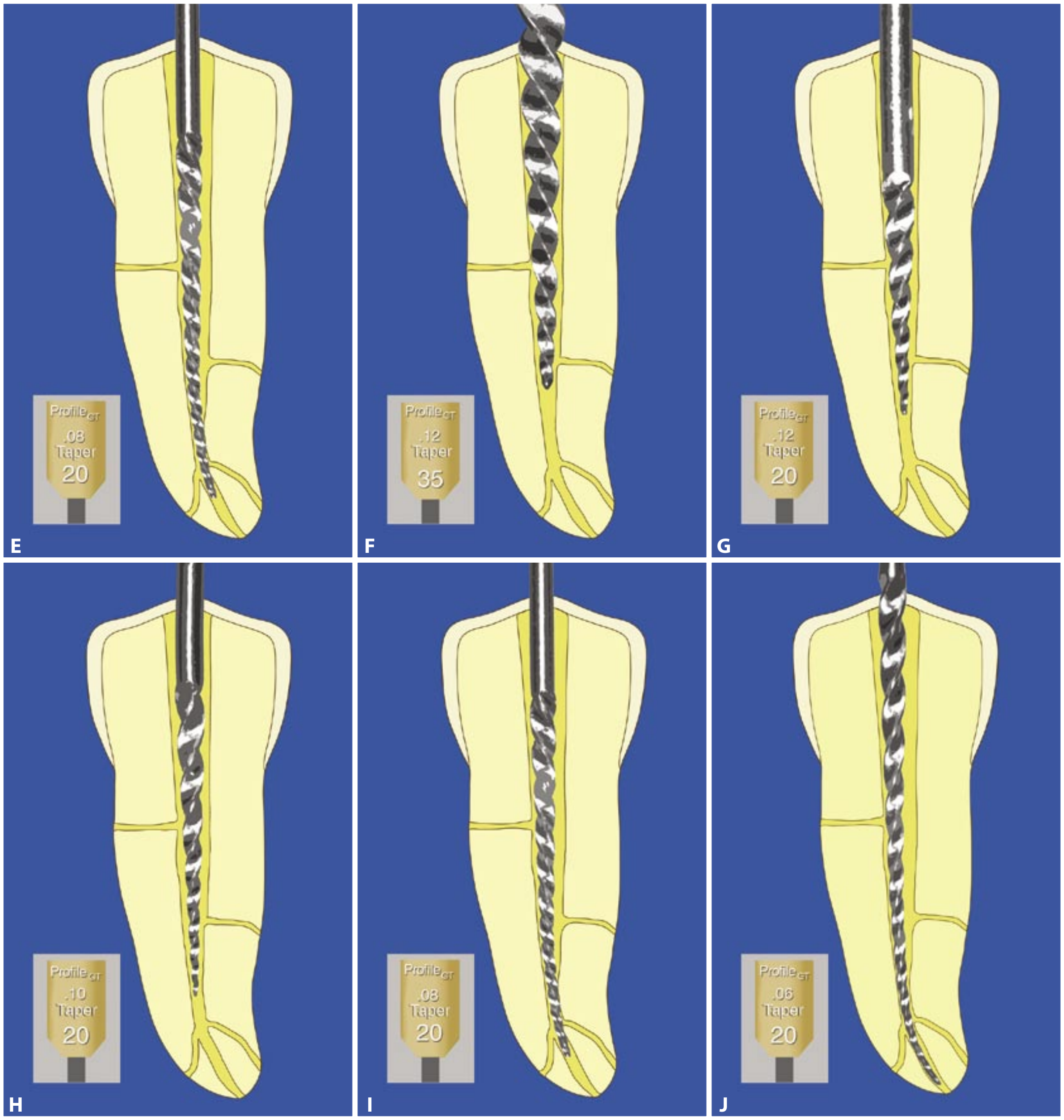


Fig. 16.26. **E-J**. (Continued) Safe use of these instruments requires a pilot preparation or pre-enlargement phase similar to the one already described. Utilization of handpieces that control the speed and torque are also helpful. When they are used, they are usually used in sequence from largest to smallest, i.e., in a crown-down fashion. Generally, the sequence must be repeated at least twice, because these instruments do not display the sharpness of stainless steel, particularly those with radial lands. The Profile or Profile GT designed by Tulsa Dental Products are examples. The sizes of the Profile that are useful vary from 15/0.06 to 40/0.06. These instruments are particularly well suited for long, narrow and tortuous canals. The sizes of the Profile GT that are useful vary in size from 20/0.02 to 50/0.12. These instruments are well suited for larger root complexes, particularly anteriors and bicuspids These instruments should be used in a push-pull motion and care should be taken to avoid the apical 1-2 mm to prevent transportation of the foramen (Scianamblo, 2004).

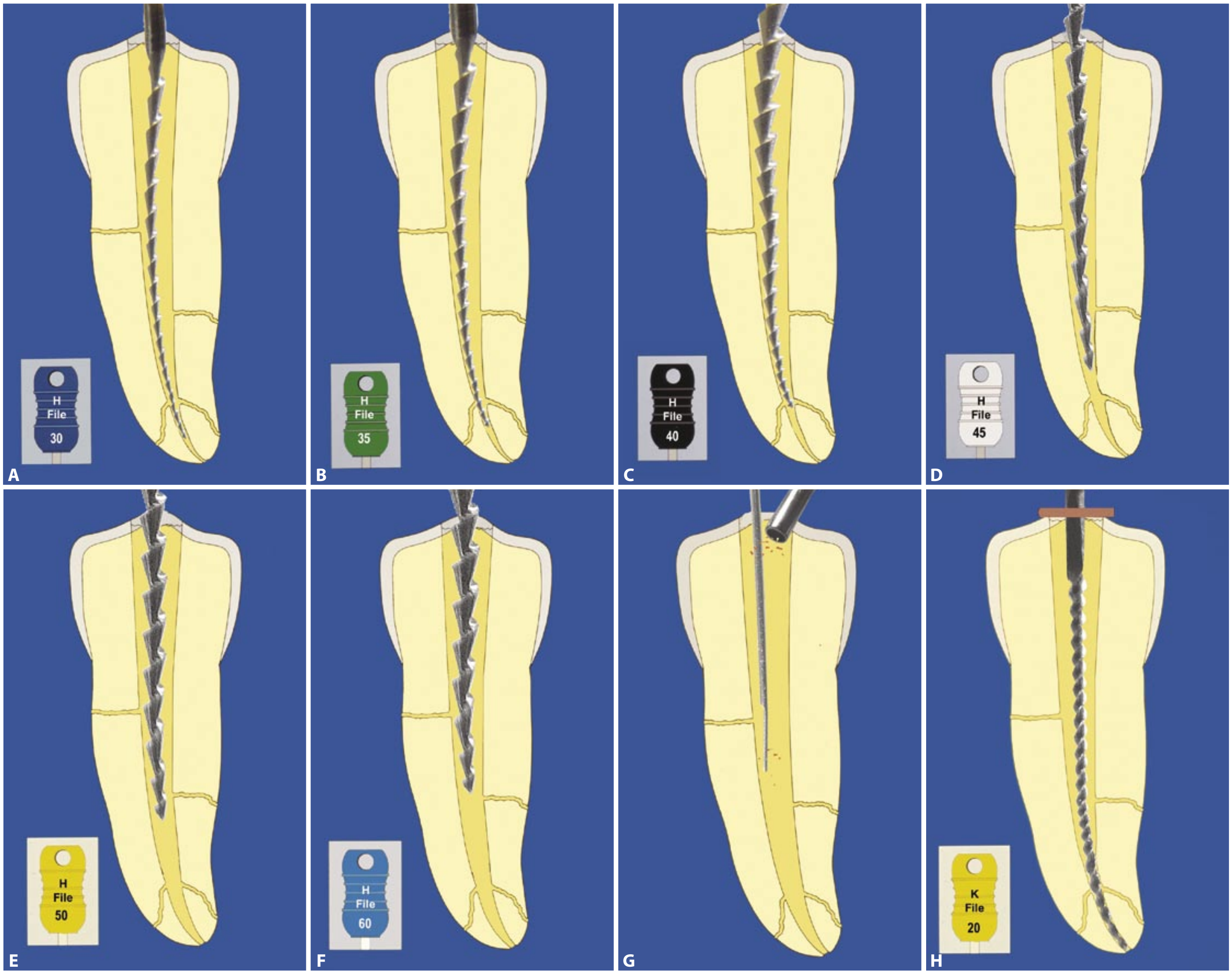


Fig. 16.27. **A**-**H**. During the blending phase of preparation, effort is directed toward development and perfection of the continuously tapering shape. This shape occurs via a marriage of the apical, middle, and coronal thirds of the preparation, which have been expanded via the pre-enlargement and enlargements phases. A step back filing using push-pull strokes is ideally suited for this phase of the procedure. Emphasis is placed on direct access to the apex with the removal of material from the outer walls of curvature or anti-curvature filing. This part of the preparation is often accomplished with Hedstrom files, however, K-files may be used. This phase of preparation would typically include 25, 30, 35 40, 50 or 60 file. Copious irrigation and recapitulation with 15 or 20 K-files is required (Scianamblo 2001).

Apical finishing and refinements

During this phase of the preparation, the walls should be checked for smoothness to insure patency and the flow of material to the apex during compaction. If possible, the apical foramen should be opened to 20 or 25 file. If the apical region is unyielding and risk of transportation is imminent, a smaller size will suffice. Enlargement of the foramen should be considered safe, however, since considerable access and freedom has been created by the removal of resistive coronal tooth structure. The resultant preparation should now fulfill all the requirements previous ascribed to an ideal preparation and lend itself to the complete obturation of the endodontic cavity space (Fig. 16.28).

Enlargement and blending is continued until a # 45 file or a # 8 or 9 Schilder plugger can be accommodated freely within approximately 5 mm of the foramen (Figs. 16.29 A, B).

The advent and use of the operating microscope, nickel-titanium instruments and computer-controlled handpieces has greatly enhanced our technical ability in endodontic cavity preparation. The clinician, howe-

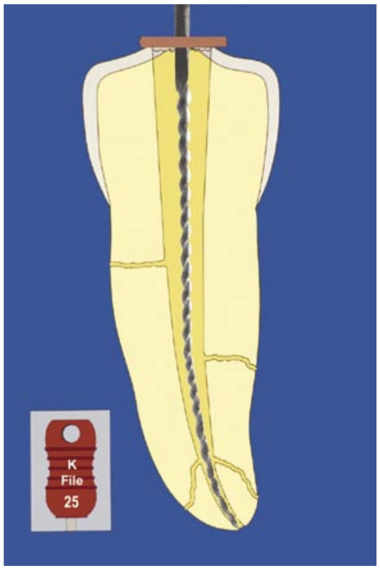
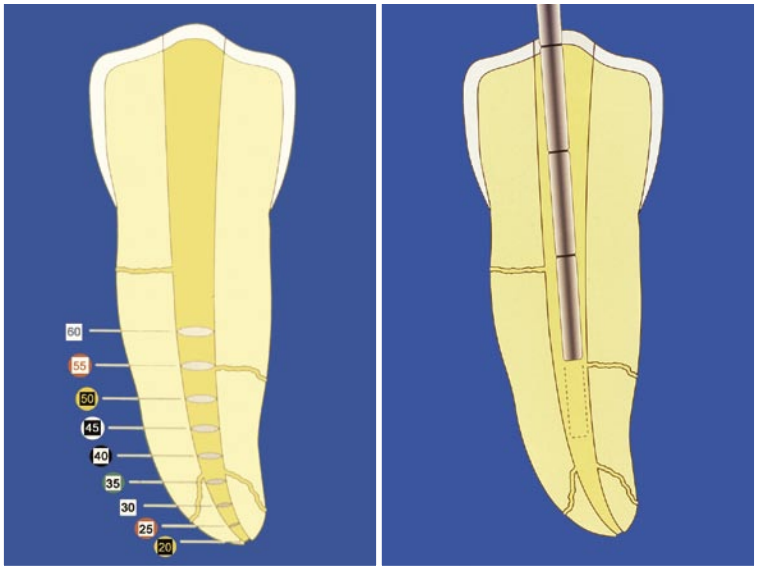


Fig. 16.28. The endodontic cavity preparation has been finished and the apical foramen refined. Ideally a 20 or 25 K-file can negotiate the foramen passively. The resultant preparation should now fulfill all the requirements previous ascribed to an ideal preparation and lend itself to the complete obturation (Scianamblo 2004).



A B

Fig. 16.29. **A**, **B**. Enlargement, blending and finishing has continued until a 45 file or a no. 8 or 9 Schilder plugger fits within 5 mm of the apical foramen (Ruddle and Scianamblo 1992).

ver, must still rely on his knowledge and clinical experience, and on his tactile sensations as he manipulates endodontic instruments within the canal. As this knowledge, experience and skill is applied, the clinician should, not only fulfill the requirements for the ideal root canal cavity preparation, but render an artistic sculpture that is unique, engraved by his own "signature".

SUMMARY

Earlier investigations and philosophies emphasized the complexity of endodontic systems. This, in combination with the theory of focal infection, undermined the development of endodontics until the middle 1900s. The apparent success achieved with rudimentary approaches to endodontic therapy encouraged a measure of complacency about endodontic technique until recently.

Endodontic failure and the concomitant frustration with inadequate endodontic delivery systems have prompted considerable expansion of endodontic concepts up to the present time.

This chapter attempts to eradicate that complacency and endorses an endodontic delivery system that is both efficient and effective. A different approach to endodontic cavity preparation, which is indispensable to endodontic success, has been discussed. This approach is an extrapolation of previous methodology in addition to some new ideas.

The requirements for ideal endodontic preparations are outlined. They include complete access, a continuously tapering shape, maintenance of the original anatomy, and conservation of tooth structure. The materials and methods that are employed in the delivery are also discussed. Finally, a detailed discussion of the procedure itself is elaborated. This procedure is outlined in six sections using some new terminology. They are initial access, preliminary enlargement, establishment of patency, enlargement, blending, and apical finishing and refinement.

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17

Curved Canals

ARNALDO CASTELLUCCI

Numerous studies of the anatomy of the root canal system have abundantly demonstrated that they are rarely straight and that even when they do appear so by intraoral radiography, in reality they almost never follow the linear direction suggested by their two-dimensional radiographic image. The upper lateral incisors, which according to Ingle[10] have the second highest failure rate of all the teeth of the two dental arches, very often have a palatally-directed curvature in the apical third; therefore, it is not appreciable radiographically. The mesiobuccal canal of the lower first molars often has a curve directed distally, which can be appreciated radiographically, but a buccolingually-oriented curvature is also frequently concealed, as it cannot be demonstrated radiographically.

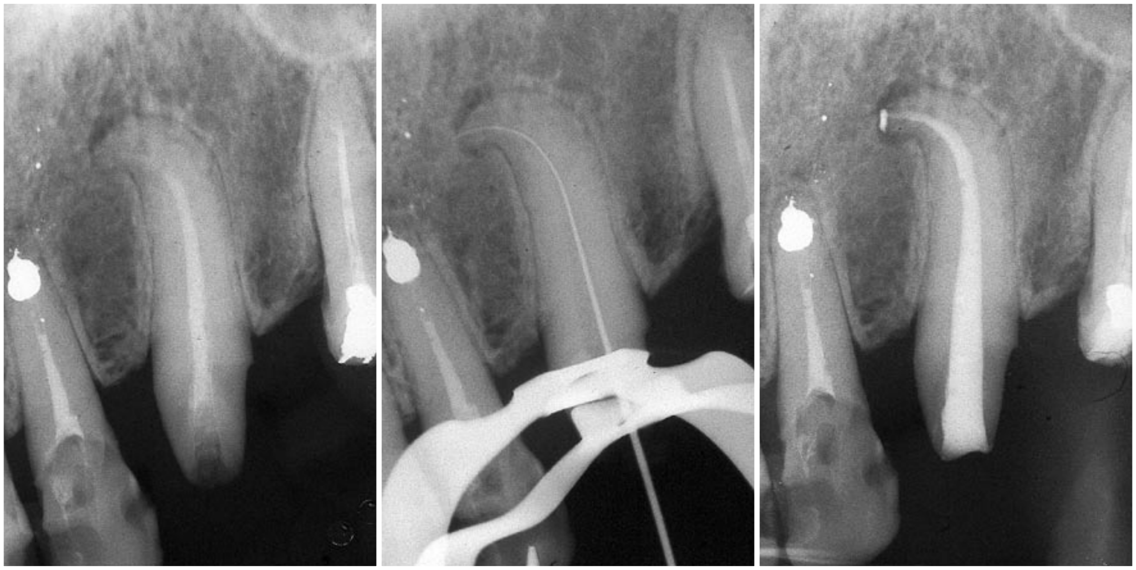
Almost all the canals, then, have curvatures on many planes. These curvatures should always be suspected, even when the radiograph fails to demonstrate them. They require care and attention, which will vary according to the site. One may distinguish curves of the apical, middle, or coronal third, each of which requires particular treatment. Even though the preparation of curved canals is much easier with the use of nickel titanium instruments, taking into consideration the fact that the suggested technique is a combined technique, using hand and subsequently rotary instruments, and also considering that sometimes the apical curvature can only be prepared with stainless steel hand instruments, for all these reasons it is still useful to discuss the hand preparation of curved canals.

CURVES OF THE APICAL THIRD

These curves must be absolutely respected and never straightened, even minimally (Figs. 17.1, 17.2, 17.3). Straightening these curves would mean displacing the apical foramen from its original position and altering its shape. This is an extremely serious error that will lead to certain treatment failure. Displacement of the apical foramen leads to three errors: first, "direct perforation", which occurs when a straight, large-size instrument perforates the root surface at a point other than the anatomical foramen (Fig. 14.38); second, "ledges" or "false canals," which consist of the formation of a new canal which branches off tangentially to the original canal, but does not perforate the root (Fig. 17.4); and third, the creation of a "teardrop foramen" (Fig. 17.5), with all the complications associated with the obturation of such an apical orifice (see Chapter 14).

Preservation of the curve of the apical third is assured by always starting the cleaning and shaping of this segment of the root canal with small, precurved instruments, such as a # 08 or 10 K-type file. The precurvature should reflect the degree of apical curvature of the canal being treated (Fig. 15.2). The instrument should not be worked until the radiograph confirms that it is exactly at the radiographic end of the canal. Once this is verified, one may begin to work it, but always bathed in sodium hypochlorite, with small excursions of fractions of a millimeter. The small excursions serve to limit the precurved portion of the file to working in the curved portion of the canal and thus to preserve as much as possible the precurvature that it has been previously given. If instead one used large excursions, the precurved portion would pass alternately from the curved to the straight portion of the canal, and the instrument would lose its precurvature. It would straighten out, and, as noted above, this would predispose to transportation of the apical foramen.

Nonetheless, even if one is careful to use small excursions, the instrument tends to straighten out. It is therefore necessary to withdraw it from the canal pe-



A B C

Fig. 17.1. An upper left canine with an apical curve of about 90°, cleaned, shaped and filled according to the Schilder technique. **A**. Preoperative radiograph. **B**. Intraoperative radiograph. Note that, at the time of measurement of the working length the enlargement of the middle and coronal thirds of the canal had already been performed with the aim of achieving easier access to the apical curvature. Early enlargement of the coronal two-thirds of the canal is documented by the complete removal of old obturation material. **C**. Postoperative radiograph. Note the preservation of the position of the apical foramen.

A B C

Fig. 17.2. A lower left third molar with an apical curve of about 90° in the distal root. **A**. Intraoperative radiograph. **B**. Postoperative radiograph. **C**. Two year recall (Courtesy of Dr. M.J. Scianamblo).

riodically, clean it, and re-curve it before re-introducing it in the canal with the precurvature facing the canal curve.

If, in a canal of average difficulty and mainly straight, it is important never to advance to the next larger instrument if the instrument being used doesn't appear to be "lost" in the canal, it is more important still in the case of canals with curves of the apical third.

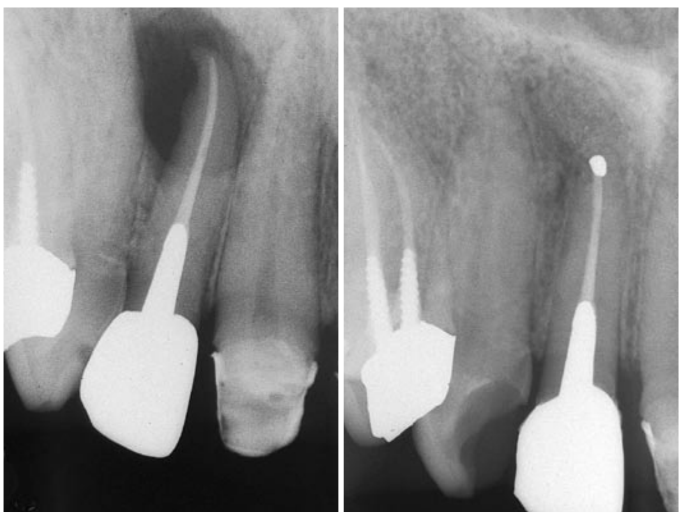
The small file will therefore be withdrawn several times, cleaned, re-curved, and re-introduced, each time renewing the irrigating solution, before advancing to a larger file. This will then be used according to the same principles, as will the files that follow. It is advisable, if not mandatory, to re-introduce the file immediately smaller before advancing to the next larger file (a # 20 in this example), to ensure that the apical curvature and its patency are maintained. This sequence, as proposed by Mullaney,[19] is illustrated in Tab. I.

In the case of canals curved in the apical third, the use of reamers is inadvisable.

By moving reamers within these curves, one may cause an unwanted "hourglass effect" (Fig. 15.3), with consequent enlargement and displacement of the foramen, apart from the risk of creating, most often in the external wall of the curve, notches and ledges that

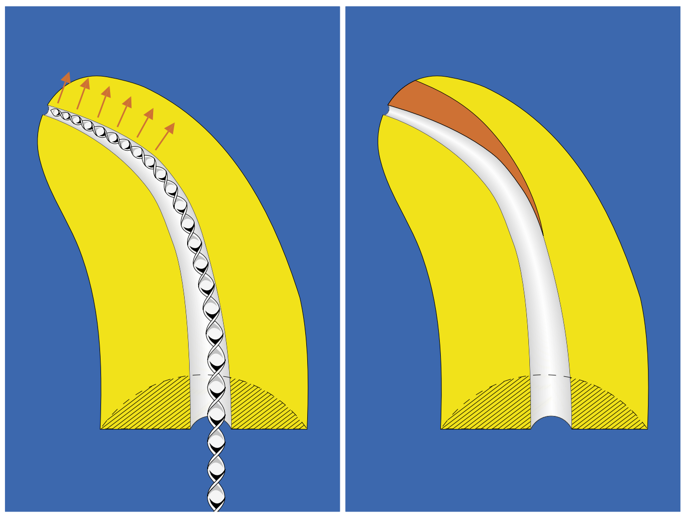
A B

Fig. 17.3. A lower left second molar with a curvature of the entire mesial root and a fairly marked apical curve in the distal root. **A**. Preoperative radiograph. **B**. Postoperative radiograph.



A B

Fig. 17.4. The use of straight instruments in the upper lateral incisors often leads to the formation of ledges or false canals, given the frequent distal or palatal curvature of the root. In these cases, surgery is often the only possible therapy. **A**. Preoperative radiograph. **B**. Three year recall after apicoectomy with amalgam retrofilling.



A B

Fig. 17.5. **A**, **B**. Because of their elastic memory, straight instruments introduced into a curved canal remove dentine particularly at the expense of the external wall of the apical curve, causing the formation of a teardrop foramen.

can complicate preservation of the apical curve.

Table I

Correct sequence of use of files in curved canals

File		
08		CONSTANT WORKING LENGTH
10	08	
15	10	
20	15	
25	20	

If one happens to create a ledge, so that the file no longer advances as before, one must not lose heart. The canal is still there, but it must be located. However, the instrument should certainly not be forced if it does not enter, nor should it be screwed into the canal, because this inevitably creates false canals or perforations, or fracture of the instrument.

Rather, one must start over again with the first small file (# 08 or # 10) which should be given a very short, accentuated apical precurvature (Fig. 17.6). The instrument must be introduced with the precurvature facing the same direction as the apical curvature. Once the original canal has been relocated (in which the file should descend without the least effort), the ledge can be eliminated using files in step back, with several recapitulations, with watch-winding movement or the balanced forces.

An easier and faster way to get the same result is today represented by the use of the hand GT Files.

Using an EndoBender plier, the nickel titanium Hand GT File can be gripped by the plier's clamp jaw, overbent to 180 degrees, and pulled firmly against the plier's bending fulcrum jaw. If we radically bend a nickel titanium file, we can overcome its shape memory and impart a lesser residual bend of 35 to 60 degrees, enough curvature to dance past a canal impediment (Fig. 17.7). At this point the bend is irrelevant so it can be used in a rotational manner without consequence, specifically the Hand GT *Reversed* Balance Force Technique (Fig. 20.15).[3]

The GT File is rotated counter-clockwise (the direction of the flute twists) until it snugs tightly into the canal, firm apical pressure is placed on the handle and it is turned 360 degrees in a clockwise direction. Initially the file progressively tightens and then, at about 180 degrees, it releases and turns easily, having made the dentinal cut. The file is then rotated further into the canal by again rotating it CCW, and then it is reversed in a CW direction with apical pressure for the 360 degree cutting stroke. Three of these engaging and cutting cycles are usually accomplished before removing the file to clean it. It is rebent, negotiated past the impediments and cut further into the canal.

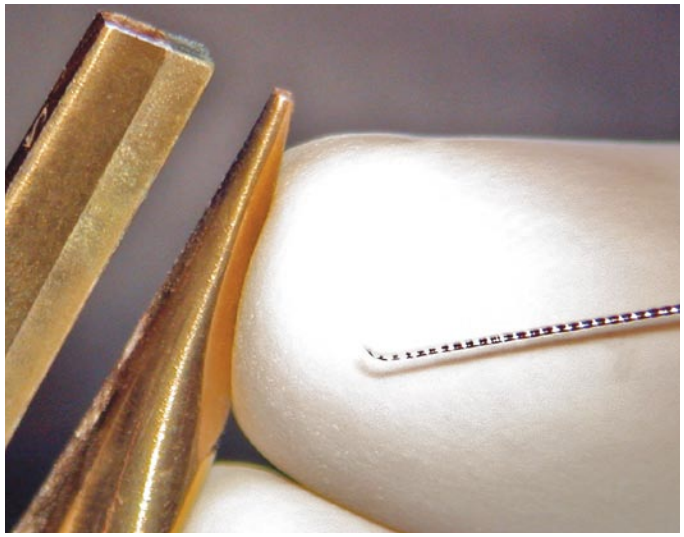


Fig. 17.6. EndoBender pliers with ideally curved #10 K-file. Note the smooth bend to the last flute, necessary when negotiating apical irregularities (Courtesy of Dr. L. S. Buchanan).

Fig. 17.7. Nickel titanium 20-.06 Hand GT File after significant radical bending to overcome its shape memory (Courtesy of Dr. L. S. Buchanan).

CURVES OF THE MIDDLE THIRD

These curves also must be respected and mantained to give a sense of "flow" to the canal obturation.

Partial straightening of these curves, which will be slightly blunted and smoothed at the end of the canal preparation, is nonetheless inevitable.

Double curves of the middle third or bayonet curves, which are among the most difficult to preserve, deserve special discussion (Fig. 17.8). They are fairly frequent in the upper and lower second premolars, where they are characterized, corono-apically, by the presence of a first curve directed mesially and a second directed distally (Fig. 17.9).

It is obvious that of these two curves the second must be absolutely respected, as straightening it would lead to displacement of the foramen. It is nonetheless important to maintain the first as much as possible to prevent thinning of the root which would be as damaging as it would be useless, as it would lead to lateral perforation or stripping (Figs. 17.10, 17.11).

To maintain and respect the second curve, namely the more apical one, it is necessary to observe all the rules stated above with regard to curves of the apical third.

To preserve and respect the first, more coronal curve, it is also necessary to follow other rules.

Obviously, all files must have a double curvature and must be introduced with the curves facing in the same direction as the canal. One will further have to work them with minimal excursions, so as not to straighten and, thus, enlarge the canal at undesired points.

Here it is also necessary to withdraw the file from the canal periodically, irrigate, repeat the precurvature of the instrument, and then re-introduce it, always orienting it properly.

A

B

C

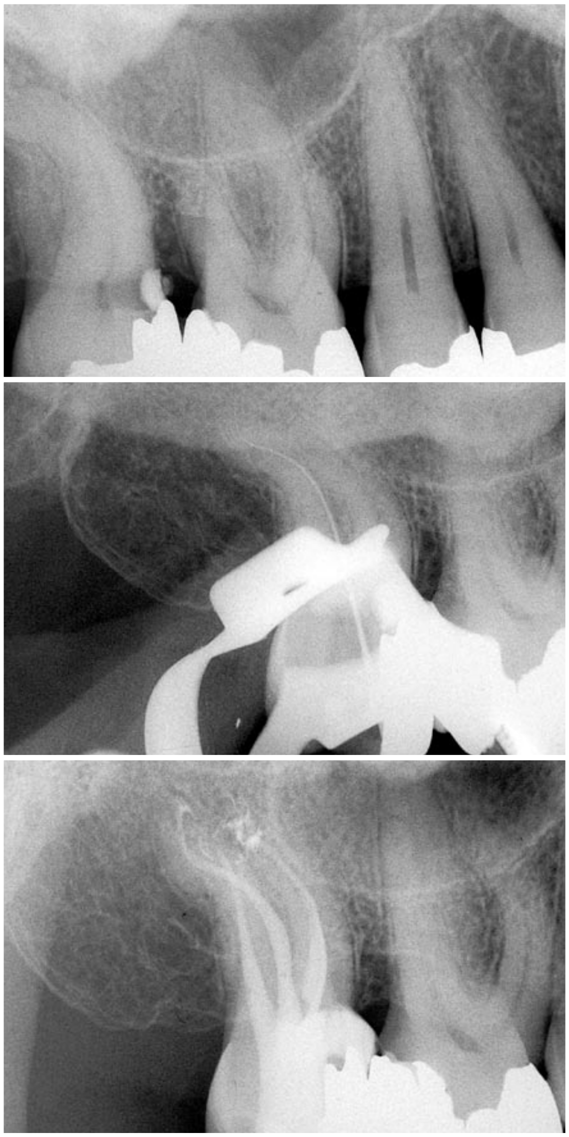


Fig. 17.8. An upper right second molar with a double bayonet curve in the palatal root. **A**. Preoperative radiograph. **B**. Intraoperative radiograph. **C**. Postoperative radiograph.

A

B

Fig. 17.9. An upper left second premolar with a double bayonet curve. Note, proceeding corono-apically, the first curve directed mesially and the second directed distally. **A**. Preoperative radiograph. **B**. One year recall.

Furthermore, beginning with a # 15 file, one can remove, for example with an Arkansas bur,[27] the cutting edges of the instrument from those points at which one does not want to work them: in this case, the distal part of the apical curve and the mesial part of the more coronal curve or, in other words, the cutting edges that correspond to the internal zones of the two curves (Fig. 17.12).

Obviously, this must be done without affecting the shaft of the instrument and thus without notching it, so as not to risk fracturing it within the canal.

Furthermore, it is once more necessary to perform small excursions and pay attention to the instrument's orientation at the moment of its re-insertion in the root canal. In this case also, the use of files is preferable to reamers.

The final result is certainly softer, slightly blunted curves, but they are still present and thus respected (Fig. 17.13).

The introduction of hand and rotary nickel titanium files made the preparation of the curves of the middle third and in particular of the bayonet curves a lot easier. The nickel titanium instruments, in fact, remain centered within the root canal while they work, removing dentin on 360°. The result is that they don't straighten the curvatures but they maintain them, assuring a better respect of the root canal anatomy (Figs. 17.14, 17.15).

Fig. 17.10. An upper left second premolar with a bayonet curve that has not been respected.

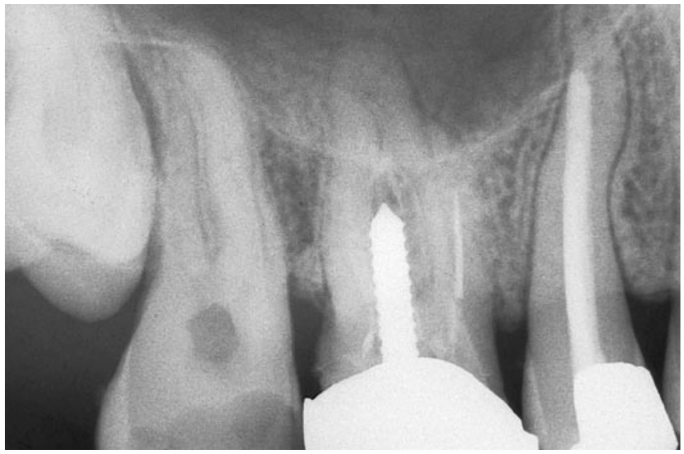
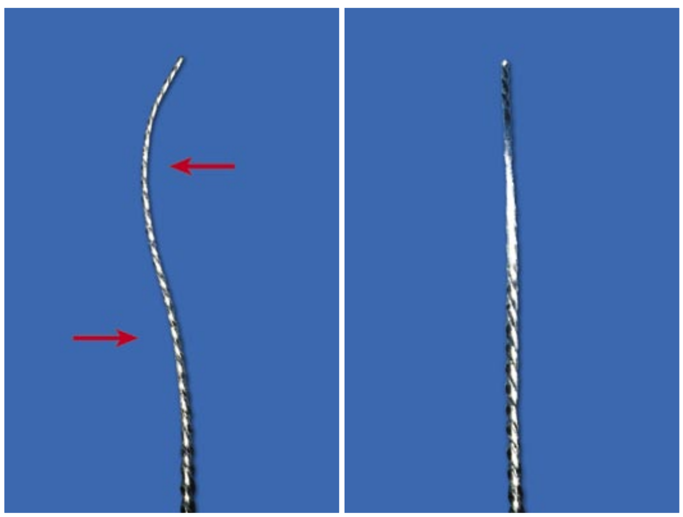


Fig. 17.11. The use of straight instruments in the case of bayonet curves consequently leads to internal transportation of the apical foramen (short obturation and in a false canal) and to excessive thinning of the internal zones of the two curves, with the possibility of stripping.

A



B

Fig. 17.12. **A**, **B**. The cutting edges of the internal zones of the two curves have been blunted with an Arkansas bur.

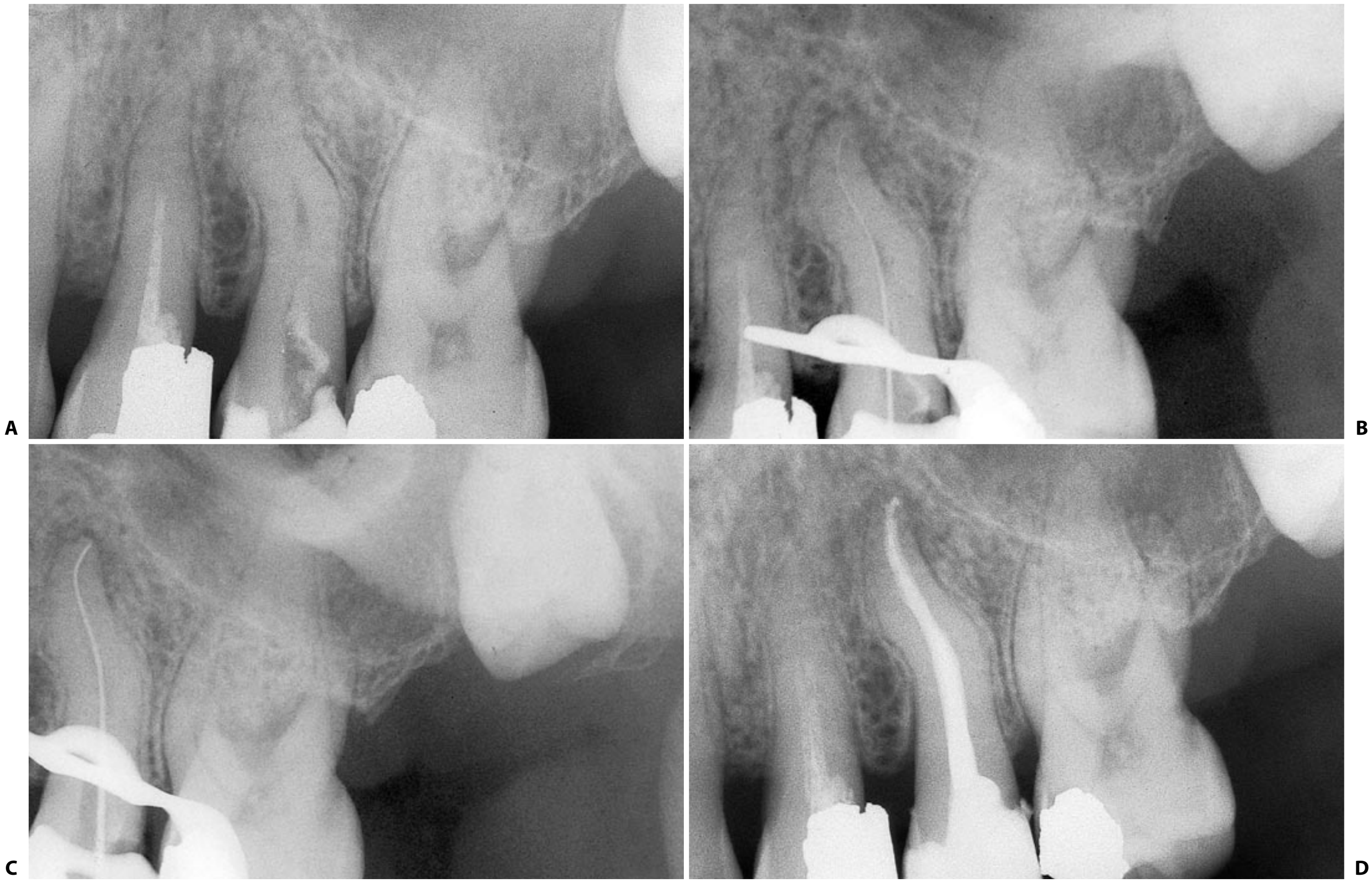


Fig. 17.13. An upper left second premolar with a bayonet curve. Note the preservation of the position of the foramen and the slight blunting of the two curves. **A**. Preoperative radiograph. **B**. Intraoperative radiograph with the first instrument at the radiographic terminus of the canal. **C**. Intraoperative radiograph with the last instrument at the radiographic terminus of the canal. **D**. Postoperative radiograph.

Fig. 17.14. The postoperative radiograph of the lower right second molar shows a bayonet curvature in the mesial root. Stainless-steel hand instruments (K files # 10-17), nickel titanium hand instruments (K files # 20-35) and rotary nickel titanium instruments (Profile .04 tapers) have been used (Courtesy of Prof. E. Berutti).

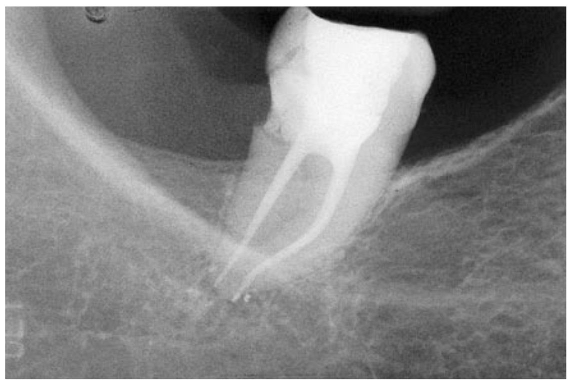


Fig. 17.15. The postoperative radiograph of the lower right third molar shows a bayonet curvature in the mesial root. Stainless-steel hand instruments (K files # 10-20) and rotary nickel titanium instruments (Profile .04 tapers) have been used.

CURVES OF THE CORONAL THIRD

While the curves of the apical third must be respected, and while the curves of the middle third are blunted and smoothed during routine canal preparation, the curves of the coronal third must be eliminated before commencing normal cleaning and shaping.

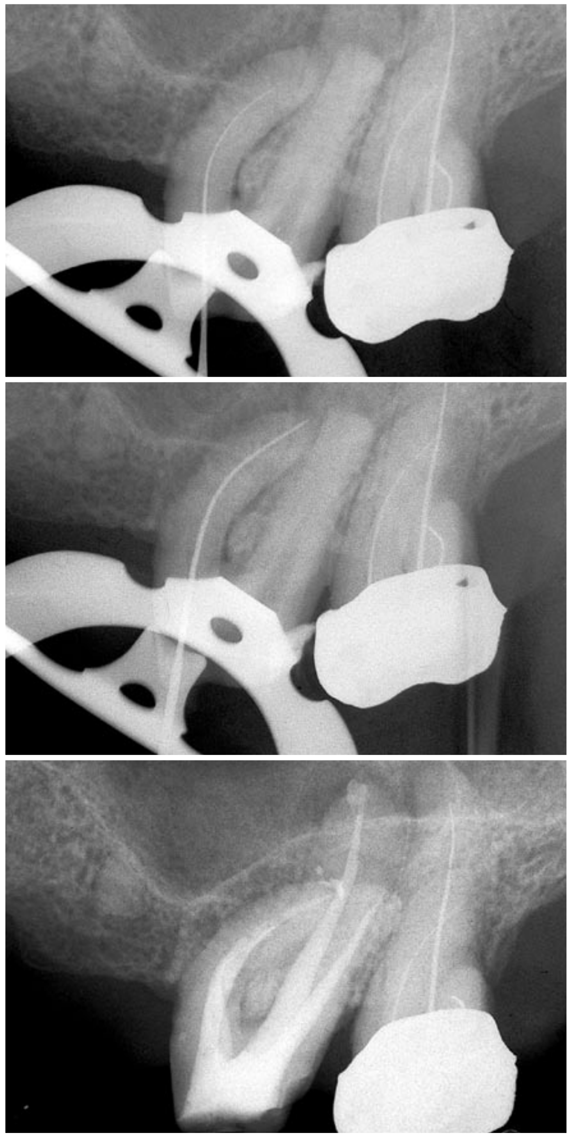
The preparation of straight canals and those with curves of the apical and middle third can be performed either according to the technique described in Chapter 16 or according to Schilder's technique (described in Chapter 15), which numerous American authors,[9,10,19,24,25,26] albeit with small personal variations, call "Step-back technique". This requires the immediate introduction of the instruments to the radiographic terminus of the canal and then the introduction of larger instruments increasingly short of the foramen, so as to give conicity to the canal preparation, recapitulating the various instruments several times in a way that the preparation, in addition to conical, is also smooth. During each recapitulation, the instruments progressively and spontaneously work in a more apical level, and this is also a crown-down approach to the root canal preparation.

In the case of curves of the coronal third of the canal, on the other hand, particularly frequent in the mesial roots of lower molars (Fig. 17.16) and mesiobuccal roots of upper molars (Fig. 17.17), before introducing the instruments to the foramen and before working them it is necessary to straighten these curves and perform an early enlargement of the coronal and

A

B

Fig. 17.16. A lower right second molar with a slight curve in the coronal third of the mesial root. **A**. Preoperative radiograph. **B**. Postoperative radiograph.



A

B

C

Fig. 17.17. An upper left first molar with a curvature in the coronal third of the mesiobuccal root. **A**. Intraoperative radiograph. The instrument is unable to advance to the radiographic terminus of the canal because of large interferences in the curve of the coronal third. Note the distal inclination of the instrument shaft. **B**. Intraoperative radiograph of the last instrument at the radiographic terminus of the canal. The curve of the coronal third has been eliminated by the first file introduced in the canal and then the various instruments can comfortably reach the apical third. Note the mesial displacement of the instrument shaft. **C**. Postoperative radiograph.

middle thirds of the canal. This carries several advantages, as already discussed in Chapter 16:[5,8,23,25]

– it permits more direct access to the apical region[18,22]
– eliminating the restrictive dentin in the coronal two-thirds of the canal, it permits safer, quicker, and more effective apical instrumentation,[24,25] and it gives the clinician more tactile sense and control when directing files apically
– it reduces the risks of ledges, transportation of the apical foramen, stripping in the area of the bifurcation and fracturing instruments
– the enlargment of this "radicular access" permits deeper penetration of the irrigating solutions[2,6] and better removal of debris from the apical zone[18]
– the working length is less subject to change during the subsequent apical instrumentation, since the canal curvature has already largely been eliminated prior to the working length being established.[4,15]

Straightening of this curve has been described by several authors with different techniques.

In his "Step-down" technique, Goerig[8] eliminates the curve of the coronal third with the help of Hedstroem files of increasing size (# 15, 20, and 25), which are introduced to the point at which they engage the walls, after which he advances to the use of Gates-Glidden drills. Only in narrow or calcified canals does he suggest preceding their use with a small file, such as a # 08 or 10 to the apical portion, to facilitate the use of the Hedstroem files and to establish the patency of the canal.

Starting from the observation that the coronal portion of the canals of the lower molars is often the narrowest area on account of the natural apposition of dentin,[21] Leeb[12] suggests first "opening" this coronal zone with Largo or Peeso drills mounted on a slow speed handpiece, so that the instrumentation of the remaining portions of the canal occurs without interference during the movement of the files.

In this author's opinion, it is preferable to achieve the same final result with other instruments, without employing Hedstroem files or rotating instruments, like Gates-Glidden or Largo drills, which might create ledges, block the canal, or perforate the root. Rather, one should simply use smaller K-type files.

Very often, the canal is so narrow that the only instrument that can enter without risk of ledges or perforation is a # 08 or 10 file. Physically, there is no space to introduce any rotating instrument, and in these cases the manual technique is definitely safer than the use of rotary stainless stell instruments.[7]

The preoperative radiograph should have revealed the presence of such curves (Fig. 17.18 A), and the intraoperative radiograph with the # 08 file confirms the degree of this curvature (Fig. 17.18 B).

The positions of the instrument shaft and of the rubber stop in relation to the access cavity must also be examined carefully. An instrument introduced in the mesial canal will appear distally inclined, its stop associated with the distal cusp (Fig. 17.18 C). In such a situation, it is necessary to eliminate the dentin triangle that is forcing the instrument into this position; this is equivalent to straightening the curve in question (Fig. 17.18 D).

The simplest, most portable, and least dangerous instrument to use is the # 08 file. It must be worked short of the foramen, occasionally advancing to a more apical position to ensure not to create ledges or block the foramen. It must exert its action on that triangle of dentin in a direction opposed to the site of the bifurcation, following the "anticurvature filing method" suggested by Abou-Rass, Frank, and Glick for the preparation of curved canals.[1] The work of this file will have to proceed until it is possible to position the rubber stop at the cusp associated with the canal that is being prepared (Figs. 17.18 E, F).*

When the cusp corresponding to the canal in question can be used as a reference point for the stop, one can be certain that the dentin triangle has been eliminated, that the curve of the coronal third has been straightened, and that the access to the apical third of the canal is straightline. Once the curve of the coronal third is eliminated, the preparation is completed in the traditional manner (Figs. 17.18 G-I).

When the clinician performs the "Early Coronal Enlargement" according to the Ruddle[23] technique (see Chapter 16), the elimination of the coronal curve of the root canal is automatically made.

After enough room has been made with small hand instruments, the triangle of dentin can also be removed rapidly using the Gates Glidden drills, the CPR ultrasonic tips or the rotary nickel titanium ProTaper S1 and if necessary ProTaper SX (Figs. 19.21, 19.22).

(*) Obviously, if there is also coronal interference at the level of the enamel that protrudes into the access cavity, it must be eliminated with a diamond bur, preferably a tapered fissure with a non cutting tip. Beware of amalgam or gold rather than enamel interference, because their elimination may push metallic dust into the canals (Fig. 11.8). To prevent this, the amalgam and gold must be generously eliminated in advance.

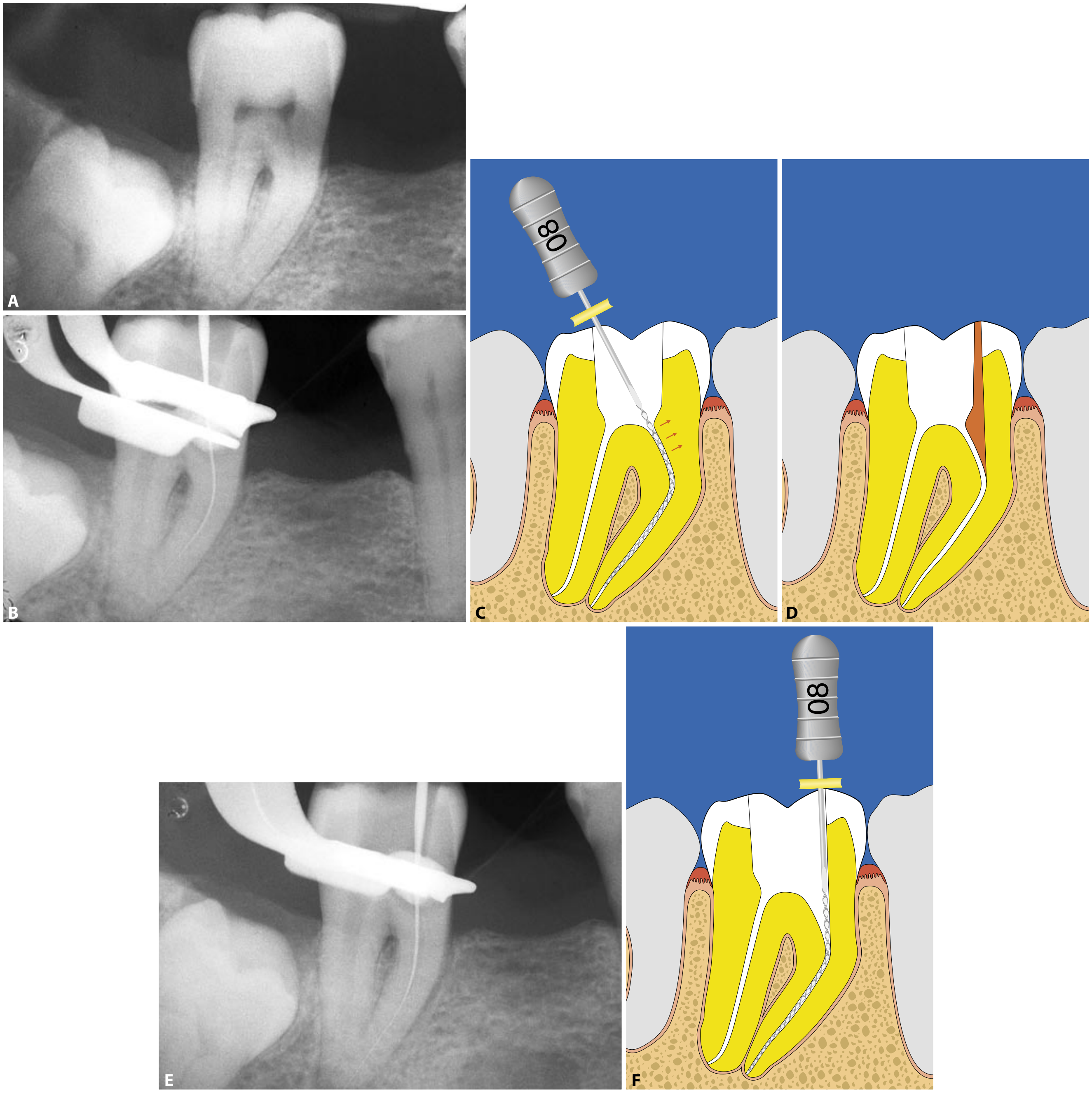
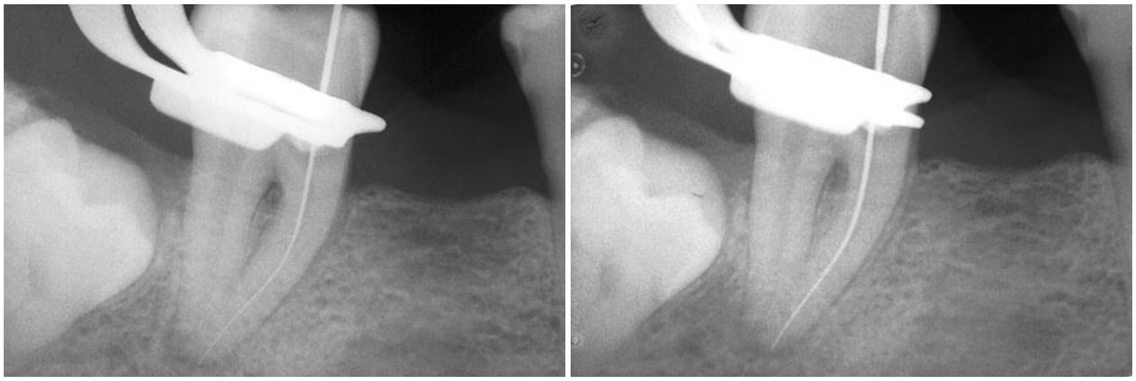


Fig. 17.18. **A**. Preoperative radiograph of a lower right second molar with a curve of the coronal third in the mesial root. **B**. A # 08 file, the first instrument introduced in the canal, is unable to advance to the desired depth because of obstructions that its shaft encounters in the coronal third of the canal. Note the distal inclination of the instrument shaft, which is shifted several millimeters from the occlusal margin of the access cavity. **C**. Schematic representation of the preceding radiograph. To eliminate the obstructions and straighten the coronal curve, it is necessary to work the first instrument in the direction of the arrows. The shaft and the handle of the instrument are very distally inclined, and the rubber stop rests on the distal cusp. **D**. The dentin is represented in red. It must be removed to allow straightening of the curve of the coronal third, eliminate the obstructions around the file shaft, and then comfortably carry the instruments to the radiographic terminus of the canal. **E**. The instrument now has straightline access to the apical third of the canal, and the reference point of the stop is the cusp associated with the canal. Note the closeness of the instrument shaft to the mesial wall of the access cavity. **F**. Schematic representation of the preceding radiograph (continued).

G



H

I

Fig. 17.18. (Continued) **G.** Intraoperative radiograph of a # 10 file at the proper working length. **H.** Intraoperative radiograph of the last instrument (# 20 file) at the radiographic terminus of the canal. **I.** Postoperative radiograph.

ANTICURVATURE FILING METHOD

This method was proposed by Abou-Rass, Frank, and Glick[1] for the preparation of curved canals, but in practice the technique should always be performed in preparing the canals of the molars, either upper or lower, particularly in the mesial canals of the lower molars and the mesiobuccal canals of the upper molars, whose roots always present a buccolingual concavity on their distal surface. This means that these canals are closer to the distal surface of the respective root than they appear to be radiographically.[11]

In practice, the anticurvature filing method consists of working the endodontic instruments constantly against the external wall of the curve.

The goal of the anticurvature filing method is to prepare the canal, especially at the expense of the thickest portion of the root, staying far away from the area of the curve and from the bifurcation; in other words, from that area in which the root is dangerously thinner.

In round but more or less straight roots, in which the canal is in a central position, the wall thicknesses are approximately the same, buccolingually and mesiodistally. Consequently, the circumferential filing, which requires concentric enlargement of the original canal, can be used confidently.

In curved roots, on the other hand, but particularly in the molars, the canal is not in a central position. Rather, it is displaced closer to the internal zone of the curve, that is, toward the bifurcation (Fig. 17.19). Therefore, enlargement and flaring of these canals must take into consideration these anatomical peculiarities.

In a cross section, the three American authors identify a bulky or "safety zone", far from the bifurcation, where the dentin is thicker and which corresponds to the mesial wall of the mesial roots of the lower molars and of the mesiobuccal roots of the upper molars; and a thinner area, or "danger zone", in which the dentin is thinner and the canal is closer to the periodontium (Fig. 17.20). This danger zone comprises the distal wall of the mesial roots of the lower molars and of the mesiobuccal roots of the upper molars.

In these cases, a circumferential filing should obviously be avoided, since it would as a certain consequence lead to excessive thinning of the root or even to perforation from stripping* in the area of the

(*) Abou-Rass et al. define "stripping" as thinning of the dentin in the direction of the radicular cementum, which can lead as far as perforation.

bifurcation[13,16] (Fig. 17.21).

A wall thinned in this way could also fracture during the condensation of the obturating material (Fig. 17.22) or later, on mastication.[8]

This problem must also be considered during the reconstruction of an endodontically treated molar[20] (Fig. 17.23).

The mesial roots of the lower molars and the mesiobuccal roots of the upper molars are very often completely inadequate to receive sufficiently retentive posts without running the high risk of perforation (Figs. 17.24, 17.25).

The anticurvature filing method safeguards against such risks, in addition to providing straighter access to the apical third of the canal.[11]

Thus, from a practical point of view, this method should always be used in the preparation of the molar canals, either upper or lower, which therefore, particularly in their middle and coronal thirds, must be especially prepared at the expense of the areas where the dentin is thicker (Fig. 17.26). To do this, the instruments must be constantly worked against the external wall of the curve (Fig. 17.27).

In applying the anticurvature filing method, it is im-

A

B

Fig. 17.19. **A**. Cross section of the mesial root of a lower first molar. Note the different thicknesses of the dentin mesial and distal to the two canals. **B**. Cross section of the mesiobuccal root of an upper first molar. Note the closeness of the two canals with respect to the area of the bifurcation.

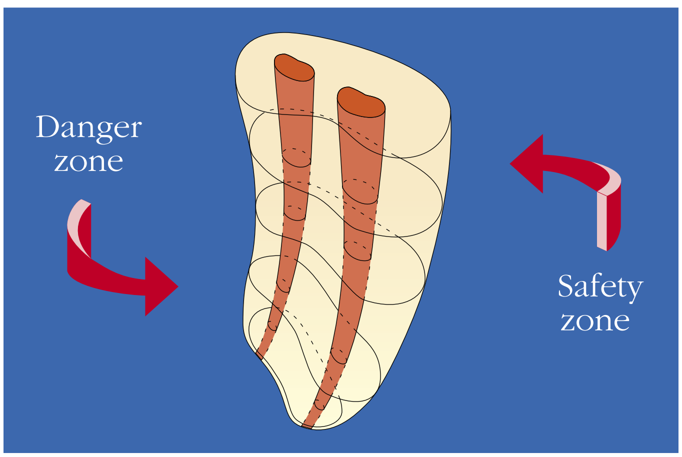
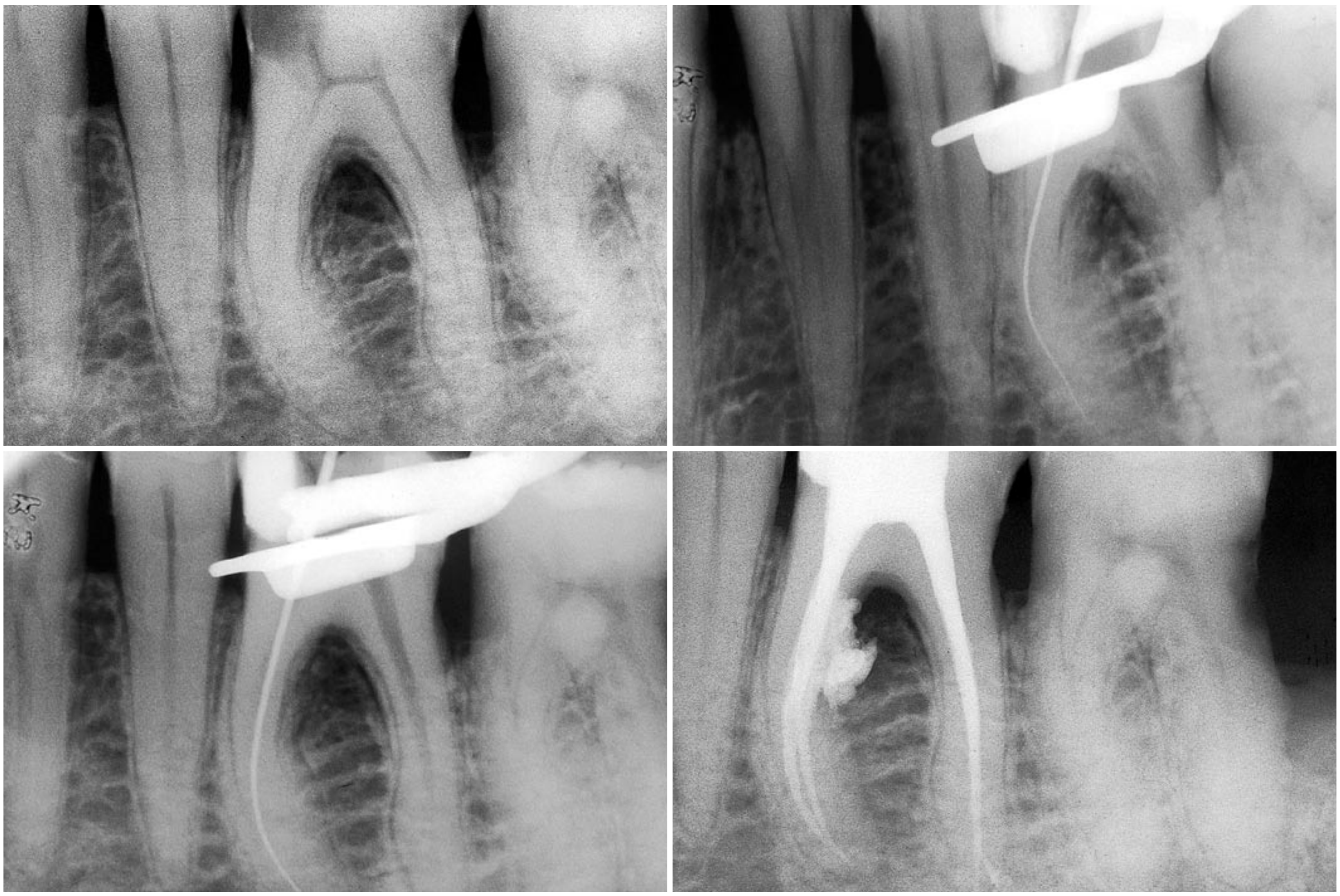


Fig. 17.20. Schematic representation of the mesial root of a lower molar. The "safety zone" is the mesial portion, while the "danger zone" is the distal portion of the root (Adapted from Abou-Rass, Frank, and Glick).

portant that a sufficient amount of dental structure be removed from the mesial wall of the access cavity, so as to permit the instruments a straightline access toward the apical third of the canal.[14]

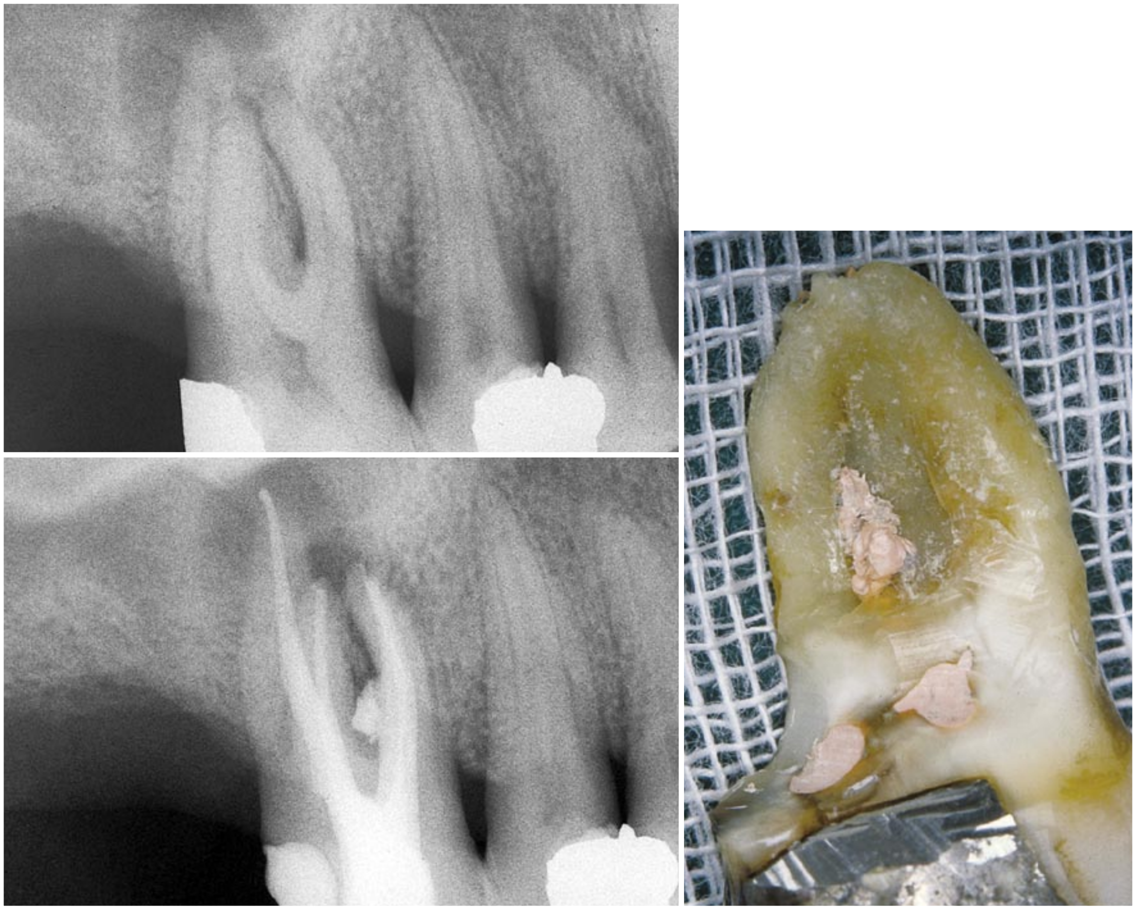
So as not to forget to apply this method, it suffices to recall that the reference point of the instruments' rubber stop must correspond to the cusp of the canal that is under treatment.

This obliges the dentist to apply the instruments to the areas in which the dentine is thicker and far from bifurcations, and thus to consistently apply the anti-curvature filing method during the cleaning and shaping procedure.



A B C D

Fig. 17.21. Lack of application of the anticurvature filing method easily leads to stripping in the area of the bifurcation. **A**. Preoperative radiograph. Note the slight curvature in the middle and coronal thirds of the mesial root of the first molar, and the closeness of the mesial canals to the roof of the bifurcation. **B**. Intraoperative radiograph of the first instrument at the radiographic terminus of the canal. One can imagine the strong distal inclination of the instrument handle. The radiograph was taken with an excessive apico-coronal inclination of the cone of the X-ray machine. **C**. Intraoperative radiograph of the last instrument at the radiographic terminus of the canal (# 20 file). Note the distal inclination of the instrument shaft and the extreme closeness of its cutting edges to the bifurcation. Consider that the canal still needs to be enlarged to develop a continuously tapering conical form. **D**. Postoperative radiograph. The excess material issuing from the area of stripping and the lesion which in the meantime has established itself at the bifurcation, is evident (By kind permission of Dr. G. P.).



A

B

C

Fig. 17.22. Stripping in the mesial root of the upper first molar. **A**. Preoperative radiograph: the mesial root reveals a slight distal curvature. **B**. Postoperative radiograph: at the moment of compaction of the gutta-percha, the too thin wall has fractured, causing the issuance of obturation material in the area of the bifurcation. **C**. The extracted root demonstrates the stripping that has occurred in the mesiopalatal canal (MB-2).

Fig. 17.23. The screw post, which is positioned in the distal canal, seems to be contained within the root. In reality, because the root is slightly concave buccolingually, the screw appears in the periodontium, and the stripping created to accomodate it is the cause of the large lesion at the bifurcation.

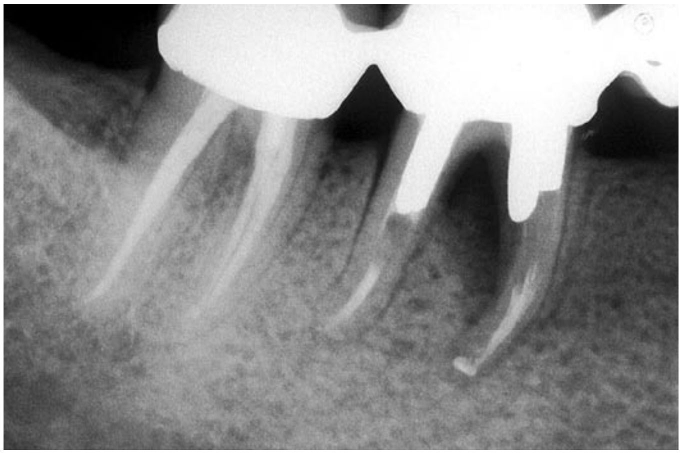


Fig. 17.24. The large post introduced in the mesial root of this lower first molar dips into the periodontium.

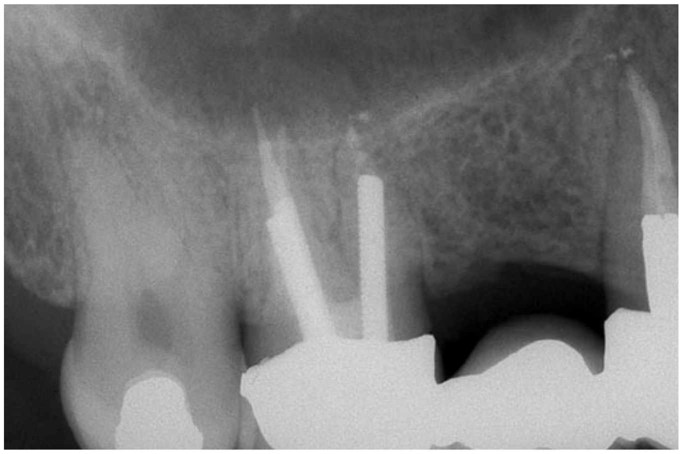


Fig. 17.25. The buccal roots of upper molars are not absolutely adapted to receiving large screws or posts. Their introduction is associated with great risks of perforation, stripping, and root fracture.

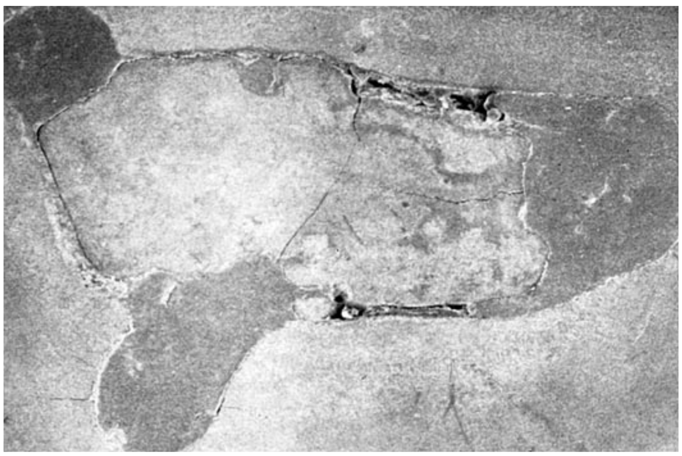


Fig. 17.26. S.E.M. photomicrograph of an endodontically treated upper molar that has been extracted for periodontal reasons and sectioned transversally at the level of the floor of the pulp chamber. Note that the three canals have been prepared according to the anticurvature filing method at the expense of the external dentin with respect to the perimeter of the floor of the pulp chamber and thus with respect to the bifurcation. Note, furthermore, the retrograde filling of the mesiopalatal canal that has automatically occurred during the compaction of the gutta-percha in the mesiobuccal canal: evidently, the two canals converge at a common apical foramen.

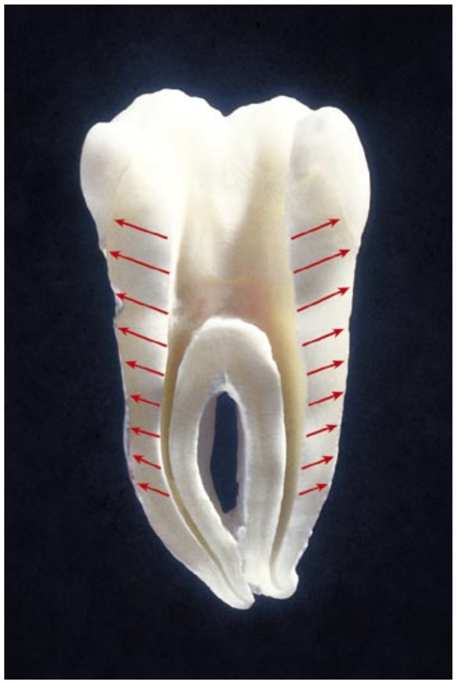


Fig. 17.27. In applying the anticurvature filing method, the instruments must be worked in the direction indicated by the arrows.

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18

Rotary Instruments in Nickel Titanium

Elio Berutti, Giuseppe Cantatore

Over the last few years endodontics has undergone a complete revolution with the introduction of the NiTi alloy for the manufacture of initially manual and then rotary endodontic instruments. The extraordinary characteristics of superelasticity and strength of the NiTi alloy[83,84] have made it possible to manufacture rotary instruments with double, triple and quadruple taper compared to the traditional manual instruments (Fig. 18.1).[26]

This has made it possible to achieve perfect shaping with the use of very few instruments[22,58] in a short period of time and without the need for above average skills on the part of the operator.

CHARACTERISTICS OF NITI ALLOY

The NiTi alloy came to the fore when used at the beginning of the 60's by W. H. Buehler in a space program of the Naval Ordnance Laboratory at Silversprings, Maryland, USA.[18]

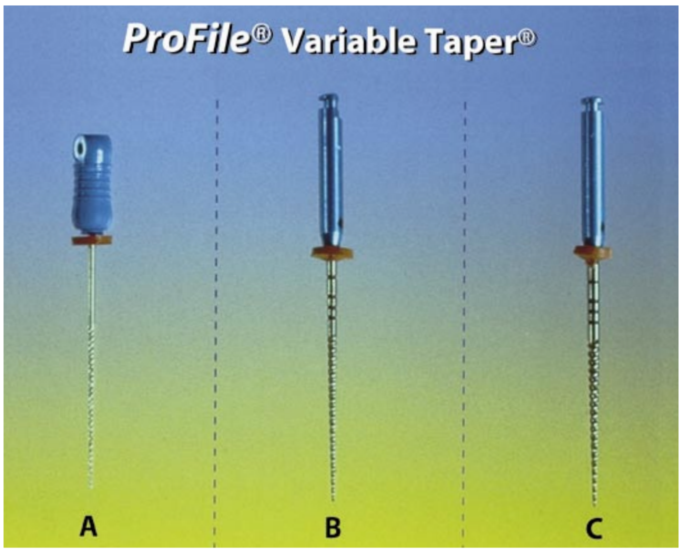


Fig. 18.1. **A.** ProFile hand file .02 taper. **B.** ProFile rotary instruments .04 taper. **C.** ProFile rotary instruments .06 taper

The alloy was called Nitinol, an acronym for the elements from which the material was composed: ni for nickel, ti for Titanium and nol from the Naval Ordnance Laboratory.

It was introduced into dentistry in 1971 by Andreasen et al.[1-3] in order to create orthodontic wires.

The NiTi alloy belongs to the family of the Nickel and Titanium intermetallic alloys, characterized by two properties which distinguish them, the memory of shape and superelasticity.[17]

Shape memory

By shape memory we mean the capacity of NiTi alloys to reacquire its initial shape through heating after strain.[18] This property is utilized in orthodontics but not in endodontics.

Superelasticity

We define elasticity as the property of bodies to deform by the action of external forces and once these external forces cease the ability to return to the original state. There is a limit which is defined "elastic limit", beyond which there is a component of plastic strain which can no longer be recouped by the elimination of external forces. For example if we compare two wires of equal cross section, one in stainless steel and one in NiTi, we can better understand the extraordinary property of superelasticity which NiTi has. If we apply a moment of force to a stainless steel wire that is able to produce an angular deformation of 80°, when the moment ends a permanent angular deformation of 60° will

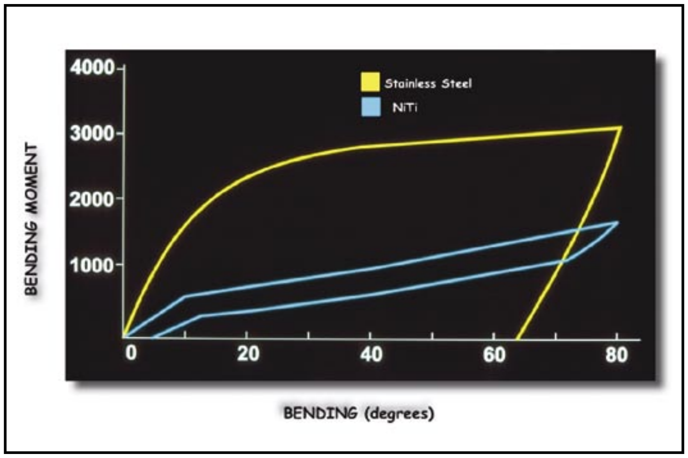


Fig. 18.2. Strain-stress diagram.

remain (Fig. 18.2). It can be deduced that the stainless steel wire has an elastic deformation limit of 20° above which every deformation becomes permanent.

If we apply a bending moment which is able to produce a deformation of 80° to a NiTi alloy wire of equal cross section, when the moment ends a permanent angular deformation of less than 5° will remain. The wire in NiTi will undergo deformation which is almost completely elastic, leaving a minimum permanent deformation (Fig. 18.2).[44,70,83]

This characteristic (superelasticity) is particularly evident when for example, using a finger, we try to bend two identical endodontic instruments, one in stainless steel, the other in NiTi. The stainless steel endodontic instrument presents a higher stiffness while the NiTi instrument is particularly compliant. The use of endodontic instruments in NiTi is particularly advantageous for shaping the canal system in harmony with the original anatomy.

Strength

Walia et al.[83] and Camps et al.[20] have demonstrated that files in NiTi were much more resistant to clockwise and counter-clockwise torsional stress compared with files of equal size but in stainless steel. This elevated strength of the NiTi alloy has made it possible to manufacture rotary instruments that have greatly simplified the shaping of the root canal system.

Metallurgy of nickel-titanium alloys

The NiTi alloy used in root canal treatment contains approximately 56% (in weight) of Nickel and 44% (in weight) of Titanium. In some NiTi alloys, a small percentage (<2% in weight) of Nickel can be substituted by cobalt.[72] The resultant combination is a one-to-one atomic ratio (equiatomic) of the major components (Ni and Ti). This alloy has proved to be among the most biocompatible materials and it is extremely resistant to corrosion.[72] As we have previously said, NiTi belongs to the family of inter-metallic alloys. This means that NiTi alloy can exist in various crystallographic forms, with distinct phases and different mechanical properties: austenitic, transformation and martensitic (Fig. 18.3).[85]

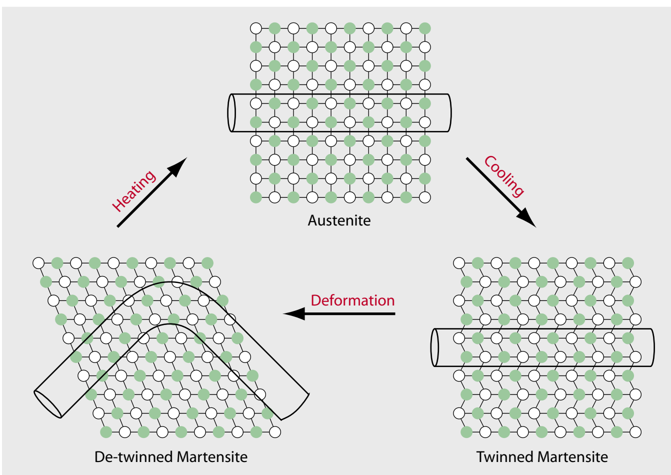


Fig. 18.3. Diagrammatic illustration of the martensitic transformation and shape memory effects of NiTi alloy (By Thompson S.A.; Int. Endod. J. 33:297, 2000).

1) AUSTENITIC PHASE (A): with body-centred cubic lattice. It's the most stable phase.
2) MARTENSITIC PHASE (M): with hexagonal compact lattice. It's the most unstable and ductile phase.
3) TRANSFORMATION PHASE (T): it is made up of a series of intermediate phases which transform one into the other, causing a movement of the Ni and Ti atoms onto opposite and parallel crystalline levels; this doesn't entail a variation of the crystallographic shape.

Each crystalline phase exists in a specific temperature interval.[53] The transition from one phase to the other is possible only within a temperature range including those at the beginning and at the end of transformation (Fig. 18.4):

As: temperature at the start of Austenitic transformation
Af: temperature at the end of Austenitic transformation
Ms: temperature at the start of Martensitic transformation
Mf: temperature at the end of Martensitic transformation

Cooling the alloy below the T.T.R. (transformation temperature range), besides the crystalline modification, we also have a change of its physical properties with an increase in malleability (Martensitic phase). Raising the temperature above the T.T.R. one returns to the energetically more stable phase with a body-centred cubic lattice (Austenitic phase).

Such phase changes can also be induced by the application of deformation states, as happens with NiTi endodontic instruments during their work inside the root canals.[72]

The NiTi alloy therefore has a strongly non-linear mechanical behaviour.[55,85,86] This means that there isn't a (linear) proportional correspondence between stresses and strains.

The NiTi alloys are characterized by a stress-distorsion diagram which is divided into three distinct portions, corresponding to the three crystalline phases: austenitic, transformation, martensitic (Fig. 18.5).

The most performing phase of the NiTi endodontic instruments corresponds to the second section of the diagram (transformation phase), where we have the passage between the more stable crystalline phase (the austenitic type), and the more unstable phase (the martensitic type), where the alloy manifests important distorsions which culminate firstly in the yield point and then in the fracture.[2,72]

In the transformation phase the characteristics of superelasticity appear. If we observe the diagram we see how in this phase the strains can increase while the stresses remain constant. The alloy can deform over quite a wide range while the fatigue damage that accumulates remains constant. It's like having a motor car that has the extraordinary characteristic of being able to travel from 60 km/h to 130 km/h using the same quantity of the fuel.

It is evident that the more the alloy works in this phase, the more the characteristics of compliance and strength are established.[36] The Niti rotary endodontic instruments will thus be able to shape the root canal following the original root canal anatomy even if complex, without reaching elevated values of stress.[14,39]

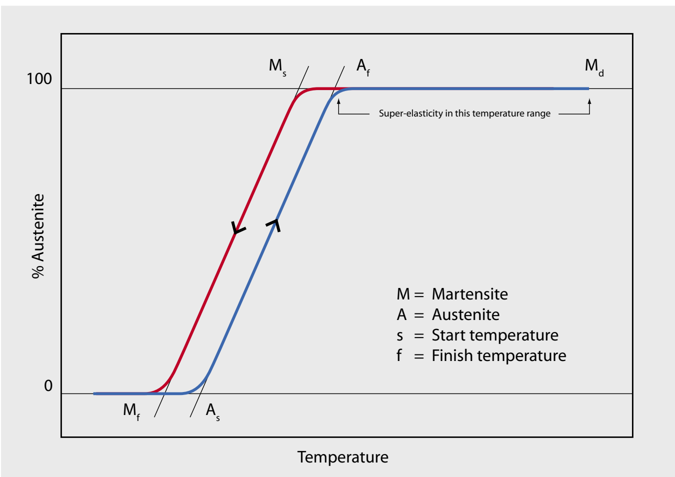


Fig. 18.4. Hysteresis of martensitic transformation (By Thompson S.A.; Int. Endod. J. 33:297, 2000).

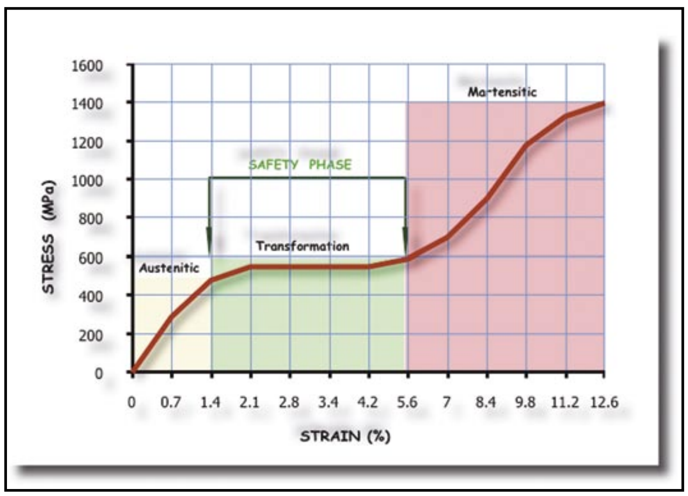


Fig. 18.5. NiTi phase transformation.

Advantages

In 1974 H. Schilder[69] stated what the mechanical and biological objectives to be followed to achieve a correct cleaning and shaping of the root canal system. From that time until a few years ago, numerous manual techniques have been proposed and many endodontic stainless steel instruments (manual or rotary) have been commercialized.[34,50,63] There are two disadvantages:

1) the stainless steel with which the endodontic instruments were and are still made, is a material with an elevated stiffness which often doesn't adapt well to the convoluted root canals
2) the stainless steel instruments available are almost cylindrical (.02 taper). To achieve a tapering conical shape required laborious operative sequences, which demanded good skill and a lot of patience.

The introduction of the NiTi alloy has allowed one to simultaneously solve these two problems. The superelasticity and the strength of the NiTi alloy has made it possible to obtain rotating instruments with a taper which is double, triple and beyond with respect to the standard .02 taper of the stainless steel hand instruments. The greater taper has drastically reduced the number of instruments needed to shape a canal. The superelasticity has furthermore made it possible to carry out extremely conservative shapes, better centered, with less canal transportation and therefore with more respect of the original anatomy.[15,33,37,41,56,62,68,73-78,82]

The strength of the NiTi alloy has made it possible to mechanize these endodontic instruments with an increased taper, making it possible for all the Operators (even those without exceptional skill) to obtain perfect shapings and in a short period of time.

To better understand the enormous differences between the shapes obtained with stainless steel endodontic instruments and those obtained with NiTi rotary instruments with a greater taper it is useful to compare the cross-sections of the two canals of mesial roots of lower first molars, at the level of the coronal one third, before and after instrumentation with each technique.

The canals shaped with stainless steel files using the step back technique are dangerously transported towards the bifurcation. J.B. Roane[60] states that this was caused by the "restoring force" of the file which, even if precurved, tries to regain its straight primitive shape. Observing the shape of the cross section of the canal, it is evident how the large and oval shape is the expression of the dynamic movement of the file in the space and of the "restoring force" and not of the cross section of the instrument that has worked at that level. The shape is not centered in the original canal (Fig. 18.6). The curves are straightened and consequently the shape in those areas is much larger than the instrument cross-section, which has worked at that point. These considerations are not only important to avoid excessive weakening of some canal walls, with the risk of creating perforations (stripping), but they are also very important in order to obtain a truely three dimensional obturation of the root canal system. Indeed, the gutta-percha cone having a round cross-section adapts badly to an oval shaped canal. The condensation forces of the warm gutta-percha during the obturation will be dissipated filling the empty spaces between the round gutta-percha cone and the oval canal and consequently the root canal system will be underfilled (Fig. 18.7). If we analyze the result of the

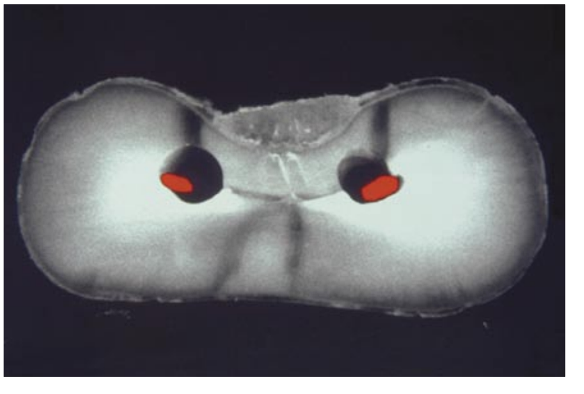


Fig. 18.6. Cross section of the mesial root of the lower first molar at the coronal third level: in red is the original canal, in black the canal shaped with hand files in steel using the step-back technique. The shaped canals are enlarged in an oval shape with transportation towards the furcation.

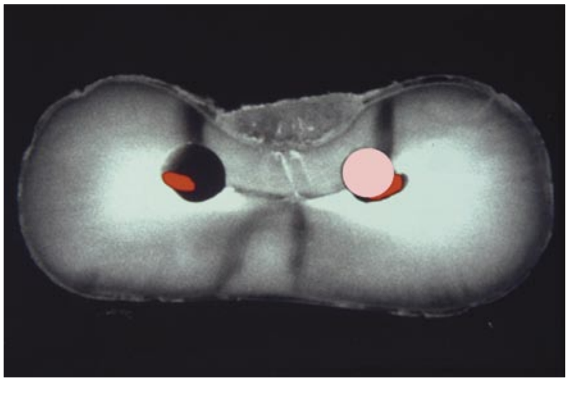


Fig. 18.7. In pink the cross-section of a gutta-percha cone adapted to the canal. Note the gap between the gutta-percha cone and the oval shaped canal.

work done by the NiTi rotary instruments, in this case Profile .06, still in a mesial root of a lower first molar, before and after instrumentation we see how the shape developed exactly concentrically with respect to the original canal, thanks to the extraordinary compliance of these instruments. The shaped canals are perfectly round, an expression of the corresponding NiTi rotary instrument cross section that has worked at that level of the canal (Fig. 18.8). As has previously been said, this is of extreme importance in the obturation phase. The gutta-percha cone will thus have intimate contact with the canal walls and the compacting forces will be exploited fully to three dimentionally fill the canal system (Fig. 18.9).

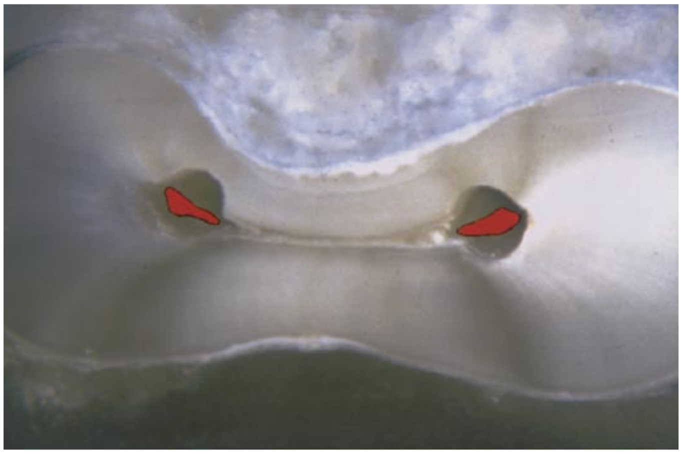


Fig. 18.8. Cross section of the mesial root of a lower first molar at the coronal third level: in red the original canal, in grey the canal shaped with a .06 ProFile rotary instrument. The canals are shaped with minimal enlargement and have a round form. The shaping was developed centrally in the original canal.

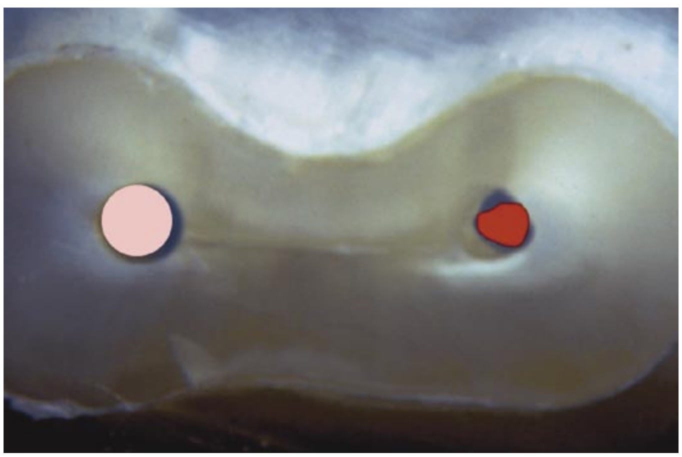


Fig. 18.9. In pink a cross-section of the gutta-percha cone adapted to the canal. Note the perfect adaptation of the gutta-percha in a canal shaped to a round form.

FUNCTIONING OF THE NITI ROTARY INSTRUMENTS

Let us now analize the functioning of the NiTi rotary instruments during the shaping of the canal system.

The states of stress to which the NiTi rotary instrument is cyclically subjected are responsable for the strain (deterioration).

The strain is determined by two principal types of stresses: bending stress and torsional stress.

Torsional stress

Torsional stresses are very harmful and if they are of elevated intensity, they rapidly cause the fracture of the instrument. This generally happens in three situations:

1) when a large surface of the instrument rubs excessively against the canal walls (taper lock)
2) when the instrument tip is larger than the canal section to be shaped
3) when the operator exerts excessive pressure on the handpiece

Unlike the bending stresses which are largely dependent of the original anatomy of the canal, and therefore not easily modified, we can intervene on the torsional stresses partially reducing the effect (impact) through the correct use of the instruments and some other techniques.

Large contact surface

The cutting action and therefore the blade dentine contact surface must be reduced to a fraction of the working part of the NiTi rotary instrument with greater taper. The larger the blade-dentine contact surface the higher the torque required to allow the rotation of the instrument and therefore the cutting of the dentine[54] (Fig. 18.10). This means an elevated torsional stress which the alloy stores, in this way rapidly reducing the life of the instrument. Furthermore if the torque values necessary to make the instrument rotate exceed the values of the maximum torque moment that the instrument can endure, the instrument distorts and fractures.

To avoid this dramatic inconveniece the NiTi rotary instruments with greater taper must be utilized with the crown-down technique.[24,25]

Blum et al.[10] have demontrated that the NiTi rotary instruments are subjected to lower stress levels if utilized with the crown-down technique rather than if utilized with the step-back technique.

Even the cutting ability of the instrument is more efficient if used with the crown-down technique.[43,69]

The instruments must be used in sequence from the largest to the smallest (Fig. 18.11).

The NiTi rotary instruments with greater taper once introduced into the canal creates a shape similar to its own shape. It will go forward in the canal as far as the original anatomy will make it possible. The next smaller instrument will descend more apically and will no longer work in the areas where the previous instrument, which was larger, had already shaped the canal. In this way the canal will be prepared in successive corono-apical sections that fit one into the other. The instruments work in this way using only a small portion of their working surface.

Another element that can increase the surface contact between canal wall and instrument and so increase the torsional stress, is the accumulation of dentinal debris between the blades of the instrument. This dentinal mud accummulates in large quantities between the blades and if not removed, compacts more and more during successive use of the instrument.

Not only the blade surfaces of the working part come into contact with the canal walls but also the dentinal mud compacted between the blades.The working part of the instrument in this way is transformed into an entire contact surface, as though it is a uniform frustum of cone.

This causes an immediate and notable increase in torsional stress.

The operator must become aware of when the speed with which the NiTi rotary instrument advances inside the canal starts to diminish, this is a sign of an excessive accumulation of debris between the blades.

It is therefore important, after every passage, to methodically clean the blades of the NiTi rotary instruments having a greater taper.

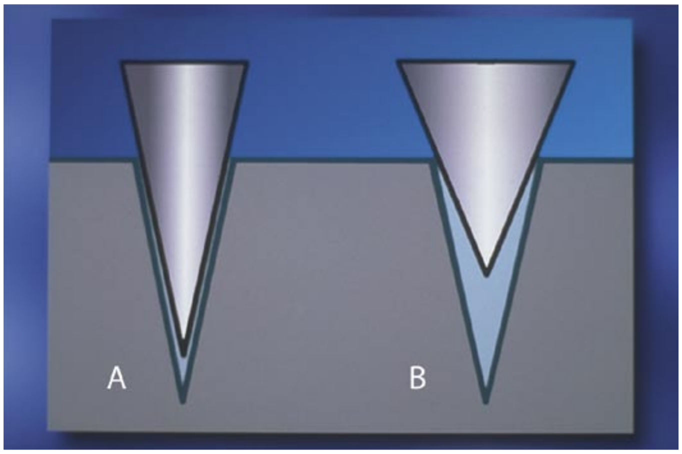


Fig. 18.10. **A.** The blade-dentine surface contact is very large. The torque required to maintain a constant rotational speed of the instrument will therefore also need to be very large. **B.** The blade-dentine surface contact is very small: the torque required to maintain a constant rotational speed of the instrument will therefore also be small (Courtesy of Dentsply Maillefer).

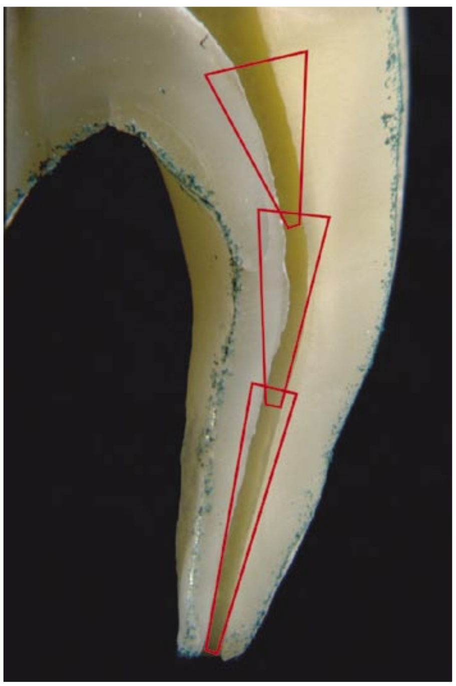


Fig. 18.11. Crown-down technique.

Instrument tip and canal width

At the moment the vast majority of rotary NiTi instruments with greater taper have a non cutting tip (non active) (Fig. 18.12) or moderately cutting (moderately active) (Fig. 18.13).

This is to prevent the formation of ledges, false paths or apical foramen transport. If on the one hand the non active or moderately active tip, allows one to avoid the above mentioned errors, on the other hand it presents one with another problem. If the tip with poor or non cutting ability encounters a canal or a canal portion with a smaller cross-section, the tip advances with great difficulty. Torsional stress increases enormously and if the tip binds and the gearing of the motor is higher than the maximum torque that the instrument can withstand, this immediately undergoes plastic strain and then fractures.[10] This condition, to-

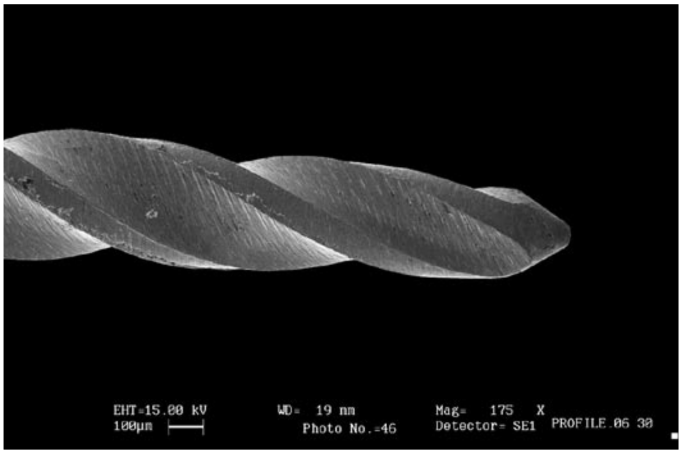


Fig. 18.12. ProFile .06: particulars of the tip.

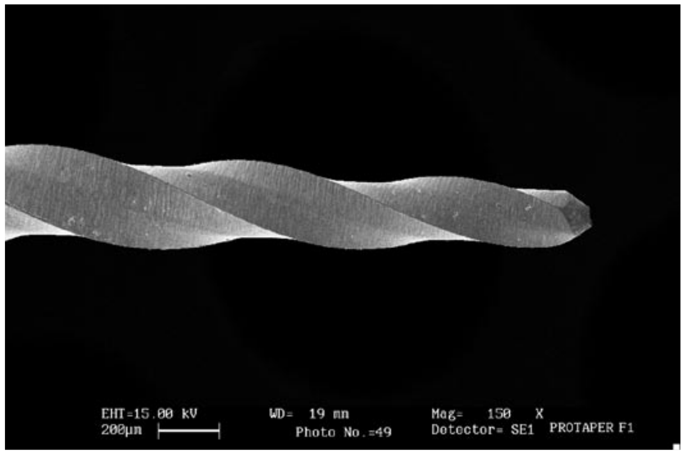


Fig. 18.13. ProTaper: particulars of the tip.

gether with the complexity of the original anatomy are the major factors responsable for the fracture inside the canals of the NiTi rotary instruments with increased taper. It is therefore essential to manually create (manual pre-flaring) a glide path for the tip of the greater taper NiTi rotary instrument that will have to be utilized.[65]

Initially a brief manual instrumentation, allows us to:

– drastically reduce the torsional stresses, by creating a canal at least as large as the diameter of the NiTi rotary instrument tip with greater taper, that will be used successively
– interpret the original anatomy.

To understand the importance of the manual pre-flaring, research carried out by E. Berutti et al.[7] is meaningful. The study calculated how many endodontic simulators (Endo-Training-Block, Maillefer, with a 0.15 mm canal diameter and .02 taper), the first NiTi rotary instrument of the Protaper series S1 could shape, before breaking, under two separate conditions: with and without manual pre-flaring.

The S1 has a tip diameter of 0.17 mm. The endodontic motor utilized was the Tecnika (ATR) with the following characteristics: 300 rpm speed and 100% torque corrisponding to 68 Nmm.

In the first group (group A) S1 shaped on average (reached the apex) 10 new endodontic simulators before breaking.

In the second trial group (group B) a brief pre-flaring was achieved manually using 3 files size 10, 15 in stainless steel and 20 in NiTi, so as to enlarge the apical foramen to a greater dimension than the calibre of the instrument being used.

The aim of manual pre-flaring was to probe the apex with a 20 NiTi file. By so doing a guide path was achieved (canal diameter after the manual pre-flaring was equal to 0.20 mm and .02 taper) for the tip of the NiTi rotary instrument (the S1 has a 0.17 mm tip diameter). In these conditions the S1 was able to shape (reach the apex) on average 59 endodontic simulators before breaking (Fig. 18.14). The manual pre-flaring avoided subjecting the tip of the S1 to torsion while trying to make a path in a canal with a very small cross-section. In this way one created a guide path for the tip of the NiTi rotary instrument thereby enormously reducing the torsional stress that the instrument experiences and in so doing increases its life span six fold. This means a cost reduction and a reduction of the fracture risks of the instrument in the canal. In recent years scientific studies have confirmed the importan-

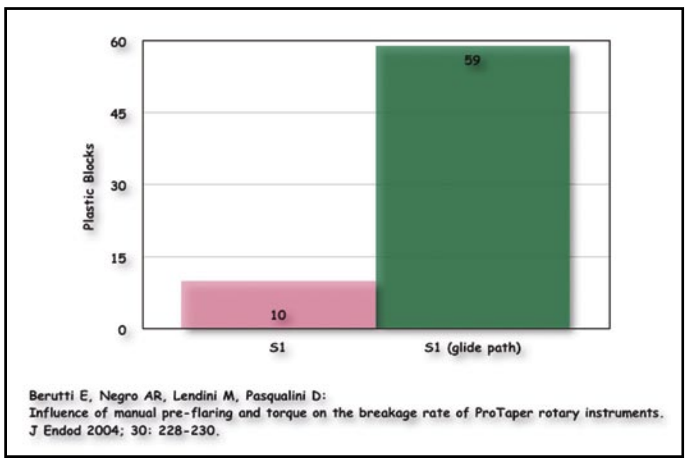


Fig. 18.14. Diagram illustrating the number of plastic blocks shaped by the ProTaper S1 before instrument breakage. In pink the number of virgin plastic blocks shaped. In green the number of plastic blocks shaped after creating a glide path using a # 20 hand file.

ce of manual pre-flaring. Roland at al.[61] showed on extracted human teeth that manual pre-flaring significantly reduced the risk of fracture of the Profile .04 inside the canal. Blum J.Y. et al.[12] used the Endographe, an instrument able to measure, register and graphically reproduce the vertical forces as well the torque values that develop when using the Protaper instruments (Dentsply Maillefer, Ballaigues, Switzerland) in the root canals of extracted teeth with different anatomy.

The Authors showed that manual pre-flaring is essential for the safe use of NiTi rotary instruments and that it significantly reduces the time that each instrument is used and consequently the total time for shaping the root canal. Peters O. A. et al.[57] did not record any Protaper fractures in the canals of extracted human molars when sufficient manual pre-flaring was carried out.

We can therefore conclude that manual pre-flaring is an essential and irremissible phase of canal shaping with NiTi rotary instruments. This guarantees a reduced fracture risk of the NiTi rotary instruments, reduced working time and not least of all also allows us to mentally develop a three dimensional image of the canal system which we have to shape. This is decisive in making the correct operative sequence which will follow (Fig. 18.15).

Fig.15. Clinical cases of teeth with calcified canals where the preshaping with hand files is very important. **A.** Preoperative radiograph of the lower right first molar. **B.** Postoperative radiograph (E. Berutti). **C.** Preoperative radiograph of lower left first molar. **D.** Radiograph to check the working length of the distal canal. **E.** Postoperative radiograph (G. Cantatore).

Excessive manual pressure on the handpiece

An excessive manual pressure on the handpiece causes a notable increase in the friction between the instrument and the canal wall. The rotation velocity reduces and the gearing immediately increases to keep the velocity constant.

Consequently at the instrument tip level and /or on the surfaces where the instrument makes contact with the canal walls, very high torsional stresses are generated which could immediately cause the fracture of the instrument.[79]

Bending stresses

The bending stresses are the main causes of strain[28,58,71] and they depend on the original anatomy of the canal which, with its curves, forces the instrument to bend as it passes through it. Pruett et al.[58] have demonstrated that the curve radius, the bend angle and the largeness of the instrument are the factors responsible for the fractures due to bending fatigue.

If one imagines a stationary rotary instrument inside a curved canal it follows that it will be subjected to two different types of stresses (Fig. 18.16):
- compression stress on the internal surface of the curve
- tensile stress on the external surfaces of the curve.

In the central part of the instrument, there exists, theoretically speaking, a neutral plane where stresses don't exist. This divides the two different types of stress. The tensile and the compression stresses are at their highest in the section where the curve radius is at its minimum, then it reduces gradually as one gets further away from the area of maximum stress (Fig. 18.17).

If one imagines the instrument in motion (continual rotation) all the above mentioned stresses will continuously change with every revolution.[67]

We will have the continuous passing from tension to compression, from compression to tension and so on, in other words the alloy will be continuously subjected to stress of the opposite type.

Therefore it is important to never stop inside a curved canal with the instrument in motion.[47] The instrument portion at the section with the least curve radius will be extremely stressed and the alloy will experience an excessive quantity of stress, creating at that point, a damaged area.[58]

We must imagine the NiTi rotary instrument as made up of millions of small NiTi alloy bricks. Each brick will experience quantities of strain perfectly proportional to the amount of stress it has been subjected to. It is therefore important to know how to utilize the NiTi rotary instrument in the best way possible, distributing the stresses in a homogeneous way throughout the alloy, thereby not creating areas of damage.[81] Consequently the instrument must be introduced, already rotating, into the canal and advanced in-

Fig. 18.16. Bending stress: on the internal aspect of an instrument rotating in a curved canal compression develops while on the external aspect tension develops. In the centre of the instrument there is theoretically a neutral zone that does not develop stresses.

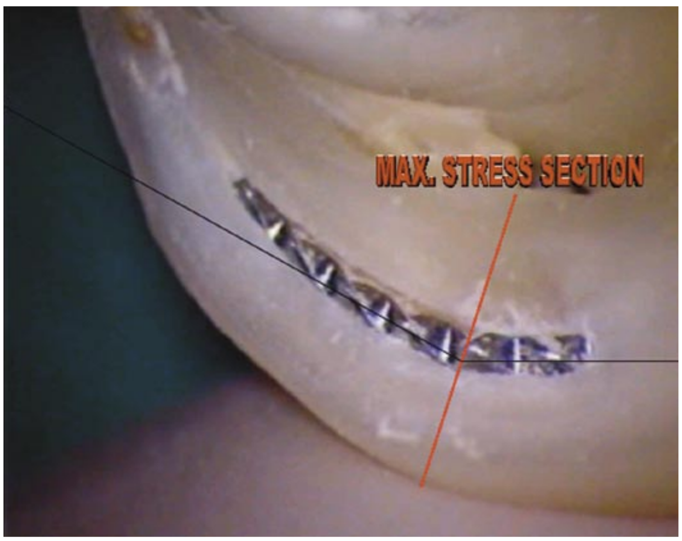


Fig. 18.17. In the rotary Niti instrument working in a curved canal the tension and compression are at a maximum in correspondence to the cross section of the instrument where the radius of the curvature is the least.

to its interior with light manual pressure. The movement must be fluid, continuous, without interruption. The operator must become aware of when the instrument has terminated its penetration further into the canal and can go no further. The operator must immediately extract the instrument, always doing so slowly, with a continuous movement, without ever interrupting its rotation.

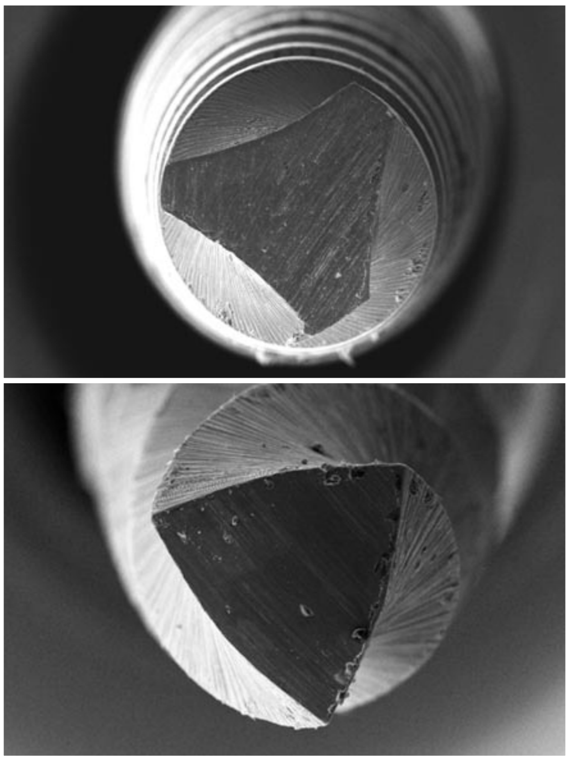
IMPORTANCE OF THE SECTION OF THE NITI ROTARY INSTRUMENT

The NiTi rotary instrument with greater taper works inside the canal in continuous rotation and is therefore subjected to continual and variable stresses based on the original canal anatomy and on the hardness of the dentine which it has to cut.[70]

The ideal NiTi rotary instrument should therefore be sufficiently compliant to be able to create a centrifugal shaping of the canal and to be sufficiently resistant to withstand the torsional and bending stresses which occur during its work. Its section is very important, because it directly determines the strength characteristics to the different stresses and the ability to cut the dentine is determined by the shape of the blades.[21] To have a better understanding of how the section is able to condition the way in which the NiTi rotary instrument performs, it is interesting to analize the research carried out by Berutti et al.[6]

The authors have analized the mechanical behaviours of two sections, the ProFile (U File) and the ProTaper (convex triangular section) through the method of finite element analysis (Fig.18.18). This foresees, first the realisation of mathematical models of the structures to be analized, then the attribution of the physical characteristics of the constitutive material to the mathematical models and finally the imposition of work conditions. The method makes it possible to highlight the different degrees of stress through the colorimetric scale and their distribution in the analized models.

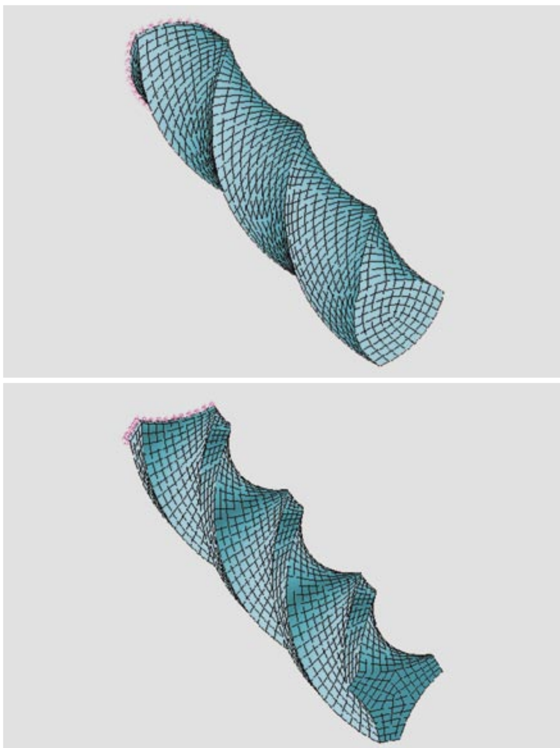
In this research stresses were compared resulting from torsion and bending moments of two cylindrical models with a diameter of 0.4 mm, one with a ProFile section the other with a ProTaper section (Fig. 18.19). First the torsion stresses were analized applying to both models a 2.5 Nmm torque. The distribution of torsion stresses in the model with the ProTaper section resulted regular and uniform, while in the ProFile



A

B

Fig.18.18. **A.** NiTi ProFile rotary instruments: cross-section particulars. **B.** NiTi ProTaper rotary instruments: cross-section particulars.



A

B

Fig. 18.19. Discrete models used to analyze the instruments with the finite element method: **A.** ProTaper model; **B.** ProFile model.

section model, high stress peaks were evidenced at the base of the blade grooves and their distribution was heterogeneous (Fig. 18.20).

Even the intensity of the stresses was in favour of the model with the ProTaper section that was working in its more superficial portion in the superelastic field (transformation phase).

The ProFile section model instead reached more elevated stresses concentrated at the base of the blade grooves, where the material had lost the characteristics of superelasticity (martensitic phase). It therefore appears evident how in the ProTaper section model the stress reach a lower intensity and a homogeneous distribution.

Then the bending stresses were analized, applying to both models a 2.9 Nmm bending moment. Even in this instance the analysis of the stresses in the two models showed how the model with the ProTaper section under equal loading reached lower stress levels which were homogeneously distributed over all the surfaces compared to the ProFile section model, which always showed higher stress values that were concentrated at the base of the blade grooves (Fig. 18.21).

A further important fact which emerges from this work is that the ProTaper section presents a larger area of almost 30% compared to the ProFile section. This translates into a lesser mass of the ProFile section compared to the ProTaper section and therefore in a moment of bending inertia noticibly lower for the ProFile section, which therefore results more compliant than the ProTaper section. The section therefore, with its shape conditions the more determinant characteristics of the NiTi rotary instruments namely: strength and compliance.

The variety of the instruments at our disposal are increasing all the time. It will be the operator who, on the basis of the endodontic anatomy to be shaped, will chose the correct operative sequence.

One must not think of the NiTi rotary instrument system as a closed system. Once the operator has interpreted the endodontic anatomy he can substitute some instruments of one system with others of another system if these should prove to be more suitable in obtaining a correct shaping.

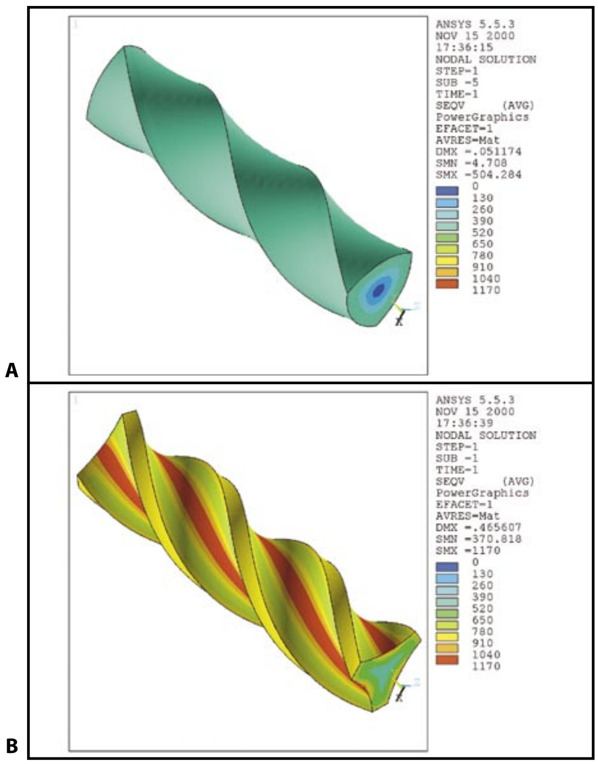


Fig. 18.20. Distribution of Von Mises stresses with an applied torque of 2.5 Nmm. **A**. One notes with a ProTaper model the even and homogenous distribution of the stresses (transformation phase). **B**. One notes with the ProFile model the high stress level (martensitic phase) reached in the base of the blade troughs.

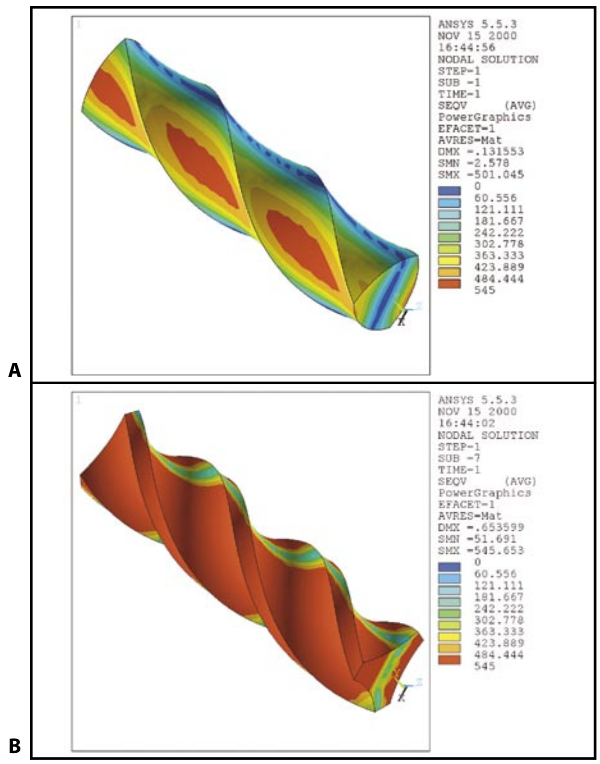


Fig. 18.21. Distribution of Von Mises stresses with an applied bending moment of 2.9 Nmm. **A**. One notes with the ProTaper model the low level of tensions (transformation phase) reached and their even and homogenous distribution. **B**. One notes with the ProFile model the high level of tensions (martensitic phase) concentrated on the base of the blade troughs.

We have already seen the different mechanical characteristics of the ProTaper and the ProFile systems.

The ProTaper is made up of six NiTi rotary instruments. Three shaping files (SX, S1, S2) with multiple and progressive taper to shape the coronal third and middle third of the canal. Three finishing files (F1, F2, F3) with respective tip diameters of 0.20, 0.25 and 0.30 mm to shape the apical third and link it up to the previously shaped coronal and middle third of the canal (Fig. 18.22).

The Pro System GT (section U File) is made up of 12 instruments with tip diameters of 0.20, 0.30 and 0.40 mm available in .04, .06, .08 and .10 taper. The maximum blade diameter is 1mm and this determines a different length for the working part of each instrument (Fig. 18.23).[16]

As we have previously seen, the characteristics of the ProTaper section make these instruments particularly strong, while the characteristics of the U File section of the Pro System GT make these instruments particularly compliant.

In complex anatomies with accentuated curves, consequently a correct operative sequence could be to use the Pro System GT instead of the ProTaper finishing to make use of its compliance in the shaping of the apical third, in harmony with the diameter of the apical foramen and using a taper indicated by the original anatomy (Fig. 18.24).

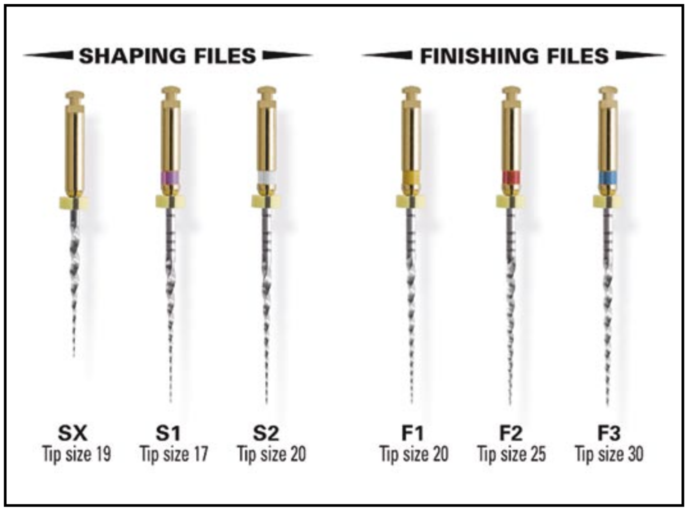


Fig. 18.22. ProTaper System.

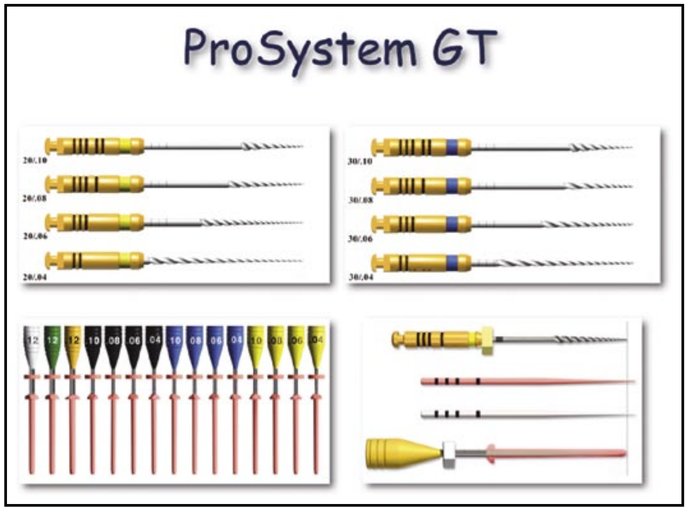
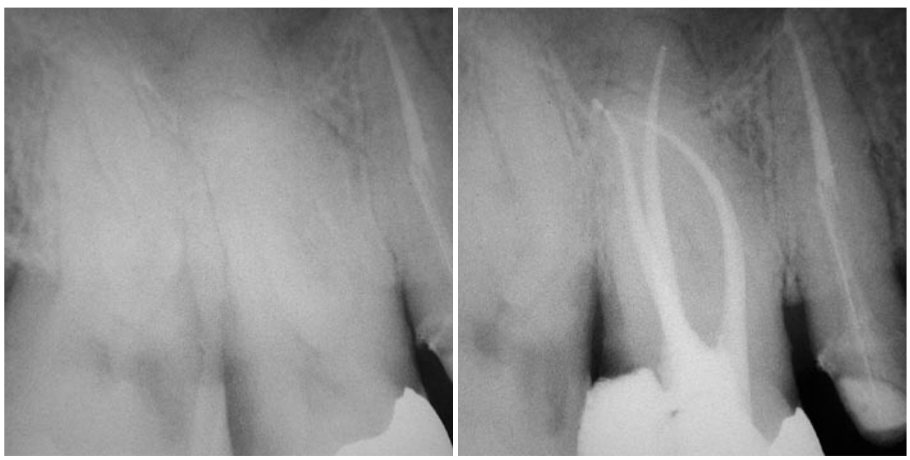


Fig. 18.23. ProSystem GT.



A B

Fig. 18.24. Clinical cases of teeth with curved canals. ProTaper S1 and S2 were used to shape the coronal third of the canal and the instruments of the ProSystem GT Series to shape the apical one third. **A**. Preoperative radiograph of the upper right first molar. **B**. Postoperative radiograph (E. Berutti) (continued).

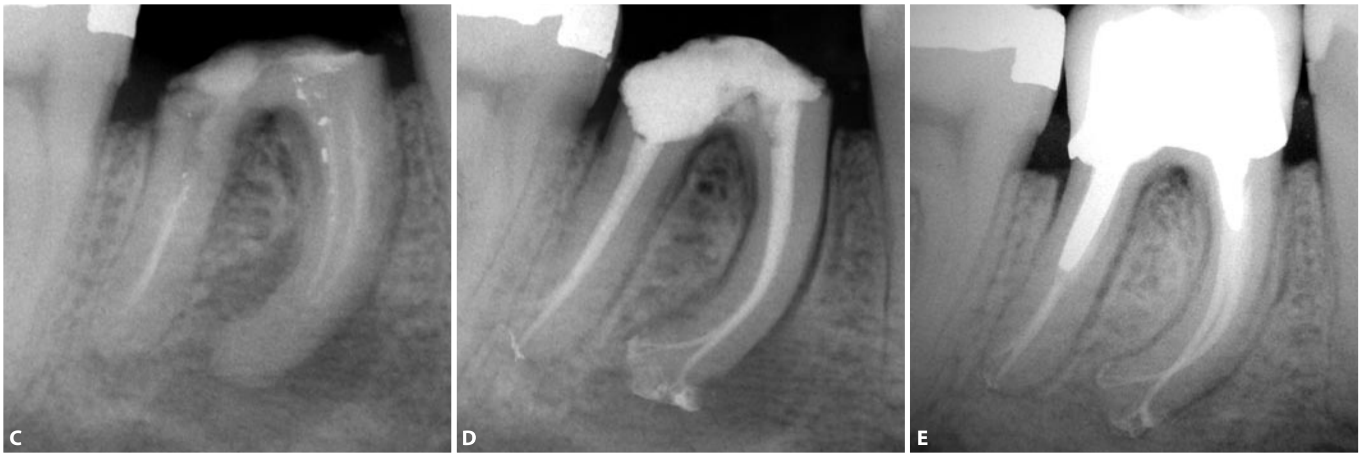


Fig. 18.24. (Continued) **C**. Preoperative radiograph of the lower right first molar. **D**. Postoperative radiograph. **E**. Follow up radiograph at six months (G. Cantatore).

ENDODONTIC MOTORS

Characteristics

As we have previously seen, the characteristics of the NiTi alloy depend on its strongly non linear behaviour. The most performatory phase for the work of the NiTi rotary instrument is the transformation phase, where one sees the superelastic characteristic and the increase in strain without a corresponding proportional increase in stress (Fig. 18.5).

To avoid an excessive and dangerous damage due to cyclic stresses in the NiTi rotary instrument, the alloy should work within this security phase.

The stress which the NiTi alloy absorbs, which is responsible for the phase variations, should be large enough to maintain it in the transformation phase.

The stress to which a NiTi rotary instrument is subjected to is completely different to the stress that a hand instrument is subjected to.

The NiTi rotary instrument in continuous rotation within a canal is subjected to bending stresses, due exclusively to the original canal anatomy and to torsional stresses, that vary as a function of the effort required to cut the dentine. A dedicated motor with which one can operate to maintain the stresses of the NiTi alloy constant is therefore decisive.

The first devices utilized were air driven. They were mounted on dental units replacing the turbines. However, they were soon abandoned because the variations in the air pressure caused the instrument to have dangerous variations of rotational speed.[79,92] Then we had electric motors dedicated to NiTi rotary instruments, able to maintain a perfectly constant rotational instrument speed. In order to do this, the torque utilized was quite high. This sometimes brought about such high stresses that breakages of the rotary NiTi instruments occurred inside the canal.

To avoid fractures as much as possible, in recent years highly soffisticated endodontic motors have been introduced on the market, with which it it possible to control the speed as well as the maximum torque (Figs. 18.25, 18.26).

To keep the speed constant, the torque varies continuously depending on the cutting difficulty and the instruments progression. Each instrument however, has a maximum torque security limit which should not be exceeded. Hence the importance of being able to regulate the maximum utilizable torque that can be reached for that instrument (type, size) for specific work conditions (original anatomy, dentine hardness).

These latest generation endodontic motors are made up of a control system that drives the electric motor which has a contra-angle reduction handpiece attached to its shaft. (ATR Tecnika contra-angle 1:16, Aseptico contra-angle 1:8).

The control system allows one to set the rotational speed and the maximum utilizable torque best indicated for each individual instrument and for each specific working condition. This data can be memorized and therefore successively re-used. The control system is able to store a large amount of data, thereby allowing the operator to utilize many different NiTi rotary instrument systems.

As we have said these endodontic motors allow one to set the desired maximum utilizable torque. When

A

B

Fig. 18.25. **A**. Endodontic motor Tecnika Vision (ATR and Sirona Company, Italy). **B**. Endodontic motor DTC (Aseptico, USA).

A

B

Fig. 18.26. **A**. Endodontic motor DentaPort (J. Morita Corp., Japan). **B**. Endodontic motor X-Smart (Dentsply Maillefer, Ballaigues, Switzerland).

the instrument, working in the canal, reaches this value, the operator can choose to utilize a signalling system provided for in the motor: acoustic signal and /or inversion of the rotational direction (autoreverse).

When the maximum torque value preset by the operator has been reached the motor will reverse the rotation and the instrument turning anti-clockwise, will automatically exit the canal.

The most evolved endodontic motors (ATR Tecnika) pride themselves on having a soffisticated autoreverse control system which is primed in a fraction of a second, so as to prevent further stress fatigue damage in the NiTi rotary instrument, once the preset maximum torque value has been reached.

Formulation

The correct formulation of the endodontic motors is indispensable to guarantee the efficient use of the NiTi rotary instruments. Efficiency means maximum durability of the instrument without risk of fracture. We have previously seen how all endodontic motors available today are torque controlled. On the basis of the NiTi rotary instrument characteristics and on the basis of the original anatomy characteristics, the operator will have to set the rotational speed and the maximum utilizable torque, that is the highest torque value that the instrument can reach before the endodontic motor automatically triggers the autoreverse.

Until now we have spoken of rotational speed and maximum utilizable torque that the instrument can withstand without risks. It is evident how the two parameters are closely linked.

If the speed increases then as a consequence the torque will increase so as to maintain the rotational speed increase of the instrument constant.[79,91] Proportionally however, the risks of fracturing the instrument inside the root canal also increases.[5,92]

If the rotational speed is too low, the instrument will tend to come to a halt within the canal, its work will be discontinuous, with the risk of an excessive fatigue damage due to stresses especially in the successive anti-clockwise rotation which is necessary to disengage the instrument.[35]

The correct balance is therefore needed between these two values to obtain the maximum efficiency without risks.

The introduction of an endodontic motor that allows the regulation of the utilizable maximum torque value that the NiTi rotary instrument will be able to reach during its work, has the aim of preventing the fracture of the instrument inside the canal. Consequently the utilizable maximum torque value that the operator sets on the endodontic motor will have to be lower than the torque value able to produce plastic strain and then fracture of the NiTi rotary instrument at that speed of rotation.[40,91,92]

The maximum utilizable torque value must however not be too low because in this case the cutting efficiency of the instrument would decrease excessively and the progression of the instrument in the canal would be difficult. Consequently the operator would tend to push on the handpiece of the endodontic motor to aid the progression of the instrument in the canal with a high risk of fracturing it.[40,91,92] These two parameters, speed and torque, are specific for each system of NiTi rotary instruments and often for each instrument within the system.

These parameters are determined by the mechanical characteristics and size of the instruments.

We have previously seen how the section of the mechanical instrument determines its properties. For example the ProTaper section (triangular convex) proved to be very resistant to torsional and bending stresses. It follows that it will be able to withstand elevated stress in terms of rotational speed and utilizable maximum torque.

The ProFile (U File) section proved to be more flexible by comparison to the ProTaper section because the ProFile section, for equal diameter, has a 30% inferior mass compared with the ProTaper section and therefore proves to be more compliant. This lower mass means however, also a lesser strength to the stresses and consequently to the rotational speed values and utilizable maximum torque that the instrument is able to withstand without risks.

Even the design of the blades and therefore the cutting capacity are important.

The more the blades are active, (ProTaper System; Dentsply/Maillefer) and therefore able to cut the dentine, the more the utilizable maximum torque value can rise (Fig. 18.18). This because the cutting efficiency is translated into ease of progression in the canal by the instrument and generically because cutting efficiency is determined by a reduced surface contact between blade and canal walls.

It follows that the torsional stresses during the cutting of the dentine are reduced. The NiTi rotary instrument in this way be able to work with a high maximum torque, without fatigue damage increase. On the contrary, if the blades have a reduced cutting capacity (ProFile System, Dentsply/Maillefer) the stresses which are generated during the working of the instrument are increased (Fig. 18.18). These are principally determined by the friction that occurs between the blades and the canal walls. The torque required to induce the instrument to advance in the canal will be high because the removal of the dentine will be less effective with the risk of an excessive fatigue damage due to cyclic stresses.[89] These instruments must therefore be used cautiously and with low maximum torque values, to prevent an excessive accummulation of stress on the part of the instrument.

A further characteristic of the NiTi instrument is its size and calibre.

If the instrument size increases then its resistance to torsional stress also increases.[10,66] On the contrary instruments with small apical portions will not be able to withstand elevated torsional stresses (Fig. 18.27).[10,89,92] This consideration is only valid for the NiTi rotary instruments with constant taper (ProFile, System GT, Hero, K3 etc). The NiTi rotary instruments with multiple taper (ProTaper), having in the shape of the instrument itself the crown-down technique and therefore each one working in a specific sector of the canal, are all utilized at the same rotational speed and with a high utilizable maximum torque. (300 rev. per minute, 100% torque value in Tecnika ATR). Such a high torque enhances the marked cutting ability of the ProTaper, thereby considerably reducing the working time.

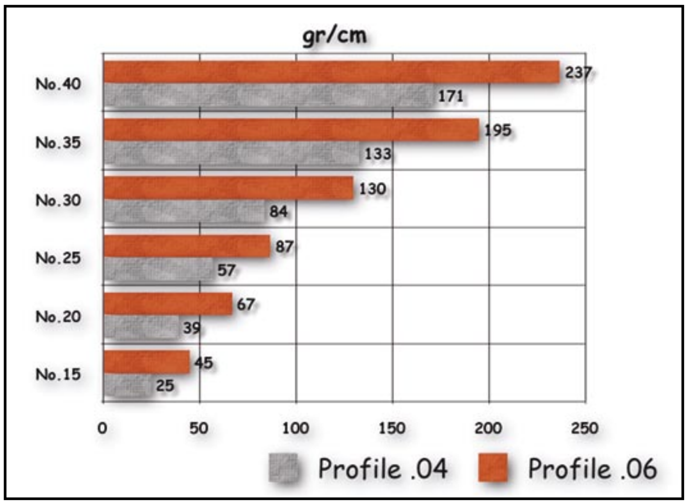


Fig. 18.27. Diagram illustrating how the torsional resistance increases with the increase in taper. Comparison between the ProFile .04 and the ProFile .06.

LIFE OF THE NITI ROTARY INSTRUMENT

After having examined the technical characteristics and the operative sequence, the obligatory questions are: “how long do these instruments last? how many canals are we able to shape?”

We have previously seen how the stress accummulated by the instrument during its work is dependent on the tip size, on the taper, on the canal width and on the manual pressure exerted on the handpiece of the endodontic motor, by the operator.[66]

The life of the NiTi rotary instrument is directly proportional to the stress which it accummulates during its work within the canal.[31,88,95]

Pruett et al.[58] have demonstrated that the life of the NiTi rotary instruments are strictly related to the number of cycles performed by the instruments within the canal.

Naturally, life is different for each type of instrument, but it is extremely constant for instruments having the same characteristics.

We can compare the NiTi rotary instrument with a car having a full tank of fuel. The fuel can be used to go uphill, downhill, on a flat terrain, on a motorway or to journey on a mixed terrain. Naturally the consumption and consequently the distance covered will be different.

An important role is also played by the driver: if he uses the accelerator sparingly the comsumption will most likely be reduced and it follows that the distance covered will be greater.

The NiTi rotary instrument, created with its tank full of fuel (life), will be used to shape simple endodontic anatomies, complex ones, or a combination of these.

Let us now examine the criteria that will influence the life of the instrument:

1) Original canal anatomy
2) Mechanical characteristics of the NiTi rotary instruments
3) Rotational speed and maximum torque values when using NiTi rotary instruments
4) Characteristics of the work carried out by the NiTi rotary instruments
5) Operator ability

1. Original anatomy of the canal

The original anatomy of the canal is certainly the factor that most conditions the life span of the NiTi rotary instrument.[66]

We have previously seen how strain is to a large extent determined by the bending stress that the NiTi rotary instrument experiences during preparation of the curvature of the root canal.[71] Some Authors[32,58] do not consider rotational speed significant as a factor favouring the fracture of NiTi rotary instruments. On the contrary various studies[27,29,51] have shown that instrument rotational speed in curved canals has a notable influence on the life of the NiTi rotary instruments. It is intuitive that increasing the speed also increases the contact with the canal wall and therefore the amount of debris between the instrument blades and the wall.[29,67] But the determining factor always seems to be the number of rotations the instrument makes in the curve. Yared[88] has shown that the longevity of the instrument is strictly correlated to the number of rotations it makes inside the canal. The more complex the anatomy is, the more wear there is in terms of increased fatigue damage and therefore the life of the instrument is reduced. Therefore the curve radius and angle of the canal which the instrument has to shape is determinant in the cyclic fatigue of the instrument (Figs. 18.28, 18.29).[42,51,58,93]

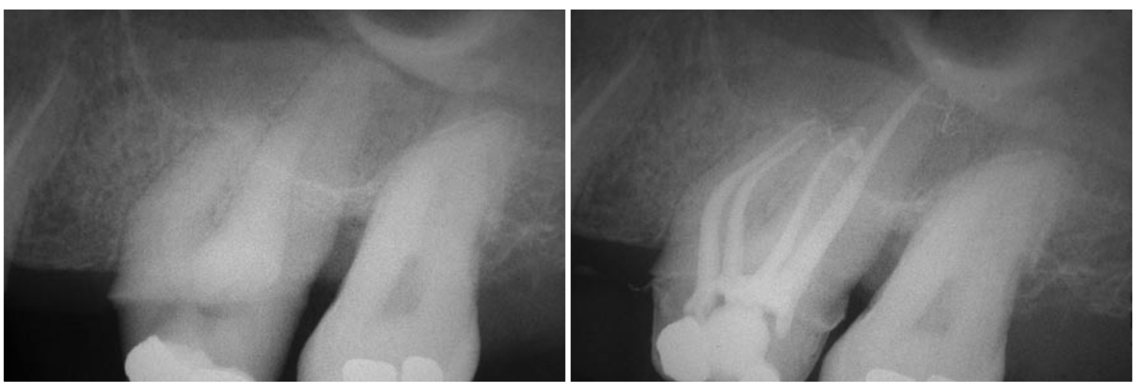
A  B

Fig. 18.28. Clinical cases of teeth with canals having moderate curvatures. **A.** Preoperative radiograph of the upper left first molar. **B.** Postoperative radiograph (E. Berutti) (continued).

C D E

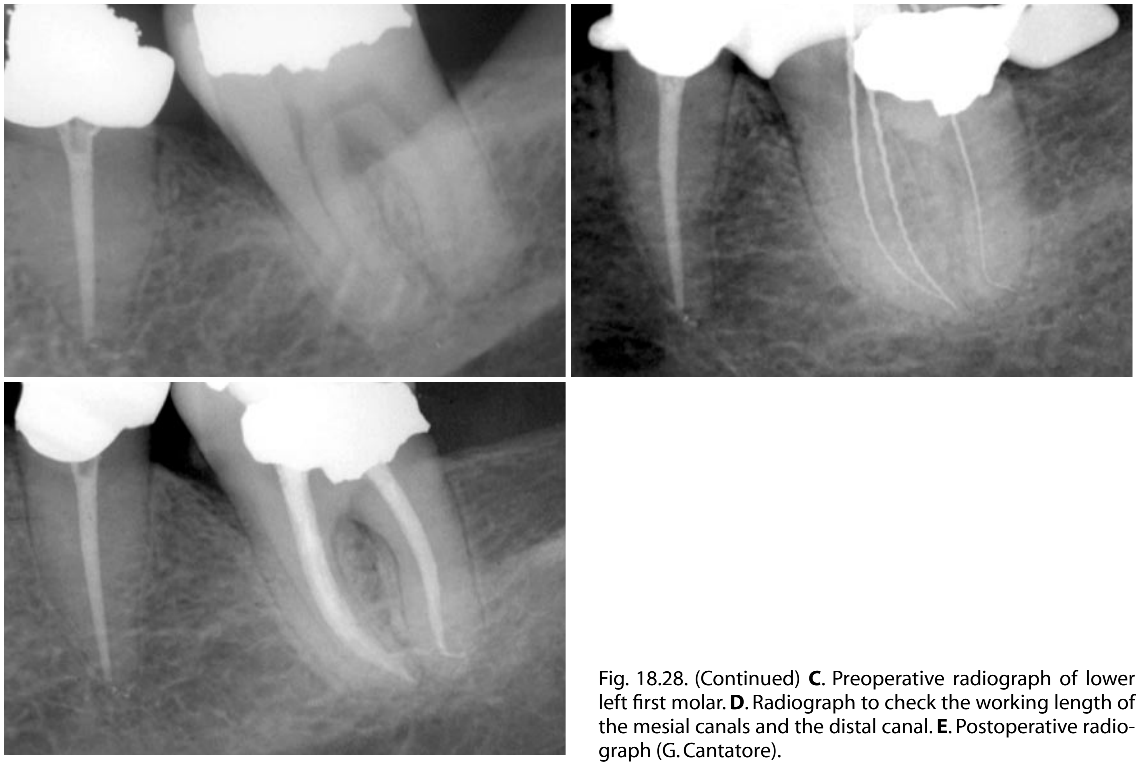


Fig. 18.28. (Continued) **C**. Preoperative radiograph of lower left first molar. **D**. Radiograph to check the working length of the mesial canals and the distal canal. **E**. Postoperative radiograph (G. Cantatore).

A B C

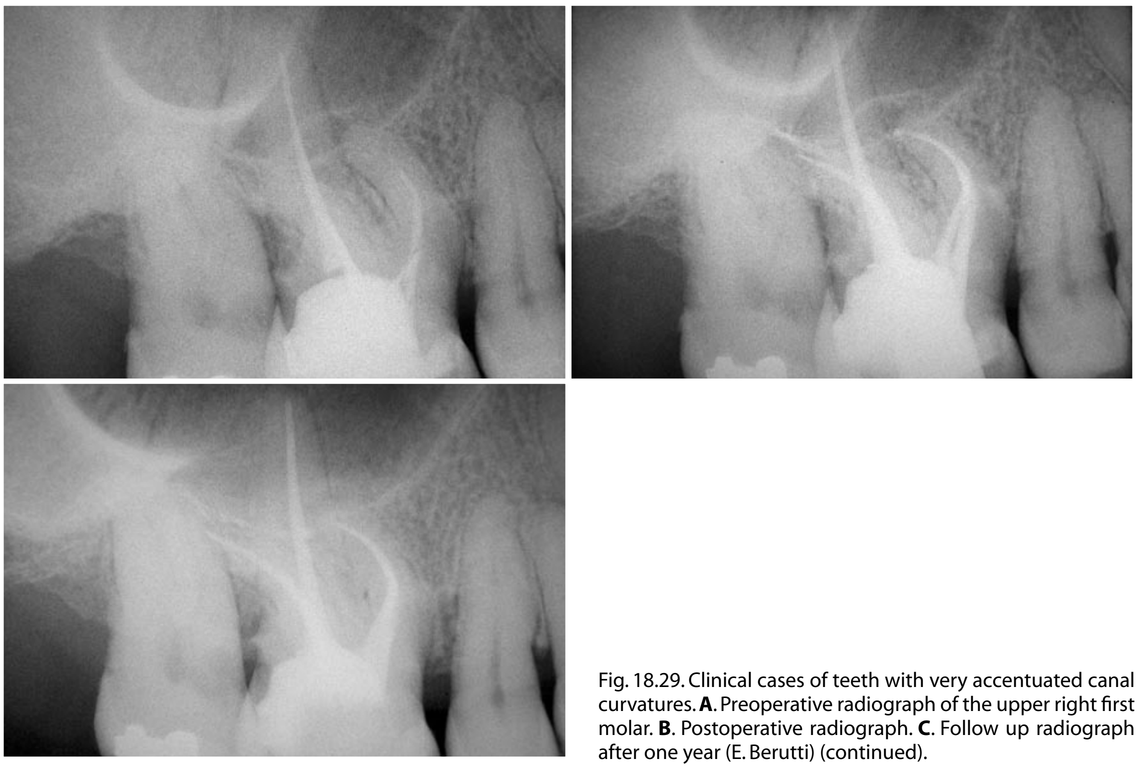
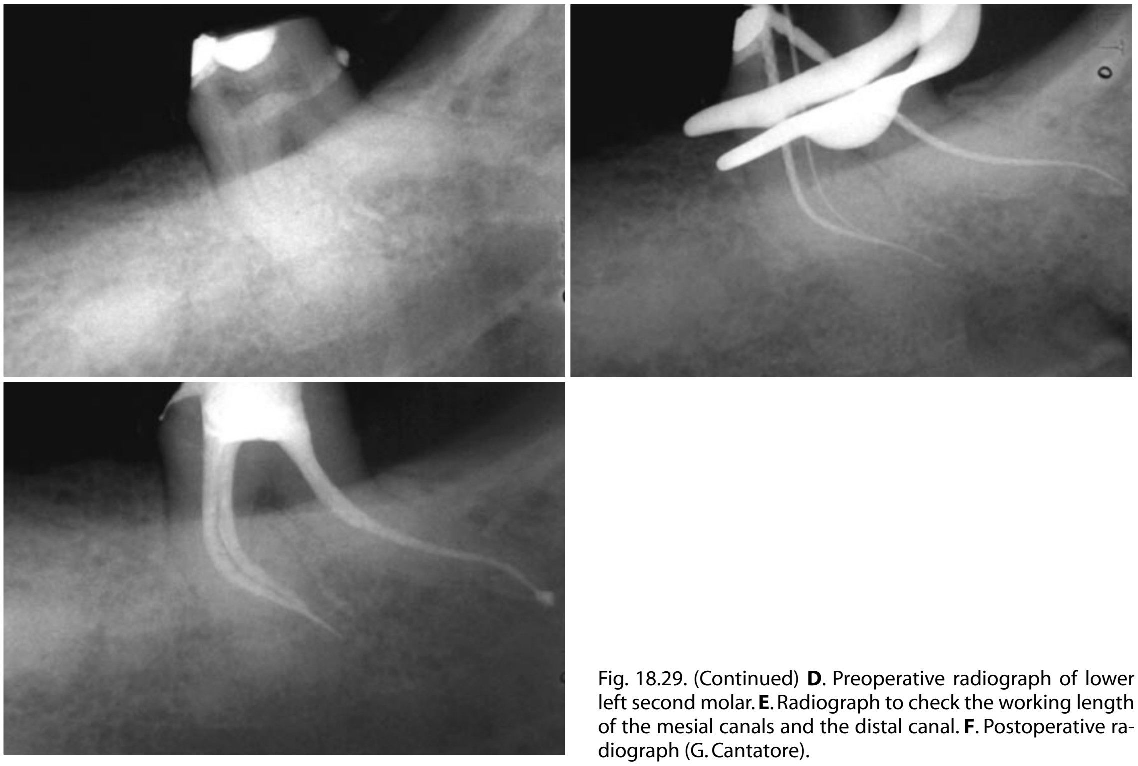


Fig. 18.29. Clinical cases of teeth with very accentuated canal curvatures. **A**. Preoperative radiograph of the upper right first molar. **B**. Postoperative radiograph. **C**. Follow up radiograph after one year (E. Berutti) (continued).



D E F

Fig. 18.29. (Continued) **D**. Preoperative radiograph of lower left second molar. **E**. Radiograph to check the working length of the mesial canals and the distal canal. **F**. Postoperative radiograph (G. Cantatore).

The original anatomy of the canal however, with its curvatures is not the only factor in reducing the life of the instrument, since the size of the canal and the characteristics of the dentine are also decisive.

The cutting ability of the NiTi instrument tip is not generically very efficient. This causes an immediate increase in the torsional stress that the instrument accummulates when it must advance in those canal sections of equal or inferior diameter to its tip diameter.[10]

This is easily detectable by the immediate increase of the torque values that the engine must supply to overcome the obstacle. This fact is easily detectable for example on the Tecnika ATR motor display, where one can see the torque variations on a digital and acoustic indicator. To this end we must recall the importance of a manual preshaping which prevents the engagement of the NiTi rotary instrument tip against the canal walls, in this way drastically reducing the torsional stress.[4,12,45,57,65] Even bending stress is partially reduced after a manual preshaping. The enlargement of a root canal will produce gentler curves which are therefore less demanding. The life of the instrument will thus be considerably increased. Blum et al.[10] have shown that the coronal interferences are responsible for high levels of stress that the NiTi rotary instrument accummulates during its work.

Dentine hardness also affects the accummulation of torsional stress. Pulp characteristics and consequently those of the dentine change as time passes due to normal ageing or to pathological events such a, pulpal inflamation and trauma. The result of these events frequently results in a dentine hypermineralization and in a considerable reduction of the endodontic space.

Harder dentine requires a proportional increase in the torque value needed to cut it. This results in an increase of the torsional stress which reduces the life of the instrument.

Even in these specific clinical conditions a manual pre-flaring and the abundant use of chelators and lubrificants aid the work of NiTi rotary instruments.

2. Mechanical characteristics of the selected instruments

Theoretically to optimize the use of NiTi rotary instruments and to avoid problems (fractures) the instrument should be subjected to low levels of stress. We have previously seen at great length how the shape of the instrument determines the mechanical properties. The more the section is able to withstand high levels of torsional stress the more it is resistant. The more the section has a low bending moment, the more compliant it is and therefore able to respect the original canal anatomy.[58,81]

The capability of an instrument to resist the stress and at the same moment to respect the curvature of the canal is therefore a compromise between the torsional and bending characteristics of its section.[22,38]

If we want an extremely compliant instrument we must accept that its working life will not be as long as that of an instrument which is more resistant but less flexible. Strength and compliance are correlated to the mass of the section: the more the mass is reduced, the more the instrument will be compliant and consequently less resistant and vice versa.

Instruments with the same characteristics have different mechanical behaviours in relation to their size. If the instrument has a small calibre, it has reduced strength capabilities to torsional stress, if on the contrary it is big, it is more prone to fracture because of bending stress (Figs. 18.30, 18.31).[58,67] This in part explains the unexpected fractures when we work with large instruments in the final phases of the shaping. We must therefore think of small instruments as having a low strength to torsional stress and of large instruments as having a low strength to bending stress.

The operator will be able to prevent the fracture of the instruments within the canal by a having a precise treatment plan that provides for the correct choice of instruments and operative sequence suited for the specific canal anatomy that has to be shaped. If for example one has to shape a canal that has an extreme curvature , one should use an instument with reduced taper (.06, .04) because as we said before they more resistant to cyclic fatigue (Fig. 18.32). Instead if one has to shape a canal that is extremely narrow and calcified it would be necessary to firstly carry out an adequate manual preshaping to to reduce the torsional stress (Fig. 18.33). Finally to prevent possible fractures, all the NiTi rotary instruments must be accurately checked, using magnification, before and after every use.

The instrument which presents the slightest sign of plastic strain (increase or decrease of the spiral gaps) should be eliminated immediately (Fig. 18.34).[30,80]

The NiTi rotary instruments differ from the stainless steel instruments in that the first signs of fatigue are not always visible.[49,58] If a fracture has occurred because of torsion in some cases signs of plastic strain are visible just above the fracture point.[67] If instead the fracture has occurred because of fatigue(flexion)the signs of instrument deterioration are not evident.[67] If the canal anatomy is extremely complex (severe curvatures, calcified canal) the NiTi rotary instruments must be considered single use only.[4]

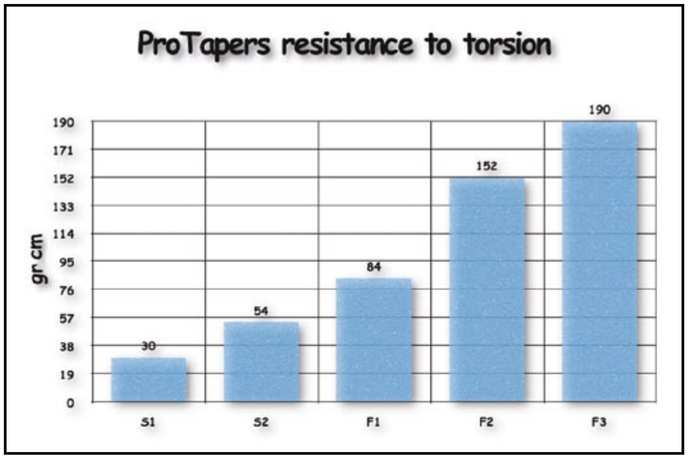


Fig. 18.30. Diagram illustrating how the strength to torsion increases with the increase in the diameter of the instrument. Comparison between the instruments of the ProTaper Series.

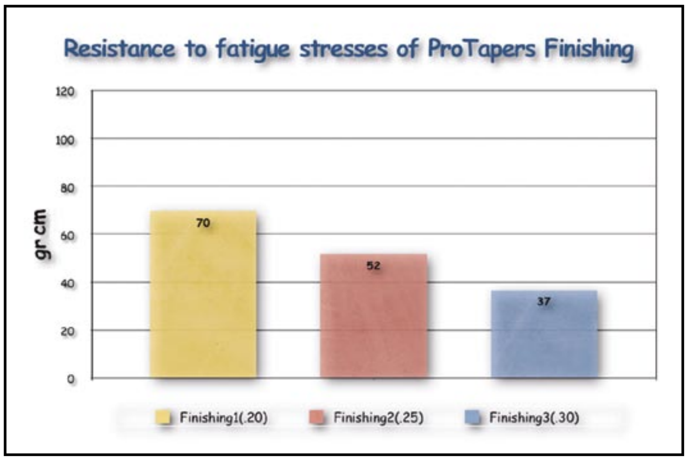


Fig. 18.31. Diagram illustrating how the resistance to bending increases with the reduction of the cross-section diameter of the instrument. Comparison between the Finishing instruments of the ProTaper Series.

Fig. 18.32. Clinical cases of teeth with very accentuated canal curvatures. In these cases it is important to use NiTi rotary instruments with low taper to prevent fracture due to cyclical fatigue. **A**. Preoperative radiograph of a lower left third molar. **B**. Postoperative radiograph. **C**. Follow up radiograph after one year (E. Berutti). **D**. Preoperative radiograph of a lower right second molar. **E**. Postoperative radiograph (E. Berutti). **F**. Preoperative radiograph of a lower right second molar. **G**. Radiograph to check the working length of the mesial canals and the distal canal. **H**. Postoperative radiograph (G. Cantatore).

Fig. 18.33. Clinical cases of teeth with calcified canals. In these cases it is very important to have an adequate manual preflaring to reduce torsional stresses. **A**. Preoperative radiograph of the lower right first molar. **B**. Post operative radiograph (E. Berutti). **C**. Preoperative radiograph of the lower left third molar. **D**. Postoperative radiograph (G. Cantatore).

Fig. 18.34. ProFile .06 with visible plastic deformation.

3. Rotational speed and maximum torque values for NiTi rotary instruments

We have seen before how important the balance is between the rotational speed, which should be constant and the maximum torque used, which should be less than the torque value necessary to cause plastic strain and subsequently fracture of theNiTi rotary instrument.[40,91,92]

It is therefore essential to use an electric motor that allows one to set the rotational speed and maximum torque value to be used according to the recommendation of the manufacturer for the particular rotary NiTi rotary instruments.

4. Characteristics of the work carried out

The characteristics of the work carried out by the NiTi rotary instrument have a very important role.[23] There are two factors which influence the work of the instrument:
- the section of the working part directly involved with the cutting
- the depth at which the instrument carries out its work within the canal.

The smaller the working portion of the instrument directly involved with cutting the dentine, the lower the torsional stresses. This is carried out with the instruments using the crown-down technique (Figs. 18.10, 18.11).

The more the instruments work deeply into the canal, the more their life is reduced, whether they work in areas where the canal is narrow and often with accentuated curvatures, or because the instrument works with the smallest portion of its working part. To this end we must remember the importance of not remaining stationary with the NiTi rotary instrument within the canal. Once the maximum working depth for that instrument is reached, one must remove it immediately. This allows a homogenous distribution of bending and torsional stress in the entire working area of the instrument. In this way dangerous areas due to damage will not be created.

At this point it is important to make a comment: within a series of NiTi rotary instruments each one has a different life in relation to its size and to the characteristics of the work carried out within the canal. This is particularly evident for the instruments of the ProTaper System (Dentsply/Maillefer) instruments with multiple taper along their working part.

Berutti et al.[7] have verified how many endodontic simulators the instruments of the ProTaper System S1, S2, F1, F2 utilized in sequence were able to shape before breaking.

These were the results:

S1: 59 endodontic simulators before breaking. The multiple taper of the S1 limits the work to only the coronal one third of the canal.

S2: 48 endodontic simulators before breaking. The multiple taper of the S2 limits the work to the middle one third of the canal. The first observation is that the life of these two instruments under these conditions is very long. However, they work in the areas of the canal, closest to the crown with the largest and strongest sections of their working parts.

F1: 23 endodontic simulators before breaking.

F2: 11 endodontic simulators before breaking.

These two instruments shape the apical one third of the canal. They are subjected to very high bending and torsional stresses in the smallest and consequently weakest section of their working part (apical 3 mm). A further important fact that emerged from this study is that if the instruments of the ProTaper System work with a lower torque, they have a considerably shorted life.

The following results were obtained using the Tecnika ATR endodontic motor (Fig. 18.35):

S2: torque 20%, speed 300 rpm = 28 simulators before breaking.

S2: torque 80%, speed 300 rpm = 48 simulators before breaking.

F1: torque 28%, speed 300 rpm = 8 simulators before breaking.

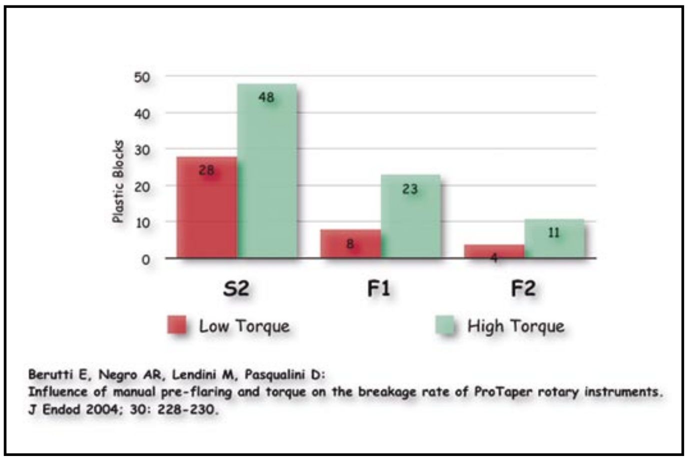


Fig. 18.35. Diagram illustrating how torque influences the longevity of ProTaper S2, F1, F2 NiTi rotary instruments.

F1: torque 100%, speed 300 rpm = 23 simulators before breaking.
F2: torque 40%, speed 300 rpm = 4 simulators before breaking
F2: torque 100%, speed 300 rpm = 11 simulators before breaking.

This notable and constant difference in the life of the tested ProTaper System instruments resulted from the frequent insertion of the autoreverse of the endodontic motor when the utilizable torque was low. Instead when the instruments worked with a high torque, the autoreverse was never switched on. The autoreverse is not harmful, infact it is an excellent security system, especially for the instruments that have to work with a low utilizable maximum torque (ProFile, System GT etc).

It is however a system that in inverting the clockwise rotation of the instrument when it reached utilizable maximum torque value involves a certain effort (Fig. 18.36). This means stresses that the instrument stores and consequently a reduction of its life.

If possible, the operator should avoid all superfluous work for the NiTi rotary instrument. If the instruments require a low usable torque, it is sufficient to allow oneself to be guided by the digital and acoustic indicator of the endodontic motor and to withdraw the instrument just before the autoreverse sets in. In this way we will avoid superfluous stress, limiting the life of the endodontic instrument to only the cutting of the dentine in harmony with the complexity of the endodontic anatomy.

If one analyses the diagrams that summarise the number of simulators shaped using the ProTaper S1, S2, F1, F2 in the study done by Berutti et al.[7] it becomes evident that there is a continuous reduction in the life of the ProTaper rotary instruments from S1 to F2 (Fig. 18.37). This is true although only for canals shaped using endodontic simulators.

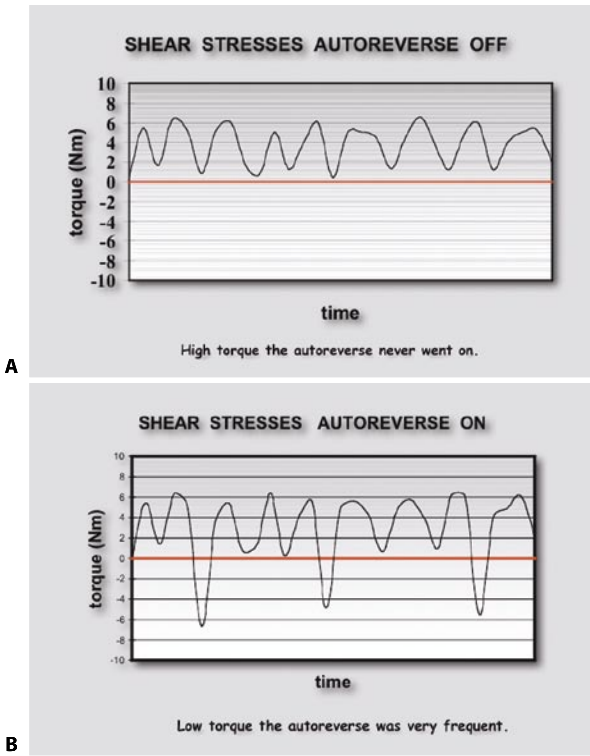


Fig. 18.36. Registration of the torque variation during use of a ProTaper F2 to reach the canal terminus in a plastic block. **A.** High torque: one notes the regular variation of torque and their low intensity. **B.** Low torque: one notes the enormous variation of the torque during activation of the autoreverse by the endodontic motor. The instrument carries out twice the work load when the autoreverse is activated.

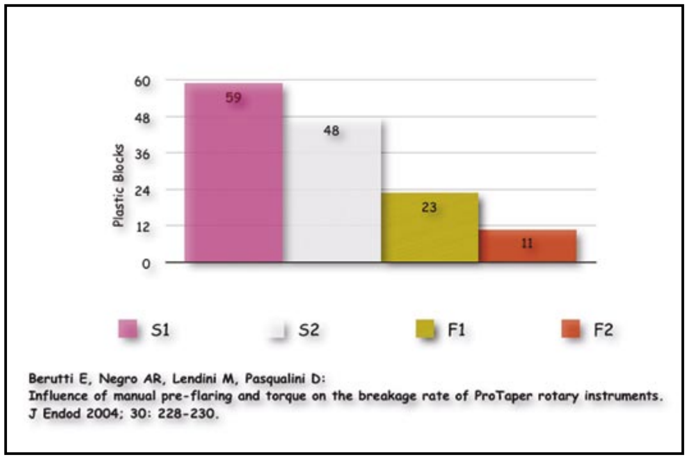


Fig. 18.37. Diagram illustrating the number of plastic blocks shaped by the ProTaper S1, S2, F1, F2 NiTi rotary instruments before fracturing.

The endodontic simulators do not crrespond to the clinical reality for two reasons:
1) the simulator canals are all the same which explains the propotionality of the data obtained
2) the simulators are made from plastic which has completely different characteristics to that of root canal dentin.

To obtain data closer to reality one must therefore simulate the clinical situation as closely as possible by using root canals of human teeth. In this regard, the successive work done by Berutti et al.[8] done on 410 extracted permanent human teeth with a total of 677 canals is particularly interesting. In this study the ProTaper S2 proved to have the longest life of the series while the F2 had the shortest life.

5. Operator ability

It has been demonstrated that the experience of the operator is decisive in preventing the fracture of the NiTi rotary instruments inside the canal.[40,48,90-92]

The inexperienced operator probably exercises an excessive apical pressure during the use of the NiTi rotary instruments.[48,54] This brings about excessive friction of the instrument blades against the canal walls. The NiTi rotary instrument is in this way immediately subjected to very high torque levels necessary to maintain the speed constant.[79] The result is either an excessive accumulation of fatigue damage due to torsional stresses or even a plastic strain and then the instrument fractures. Sattapan et al.[67] have demonstrated that torsional fractures are more frequent (55,7%) compared with fractures from bending stress (44,3%) and they are brought about by the operator who excercises an excessive apical pressure during the use of the NiTi rotary instruments. Blum et al.[10] have shown that the levels of maximum stress are generated during the penetration phase of the instrument in the canal rather than during the retraction phase.

Very important in fracture prevention is also the method of use.[11,74] The inexperienced operator also tends to hesitate with the instrument in rotation inside the canal for too long. Mesgouez et al.[52] studied the relationship that exists between the experience of the operator and the time required to shape the canals. They used the NiTi Profile rotary instruments and endodontic simulators. The results showed that the time required to shape a canal was inversely proportional to the operators experience. Berutti et al.[8] previously carried out a similar study using 410 extracted permanent human teeth with a total of 677 canals. The NiTi rotary instruments used were the ProTaper. The diagram showed in Fig. 18.38 summarises the average time each instrument of the ProTaper series was used to shape a single canal by an experienced operator and by an inexperienced operator. The experienced operator is able to shape more canals because the average working time with each instrument is inferior to that of an inexperienced operator. The inexperienced operator is afraid of advancing and withdrawing the instrument in the canal. Therefore more time is required. This causes an unecessary stress overload which the instrument accumulated during the excessive amount of time spent rotating in the canals. If it is true that the operator must not apply excessive manual pressure on the handpiece,[79] then it is also true that the instruments must complete their work inside the canal in the least amount of time possible.[8,47,52,58,81] As we have emphasised previously the movement must be continuous and fluid on entering the canal and also on withdrawal.

This brings about a useless overload of stress that the instrument accummulates. If the operator then keeps the rotating instrument stationary while in a curve of the canal, a damaged area is created that corresponds to the section with the lowest curvature radius, where the bending stress are at a maximum. Sattapan et al.[66] have demonstrated that if the instrument is utilized with a light back and forth movement, the stress which develop in the apical area of the instrument are relatively low even in narrow canals, independantly of instrument size and taper. The expert operator is able to feel the advance of the NiTi rotary instrument in the canal on the handpiece and can therefore guide it with the correct pressure and extract it immediately when it reaches the desired working length.

Some operators have the tendency to incline the endodontic motor handpiece.

In this way a curvature is created of the instrument outside of the canal and an increase in the load on the instrument portion inside the canal. Even in this case there will be an increase in stress and in the risk of fracture of the NiTi rotary instrument.[79]

One must also note how many times accidents happen at the end of the shaping, during final passage with the last instrument.

This is perhaps brought about by a decrease in concentration on the part of the operator, who knowing that he/she is at the end of the work, doesn't keep rigidly to the rules and perhaps exerts excessive pressu-

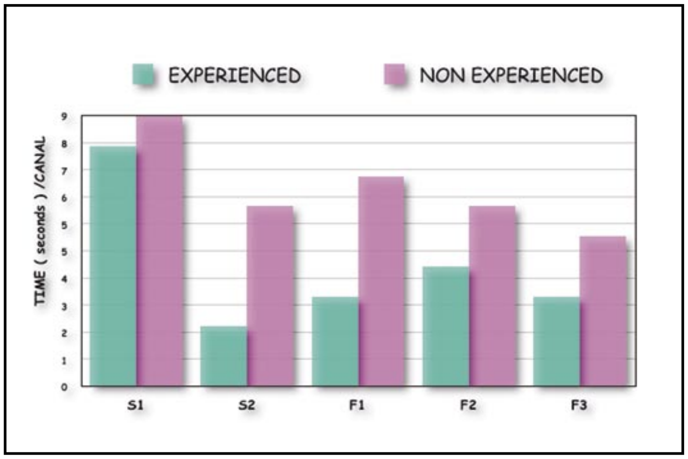
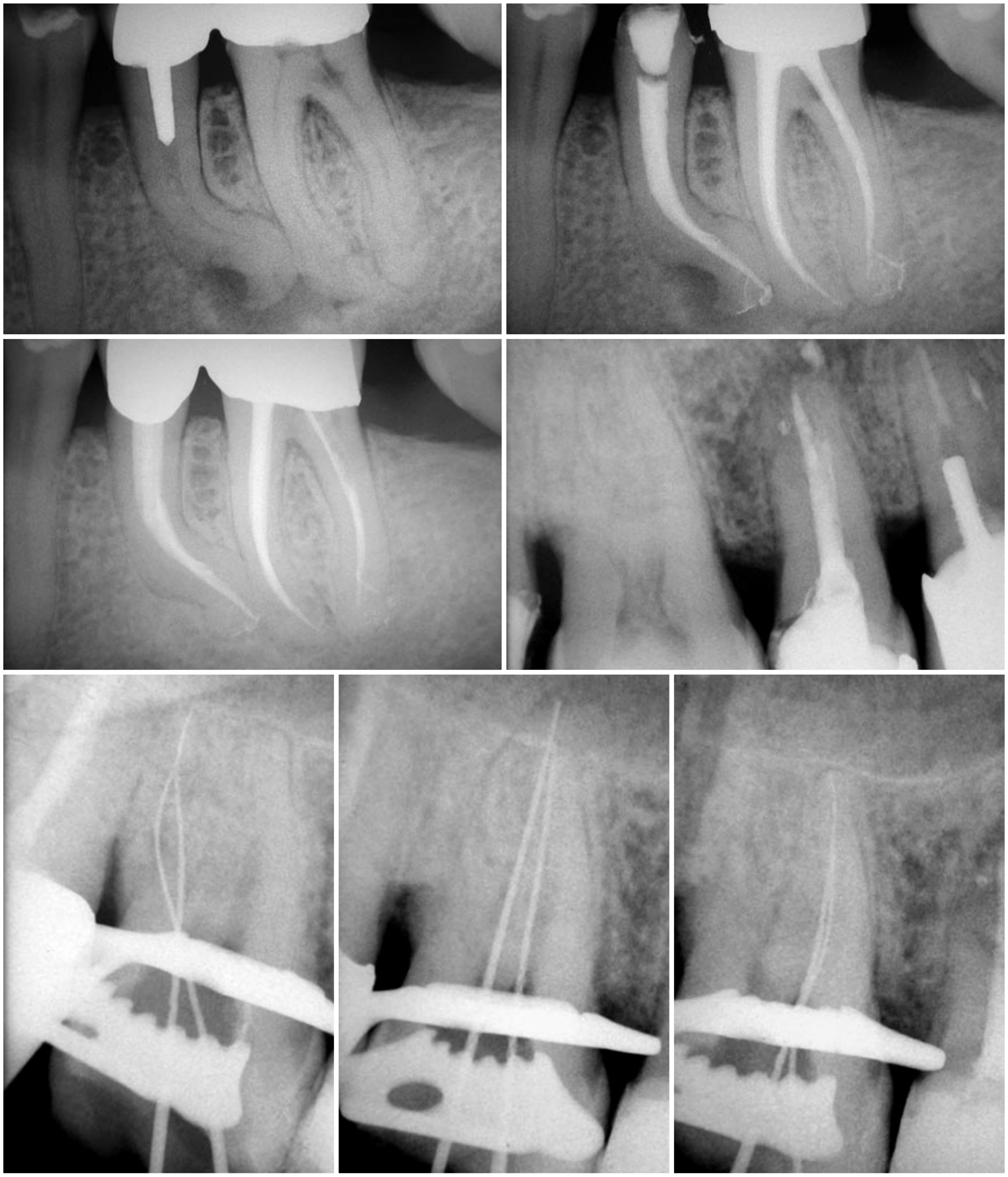


Fig. 18.38. Diagram illustrating the average time of use of each ProTaper S1, S2, F1, F2, F3 NiTi rotary instruments to shape a root canal by a skilled operator (green) and by a not skilled operator (purple).

re on the handpiece to end the treatment rapidly.[19,47,88] Yared et al.[88] recommend that the use of NiTi rotary instruments follows rigid guidelines: the apical pressure that is exerted on the instrument must be very light, and its use inside the canal must last only a few seconds.

During the manual preshaping, the experienced operator will be able to enterpret the difficulties presented by the original canal anatomy. If the original canal anatomy is complex, manual shaping will be more important in reducing the stresses in the NiTi rotary instruments that will follow (Fig. 18.39).



A B C D E F G

Fig. 18.39. Clinical cases of teeth with canals having a complex original anatomy. In these cases manual preflaring will be more important in order to reduce stresses in the successive NiTi rotary instruments. **A**. Preoperative radiograph of a lower left second premolar. **B**. Postoperative radiograph. **C**. Follow up radiograph after one year (E. Berutti). **D**. Preoperative radiograph of the upper right first molar. **E**. Radiograph to check the working length of the distal canals. **F**. Radiograph to check the working length of the palatal canals. **G**. Radiograph to check working length of mesial canals (continued).

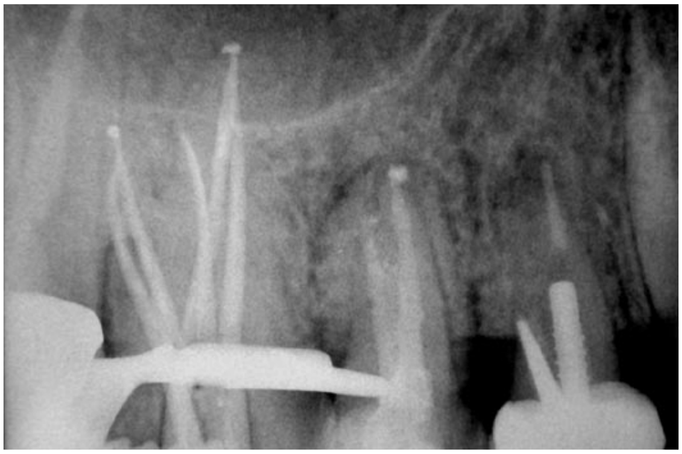


Fig. 18.39. (Continued) **H**. Postoperative radiograph (G. Cantatore).

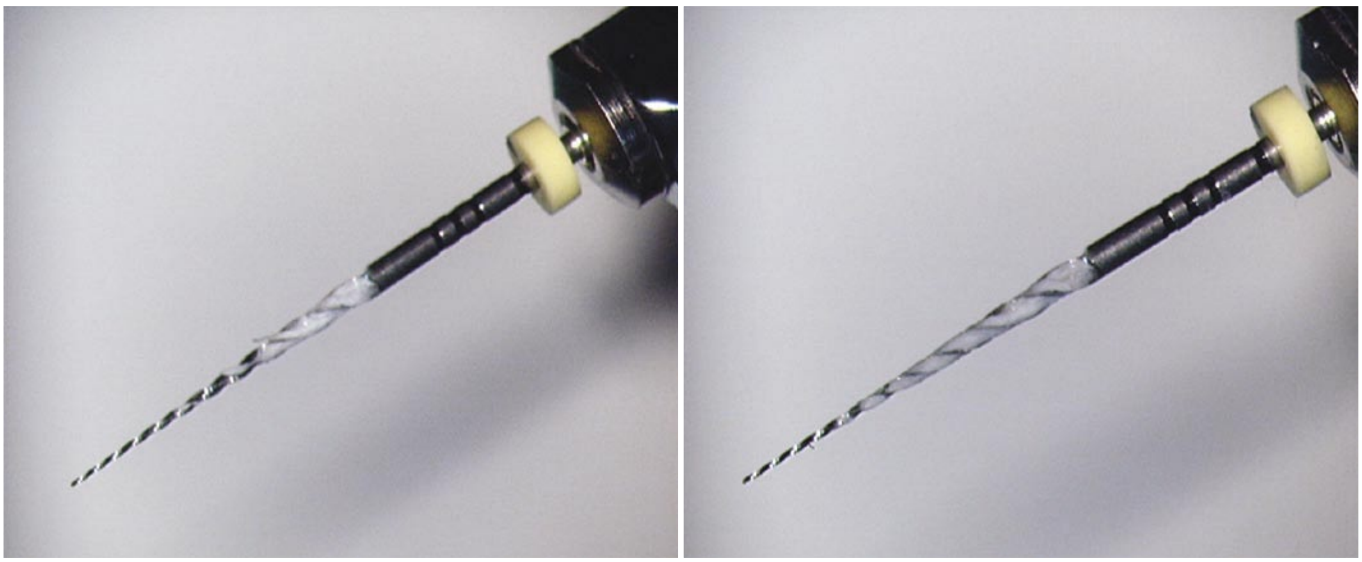
We must be aware that, as Ruddle taught us "its the original canal anatomy that determines the game plan". The experienced operator will have to carefully check, using a magnification system, each instrument after having used it inside the canal, not only to verify its good working condition, but also to understand the workload it carried out. If a large portion of the working part is full of dentinal debris, the work carried out by the instrument has been significant. If then the portion of the working part concerned with the cutting was the apical part, it means that the instrument has worked in a very narrow canal and that the price for enlarging it was very high in terms of accummulated stresses (Fig. 18.40). The life of that instrument could be at an end.

The working length of the NiTi rotary instruments often does not have to coincide with the working length of the canal. This is especially so when the complexity of the anatomy of the apical third can favour the fracture of the NiTi rotary instruments and / or the incorrect shaping of this important portion of the root canal (Fig. 18.41).

Even the choice of the NiTi rotary instruments and the correct operative sequence will have to be modulated in relation to each specific clinical case.

In this mechanistic age therefore it will always be the operator with his choices and his manual dexterity, that will know how to make the difference.

A



B

Fig. 18.40. **A**. Protaper S1 at the end of its use in a root canal of average difficulty. Note how the dentinal debris is only on the coronal third of the instrument's blades. **B**. ProTaper S1 at the end of its use in a difficult root canal. Note how the dentinal debris are on most of the instrument's blades. In these cases the instrument must be considered disposable.

Fig. 18.41. Clinical cases of teeth with canals having an original complex anatomy in the apical one third. In these cases it is wise not to force the rotary NiTi instruments to the terminus of the canal. **A**. Preoperative radiograph of a lower left first molar. **B**. Postoperative radiograph (E. Berutti). **C**. Preoperative radiograph of the lower right first premolar. **D**. Postoperative radiograph (E. Berutti). **E**. Preoperative radiograph of the lower right third molar. **F**. Postoperative radiograph (G. Cantatore).

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19

The ProTaper Technique
Shaping the Future of Endodontics

CLIFFORD J. RUDDLE

There have been significant advancements in the development of NiTi rotary instruments in recent years. This evolution is driven by market demand and the continuous improvement in the manufacturing process. Dentists have increasingly identified the features they deem essential on the endless journey towards a more perfect file. These features include flexibility, efficiency, safety, and simplicity. The ProTaper system has been designed to provide these features; consequently, its entrance into the marketplace has had a profound effect.

The ProTaper NiTi files (Dentsply Maillefer; Ballaigues, Switzerland) represent a revolutionary generation of instruments for shaping root canals (Fig. 19.1).[14] This chapter will review the ProTaper geometries, then describe the ProTaper concepts, techniques and finishing criteria that may be utilized to fulfill the mechanical and biological objectives for shaping canals. Learning the ProTaper concept will lead to discovery then appreciation for this six instrument set, comprised of just three Shaping and three Finishing files (Fig. 19.2).

PROTAPER GEOMETRIES

The following will describe the ProTaper geometries and specific features that make these Shaping and Finishing files remarkably unique.

The shaping files

Shaping File # 1 and Shaping File # 2, termed S1 and S2, have purple and white identification rings on their handles, respectively. The S1 and S2 files have D_0 diameters of 0.17 mm and 0.20 mm, respectively, and their D_{14} maximal flute diameters approach 1.20 mm (Fig. 19.3). The Auxiliary Shaping File, termed SX, has no identification ring on its gold-colored handle and, with a shorter overall length of 19 mm, provides excellent access when space is restrictive. Because SX has a much quicker rate of taper between D_1 and D_9 as compared to the other ProTaper Shaping files, it is primarily used, after S1 and S2, to optimally shape canals in coronally broken down or anatomically shorter teeth. The SX file has a D_0 diameter of 0.19 mm and a D_{14} diameter approaching 1.20 mm (Fig. 19.4).

Fig. 19.1. This endodontically treated mandibular second bicuspid demonstrates a smooth flowing dilacerated preparation, apical bifidity and the ProTaper advantage (Courtesy of Dr. Fabio Gorni; Milano, Italy).

Progressively tapered design

A unique feature of the ProTaper Shaping files is each instrument has multiple "increasing" percentage tapers over the length of its cutting blades. This progressively tapered design serves to significantly improve flexibility, cutting efficiency, and safety.[3] Fortuitously, a progressively tapered design typically reduces the number of recapitulations needed to achieve length, especially in small diameter or more curved canals. As an example, the SX file exhibits nine increasingly larger tapers ranging from .035 to .19 between D_1 and D_9, and a fixed .02 taper between D_{10} and D_{14}. The S1 file exhibits twelve increasingly larger tapers ranging from .02 to .11 between D_1 and D_{14}. The S2 file exhibits nine increasingly larger tapers ranging from .04 to .115 between D_1 and D_{14}. This design feature allows each shaping file to perform its own "crown down" work. One of the benefits of a progressively tapered shaping file is that each instrument engages a smaller zone of dentin which reduces torsional loads, file fatigue and the potential for breakage.[6]

The finishing files

Three Finishing files named F1, F2 and F3 have yellow, red and blue identification rings on their handles corresponding to D_0 diameters of 0.20 mm, 0.25 mm, and 0.30 mm, respectively. Additionally, F1, F2, and F3 have fixed tapers between D_1 and D_3 of .07, .08, and .09, respectively (Fig. 19.5). However, unlike

Fig. 19.2. ProTaper files represent a revolutionary progression in flexibility, efficiency, safety and simplicity for preparing root canals.

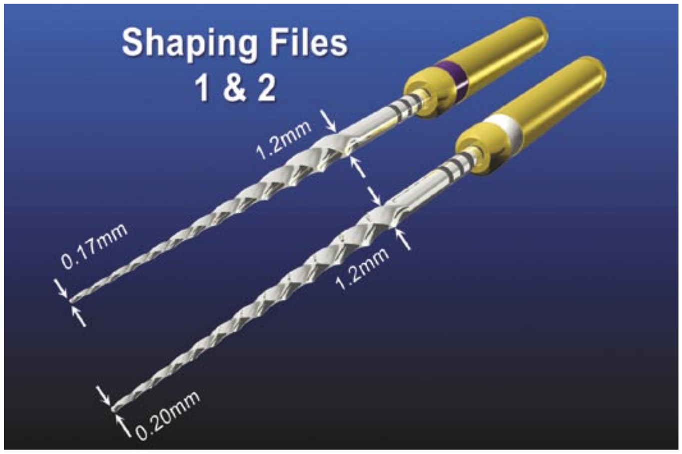


Fig. 19.3. S1 and S2 each have progressively larger tapers over the length of their blades allowing each instrument to perform its own crown-down work.

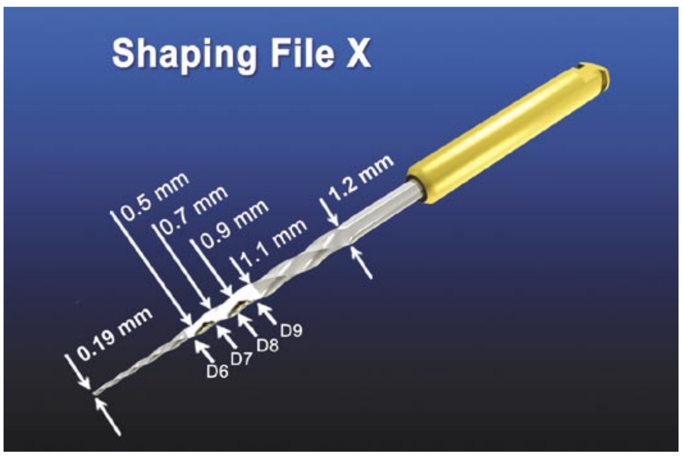


Fig. 19.4. Shaper X has 9 increasingly larger tapers ranging from .035 to .19 and is used in a brushing motion to cut dentin, between D_6 and D_9, on the outstroke.

Fig. 19.5. The finishing files have variable D_0 diameters and tapers, and blend the deep shape into the middle one-third of the canal.

the Shaping files, the Finishing files have "decreasing" tapers from D_4-D_{14}. This design feature serves to improve flexibility, reduce the potential for dangerous taper-lock, and prevent the needless over-enlargement of the coronal two-thirds of a root canal.

Convex triangular cross-section

Another feature of the ProTaper instruments relates to their convex triangular cross-section (Figs. 19.6 A, B).

This feature decreases the rotational friction between the blade of the file and dentin, enhances the cutting action, and improves safety, as compared to radial-landed instruments.[3] As is true with any instrument, increasing both its D_0 diameter and taper correspondingly increases its stiffness. To improve flexibility, ProTaper Finishing files F2 and F3 have recently been machined with a reduced core, as compared to the other instruments in the series. The core is reduced by machining a small concavity within each of the three convex sides of the triangular cross-section.

Helical angle & pitch

ProTaper files have a continuously changing helical angle and pitch over the length of their cutting blades (Figs. 19.7 A, B). Changing the pitch and helical angles over the active length of blades optimizes its cutting action and more effectively augers debris out of the canal. Importantly, changing the pitch and helical angles of a file, in conjunction with a progressively tapered design, prevents each instrument from inadvertently screwing into the canal.[10]

Modified guiding tip

Another feature of the ProTaper files is each instrument has a modified guiding tip. A modified guiding tip is created by machining off 25% of the most apical extent of each file's rounded, non-cutting, and parabolic-shaped tip. This design feature allows each instrument to accurately follow a smooth reproducible glide path, and importantly, enhances its ability to load soft tissue and loose debris into the intrablade flutes, where it can be efficiently augured out of the canal (Fig. 19.8).[7]

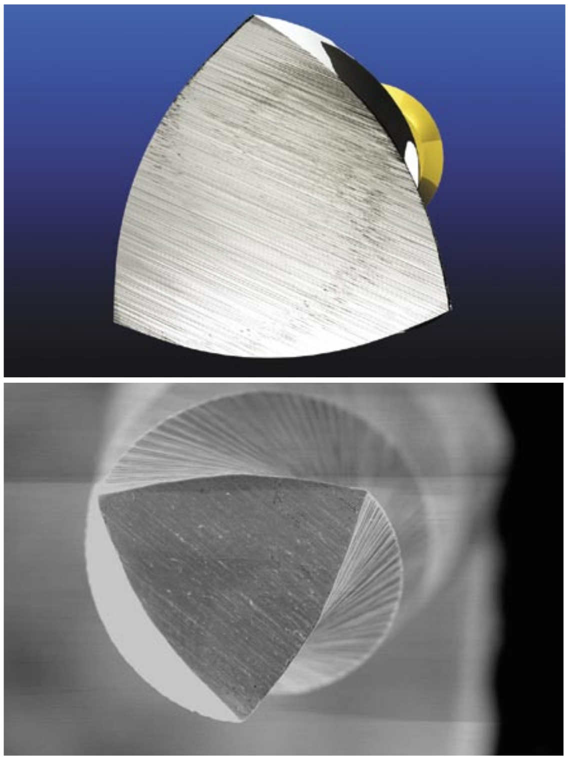
A
B


Fig. 19.6. **A**, **B**. The ProTaper instruments have a convex triangular cross-section which improves cutting efficiency while maximizing core strength (Fig. B courtesy of Prof. Elio Berutti; Torino, Italy).

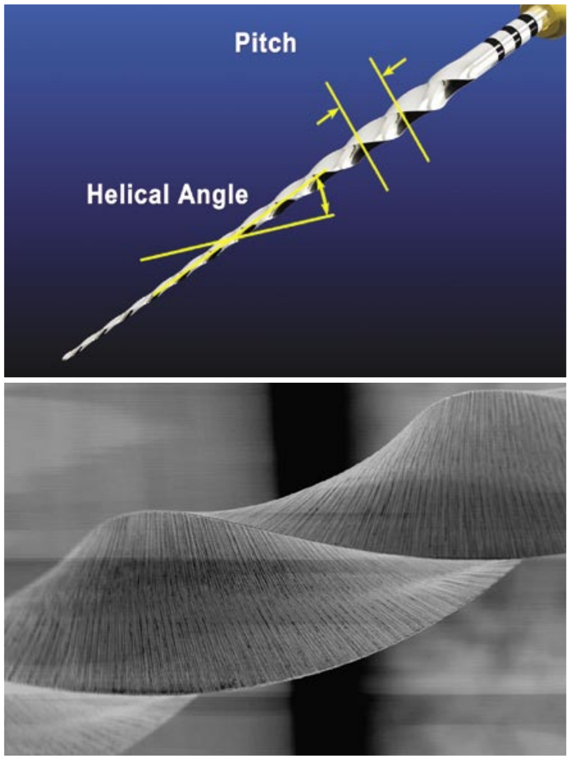
A
B


Fig. 19.7. **A**, **B**. ProTaper files perform smoothly, efficiently and safely as a result of their progressively tapered design and continuously changing pitch and helical angle (Fig. B courtesy of Prof. Elio Berutti;Torino, Italy).

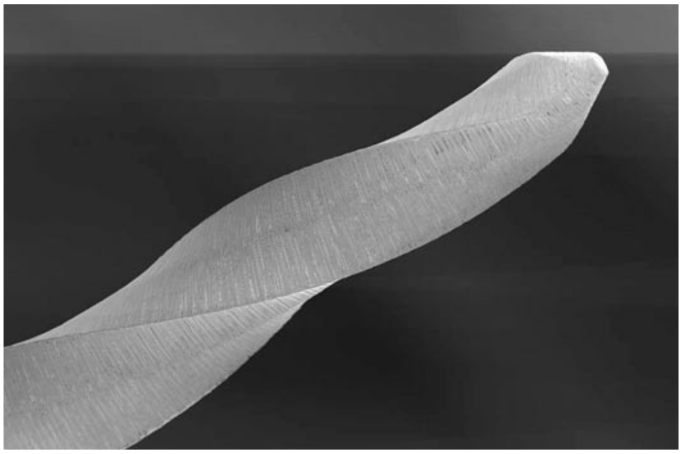


Fig. 19.8. ProTaper files have a modified guiding tip which enables the tip of the file to safely follow the glide path and better auger soft tissue and loose debris out of the canal (Courtesy of Prof. Elio Berutti; Torino, Italy).

PROTAPER CONCEPTS & GUIDELINES

There are a few basic concepts that, when followed, will promote efficient performance and excellent safety when using NiTi rotary instruments (Fig. 19.9). Rotary instruments should only be placed in portions of the canal that have a confirmed, smooth and reproducible glide path.[6] Further, rotary NiTi instruments should only be used in the apical one-third of a canal that has a known, accurate working length and is patent. Finally, when incorporating the ProTaper instruments, clinicians should follow the specific directions for use, observe the recommended sequencing of files, and adhere to the correct range of speed and prescribed torque.

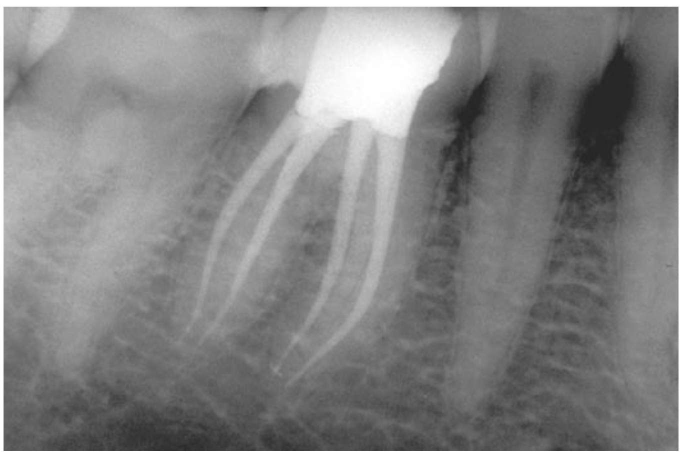


Fig. 19.9. ProTaper files were utilized in the endodontic treatment of this mandibular first molar. Note four optimally prepared systems exhibiting multiplanar curvatures (Courtesy of Dr. Pierre Machtou; Paris, France).

The following summarizes the ProTaper rotary shaping file concepts and guidelines:

Straightline access

The access preparation is an essential element for successful endodontics.[8] Preparing the endodontic access cavity is a critical step in a series of procedures that potentially leads to the three-dimensional obturation of the root canal system. Access cavities should be cut so the pulpal roof, including all overlying dentin, is removed. The size of the access cavity is dictated by the position of the orifice(s). The axial walls are extended laterally such that the orifice(s) is just within this outline form. The internal walls are flared and smoothed to provide easy, straightline access into the orifice and the root canal system (Fig. 19.10).

Access preparations are expanded to eliminate any coronal interference during subsequent instrumentation. Access objectives are confirmed when all the orifices can be visualized without moving the mouth mirror. Ideally, endodontic access cavities should parallel the principle of restorative dentistry where the axial walls of a "finished" preparation taper and provide draw for a wax pattern. Cleaning and shaping potentials are dramatically improved when instruments conveniently pass through the occlusal opening, effortlessly slide down smooth axial walls and are easily inserted into a preflared orifice (Fig. 19.11).

Spacious access cavities are an opening for canal preparation.[9,20]

Fig. 19.10. A photograph at 15x shows straightline access, divergent axial walls and the orifices just within this outline form.

Fig. 19.11. The canals of this endodontically treated mandibular first molar were gauged and tuned, and the pack demonstrates the uniform and fully tapered shapes.

Irrigation & lubrication

No instrument should be introduced into the root canal space until the appropriate irrigant is introduced into the pulp chamber. The importance of irrigants, their methods of use and their role in negotiating and shaping canals and in cleaning the root canal system has been described in several clinical articles.[5-13]

Reproducible glide path

Cleaning and shaping outcomes are significantly improved initially utilizing stainless steel 0.02 tapered sizes 10 and 15 hand files (Dentsply Maillefer; Ballaigues, Switzerland). Small-sized hand files are optimally utilized, in the presence of a viscous chelator, to scout any portion of the overall length of a canal.[13-15]

Hand files create or confirm a smooth, reproducible glide path before introducing any rotary NiTi instruments into this secured length of the canal.[6,7] With the onset of NiTi rotary instrumentation, the role of hand instruments has diminished and been redefined. For many rotary file users, small hand instruments are primarily used to gather reconnaissance information, to confirm available space, or when necessary, to create sufficient space prior to using more efficient rotary NiTi instruments. The 10 and 15 "scouter files" should not be thought of as just measuring wires, rather they can additionally provide feedback regarding:[15]

1) *Cross-Sectional Diameter*
Scouter files immediately reveal the cross-sectional diameter of a canal and provide information as to whether the canal is open, restricted, or significantly calcified. Before a ProTaper rotary instrument can be safely introduced into the canal, sufficient space must exist to passively accommodate and guide their tips. In other words, there must be a pilot hole of circumferential dentin and a smooth glide path for a NiTi rotary instrument to follow. As an example, if a canal has been scouted to within 3-4 mm of anticipated working length with 10 and 15 hand files, then more space exists than the files' numerical names suggest. Recall the 10 and 15 hand files taper 0.02 mm/mm, have 16 mm of cutting flutes and their D_{16} diameters are 0.42 and 0.47 mm, respectively. Generally, these small-sized instruments will provide a sufficient "opening" for the implementation of rotary instruments.
2) *Coronal & radicular access*
Scouter files confirm the presence or absence of straightline coronal and radicular access. Clinicians can observe the handle position of the smaller sized instruments to see if they are upright and paralleling the long axis of the tooth or skewed off-axis. In the instance where the roots are under the circumferential dimensions of the clinical crown and the file handle is upright, or "ON" the long axis of the tooth, then the clinician is able to confirm both coronal and radicular straightline access. In instances where the handle of the initial scouting instrument is "OFF" the long axis of the tooth, then pre-enlargement procedures should be directed towards uprighting the file handle (Fig. 19.12).[16,21]

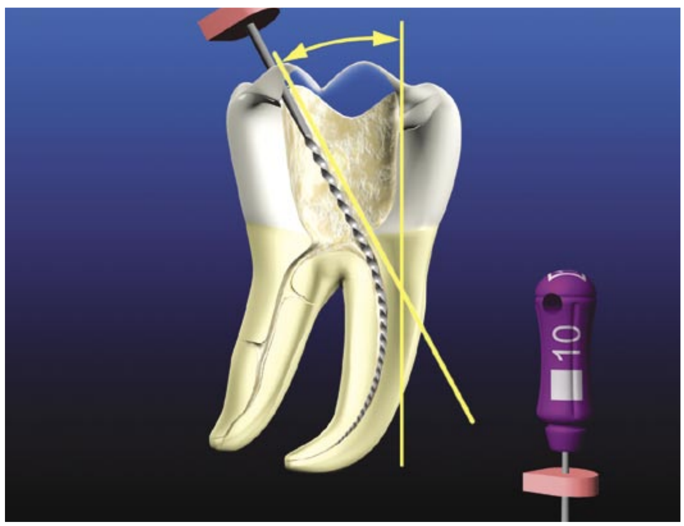


Fig. 19.12. The handles of small hand files are frequently "OFF" axis in furcated teeth due to internal triangles of dentin.

To upright the handle of the small scouter files oftentimes requires refining and expanding the access preparation and selectively removing the triangle of dentin from the coronal one-third of the canal. This procedural distinction is critical and simplifies all subsequent instrumentation procedures while virtually eliminating many cleaning and shaping frustrations (Fig. 19.13).[16,18]

3) *Root canal system anatomy*
Scouter files can provide information regarding root canal system anatomy. Clinicians need to appreciate the five commonly encountered anatomical forms which include canals that merge, curve, recurve, dilacerate or divide. Scouter files provide information regarding the anatomy and give important feedback regarding the canal's degree of curvature, recurvature, or if there is a dilaceration (Fig. 19.14). Further, before introducing rotary instruments, clinicians need to know if a single canal coronally subsequently divides or if two or more systems within a root merge along their length. It must be recognized that certain root canals exhibit anatomical configurations which preclude the safe use of NiTi rotary files. In these instances, precurved manual ProTaper files afford a safe alternative, as compared to the risk associated with using rotary instruments (Fig. 19.15).

Working length & patency

The breakthrough to predictable shaping procedures is to have both an accurate working length and a patent canal. Patency is performed by gently directing small, highly flexible files to the radiographic terminus (RT).[20]

To ensure patency, the file tip is intentionally inserted minutely through the foramen to discourage the accumulation of debris (Fig. 19.16). Importantly, working a small, flexible file to the RT will encoura-

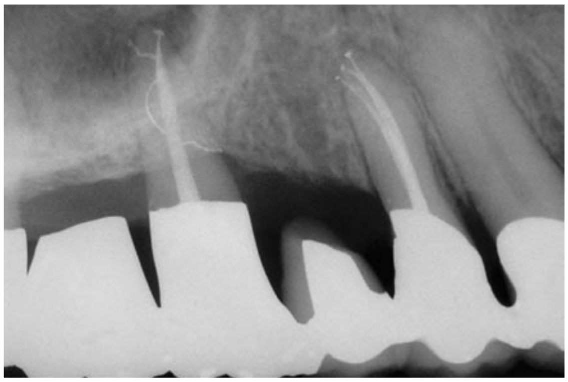


Fig. 19.13. Sequencing the preparation facilitates shaping canals and cleaning root canal systems. Complete endodontic treatment is the foundation of perio-prosthetics.

Fig. 19.14. This endodontically treated mandibular bicuspid demonstrates a corkscrewing and spiraling system that has been optimally treated.

Fig. 19.15. ProTaper hand files (Courtesy of Dentsply/Maillefer; Ballaigues, Switzerland).

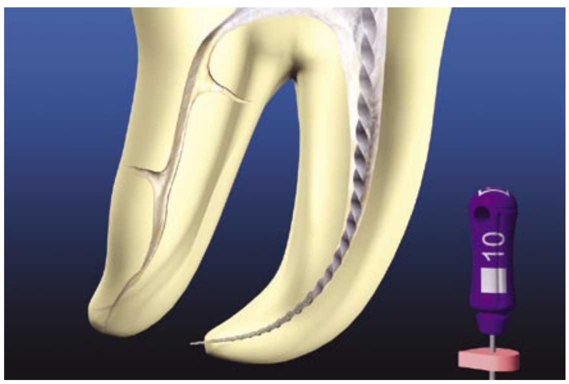


Fig. 19.16. Vital and necrotic canals are negotiated to length and patency is established and maintained to promote the preparation objectives.

ge the elimination of dental pulp, related irritants, and dentinal mud. Keeping the canal terminus patent discourages blocks, ledges and perforations.[16,18] It is illogical to assume that passing a small file passively and minutely through the apical foramen is going to prejudice the result or predispose to any irreversible conditions when one reflects on the rich collateral circulation and healing capacity available in the attachment apparatus. Clinicians should stop fretting over the use of patency files and recall the well-known, often used, and more invasive disciplines, such as endodontic surgery and dental implants.

Researchers, academicians and clinicians are well aware that when a file is passed through the entire length of a canal and its most apical extent is observed to be at the radiographic terminus, then, in actuality, the instrument is minutely long. Traditional wisdom advocates that since the apical extent of a canal terminates at the cementodentinal junction (CDJ) then working length should extend to this anatomical landmark.[11] Although the CDJ exists in a non-pulpally involved tooth, its position can never be precisely located clinically as this histological landmark varies significantly from tooth to tooth, from root to root, and from wall to wall within each canal. Working arbitrarily short of the radiographic terminus based on statistical averages encourages the accumulation and retention of debris, which frequently results in apical blocks that predispose to ledges and perforations. Working short has led to many frustrations, interappointment flare-ups, "unexplained" failures, surgical procedures and extractions.[16,18]

Electronic apex locators represent an improvement over radiographs for more accurately identifying the position of the foramen.[22] Technological advancements in specific apex locators provide greater accuracy in length determination even in canals that contain exudates or electrolytes. It should be understood that apex locators do not replace films but are used intelligently in conjunction with radiographs. When a predictable and smooth glide path is established to the RT and working length is confirmed, then the apical one-third of the canal can be shaped and finished in a variety of ways.[15]

Directions for use

Rotary instruments should be employed in strict accordance with their prescribed directions for use. If any NiTi rotary instrument ceases to advance deeper into a canal, withdraw it, and recognize the four factors that typically prevent the file from passively moving in an apical direction:

1) *Insufficient canal diameter*. Insufficient canal diameter will prevent a rotary NiTi instrument from passively moving deeper into the canal. Recognize that the working end of a rotary file may be too big or stiff to follow the anatomy or diameter of a canal. It is important to appreciate NiTi rotary instruments may not be able to follow a canal that abruptly curves, divides, or whose walls exhibit resorptive or iatrogenic defects. In smaller diameter or more curved canals, use the 10 and 15 hand files, in conjunction with a viscous chelator. If necessary, a few larger hand instruments may be required to create a smooth, reproducible glide path for manual or rotary NiTi instruments to predictably follow.
2) *Intracanal debris*. Intracanal debris may accumulate in a canal that previously exhibited a confirmed and reproducible glide path. To eliminate intracanal debris, after each rotary file, voluminously irrigate the root canal space, recapitulate with a # 10 file to break-up debris and move it into solution, then re-irrigate to flush-out this loosened debris. Use a 10 or 15 file to confirm a smooth, reproducible glide path before commencing with rotary shaping procedures.
3) *Intrablade debris*. Another possibility that limits the apical movement of an instrument is the accumulation of debris within the depth between the cutting blades. Intrablade debris tends to deactivate an instrument as it pushes the active part of the file off the wall of the canal. In this latter case, withdraw the instrument and clear its blades, irrigate the canal, recapitulate with a small hand file to confirm the existence of the previously established glide path, then re-irrigate to flush out debris.
4) *Root canal anatomy*. Certain systems exhibit difficult anatomical configurations that discourage or prevent the tip of a rotary instrument to passively and safely follow the canal (Figs. 19.17 A-D). In these instances, irrigate and recapitulate with small hand files to improve the diameter of the glide path of the canal or precurve a ProTaper hand file to bypass the anatomical impediment. It should be recognized that certain anatomical configurations, pathological defects, or iatrogenic ledges are best shaped with hand files. The ProTaper files can be precurved and used manually to follow any part of a canal that has been negotiated and enlarged to at

least a size 15 hand file. However, ProTaper rotary files should not be used until there is a confirmed, smooth, and reproducible glide path.

Multiple vs. single use

The two most important causes that contribute to NiTi rotary instrument breakage are "method of use" and "multiple use" of files. During use, any given ProTaper file should be inspected for wear and its cutting blades frequently cleaned to optimize efficiency and reduce the potential for breakage. In the author's opinion, all NiTi rotary instruments should be discarded after each case due to metal fatigue, loss of cutting efficiency, and the great variation in length, diameter and curvature of any given canal. When the guidelines for use are carefully followed then the ProTaper files' unique geometries afford unsurpassed *safety*, *flexibility* and *efficiency*.[3,23,24]

Motors

All the ProTaper instruments should be utilized in a gear reduction handpiece in conjunction with a torque controlled electric motor. The motor should be set to provide a torque of 520 g.cm and speeds ranging from 250-300 RPM.[6] Advancements in electric motors in the years immediately ahead hold the promise to improve clinical performance and safety when using NiTi rotary files.

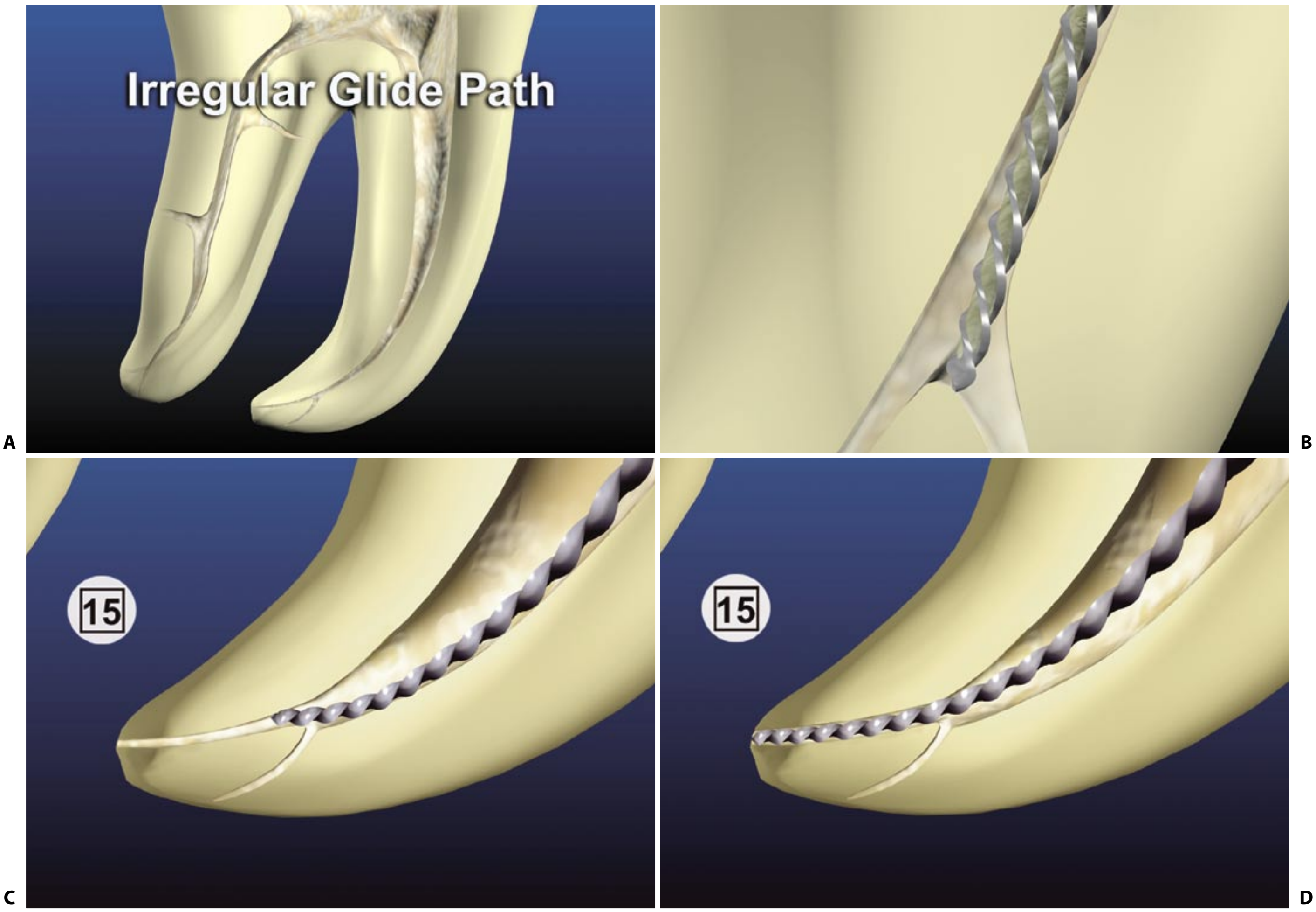


Fig. 19.17. **A**. Small hand files should be used to verify if the apical one-third of a pre-enlarged canal has either a smooth or irregular glide path. **B**. When small hand files cannot easily slide along a canal, then NiTi rotary-shaping instruments should not be used. **C**. A graphic illustrates a pre-enlarged canal can more readily accommodate a precurved hand file and improve the predictability of achieving length. **D**. A graphic illustrates a 15 file can be utilized to determine if there is a smooth reproducible glide path to safely accommodate a rotary shaping file.

THE PROTAPER TECHNIQUE

Preparing a root canal can commence after completing straightline access to the orifice(s). In teeth exhibiting calcification, dentin can be precisely sanded away and orifices more readily identified by utilizing contra-angled, parallel-walled and abrasively coated ultrasonic instruments (Fig. 19.18) (ProUltra Endo Tips, Dentsply Maillefer; Ballaigues, Switzerland).[17] In combination, microscopes and ultrasonics have driven "microsonic" techniques that have improved successfully locating receded orifices. Once any orifice has been located, it can be advantageously flared with one or more gates glidden drills (Dentsply Maillefer; Ballaigues, Switzerland). Attention to detail when finishing the access cavity facilitates the subsequent shaping of a root canal (Fig. 19.19).

Fig. 19.18. The ProUltra ENDO 1-5 stainless steel instruments have an abrasive zirconium nitride coating to improve efficiency, precision and clinical performance.

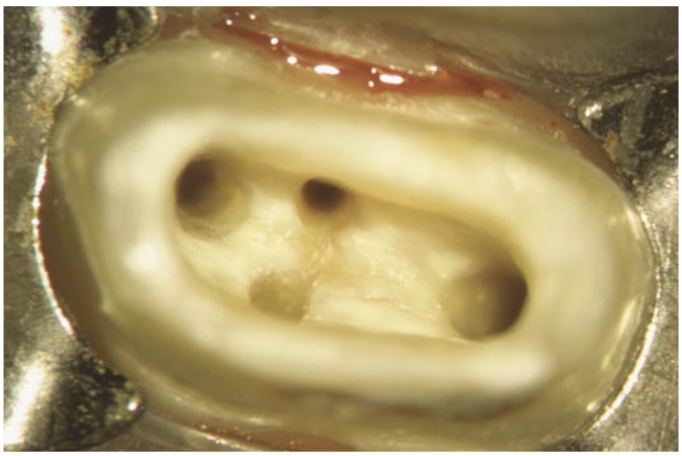


Fig. 19.19. A photo at 12x demonstrates an access cavity through a prosthetically prepared crown. Note the outline pattern, smooth axial walls, and four orifices.

Scout the coronal two-thirds

The potential to consistently shape canals and clean root canal systems is significantly enhanced when the coronal two-thirds of the canal is first pre-enlarged followed by preparing its apical one-third (Figure 19.20).[15,17] The concept of first pre-enlarging a canal followed by finishing its apical one-third is analogous to a crown preparation procedure in which the tooth is first reduced prior to finishing the margins.

When straightline access is completed, the pulp chamber may be filled brimful with a viscous chelator. Based on the pre-operative radiographs, ISO 0.02 tapered sizes 10 and 15 hand files are measured and precurved to match the anticipated full length and curvature of the root canal. However, in this method of canal preparation, these instruments are initially limited to the coronal two-thirds of a root canal. The 10 and 15 hand files are utilized within any portion of the canal until they are loose and a smooth reproducible glide path is confirmed (Figs. 19.21 A, B). The loose depth of the 15 file is measured and this length transferred to the ProTaper S1 and S2 files.

Shape the coronal two-thirds

The secured portion of the canal can be optimally pre-enlarged by first utilizing S1 then S2. Prior to ini-

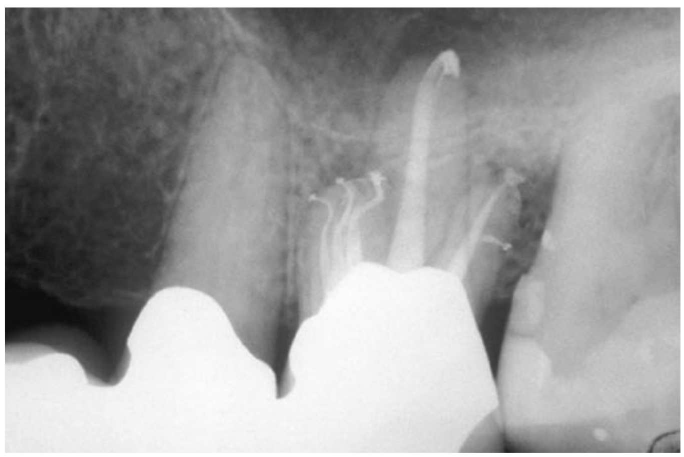


Fig. 19.20. An endodontically treated maxillary first molar demonstrates five treated canals and that each system exhibits various anatomical configurations.

A

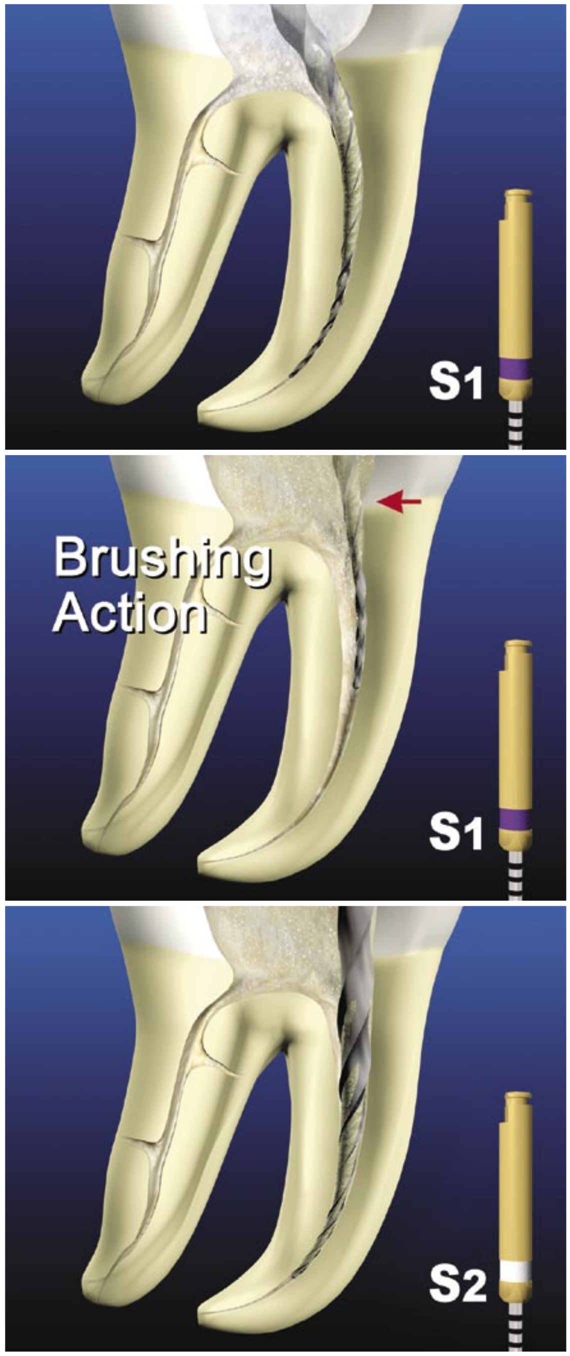
B

Fig. 19.21. **A**, **B**. Small files confirm the presence or absence of straightline access and reveal information regarding the diameter and anatomy of a canal.

tiating shaping procedures, the pulp chamber is filled with a full strength solution of NaOCl. Without pressure, and in one or more passes, the ProTaper Shaping files are allowed to passively "float" into the canal and "follow" the glide path. To optimize safety and efficiency, the Shaping files are used, like a "brush", to laterally and selectively cut dentin on the outstroke.

A brush-cutting action creates lateral space which will facilitate the shaping file's larger, stronger and more active cutting blades to safely and progressively move deeper into the canal. If any ProTaper file ceases to easily advance within the secured portion of a canal, withdraw it, and recognize that intrablade debris has deactivated and pushed the instrument off the wall of the canal. Upon removing each Shaping file, visualize where the debris is located along its cutting blades to better appreciate the region within the canal that is being prepared.

Following the use of each Shaping file, irrigate, recapitulate with a 10 file to break up debris and move it into solution, then re-irrigate. Without pressure, and in one or more passes, S1, then S2, is used in this manner until the depth of the 15 hand file is reached (Figs. 19.22 A, B, C).



A

B

C

Fig. 19.22. **A**. S1 has a D_0 diameter of 0.17 mm and its modified guiding tip easily follows a previously scouted and secured canal. **B**. S1 is used in a brushing motion to cut dentin, remove internal triangles of dentin in furcated teeth, and safely relocate canals away from external root concavities. **C**. S2 follows S1, and is used in the same brushing motion until the depth of the 15 hand file is reached.

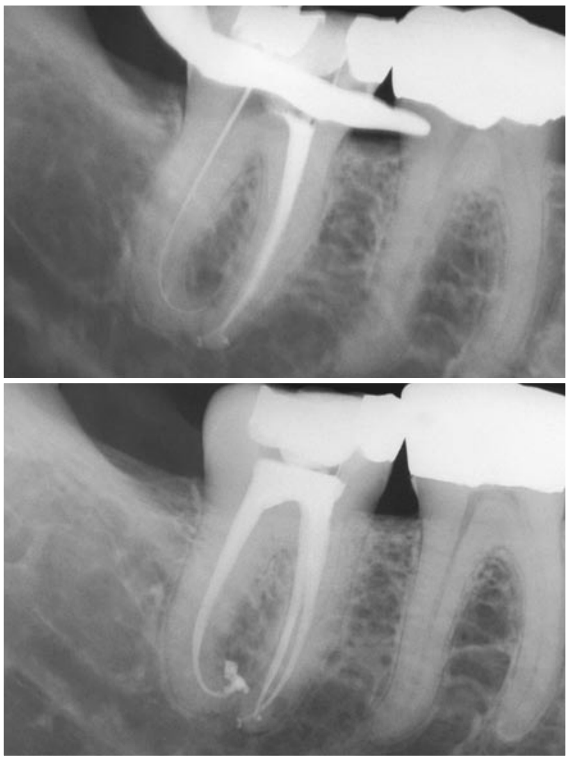
Scout the apical one-third

When the coronal two-thirds of the canal is shaped, then attention can focus on apical one-third procedures. With the pulp chamber filled brimful with a viscous chelator, the apical one-third of the canal is fully negotiated, working length established and patency confirmed (Fig. 19.23).[15] When the apical one-third of the canal has been enlarged to at least the size of a 15 hand file, then a decision must be made between whether to finish the apical one-third with rotary or hand instruments. If a new and straight 15 file can gently "slide" and passively "glide" to length, then rotary instruments will follow this confirmed and reproducible glide path.[7,15] However, certain canals exhibit anatomical challenges that necessitate a reciprocating handle motion in order to move precurved 10 and 15 files to length. When there is an irregular glide path then the apical one-third of a canal may be advantageously finished with precurved manual ProTaper instruments (Figs. 19.24 A, B and 19.25 A, B).

Fig. 19.23. Following pre-enlargement procedures and working length confirmation, the 10 file is gently moved through the foramen to confirm, then maintain, patency.

Shape the apical one-third

When the apical one-third of the canal has been secured, then the pulp chamber is filled brimful with NaOCl. The ProTaper sequence is to carry the S1, then the S2, to the full working length. As previously described, float, follow and brush as previously descri-



A

B

Fig. 19.24. **A**. A working film of a mandibular second molar demonstrates a 10 file following a 180° curvature and the packed MB and abruptly recurved ML systems. **B**. The post-treatment film confirms the mechanical objectives for shaping the root canals were achieved.

A

B

Fig. 19.25. **A**. An endodontically treated maxillary first bicuspid exhibits branching systems that terminate into three apical portals of exit. **B**. An endodontically treated mandibular second bicuspid demonstrates a single straightforward canal that divides deep into three apical portals of exit.

bed until the terminus of the canal is reached. S1, then S2, will typically move to length in one or more passes depending on the length, diameter and curvature of the canal (Figs. 19.26 A, B). Following each ProTaper file, irrigate, recapitulate with a 10 file, then re-irrigate. After using the Shaping files, particularly in more curved canals, working length should be reconfirmed, as a more direct path to the terminus has been established. At this stage of treatment, the preparation can be finished using one or more of the ProTaper Finishing files in a "non-brushing" manner. The F1 is selected and passively allowed to move deeper into the canal, in one or more passes, until the terminus is reached (Fig. 19.27). When the F1 achieves length, the instrument is removed, its apical flutes are inspected and if they are loaded with dentin, then visual evidence confirms this instrument has carved its shape in the apical one-third of the canal. Following the use of F1, flood the canal with irrigant, recapitulate and confirm patency, then re-irrigate to liberate debris from the canal.

ProTaper finishing criteria

Following the use of the 20/.07 F1, the "ProTaper Finishing Criteria" is to gauge the size of the foramen with a 20/.02 tapered hand file to determine if this instrument is snug or loose at length (Fig. 19.28). If the 20 hand file is snug at length then the canal is fully shaped and, if irrigation protocols have been followed, ready to pack. Following the use of F1, if the 20 hand file is loose at length, then gauge the size of the foramen with a 25/.02 tapered hand file. If the 25

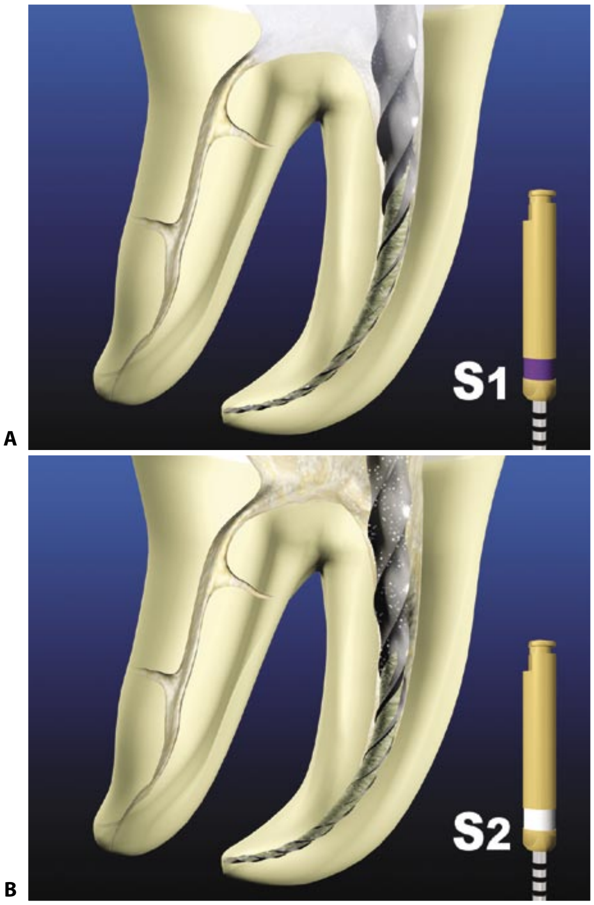


Fig. 19.26. **A.** S1 easily follows a canal that has a confirmed, smooth and reproducible glide path. **B.** S2 is designed to perform its own crown-down work and carries another wave of shaping deeper into the canal.

Fig. 19.27. The flexible F1 smoothly carves the deep shape and blends this region into the middle one-third of the canal.

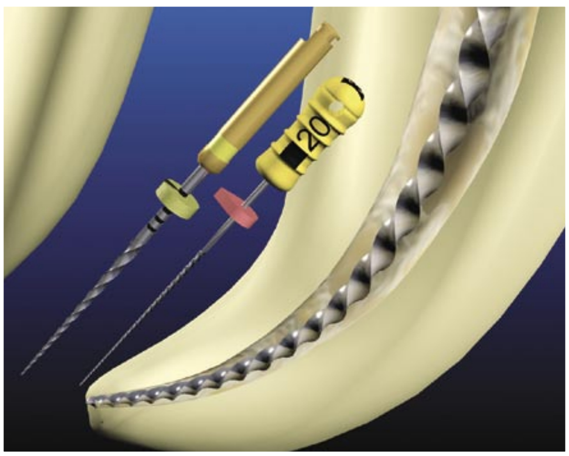


Fig. 19.28. Following the use of the 20/.07 F1 rotary file to length, the foramen is gauged using a 20/.02 hand file.

file is snug at length, then the canal is fully shaped and ready to pack. If the 25 file is short of length, proceed to the 25/.08 F2 and, when necessary, the 30/.09 F3, gauging after each Finisher with the appropriately sized hand files (Figs. 19.29 A, B). If the 30 file is loose at length, then an alternative NiTi rotary file line or manual files may be utilized to finish the apical extent of these larger, easier and more straightforward canals.

In the instance of a longer, smaller diameter, and a more curved canal, generally only three ProTaper instruments are required to produce a cleaned, tapered canal that exhibits shape over length. Regrettably, there are ongoing debates regarding the extent of apical enlargement. It is needless to over-prepare the foramen if we understand and fully appreciate the relationship between apical file size and apical one-third taper.[1] In fact, it has been shown that irrigating with EDTA, followed by NaOCl, can produce clean dentinal surfaces that are free of debris on uninstrumented surfaces of root canals.[2] ProTaper shapes are easy to fill utilizing a ProTaper matching gutta percha obturator or master cone in conjunction with a warm vertical condensation technique (Figs. 19.30 A, B).

A B

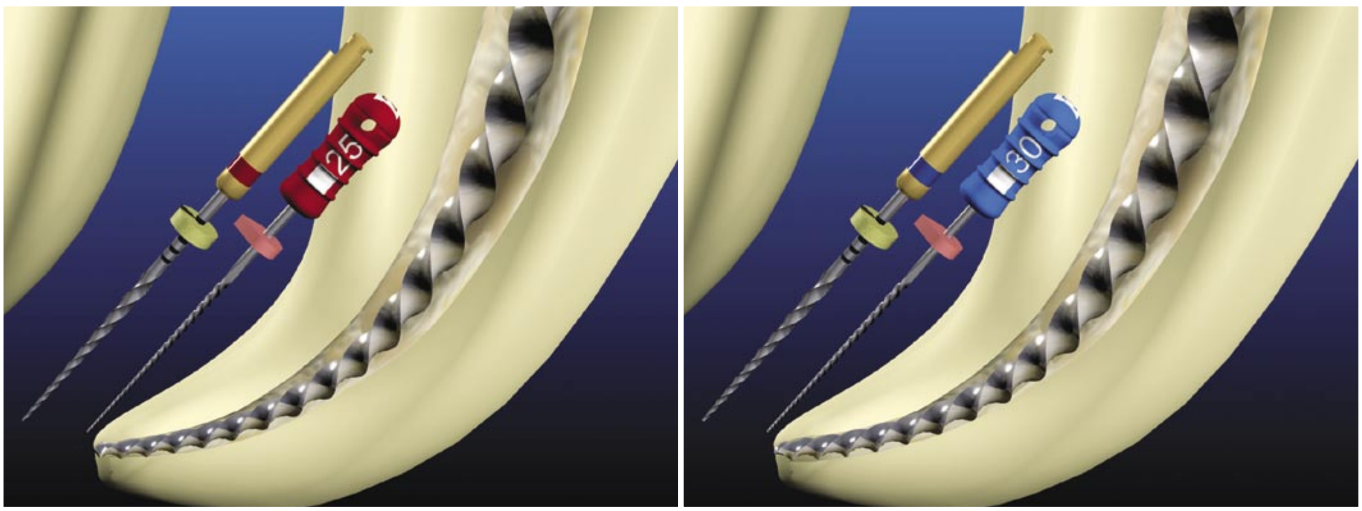


Fig. 19.29. **A**. Following the use of the 25/.08 F2 rotary file to length, the foramen is gauged using a 25/.02 hand file. **B**. Following the use of the 30/.09 F3 rotary file, the foramen is gauged using a 30/.02 hand file.

A B

Fig. 19.30. **A**. A three-dimensionally packed maxillary second molar demonstrates the smooth flowing, uniformly tapered shapes that ProTaper files consistently create (Courtesy of Prof. Elio Berutti; Torino, Italy). **B**. The canals of this mandibular molar were shaped with ProTaper files. The three-dimensional pack demonstrates flowing shapes, apical one-third curvatures and multiple portals of exit (Courtesy of Dr. Jason West; Tacoma, Washington).

Finishing larger systems

In instances where the foramen is gauged and determined to be greater than 0.30 mm, and a smooth glide path has been verified, then an alternative NiTi rotary file line may be used. The decision as to which specific line of instruments to select should be based on cutting efficiency, flexibility and safety. Importantly the instruments chosen and the techniques employed must create deep shape and the resistance form to hold filling materials during three-dimensional obturation (Fig. 19.31).

Research evaluating canal cleanliness compared to apical one-third shape has clearly shown that preparations need to taper greater than 0.06 mm/mm to ensure that a sufficient volume of irrigant over an adequate interval of time can efficaciously circulate, penetrate, and promote deep lateral cleaning.[4,15,19] Except in larger and straighter canals, rotary files that have D_0 diameters greater than 0.30 mm and tapers greater than 6% are frequently too stiff to safely place into the apical one-third of a more curved root canal. As such, NiTi 0.04 or 0.06 tapered rotary files, like ProFiles (Dentsply Maillefer; Ballaigues, Switzerland) will provide the flexibility to safely shape the apical extent of these larger, more open canals. As noted with hand files, NiTi rotary files can be employed in a step-back technique to create virtually any tapered shape that is desired.

Fig. 19.31. An endodontically treated maxillary central incisor demonstrates that a shaped canal provides resistance form to achieve three-dimensional obturation.

Expanding the deep shape

There are cases when a ProTaper 20/.07 Finishing file is snug at length, the foramen is confirmed to be 0.20 mm after gauging with a 20/.02 hand file, yet the clinician may find it advantageous to expand the deep shape of the canal. In the instance where the F1 was at length, then a fuller shape can be easily and safely accomplished by carrying the F2 1.0 mm short and the F3, 2.0 mm short of the working length.

This clinical method of carrying each larger ProTaper Finishing file progressively shorter than the previous one will maintain the size of the foramen while expanding the overall shape in the middle and apical one-thirds of the canal.[10] This step-back method is not done routinely and is only appropriate when different, well-angulated radiographs confirm that the dimensions of a root can safely accommodate a fuller shape.

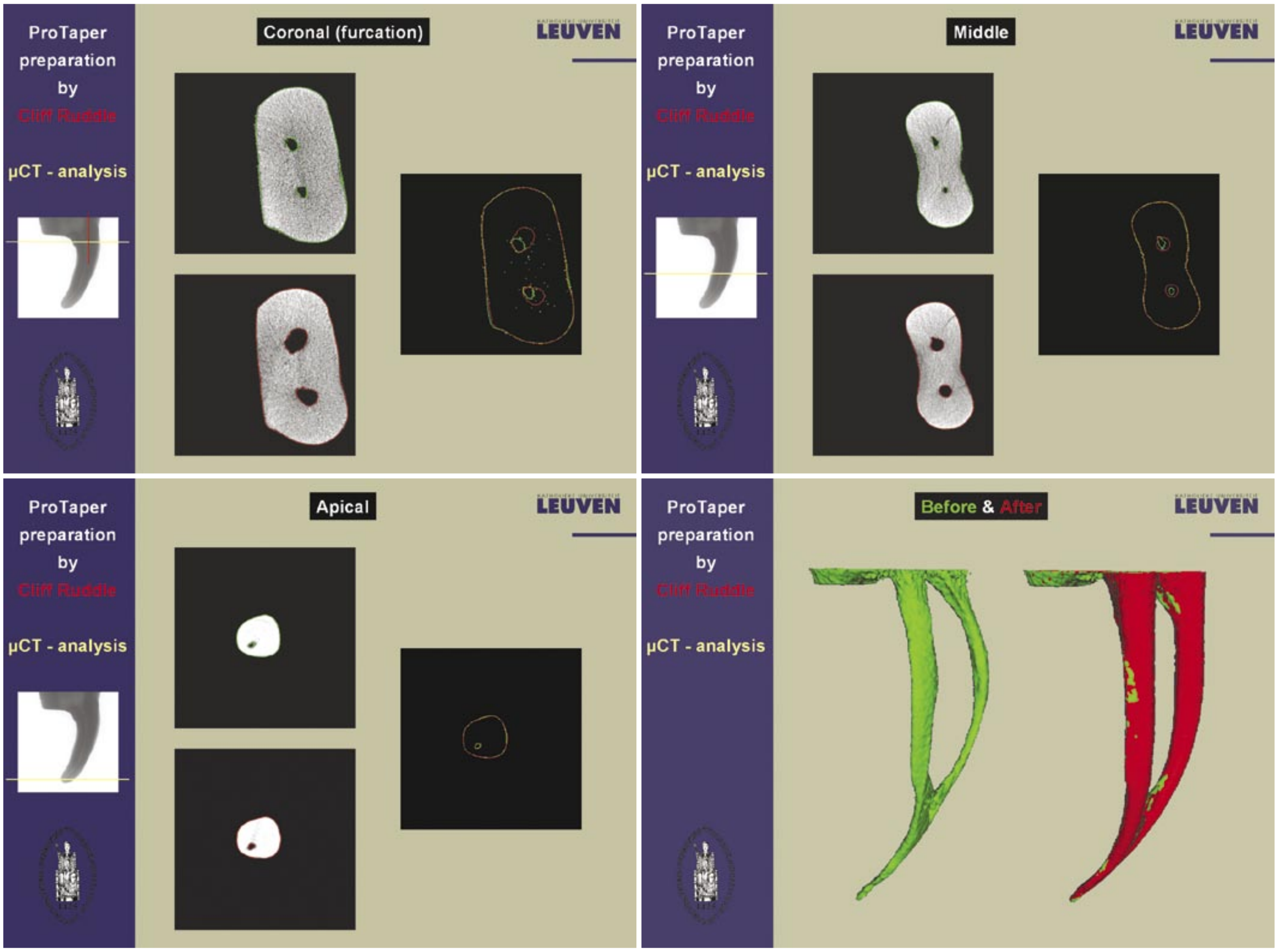
Evidence for clinical success

A clinical investigation of the ProTaper technique, emphasizing method of use, was conducted on mesial canals of extracted mandibular molar teeth using µCT-Analysis.[19] In this particular study, horizontal sections from different radicular levels were analyzed using µCT slices and volume renderings. The green color represented the anatomical contours before instrumentation whereas the red color indicated the shape after instrumentation.

The results from this investigation are clinically relevant and a portion of the data is available for review in Figs. 19.32 A-D.

The advantages of the Shaping files to brush laterally and selectively cut dentin on the outstroke are summarized below:

1) The Shaping files were essentially loose within a canal during the majority of their work.
2) The coronal aspects of the canals were safely relocated away from an external root concavity.
3) A brush-cutting action achieved a centered preparation and maximized remaining dentin.
4) The Shaping files physically contacted over 90% of the internal walls of the canals.



A B C D

Fig. 19.32. **A.** This figure shows horizontal µCT sections through the coronal one-third of the root. Note the intentional and successful relocation of the canals at this level. **B.** This figure reveals horizontal µCT sections through the middle one-third of the root. Note the ProTaper shapes are round and centered within the root. **C.** This figure shows horizontal µCT sections through the apical one-third of the root. Note the ProTaper shape perfectly includes the original canal diameter. **D.** This figure compares before and after instrumentation with the S1, S2, and F1 files. Note the shapes are full, smooth flowing and centered, and the files have physically contacted virtually all the internal anatomy (Figs. 19.32 A-D, courtesy of Dr. Lars Bergmans and BIOMAT Research Cluster, Catholic University, Leuven, Belgium).

CONCLUSION

ProTaper instruments may be used safely and effectively by both inexperienced and experienced NiTi rotary users. The ProTaper instruments provide unique geometries that when sequenced and used correctly, afford extraordinary flexibility, efficiency, safety and simplicity. The ProTaper sequence is always the same regardless of the tooth or anatomical configuration of the canal being treated (Fig. 19.33). In many cases it's as easy as one, two, three or, in endodontic language, purple, white, yellow.

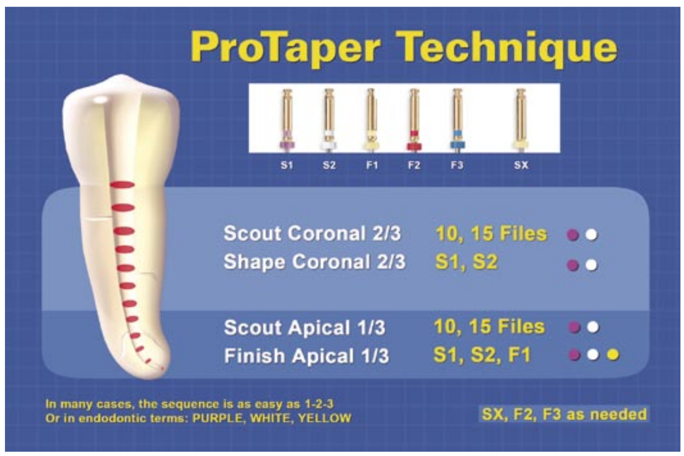


Fig. 19.33. This chart summarizes the ProTaper shaping technique. The ProTaper sequence is always the same regardless of the length, diameter or curvature of the canal.

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20

ProSystem GT

L. Stephen Buchanan

GT files represent, to date, the only system-based approach to shaping, obturating, and restoring endodontically involved teeth (Fig. 20.1). GT Files offer simple shaping solutions for the widest range of endodontic anatomy, from the smallest most tortuous canals to those with apical diameters just short of open apex classification (Figs. 20.2 A, B). GT Files have radiused tips and radial-landed cutting flutes that more accurately maintain original canal paths than shaping files having sharp tips and non-landed flute edges (Figs. 20.3 A, B). While GT Files were one of the first nickel titanium shaping file sets on the market, the GT System of instruments and materials have been updated, improved, and added to virtually every year since their introduction in 1994.

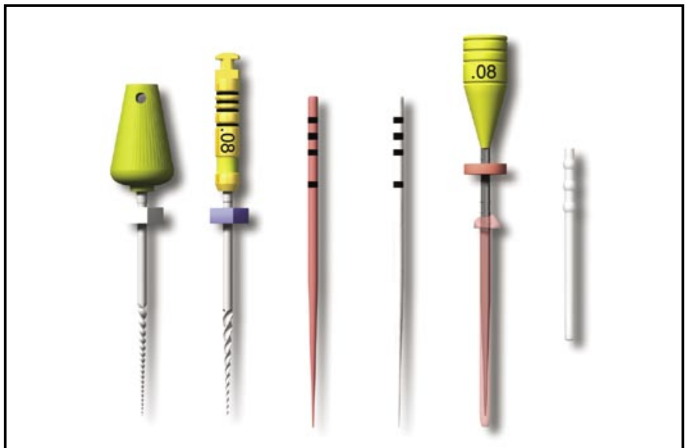


Fig. 20.1. The GT System of instruments and materials including (left to right) 20-.08 GT Hand File, 20-.08 GT Rotary File, .08 taper GT gutta-percha Point, .08 taper GT Paper Point, 20-.08 GT Obturator, and 1.0 mm diameter GT Restorative Post.

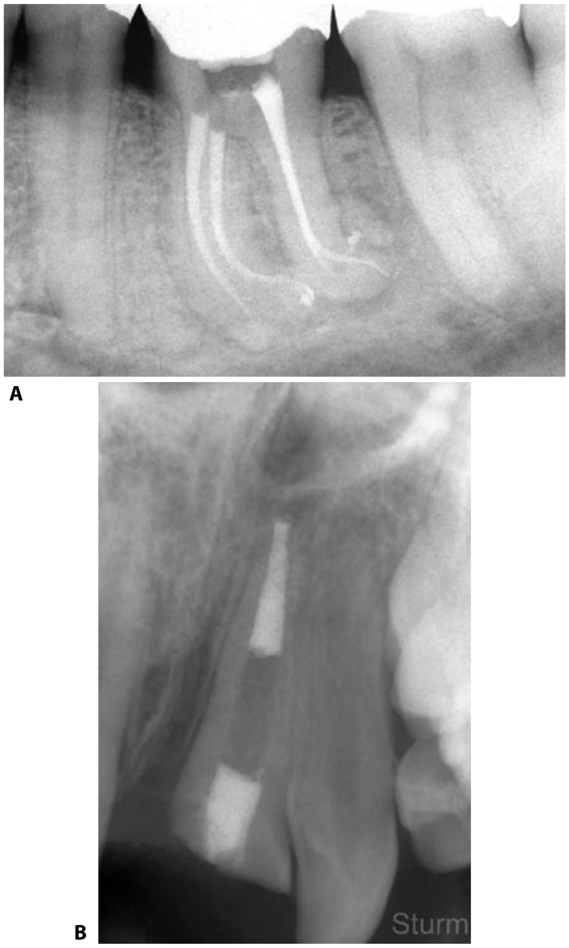


Fig. 20.2. **A**. Mandibular molar with small dilacerated canals shaped with GT Files. **B**. Maxillary central incisor with large canal shaped with a 90-.12 Accessory GT File (courtesy Dr. Jack Sturm).

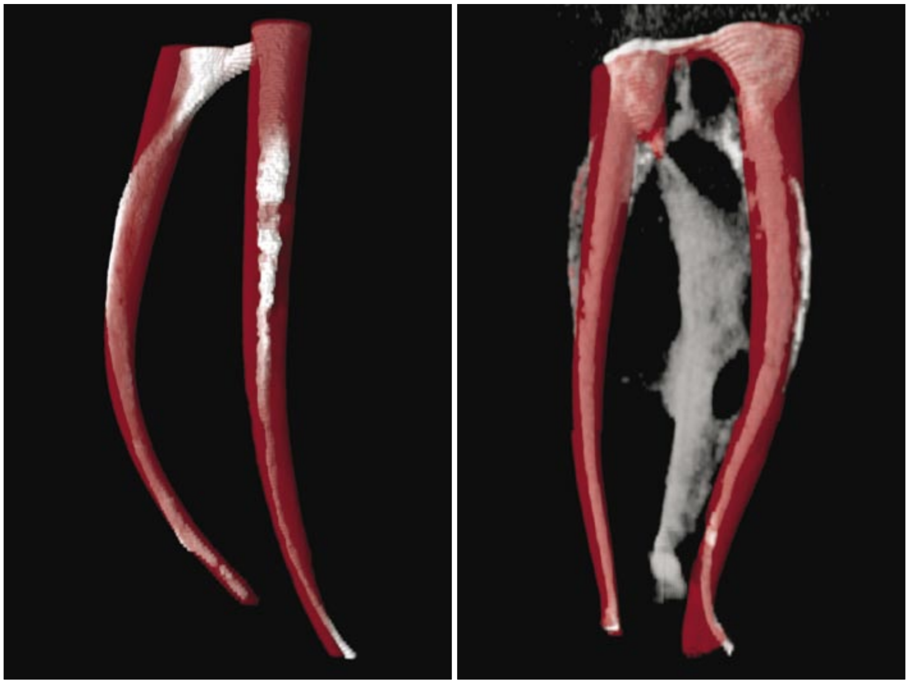


Fig. 20.3. **A**, **B**. µCT reconstructions of mesial canals of mandibular molars with white indicating original canal paths and transparent red showing final shapes with landed-flute GT Files on left and non-landed-flute ProTaper Files on right. Note lack of ProTaper shapes.

FILE DESIGN

Traditionally, endodontic files have been tip-centric, all of the files in a set having the same .02 mm/mm taper and differing only by their tip diameters. Creating a tapered preparation with these relatively non-tapered instruments required a lot of instruments (8-12) and a lot of procedural steps (20-55) as each of the instruments were taken to a different position in the canal to create a tapered preparation.[4] Needless to say, shaping outcomes with these instruments and techniques were inconsistent, although the more talented clinicians, with enough patience and experience, were able to approach a certain predictability of shape.

GT Files are taper-centric, meaning that they vary primarily by their tapers, rather than by their tip diameters (Fig. 20.4). GT Files have limited maximum flu-

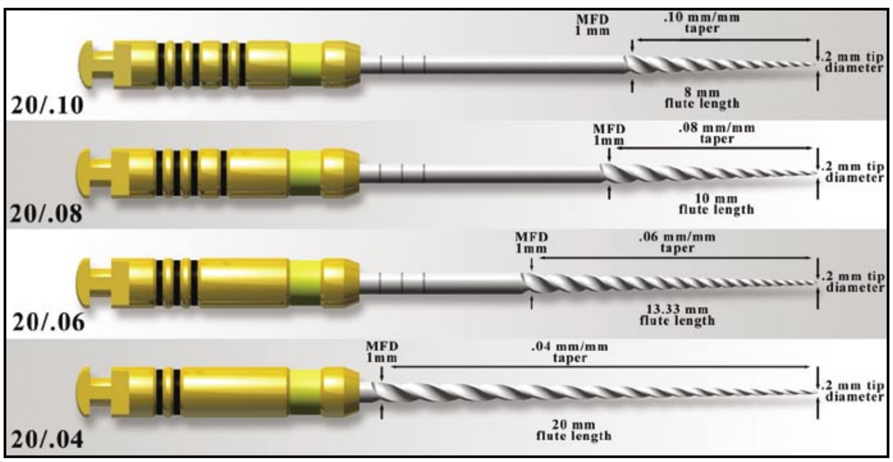


Fig. 20.4. The 20 Series GT File set. Note how the tapers vary but the tip and maximum flute diameters are consistent through the series of instruments.

te diameters (MFD's), allowing files of greater taper to be safely taken to full length in root canals, rather than using step-back shaping with numerous less-tapered instruments. Limiting the maximum flute diameter to 1 mm allows GT Files with tapers greater than .06 mm/mm to be taken to full length without over-shaping the coronal portions of canals in small and medium sized roots.

A shaping file with a 40-.10 geometry but the traditional 16 mm's of tapered flute length (with no MFD limitation) would be very dangerous in medium or large size roots because the cutting flutes at its shank end would be a full 2 mm's in diameter! Because of their cutting flutes being limited to safe diameters, GT Files with .08, .10, and .12 tapers can be safely used to full length in canals. Because a single GT File cuts the final preparation in the canal, from terminus to orifice, without Gates Glidden or Peezo burs being needed, the coronal shaping extent is totally controlled, eliminating the possibility of strip perforation or needless structural weakening, regardless of the clinician's skill or experience level.[2]

GT Files have passive, radiused tip geometry that dramatically reduces the chances of apical ledging (Fig. 20.5 A). Files with aggressive or semi-aggressive tip designs can easily cause dangerous laceration of apical anatomy during preparation procedures, significantly decreasing the chances of successful obturation. Because of this tip geometry, erroneously shaping root canals short of full length with GT Files will not cause a ledge to be formed, so it is easy to fix this mistake. The stop is reset to the correct length after discovery of the error, and the final GT File is simply cut to the terminus of the canal.

The cutting flutes of GT Files are landed, adding further safety in apical regions of canals. Because of this flute design, GT Files are much less likely to transport canal paths toward the outside of an apical canal curvature allowing these instruments to be taken beyond the apical terminus, either by accident or by intention, without ripping the apical foramen to an elliptical shape. Therefore, if an erroneously long working length has been used during shaping procedures, recovery from the mistake is as simple as cutting back the already-fit GT gutta-percha cone, or when using a GT Obturator, by adjusting the stop to the correct length and finishing the fill. Conversely, making the same length determination error when using non-landed shaping files may require apical surgery to achieve success after the foramen is ripped, destroying the apical resistance form.

Landed flute edges also add safety in the shaping of coronal regions of molar root canals, as they minimize the transportation of the preparation into the inside of canal curvatures in the thin, furcally-fluted parts of these roots. While it is unusual that non-landed shaping files cause enough coronal transportation to perforate a curved root, it is common that files with aggressive blade geometry straighten the canal path enough to significantly shorten its length, causing their tip portions to be taken beyond the apical foramen: a set-up for apical ripping.[3]

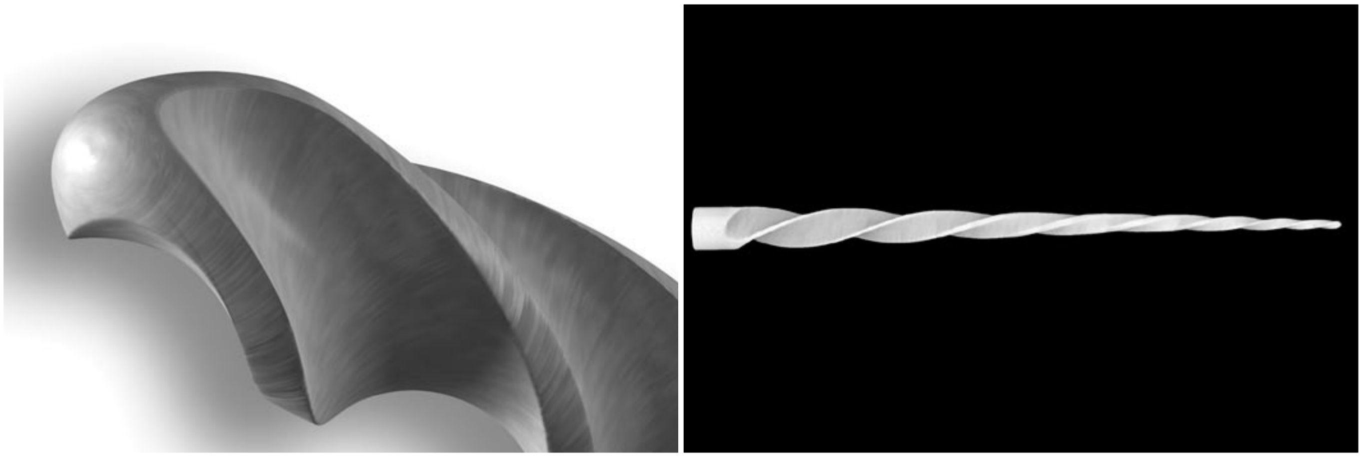
GT File blades have recently been redesigned to cut dramatically faster without giving up the safety of landed flutes. This greatly improved efficiency was accomplished by opening the flute angles along the length of the file and by thinning the land widths in the tip and shank regions. The safety was accomplished by maintaining the landed flute design and by rendering the mid-file region with a slightly wider land (Fig. 20.5. B).

This is a safe geometry despite the sharper flute design because the tip of the file is very flexible and is therefore less likely to transport, and because the shank flutes are usually cutting in the straightest regions of the canal (the coronal third). In the mid-file region the file is becoming stiffer and is more likely to cut into the inside of a mid-root canal curvature—a dangerous chance to perforate—so we made the lands wider there.

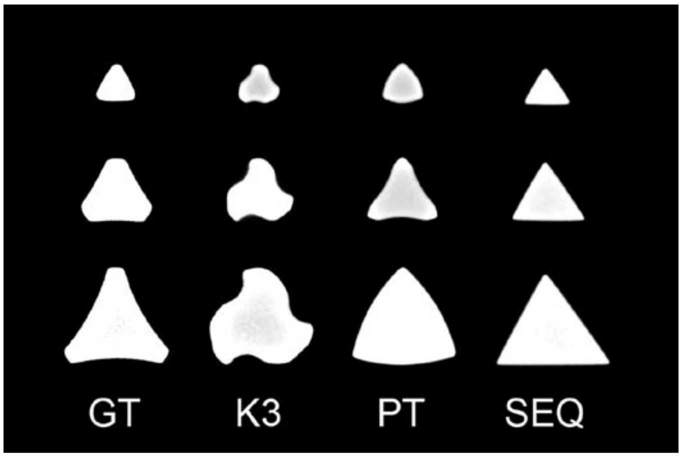
Besides the added efficiency of thinning the tip and shank blades, a major improvement in cutting speed was gained by opening up the flute angles along the whole length of the file. This created more of a reamer action that is more aggressive in rotational movement, eliminates any chance of threading into canals, and it also greatly increased the depth and width of the chip space between flutes so that the improved files can cut further through the canal before clogging. Enlarging the flute space also decreased the core mass of the file and therefore increased the flexibility of the file without decreasing its strength. The relative mass at the periphery of the file is the greatest determinant of torsional file strength and with landed flutes that peripheral mass is roughly the same (Fig. 20.5 C).

Unlike many rotary files, GT Files have more open flute angles at the shank end of the instruments. This eliminates threading into the canal during use as well as allowing for more cutting ability in the stronger shank region where more dentin needs to be removed.

GT Files are available in four basic categories of sizing, the 20 Series, the 30 Series, the 40 Series, and the .12 Accessory Series (Figs. 20.4, 20.6 A-C). The 20, 30, and 40 Series GT Files have the same range of tapers, .04, .06, .08, and .10 mm/mm in each file set but vary by their designated tip diameters. The .12 Accessory GT Files vary by their tip diameters and have a constant rate of taper within the file set, namely .50, .70,

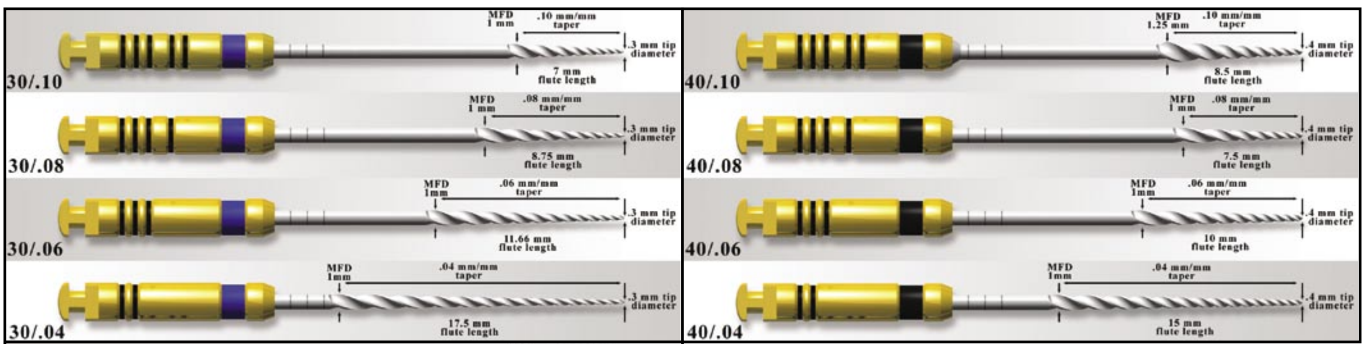


A B



C

Fig. 20.5. **A**. Tip geometry of GT Rotary File with radiused tip and landed flutes. **B**. Close-up side view of new GT File geometry with variable width lands, more open flute angles, and bigger flute space. **C**. µCT reconstructed cross-sectional views (at D_1, D_5, and D_8 levels) of four different rotary file designs (left to right, GT, K3, ProTaper, and Sequence, respectively) in their 30-.06 sizes. Note the different core diameters (GT with the smallest and K3 with the greatest), the presence or absence of flute lands (GT and K3 with lands), and the K-file cross-section of the Sequence Files with the only modification being a single higher flute.



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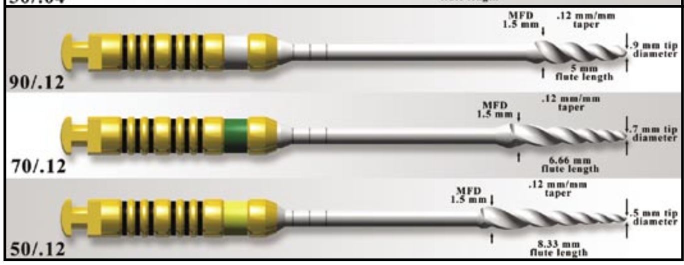


C

Fig. 20.6. **A**. 30 Series GT Files. **B**. 40 Series GT Files. **C**. .12 Accessory GT Files.

and .90 mm's–all with a large .12 mm/mm taper.

GT instruments have long been available in GT Hand File form in sizes 20-.06, 20-.08, 20-.10, 35-.12, 50-.12, and 70-.12. By the time this book is printed, Hand GT Files will be available in the same full range of sizes and the same identification codes as Rotary GT Files (Fig. 20.7). GT Hand Files have triangular cross-sectional blade geometry and counter-clockwise flute paths but cut the same preparation shapes as same-size GT Rotary Files (see chapter 13).

The GT File and product identification scheme is simple (Fig. 20.8). The number of black bands on the shank-ends, times two, equals the taper of the file, i.e., 3 bands indicates a .06 mm/mm taper, four bands would indicate a .08 mm/mm taper. The color bands on the shanks (or handle color in the case of GT Obturators) indicate the tip diameters in the ISO convention (times 10^{-2}), i.e. yellow equals a # 20 tip size (.2 mm's), blue equals a # 30 tip size (.3 mm's), and black equals a # 40 tip size (.4 mm's). In the .12 Accessory GT File set, the color bands designate tip diameters as follows: green equals a # 35 tip size (.35 mm's), yellow equals a # 50 tip size (.50 mm's), green (with a much larger fluted portion) equals a # 70 tip size (.70 mm's), and white equals a # 90 tip size (.90 mm's).

The GT Gutta-percha and Paper Points all have the same small tip diameters so they only have the black bands indicating their tapers.

For those clinicians new to variably tapered shaping files, the convention is as follows. The tip diameter, times 100, is listed first—just like the traditional ISO designation of K-files, hedstrom files, and reamers, i.e., a # 20 K-file has a tip diameter of .2 mm's. The taper size is listed second and, without moving the decimal point, is described in terms of the increase in the file's diameter each millimeter back from the tip. Therefore, a 20-.10 GT File has a tip diameter of .2 mm's and a taper of .10 mm/mm.

Fig. 20.7. GT Hand Files, from left to right, 20-.06 (white handle), 30-.06 (yellow handle), 40-.06 (red handle), 50-.12 (blue handle), 70-.12 (black handle), 90-.12 (green handle).

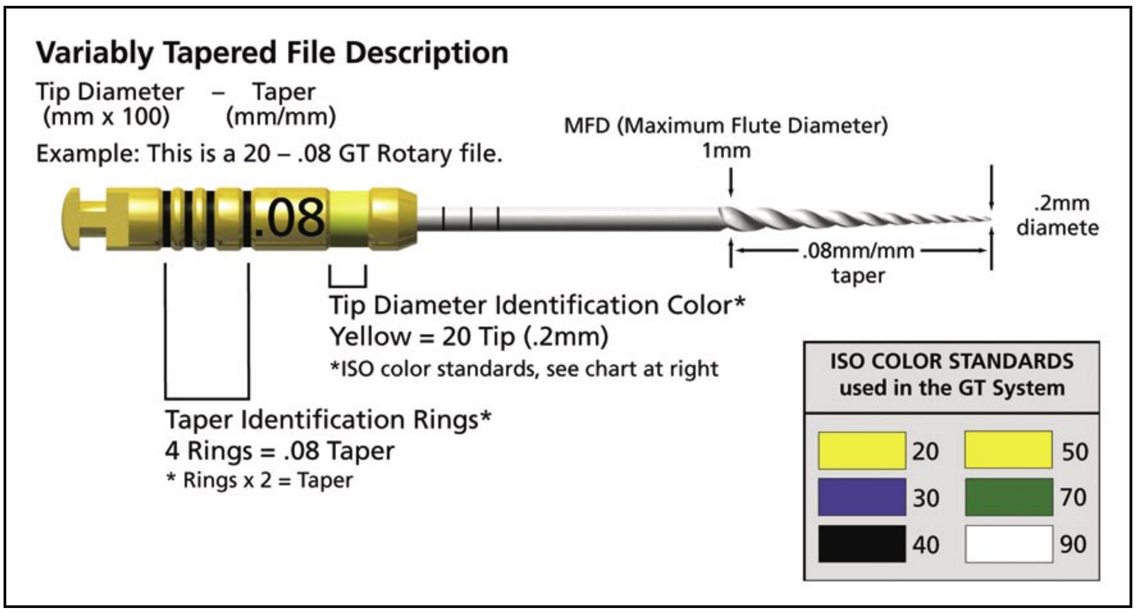


Fig. 20.8. GT Rotary File identification code and file geometry.

BASIC TECHNIQUE

The GT shaping technique consists of three steps: cutting an initial shape, measuring the apical diameter of the canal (gauging), and final adjustment of the preparation shape if necessary. In medium and large canals with small apical diameters, shaping can often be accomplished with a single GT File. In medium and large canals with apical diameters larger than .2 mm's, final shape is usually cut with two GT Files. Small unconstricted root canals are usually shaped with 2-3 GT Files, while those with calcification and/or severe curvature are usually shaped using 4-5 GT Files. As such, the GT File System, of all rotary file types, is the most efficient, in terms of the number of files and steps needed to shape a given root canal morphology.

Before shaping it is essential that the canal be negotiated to length up to a size # 15 K-file so that a glide path has been established and to insure the pulp has been removed from the primary canal (broach if necessary). Line angle extensions in access cavities must be taken to working cusps and incisal edges to reduce GT File breakage due to cyclic fatigue.

Initial shaping

The clinical objective of initial shaping is to cut a shape to the end of the root canal that has a taper greater than .04 mm/mm. This is done so that the terminal diameter of the canal can be accurately gauged (measured), a necessity in order to choose a final preparation shape appropriate for that canal. Since .02 tapered K-files are used in gauging, a canal shape of greater than .04 is needed so that the gauging instruments bind the canal only at their tips.

Initial shaping always begins with the 20-.10 GT File, regardless of the root size or the morphology of the root canal being prepared.

Rotary GT Files are used by placing the spinning instrument (usually at 300 rpm) into the canal until the cutting flutes contact the canal walls, holding a light, steady, apically directed pressure on it as it walks into the canal. Most important is that it be immediately removed after the file stalls. Stalling is when the file is still spinning but is no longer advancing further apically. This usually occurs within 4-6 seconds after cutting commences. Stalling is caused by one of two situations. Either the flute spaces of the file are full of debris or the file is too stiff to flex around a curve that it has encountered as it cuts deeper into the canal. If the flute spaces are full of debris, simply cleaning the file with alcohol gauze will allow it to cut deeper into the canal after it is re-introduced. If the file stalls and is not full of debris, drop down to a GT File smaller in taper size and continue shaping.

Letting a stalled shaping file continue to spin in the canal, accumulating cyclic fatigue, is extremely dangerous as instrument separation can and will eventually occur. Therefore a critical observation during GT File shaping is whether the file is walking into the canal (cutting) or stalled (not cutting), and a critical technique requirement is to immediately remove the file when it stops advancing. Also beware of unconsciously increasing manual pressure on the file as it slows its apical progress.

During the clinician's initial learning phase, placing the torque limiter of an electronic handpiece on a lower setting will help develop this touch. Also clinicians should consider removing these rotary files after 4-6 seconds, regardless of whether they are cutting or not. In medium or large roots, it is common that this single 20-.10 GT File will cut to full length in one or more cutting cycles. In small roots (as well as in medium and large roots with small and/or curved canals) it will require more than just the 20-.10 GT File to cut initial shape to full length.

In these cases it will be necessary to use progressively smaller-tapered 20 Series GT Files, each cutting deeper, until the root canal terminus is reached during this first phase of shaping. In straight canals it may only require a 20-.08 GT File to cut to length, in straight or moderately curved canals that are tight it may require stepping down to the .06 GT File size, in narrow highly curved canals it may require the .04 taper GT File to get to length.

Using a series of larger to smaller instruments to cut shape in a root canal in a coronal-to-apical-direction is called Crown Down shaping. The key advantage of this technique is safety. Crown Down shaping uses larger, stiffer, and stronger files to first cut coronal shape in the straighter portions of canals thereby freeing up the smaller, more flexible, and more fragile instruments to bind only at their tips as they cut through the more curved apical regions.

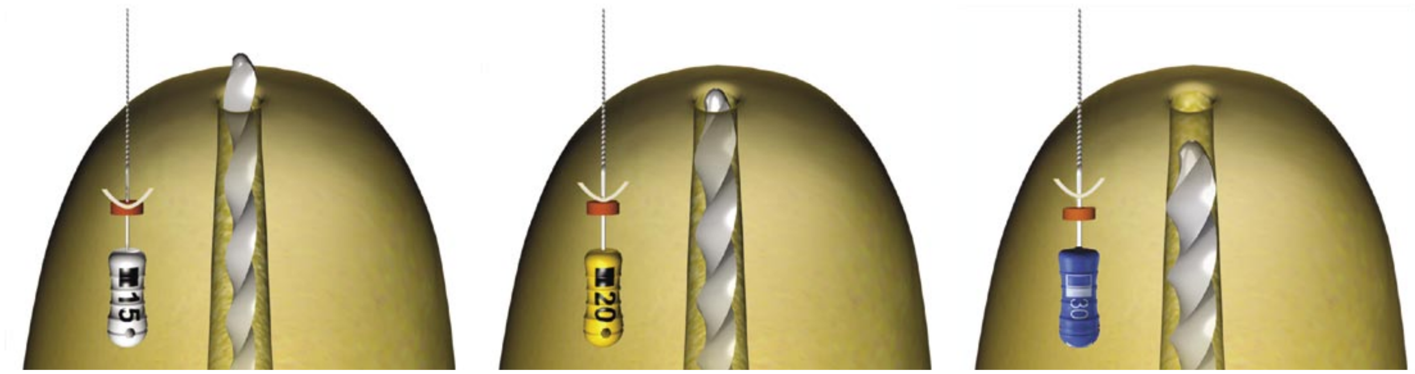
As soon as one of the GT Files in the 20 Series has reached terminal length in the canal, it is time for apical gauging in preparation for creating the ideal final shape.

Apical gauging

Apical gauging is defined as the measurement of the terminal diameter of a canal.[1] This is done the same way the gap in an automotive spark plug is measured, with a series of different size feeler gauges, the size that binds the space indicating that dimension. Because these gauging procedures must be accomplished through the root canal rather than from its end, it is necessary to use instruments of lesser taper than the canal form so that the gauging devices are confirmed to be binding at their tips, not in their shank portions. Obviously, it is virtually impossible to measure this dimension by reaching through an unshaped root canal because in this case even a parallel-sided instrument will likely bind somewhere short of its tip and therefore short of the canal terminus. To date, the best instruments to use for gauging procedures are nickel titanium K-files as they are very flexible and have a .02 mm/mm taper along their lengths, requiring only a .04 mm/mm taper in most root canal preparations. Stainless steel K-files can gauge accurately in straight canals but will give inaccurate results in curved canals due to their relative inflexibility.

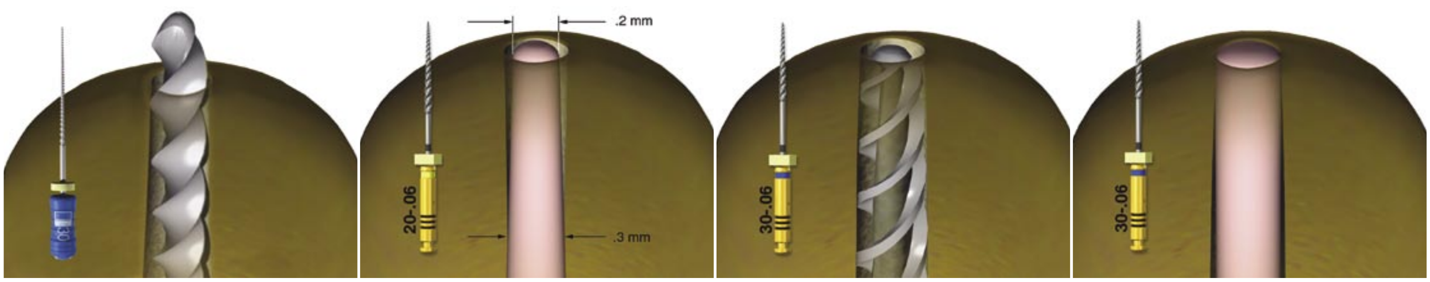
Gauging is accomplished after initial shaping procedures have allowed at least a 20-.04 GT File to cut to length and usually begins, in the presence of aqueous EDTA solution, by passing a stainless steel # 15 K-file through the foramen to confirm patency. Then, starting with a # 20 NiTi K-file, progressively larger instruments are taken to length in the canal to see which sizes will pass through the terminus, which size binds at length, and how progressively larger instruments step back from that position (Figs. 20.9 A-C).

In this manner, the apical geometry of root canals can be read indirectly by the clinician—allowing well-informed shaping decisions to be made. Shaping techniques done without apical gauging are inconsistent at best and are a set up for over-instrumentation or overfilling (Figs. 20.10 A-D).



A B C

Fig. 20.9. **A**. # 15 K-file sliding through root canal terminus. **B**. # 20 NiTi K-file binding at length, reading the terminal diameter to be .2 mm. **C**. # 30 NiTi K-file stepping back from terminus and confirming apical continuity of taper created by a 20 Series GT File. Shape is complete and ready for obturation, whether by conefitting and condensation or placement of GT Obturator.



A B C D

Fig. 20.10. **A**. # 30 NiTi K-file slipping through root canal terminus, revealing lack of apical continuity of preparation. B. Gutta-percha conefit in incomplete apically parallel preparation, a set up for an overextended fill. **C**. GT File, with same tip diameter as gauging file that bound at length, creating apical continuity of taper. **D**. GT Gutta-percha Point binding ideally at its tip, ensuring apical accuracy during condensation.

Because of the sharp flute edges of the K-files used for gauging, it is critical that the instruments be taken straight in and straight out of canals without watch-winding or rotation, otherwise unnecessary foraminal enlargement and destruction of apical resistance form will result. Because the helical flute path in K-file geometry is essentially a radial inclined plane, the tremendous physical leverage exerted on the file tip by a light rotational force being applied is grossly disproportionate to the tactile sense received by the clinician. Hopefully non-fluted gauging instruments will be available some time in the future.

Final shaping

Apical gauging allows a well-informed decision to be made about what size the final apical diameter of the preparation should be for each canal treated. The clinician must, however, make a decision regarding their apical shaping objectives. Some dentists want to retain the original foraminal diameter of the canal, so they (myself included in virgin cases) will choose a final GT File with a tip diameter equal to or one ISO size greater than the tip size of the gauging file that bound at length. For example, if the canal gauges at a # 20 file size, a GT File in the 20 Series would be ideal, if the canal gauged at a # 30 file size a 30 Series GT File would be appropriate. Half size gauging results, such as a # 25, 35, etc., are finished at the next GT File tip size.

Other clinicians (and it doesn't make them bad people) prefer to cut dentin the whole length of the canal, so they would choose a final GT File having a tip diameter at least one ISO size greater than the gauging file that binds at length, i.e., if it gauges at a # 20 K-file size a 30 Series GT File would be selected, if a # 30 file bound at length a 40 Series GT File would be ideal. I would have to say that I am of this mind in retreat cases since previously filled canals are tougher to clean and may have hardier bacteria living in them.

Next, the ideal taper for the preparation must be chosen. This is done with the root size in mind first, and the canal size and curvature used as the second consideration. Roots can be divided into small, medium, and large classes (Fig. 20.11). Small roots are lower incisors, multi-rooted premolars, buccal roots of maxillary molars and mesial roots of mandibular molars. Medium roots are the large molar roots, palatal roots of upper molars and distal roots of lower molars. Large roots are all the rest–maxillary anteriors, mandibular cuspids, and single-rooted premolars.

Small roots are shaped to .04, .06, or .08 mm/mm tapers with .08 being the favored size, for conefit obturation techniques, if it is safe. An .06 taper size is more often chosen when carrier-based filling is anticipated. Canals with moderate to severe curvature or small roots that are extremely thin are shaped to a .06 mm/mm taper, MB2 canals being a good example of both criteria. Canals with severe cervical curvatures or multi-planar bends may only be safely shaped to a .04 mm/mm taper (Fig. 20.12). Those canals are best filled with a carrier-based GT Obturator.

Medium-sized roots may be safely shaped to a .08 or

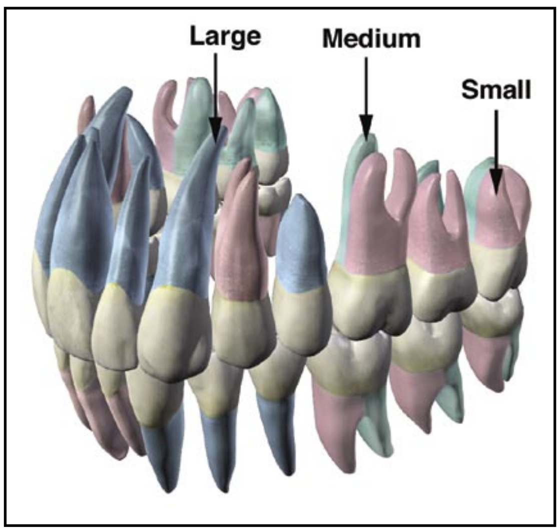


Fig.20.11. Classification of root sizes.

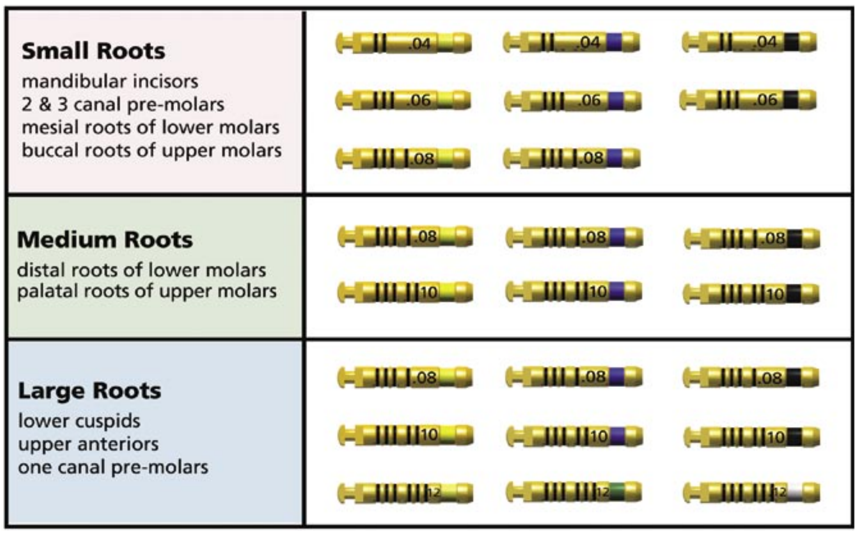


Fig. 20.12. Appropriate GT File selection for different root sizes.

a .10 taper-.08 for carrier-based filling and .10 for conefit fills. Large roots are shaped to .10 or .12 mm/mm tapers with .10 being chosen unless it is a larger root with an apical diameter bigger than .40 mm's, in which case one of the .12 Accessory GT Files would be ideal.

After the clinician has chosen the GT File with the appropriate tip size and taper, it is simply cut to length in the canal—usually in one or two cutting cycles—to finish the preparation. Crown-down preparation is unnecessary when using 30 Series or 40 Series GT Files to finish the shape. In canals with significant curvature, the added stiffness of larger tipsize GT Files may cause the GT File chosen to finish the shape to resist cutting to length. In these cases, a file with a smaller taper and the same tip diameter will usually cut to length, after which the chosen final file can finish the shape. I feel most confident that the apical shape is ideal when I gauge the terminus one last time to confirm that the terminal diameter of the canal matches the tip diameter of the final GT File taken to length.

Two additional notes on standard GT technique:

– first, the GT File system of instruments provides shaping solutions that address the full range of endodontic anatomy, excepting the open apex case. In those situations, canals having open apices are best filled with ProRoot MTA and do not require traditional apical resistance form
– second, and most important; although GT Files cut extremely consistent shapes, it is still required that clinicians make safe and effective taper selections. Choosing too small a taper for medium or large roots will encourage overfills. More dangerous, choosing too large a taper for small root canals, especially those with significant curvature, invites file breakage or root damage.

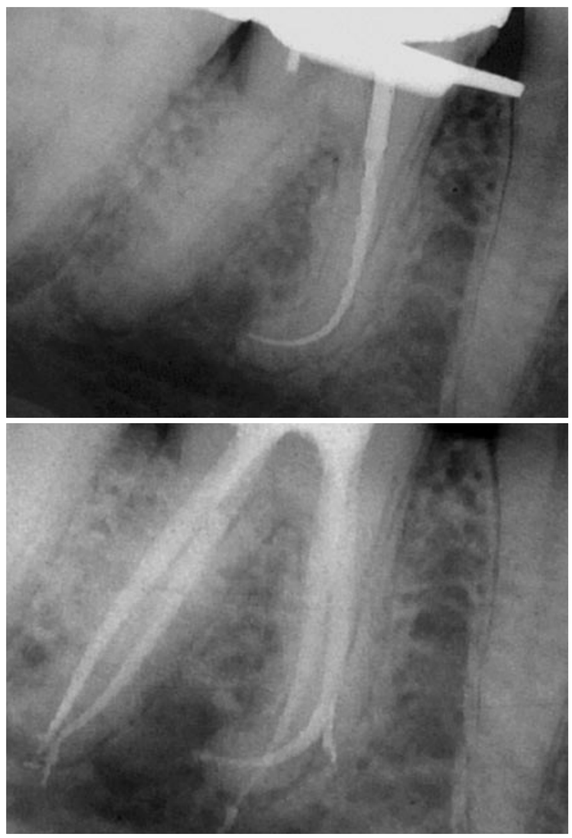
TOUGH CASES

Tortuous canals

Most slight to moderately curved canals are easily shaped with GT Files due to the design of the instruments, the flexibility of nickel titanium, and the crown-down shaping technique described above. However, canals with severe curvatures present greater opportunities for instrument breakage, so they require more sophisticated techniques be used during shaping procedures. Most important among these is the use of a light touch and an acute willingness to remove any stalling file immediately.

In these especially nasty cases the clinician may be frustrated by an inability to get even a 20-.04 Rotary GT File to length after using the larger 20 Series GT Files in a crown-down manner. The best work-around I have found is to simply move down in size to the next smaller taper, a # 20 NiTi K-file (which is essentially a 20-.02 geometry in hand file form) and use it with the Balanced Force motion to cut it to length. After crown-down shaping with the 20 Series GT Files, this instrument will cut around virtually any curve barring those with impediments. Once the # 20 K-file cuts to length, the 20-.04 Rotary GT File will almost always cut to length also, as its tip is the same size and is now a passive pilot guide after the K-file has cut the end of the canal to a .2 mm diameter.

The tipping point in these cases is whether the 20-.06 Rotary GT File will cut to the same length. Be very wary of any resistance the 20-.06 GT File encounters, and when faced with that challenge, immediately put the handpiece away and bring in a 20-.06 Hand GT File to cut the final shape, as it is ex-



A

B

Fig. 20.13. **A.** 20-.06 GT Hand File cut to length in severely curved mesial canal of mandibular molar. **B.** Post-operative radiograph.

tremely safe in this application (Figs. 20.13 A, B).

Hand GT Files are reverse-fluted to allow a reverse Balanced Force cutting technique to be used, a method of use that is more intuitive and easier for most clinicians than the standard Balanced Force technique that is used with conventionally-fluted K-files. The Hand GT File technique is as follows: rotate the file in a counter-clockwise direction until the file tightens in the canal, push firmly and rotate the file at least 180 degrees in a clockwise direction until it is felt to give, indicating that the cut is complete. Do not withdraw the file unless the desired length has been achieved, instead rotate it further into the canal in a CCW direction, push firmly and make the 180 degree CW cutting motion again. Typically, 3-5 engagement and cutting cycles are done before the Hand GT File flutes are full of debris and need to be removed for cleaning. If further depth is desired the file is placed back into the canal then and the shaping continued.

It is a rare canal curvature that a 20-.06 Hand GT File cannot cut around, those having severe, abrupt, cervically positioned curvatures being the exception. These cases would be held to a 20-.04 GT File shape with a GT Obturator being indicated for filling.

Hidden curves

Cutting initial shape before choosing the final GT File size is helpful, as information about the presence of hidden curvatures can be gained and a mistakenly large taper choice avoided. If the root canal being shaped appears relatively straight on the pre-operative radiograph but the Crown Down shaping procedure is more difficult than expected, i.e., it's hard to cut to length with a 20-.04 GT File, there may be a hidden curvature in the buccal-lingual plane. This is common when there are two canals in the same root that are apically confluent.

Most confluent canals have a relatively straight exit. However some of them curve sharply in a buccal or lingual direction as they join and exit. When this is the case, one canal will have a smooth continuous curvature and the other will curve initially toward the center of the root and then will break sharply in the reverse direction to join the other canal as it approaches the buccal or lingual root surface (Fig. 20.14).

The set-up for breakage in these cases occurs when the clinician is doing initial shaping in both canals simultaneously. The more smoothly curved canal will allow trouble-free shaping to length while the re-bent canal will resist apical shaping progress. If the clinician is only thinking in two dimensions and doesn't consider the possibility of a hidden curve in one of the canals, he or she may decide to add a little pressure on the handpiece when the file meets the apical dilaceration and balks. These are the most surprising file breakages. Obviously, the technique for completing shape in these cases is to go to smaller shape GT Rotary Files and/or GT Hand Files.

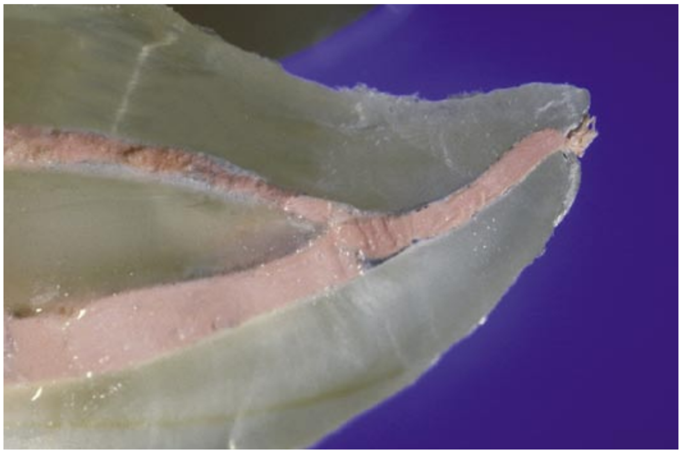


Fig. 20.14. Many molar root canals harbor canals with severe, but hidden, multi-planar curvatures. These hidden curvatures often occur when two canals in the same root are apically confluent and one of the canals has a sweeping curvature that exits on the opposite side of the root.

Impediments

Impediments are diagnosed by pushing a new # 10 K-file through a negotiated canal. If it goes to and through the canal terminus, there is no impediment and the canal can be fully shaped with rotary files. If the # 10 K-file hangs up short of length and exhibits loose resistance to apical file placement, an impediment exists beyond which rotary files cannot pass. In this case the stop on the # 10 file is shortened to the reference point (Figs. 20.15 A, B), measured, and all rotary files are measured 1 mm short of that length to prevent ledging the canal wall at the point of impediment (Figs. 20.15 C, D). Initial shape is cut to this point in the canal with GT Rotary Files in preparation for hand filing in the apical region of the canal. This will take one or two rotary GT files in the 20 Series. Once this initial coronal enlargement is completed, it is necessary to use the following technique to finish the preparation beyond the impediment.

First, serial step-back instrumentation with pre-bent stainless steel K-files is done beyond the impediment to create a tapered apical shape. Prebend K-file sizes #20-30 after measuring them to full length. Use these in a watch-wind-pull motion, in series from small to large. After two or three recapitulations through the series of files, they should fit within 0.5 mm increments of each other (Figs. 20.15 E-G).

At this point the canal has been shaped coronally and apically, but there is discontinuity of shape centered at the impediment. It is then necessary to use a pre-bent GT Hand File, maneuvered past the impediment, to complete the shape. There is a myth that nickel titanium, because of its remarkable shape memory, cannot be effectively pre-bent. The material can hold a bend of 35° to 45° if the file is over bent by 180° to 360° (Figs. 20.15 H, I). Sometimes it will take several attempts before the bend will hold. Once the bend is accomplished, direct the bent tip around the impediment using a careful watch-winding motion. When the file tip is past the impediment, the hard work is over (Fig. 20.15 J).

Because apical step back preparation preceded this final step, the GT Hand File's tip is acting as a passive pilot guide, pulling the rest of the file by the im-

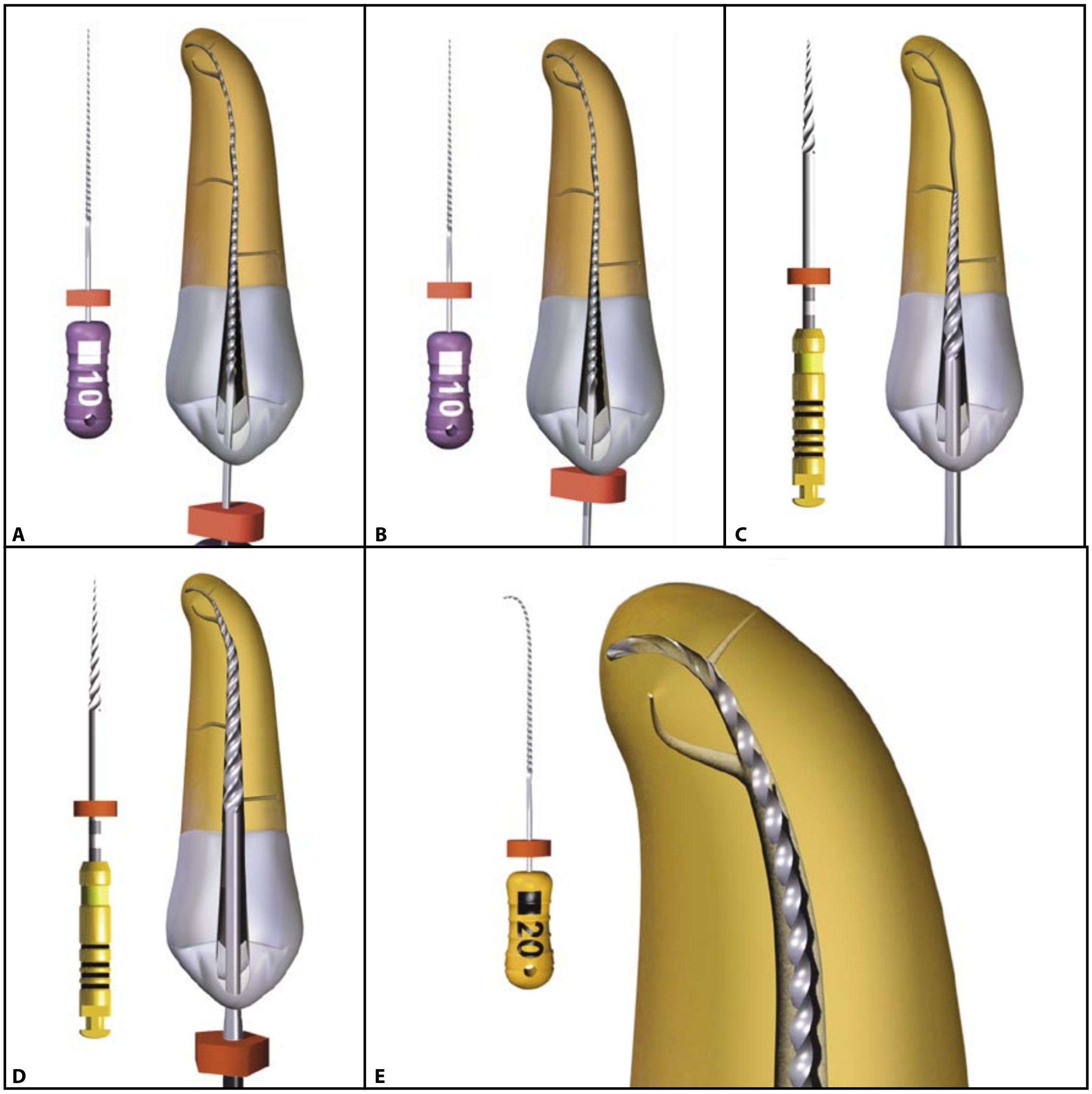


Fig. 20.15. **A**. A # 10 K-file meeting loose resistance to apical file placement, indicating the presence of an apical impediment. **B**. The stop is shortened to this length, indicating the distance from the reference point to the impediment. **C**. A 20-.10 GT Rotary File, measured short of the impediment length, starts the crown-down shaping procedure. **D**. A 20-.08 GT Rotary File continues the crown-down development of shape, to a point one mm short of the impediment, after the 20-.10 meets resistance. **E**. A pre-bent # 20 K-file starts the apical shaping beyond the impediment, used with watch-winding-pull motions (continued).

pediment. These files have reverse-cut flutes, so start by spinning the file counter-clock-wise (Fig. 20.15 K). This will feed the file into the canal. When resistance is met, apply apical pressure to the file so it cannot back out of the canal, and rotate it at least 360° in a clock-wise direction (Fig. 20.15 L). As the blades snap past the previously cut screw threads, it will be possible to hear and feel the file "click". After two or three clicks, it is usually smooth, but don't remove the file yet.

Again, rotate the GT File counter-clock-wise to feed it back in, push on it, and make the cut in a clock-wise direction (Figs. 20.15 M-P). After three to five of these cutting cycles, the file will stop advancing in counter-clock-wise rotation because the flutes are full of debris. Rotate the file counter-clock-wise as it is retrieved from the canal to keep the debris loaded on the file flutes.

Quite often the impediment will be gone at this point and conefit is straightforward (Fig. 20.16). In cases where the impediment remains after shaping and conefit is impossible, a GT Obturator is indicated as filling material can be effectively pushed ahead of carriers but not ahead of gutta-percha cones.

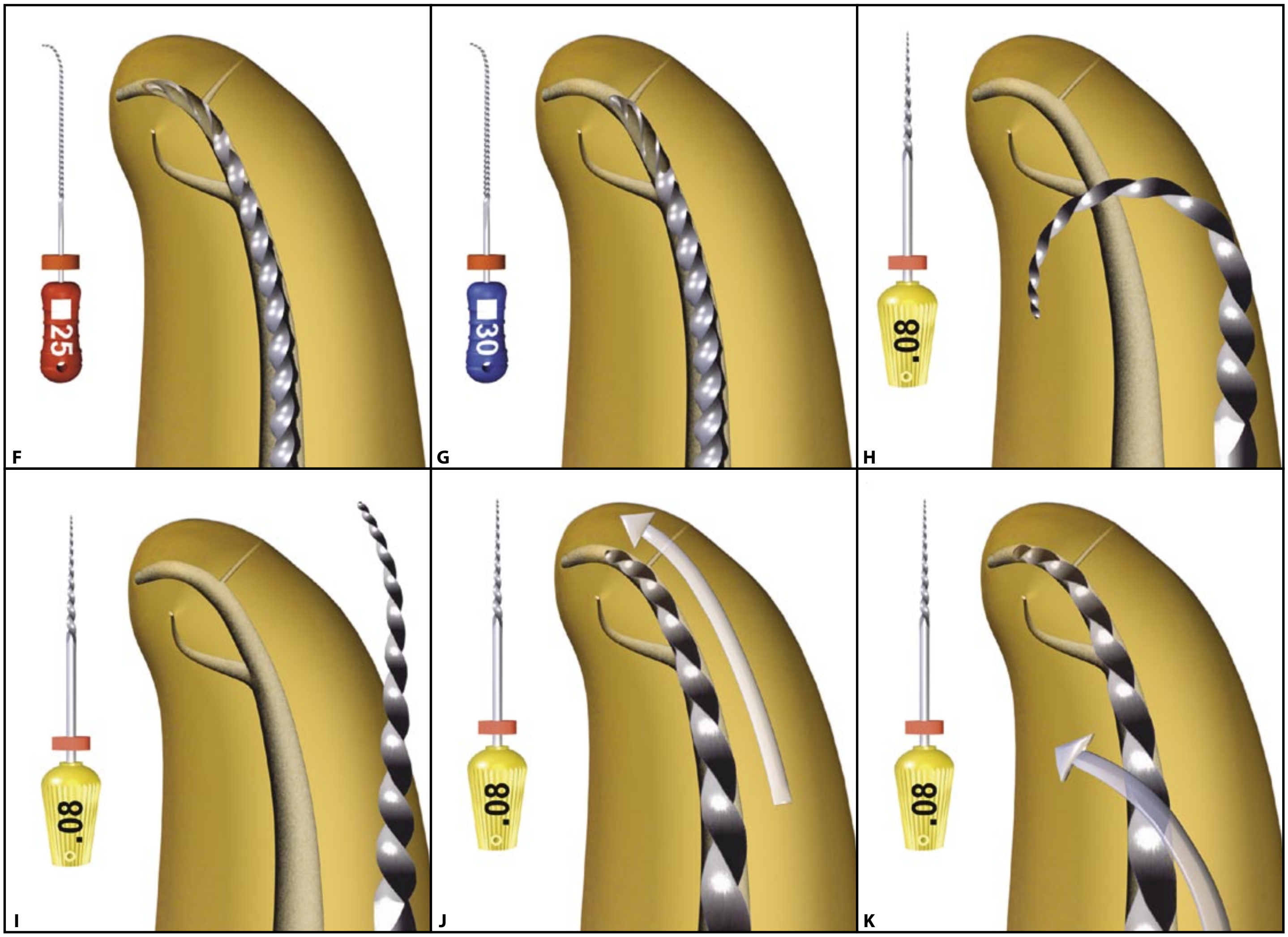


Fig. 20.15. (Continued) **F**. A pre-bent # 25 K-file cuts to 0.5 mm short of terminal length. **G**. A pre-bent # 30 K-file is watch-wound to about 1 mm short of terminal length. **H**. A GT Hand File of adequate taper (a 20-.08 in this case) is brought in at this point because pre-bending and directed introduction is possible where unbent rotary files cannot bypass the impediment. Because of NiTi's shape memory, the file must be dramatically overbent, 180° to 270°, using the EndoBender plier by SybronEndo. **I**. When bent far enough, even a NiTI file will hold a residual 35-45° bend. **J**. The pre-bent GT Hand File, used with a directional stop pointing towards the file bend, will in most cases, then traverse the impediment. **K**. The GT Hand File is first rotated in a counter-clockwise direction with no apical pressure, pulling the instrument into the canal walls, similar to tapping a screw thread in a hole (continued).

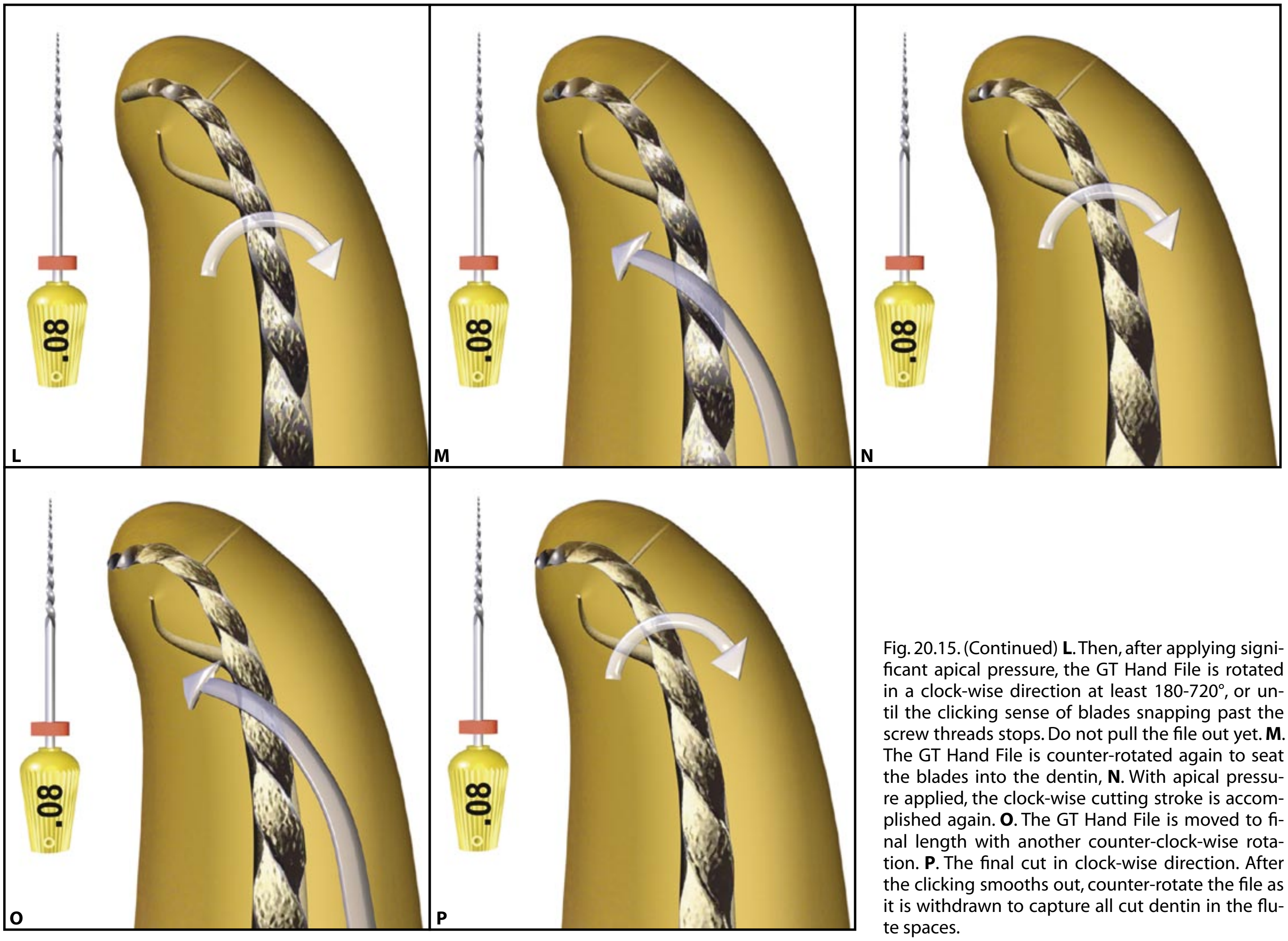


Fig. 20.15. (Continued) **L**. Then, after applying significant apical pressure, the GT Hand File is rotated in a clock-wise direction at least 180-720°, or until the clicking sense of blades snapping past the screw threads stops. Do not pull the file out yet. **M**. The GT Hand File is counter-rotated again to seat the blades into the dentin, **N**. With apical pressure applied, the clock-wise cutting stroke is accomplished again. **O**. The GT Hand File is moved to final length with another counter-clock-wise rotation. **P**. The final cut in clock-wise direction. After the clicking smooths out, counter-rotate the file as it is withdrawn to capture all cut dentin in the flute spaces.

Fig. 20.16. Mandibular molar with severe multi-planar curvatures in mesial canals and distal canal with an abrupt apical curvature that presented as an impediment and was shaped with a pre-bent GT Hand File.

CHOOSING AND USING GT SYSTEM MATERIALS

Gutta-percha

GT Gutta-percha points are available in five sizes with .04, .06, .08, .10, and .12 tapers and are slightly less tapered than each indicated size to ensure that they bind only at the end of the preparation (Fig. 20.17 A). They are all rolled to a feather tip-size and are thus intended to be cut at their tips. The clinician may use a GT Gutta Gauge (Maillefer) into which the cone tip is placed and sliced off with a bladed instrument to adjust the tips of these cones or may simply place the cone to its binding point in the shaped canal, grab it carefully with cotton pliers at the reference point on the tooth, measure it, and cut it to be one-half millimeter short of full length. Conefitting should take less than 30 seconds per canal.

This is a taper-centric conefitting method as opposed to tip-centric methods used traditionally. There are key advantages. Only five sizes of cones are needed for all 15 GT File sizes. And if the canal has been accurately gauged and apical continuity of taper has been created, you can achieve really dependable apical control during condensation procedures.

GT Paper Points

GT Paper points are made in the same five sizes as GT Gutta-percha points. Because GT Paper Points ideally fit root canal preparations made by GT Files it usually takes only 2-3 points to dry each canal. Because these paper points are also rolled to a feather tip, they can also be used as a final length confirmation device after the canal is dry, a remarkably accurate method. After the canal has been dried with two or three paper points, another paper point is immediately placed to binding length, is grasped with locking cotton pliers at the reference point on the tooth, and is removed.

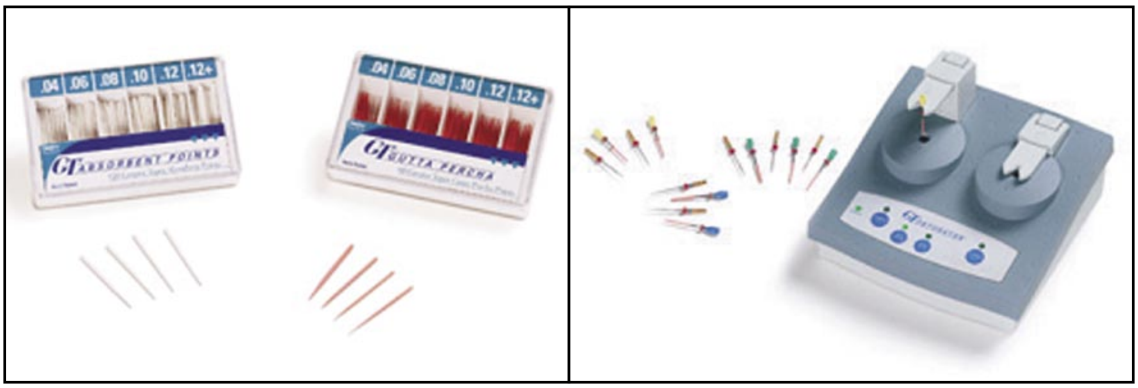
The tip of the paper point, which has slipped through the root canal terminus, will have been wet by periapical tissue fluids and will bend when touched by a gloved finger. Measure the unbent portion and the canal length will usually be very accurately represented. If there is any doubt, re-dry the canal and use another point to measure with. I will believe a paper point measurement over most other methods, usually eliminating the need for a conefit film prior to obturation (Fig. 20.17 A).

GT Obturators

GT Obturators are chosen to match the GT File used to cut the shape in a given canal, so there are fifteen Obturators to match the fifteen Files. GT Obturators are measured 1 mm short of full canal length and are slowly (5-6 seconds) placed into the canal to achieve apical accuracy of filling (Fig. 20.17 B).

GT Posts

GT Posts come in three sizes, 1.0 mm, 1.25 mm, and 1.5 mm diameters, and three different materials, stainless steel, titanium, and fiber reinforced composite. They are meant to be bonded in place and either their tip or their head portions adjusted to length (Fig. 20.17 C).



A B

Fig. 20.17. **A.** Paper points and GT gutta-percha points. **B.** GT Obturators.

Fig. 20.17. **C.** The GT Posts.

CONCLUSION

With the plethora of nickel titanium shaping files available today, it can be intimidating for dentists to choose which set of instruments are right for their endodontic needs. I would suggest that clinicians who are in that decision mode consider the following questions: Do the files you are considering make the same preparation shape every time or do they change the paths of canals? Are the files a part of a system of instruments and materials that are designed to work together? Do the tip and flute designs cut safely with little or no transportation of the canal path when shaping curved canals? Are the files forgiving of length determination errors? Are the shaping instruments available in hand file as well as handpiece-driven versions? Can the file set address a wide range of apical canal diameters? Are they available in a wide range of tapers? Can they cut the whole preparation in a simple canal with a single file (Fig. 20.18)?

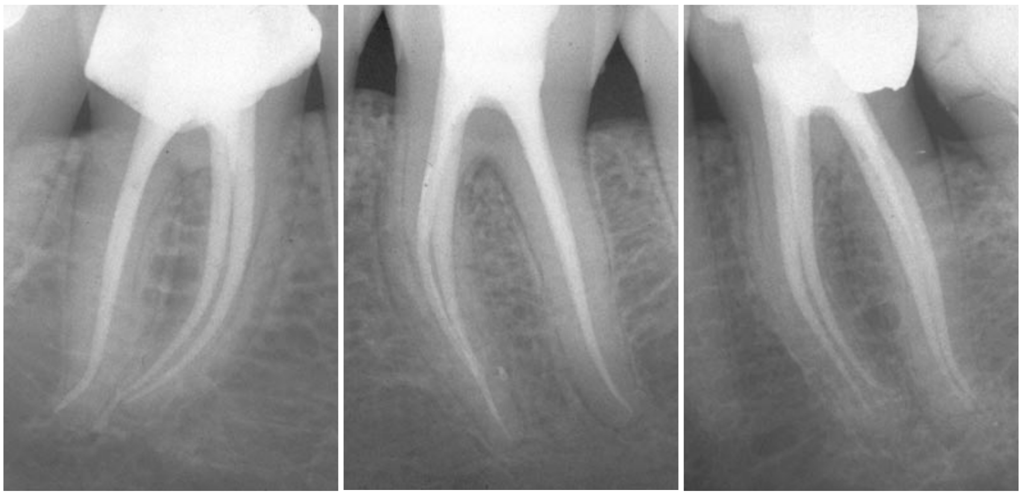
Remember, the patient's best interest must be considered above all else, so safety is the prime objective. After that, the consistency of shaping outcomes and the ease of use take precedence (Figs. 20.19 A-I). Finally, at the end of the day, the clinician's skill, experience, and attention to detail is far more important than the specific tools or techniques that are used. Beware of claims to the contrary.

Fig. 20.18. Maxillary cuspid with preparation that was cut with a single 20-10 GT Rotary File in 90 seconds.

A B

Fig. 20.19. **A-I.** Post-operative radiographs of teeth shaped using the GT Rotary files (Courtesy of Dr. A. Castellucci).

C D E F



G H I

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21

The K3 Rotary Nickel Titanium Instrument System

Richard E. Mounce

THE K3 SYSTEM FEATURES

Introduced in January 2002 in North America, the K3 was designed by Dr. John McSpadden (Lookout Mountain, GA). The system has:

1) Canal shaping files which are available with a fixed taper of .02, .04 or .06. The .02 tapered K3 files are available in 15-45 tip sizes and 21, 25 and 30mm lengths, the .04 and .06 tapered K3 files are available in 15-60 tip sizes and 21, 25 and 30 mm lengths
2) A slightly positive rake angle (Fig. 21.1)
3) A variable core diameter (Fig. 21.2)
4) Three radial lands with a relief behind two of the three (Fig. 21.3)
5) Asymmetrically placed radial lands as well as unequal land widths, flute widths and flute depths (Fig. 21.4)
6) An "Axxess" handle design, which shortens the file handle by approximately 5 mm without affecting the working length of the file (Fig. 21.5)
7) A variable flute pitch (Fig. 21.6)
8) A color-coding to distinguish between different tip sizes and tapers (Fig. 21.7)
9) A safe ended cutting tip (Fig. 21.8)
10) K3 Enhanced Taper Body Shaping (ETBS) files have recently been introduced with an enhanced taper of .08, .10, and .12. The ETBS can act as canal shaping files, orifice openers and deep body

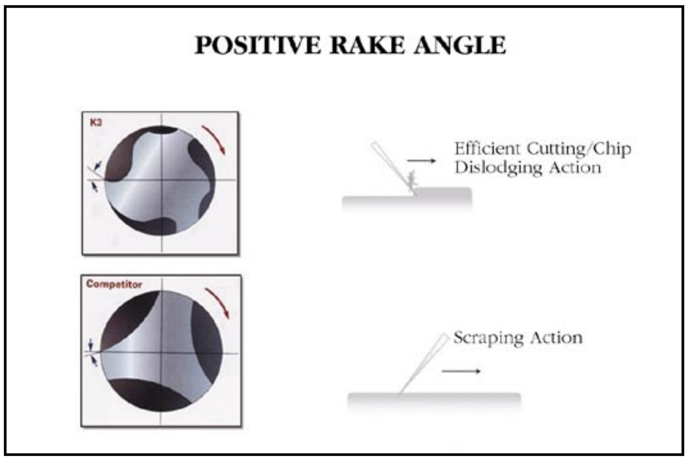


Fig. 21.1. The K3 has a positive rake angle providing an effective cutting blade.

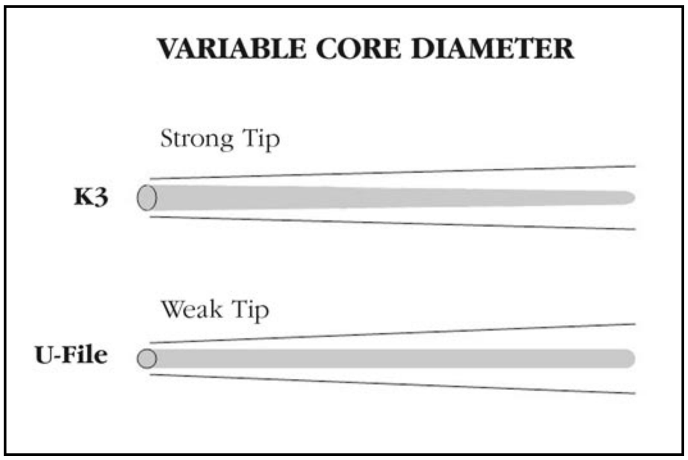


Fig. 21.2. The K3 has a variable core diameter to increase flexibility over its cutting length.

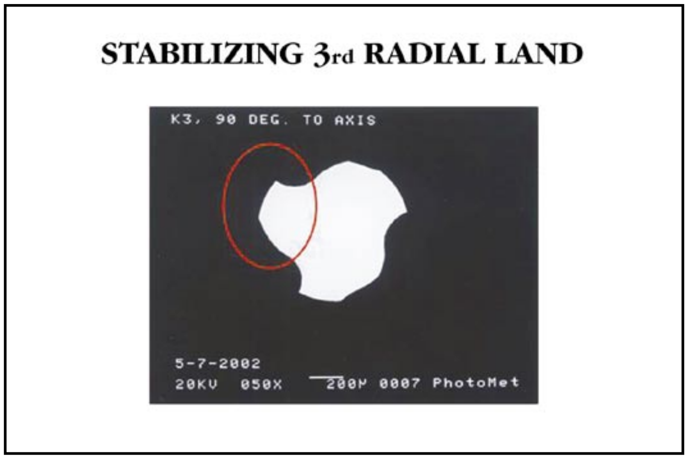


Fig. 21.3. The K3 has a series of three radial lands when viewed in cross section, with relief behind two of the lands. The feature reduces friction on the canal wall and prevents overengagement and helps keep the file centered.

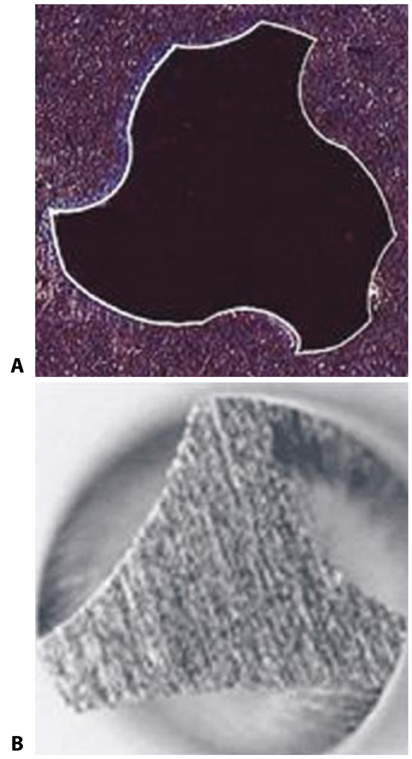


Fig. 21.4. **A**. The K3 has asymmetrically placed radial lands of unequal width, unequal flute widths and depths preventing the file from acting like a screw. **B**. U shaped files are symmetrical promoting such a "screwing in" which risks separation.

Fig. Fig. 21.5. The K3 has an "Axxess" handle design shortening the file handle by 5 mm leaving the working length of the file identical.

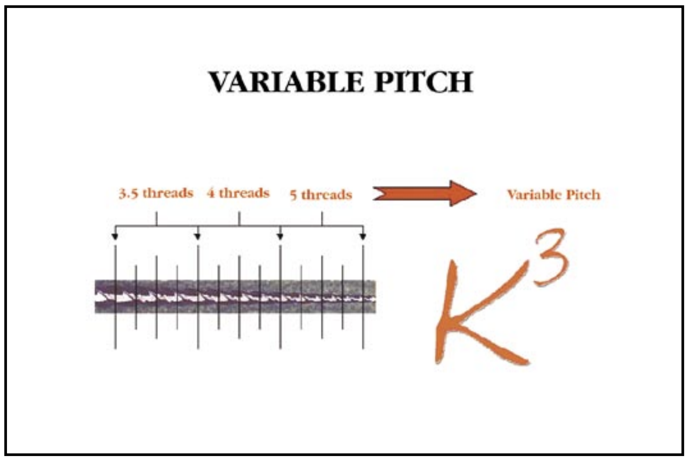


Fig. 21.6. The K3 has a variable flute pitch again to resist the "screwing in" of the file.

Fig. 21.7. The K3 is color-coded.

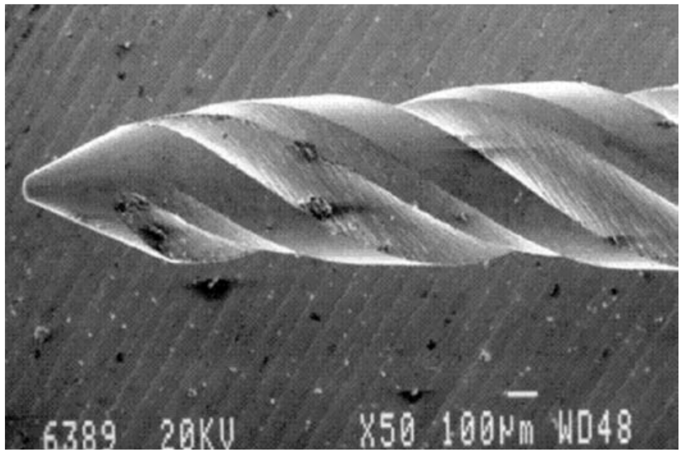


Fig. 21.8. The K3 has a safe ended cutting tip.

Fig. 21.9. The K3 system includes "Enhanced Tapered Body Shaping" files with fixed tapers of .08, .10, and .12 which can act as canal shapers, orifice openers and deep body shapers

shaping files. These are available in a fixed 25 tip size, and 17, 21 and 25 mm lengths.* (Fig. 21.9)

These attributes provide (amongst many positive characteristics):

1) canal tracking virtually eliminating canal transportation
2) tactile control over the file which prevents the file from screwing into the canal
3) peripheral strength
4) debris removal
5) fracture resistance
6) effective cutting of dentin and debris removal on the file
7) file flexibility
8) reduced friction on the canal wall

Literature review

Using micro-focus computer tomography (XMCT with extracted teeth), Bergmans, et al.[2] concluded that both the ProTaper (Dentsply Tulsa Dental, Tulsa, OK) and the K3 "were capable of preparing canals with optimum morphological characteristics in curved canals". In addition, "the amount of dentin removal at all separate horizontal regions was comparable for both groups". "Under the conditions of the present study, statistical analysis could not reveal any difference between the ProTaper and K3 group for the amount of transportation and centering ability."

Shafer and Florek[4] in Part 1 of a 2 part study concluded that the K3 instruments achieved better canal geometry and showed significantly less canal transportation than hand powered K-Flexofiles. A total of 11 K3 instruments fractured during the preparation of 96 canals. These authors compared K3 to stainless steel K-Flexofiles in simulated resin block canals with 28 and

(*) The ETBS have a shorter taper length of 8 mm at the apical end of the file and the ETBS have a slightly different helix angle relative to the other K3 sizes and tapers.

35 degree curves at 250 rpm in a crown down technique to a size 35 master apical rotary size. Material removal was measured at 20 points beginning 1 mm from the apex comparing pre and post instrumentation images.

These findings do not bear out the author's clinical experience and are likely a limitation of the performance of the K3 in plastic blocks and the fact that no glide path was created for the K3's nor were they used in the sequence recommended by the manufacturer. Also, the master apical rotary file size used (35) is larger than that most often used clinically. In addition, a rotational speed of 250 rpm is not recommended by the manufacturer (350 rpm).

Schafer and Schlingemann in Part 2 of this study[5] instrumented extracted molars with curvatures ranging between 25-35 degrees with K3 instruments and K-Flexofiles. Straightening of canal curvatures was measured. Debris and smear layer remaining were also evaluated with SEM studies. Completely clean root canals were never observed. Under the conditions of the study, K-Flexofiles allowed significantly better removal of debris than K3 instruments but K3 files maintained the original curvature significantly better. A number of K3 instruments fractured. The results for remaining smear layer were similar.

Again, as in the previous study, these results must be interpreted with great caution. The two sample sets were treated differently. The K3 group was used in a crown down fashion and the K-Flexofiles using a reaming motion up to size 35. The canals were irrigated with 2.5% sodium hypochlorite and the paper does not explain why full strength hypochlorite (5.25%) was not used. The authors do not explain how the K3 could have left more debris in the canal and yet left a similar smear layer as the K-Flexofiles. Why the smear layer was measured as a parameter of the study given the fact that the smear layer was not removed (as it would be clinically) was also not explained. In addition, it does not make intuitive sense that the K3 would maintain the original curvature better yet leave more debris and this was not explained. Generally, a less ideal canal shape will leave more debris after irrigation. This study also suffers from the fact that different rotary systems are not compared with the K3 to evaluate if there is bias built into the study against the K3 aside from those mentioned here. Also, these authors did not achieve or maintain apical patency as instrumentation was taken 1 mm shy of the anatomic apical foramen. Furthermore, the crown down sequence used by the operators is not that recommended by the manufacturer. Worse still, there is no mention of a glide path being created prior to K3 use which runs counter to manufacturers instructions and would explain why the K3 files that separated did so. In essence, the clinical relevance and value of this study does not exist. The K3 in clinical practice is in fact challenging to fracture and in essence both of these studies above treated the K3 in a fashion in which it would never be clinically employed.

Martin B. et al.[3] evaluated the effect of rotational speed (150, 250 and 350 rpm) and the angle and radius of curvature of root canals on the fracture with K3 and ProTaper. All fractures occurred in canals with curves greater than 30 degrees. Files used at a rotational speed of 350 rpm were more likely to fracture than those used at 250 rpm and than those used at 150 rpm (contrary to manufacturers recommendations). A decrease in the angle of curvature of the canal significantly reduced the incidence of fracture. No significant differences were found between the files.

Ankrum[1] studied the incidence of file breakage and distortion with ProTaper, K3 and ProFile in severely curved roots (45-70 degrees). The study showed that there was not a statistical difference with regard to breakage between the three systems although the ProTaper group fractured most (6.0%); the ProFile group fractured least (1.7%) with the K3 group intermediate between the two at 2.1%. In essence, the ProTaper fractured 3 times more than the K3. There were significantly more distorted files in the ProFile group compared to the ProTaper. The proportion of files distorted was 15.3% for the ProFile, 2.4% for the ProTaper and 8.3% for the K3.

ENHANCING K3 PERFORMANCE

The performance of the K3 is enhanced by copious irrigation (5.25% sodium hypochlorite, approximately 80-120 cc per average molar), achievement and maintenance of apical patency, EDTA gel employed initially in vital cases and crown down instrumentation (where the coronal third is instrumented first, the middle third second and apical third last) (Fig. 21.10). Scouting of the canal in the apical two thirds with small K files and creation of a glide path for subsequent rotaries as detailed below is desirable.

In addition, K3 insertion should be slow, gentle and deliberate with approximately 4 mm of the file engaged at any given moment if possible. It is recommended that the operator use an electric torque control motor with auto reverse (TCM Endo III motor, SybronEndo, Orange, Ca) at approximately 300-350 rpm (Fig. 21.11).

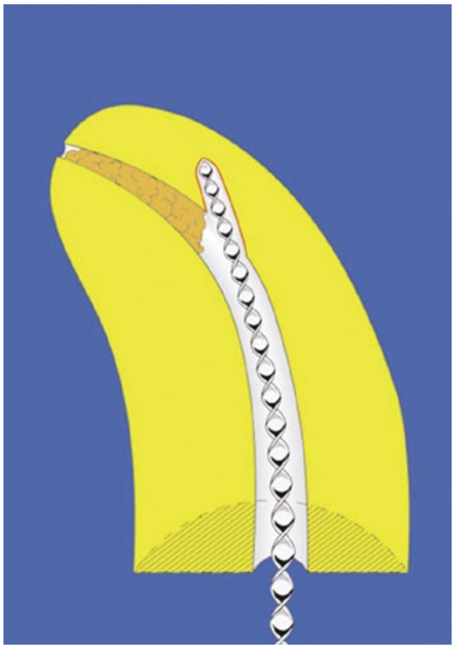


Fig. 21.10. Loss of apical patency predisposes the endodontic result to failure as debris remains harbored in the apical third and blockage can lead to ledging and separated instruments as well as other iatrogenic events.

Fig. 21.11. An electric torque control motor with auto reverse is recommended for K3 use such as the TCM Endo III motor (SybronEndo, Orange, CA) at 350 RPM for maximum efficiency.

CLINICAL K3 TECHNIQUE

1) Pre-operatively, assess for an estimated length of the tooth, strategic value of the tooth, estimated numbers of canals and roots, root curvature, calcification, periodontal status, restorability, access difficulties, etc. and take multiple angles[3] of pre-operative radiographs.
2) Access is always straight line.
3) Initially, in the presence of EDTA and/or sodium hypochlorite, a K3 Enhanced Tapered Body Shaper (ETBS) is used to gain a "toehold" in the canal assuming the orifice will accept it easily. The .12 is used first in larger canals (palatal roots), .10 is used first in medium sized canals (bicuspids) and the .08 is used first in smaller canals (lower anteriors). The .12, .10 and .08 are used successively in the coronal third. If the .08 is used first in a small canal, then a .12 and .10 can follow and the sequence repeated.
   The ETBS can act as orifice openers, canal shaping files and/or be taken to true working length as the master apical file. If the ETBS will progress easily beyond the coronal third, let it advance passively, but no farther than the junction of the middle and apical third at this stage.
4) If the ETBS will not advance beyond the coronal third, scout the middle third with a #6-10 K file to determine patency and canal curvatures. Instrument to a 15 K file to the junction of the middle and apical third. After opening the middle third up to a 15 K file, the .06/35 K3 is inserted passively. If the .06/35 K3 will not advance to mid root or slightly beyond, the .06/30, .06/25, .06/20, .06/15 can be used instead. Recapitulation and irrigation are frequent. At this stage, no attempt should be made to enter the apical third.
   The goal of middle third shaping is to instrument the canal to the junction of the middle and apical third. Ideally, a .06/35 or .06/30 or .06/25 should be taken to this level. In small canals, a .04 taper can be used in the same way.
   Middle third shaping is sequenced:
   .06/35 or .04/35 to resistance
   .06/30 or .04/30 to resistance
   .06/25 or .04/25 to resistance
   .06/20 or .04/20 to resistance
   Usually, this sequence (repeated as many times as needed) will allow instrumentation to the junction of the middle and apical third.

5) The apical third requires a gentle touch. Extensive time per canal is often required to scout the apical third with hand files starting with 6, 8 and 10 K files to reach the estimated working length (EWL). Once a 10 K file reaches the EWL, a radiograph should be exposed to determine the true working length (TWL) and be confirmed by tactile sense, a bleeding point and electronic apex location.
   Once TWL is established, a glide path for subsequent K3 files should be established to approximately a size 15-20 K file. The glide path is complete when a 15-20 K file will spin freely at TWL. After the creation of the glide path, a .02 tapered/15 and .02 tapered/20 can be used to TWL to help accentuate and refine the glide path. This creates efficiencies with regard to the use of subsequent K3 canal shaping files. In essence, these files provide a transition, or bridge, between hand and rotary instrumentation especially in the apical third.

6A) Once the glide path is created, the K3 is introduced in a crown down fashion varying either the tip sizes utilizing the same taper or varying the taper with progressively smaller tip sizes (see 6B and 6C below). These sequences are repeated as needed. .04 K3 files can be used in narrow canals as indicated with a varying tip sequence in 6B below.

6B) Varying tip sequence
   - .12 ETBS to resistance (coronal third)
   - .10 ETBS to resistance (coronal third)
   - .08 ETBS to resistance (coronal/middle third)
   - .06 K3 35 to resistance (middle third)
   - .06 K3 30 to resistance (middle third)
   - .06 K3 25 to resistance (apical third)
   - .06 K3 20 to resistance (apical third)
   - .06 K3 15 to TWL
   - .06 K3 25 to TWL

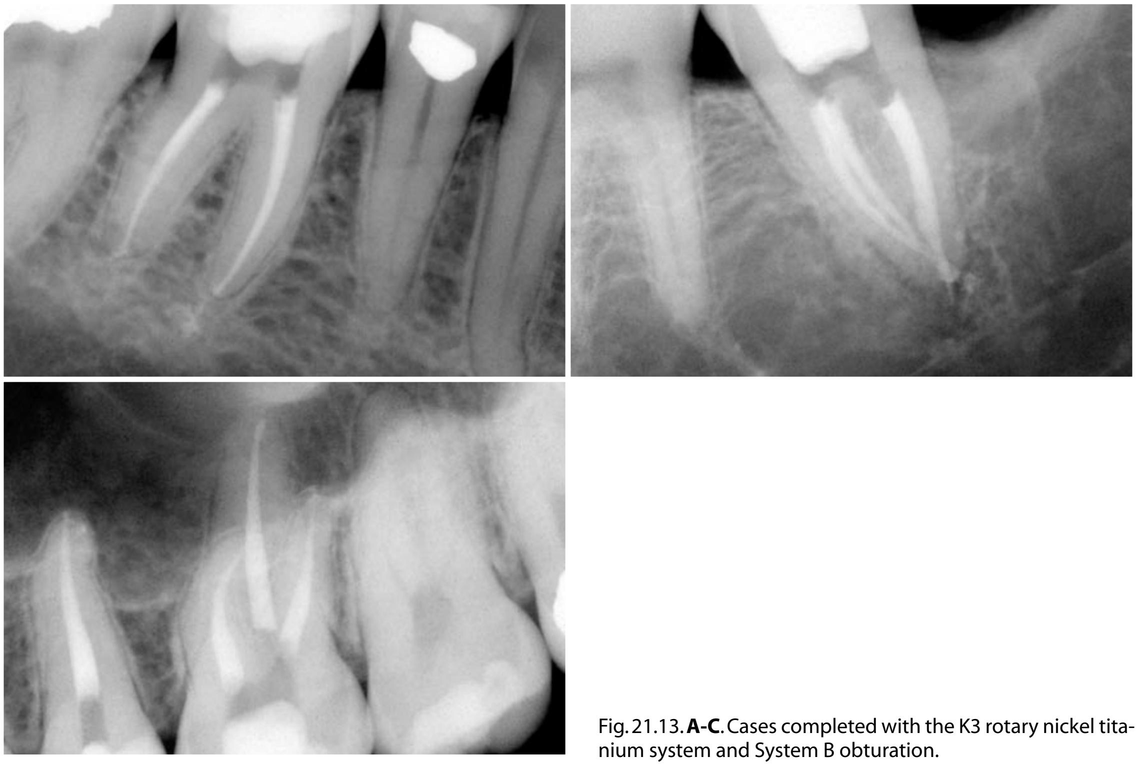
6C) Varying Taper Sequence
   - .12 ETBS to resistance (coronal third)
   - .10 ETBS to resistance (coronal third)
   - .08 ETBS to resistance (coronal/middle third)
   - .06 K3 40 to resistance (coronal/middle third)
   - .04 K3 35 to resistance (middle third)
   - .06 K3 30 to resistance (middle third)
   - .04 K3 25 to resistance (apical third)
   - .06 K3 20 to TWL
   - .04 K3 25 to TWL
   - .06 K3 25 to TWL

7) Prior to deciding to what size to shape the apex, it may be desirable to determine the diameter of the foramen ("gauge the apex"). Gauging is best described by example: If a #20 K file will slide to the TWL and resists movement beyond the foramen, then an appropriately tapered K3, 25 tip size, (if it will advance passively) is taken to TWL to finalize the preparation (canal size dependent).

Autofit paper points (SybronEndo, Orange, CA) can be used in tandem with Autofit gutta percha points to make cone fit relatively straightforward (Figs. 21.12 A, B). A paper point which slides passively and easily to TWL without kinking or deformation in a dry canal can be matched by a gutta percha point of the same taper and length simplifying cone fit. Gutta-percha cone fit radiographs prior to obturation verify that both the correct shape of preparation has been obtained and confirm TWL. Once cone fit is examined radiographically and found to be acceptable, obturation via the Continuous Wave of Condensation (System B obturation) can be employed to fill a molar tooth in literally minutes without leaving a carrier as advocated in carrier based obturation techniques (Figs. 21.13 A-C).

A B

Fig. 21.12. **A-B**. Autofit gutta percha and paper points, Sybron Endo, Orange, CA.



A B C

Fig. 21.13. **A-C.** Cases completed with the K3 rotary nickel titanium system and System B obturation.

K3 TECHNIQUE SUMMARY

1) Coronal third is instrumented first with the ETBS.
2) The Middle third is instrumented next with the ETBS, .06 and .04 K3's.
3) TWL is established after scouting with K files.
4) A glide path is created to TWL with K files up to a 15 K file and enhanced by using a .02 tapered 15 and 20 file to TWL.
5) The K3 is introduced in a crown down fashion varying either the tip sizes utilizing the same taper or varying the taper with progressively smaller tip sizes until the appropriate tip size and taper reaches TWL. If desired, the apex can be gauged to measure the diameter of the apical foramen and determine if enlarging the apical preparation is warranted for the given canal.
7) It is important to remain patent and irrigate frequently at all times.
8) The K3 is optimally used with full torque at 350 rpm.

Additional considerations

The "average" molar will require a limited number of K3 files most usually the .06 taper (15-35 tip sizes), the .04 and .02 taper (15 and 20 tip sizes), the 17 mm ETBS. It is uncommon to need other K3 files than these listed for the vast majority of clinical cases, especially if the operator is using a fixed taper (.06) diminishing tip size crown down approach as detailed in 6B above. In addition, under a surgical microscope, in order to read the mm markings, a 25 mm length K3 has greatest visibility.

K3LS HYBRID TECHNIQUE

A "K3LS Hybrid Technique" is gaining recognition in which the K3 system is used for coronal two thirds shaping and the apical third is instrumented with the LightSpeed (LightSpeed Technology Inc., San Antonio, TX) rotary file. K3 files can of course be used for the entire canal preparation, but some operators prefer to create a larger final apical diameter with the LightSpeed creating a blended or "hybrid technique". For example, once upper two thirds shaping is done with the K3, the LightSpeed can predictably create a size 50 apical preparation in the buccal roots of upper first molars. Intuitively, larger apical sizes are desirable if created judiciously. Larger apical diameters facilitate enhanced irrigation, more predictable cone fit, and arguably a cleaner canal as more dentin is removed circumferentially in the apical third. The LightSpeed is a smooth shafted instrument with U blade cutting flutes that resemble a Gates Glidden drill. This feature promotes larger tip sizes introduced further apically than many other brands of rotary files.

SUMMARY

With few if any limitations, the K3 system by SybronEndo represents the state of the art in rotary nickel titanium Endodontic instrumentation and has virtually universal indication across the widest variety of clinical cases. Amongst its many positive features, the file resists fracture, cuts efficiently and possesses a robust sense of tactile control. For profitability, the file can also be used on more than one tooth before discarding, especially above a 25 tip size in all tapers assuming that the file exhibits no deformation or any type.

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22

The Quantec™ Rotary NiTi Instrumentation System

John T. McSpadden, Gary D. Glassman, Kenneth S. Serota

The K-type steel file has remained the instrument of choice for preparing root canals for over three quarters of a century. Until recently, we have been limited to stainless steel for the fabrication of endodontic instruments. With the emergence of exotic metals, the most notable of which is nickel-titanium, there has been a surge in the manufacture of instruments made of this material because of its flexibility and more importantly, its ability to accommodate more stress in curved root canals.

WHY NICKEL-TITANIUM?

The significant advantage of a nickel-titanium file is its unique ability to negotiate curvatures during continuous rotation without undergoing the permanent deformation or failure that stainless steel files might incur. Nickel-titanium is termed an exotic metal because it does not conform to the normal rules of metallurgy. As a super-elastic metal the application of stress does not result in proportional strain.

This unusual property is the result of undergoing a molecular crystalline phase transformation when stressed. External stresses transform the austenitic crystalline form of nickel-titanium into the more forgiving martensitic crystalline form. Restated, nickel-titanium is the only readily available material that has the flexibility and strength necessary for use as an effective rotary endodontic file.

WHY ROTARY INSTRUMENTATION?

One benefit of mechanical rotation is the enhanced ability to collect and remove debris from the canal system. Hand instrumentation using file insertion motions without rotation or with counter-clockwise motion pushes debris into the intricacies of the canal anatomy or even apically through the portals of exit. In contrast, continuous rotation augers debris only in a coronal direction from the root canal space.

Mechanical rotation of nickel titanium files can provide better control for maintaining the central axis in curvatures that results a more conservative canal preparation. The most obvious benefit is the reduction in the time required for instrumenting canals. Although rotary instrumentation can offer the operator numerous advantages, the prevention of file failure requires greater consideration.

The most important relationships of the components of NiTi ground files designs and canal anatomies that enable us to improve our technique include:

- a file with a more efficient cutting design requires less torque and/or pressure to accomplish the same degree of root canal enlargement
- in a straight canal, the ability of a file to withstand torque varies directly with the square of its diameter
- in a curved canal, the ability of a file to resist fatigue varies inversely with the square of its diameter
- the torque required to rotate a file varies directly with the surface area of the file's engagement in the canal
- fatigue of a file increases with the number of rotations of the file in the canal
- fatigue of a file increases with the degree of curvature of the canal
- to improve efficiency, the smaller the surface area of a file engaged in the canal, the greater the rotation speed should be

- the more spirals a flute has per unit length around the shaft of a file, the greater the torque is required to rotate a file and the more stress concentration points there are for potential failure, but the more flexible it is
- the fewer spirals a flute has per unit length around the shaft of a file, the more it resists deformation, but the more rigid it is
- the sharper the cutting blade of a file, the fewer spirals per unit length the file should have
- the greater the number of flutes with similar helix angles, the greater tendency a file has to screw into the canal and become bound
- maximum engagement of a file occurs when it progresses into the canal at a rate that is equal to its feed rate.

WHAT CAUSES BREAKAGE? WHAT IS TORSION?

Breakage is directly related to excessive stresses of torsion and fatigue. Torsion is the axial force of being twisted that results when one part of a file rotates at a different rate than another part. Any distortion of a file that results from twisting, such as unwinding, is caused by stress of torsion. When a file resists rotation during hand instrumentation, excessive torque can be perceived and file breakage can usually be avoided. However, as torque is essentially impossible to sense during automated instrumentation, understanding the factors of file breakage is the most important aspect for learning this modality for canal preparation.

WHAT IS FATIGUE?

File fatigue is the result of repetitive stress predominantly during flexion while rotating around a canal curvature. A file can withstand more stress during a single rotation around a curvature than it can after numerous rotations. Metal fatigue usually begins at the surface where minute defects act as points where stresses become concentrated. A fatigue failure is particularly insidious because it can occur without any obvious warning. Knowledge of the relationships of file sizes and canal anatomy is especially important when dealing with the combined stresses of torque and fatigue. Computerized handpieces address some of the problems of torque but offer no future promise for replacing the dentist's judgment for appropriate technique.

WHAT ARE THE SMALLEST FILE DIAMETERS THAT CAN BE USED TO MEET THE TORQUE REQUIREMENTS THAT WE ARE LIKELY TO ENCOUNTER IN CANALS?

The smaller the diameter the file has when it becomes bound the more likely it is to break. However, binding of a small diameter can usually be detected and prevented if that part of the instrument that is likely to become bound is the only part that is engaged in the canal. If the torque and pressure required for rotation of an engaged larger diameter of a file exceeds the torque required to break the smaller diameter should it become bound, the file is particularly vulnerable.. Even establishing glide paths (canals enlarged to a diameter larger than the tip of a subsequent file) is no assurance that a small tip size cannot be pushed into aberrations such as fins or anastomoses when the force necessary for engaging the larger diameter is applied.

WHAT CAUSES FATIGUE?

On the inside of the curvature, a rotating file is compressed. On the outside of the curvature the file undergoes tension. As a file rotates around a curvature each surface undergoes compression and release destruction. When tension is applied, faults in the file are propagated. Generally, the greater the distance between the stress of tension and the stress of compression, the greater the total stress on the instrument. The smaller the diameter of a file, the longer it can rotate around a curvature without fatigue failure. The file's resistance to fatigue varies inversely with the square of the diameter. Therefore, a size .20 diameter can resist fatigue 50% more than a size .25 diameter. As the diameter of a tapered file increases as it progresses through a curvature the stress on the file eventually reaches the point of potential failure and the use of the file should be terminated in favor of a smaller diameter or smaller tapered file.

WHAT IS THE LARGEST FILE DIAMETER OR TAPER THAT CAN BE USED IN CURVATURES THAT WE ARE LIKELY TO ENCOUNTER?

If one attempts to bend the largest diameter handle end of a 25/.02 file, it is easy to imagine how quickly this .57 mm diameter would fail in a curvature. The rigidity of this diameter would cause concern for canal transportation even if the file did not fail. As the taper of a file increases, the diameter that can resist fatigue decreases and the rigidity of the file increases.

HOW CAN FILES OF THE SAME DIAMETER HAVE DIFFERENT FLEXIBILITIES?

The most common means of increasing file flexibility is to increase the depth of the flute (decrease the cross-sectional area) or to increase the number of spirals of the flute per unit length. Either change, however, may influence the file's susceptibility to failure. How much flexibility a file design may exhibit at a specific point along its working surface may vary as it rotates in a curvature and the flexibility may be due to the file yielding to stress rather than accommodating it (exceeding the elastic limit), in which case failure may be the result. Finite element modeling and dynamic testing become extremely important in determining what design modification constitutes an improvement. One main objective of file design is to minimize the distance between the stress of compression and tension while maximizing torsion strength and cutting efficiency.

WHAT TACTILE SENSATIONS ARE THERE WITH ROTARY INSTRUMENTATION?

Contrary to the practitioner's usual reliance on tactile sensations, stress on a file as the result of the force of cutting can most accurately be determined by testing. Since variations in torque (those rotational forces that would urge the hand-piece to move in a counterclockwise direction if the file remained in a stationary position) are difficult to feel. The tactile sensations of a rotary file are primarily due to variations in pressure. With no comparative basis for applied pressure, the uninformed user may likely select a file with inefficient scraping edges for having a smoother feel than one with more efficient less stressful cutting edges. Cutting efficiency, it should be pointed out, depends on more than just the sharpness of the cutting blades. It is the result of several design relationships including blade angles, helix angles and flute designs.

HOW DOES FILE ENGAGEMENT AFFECT BREAKAGE?

Breakage as a result of torque is directly related to the amount of file engagement. The torque required to rotate a large area of the working length of a file may be excessive for the smaller diameter portion of the file resulting in failure. Since the area of the working surface is comprised of the length and the diameter, the torque required to rotate a tapered instrument with 16 mm of engagement may be significantly more than two times as great as is required for one with 8 mm of apical engagement. Reducing the length of the working surface can certainly reduce the potential of engagement and therefore it's propensity for failure since torque is directly related to the area of engagement.

HOW DO I DETERMINE THE OPTIMUM ROTATION SPEED?

The optimum speed of rotation is determined by two factors; the helix angle and the amount of engagement. The feed rate of the file, or how fast the file would screw in if no resistance were met or no force were applied, is determined by the helix angle. If the file progresses into the canal at the same rate as its feed rate, maximum engagement occurs. For this reason slowing the rotation for the sake of reducing the threat of failure in complex anatomies may actually increase the likelihood of failure. If the file progresses into the canal faster or slower than the feed rate, the depth that the blades become engaged is reduced.

Optimum rotation speed is also determined by the amount of the circumference of the file is engaged. If only the side of the instrument is in contact with the canal the speed of rotation can be substantially increased to increase efficiency if the file is prevented from becoming circumferentially engaged. Using this technique can very effective in preparing an anastomosis. If only a short length of the file can become engaged, as with a Light Speed instrument, cutting can be more efficient a higher speeds of rotation.

The considerations for designing an ideal endodontic file include:

- cutting angle: sharpness and angle of the blade
- flute design: groove design for the removal of debris
- helical angle: angle of the spiral of the blade and flute to cut and spiral debris from the canal

– support of the blade: the prevention of crack propagation
– frictional resistance: the circumference area of the file in contact with the canal
– notch phenomenon: the concentration of stress at the depth and angle of a groove
– working surface: total surface area of the file engaged in the canal
– non-cutting safe tip vs. cutting tip
– balanced forces of the working surface: maintaining the central axis of the canal.

THE QUANTEC FILE™

The Quantec File™, introduced in 1995, represented a significant departure from contemporary file designs by addressing each of these considerations for providing an efficient and user-friendly rotary file (Fig. 22.1).

Cutting angle

If the file is sectioned perpendicular to its long axis, the rake angle is the angle formed by the leading edge and the radius of the file. If the angle formed by the leading edge and the surface to be cut (it's tangent) is obtuse, the rake angle (angle of incidence of the blade) is said to be positive or cutting. If the angle formed by the leading edge and the surface to be cut is acute, the rake angle is said to be negative or scraping. Rake angles have historically been used as an indication of a conventional file's cutting ability. However, in considering the asymmetrical design of the Quantec File™, the cutting angle (effective rake angle) is a better indication of the cutting efficiency.

The cutting angle is obtained by measuring the angle formed by the cutting (leading) edge and the radius when the file is sectioned perpendicular to the cutting edge. In some instances, as with some Quantec Files™, a file may have a negative rake angle and a positive cutting angle (Fig. 22.2).

Flute design

The flute of the file is the groove in the working surface used to collect debris removed from the wall of the canal. The surface having the greatest diameter that follows the groove as it rotates forms the leading (cutting) edge or the blade of the file. The Quantec File™ has a asymmetrical flute deigned to be an effective trough for channeling debris in a coronal direction. Ineffective debris removal can result in it becoming compressed between the file and the wall of the canal and causing resistance for the file rotation. A positive cutting action and efficient debris removal can reduce the stress the file encounters during rotation (Fig. 22.3). In contrast to most files the flutes of the Quantec File™ become proportionately deeper as

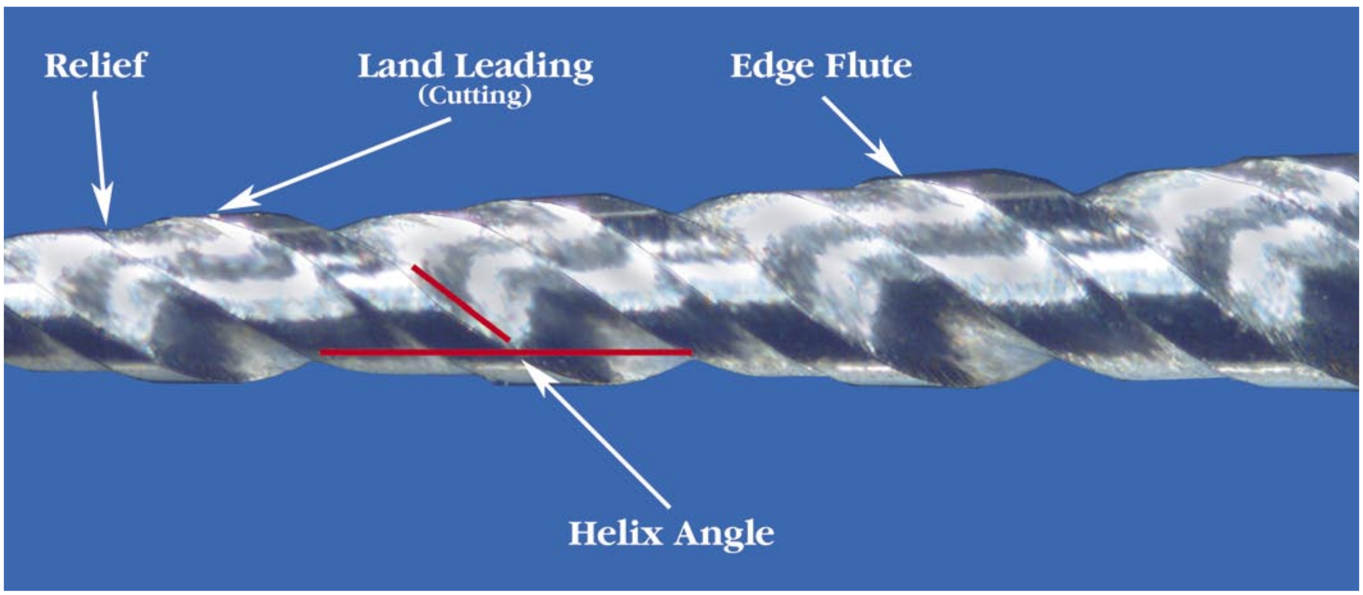


Fig. 22.1. Quantec File ™ components.

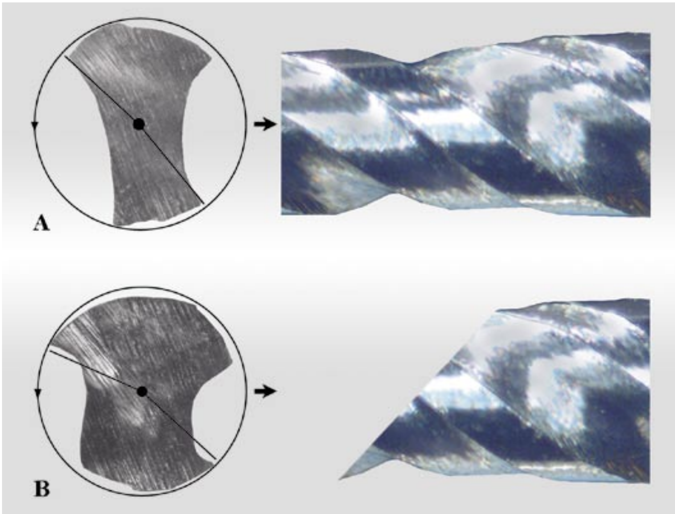


Fig. 22.2. The rake anglein ill. **A** is shown when the file is sectioned perpendicular to the Quantec File's™ long axis and is slightly negative. The cutting angle in ill. **B** is shown when sectioned perpendicular to its cutting edge is slightly positive.

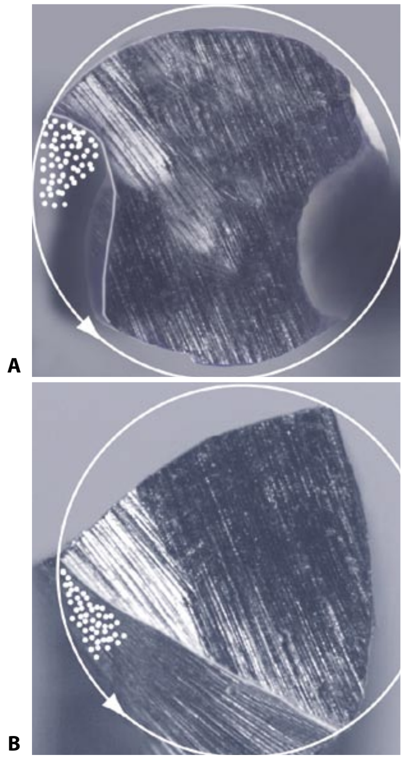


Fig. 22.3. Sectioned perpendicular to its blade, the Quantec File™ (**A**) utilizes a positive cutting action and an asymmetrical flute for removing debris. A conventional triangular design (**B**) uses a scraping action for enlarging the canal.

the diameter increases with its taper to provide addition space in order to reduce the chance for compression of debris.

The Quantec File™ design is particularly efficient in advancing into the canal when 360 degrees engaged. Its efficiency is thought to be, at least partially, due the positive cutting angle and its ability to augur debris from the canal. A study performed by Dr. Melissa Marchesan (Sao Palo, Brazil) while at the Cloudland Institute (Lookout Mountain, GA) assessed the torque requirements of files during enlarging a .70mm diameter canal in a plastic block to the file's largest diameter. The torque requirement for the Quantec File™ was significantly low (Fig. 22.4).

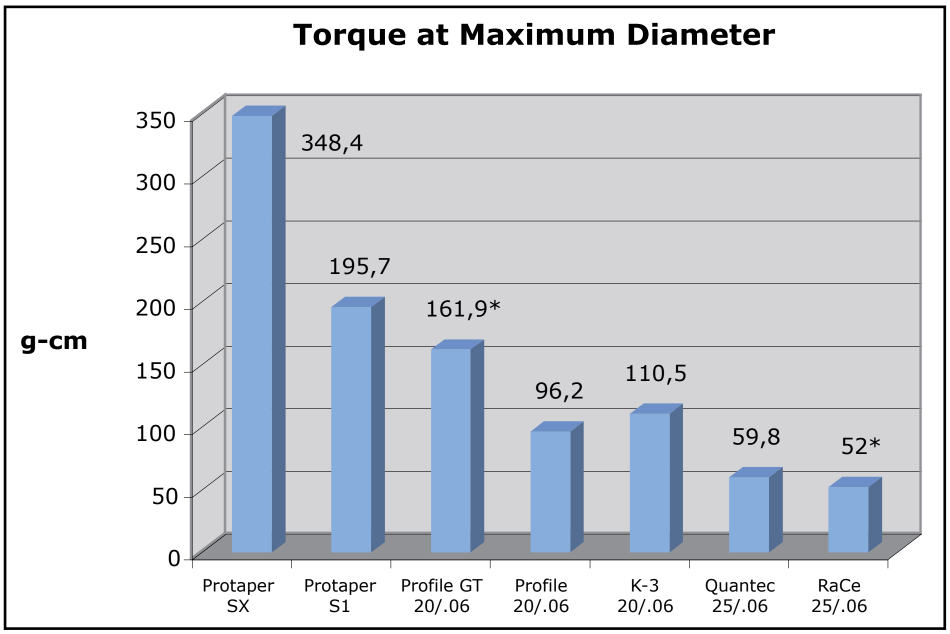


Fig. 22.4. Each file rotating at 300 rpm was introduced into a canal in a section of plastic and advanced at a rate of 1 mm per second. The canal was 4 mm long, open each end and had a constant .70 mm diameter. With the exception of the Profile GT™ and the RaCe™ file, all files were carried to its 1.19 mm diameter and its corresponding maximum torque was measured and recorded. The Profile GT™ was carried to its 1.00 mm maximum diameter and the RaCe™ was carried to its .73 mm maximum diameter. These smaller diameters result in the lower recorded torques for the Profile GT™ and RaCe™ files when compared to the other diameters.

Helical angle

The angle that the cutting edge makes with the long axis of the file is called the helix angle. A file has a greater tendency to screw into the canal when the helix angle is more perpendicular to the file's long axis (there are more spirals) and each of the angles are parallel. The helix angles of the Quantec File™ vary in order to reduce it propensity for screwing-in (Fig. 22.5).

Blade support (radial lands)

If there is a surface that projects axially from the central axis as far as the cutting edge between flutes, this surface is called the land. The land helps prevent the file from screwing into the canal , supports the cutting edge and reduces the propagation of cracks inherent in the cutting edge (Fig. 22.6). In order to reduce frictional resistance, some of the surface area of the land that rotates against the canal wall may be reduced to form the relief (Fig. 22.7).

The cutting angles, helix angles and taper may vary along the working surface of the file. Any change of any of these features may influence the file action or its propensity for breakage as it progresses into the canal space.

Balanced forces of the working surface

The Quantec File™ is designed to enhance the balance of the cutting actions on each wall of canal curvatures. Incorporating cutting edges having unequal efficiencies causes cutting to occur on the canal wall opposite the pressure surface. By using alternate cutting efficiency throughout the canal, transportation of the central axis in curved canals is reduced (Fig. 22.8).

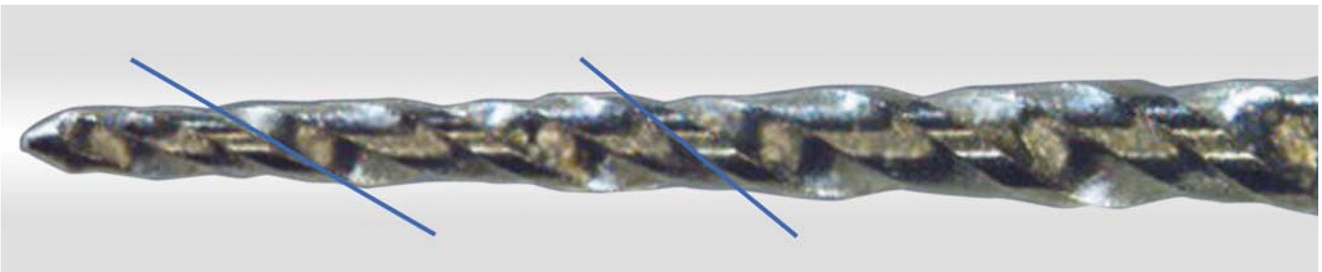
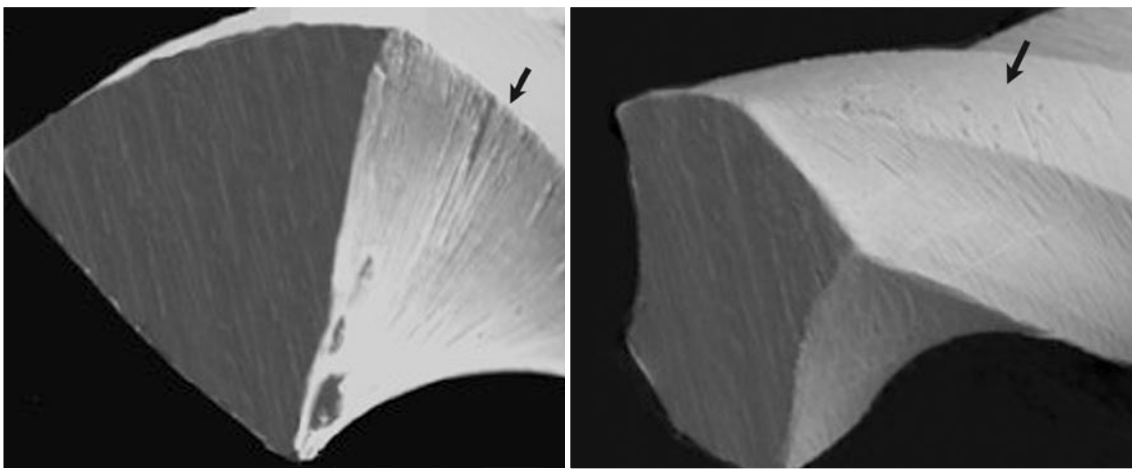


Fig. 22.5. The helix angle of the Quantec File™ varies along its working to reduce the screwing -in forces.



A B

Fig. 22.6. Inherent cracks have a greater tendency to propagate when the forces of compression and tension are applied on edges rather than on flatter surfaces. The micro-cracks that are unsupported on the blade of a tri-angular file (**A**) are avoided by incorporating a land that follows the blade on the Quantec File™ (**B**).

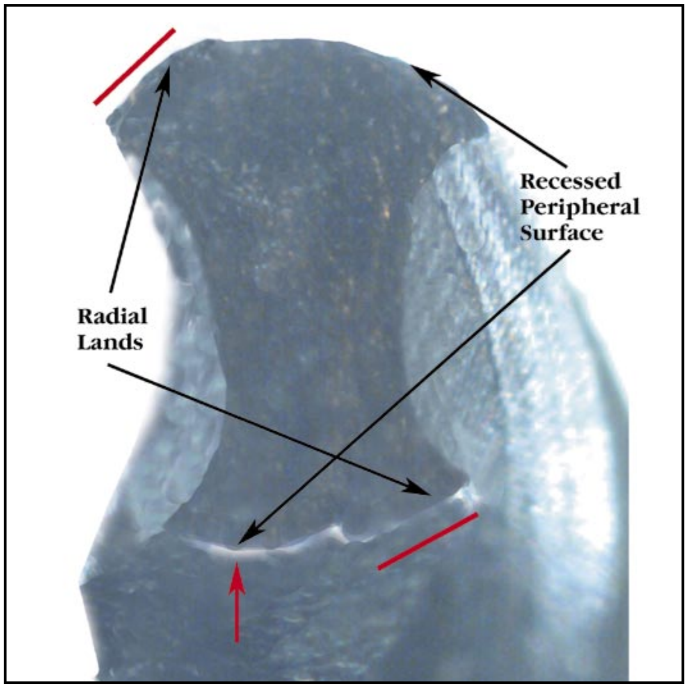


Fig. 22.7. The lands of the Quantec File™ support the cutting edges, but cause resistance to rotation by abrading the walls of the canal. Recessing the surface of lands maintains the support while eliminating any resistance.

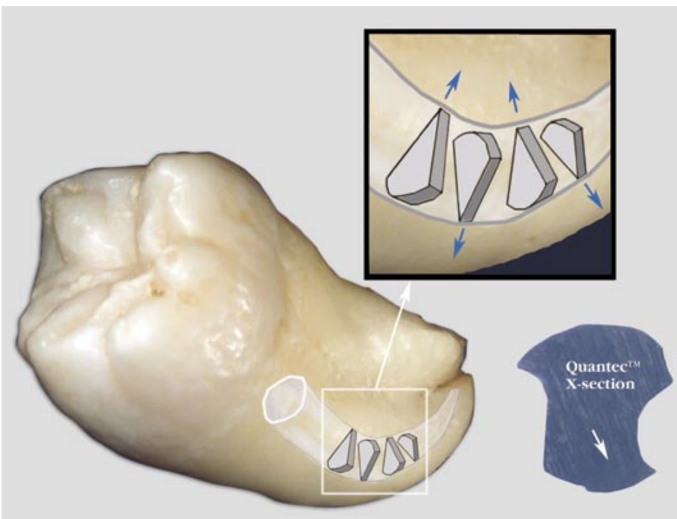


Fig. 22.8. Unequal cutting efficiencies of the blades of the Quantec File™ are designed to aid in maintaining the central axis of canals in curvatures by directing the force toward the more efficient cutting edge during rotation.

Non-cutting "safe tip" vs. cutting tip

Non-cutting "safe" tips help prevent canal transportation by deflecting the instrument around a curvature before the blade becomes engaged. The problem that ensues is that "safe" tips may exert undue stress on the instrument as the non-cutting tip may be forced or burnished into canals that are smaller than the instrument tip. The Quantec File™ is available with a cutting tip for negotiating canals that may have diameters smaller than the file tip and non-cutting tips for canals known to have diameters larger than the file tip (Fig. 22.9).

The Quantec File™ is also available with two handles. One handle has the standard length common to most files while the Axxess™ handle also available is 4 mm shorter. The shorter length provides easier access when vertical space is limited (Fig. 22.10).

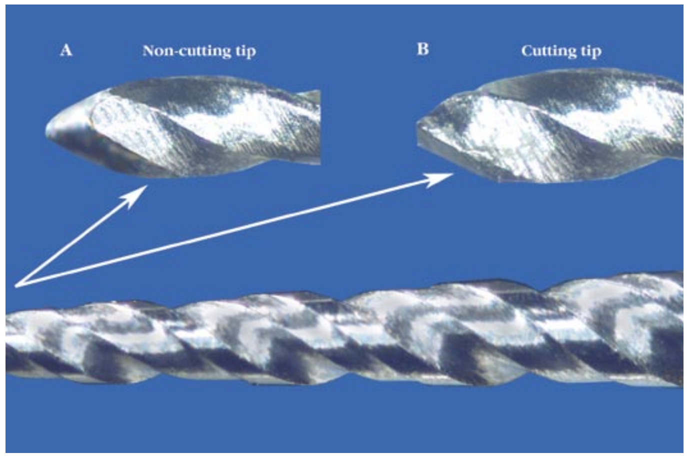


Fig. 22.9. The Quantec File™ is available with cutting tips for negotiating canals with diameters smaller than the tip and non-cutting tips for canals with larger diameters.

Fig. 22.10. The Quantec File™ is available with the standard length handle and the Axxess™ handle that is 4 mm shorter.

The Quantec™ series by Analytic

The Quantec™ series of instruments is comprised of files having the same .25 mm tip size but different tapers ranging from a .12 taper to a .02 taper that can be used with either a crown-down or step-back technique (Fig. 22.11). The series is supplemented with ISO sizes.

By progressively changing the tapers of files, the Quantec™ Series provides the means to reduce the surface area engaged and thus the torque required for rotation. A larger tapered file initially engages only the coronal portion of a canal prepared by a smaller tapered file of the same tip size. A smaller tapered file initially engages only the apical portion of a canal prepared by a larger tapered file with the same tip size.

The working surface taper

Maximizing cutting efficiency by minimizing the surface of the instrument in contact with the canal wall validates the concept of taper variations. Rather than flaring with a conventionally tapered file to change the taper of the canal, the taper of the file is changed which concentrates the forces in a small area (Fig. 22.12). The nomenclature, however, for the techniques for using tapered files can be confusing in conceptualizing the action that is occurring. If a smaller tapered file is inserted into the preparation of a larger tapered file, only the apical portion of the file initially becomes engaged, yet the technique is termed crown-

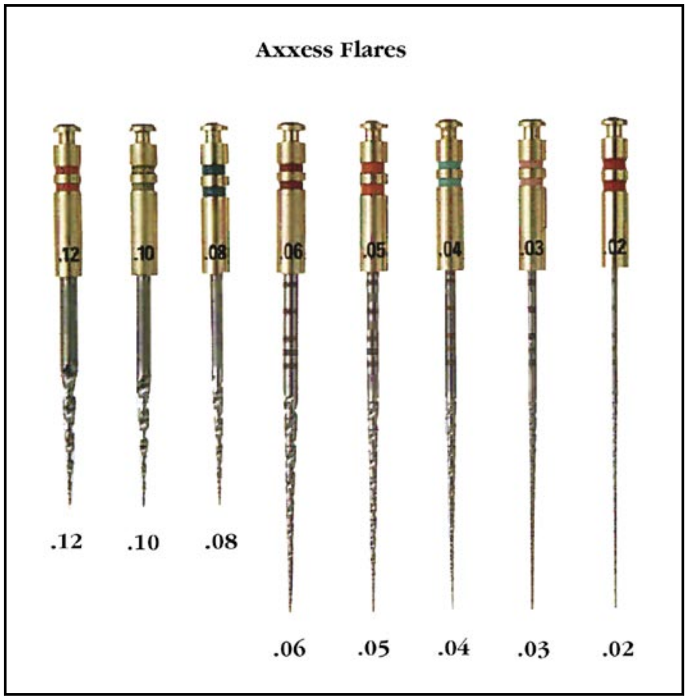


Fig. 22.11. The Quantec™ variable tapers all have a tip size of .25 mm and range in taper from .12 to .02. The degree of case difficulty will determine the number of tapers used in sequence as well as the number of times the sequence has to be repeated. The series is supplemented with ISO sizes.

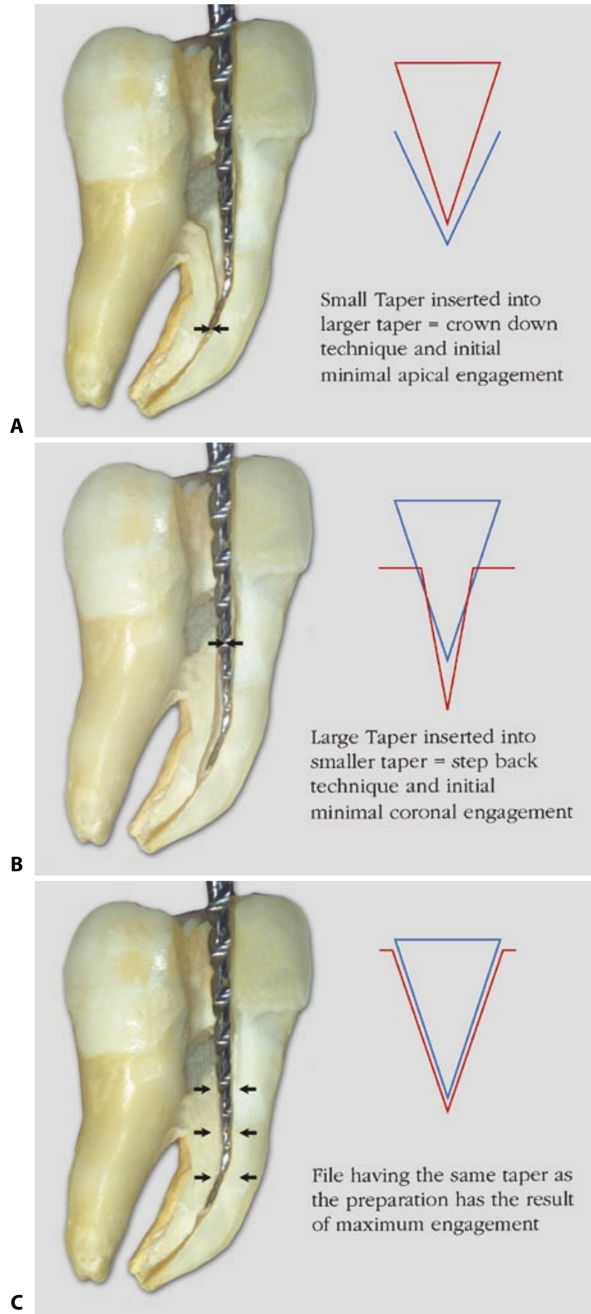


Fig. 22.12. Instruments having tapers different from the taper of the canal causes engagement in different parts of the canal.

down (Fig. 22.12 A). If a larger tapered file is inserted into a smaller tapered canal, the file initially engages and prepares only the coronal aspect of the canal yet the technique is called step-back (Fig. 22.12 B).

In either technique, the initial engagement is minimal; however, as the file progresses into the canal, engagement increases until the file could become fully engaged. The advantage in changing from one taper to another is that the initial engagement is minimal and any increase in engagement is gradual, thereby enabling a better opportunity to interpret variations in resistance as progress occurs. In contrast, if the canal preparation of one file is followed with a file having the same taper, file engagement is maximized and the torque requirement is increased with the obvious negative potential outcome of file separation (Fig. 22.12 C). Usually the operator is better served if progress into the canal is terminated before maximum engagement occurs.

CROWN DOWN VS. STEP BACK TECHNIQUE

Does the location of a curvature make a difference with either technique?

Knowing the diameter of a file at the point of curvature helps in determining the possibility of file breakage or canal transportation. If the curvature of a canal is acute or compound, larger less flexible file diameters are more likely to transport the canal due to rigidity or fail since fatigue is related to the square of the diameter and the severity of the curvature.

The apex last, crown-down approach to root canal preparation provides an effective protocol for minimizing iatrogenic problems and optimizing chemomechanical debridement of the root canal system. It affords easier access to the deeper confines of the root canal system, provides a reservoir for improved distribution of irrigants, and facilitates the removal of pulpal contents and dentin debris in a coronal direction away from the periapex.[12] This section will address the procedural changes associated with instrumentation of the root canal system using rotary nickel-titanium instrumentation in a crown-down protocol (Fig. 22.13).

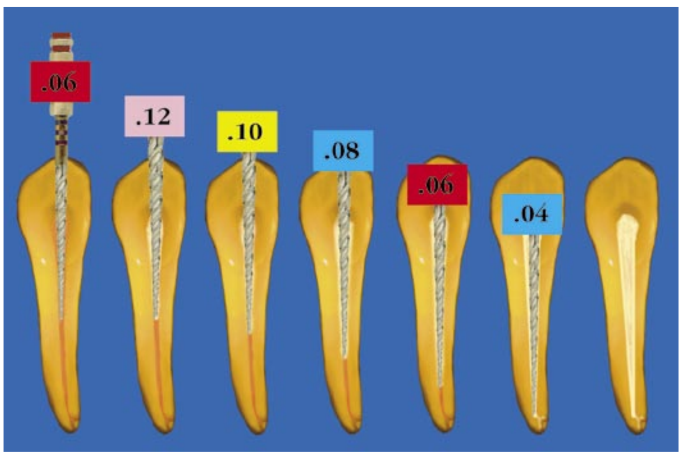


Fig. 22.13. The crown down, apex last protocol for using the Quantec™ variable tapers can usually be accomplished as illustrated. In simpler cases fewer instruments may be used and in more complex cases more may be used. The access to the apical terminus of the canal is provided to facilitate apical enlargement with rotary .02 taped files with larger tip sizes.

Access

The root canal system is made up of a branching network of accessory and lateral canals that need to be acknowledged for predictable clinical success.[30] With the introduction of loupes and microscopes, identification of root canal orifices has never been more predictable. The axiom, "you can't treat what you can't see", is all the more relevant with the use of rotary nickel-titanium instrumentation. These instruments make small holes bigger ones; they are not to be used as canal pathfinders.

The creation of a Glide Path[15] is needed to facilitate a straight-line access approach to the apical constriction. The access is initiated by the creation of a Class I inlay style preparation using a radial brushing stroke from the central fossa to de-roof the pulp chamber.

Spatial alignment and straight line access of the cusp tip, the pulp horn, the canal orifice and the interface of the middle and apical one-third intersection is essential to retaining the apical constriction in its naturally occurring anatomical position. By optimizing a straight-line access pathway, rotary nickel-titanium instruments with their self-centering ability and their super-elastic capacity can readily negotiate most complex anatomical systems (Fig. 22.14).

Furthermore, the creation of the Class l inlay style preparation defines the intra-chamber preparation for the coronal restorative component that will be placed after root canal treatment has been completed. The seamless integration of root canal space and restoration minimizes interface steps that can produce stress vectors on the tooth under function.

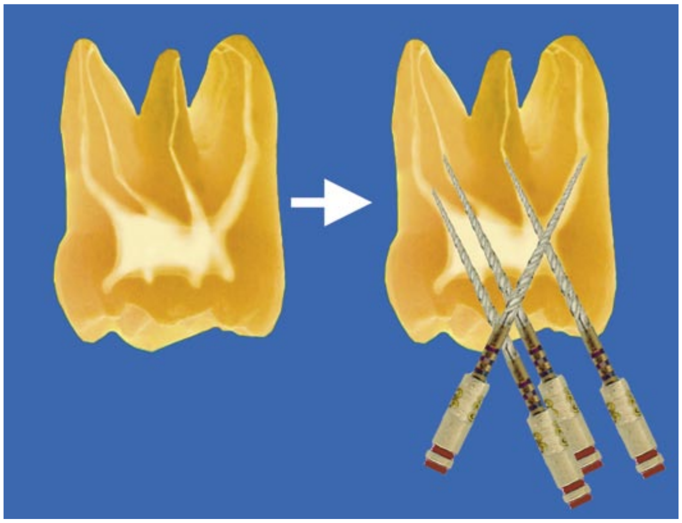


Fig. 22.14. A Class I type preparation provides a straight line access pathway.

Initial preparation

Surveying and passive exploration

After access into the pulp chamber and removal of the coronal pulp tissue, warm sodium hypochlorite is allowed to soak in the chamber for 5 to 10 minutes.[6] The chamber is flushed and a caries detection agent is placed to help in the identification of all orifices.

A # 10 stainless steel (SS) file is introduced into the orifice of each canal to ensure that the axial wall pathway allows for straight-line entrance into the canal. If not, the access must be adjusted by diverging the axial walls more dramatically to prevent file contact before entrance into the canal orifice.

Preliminary debridement and passive exploration of the canal confines is made with ISO standard .02 taper stainless steel files, #'s 08 through # 15 in sequence. Negotiation of the root canal system with hand instruments orients the operator as to the x, y, and z direction of the root canal space and identifies obstructions that may prevent the NiTi instruments from reaching the apical constriction.

This further assists in the preliminary removal of canal debris that, if compacted, can produce torque stress at the tip of a NiTi file resulting in separation.[26]

If the SS files can initially traverse the root canal space and negotiate to the apical constriction at this juncture, all the better, however; in calcified root canals this is neither expected nor is it the intention of this initial phase of the shaping procedure. The "apex last approach" will eventually enable determination of an accurate working length without forcing instruments to place regardless of the degree of anatomic challenge presented by the canal.

RC-Prep™ (Premier Dental Products, King of Prussia, PA) or any other chelating agent that contains urea peroxide may be used during the initial phase of instrumentation.

The urea peroxide allows emulsification of the dental pulp that will help in the prevention of soft tissue compaction. All stainless steel files are used with a "watchwinding" motion of quarter turn clockwise followed by a quarter turn counterclockwise. This will feed the file into the canal until it first binds. At the initiation of treatment, instruments bind in the coronal aspect of an unflared canal, not in the apical region.[23] Once engaged, the file is retrieved coronally away from the furcal wall along a linear path of no more than 2 mm to ensure that the path of penetration is retained.

Coronal flaring

A # 1 Quantec™ (Analytic Endodontics, Orange, CA) file (.25 tip, .06 taper, 17 mm length) is used at this point to initiate the canal flaring and expand the reservoir of the coronal 1/3 of the root to enhance the distribution of irrigants.

Dentin debris from the canal space is directed coronally by rotary NiTi instrumentation, minimizing inoculation of the periapical tissue through the apical constriction and thereby decreasing post-operative inflammation. The chamber and the canals are flushed copiously with warm (50°C) NaOCl and room temperature liquid EDTA. Warming up sodium hypochlorite will increase its chemical reactivity and facilitate tissue dissolution.

Establishing glide path

Stainless steel files, # 08 through to # 25 are now used in sequence to continue the Glide Path apical to the most apical point reached by the # 1 Quantec™. This will provide a pathway for the shaping tapers, the Axxess™ Flares that are available with .12, .10, and .08 tapers and .25 mm tips (SybronEndo, Orange, CA).

Canal length determination

Except in the most extremely calcified cases, it is reasonable to assume that an # 08 or # 10 ISO standard stainless steel file may be negotiated to the apical constriction and an electrometric length determination reading taken at this juncture. The new generation apex locators use the impedance principle of resistance [Endo Analyzer 8005™ (Analytic Endodontics, Orange CA)] thereby ensuring the accuracy of the coronal-apical length determination reading regardless of residual canal contents. An arbitrary working length, the distance between reproducible occlusal and apical reference points, may be determined initially by a radiograph (a # 15 file is the minimum size necessary for accurate radiographic interpretation).

Deep preparation – crown-down

The next phase of intra-canal treatment utilizes the Axxess™ Flares in a crown-down manner. All the variable tapered Quantec™ files have a tip size of .25 mm. The .12 taper, .10 taper, and .08 taper are used in series to open the coronal and middle thirds of the root canal space. They are *passively* manipulated to their most apical position. It must be emphasized repeatedly that judicious force control is required at all time with these instruments. Excessive vertical force vectors will cause instrument fracture or the creation of ledges; they are not drills. Nickel-titanium instruments must be introduced into the canal with a pressure no greater than that which would break a sharp lead pencil and must never be left to linger in the canal for any period of time at a constant position.

The enlargement of the coronal and middle thirds of the root canal space in conjunction with the surveying phase of canal preparation creates a pathway to the apical constriction. The uses of the Quantec Axxess™ tapers will prevent alteration of the original canal pathway in even the most severely curved conditions. This further enlarges the irrigant reservoir to hold the warmed sodium hypochlorite interspersed with liquid EDTA.

At this point, a # 8 Quantec™ [.06 tapered instrument (21mm and 25 mm available) - .25mm tip size] is introduced into the canal, and in the vast majority of cases will drift passively to the full working length. If not, a Quantec .04 taper is used and then recapitulation with the .10 Axxess™ Flare, followed by the .08 Axxess™ Flare and finally the # 8 Quantec™ (.06 taper) is recommended. As the larger tapers eliminate coronal obstructions, the succeeding smaller tapers used in sequence will automatically and passively drift closer towards the apical constriction. The apical constriction in an average premolar and molar tooth varies between .28 to .34 mm[16,17] The constriction should never be altered intentionally either spatially or in size or shape. Shaping of the canal is merely a vehicle for sodium hypochlorite and EDTA solutions to penetrate to the full length of the canal where it will dissolve organic tissue and decrease the bacterial contaminants. In cases where the canal has an extreme curvature the apical one-third may be shaped using hand instrumentation with precurved .02 stainless steel files as the nickel-titanium files may undergo to much stress and separate.

The Quantec™ system should only be used in an electric handpiece running at a constant speed ranging between 300-350 rpm. The rotating instrument is introduced 1 mm, then withdrawn 1 mm, introduced 2 mm, withdrawn 1 mm, introduced 3 mm, withdrawn 1 mm until the first indication of increased resistance is met during further apical advancement. Levels of resistance to the NiTi files will differ; however, the pressure applied to each succeeding file must never vary. The files should be examined frequently for accumulated debris and plastic deformation characterized by alterations in the flute pitch. Instrumentation must be done in a wet environment; continual replenishment of the irrigating solutions is essential.

Gates Glidden drills (#'s 1 and 2) may be used depending on the degree of calcification. Always be aware of the furcation "danger zone" and never run the handpiece on entrance into the canal, only on retrieval towards the bulky safe areas of the root. Resurvey with the # 08 hand file to ensure canal patency and that no dentin debris blocks straight-line access through the coronal and middle one-third of the root canal space. Gates Glidden usage prior to instrumentation will invariably lead to blockage or canal misdirection. The Axxess™ Flare instruments (.12, .10, and .08 tapers) eliminate the need for Gates Glidden drills in many cases. The "bud" of a Gates Glidden # 3 can be used in certain canals to eliminate cervical horns and calcifications in the coronal 1/3.

In the majority of cases, the root canal can be prepared entirely using the protocol as described above. In thin rooted teeth or teeth with dramatic concavities where perforation is at risk or if the apical portion requires additional enlargement, Quantec™ has smaller tapered instruments available that range in taper from

.03 -.05 with .25 mm tips or .02 tapers in ISO sizes.

Size, length, and curvature of the canal as well as the hardness of the dentin will dictate how many instruments in sequence are required to prepare the canal. For example, in a case where the canal is large, straight, short and has soft dentin, only as few as one, two or three instruments may be needed to prepare the canal. In a calcified, curved, long canal that has hard dentin, the entire sequence may have to be utilized and recapitulation of that sequence may have to be repeated several times. Every case is different and will need to be assessed on an individual basis.

Using the larger diameters of the *crown down* technique for canal preparation can be a problem for coronal or mid-root curvatures and should only be used to a depth short of any substantial curvature. Once a severe curvature is encountered, smaller diameter files should be used in a *step back* technique apical to the curvature in order to minimize instrument stress and canal transportation. By inserting non-rotating files with smaller diameters around curvatures and stepping back with rotation, the severity of the curvature can be easily determined while avoiding excessive stress.

Rather than following a regimented sequence that is acceptable for usual cases, the primary consideration for the consummate endodontist is to set parameters for preventing file failure and eliminating unnecessary or counterproductive procedures. The canal anatomy dictates the most efficient approach for instrumentation. While slight canal curvatures pose no particular problem, coronal, mid-root and more severe curvatures require greater consideration. The greater the distance the curvature is from the apex, the larger the diameter of the file is that transverses the curvature. The propensity for breakage of large file diameters in curvatures becomes a factor for adjusting the preparation technique.

Beyond a the point of curvature preliminary testing suggests that the file diameter should be no more than .60 mm for a .02 taper, .55 mm for .04 taper, .50 mm for .06 taper, and .35 mm for a .08 taper. (This consideration is the result of testing for 45 degree curvatures having 8 mm radii and applies only to these dimensions for rotary NiTi files). File diameters should be smaller for more severe curvatures and can be adjusted larger for less severe ones. This determination by necessity requires subjective and arbitrary judgments since there is no one point at which file breakage definitely occurs or definitely does not occur. However, even an awareness of the concept can facilitate the operator's judgment and has lead to the development of the zone technique.

The zone technique for canal preparation

The zone technique was designed with two objectives for minimizing file stress for any type of NiTi rotary file. One, the canal diameter should be large enough coronal to a curvature to prevent any engagement in that portion of the canal when any file is being used apical to the curvature. Two, the file diameter is not too large to rotate safely in a curvature.

The first step is to determine if there is a curvature of any significance and how far the curvature is from the apex. Withdrawing the file used to establish the working length and passively re-inserting it will indicate a curvature if it meets any resistance since the canal is now larger than the file. The canal portion short of the resistance defines the coronal zone and the portion beyond the resistance defines the apical zone (Fig. 22.15). The length of the canal to the curvature, the coronal zone, is determined and recorded in the same manner as determining the working length. The working length minus the coronal zone length provides the distance the curvature is from the apex, the apical zone length.

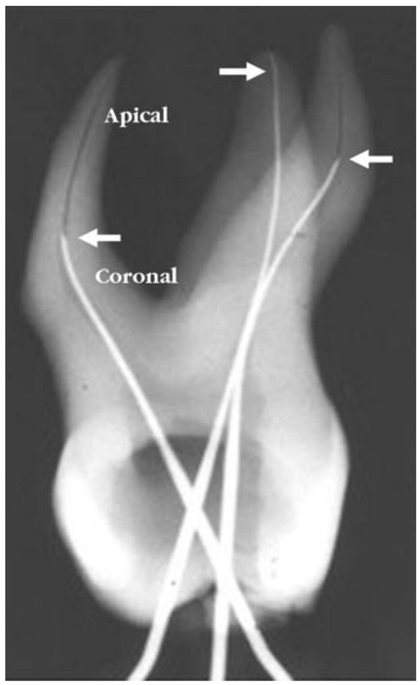


Fig. 22.15. The points of resistance files encounter, indicated by the arrows, when passively being inserted into canals with a larger diameter divides the canals into coronal and apical zones. The zones require different preparation approaches.

The second step is to determine the distance each of the files having different sizes and tapers can safely be advanced around the curvatures and which size file will need to be used in the coronal zone to prevent them from binding in that zone. By using the parameters suggested above (.60 mm for a .02 taper, .55 mm for .04 taper, .50 mm for .06 taper, and .35 mm for a .08 taper), we can calculate if the diameter of a selected file would exceed our limitations. That determination can be calculated by using the following formula:

$$\frac{(\text{Ø limitation}) - (\text{Tip size})}{(\text{Taper})} = \text{The length the file can be projected around a moderate currvature}$$

Example 1

If we select a size .25/.04 taper file to negotiate the canal illustrated in Fig. 22.16, the diameter limitation suggested in the parameter is .55 mm. .55 mm minus the tip size, .25 mm, is .30. .30 divided by .04, the taper, equals 7. 7 is the number of millimeters a .25/.04 file can be advanced beyond a moderate curvature and, therefore, can be used to the working length in this situation. A size .55/.04 or larger would be required to enlarge the coronal zone to prevent any engagement in that portion of the canal while using a .24/.04 file to the working length.

Example 2

If we select a size .25/.06 taper file to negotiate the canal illustrated in Fig. 22.16, the diameter limitation suggested in the parameter is .50 mm. .55 mm minus the tip size, .25 mm, is .30. .30 divided by .06, the taper, is 5. 5 is the number of millimeters a .25/.06 file can be advanced beyond a moderate curvature or into the apical zone and, therefore, should be advanced no closer than 1 mm from the working length in this situation. A size .55/ 06 or larger would be required to enlarge the coronal zone to prevent any engagement in that portion of the canal while using a .24/.06 file to the working length.

Once this procedure is followed the terminus of the canal can easily be enlarged by using .02 tapered files. If the curvature is more severe the file sizes need to be reduced accordingly. Although the zone technique requires a minimum of mental exercise its advantages include significant reductions in preparation time and file stress.

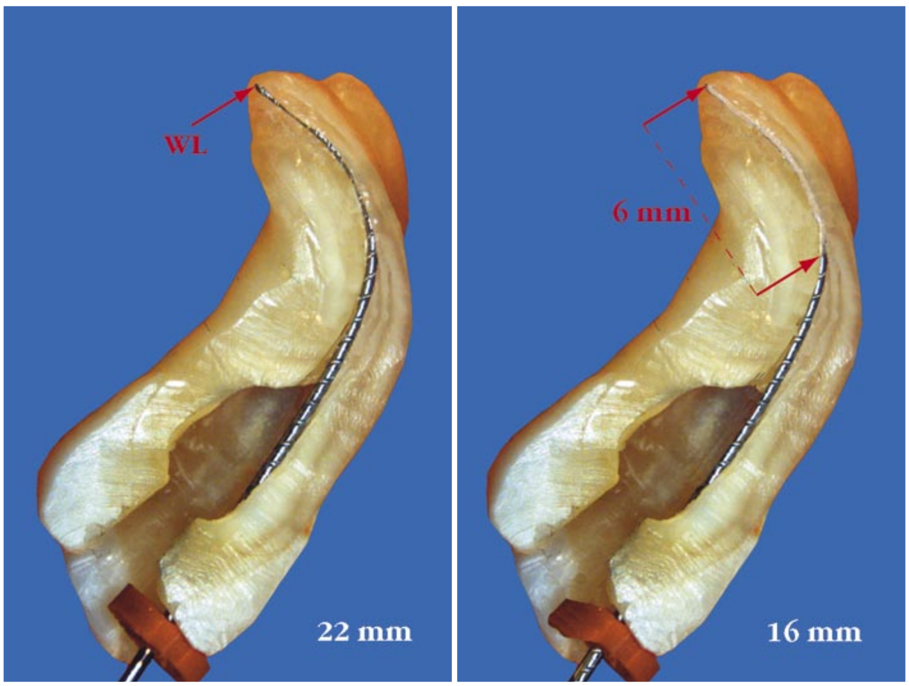
A  B

Fig. 22.16. The recorded length at which the smaller file encounters resistance in a larger canal can be subtracted from the working length to obtain the distance the curvature is from the working length.

Samuel Johnson (1784) recognized that "genius is nothing more than knowing the use of tools, but there must be tools first to use". No protocol is inviolate, just as no tool is a panacea. Compensation for the unforeseen and the unexpected is the hallmark of the skilled practitioner. It is the amalgamation of tools, knowledge and skill that will continue to enhance the predictability of clinical success.

Does irrigation reduce torque requirements?

Irrigation and lubrication can reduce torque requirements by as much as 400% compared to rotating in a dry canal. However, shorter strokes of insertion are more effective than carrying the rotating file to greater depths into the canal with fewer insertions. The amount of engagement plays an important role in influencing the torque reduction resulting from lubrication. When the file rotates fully engaged the amount of irrigation is reduced between the surface of the canal and the file and has little effect in reducing torque.

Evidence suggests surface treatment and irrigation may have a synergistic effect in reducing torque. By providing lubricity, surface treatment of the files can decrease the torque required in order to rotate nickel-titanium files by as much as 25% without diminishing cutting ability. Surface treatments on stainless steel files have been demonstrated to reduce torsion forces by as much as 600% and may render stainless steel files to be a viable alternative to nickel-titanium files in situations where little flexibility is required.

Apical patency

A study performed by Dr. Gary Carr (personal communication) of the PERF Institute (San Diego, CA) assessed the level of penetration of commonly used irrigants when optimized by the introduction of over-proof/absolute (96% by volume) alcohol into root canals. Teeth were shaved sagittally leaving a thin layer of dentin over the root canal space that appeared transparent when wet.

It was possible to view the manner by which the motion of the file impacted on the flow of the irrigant along the length of the root canal. In this model, it was observed that the irrigant did flow into the apical area after the file was removed. However, it was noted with even more significance that as sodium hypochlorite (NaOCl) was alternated with absolute alcohol, the irrigant would flow into the apical area as if a file were being used, provided apical patency had been established.

Absolute alcohol reduces the dentinal surface tension and enables the irrigant to flow unimpeded through the entire length of the root canal and into the vagaries and intricacies that exist in the root canal system. The conclusion reached by this experiment was that the failure to get irrigant into the apical third of the root canal when patency files were not used was more of a surface tension issue than a mechanical one.

A recent study by Gambarini[14] demonstrated that the use of 1% Triton X-100 (Sigma Corp., St. Louis, MO), a tensioactive agent, would enhance debridement when used in combination with NaOCl and 17% EDTA. It would appear that surfactants of one form or another will play an increasingly important role in the endodontic irrigation protocol.

At this juncture however, the authors' conclusion is that it is reasonable to include over-proof alcohol during the irrigation protocol to enhance the penetrability of other irrigants throughout the root canal system and dentinal tubules.

Irrigant delivery

It has been shown has shown clearly that the deeper penetration afforded by side irrigation needles such as the Maxi-i-Probe (MPLTechnologies, Franklin Park, IL, Monoject - BD, Franklin Lakes, NJ, Endo-Eze, Ultradent Products, South Jordan, Utah) with diameter sizes as small as .032 inches leads to more effective irrigation.[1] Indeed, there are studies that suggest that effective irrigation may not occur unless the canals are enlarged to at least the diameter of a No. 40 instrument. Other studies have shown that no apical flushing will occur until proper flaring of the canal and an apical diameter of a # 25 instrument has been achieved.[25,29] The use of apical patency files must be used to allow penetration of the root canal irrigants to working length.

Numerous case reports describing extreme pain, edema, and hematoma formation following the inadvertent extrusion of sodium hypochlorite into the soft tissues. This occurs when end vented irrigating needles are used by injecting the irrigating solutions under pressure. This adverse affect is easily avoided by introducing side vented irrigating needles into the root canal and delivering the solutions in a passive manner avoiding any binding of the needle in the canal whatsoever. When delivered in this manner the incidence of reported cases of so called "irrigating accidents" will decrease dramatically.

Sodium hypochlorite

Three percent hydrogen peroxide solution has long been out of favour in the endodontic irrigation protocol; its inclusion did not increase the solvent action of NaOCl.[33] Furthermore, It has been well documented for more than 100 years that sodium hypochlorite (hypochlorous acid) alone will remove pulpal remnants, organic debris and predentin from instrumented and uninstrumented surfaces of the root canal space. Only recently have researchers determined theoretically how chlorine derivatives disinfect by their action on gram-negative bacteria. They act by attacking the bacterial cell wall, altering it physically, chemically and bio-chemically thereby terminating the cells vital functions and killing the microorganism.

A possible sequence of events during chlorination would be:
1) disruption of the cell wall barrier by reactions of chlorine with target sites on the cell surface
2) release of vital cellular constituents from the cell
3) termination of membrane-associated functions
4) termination of cellular functions within the cell

During the course of these events, the microorganism dies, meaning it is no longer capable of growing of and causing disease. Shuping et al.[31] have recently shown that when using 1.25% NaOCl, the apical portion of the root canal must be enlarged to at least a diameter 0.279 mm for it to be more effective in eliminating microorganisms than saline. The question of concentration has been addressed by Baumgartner and Cuenin.[5] While varying dilutions were still effective in removing organic debris, a full strength solution (5.25%) of NaOCl delivered with either an endodontic irrigation needle or an ultrasonic device proved most effective with no perceptible injury of the peripheral attachment apparatus.

Of note; one of the primary disadvantages of NaOCl (Chlorox) has been its smell. The introduction of "fresh scent" sodium hypochlorite (Clorox) has eliminated that problem. Harrison et al.[19] demonstrated that formulary changes involved in the manufacture of the "fresh scent" sodium hypochlorite had no apparent effect on its antimicrobial properties.

Thermo-acceleration

A study by Cunningham et al.[11] demonstrated that while the in vitro bactericidal action of sodium hypochlorite solution was comparable at room temperature (22°C) and at body temperature (37°C), sterility was achieved in significantly less time at 37°C. A study by Berutti et al.[7] compared the effect of 5% sodium hypochlorite solution at 21°C and at 50°C. The findings demonstrated that in the middle third of the root canal space, where NaOCl had been used at 50°C, the smear layer was thinner and made of finer, less well-organized particles than where it had been used at 21°C. In the apical third, the smear layer was of almost the same thickness in the two groups of specimens, although the particles were finer where the NaOCl had been used at 50°C.

Irrigation syringe warmers are now commercially available (Vista Dental, Racine WI). Thermo-acceleration of an irrigation solution would logically speed up the dissolution of organic debris in much the same way that sugar dissolves in hot water quicker than in cold water. Alternatively, the solution can be microwaved before the procedure and coffee cup warmers can be used to hold the solution container during the procedure.

Antimicrobial effect of irrigant combinations within dentinal tubules

The most effective irrigation sequence for removing the smear layer and other debris was EDTAC/NaOCl/EDTAC etc. The inclusion of CHX (chlorhexidine) in this sequence has been demonstrated to further synergize its effectiveness. Many studies have noted a significant decrease in cleaning efficiency as the apical end of the canal was approached. This was corrected in a study by wherein it was demonstrated that 30 second ultrasonic pulses of the irrigant between file sizes particularly as the apical terminus was approached would effect almost total smear layer removal.[2]

Efficacy of the crown-down approach in reservoir creation

It is generally appreciated that various techniques for root canal instrumentation may have different effects in cleaning curved root canals, especially their apical portions.[27] The consensus indicates that the balanced-force technique produced a cleaner apical portion of the canal than did the other techniques studied. The Balanced Force or Crown Down technique first advocated by Roane[28] creates a reservoir of increasing diametral size that facilitates the ionic exchange demonstrated by EDTA to work and enhances the reactivity of the constantly replenished and heated NaOCl. This same effect can be achieved by practicing a crown-down shaping approach using variable tapered Ni-Ti instruments.

Chlorhexidine

A study by Leonardo et al.[24] suggests that 2% chlorhexidine prevents microbial activity in vivo with residual effects in the root canal system up to 48 h. In a study by Vahdaty[34] solutions of 0.2% and 2% chlorhexidine, 0.2% and 2% sodium hypochlorite (NaOCl) and normal saline were tested for their efficacy in disinfecting dentinal tubules following root canal irrigation in vitro. The results indicated that chlorhexidine and NaOCl were equally effective antibacterial agents at similar concentrations against the test microorganism. They significantly reduced the bacterial counts in the first 100 microns of dentinal tubules.

Studies[8,9,10] have demonstrated that the 2% CHX concentration instilled greater and longer lasting antimicrobial activity then the 0.12% CHX concentration.

Time

The duration of irrigation remains the most important variable contributing to an effective and efficient cleansing action of the prepared root canal system.[35] The longer the irrigant is in contact with the root canal, the greater the antimicrobial, tissue dissolving and smear layer removal effectiveness will be. The advent of NiTi rotary instruments has proven to be more effective in the tapering design of the root canal space than traditional hand instrumentation. However, the cutting speed of NiTi instrumentation may reduce the time component that under the circumstances may prove to be disadvantageous to a successful end result. The variables of heat, ultrasonic vibration, and variable irrigant combinations must be factored into the equation to compensate for time adjustment that may be decreased by using NiTi instrument systems.

Ultrasonic instrumentation

Perhaps the most dramatic study conducted on the debridement efficacy of the ancillary usage of ultrasonics in canal preparation is the work of Archer et al.[4] This study evaluated two groups of mandibular molars. Group I was prepared using a traditional instrumentation technique and intermittent irrigation with 5.25% NaOCl. In Group II, 3 minutes of ultrasonic instrumentation was performed per canal after instrumentation. The results were assessed at mm levels from the apical terminus. At every point of comparison, the cleanliness levels with the ultrasonic usage were as much as 30% higher in Group II. Of particular significance was the dramatic percentage differential in the isthmus areas (the thin areas of communication between principal canals) of Group II.

Ahmad et al reported that the physical mechanisms of ultrasound, namely cavitation and acoustic streaming, in conjunction with 2.5% sodium hypochlorite solution demonstrated powerful bactericidal activity.[3] Studies[21,32] demonstrated that ultrasonic irrigation with 5.5% NaOCl successfully eradicated bacteria from an artificially created smear layer while the introduction of 5.5% NaOCl irrigation with a syringe was insufficient. Ultrasonic irrigation with less concentrated NaOCl failed to eliminate bacteria completely from reservoir channels in most samples.

Optimizing clinical success

1. Sodium hypochlorite solutions not be stored from use to use. The reservoir, especially if uncovered, should be replenished with new solution for each new procedure. The stability of sodium hypochlorite is adversely affected by exposure to high temperature, light, air, and the presence of organic and inorganic contaminants. The tissue-dissolving ability of 5.25% sodium hypochlorite remains stable for at least 10 weeks. The tissue-dissolving ability of 2.62% and 1.0% sodium hypochlorite remains relatively stable for 1 week after mixing and then exhibits a significant decrease in tissue-dissolving ability at 2 weeks and beyond.[22]
2. Sodium hypochlorite should be heated to between 60 and 70°C to enhance the chemical reactivity of the solution during usage.
3. RC-Prep (Premier Dental Products, King of Prussia, PA) or any other chelating agent that contains urea peroxide may be used during the initial phase of

instrumentation. The urea peroxide allows emulsification of the dental pulp that will help in the prevention of soft tissue compaction. A 2.5 cc NaOCl flush is recommended after each instrument during this phase to remove the accumulated dentin debris. Replenishment of the RC-Prep et al is recommended before the next instrument usage.

4. Heated 5.25 % NaOCl and room temperature 17% aqueous EDTA may be used. The most effective irrigation sequence for removing the smear layer and other debris was EDTAC/NaOCl/EDTAC etc. This should be performed during the entire shaping protocolof the root canal preparation.
5. A 2% solution of chlorohexidine may be used to flush each canal at this time to increase bacterial elimination.
6. After completion of the canal shaping, it is recommended that a 5 cc flush of 17% EDTA be used with ultrasonic vibration (performed with a file tip in many proprietory ultrasonic devices) for approximately 3 to 5 minutes, followed with a 10 cc flush of each canal using 5.25% NaOCl.
7. Absolute alcohol is then used to flush out the root canal to allow drying and dehydration. Minimal paper points will be required to absorb residual moisture. Access to accessory and lateral canals as well as dentinal tubules is maximized prior to obturation by following this protocol.

CONCLUSION

The future holds the possibility that lasers will be used to sterilize the root canal system, heat the irrigants and "weld" the dentinal tubules shut. The ND-Yag laser and experimental procedures with the Erbium Wavelength laser are being assessed for these purposes.[13,18] Other studies are evaluating the use of electrolyzed neutral water which exhibits a bacteriostatic/bactericidal action against isolates obtained from infected root canals.[20]

As the biochemical cleansing protocol of the root canal system evolves, the science of endodontics is rapidly approaching a time when 100% predictable clinical success will be a reality rather than an objective.

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23

Obturation of the Root Canal System: Biological principles, Materials, and Techniques

Arnaldo Castellucci

The ultimate objective of the root canal therapy is the three-dimensional obturation of the endodontic space after it has been completely cleaned, shaped and disinfected.

The purpose of obturation is to seal all "portals of exit" to impede any sort of communication or exchange between the endodontium and periodontium. It must therefore completely and durably fill the root canal space, in which no empty spaces should remain at all. It has been amply demonstrated that the vast majority of endodontic failures are related to incomplete obturation of the endodontium.[41,71,163]

Before undertaking an examination of the techniques of canal obturation, the biological reasons for which a cleaned, shaped root canal requires obturation will be discussed. This will help in understanding which techniques can better assure a successful outcome.

BIOLOGICAL CONSIDERATIONS ON ROOT CANAL OBTURATION

In 1931, Rickert and Dixon[125] formulated the "hollow tube theory," according to which an empty space within a living organism tends to fill with tissue fluids in a short period of time. This theory was based on the observation of an inflammatory reaction around the ends of hollow steel and platinum anesthetic needle fragments implanted in experimental animals. This reaction did not occur if the implant was made of a solid, non-porous material.[125]

Two years later, Coolidge[33] arrived at the conclusion that, just as within unfilled or underfilled root canals, fluids that accumulate within empty spaces are rapidly colonized by bacteria which reach these spaces by means of a phenomenon of "anachoresis". In other words, bacteria transported by the blood circulation (bacteremia) colonized these areas, where they remained sheltered from phagocytosis by the organism's defenses. In the tissue fluids that had collected, the bacteria found a nutritional source that could sustain them. The irritating substances derived from the breakdown of the organic material contained in the tissue fluid and from the products of the bacterial metabolism were supposedly the cause of the surrounding inflammatory reaction.

For years, this theory has influenced the concept that the root canals must be filled to the apex and therefore that any empty spaces must be completely obliterated: no unfilled portion of the root canal must serve as a reservoir for the accumulation of tissue fluids and inflammatory exudate, as this would quickly be colonized by bacteria through anachoresis, which would prevent or delay the healing of the periapical lesion.

More recent studies have questioned this postulate, demonstrating that it is possible in experimental animals to implant sterile empty glass[140] or polyethylene[87,155] tubes or even empty root canals,[36] causing only mild inflammation or none at all around the open ends of the tubes.

Other authors[69] have demonstrated in experimental animals that empty spaces made inside plastic teeth implanted in fresh sockets did not produce any inflammation around the open ends, while in many cases these spaces were subsequently filled up with fibrous tissue or bone. The latter occurred more frequently with larger size apical openings.[36]

These more recent studies, therefore, strongly invalidate the previous “hollow tube theory” and make it possible for us to conclude that empty spaces within a living tissue are not necessarily accompanied by inflammation or tissue destruction; on the contrary, they can be associated with physiological repair (Fig. 23.1).

In a recent article, Delivanis et al.[39] have denied the possibility of the esistence of the anachoresis within an empty tube filled only with tissue fluids or within a root canal following pulpectomy, in experimental animals. The selective localization in areas of chronic inflammation of blood-borne bacteria (anachoresis) is a well known phenomenon, experimentally demonstrated.[1,19,54,101,104,145] For example, it explains the implantation of bacteria in a pulp that has not been exposed to the oral environment but has been compromised by a trauma. In order for the anachoresis to occur, the presence of blood vessels are, however, necessary: bacteria can easily localize in a space where tissue is present, even inflamed or on the way to necrosis, but still with blood circulation and not simply in a space filled only with tissue fluids where no blood circulation exists.

From all this it has been concluded that cleaned and shaped root canals must also be completely obliterated, not to prevent the bacterial colonization of the tissue fluids, but rather to prevent the survival and multiplication, inside the fluids which inevitably accumulate there, of bacteria remaining from even the most thorough sterilization procedures of the root canal.

It is universally recognized that complete sterilization of an infected root canal is very difficult, if not impossible, to achieve, just like the complete removal of all pulpal debris,[11,20,21,109,156,158] (Fig. 23.2).

The microorganisms remain isolated inside the root canal system, possibly within dentinal tubules that have remained infected deeper than the level of the shaped dentinal wall.[131] They therefore are beyond the reach of the organism’s phagocytic defenses, and the presence of necrotic pulp remnants in association with the accumulating exudate can serve as a “pabulum” and contribute to the maintenance of their viabilities.

Fig. 23.1. **A**. Preoperative radiograph of a lower left first molar. **B**. Radiograph two months later. This period of time elapsed because of neglect on the part of the young patient. The four canals had been cleaned, shaped, and medicated with Cresatin. Note the progression of the healing process, which has proceeded in spite of the fact that the canals had not yet been obturated and thus were completely empty.

Fig. 23.2. **A**. S.E.M. view of the apical third of a cleaned and shaped lower incisor. Note the presence of a large calcification adhering to the wall a few millimeters from the foramen (x60). **B**. Detail of the preceding figure. Note the presence of organic material in the area immediately apical to the calcification, where the instruments obviously could not be worked (x4,000).

If, however, the root canal system is completely obturated in its three dimensions, any remaining microorganism will be entrapped within the dentinal tubules between the cementum on one side and the canal filling material on the other, with no possibility of survival[3,6,100,102,115] (Fig. 23.3).

Confirming Morse's findings,[103] Moawad[97] has demonstrated that such bacteria entrapped within a completely filled root canal are nonviable within five days after root canal filling.

Peters et al.[115] recently demonstrated that there is no evidence that special measures (calcium hydroxide or iodoformic paste) should be taken to kill the bacteria in the dentinal tubules. Those bacteria either do not survive the treatment, are inactivated subsequently or remain in insufficient numbers to sustain or cause pathology. This is, of course, supported by the notion that a high percentage of "properly treated" cases are successful.[111,114,147] This is clearly not because of the almost unobtainable sterility of the treated dentin-pulp complex, but rather the low numbers of remaining bacteria just before obturation. Still according to Peters, calcium hydroxide greatly helps to reduce or inactivate bacteria (when used as an interappointment dressing). This is because of its disinfecting capacity as well as its physical obturation of the canal system, withholding from bacteria their sources of nutrients and limitating the space for multiplication. In conclusion, obturation with gutta-percha and sealer during the first appointment, after chemo-mechanical cleaning and disinfection with sodium hypochlorite, also deprives the remaining microorganisms their nutrition and leaves them no space to multiply to sufficient numbers to cause or maintain disease.

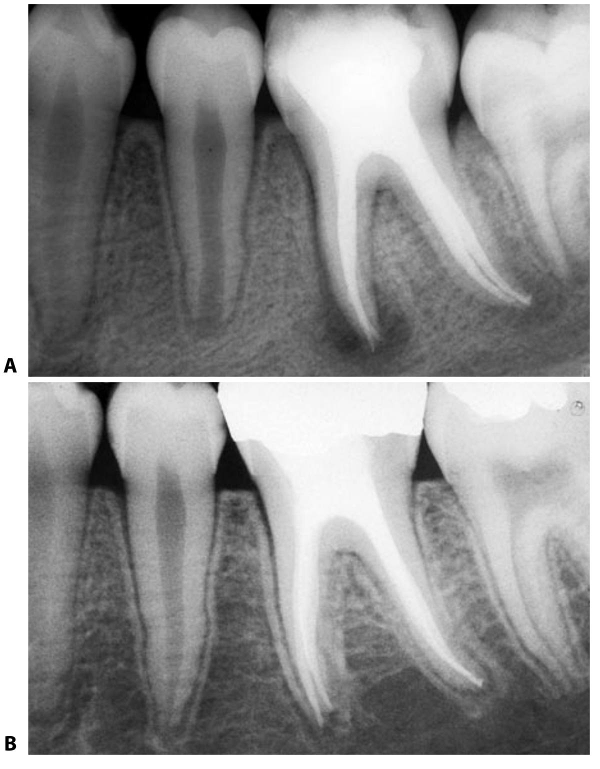


Fig. 23.3. **A.** Postoperative radiograph of the case of Fig. 23.1. **B.** Recall radiograph two years later.

Other in vitro studies demonstrated that most bacteria in the dentinal tubules died within 24 hours after removal of the nutrient medium.[113]

Recent studies by Moorer and Genet[99] have further demonstrated that gutta-percha has a certain antibacterial activity, perhaps because of its zinc oxide content.

Obviously, this is not an invitation to fill infected, non-cleaned, and non-shaped root canals with gutta-percha.

Klevant and Eggink[77] have hypothesized that, because of the deficient blood circulation in even a perfectly cleaned, shaped, but unobturated root canal, the accumulated tissue fluids could disintegrate and become themselves irritants of the periapical tissues, even in the absence of bacteria.

PROPERTIES OF THE OBTURATING MATERIALS

In view of these biological motivations for canal obturation, the qualities required to ensure a successful outcome in endodontic therapy will now be examined.

The practice of Endodontics based on chemotherapy, antimicrobial agents, and mummifiers is without a doubt out-dated. It was based on the concept that the pharmacological properties of the ideal obturation material should *assist* Nature to seal the canals with calcific or connective tissues.[163] In deference to the ancestral fear of focal infection, the emphasis was placed on bacteriologic control to ensure that all microorganisms had been completely eliminated from the root canal before proceeding to obturation. It was also motivated by the complexity and unpredictability of the anatomy of the root canal system. On account of these anatomical difficulties, Sargenti[128] felt that dentists would never be able to clean and obturate this anatomy, so that it was even pointless to try.

At the root of chemico-pharmacological Endodontics, there is also an important historical reason which explains why Endodontics has developed as a stepchild of Pharmacology.[163] As Schilder[130] has noted, many of the world's leading endodontists had previously been professors of pharmacology or other materia medica.

Underlying the practice of chemical Endodontics is the desire to save time, with all the related practical consequences, for both the patient and, even more, for the dentist.

Endodontic therapy with unpredictable chemical therapeutic agents has been replaced by biologically predictable techniques. Enormous contributions to modern Endodontics have been made by academics and researchers such as Prinz,[118] Buckley,[18] Cook,[31] Rhein,[122] and Callahan[22] since the end of the nineteenth century. These early authors developed the fundamental principles that the success of endodontic therapy and the elimination of periapical inflammation depend essentially upon adequate root canal enlargement, cleaning, and filling. These three principles were understood more than a century ago and represent the basis of modern Endodontic therapy.

In 1918, Price[117] wrote that "the human body can be considered a hermetically sealed container, the alimentary tract being an infolded tube and continuous with the exterior. Pulpless teeth are openings thru nature's protective armor and, as such, will be the port of entrance of infection into the body, unless they are hermetically *sealed*".

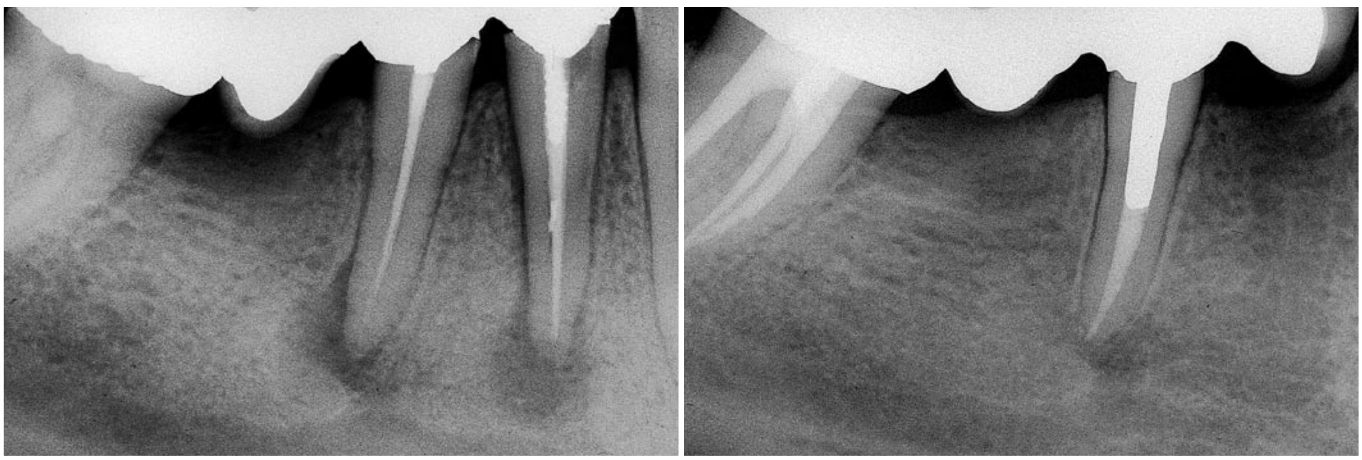
It has therefore been accepted for some time now in Endodontics, as in the other branches of Dentistry, the secret of success, apart from cleaning of the endodontium, which is comparable to the extirpation of all carious tissue in restorative dentistry, lies in the *sealing properties* of the obturation, just as amalgam in Restorative dentistry, the inlay and the crown in Prosthetic dentistry, and the marginal periodontium in Periodontics must all have the property of *sealing*.

The use of medicated pastes to sterilize and seal the root canals must therefore now be considered anachronistic. Such pastes should represent a panacea for Endodontics, but in actuality they conceal a lack of operative availability and an inexplicable fear, if not ignorance, of endodontic anatomy.

Schilder[133] emphasizes that in Endodontics the elimination of irritants from the root canal system by means of cleaning, shaping, mechanical disinfection and total obturation of the endodontium are important. "In the final analysis", he states that "it is the sealing off of the complex root canal system from the periodontal ligament and bone that ensures the health of the attachment apparatus against breakdown of endodontic origin". "The rationale of Endodontics should be designed to eliminate the root canal system as if the tooth were extracted"[134] (Fig. 23.4).

As far back as 1918, Price[117] asserted that "root fillings are castings made within the pulp chambers of teeth. They must conform so exactly to the size and shape of that chamber that neither microorganisms nor fluids, which may be external to the tooth, can enter or find lodgement. The form of this chamber is complex, uncertain, and indeterminate and may vary through a very wide range, which fact makes it necessary that the root filling material, or a sufficient part of it, be inserted in a moldable and plastic state".

A



B

Fig. 23.4. **A**. A radiolucency is present at the apex of both the first and the second lower premolars, which appear to be underfilled. The first premolar also shows a wider periodontal ligament space on the distal aspect, a screw post, an empty space between the dentin and the obturating material apical to the screw post. Clinically, there is a deep and narrow probing defect: the tooth has a vertical root fracture and therefore has to be extracted. **B**. The 3 year recall radiograph shows the complete healing of the two lesions, both where a non surgical retreatment has been performed as well as where the tooth has been extracted. In both cases the same final result has been accomplished: the complete elimination of the infected root canal system.

REQUIREMENTS FOR THE IDEAL ROOT CANAL FILLING MATERIAL

Throughout the literature[32,59,107,124,132] there have been a number of suggested requirements for the ideal root canal filling material. John West[163] states that the ideal material must:

1) be capable of being fully adapted to the prepared root canal walls
2) be dimensionally stable
3) be non-resorbable for an indefinite period of time
4) be non-irritating
5) be bacteriostatic, or at least should not encourage bacterial growth
6) prevent discoloration of teeth
7) preferably be semi-solid upon insertion and solid afterward
8) be capable of sealing canals laterally as well as apically
9) be impervious to moisture
10) be radiopaque
11) be sterile or sterilizable
12) be easily removable from the root canal, if necessary
13) be easily manipulable
14) stick to the canal walls
15) be a non-conductor of thermal changes
16) be slightly expandable after placement
17) set in a reasonable period of time.

In the history of Endodontics, seemingly innumerable substances have been used to obturate the root canals. Indeed, Grossman[58] wrote in 1958: "I doubt very much whether there is any hollow cavity in the body that has been plugged with as many different materials as the root canal of a tooth".

The most commonly used materials will be considered, weighing the pros and cons of each. Their techniques of use will then be considered separately.

Apart from solid or semisolid materials (silver cones and gutta-percha cones), root canal filling materials can be divided into cement-sealers, cements, and non-setting pastes, on the basis of their method of application and their setting characteristics in the root canal.[112]

ENDODONTIC PASTES AND CEMENTS

CEMENT-SEALERS are self-hardening cements when used in conjunction with a solid or semi-solid material.

CEMENTS are the same self-hardening cements when used to fill the entire root canal alone. They set and transform into a variably firm mass after their insertion in the canal.

Like the other two, PASTES are used to fill the entire canal. In contrast to them, however, they do not harden once placed in the canal.

The vast majority of authors agree with Langeland[81] when he states that the resorbability of endodontic cements and pastes has been exhaustively demonstrated by incontrovertible radiographic proof. All cements, which for the most part are based on zinc oxide-eugenol, are thus resorbable even from within the root canal, and their use as the sole filling material leads to certain failure.[4] The substance is transported far from where it was originally deposited, and this unfavorable condition is obviously aggravated still further when the entire canal is obturated with only a cement or paste.

The use of cements and pastes, therefore, should in principle be abolished. Biologically, it would be desirable to fill the entire canal with a solid or semi-solid material. In practice, however, this is not the ideal solution, because unacceptable empty spaces would remain between the canal walls and filling material. Cements, used as sealers, therefore have become indispensable.

Nonetheless, one must choose materials and techniques that entail the least possible risk for the patient. This means cement-sealers that are absolutely free of components toxic to the internal organs and that locally are as inert as possible, in addition to possessing the desired clinical requirements (see Table I).

Cements are assigned the task not so much of filling the root canal, as improving the seal (hence their name "sealers") provided by the solid or semi-solid material.[88,122]

For this reason, the cement or "sealer" must be used in absolutely minimal amounts, since it must only improve the adaptation to the canal walls of the other, more important, filling material, the gutta-percha. It represents the weak part of the obturation.

The choice of the ideal sealer must therefore fall to a product that is inert, easily manipulable, and sets relatively quickly. In particular, however, it must have the property of being mixed to such a consistency that it can deposit on the canal walls as a microfilm only a few microns in thickness.

The use of cements containing paraformaldehyde (just as, until a short time ago, were N-2, Rocanal, and Endomethasone) is therefore unacceptable, especially if used as the sole canal filling material. N-2, like all other cements containing paraformaldehyde, is highly cytotoxic, as innumerable histologic studies appearing in the most prestigious Endodontic journals have demonstrated. It turns out that the material in question possesses many undesirable properties.[5,9,16,30,46,57,60,65,82,98,108,116,119,127,146]

In the past 15 years, Angelo Sargenti has repeatedly changed the composition and name of his N-2 preparation. One of the last formulations (1972) consisted of hydrocortisone (1.5%), titanium dioxide (2%), trioxymethylene (7%),* lead oxide (16.5%), and zinc oxide (73%). In 1974, the Council on Dental Therapeutics of the American Dental Association[2] classified N-2 as an "*unacceptable*" preparation in the light of scientific studies indicating the potential danger of the various formulations of N-2 for the patient.[15,65,80,148] His technique of use therefore does not warrant discussion.

These substances are used by endodontists who still do not understand that the canals must be cleaned and shaped *by them* and also three-dimensionally filled *by them*. They instead prefer, because of laziness and lack of faith in their abilities as endodontists, to abandon arms and trust the miraculous power of the cements which they believe will do all that they are unable to do.

It is obvious that it is much faster (with all the practical implications that ensue) to place a little amount of cement at the apex with Lentulo's spiral, albeit without the least apical, much less three-dimensional, control of the obturation. Radiographically, the canal may even seem to be well filled, but only the walls would be smeared with cement, while enormous empty spaces remained within.

All patients, whether American or European, deserve the endodontist's time and attention, which must obviously be remunerated. It is therefore unjust when Hess and Fraisse[68] write that "In Europe a dentist (with rare exceptions) cannot afford the luxury of dedicating much time to obturating a tooth, both because of the pace of work and the fee of the official hand-book".

One may wonder further how one can think that an accidental overfilling of "Rocanal" cement is "well-tolerated"[151] when this cement contains, among other things, trioxymethylene (Fig. 23.5), while stating at the same time that gutta-percha obturation is to be avoided because "the preparation of the canal is too la-

Table I

Requirements of the ideal cement-sealer

- Easily manipulable with ample working time
- Easily mixable in very fine powder particles and liquid form
- Taky when mixed and adhesive to the canal walls
- Biocompatible
- Expansible while setting
- Absolutely inert
- Physically stable (unshrinkable after setting)
- Non-resorbable
- Insoluble in tissue fluids
- Radiopaque
- Not staining the tooth structure
- Bacteriostatic
- Easily removable with common solvents, if necessary
- Non-immunogenic in the periapical tissues[8,10,152]
- Neither mutagenic nor carcinogenic[66,83]

Fig. 23.5. Radiograph of a lower left second premolar treated with Rocanal Vital, which contained paraformaldehyde. Note the extrusion of material beyond the apex and the course of the inferior alveolar nerve. The excess material corresponds to the mental foramen, and the patient complained of complete anesthesia of the left half of the lip for over one year.

(*) Trioxymethylene" is an improper denomination of "polyoxymethylene" or "paraformaldehyde", the solid polymer of formic aldehyde or formaldehyde.[76]

borious", "the material is not tolerated by the periapical tissues", it is not "safely sterilizable with any treatment", and "it is not easy to remove".[151] Evidently, this ignores the fact that the canal *must* be cleaned, independent of the type of material that one wishes to use to fill it, and that gutta-percha is perfectly tolerated by the periapical tissues,[38] is easily sterilizable,[50,141] and is likewise easily removable.[25] One may wonder how one can speak of obturation in "perfectly compacted" cement.[37]

In conclusion, cements must not be used as the sole canal filling material, but must be used in minimal amounts and in inert chemical formulations as coadjuvants of the apical seal, together with solid (e.g., silver cones) or, preferably, semi-solid materials (e.g., gutta-percha).

SOLID MATERIALS

Especially in the past, silver cones were among the most commonly used solid materials for root canal obturation. They are not the only materials that have been tried. Techniques of canal obturation that require the use of reamers, files, or endodontic probes intentionally broken in the root canal have been described. For obvious reasons, these will not be discussed.

Jasper[72] introduced the use of silver cones in Dentistry about 60 years ago. He proposed that they be used to obturate particularly narrow and tortuous canals which would have required more enlargement to be obturated with gutta-percha, which in these cases always posed enormous difficulties in advancing apically. It was felt that a more rigid material than the flexible gutta-percha was needed to allow it to be pushed to the desired depth.

Their ease of manipulation and less need for canal enlargement, however, led very quickly to the misuse of silver cones and to numerous treatment failures, since they were increasingly introduced in canals that had not been sufficiently cleaned and shaped, though radiographically they gave the appearance of a perfectly performed therapy because of their intense radiopacity.

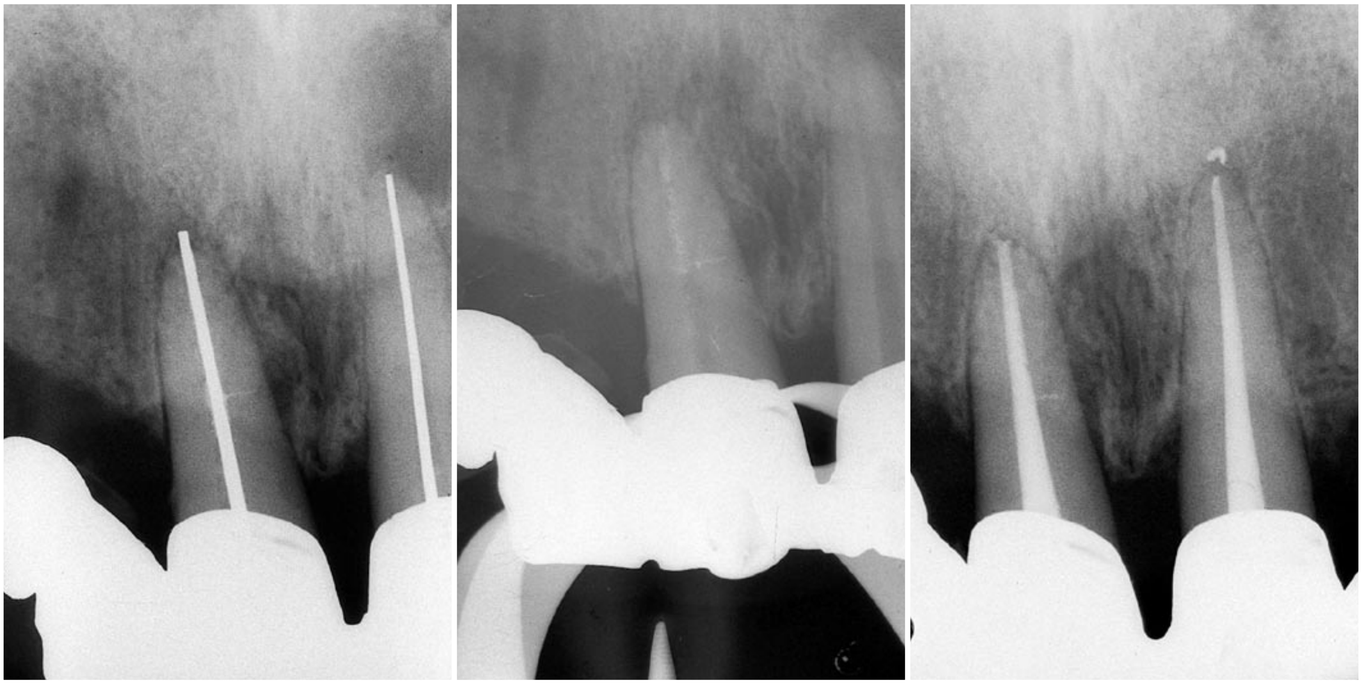
Today, silver cones are universally considered obsolete, inasmuch as they have been superceded by semi-solid materials, which offer a much higher assurance of success.[44]

The disadvantages of silver cones can be listed as follows:

– The silver cone has no adaptation at all to the surrounding endodontic anatomy. The canal will therefore remain inadequately filled (Fig. 23.6) or obturated only with sealer (Fig. 23.7).

Fig. 23.6. S.E.M. photomicrograph of an upper premolar treated endodontically with a silver cone and extracted for treatment failure. Cross section about 3 mm from the apex. Note the presence of the silver cone in the root canal, surrounded by some islands of sealer and enormous empty spaces (x90).

– The canal very often has an irregular shape; it is elliptical, eccentric, and quite far from the round cross-section of the silver cone.[134,159] As a consequence, when the apical foramen is ovoid, the seal is entrusted to a large mass of sealer, with all the consequences that derive from it, since the cone, insofar as it is apparently stuck at the apex, will touch the walls in only two points, and will never be able to seal that elliptical foramen (Fig. 23.8).
– When the silver cone is positioned at the foramen (Fig. 23.9), or even more when the cone protrudes beyond the apex[56] (Fig. 23.10), once the surrounding sealer has been resorbed (given the resorbability of sealers), metallic corrosion sets in as a result of oxidation.[14,168] This leads to the formation of products containing sulfur and chloride, which recent research has demonstrated to be cytotoxic.[139]
  This corrosion is due to contact of the cone with tissue fluids that penetrate from the apical foramen between the cone and dentinal walls. It can lead to "disintegration" of the metal.[67]
– If the silver cone has been sectioned at the canal orifice or, worse yet, within the root canal itself, its removal can be very difficult, if not impossible (see Chapter 33).



A B C

Fig. 23.7. **A**. An upper right central incisor treated with a silver cone. Note the filling of a small lateral canal midway along the root facing mesially at 90° to the main canal. Obviously, the filling was performed only with sealer. **B**. The silver cone has been removed, since the tooth was causing symptoms and, further, two lesions were present: one lateral and one at the apex. **C**. Three years later, the lesions at the apex of the two central incisors have healed, but the lateral lesion of the right central incisor has not completely resolved. Evidently, the obturation of the lateral canal is not "three-dimensional," and infected material is present within.

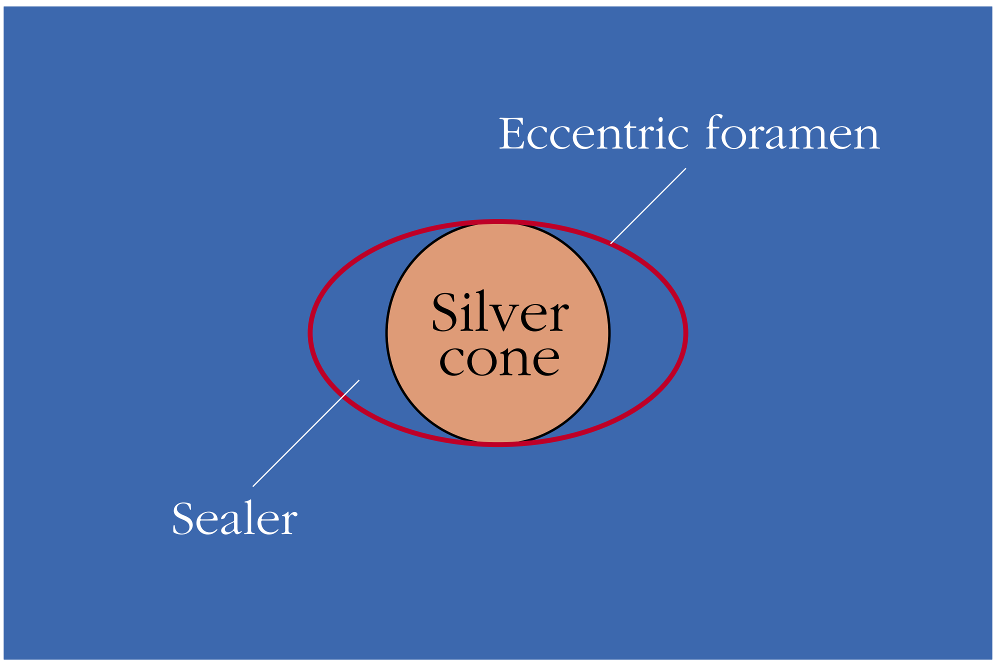
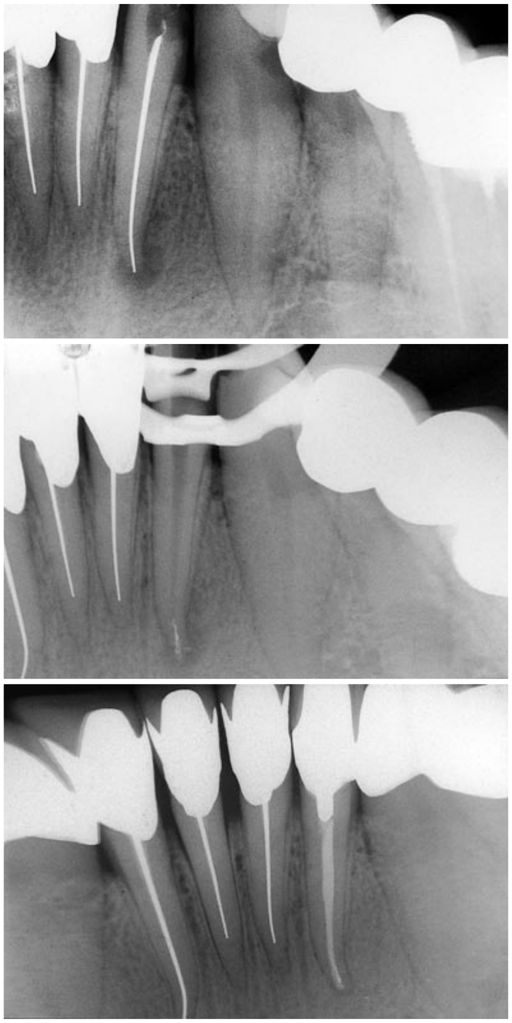
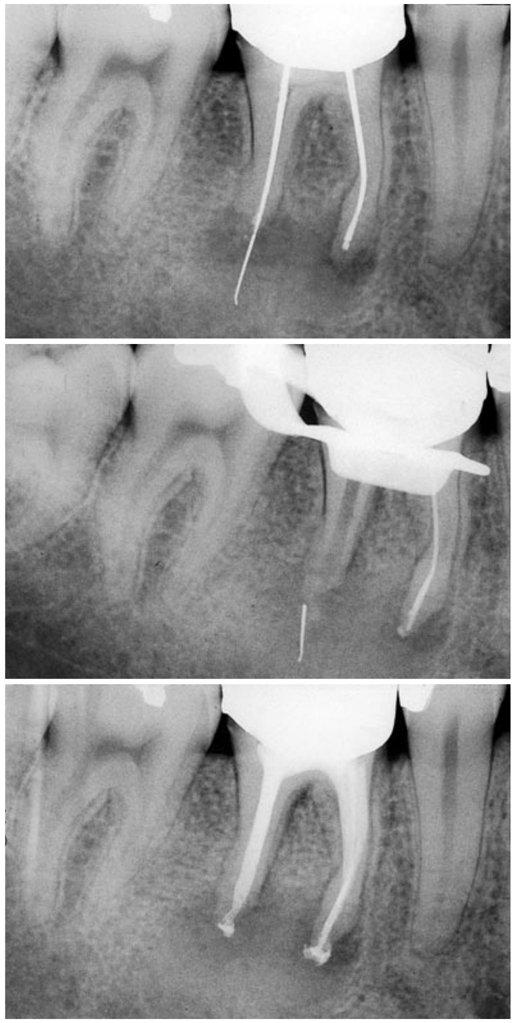


Fig. 23.8. Diagramatic representation of the relationship existing between the silver cone and the elliptical apical foramen



A B C

Fig. 23.9. **A**. Preoperative radiograph of a lower left lateral incisor, which had previously been treated with a silver cone. It requires retreatment because of a symptomatic lesion. **B**. The silver cone has been removed with an ultrasonic endodontic handpiece. Note the presence of corrosion products of the silver cone, which "paint" the canal walls, fortunately without blocking it. **C**. Radiograph three years following retreatment.



A B C

Fig. 23.10. The silver cone is seen emerging beyond the apex by several millimeters. It has become corroded, causing the separation of the cone into two fragments at the level of the apical foramen. **A**. Preoperative radiograph. **B**. The silver cone has been removed from the distal canal, but the part beyond the apex has remained in the tissues. The patient then developed an acute alveolar abscess. The tooth remained completely open for drainage for several days, and the patient was invited to rinse with warm salt water to encourage drainage. **C**. Postoperative radiograph obtained after one week. The silver cone fragment has been "drained" externally, together with the purulent exudate.

SEMI-SOLID MATERIALS

The semi-solid material most widely used in Endodontics is gutta-percha, which is derived from a rubber base obtained from several tropical plants belonging to the genera Sapotaceae.[156] It has found vast applications and wide approval for over 100 years.

Although there are still practitioners who insist that it is "obsolete"[34] and call it "the pseudo-queen of root canal filling materials",[35] the overwhelming majority of the international endodontic literature concurs that gutta-percha is the material of choice for proper canal obturation, since more than any other it reflects the qualities of the ideal material. Indeed, until a better material is found, the only problem is how to make a better use of it.[133]

– Gutta-percha optimally adapts to the canal walls because of its compactability. In fact, gutta-percha is neither molecularly condensable not compressible, but once it is softened by heat, it can be compacted against the canal walls in such a way as to eliminate and collapse any voids present in commercial gutta-percha.[136]
– Once it sets, gutta-percha is stable in size. It shrinks only when it is chemically softened (e.g., with chloroform), following evaporation of the solvent, or if

it is physically softened (e.g., by heat), during the cooling phase. For these reasons, chemical softening of gutta-percha is to be avoided, since it creates voids and softening by physical means must be accompanied by compaction of the material to compensate the volumetric changes that occur during the cooling phase.

- Although constituted primarily of zinc oxide (see Table II), gutta-percha is in practice a non-resorbable material. Nonetheless, there are cases in which gutta-percha that had inadvertently been forced beyond the apex has been partially resorbed over the course of several years, as documented by recall radiographs (Fig. 24.68).
- Gutta-percha is well tolerated by tissues, as demonstrated by numerous histologic studies in experimental animals.[38] Of all the materials used in Dentistry, gutta-percha is perhaps the most inert. Certainly, it is more inert than silver or gold.[159]

  Weine further states that since gutta-percha is so well tolerated by the periapical tissue, only rarely does one encounters treatment failure in cases of overfilling.[159]

  In most cases, the radiographic appearance is normal; in some cases, however, one notes true amputation of the excess material with phagocytosis (Fig. 24.69).

Table II

Composition of commercial gutta-percha

Materials	*Percentage*	*Function*
Gutta-percha	18-22%	Matrix
Zinc oxide	59-76%	Filler
Waxes or resins	1-4%	Plasticity
Metal sulfates	1-18%	Radiopacity (barium or strontium)

- Recent studies by Moorer and Genet[99] have demonstrated that, *in vitro*, gutta-percha has activity against several different bacterial species (*Staphylococcus aureus*, *Streptococcus mutans*, *S. pyogenes*). They have also hypothesized that the active antibacterial element of gutta-percha cones is probably zinc oxide.
- The material is semi-solid on introduction in the canal. This allows easy manipulability. It becomes malleable if heated, so that it may assume any shape if compacted with appropriate instruments during this phase. This obviously allows three-dimensional filling of all the spaces that it finds around itself, both apically and laterally.
- Because of its sulfate content (usually barium sulfate), it is radiopaque, and thus easily recognizable radiographically.
- It is also readily sterilizable, since immersion in 5.25% sodium hypochlorite for as little as 60 seconds suffices to eliminate even the most resistant *Bacillus subtilis* spores.[141,143]
- If necessary, gutta-percha can easily be removed once dissolved in its solvent (chloroform, chlorothene, eucalyptus, rectified white turpentine, or others[70,74,78]). This represents a great advantage with respect to other materials (e.g., silver cones or resinous cements), whose removal can present great difficulties.
- Gutta-percha adheres to the dentinal walls to which it fits without establishing any bonds. To rectify this shortcoming, one must also use a sealer for its "sealing" properties.
- Gutta-percha is a poor conductor of heat. This implies optimal control of its plasticity in its most apical portion when heated.
- Once introduced in the root canal and heated, gutta-percha expands. This helps to ensure a tighter seal. As already suggested, gutta-percha shrinks during the cooling phase; thus, to compensate for thermal shrinkage, any technique that requires heating must also require compaction.[138]

The only disadvantge of the use of gutta-percha is that, being that it is semi-solid or, rather, semi-plastic at the time of its insertion, it does not permit any errors in canal preparation. Lacking in rigidity, it cannot be pushed to overcome a ledge that might be present.

Gutta-percha is available commercially in the form of standardized and non-standardized cones.

Standardized cones follow the same rules of standardization already discussed with regard to the root canal instruments. They are available in numbers 25 to 140, and their apical diameter and conicity correspond to those of the instrument of the same number. These cones are indicated in the lateral condensation technique, in which the master cone is chosen on the basis of the last instrument used. This correspondence is therefore useful (Fig. 23.11).

Non-standardized cones, on the other hand, are much more conical and pointed. Rather than being distinguished by number, they are distinguished by size: extra-fine, fine-fine, fine, medium fine, fine-medium, medium, medium-large, large, and extra-large.

These cones are indicated for Schilder's technique, since their greater conicity allows better adaptation to the tapered preparation form of this technique (Fig. 23.12).

Recerntly, Stephen Buchanan introduced new gutta-percha cones called "GT gutta-percha" and "Autofit", distinguished by their taper: .04, .06, .08, .10, .12 (Fig. 23.13). They automatically fit into the preparation made with Nikel Titanium GT Files.

Fig. 23.11. ISO standardized gutta-percha cones, to be used with lateral condensation technique.

Fig. 23.12. Non-standardized gutta-percha cones, to be used with vertical condensation of warm gutta-percha.

Fig. 23.13. GT gutta-percha cones (Dentsply Tulsa Dental, Tulsa, Oklahoma, USA), to be used with vertical condensation of warm gutta-percha and with the single wave condensation technique: they have a standardized taper, corresponding to the GT Rotary files.

TECHNIQUES FOR ROOT CANAL OBTURATION WITH GUTTA-PERCHA

The techniques universally used and taught among those that make use of gutta-percha are of course the "lateral" and "vertical" condensation methods, surrounding which there has been considerable controversy for years. However, both "lateralists", such as Frank, Simon, Abou-Rass, and Glick,[49] and "verticalists", such as Schilder,[135] consider the so-called controversy an artificial one.

The former maintain that it is unrealistic to discuss whether a lateral or vertical force is to be preferred, since the two methods of condensation are interrelated: "It is physically impossible to condense either laterally or vertically alone".

Schilder notes that "the softened gutta-percha mass, which is being compacted vertically into the conically shaped canal preparation, automatically assumes a lateral component of force. This follows routine laws of physics and requires no lateral direction of the instrument on the part of the operator".

By all means, one can discuss which technique is superior, but one should not do so in terms of "lateral" or "vertical", but rather "cold compaction" or "warm compaction". This is the true difference between the two techniques.

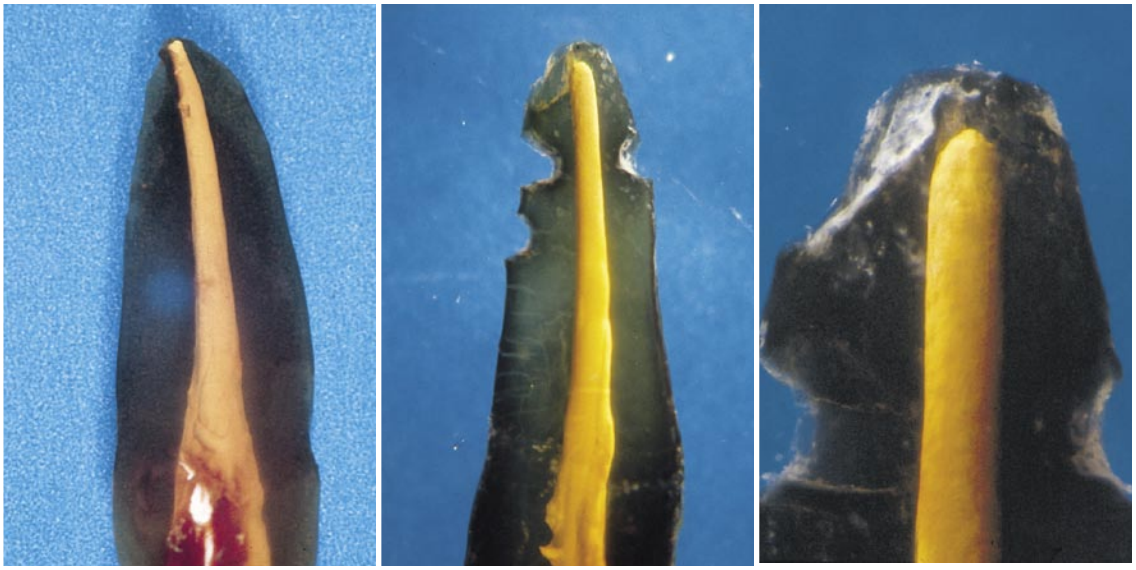
The next chapter will be dedicated to vertical compaction. The lateral condensation technique and the other techniques most commonly used will be considered here.

LATERAL CONDENSATION OF GUTTA-PERCHA

This technique requires the introduction of a gutta-percha cone that fits well to the apical preparation (master cone), together with a small amount of sealer. The appropriate metallic, rigid, conical and smooth instrument (spreader) is used cold to compress the cone against the canal wall, introducing this instrument between the dentin and gutta-percha. In this way, one creates the space into which the first auxiliary cone is to be introduced. The spreader is then re-introduced vertically. It pushes aside the gutta-percha placed previously, so as to make space for a second auxiliary cone, and so on, until one obtains a dense, well-adapted filling.

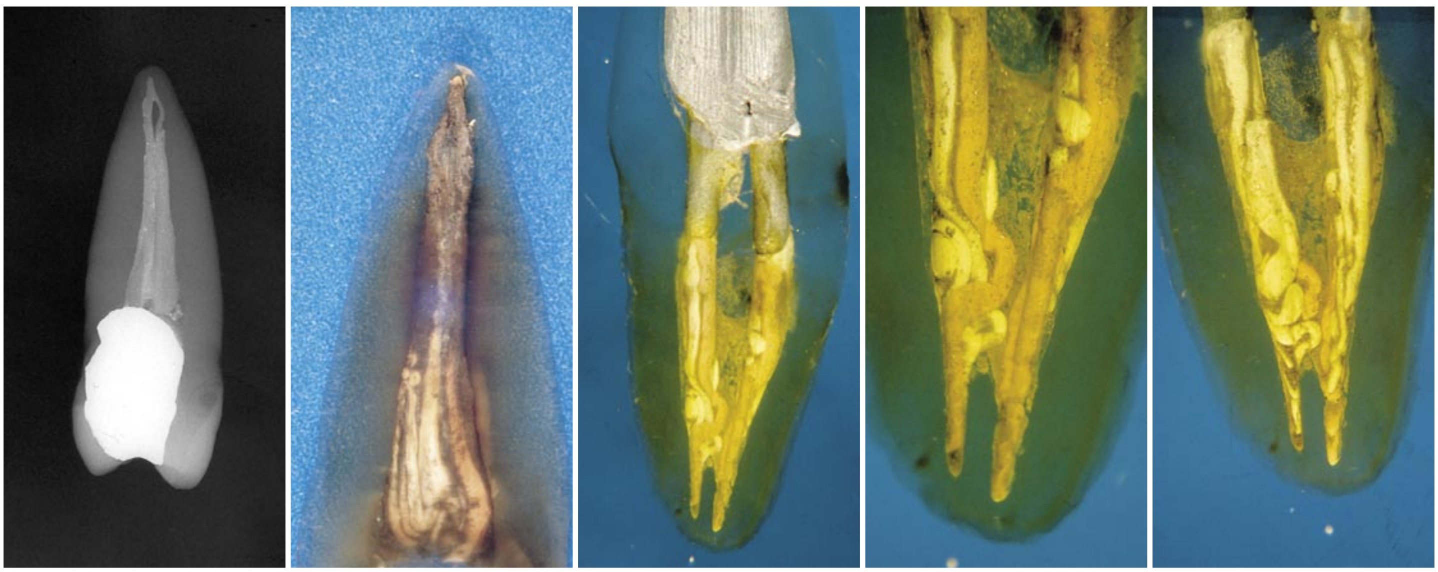
This technique has several drawbacks:

– being a "cold" technique, the gutta-percha cones never merge into a homogeneous, compact mass, but the technique will always yield an obturation comprising a number of gutta-percha cones separated by a greater or lesser amount of sealer,[16] depending on the dentist's ability (Figs. 23.14-23.18).



A B C

Fig. 23.14. **A**. An upper lateral incisor treated "*in vitro*" with the lateral condensation technique. At this magnification, the cones seem to be well condensed toward each other. No trace of sealer can be appreciated. (Courtesy of Dr. F. Riccitello.) **B**. Another example of a properly performed lateral condensation in an extracted tooth treated *"in vitro"* (Courtesy of Dr. T. Fondi). **C**. The same tooth at higher magnification.



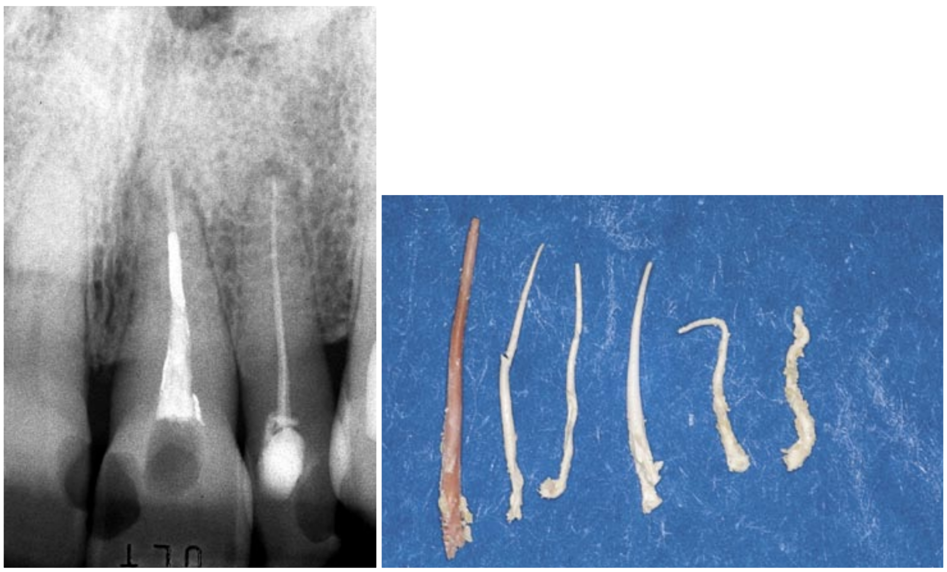
A B C D E

Fig. 23.15. Typical examples of "*in vivo*" obturations with the lateral condensation technique. **A**. The tooth in a mesiodistal view. **B**. The same tooth after decalcification and clearing. Note at the apex the two gutta-percha cones that have remained unaltered and the conspicuous lateral condensation of auxiliary cones in the middle and coronal thirds of the root canal. **C**. Mesial root of a lower first molar, treated with the lateral condensation technique and extracted for periodontal reasons. **D**. Detail of the preceding figure. **E**. The same root seen from the other side.

– Filling of the lateral canals occurs less frequently than when vertical condensation is performed, and it is always constituted of sealer, never gutta-percha.[121]
– The spreader makes its way between the gutta-percha and dentin, against which it exerts a considerable lateral force, with the risk of root fracture.[55]
– Only with difficulty can one condense several auxiliary cones next to the master cone in the most apical portion of the root canal. As a consequence, one frequently obtains an obturation performed with the lateral condensation technique in the coronal two-thirds of the canal and an obturation represented by a single cone surrounded by a bit of sea-

A B C

Fig. 23.16. A poor example of "lateral flanking" of several gutta-percha cones, without any sign of "condensation." **A**. Preoperative radiograph of the lower left first molar. Extraction was elected. **B**. The distal root in a mesiodistal view. **C**. The same root after decalcification and clearing.



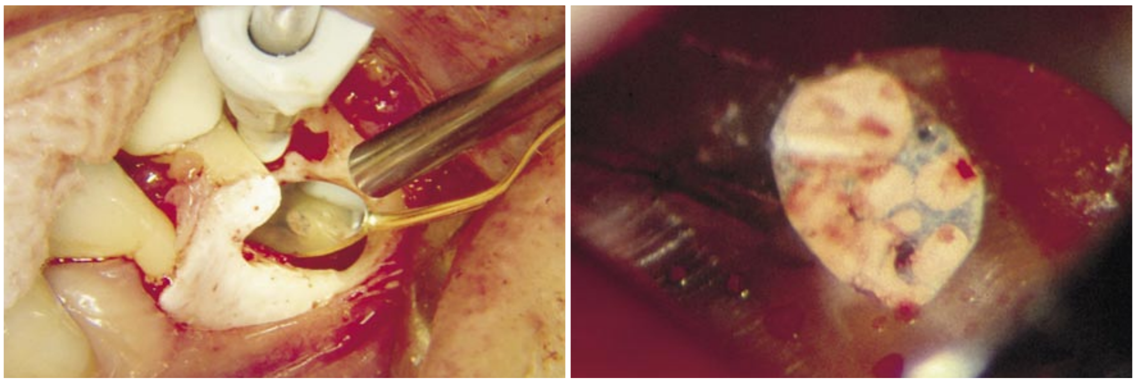
A B

Fig. 23.17. **A**. Preoperative radiograph of an upper central incisor requiring retreatment. **B**. These are the gutta-percha cones that were used to obturate the root canal using the cold lateral condensation technique. It was possible to remove every single cone that was used!

ler in the apical third, which is the critical and most important zone. In this case, the uselessness of having condensed a large number of auxiliary cones in the middle and coronal zones is obvious.

– Especially considering that heat is not used, the most apical portion of the master cone does not undergo any modification if one does not descend deeply with the spreader. The seal is therefore completely entrusted to the sealer, while the gutta-percha cone will serve the same function that a silver cone or a single cone of gutta-percha would have.
– In vitro studies[43] demonstrated that lateral condensation shows significantly greater volumetric leakage as compared to other techniques, which means that this technique cannot guarantee a good apical seal.
– Recent studies by Gimlin et al.[55] have demonstrated that, if one applies the same force in the two techniques, the stress that is produced in the area of the apex is greater in lateral than in vertical condensation. In other words, lateral condensation requires a smaller amount of force than vertical condensation to produce the same amount of stress near the apex. In practice, this can be translated into greater ease in exceeding prudent limits in lateral condensation. Furthermore, when forces are applied to create identical apical stress, the average stress that is registered throughout the entire length of the canal is higher in vertical than lateral condensation. In other words, vertical condensation produces a high lateral stress (namely, lateral forces) that is uniformly distributed over the entire root surface,[55,121] while lateral condensation creates a lesser mean lateral stress with higher stresses only in a small area, that is, near the tip of the spreader. A concentration of stress can cause fractures more easily as compared

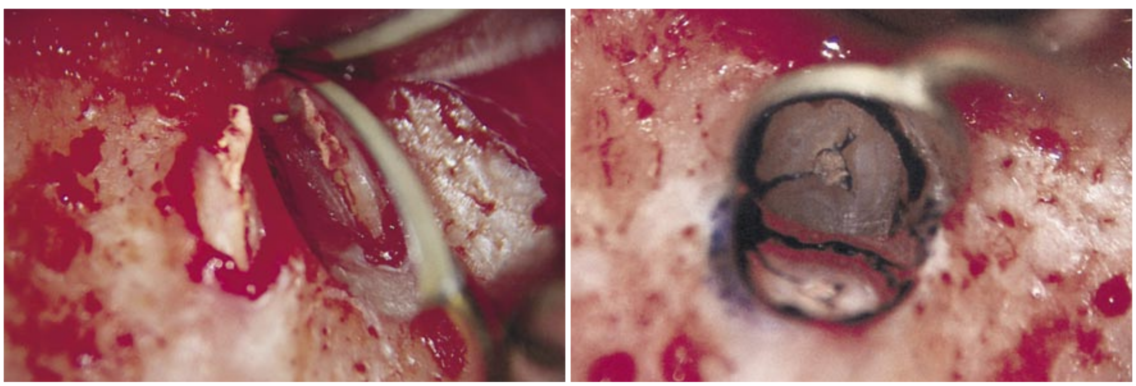
A



B

Fig. 23.18. **A**. Intraoperative photograph taken during the apicoectomy of the lower second premolar, previously treated with lateral condensation. **B**. The micromirror is showing the laterally condensed gutta-percha cones, which are surrounded by sealer (Courtesy of Dr. Gary Carr).

A



B

Fig. 23.19. **A**. Intraoperative photograph taken during the apicoectomy of the upper first premolar, previously treated with lateral condensation. An apical vertical root fracture is present. **B**. After the removal of the apical fractured fragment, a fracture line is still present on the bevel of the root, stained with methylen blue. The tooth had no coronal probing, confirming that the fracture was apically induced.

to high but uniformly distributed stresses. The only thing necessary to cause a fracture is a high stress concentrated in a small area (Fig. 23.19). The conclusion of Gimlin et al. is that, given that it produces a higher apical stress and a lesser lateral one as compared to vertical condensation, the term "lateral condensation" is in actuality a misnomer.

THERMOPLASTIC GUTTA-PERCHA

The thermoplastic gutta-percha technique was introduced by Yee et al.,[167] Torabinejad et al.,[153] and Marlin et al..[90] It consists of injecting gutta-percha heated by an electrical device into the prepared root canal.

The instrument looks like a gun (Fig. 23.20) whose cartridges are small gutta-percha cylinders that are heated to a temperature that can be regulated by the user. Exerting pressure on the "trigger" activates a piston that presses the gutta-percha toward the tip of the instrument.

Here, the gutta-percha is conveyed through a thin silver needle that, when appropriately bent, allows one to operate in the root canals of the various sectors of the mouth. The technique does not exclude the use of sealer, which in this case also has the function of lubricating the plastic material in its path toward the apex,[90] in addition to ensuring a better seal.[13]

Yee et al.[167] examining macroscopically the obturation obtained and assessing the apical seal by dye penetration studies, have demonstrated that it is possible to obtain dense obturations, without entrapped air bubbles, if the technique is accompanied by the use of a sealer. They have also demonstrated filling of lateral canals, apart from the presence of a good apical seal.

Fig. 23.20. The Obtura III, produced by Obtura Spartan.

Torabinejad et al.[153] have examined under the scanning electron microscope the obturation obtained with this technique. The gutta-percha revealed good adaptation to the dentinal walls, which was identical to that obtained with other conventional techniques, apart from the presence of some small voids, which were not visible radiographically.

A similar study by Weller et al.[161] has demonstrated with the operating microscope that the Obtura II thermoplasticized injectable technique showed the best adaptation to the prepared root canal, when compared to Thermafil and cold lateral condensation.

A clinical study by Marlin et al.[90] has demonstrated that it is possible to obtain practical results comparable to those obtained by traditional techniques, with the great advantage of a significant reduction in working time.

They emphasize the importance of combining gutta-percha with a sealer for the purpose of lubrication, which has also been confirmed by subsequent studies,[26,45,144] and warn against the danger of extrusion of material beyond the apex.

This is one of the great drawbacks of this technique: it completely lacks apical control of the obturation.[51,89,126] If one wishes to use this method for complete filling of the root canal, it is necessary to construct, during the shaping procedure, a good "apical barrier"[53] to prevent the extrusion of material into the periodontium.[52] The needle of the Obtura syringe must be positioned no less than 4-6 mm from the end of the preparation, since if it were positioned further (8 mm or more), a high percentage of underextended, that is, short obturations would result.[79]

The gutta-percha issues from the syringe already warm and plastic. Moreover, the user does not have the least control of either the pressure that is exerted or the amount of gutta-percha that he is introducing into the root canal. For this reason, in this author's opinion, this technique has precise indications. It may be confidently used only when there is no risk of introducing material beyond the apex, namely in the following circumstances:

a) Back-packing, after the apical third of the canal has been obturated by the traditional Schilder's technique.
b) Unnegotiable canals in which it is necessary to fill the endodontium as much as possible by coronal approach before performing retrofilling of the canal by surgical means (Fig. 23.21).
c) Partially unnegotiable canals: sometimes, thermoplastic gutta-percha succeeds in obturating portions

of canal that had remained unnegotiable to instruments. In these cases, there are three possible destinies for the endodontic contents: they may have been digested by the irrigating solutions; they may have been pushed by the thermoplastic gutta-percha beyond the apex, where they are phagocytosed by macrophages; or they may have remained incarcerated within the root canal between the filling material and the canal walls. In any case, after having verified from the postoperative radiograph

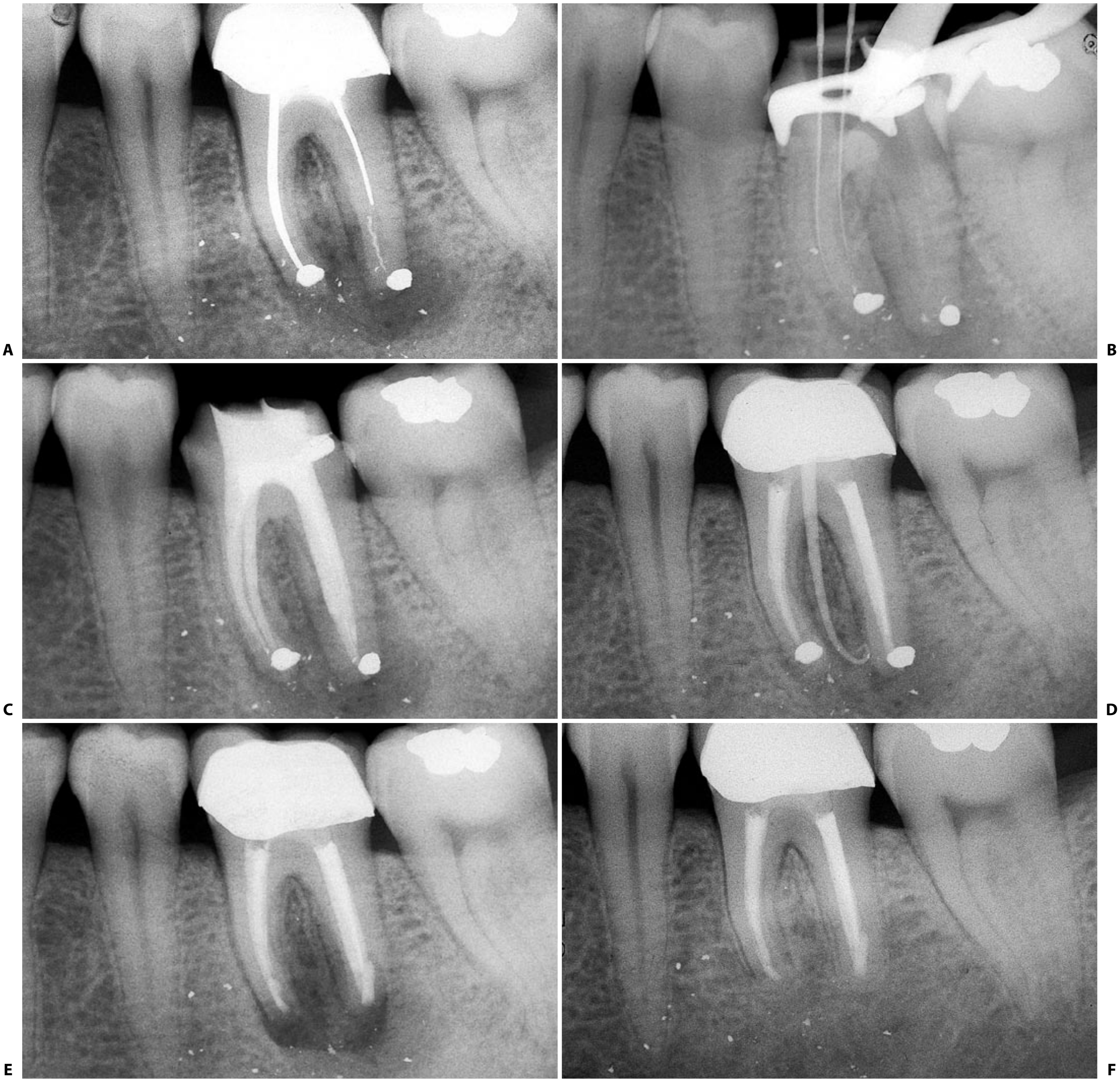


Fig. 23.21. **A**. Preoperative radiograph of the lower left first molar. The tooth has been treated endodontically with silver cones. A broken instrument is also present in the distal root. Surgical retreatment is contraindicated. **B**. Intraoperative radiograph during the non surgical retreatment: the silver cones and the broken instrument have been removed. **C**. Postoperative radiograph. **D**. Six month recall: a fistolous tract is now present: now the surgical retreatment is indicated. **E**. Postoperative radiograph after surgery. **F**. Two year recall.

that filling of these spaces has occurred, it is advisable to postpone the surgical procedure and reassess the extent of healing some time later. Apicoectomy or root amputation may no longer be necessary[27] (Fig. 23.22).

d) Root canals of teeth with immature apices after one is certain of having achieved closure and maturation of the apex using the known techniques (Fig. 23.23) (see Chapter 29).

e) Root canals of teeth with immature apices after the apical barrier technique with MTA (Fig. 23.24).

f) Root canals with internal resorptions, after the api-

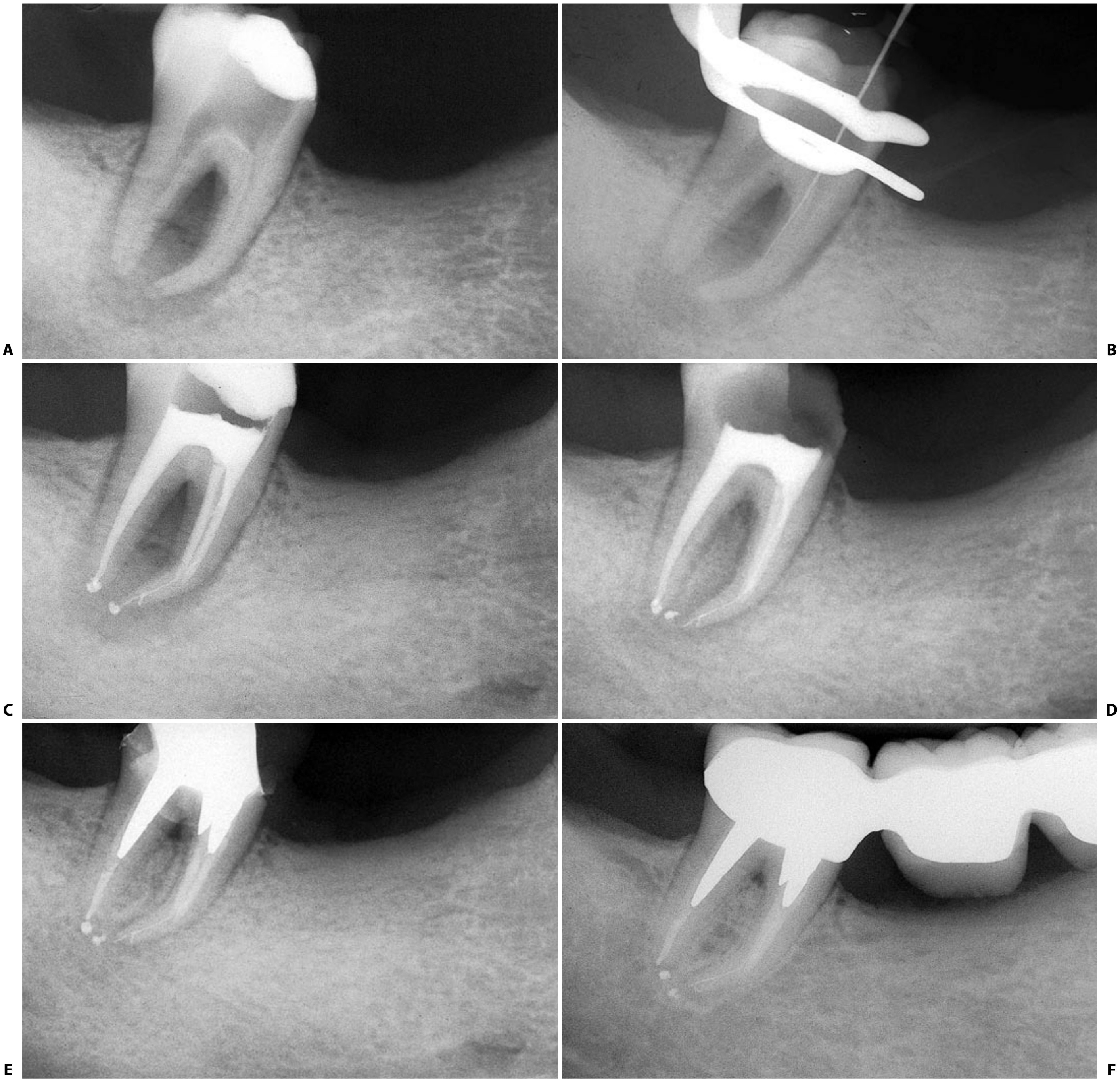


Fig. 23.22. **A**. Preoperative radiograph of a lower right second molar. The patient was referred after the distal canal had been prepared and the mesial canals were found to be partially negotiable. **B**. The mesial canals are blocked by a ledge at the beginning of the curve of the root. **C**. Postoperative radiograph. The distal canal has been obturated with warm gutta-percha, and the mesial canals with thermoplastic gutta-percha. Note the filling of the non-instrumented portion of the mesial canals. **D**. Radiograph five months later. **E**. Eleven months later. **F**. Three year recall.

cal third of the root canal has been obturated in the traditional manner, according to the warm gutta-percha technique of Schilder (Fig. 23.25).

g) Root canals in which, because of the inadequate previous shape, one is unable to fit a traditional gutta-percha cone with the tug back in the right position (Fig. 23.26) or root canals in which, because of the peculiar root canal anatomy or because of the presence of ledges, it is difficult if not impossible even to introduce a traditional gutta-percha cone (Fig. 23.27).

h) Root canals in which a perforation has been made in the apical third of the root.

i) In surgical endodontics[47] for the obturation of the root canal system with a surgical approach, before positioning the retrofilling material (Figs. 23.28-23.30).

j) In non-surgical retreatment of surgical failures (Fig. 23.31).

Another drawback of this technique is the high temperature that the gutta-percha reaches within the syringe before being introduced in the root canal.

A B C D

Fig. 23.23. **A**. Preoperative radiograph of an upper left central incisor with an immature apex and necrotic pulp in a patient nine years old. **B**. Radiograph after 6 months of therapy with calcium hydroxide. The apical barrier is evident. **C**. Postoperative radiograph following obturation with thermoplastic gutta-percha. **D**. Two year recall.

A B C D

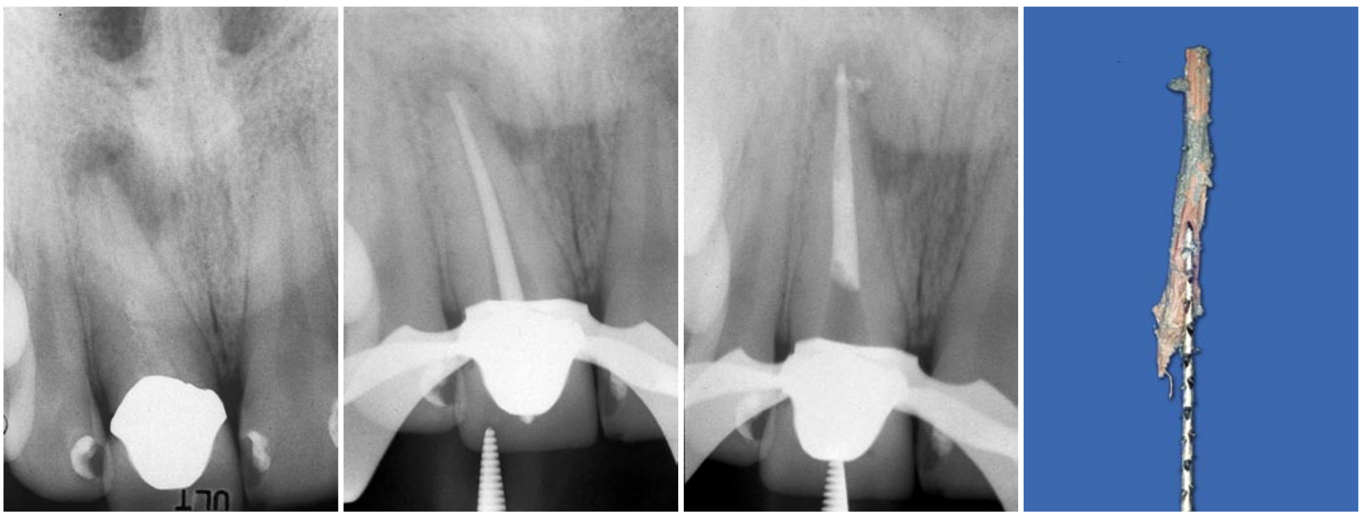
Fig. 23.24. **A**. Preoperative radiograph of an upper right central incisor with an immature apex in an adult patient. **B**. The apical barrier of MTA. **C**. Deepest point of compaction of the thermoplastic gutta-percha. **D**. Postoperative radiograph.

It is known that gutta-percha expands when heated and shrinks when cooling, and that the shrinkage is directly proportional to the thermal expansion it has experienced.[137] Therefore, the shrinkage of apical gutta-percha is quite different in Schilder's technique, in which the temperature has been increased to a few degrees above body temperature, as compared to that of thermoplastic gutta-percha, which issues at a temperature of around 55°C,[62] but which within the syringe reaches a temperature of about 160°C.

For this reason, Schilder[138] states that techniques which utilize thermoplasticity of gutta-percha but do not include vertical compaction and/or techniques which subject apical gutta-percha to temperatures above 45°C all predispose to shrinkage, irrespective of the type of gutta-percha employed.

A B C

Fig. 23.25. **A**. Preoperative radiograph of an upper left lateral incisor with considerable internal resorption. Once the resorption is diagnosed, it is always necessary to intervene quickly because the lesion could progress. **B**. Intraoperative radiograph of the apical condensation. **C**. Postoperative radiograph. The area of internal resorption has been filled with thermoplastic gutta-percha.



A B C D

Fig. 23.26. Owing to a previous improperly performed shaping, the cone introduced and compacted traditionally had a tug back in the middle third rather than the apical third, with a subsequent inevitable extrusion beyond the apex. The case was therefore completed wtih the use of the Obtura syringe according to the sectional technique, after the removal of the gutta-percha extruded in the periapical tissues. **A**. Preoperative radiograph. **B**. Radiograph of the cone fit. Clinically, the cone presents a tug-back. **C**. Evidently, the tug-back was in the middle third. Once this point was overcome, the cone slid beyond the apex without however sealing the foramen. **D**. With a large barbed broach, the gutta-percha cone was immediately removed from the canal (continued).

Fig. 23.26. (continued) **E**. Postoperative radiograph following obturation with thermoplastic gutta-percha used according to the sectional technique. **F**. Two year recall.

Commercial gutta-percha is found in the "beta" molecular configuration at 37°C and begins to transform into the "alpha" configuration when heated to 42°-49°C. It then passes to an amorphous phase when heated to 53°-59°C.[137] During cooling, amorphous gutta-percha crystallizes (with a consequent diminution of volume) and returns to the "beta" configuration between 37°C and 40°C, without passing through the "alpha" configuration unless it cools slowly. In clinical situations, cooling of thermoplastic gutta-percha occurs rapidly; consequently, there is a diminution of volume in the recrystallization phase.[62] For this reason, it is important that vertical pressure be applied during cooling to compact the gutta-percha and compensate for its volumentric diminution.[138]

Recent studies in experimental animals[63,64] and in vitro[160] have not demonstrated any damage to the periodontal tissues. This confirms that even if the gutta-

Fig. 23.27. **A**. Preoperative radiograph of a lower right second molar requiring retreatment. **B**. Note the marked bayonette curvature of the mesiolingual canal. The apical third of this canal was cleaned and shaped only with # 08 and 10 K-type files. **C**. Postoperative radiograph. The distal and mesiobuccal canals have been obturated according to the Schilder's technique, while the mesiolingual canal has been filled with thermoplastic gutta-percha. **D**. Radiograph three years later.

Fig. 23.28. **A**. Preoperative radiograph of an upper right second premolar. The patient preferred surgical retreatment so as not to touch the prosthesis, although it was inadequate. **B**. Two years later. The canal has been cleaned, shaped and filled with thermoplastic gutta-percha by a retrograde approach. Amalgam retrofilling was then performed.

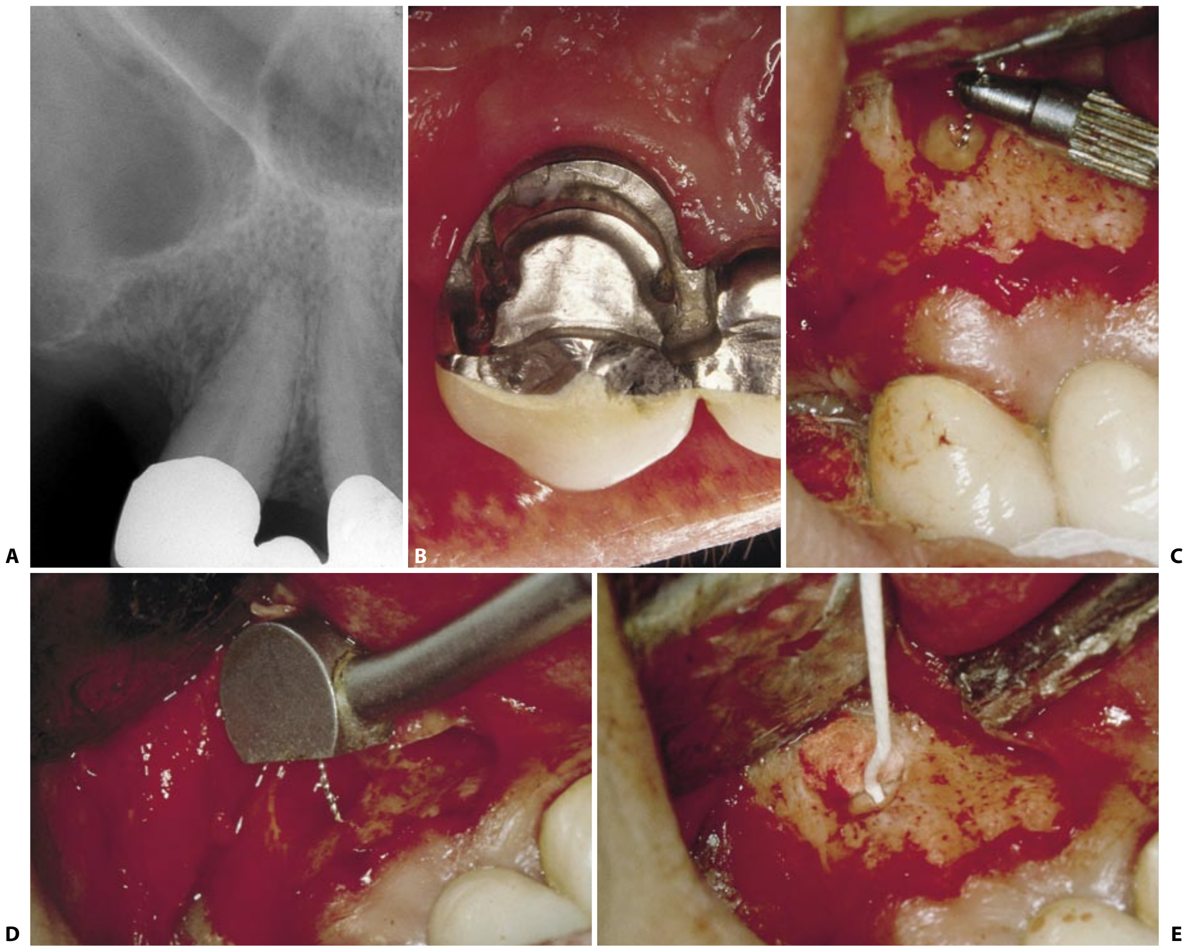
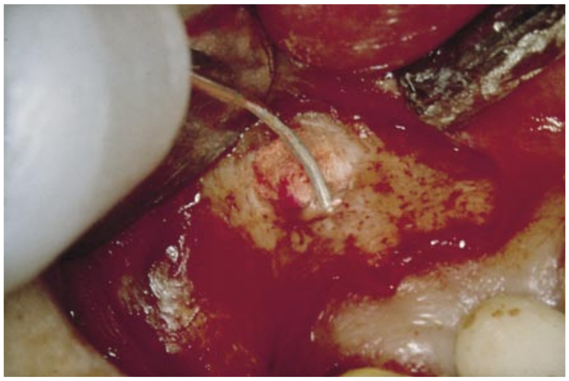
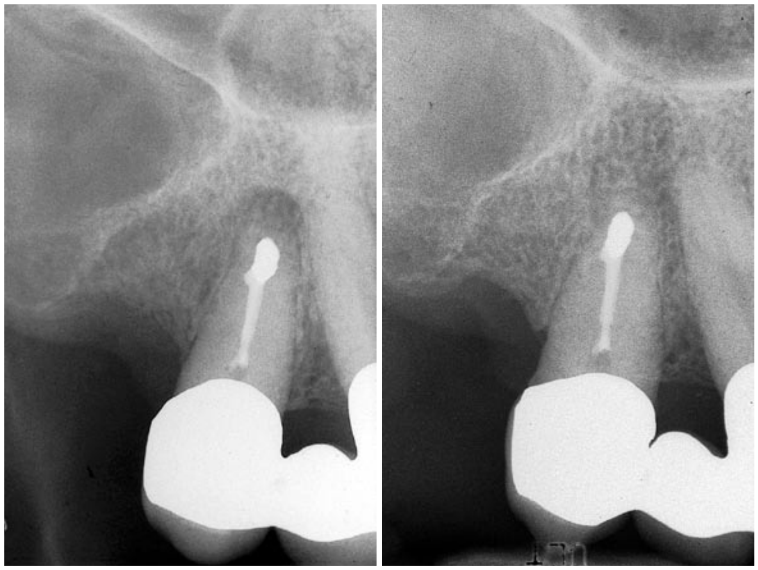


Fig. 23.29. **A**. Preoperative radiograph of an upper right cuspid with pulpitis. The onset of acute symptoms was one week following definitive cementation of the prosthesis. **B**. Palatal view of the prosthetic crown of the cuspid, on which the removable prosthesis is attached. Unable to perform an adequate access cavity, since this would have entailed destruction of the intracoronal attachment and then the need to remake the prosthesis, a surgical approach was chosen. **C**. A flap has been raised, and the root has been bevelled. The root canal is now cleaned and shaped with hand files. **D**. Cleaning and shaping is completed with ultrasonic instruments. **E**. The canal is dried with sterile paper points (continued).

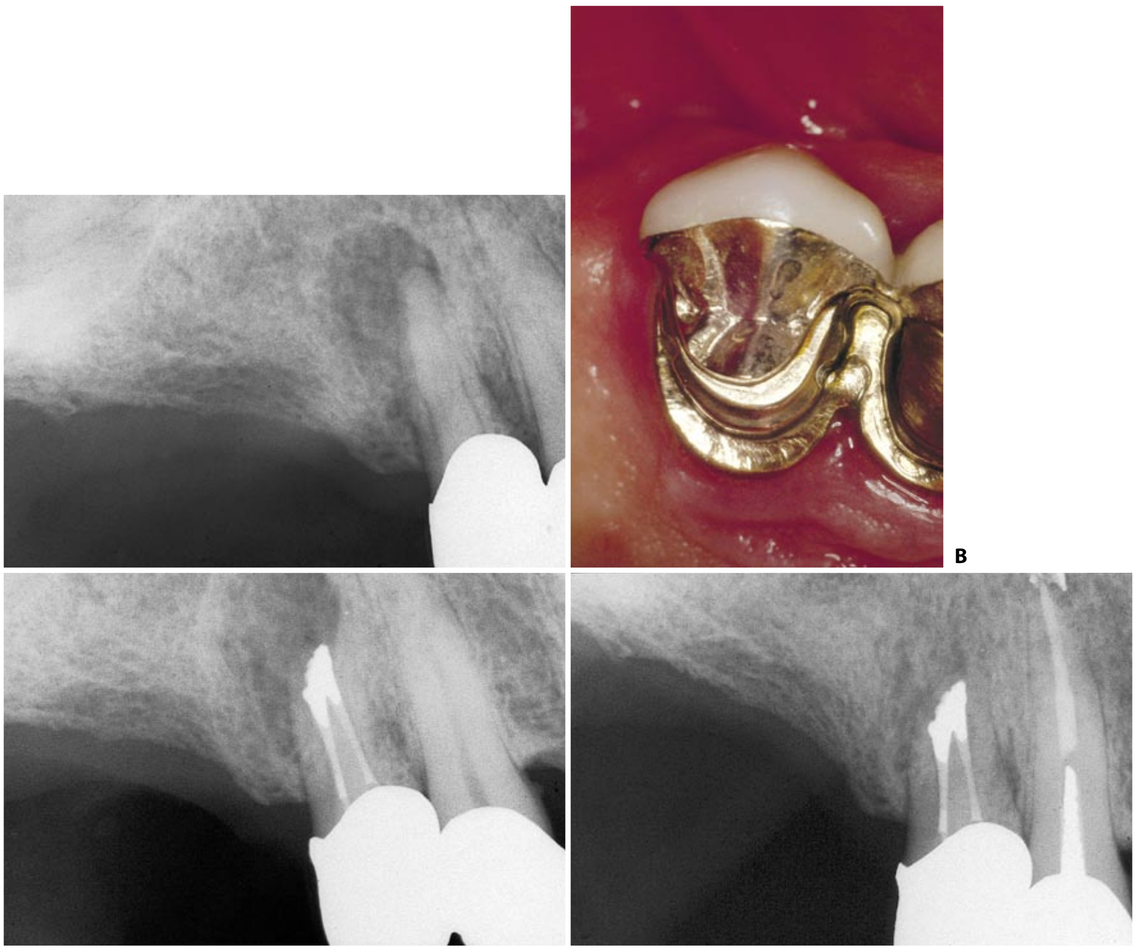


F

Fig. 23.29. (continued) **F**. After introducing a small amount of sealer, the canal is filled with thermoplastic gutta-percha. **G**. Postoperative radiograph. **H**. Recall radiograph ten years later.



G H



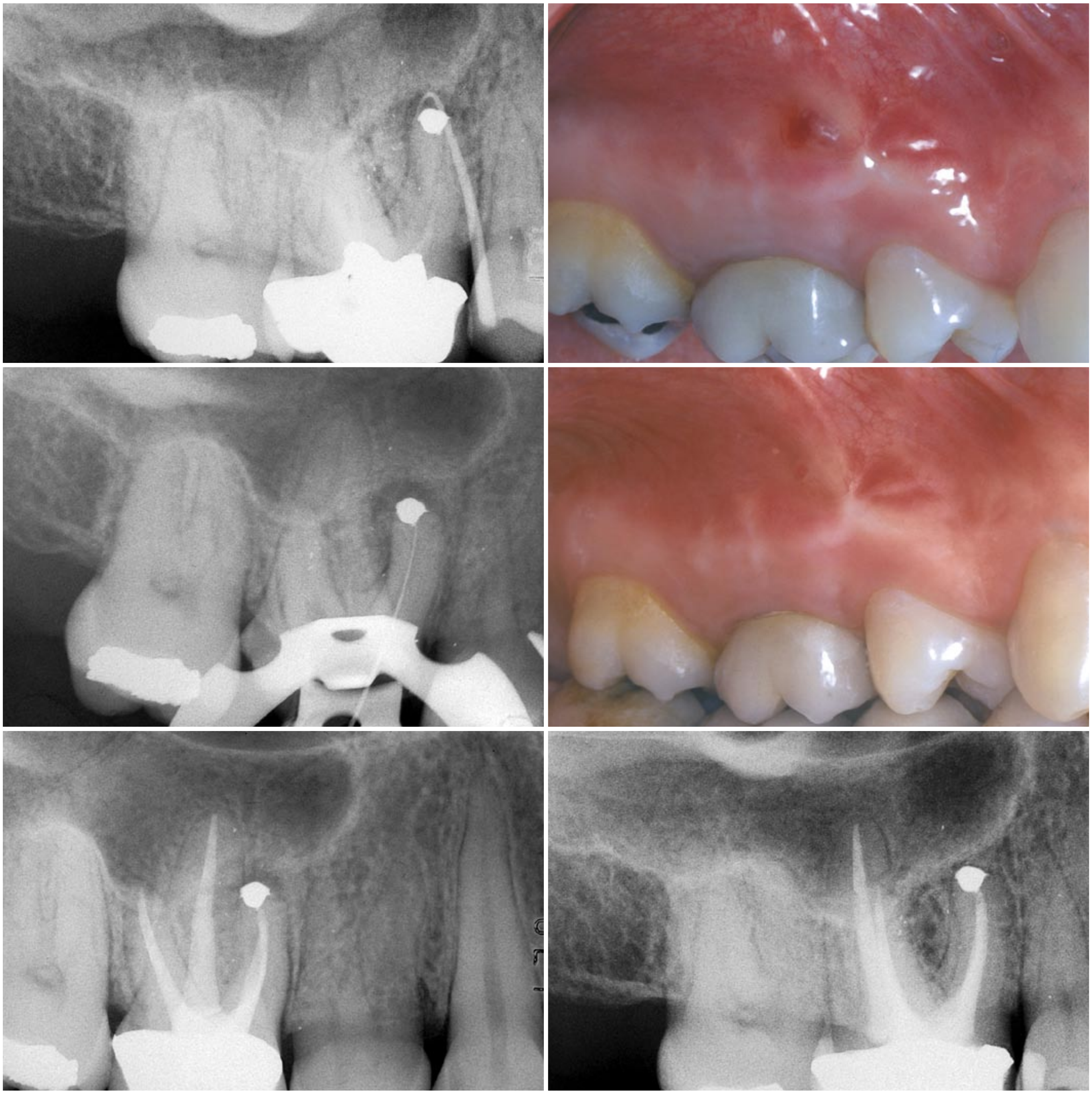
A B C D

Fig. 23.30. Retrograde endodontic therapy performed because it was not possible to perform a proper access cavity. **A**. Preoperative radiograph of an upper right first premolar with necrotic pulp and a periapical lesion. **B**. Occlusal view of the prosthetic crown of the premolar on which the removable prosthesis is inserted. So as not to destroy the complex intracoronal attachment and then so as not to have to revise the prosthesis, a surgical approach was chosen. **C**. Postoperative radiograph. The canals have been cleaned and shaped, first by hand, then by ultrasonic files, after which they were obturated with a small amount of sealer and thermoplastic gutta-percha. **D**. Recall radiograph three years later.

percha reaches high temperatures within the instrument, it is completely harmless once introduced in the root canal, where it rapidly cools.[40]

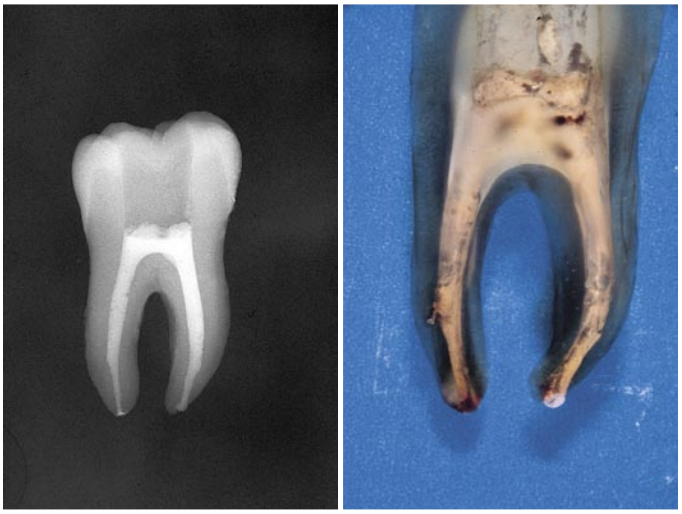
One last drawback, which has been alluded to already, is the ease with which voids form. For correct use of the technique, it is essential that the user's hand be driven coronally by the light pressure exerted by the gutta-percha as it accumulates in the root canal (passive injection) (Fig. 23.32).

Too steady application of force can cause the ma-



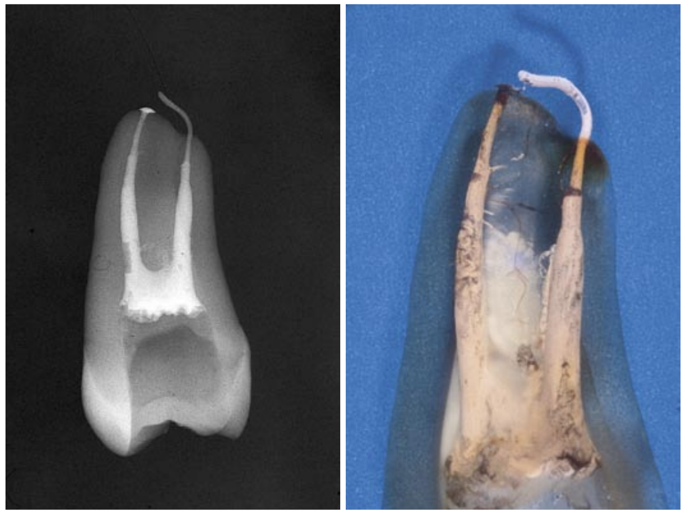
A B C D E F

Fig. 23.31. Non surgical retreatment of a surgical failure: the obturation of the mesiobuccal and mesiopalatal canals were made using the thermoplastic gutta-percha: the previous amalgam retrofilling was a perfect apical stop, and there was no risk of pushing filling material into the periapical tissues **A**. Preoperative radiograph of the upper right first molar: the gutta-percha cone is indicating the presence of a fistulous sinus tract. **B**. Clinical aspect of the fistula. **C**. Intraoperative radiograph. **D**. one week after cleaning and shaping the root canals, particularly MB1 and MB2, the fistula healed completely. **E**. Postoperative radiograph. **F**. Two year recall.



A B

Fig. 23.32. **A**. Radiograph of a lower first molar correctly obturated "*in vitro*" with thermoplastic gutta-percha. **B**. The same tooth after decalcification and clearing.



A B

Fig. 23.33. **A**. An excessive, too-steady force and a cylindrical apical preparation rather than conical are the causes of this excess obtained by obturating the canals with thermoplastic gutta-percha "*in vitro*". **B**. The same tooth after decalcification and clearing.

terial to issue beyond the apex (Fig. 23.33); on the other hand, if the technique is applied too timidly by withdrawing coronally too soon, enormous empty spaces will be left in the root canal (Fig. 23.34).

Another cause for voids formation is the injection of gutta-percha which is not warm and not plastic enough. Therefore, the suggestions to avoid entrapment of air inside the root canal are as follows.

– Before injecting inside the root canal, squeeze the gutta-percha out of the needle, so that the material introduced in the root canal will be the one which was previously inside the heating chamber and therefore will be warmer than that inside the needle.
– Insert the needle inside the orifice and wait a few seconds before injecting. The needle will have lost some heat after insertion, so it is necessary to wait until it is warm again, to keep the gutta-percha warm and fluid during injection.
– Inject small amounts of gutta-percha at the time to fill no more than five millimiters each time: one can only compact 5 mm of gutta-percha each time.
– Doing so, let the injected gutta-percha push ones hand coronally out of the canal, one must not pull ones hand out. Following all these precautions, will be very rare to have voids inside the root canal (Fig. 23.35).

A B

Fig. 23.34. **A**. A timid hand withdrew too quickly, causing the empty spaces that are visible in the canal of the mesial root. **B**. The same tooth following decalcification and clearing. The obturation had been performed "*in vitro*".

Recently, Michanowicz et al.[95] have introduced a device for the use of thermoplastic gutta-percha at a temperature of 70°C (Fig. 23.36). The instrument very much resembles the Peripress syringe for intraligamental anesthesia. It is loaded with carpules of gutta-percha with needles and then placed in a device that externally heats the carpule and the needle to 70°C.

The gutta-percha used in this case differs from other commerical gutta-percha by its much higher paraffin content. This contributes to rendering it malleable at a lower temperature than that required by the Obtura syringe. On the other hand, it is more difficult to compact.

Michanowicz et al.[96] have recently demonstrated in an S.E.M. study that this technique can even more suc-

Fig. 23.35. The extracted tooth has been treated during a hands-on course by a student. The root canal system has been filled with the Continuous Wave of Condensation Technique and the backfilling has been made using the Obtura Gun. After decalcification and clearing, the obturation appears to have no void.

Fig. 23.36. The Ultrafil syringe (Hygienic).

cessfully fill the dentinal tubules of the coronal and middle thirds of the canal with gutta-percha.

In contrast to the preceding instrument, which is ready for use one minute after being turned on and can remain on for the entire day, this one requires heating for as long as 15 minutes, and the syringe cannot remain inserted for more than four hours; otherwise, the physical properties of the gutta-percha are altered.[52] Furthermore, once the syringe has been removed from the heating device, it can be used for about one minute, after which the gutta-percha cools and no longer flows. Several minutes are required to re-heat it.

Furthermore, this instrument is not free of all the drawbacks already listed with regard to the other one, to which one may add the long waiting time before it is ready for use.

CHEMICAL SOFTENING OF GUTTA-PERCHA

This technique was described by Callahan[23] and Johnston[71] at the beginning of the century. It made use of chloroform to soften gutta-percha chemically to achieve obturation of the root canal system.

The technique has several drawbacks that cannot be ignored:

a) When the chloroform evaporates, the material undergoes a significant change in size on account of the extreme retraction, with consequent compromise of the apical seal.[165] If the root canal is filled with the chloropercha mixture alone, two thirds of the root canal will be empty once evaporation of the chloroform has occurred, since the creamy mix of chloropercha has a volume three times greater than the original material.[91]
b) One must be careful to avoid overfilling, because of the demonstrated toxicity of chloroform.[148]

Recent studies by the Food and Drug Administration[48,157] have demonstrated that chloroform is potentially carcinogenic. As a consequence, with the aim of eliminating its use by dentists, the Council on Dental Therapeutics of the American Dental Association[2] has decided to delete chloroform from *Accepted Dental Therapeutics*. Chloroform has been substituted with eucalyptol,[105] an organic solvent derived from the eucalyptus trees and the major constituent of eucalyptus oil.

Its local toxicity is much lower than chloroform, and it is used in medicine as a decongestant and rubefacient.[109]

Eucalyptol is also reported to have antibacterial action and antiinflammatory properties.[106]

TECHNIQUE OF WARM LATERAL CONDENSATION

This technique was introduced by Howard Martin[92] in 1987. It uses a special spreader whose tip is electrically heated so as to transmit heat to the gutta-percha while it is laterally condensed in the root canal (Fig. 23.37).

While the technique of lateral condensation is based on the pressure that only causes a stratification of the gutta-percha cones, the Endotec designed by Martin permits the coalescense and fusion of the various cones into a dense, homogeneous mass of gutta-percha,[28,84,85] (Fig. 23.38) with less stress for the dentinal walls[94] and a significantly simpler technique of execution.[12]

At present, there is not enough *in vitro* experimental literature or clinical documentation of this technique. After *in vitro* experimentation, Kersten[76] stated that the lateral condensation technique appeared to be markedly improved with the use of the Endotec, but also concluded that it was still unclear whether this technique would be useful in clinical practice.

Luccy et al.[86] have expressed a positive opinion following *in vitro* experimentation, as have Castelli et al.[24] after studies in experimental animals and Guldener[61] after clinical use.

The instrument has been recently modified.[93] The Endotec II is a new, advanced, endodontic condenser that incorporates several clinical benefits. The resistor has been placed within the body of the handle, allowing for a cost reduction in the condenser tip. The heating element temperature has been raised to ensure proper thermosoftening of the gutta-percha. The quick-change condenser tips are now autoclavable, and can provide an angle of canal insertion ranging from 90° to 180°. Furthermore, charged by two AA batteries inserted into the handle, the unit does not require recharging.

In this author's opinion, one can state without a doubt that the Endotec is a step forward, since it incontrovertibly proves that the "lateralists" have also realized that by softening the gutta-percha with heat and subjecting the mass thus obtained to pressure (vertical and/or lateral) one obtains better results!

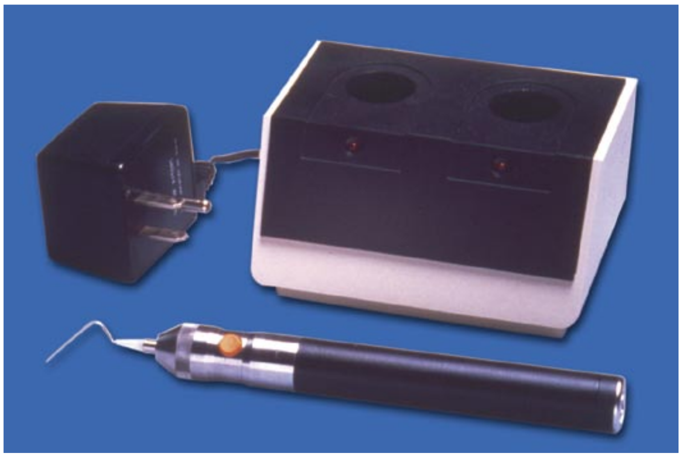


Fig. 23.37. The Endotec (Caulk).

THE ENDOTWINN

Recently a new device has been developed for both warm lateral and vertical condensation, called the EndoTwinn (MDCL N.V. Corporation, Amsterdam) (Fig. 23.39). In this new device, the possibility of application of heat and vibration are combined.

The EndoTwinn system comes with one rechargeable cordless handpiece (Fig. 23.40) and several pluggers (Fig. 23.41) for compacting, softening and cutting

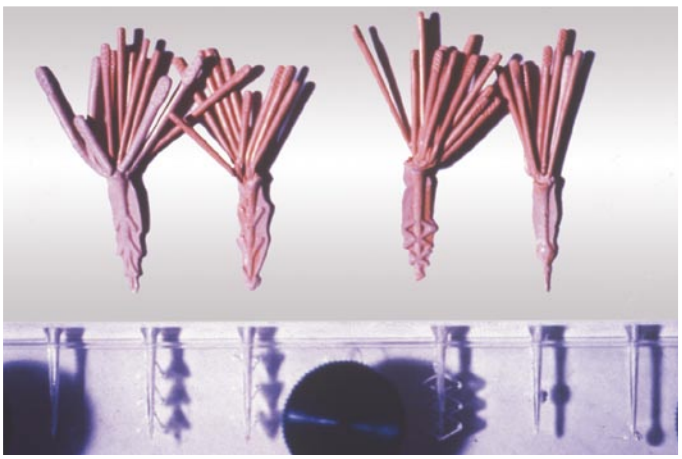


Fig. 23.38. The plastic blocks have been obturateed with warm lateral condensation: note the compact filling and, on the other hand, the large number of gutta-percha cones which have been used to achieve this result!

Fig. 23.39. The EndoTwinn (MDCL N.V. Corporation, Amsterdam).

Fig. 23.40. The EndoTwinn handpiece.

Fig. 23.41. The EndoTwinn tips.

gutta-percha points. The pluggers are available in the standard serie with 0.5 mm diameter and a range type F, FM, ML, and L, and in the Ultrasoft serie, which can be easily pre-bend before entering the root canal. For narrow and curved canals another tip is available with 0.3 mm tip diameter and .04 taper.

The kit includes also a particular "tip spoon" specifically designed for cutting plastic carriers.

The tips can be used with and without vibrations. The combination of heat and vibrations seems to give the best results. The difference in results between the EndoTwinn heat and EndoTwinn heat and vibration has to be explained by the vibration function. We already know that ultrasound has a positive effect on the adaptation of gutta-percha, however we do not have any other information of the effect of low frequency vibration. Probably the low vibration in combination with the heat is enough to give the gutta-percha more flow properties which results in a higher value of percentage of gutta-percha.

At present, there is not enough in vitro experimental literature or clinical documentation on this technique, however the instrument seems to be very promising.

ADHESIVE ENDODONTICS: RESILON

Rich Mounce, DDS, Gary Glassman, DDS, FRCD(C)

The surgical operating microscope and the advent of rotary nickel titanium instrumentation have both provided a quantum leap forward towards a higher standard of endodontics. Adhesion has done much the same for restorative dentistry. Blending the best of adhesion into endodontic obturation has now become reality. In the authors' opinion, adhesion in canal obturation represents another quantum leap forward for the specialty.

Recently, Resilon Research LLC, (Madison, CT) has introduced Resilon obturating points (a soft resin) and resin sealer which when used in combination with a self etch primer after smear layer removal, allow creation of a solid "monoblock" (a material which is contiguous from its resin tags in cleared dentinal tubules through sealer to the core canal filler). The material not only fully obturates canal anatomy (especially through the compaction possible with warm obturation techniques); it diminishes coronal microleakage through bonding to the cleared dentinal tubules. Resilon Products (RP) are marketed as RealSeal™ (SybronEndo, Orange, CA). and Epiphany (Pentron, Wallingford, CT) (Figs. 23.42 A, B). The authors experience is with the RealSeal brand and will reference it throughout the report. It is hard to overstate the advance that this represents relative to gutta-percha.

Gutta-percha, despite its many advantages (non toxic, biocompatible, thermoplastic and retreatable) and status as a time honored standard for endodontic obturation possesses one significant limitation. Gutta-percha cannot prevent coronal microleakage which places

Fig. 23.42. **A.** Resilon™ and Epiphany Sealer™ (R/E) (Resilon Research LLC, Madison, CT). **B.** RealSeal™ (R/S)(SybronEndo, Orange, CA).

the entire procedure at risk in the event of recurrent caries or subsequent microleakage if either the patient does not have the tooth restored or the subsequent restoration is not satisfactory (and microleakage occurs). Gutta-percha (with or without sealer) provides a relatively poor to non existent barrier to prevent the coronal to apical migration of bacteria after obturation as gutta-percha (with and without sealer) does not bond to canal walls, it can only adapt[7,29,129,154] (Fig. 23.43). In addition, even if the standard of endodontic therapy is excellent, a lack of coronal seal or recurrent decay significantly diminish the possibilities for endodontic success over the long term as bacteria can migrate in a coronal to apical direction and initiate failure. Ironically, coronal seal is a major indicator of the potential for endodontic success or failure aside from the quality of the endodontic treatment or the presence of gutta-percha.[120,149] As a result, gutta-percha has been more of a "filler" that took up space within the root canal system. While imperfect, gutta-percha has been the best material clinicians have had up to this point in time.

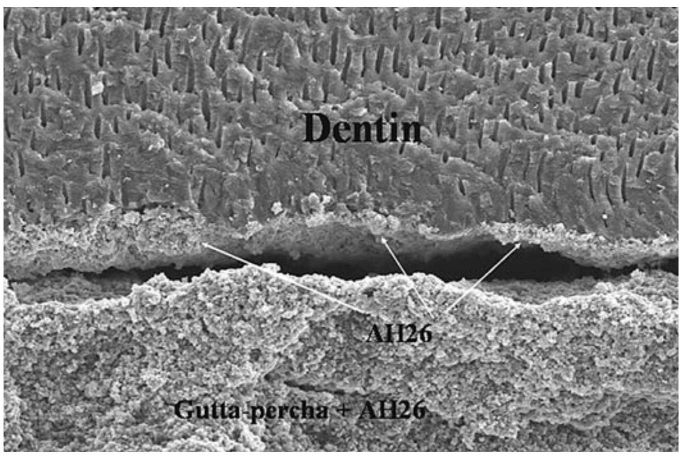


Fig. 23.43. Gap present between gutta percha and AH 26 sealer (x650).

These significant limitations are overcome by RealSeal. By removal of the smear layer (Figs. 23.44 A, B), produced during instrumentation, it is now possible to bond the obturating material into the dentinal tubules and create (as mentioned above) a "monoblock" of resin sealer and resin core filling material (Figs. 23.45 A, F). The root canal system can now be sealed to some degree (technique and clinician dependent) along the entire length of the canal (from orifice to apex) preventing microbial migration.

One strategic advantage that this gives the clinician is that if the patient does not get a coronal restoration as they should (assuming that the treatment has been performed correctly), Resilon is significantly resistant to leakage along its length and one of the key factors responsible for endodontic failure has been eliminated or dramatically reduced.

A recent study by Shipper et al.[142] found that comparing bacterial leakage using Streptococcus mutans and Enterococcus faecalis through both gutta-percha and Resilon over a 30 day period demonstrated that Resilon showed minimal leakage which was statistically significant compared to gutta-percha. In essence, now, Resilon endodontic obturating material can significantly diminish microleakage, a property not possessed by gutta-percha.

RealSeal is a thermoplastic synthetic resin material based on the polymers of polyester and contains a difunctional methacrylate resin, bioactive glass and radio opaque fillers.

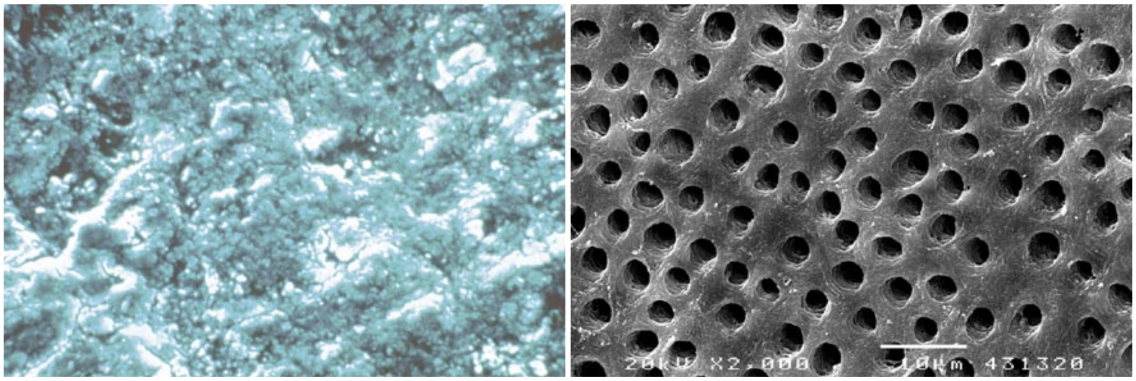


Fig. 23.44. **A**. Smear layer produced by instrumentation before removal. **B**. Smear layer removal with SmearClear™ (SybronEndo, Orange, CA).

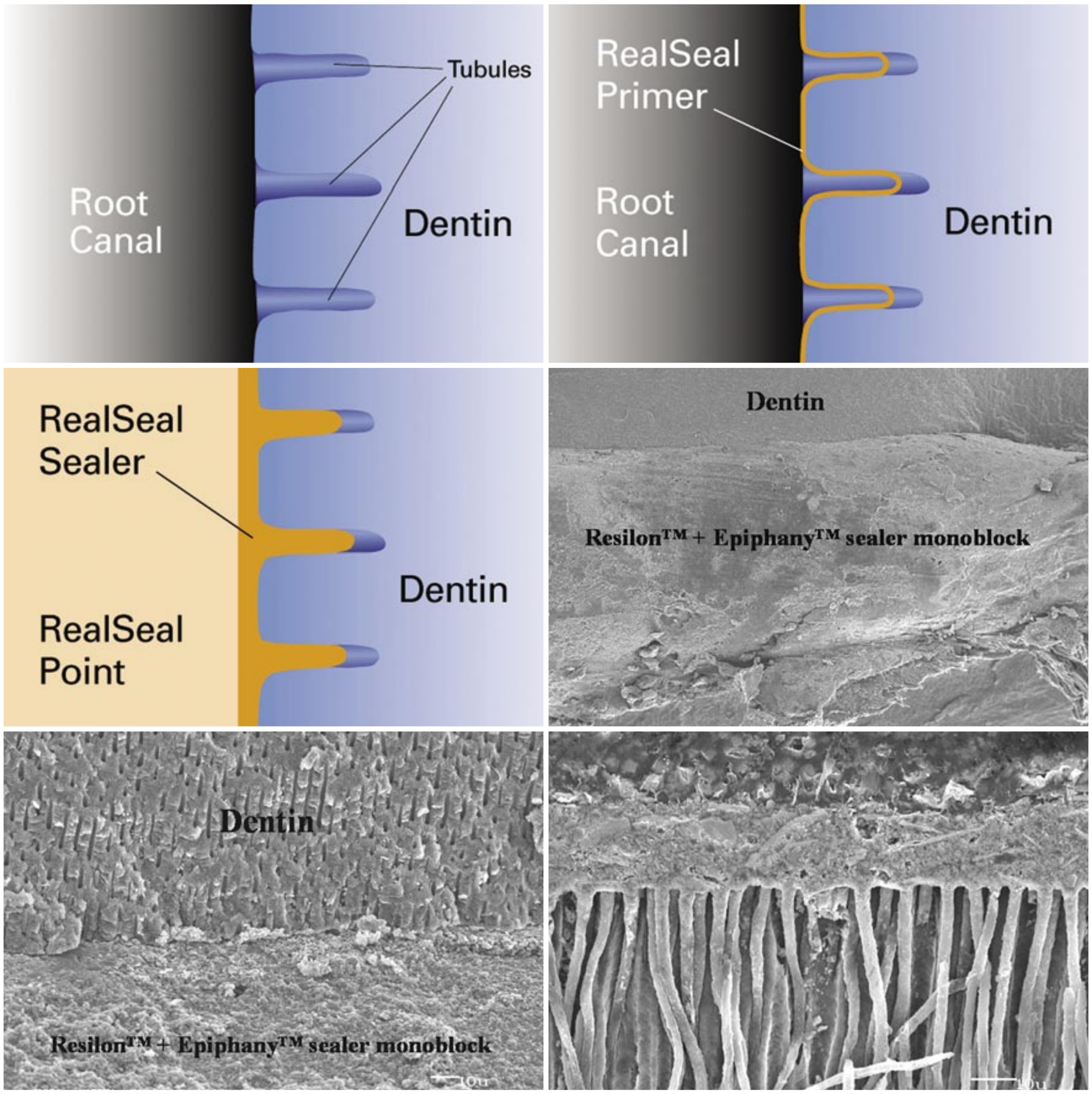


Fig. 23.45. **A**. Graphic illustration of dentinal tubules after smear layer removal. **B**. Graphic illustration of Resilon primer penetration. **C**. Graphic illustration Resilon sealer penetration and Resilon point creating a monoblock of resin. **D**. Resilon"monoblock" (x40). **E**. Resilon"monoblock" (x650). **F**. Sealer tags and Resilon (x1,000).

RealSeal sealer contains UDMA, PEGDMA, EBPADMA and BisGMA resins, silane treated barium borosilicate glasses, barium sulfate, silica, calcium hydroxide, bismuth oxychloride with amines, peroxide, photo initiator, stabilizers and pigment.

RealSeal Primer is an acidic monomer solution in water. RealSeal is non toxic, FDA approved and non mutagenic. With its radio opaque fillers, RealSeal is a highly radio opaque material. The sealer is resorbable.

Aside from its capacity to be thermoplasticized, RealSeal can be dissolved with chloroform and retreated. There are unsubstantiated statements on the internet that RealSeal shrinks substantially less than gutta-percha but this fact cannot be verified from the literature at this time.

One remarkable feature about RealSeal is that in virtually all handling characteristics, it handles and feels like gutta-percha. In other words, it can be used with all the common present forms of endodontic obturation (vertical compaction of warm gutta-percha, cold lateral condensation, lateral/vertical combinations) and there is virtually no learning curve to its use. This allows the clinician to use this new technology with only two added steps relative to common endodontic treatment regimens, clearing the smear layer and placing the self etch primer.

Between then, RealSeal points are available in introductory kits of various configurations and as individual components (.02, .04, .06 tapered cones with a variety of tip sizes along with accessory points ranging in size from x-fine to large). RealSeal cones are very flexible and pellets of the material are available for the Obtura gun (Spartan Obtura, Fenton, MO). At present, no carrier based product exists that possesses Resilon technology and none is on the horizon to the authors knowledge.

Because root canal therapy removes some amount of dentin within the tooth, the potential exists to weaken the tooth to some degree and make the tooth more susceptible to vertical root fracture. Gutta-percha has no potential to strengthen the roots after treatment. RealSeal in contrast has the potential to strengthen roots. In vitro, Teixeira, et al.[150] found that the resistance to root fracture found with Resilon was superior (P=0.037) to gutta-percha/AH 26 sealer (Dentsply Maillefer) using both lateral and vertical condensation. In essence, Resilon used in the manner tested increased the fracture resistance of single canal endodontically treated teeth as compared to other common gutta-percha techniques. While this might be considered a secondary benefit as compared to its potential to reduce coronal to apical leakage of bacteria, it is not in any way inconsequential.

Clinical technique

Canal preparation

The canal is prepared with the protocol normally used. Canal preparation techniques do not need to be altered to facilitate the use of the material.

Smear layer removal

Throughout the entire instrumentation protocol an alternating sequence of 17% EDTA and sodium hypochlorite must be used to remove the smear layer.

The smear layer is the layer of organic and inorganic debris that is created along the walls of the canals during instrumentation. While 17% liquid EDTA can be used as a final canal rinse, the authors recommend SmearClear (SybronEndo, Orange, CA) as a final rinse where the liquid is allowed to soak into the tubules throughout the entire canal system for 1-2 minutes. SmearClear contains surfactants which enhance wetting of the canal walls and provide optimal smear layer removal.

It is important not to use either sodium hypochlorite or absolute alcohol as the final rinse to dry the canal after the smear layer is removed. Sodium hypochlorite will disrupt the sealer bond and absolute alcohol will act as a drying agent. The walls need not be completely dry as the sealer is hydrophilic.

Placement of the primer

After the canal is dried with paper points, a brush provided by the manufacturer can be used to bring the self etch primer into the coronal third of the canal. Alternatively, a paper point of an appropriate taper can be super saturated with the adhesive that has been introduced into a plastic bonding well. The primer should be dispersed evenly on the canal walls yet not extrude apically. Under a surgical operating microscope, one may see if any primer remains in the canal or if the excess has been removed.

Mixing of the resin sealer

Next, the dual syringe (containing the sealer) is used to express the sealer onto the mixing pad. The dual syringe has tips, which mix the sealer as it is expressed. As an aside, it is possible to forgo the use of the mixing tip provided in the kits and hand mix the sealer with a spatula (express a small amount of both sealer components onto the pad without the mixing tip) and save a significant amount of sealer from every dual syringe although the mixing tips eliminate one step relative to hand spatulation.

Cone fit (See Chapters 24 and 25) and placement of the sealer can be performed as per the clinician's present technique. While preferred methods for sealer placement vary widely, the authors are not in favor of use of a lentulo spiral to introduce sealer of any type and this personal preference extends to the resin sealer used with RealSeal due to the unwarranted risk of apical extrusion as well as potential for lentulo separation.

Obturation

The root canal system is then obturated by any preferred method (lateral, warm vertical or System B (Fig. 23.46) (see Chapters 24, 25). Resilon™ pellets for the Obtura III delivery system are available for back-filling techniques.

Backfilling

The Obtura III™ (Obtura/Spartan, Fenton, MO) thermosoftened injection molded delivery system is used to backfill the canal space at a temperature of between 150°C-175°C. A 23 gauge applicator tip is suitable for most root canals. A thin layer of sealer is applied to the root canal walls with a paper point before backfilling. The applicator tip is placed into the root canal space until it penetrates the coronal aspect of the apical plug of RealSeal. A bolus of 5 to 6 mm of RealSeal is then deposited (Fig. 23.47). As thermosoftened RealSeal is extruded from the applicator tip, the viscosity gradient of the back pressure produced will push the tip coronally from the root canal space. The technique sensitivity requires that when this sensation occurs, the operator must sustain pressure on the trigger mechanism as the applicator tip moves from the canal. The prefit hand condensers are then used in sequence to maximize the density and homogeneity of the compressed resilon mass. This sequence of thermosoftened resilon injection and progressive compaction is continued until the obturation of the entire root canal space is achieved .

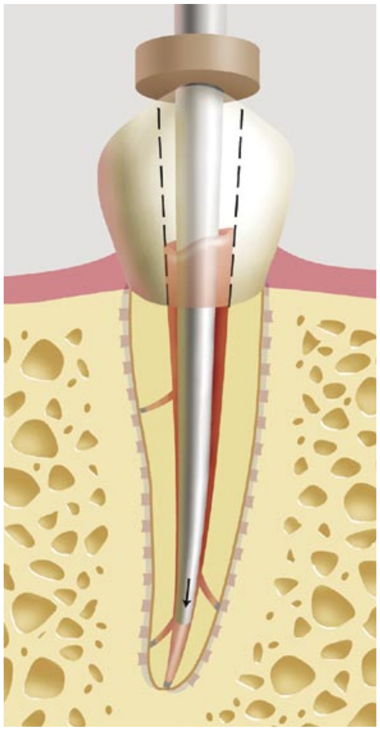


Fig. 23.46. The down-packing has been completed with the System B.

Post preparation or curing the coronal third

If required, a post space may be prepared at the time of obturation only after the canals are first filled to the level of the orifices. If any lateral/accessory canals and/or dentinal tubules have not been sealed during the down pack, perhaps they may be sealed on the back fill.

If post space needs to be prepared after the material has set up and the monoblock created, ideally, a small amount of chloroform can be introduced and the RealSeal dissolved to the desired depth in the canal and post preparation accomplished.

A curing light can also be used to help cure several mm of the material in the coronal third and the material will self cure within 1 hour.

Empirically, the authors have found the transition from gutta-percha to RealSeal to be virtually seamless and without a learning curve and are using this material exclusively. The added step of placing the primer is virtually negligible with regard to the amount of time it takes in the context of the entire procedure and the benefits derived. (Figs. 23.48 A-D)

With certainty, this material will be extensively studied, tested and reported in the literature in the years to come. Technique nuances with regard to its handling and creation of the greatest possible efficiency in its use may emerge. This said, in the authors' opinion, over the next decade, as studies in all probability will continue to validate this material, it is very possible that gutta-percha will become obsolete until another material can be found which will give greater clinical benefit with less patient risk than RealSeal. In the authors' opinion, this material truly is a quantum leap forward in the modern era of endodontics and worthy of consideration for use as an obturating material in place of gutta-percha.

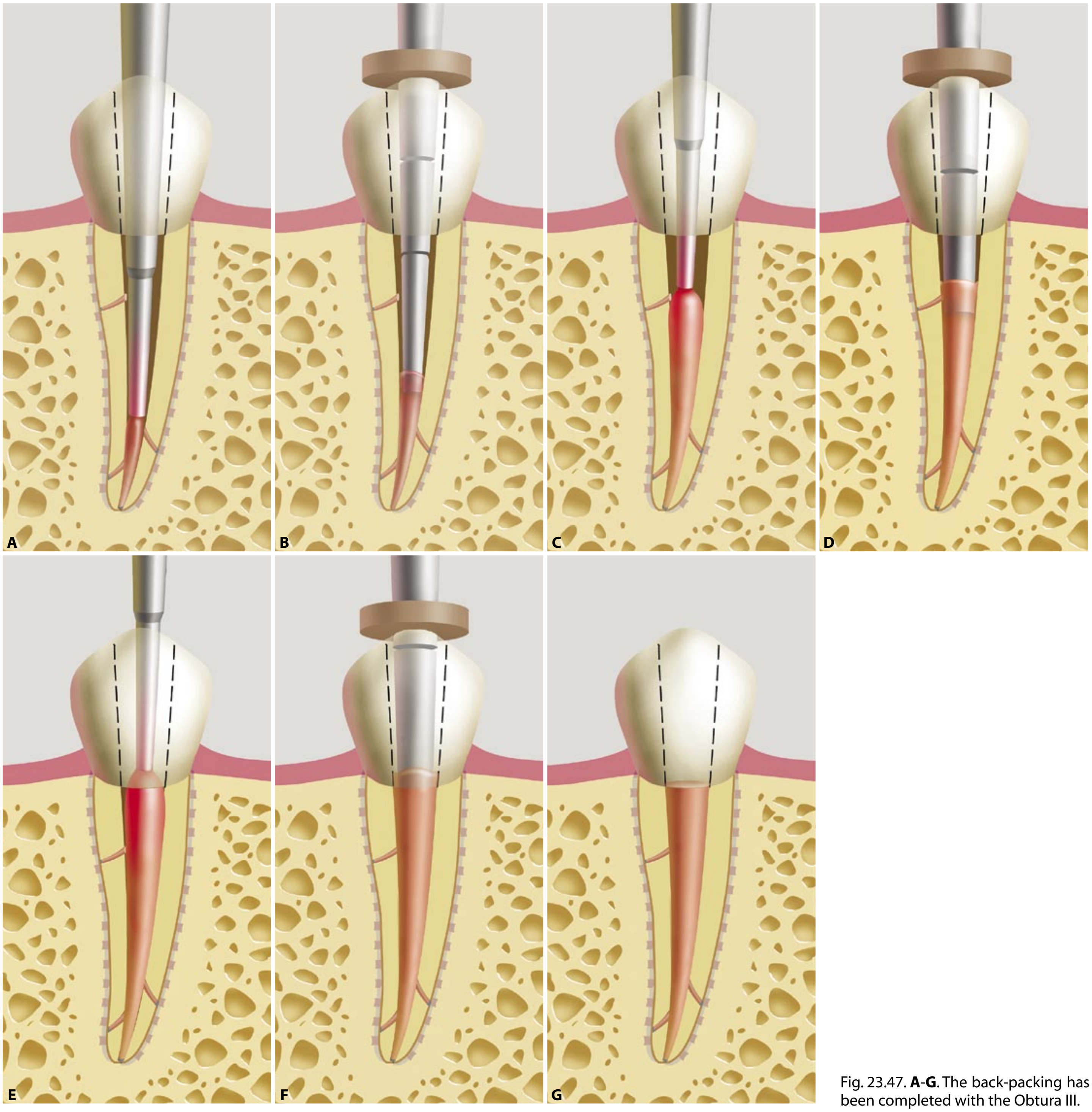


Fig. 23.47. **A**-**G**. The back-packing has been completed with the Obtura III.

Fig. 23.48. **A**-**D**. Clinical RealSeal cases. Compaction and handling characteristics of RealSeal are virtually identical to gutta-percha.

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24

The Schilder Technique of Vertical Compaction of Warm Gutta-Percha

Arnaldo Castellucci

Many endodontists are convinced that they must know several techniques of canal obturation, since each technique is indicated in certain situations, but not others.

Nguyen Thanh Nguyen[33] is of this opinion. He states: "to be married only to one obturation technique or material is to limit one's ability to undertake a diversity of complex cases".

Frank, Simon, Abou-Rass, and Glick[15] are also strongly convinced that there can be no single, rigid obturation technique that can meet all endodontic needs.

Franklin Weine[56] takes the same view. He discusses the various techniques of gutta-percha use, emphasizing that vertical compaction is to be preferred in certain, well-defined cases, namely "when the fitting of a conventional master cone to the apical portion of a canal is impossible, as when there is a ledge formation, perforation, or unusual canal curvatures, internal resorptions, or large lateral canals. The vertical compaction method then affords the operator a chance to achieve success in a case that might fail if any other kind of treatment were used".

It is interesting to note that those who share these opinions have adopted the "lateral condensation technique", yet to achieve success even in difficult cases, feel the need to make use of techniques which require heat softening and vertical compaction. The converse does not occur: those who are conversant with the technique of vertical compaction never need to resort to the lateral condensation technique to resolve easy cases...

The vertical compaction technique of warm gutta-percha, conceived and described by Schilder[43] in 1967, combines a reasonable ease of execution with maximal efficacy in obturating both simple and more complex canals.[46]

Just as one vertically compacts the plastic amalgam within a first-class cavity, gutta-percha softened by heat is vertically compacted into the conically shaped canal preparation.

ARMAMENTARIUM

Without a doubt, the instruments used in this technique for compacting the gutta-percha are similar to amalgam compactors. However, they differ in being longer and thinner, since the cavity in which they must work is longer and thinner.

These instruments are referred to as compactors or "pluggers" (Fig. 24.1). Serrations at five millimeter intervals help to know the working depth of the various instruments. In contrast to the lateral condensation technique, in which the spreaders touch the dentinal walls in order to make space for the auxiliary cones, in vertical compaction the metal instruments never touch the canal walls, but are only sunk into

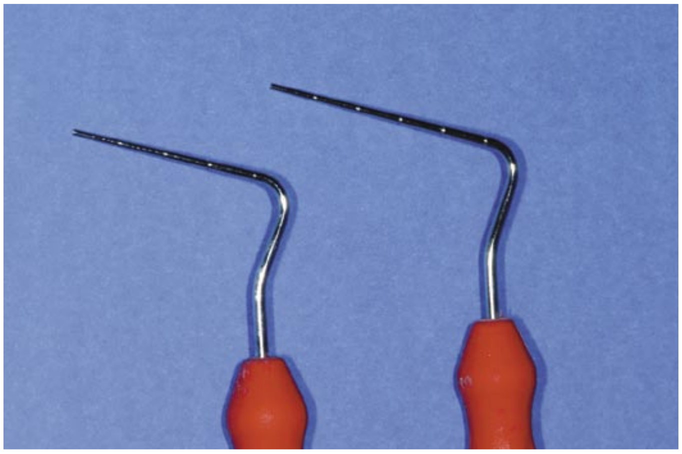


Fig. 24.1. On the left, a plugger of the "Posterior" series, for teeth of 25 mm or less. On the right, a plugger of the "Anterior" series, for teeth of 30 mm.

the mass of previously heated gutta-percha. The serrations on the surface of the pluggers are specifically made to control the working depth and to prevent them from coming into contact with the dentin.

The other instrument that this technique calls for is the “heat carrier” (Fig. 24.2). This is nothing more than a spreader; however, it is not used cold to create space among the cones, but rather warm to deliver heat to the gutta-percha cone in the root canal.

With this technique, it is therefore not correct to speak of “spreaders”, but of “heat carriers”, although the two instruments are completely identical.

Both the compactors (pluggers) and heat carriers are available in a long (30 mm) and a short (25 mm) series. Instruments of the long series are usually (Dentsply, Maillefer), marked by the letter “A” (Anterior), those of the short series by the letter “P” (Posterior). In clinical practice, the short series is routinely used, for both the posterior and anterior teeth, while the long series is only used in exceptionally long teeth (e.g., 30 mm canines).

The pluggers are available in a graded series of working end diameters, ranging from 0.4 to 1.5 mm. They are distinguished by a conventional numbering system from 8 to 12 with half sizes (Fig. 24.3), so that a number 8 has a diameter of 0.4 mm at the working end, an 8½ of 0.50 mm, and so on for a total of 9 instruments (Tab. I).

Table I

Correspondence between instrument numbers and tip diameter

# plugger	diameter (millimeters)
8	0.40
8½	0.50
9	0.60
9½	0.70
10	0.80
10½	0.90
11	1.10
11½	1.30
12	1.50

Thus, a wide assortment of pluggers is available to operate in root canals of any size. It is advisable to have the complete series in the office, even though proper execution of the technique never requires the use of all 9 instruments. Usually, 3 or at most 4 are sufficient.

The heat carrier is also available in two different calibers, designated “O” (larger) and “OO” (thinner). In this technique, heat can be supplied by the flame of a Bunsen burner. Alcohol burners are not recommended, since the heat they provide is inadequate. After many years a flameless heat source is commercially available, like the Touch’n Heat. These electric devi-

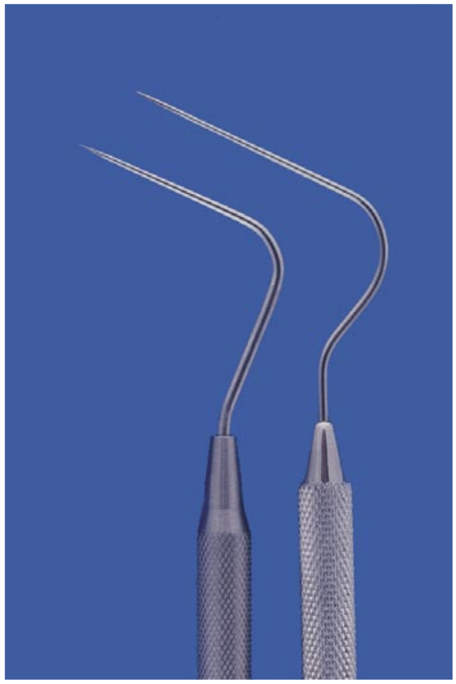


Fig. 24.2. The heat-carrier is identical to the spreader used in the lateral condensation technique. On the left, an OP heat-carrier. On the right, an OOP heat-carrier, which is thinner.

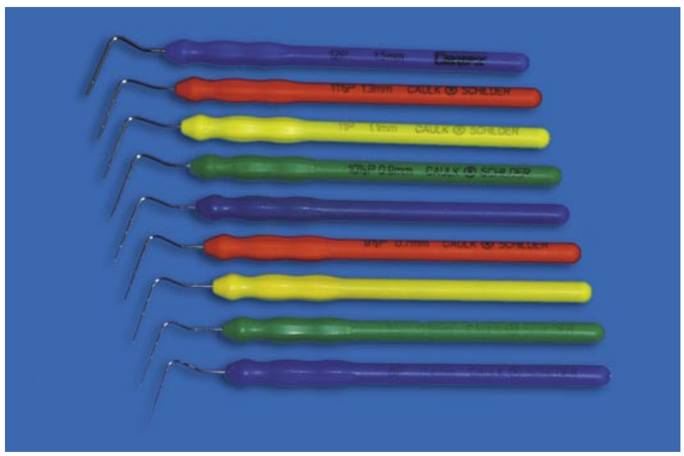


Fig. 24.3. The complete series of 9 pluggers Posterior.

ces have wires that attach to the back of the instrument (Fig. 24.4).

The technique is essentially the same. The endodontist must choose one type of heat carrier or the other.

The particular advantages of the electric device to the gas burner are: better control of the amount of heat transmitted into the root canal to soften the gutta-percha, greater control of the amount of gutta-percha removed at each application of heat, and greater speed. Heating of the heat carrier is instantaneous, while the gas burner always requires several seconds.

GUTTA-PERCHA CONES

As already indicated, the gutta-percha cones indicated for this technique are the tapered ones. Although they have the same chemical composition as the so-called standardized ones, they are more conical and thus provide a larger amount of gutta-percha on which to exert vertical force with the working surface of the pluggers. The sizes most commonly used are "fine", "fine-medium", "medium" and "medium large" (Fig. 24.5).

SEALER

A very small amount of sealer is necessary to ensure better adaptation of gutta-percha to the canal walls. It has already been explained that the sealer represents the weakest part of the filling material, which therefore must be entrusted as much as possible to the gutta-percha. For this reason, the ideal sealer for this technique is the one which can be spread onto the canal walls as a microfilm a few microns in thickness.[45,55]

Many of the endodontic sealers commercially available can be used, as long as they meet these requirements: they must be inert, biocompatible, non shrinking, and non resorbable.

A study by Weiner and Schilder[57] has shown that there is a strict relationship among the sealer's setting time, its resorbability, and its shrinkability: the longer the setting time, the more easily the sealer will shrink and be resorbed. The sealers that appear to be the least affected are the Pulp Canal Sealer (Kerr), which has a relatively short setting time (Fig. 24.6 A), and the Pulp Canal Sealer E.W.T. (Kerr), which allows an easier manipulation thanks to its extended working time (Fig. 24.6 B).

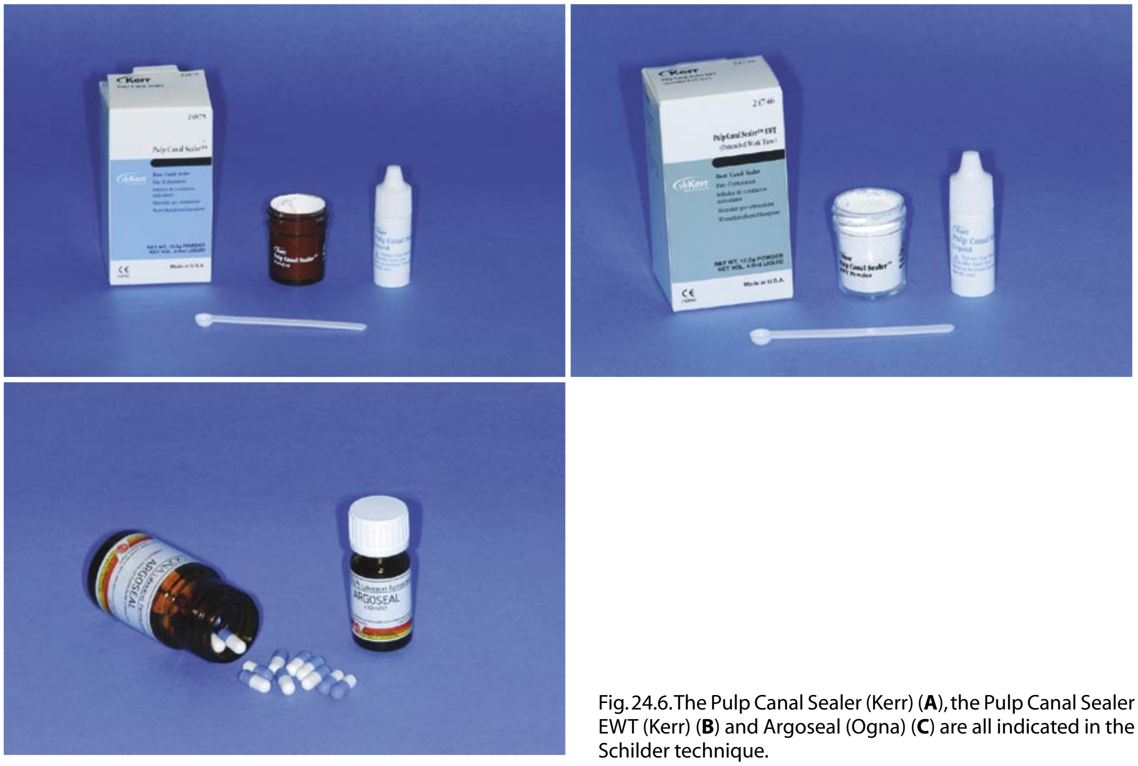
The composition of this sealer, in Rickert's 1931 formulation, is:[25]

Silver	24.74%	
Zinc oxide	34.00%	
Thymol iodide	10.55%	powder
Oleoresin	30.71%	
Eugenol	78.00%	
Balsam of Canada	22.00%	liquid

Comparable results can be obtained with Argoseal (Ogna), whose formula is very similar. Its physicochemical characteristics and biocompatibility are identical, and its slightly longer setting time allows great manageability (Fig. 24.6 C).

Fig. 24.4. The "Touch 'n Heat" heat carrier by Analytic.

Fig. 24.5. Non-standardized Fine, Fine-Medium, Medium and Medium-Large gutta-percha cones are most commonly used in the vertical condensation technique.



A C B

Fig. 24.6. The Pulp Canal Sealer (Kerr) (**A**), the Pulp Canal Sealer EWT (Kerr) (**B**) and Argoseal (Ogna) (**C**) are all indicated in the Schilder technique.

The powder of the Argoseal cement (Ogna) is composed of:

Silver	30.00%
Zinc oxide	41.21%
Thymol iodide	12.79%
White resin USP	16.00%

SELECTING THE RIGHT TIME FOR THE OBTURATION

Once cleaning and shaping of the root canal system has been completed, one may proceed to the obturation procedure when the following requirements are fulfilled:

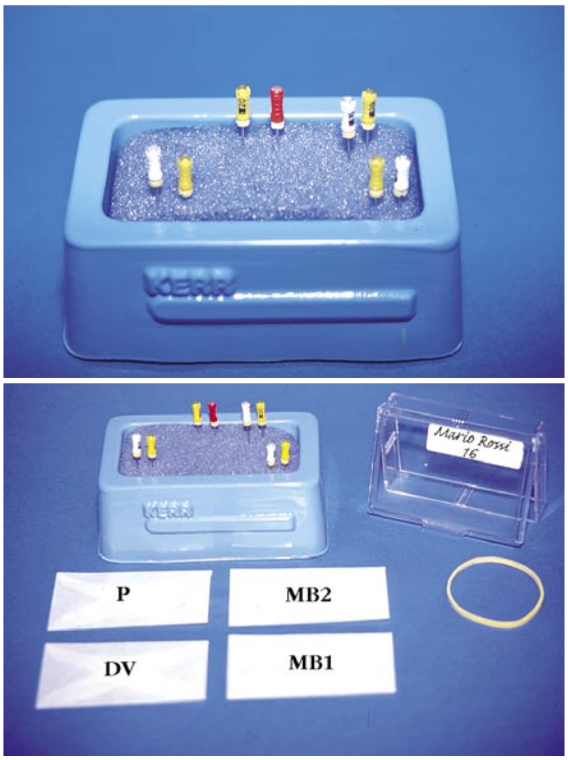
- The tooth must be asymptomatic. There must be no pain on apical palpation or on percussion, and the patient must feel perfectly comfortable.
- The canal must be dry or, at any rate, easily dried with absorbent sterile paper points. Canals with very wide apices or large, cystic lesions can cause serious problems during drying of the canal. This may even preclude complete drying of the canal, a sine qua non for proceeding to obturation. In such cases, it is advisable to perform a temporary filling of the root canal with calcium hydroxide paste and re-check the tooth after several days or weeks.
- There must be no fistula. If one was not present before, it must not have developed in the interim; if one was present at the beginning of treatment, it must have completely resolved.
- There must be no foul odor, which would indicate the presence of bacteria that have either persisted in the canals or have entered them because of inadequate sealing of the temporary cement.
- If the root canal has been shaped in a previous visit, the temporary cement must be intact, since compromise is a certain sign of canal contamination.
- In the past, another requirement given great importance was a negative bacterial culture. Today, bacterial cultures are obtained less frequently.[31] Bacterial growth occurs only in the presence of substrates in the canal, but if the canal is completely free of such protein degradation products, bacteria cannot reproduce. Performing bacterial cultures does not determine the success of the therapy, nor does not performing them lead to failure. Clinical experience demonstrates that cultures and medications play an insignificant role in the final outcome of treatment. In Endodontics, bacterial culture should therefore be considered a purely psychological comfort and a suggestive ritual,[11] which is no longer used.

PREPARATION OF THE TRAY

Before proceeding with obturation, the dental tray must have (Fig. 24.7):

– The complete series of pluggers, to which rubber stops have been attached for ease of use and better regulation of the working depth (Fig. 24.8).
– A dappen dish containing sodium hypochlorite in which several cones of the sizes felt to be necessary are sterilized for at least one minute.
– The syringes full of irrigating solutions for the final irrigation.
– A pure-alcohol-moistened sponge into which the assistant places the last instruments at the working length of the canals of the tooth in question. The assistant must make certain to position them just as the canals openings appear in the pulp chamber (Figs. 24.9 A, B).
– Several packages of sterile absorbent paper points (Fig. 24.10).
– Steiglitz' forceps with the intraoperative radiograph already positioned.

Fig. 24.7. The dental tray for the obturation procedure.



A

B

Fig. 24.9. **A**. In a sponge moistened with pure alcohol, the assitant positions the last apical file of each canal and a smaller file (to check the apical patency), reproducing the topography that the endodontist sees when he examined the pulp chamber with the dental mirror. The instruments in the photograph are positioned to obturate the canals of an upper right molar with four canals. **B**. If the obturation is going to be made in another visit, the instruments of each canal are stored in an envelop and will be used when the canals are ready for filling.

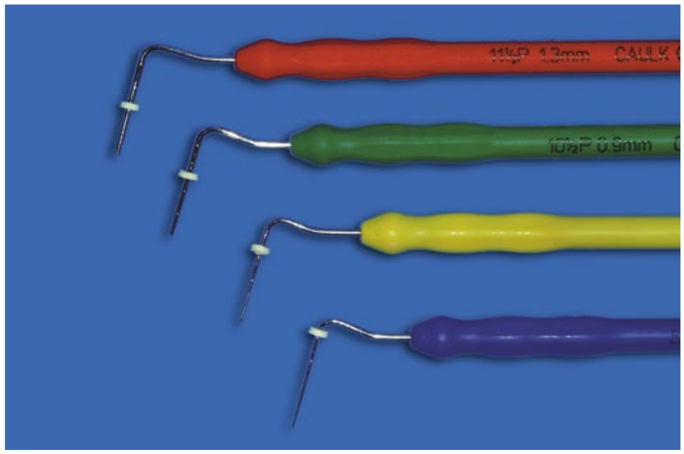


Fig. 24.8. To facilitate control of the working depth of the pluggers, the instruments can be equipped with rubber stops.

Fig. 24.10. The canals must always be dried with sterile absorbent paper points.

– A pair of scissors to remove the tip of the gutta-percha cones.
– A cotton pliers to handle the gutta-percha cones
– A mirror.
– An endodontic probe.

The dentist must also have within reach:

– A small glass plate and a sterile spatula with the powder and liquid of the sealer.
– Boxes of gutta-percha cones of the required size.

The assistant must have access to:

– A refillable gas burner.
– An old excavator to heat over the flame.
– The heat carrier.
– An electric Touch ‘n Heat heat carrier (Sybron Endo) can substitute for all the above.

PHASES OF OBTURATION

The rubber dam is applied, positioning the same clamp used in the cleaning and shaping phase, whose number should have been recorded in the chart.

If the temporary medication was sealed with Cavit, it is removed with the help of an ultrasonic instrument. If IRM or another, more resistant cement was used, it will be necessary to remove it with a high-speed bur.

The temporary medication – a cotton pellet with a dab of Cresatin – is removed from the pulp chamber, and the canals are washed with sodium hypochlorite to remove any exudate that may have accumulated in the root canals.

With the last instrument at the terminus of each canal, the patency and the size of the apical foramen is checked and the endodontic anatomy is reviewed, after which it is washed again with sodium hypochlorite, EDTA, and alcohol, which the assistant then aspirates from the pulp chamber with a surgical aspirator.

Using sterile absorbent paper points (measured by the assistant with a tweezers at the exact working length) (Fig. 24.11) and the Stropko irrigator (Fig. 24.12) using the minimum air pressure, the root canals are completely dried so as to remove any trace of moisture. A final check of the apical patency is then made, and then the gutta-percha cone is prepared.

Fig. 24.11. The paper points are measured by the assistant with a tweezers at the exact working length.

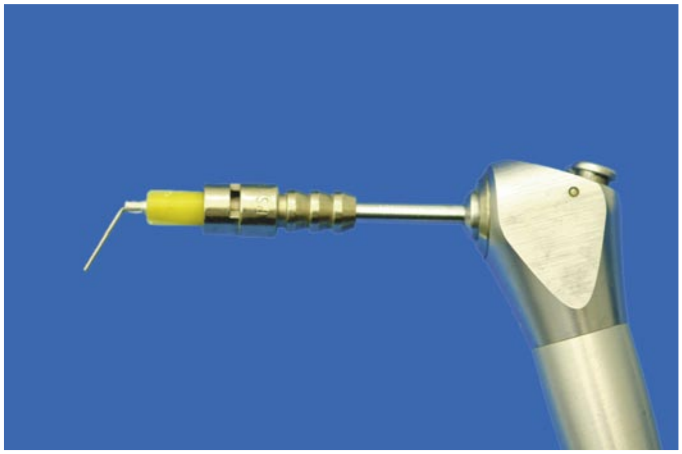


Fig. 24.12. The Stropko irrigator.

Cone fit

Gutta-percha cones cannot be used right out of the box. They must be slightly shortened (Fig. 24.13) so as to be slightly short with respect to the preparation (Fig. 24.14).

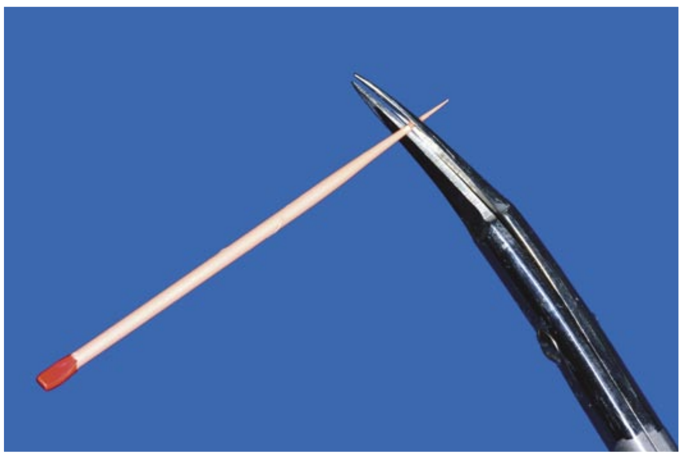


Fig. 24.13. The gutta-percha cone just removed from its wrapper must always be blunted with a pair of scissors.

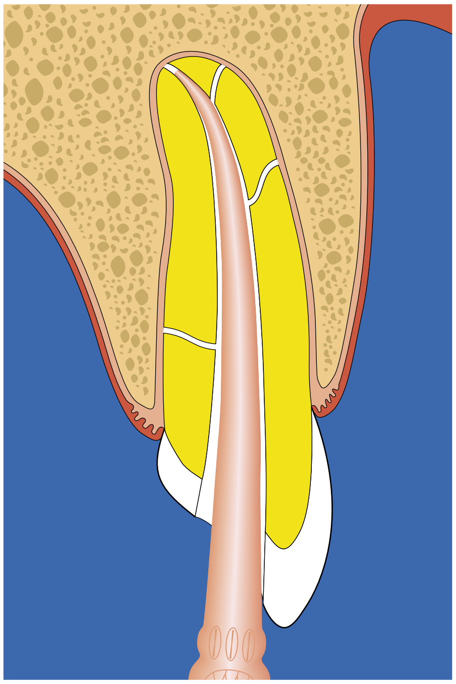


Fig. 24.14. The cone must be slightly shorter than the preparation. Note the notch left by the cotton pliers at the level of the reference point of the rubber stop.

As suggested on Chapter 14, in accordance with the second mechanical objective of shaping, the cross-sectional diameters of the prepared root canal must diminish corono-apically. This implies the use of slightly shorter cones.

When one begins to compact and push the cone vertically, the cone moves apically, and its tip will become engaged in progressively smaller portions of canal. This will lead to deformation of the cone, which ensures a good seal and a good apical control of the obturating material. The same phenomenon occurs when one forces a cork into the neck of a bottle: as the cork slowly descends, it is deformed, but this deformation ensures a tight seal.

On the other hand, if the gutta-percha cone were not shortened, it would protrude beyond the apex as a result of the vertical force until its cross section was almost equal to, if not greater than, the diameter of the apical foramen.

The gutta-percha cone, therefore, is cut off using the special gauge for gutta-percha points (Figs. 24.15 A, B) or by selective removal of varying amounts of the apical tip, until it enters the canal comfortably and binds. This must happen at the working length and the depth is marked on the cone with a notch made by the cotton pliers at the reference point of the stop.

The fit is initially checked by comparing the length of the cone with that of the last instrument at the terminus of the respective canal (Fig. 24.16), and then it is assisted by a radiographic control.

Apart from being slightly shorter than the last apical file, the cone should be able to advance without folding on itself (Fig. 24.17 A) or twisting (Fig. 24.17 B), and it should exhibit certain retention or "tug-back" within the canal. The cone must thus not be loose in the root canal, but must bind apically and oppose a certain resistance to withdrawal: this is an index of retention, which opposes the cone's removal from the root canal when heated with the heat carrier.

At this point, two questions may arise:

a) How much must the cone be shortened with respect to the canal preparation?
   The answer apparently is a little banal, but with some practical experience appears obvious. The cone must be shortened by the length, by which one expects that it will rise during the compaction phase. In other words, in wide, straight root canals, where pluggers descend easily in the apical portion and where it will therefore be easy to move the gutta-

A

B

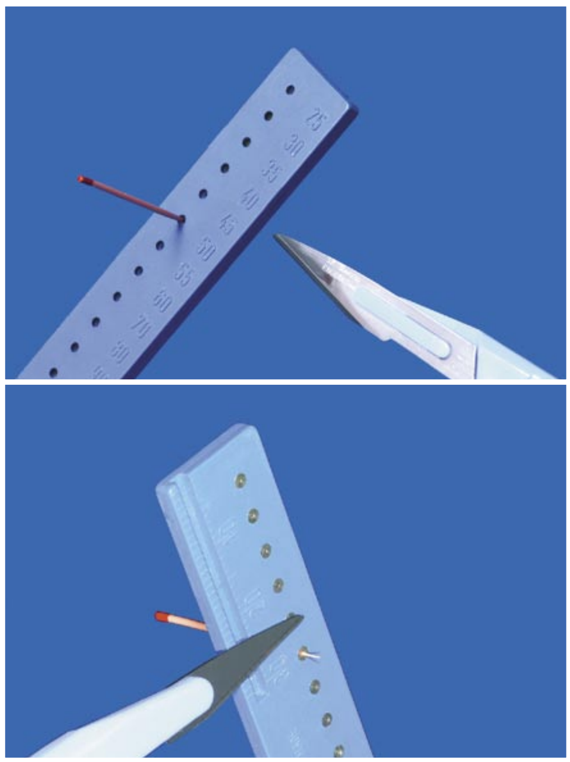


Fig. 24.15. **A**, **B**. The gutta-percha cone is cut off using the special gauge (Dentsply, Maillefer) for gutta-percha points. This instrument is very useful to cut off the gutta-percha cones to the desired diameter.

percha apically, it is better to shorten it more, by at least 1-2 mm (Fig. 24.18).

In contrast, in narrower, more curved canals, in which the pluggers descend less and it will be more difficult to move the gutta-percha apically, one must shorten the cone by only a few fractions of a millimeter, so as not to risk a short obturation (Fig. 24.19).

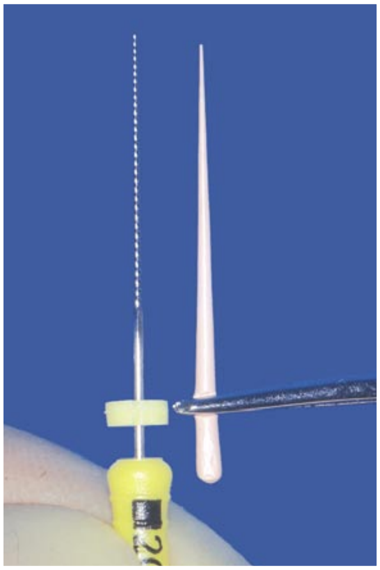
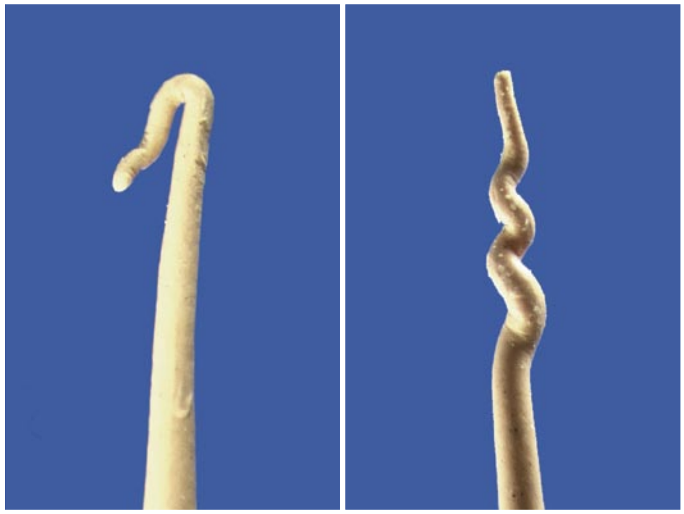


Fig. 24.16. The relation between the gutta-percha cone and the reference instrument informs the operator how short the cone is relative to the preparation.

A B

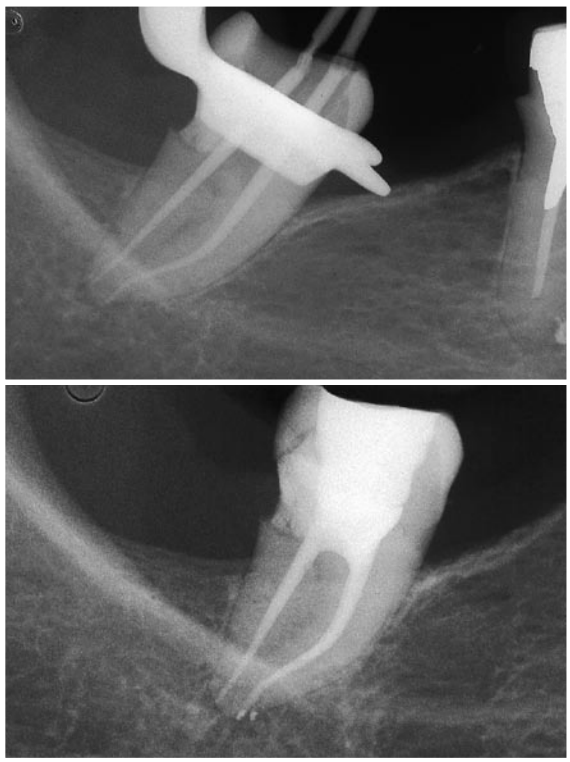
Fig. 24.18. **A**. Intraoperative radiograph of the cone fit in an upper central incisor: the canal is wide and straight; therefore, the cone is shortened by about 2 mm. **B**. Postoperative radiograph: during the vertical compaction, the cone has moved to the end of the preparation. A lateral canal has been filled, with a good apical control of the obturating material.

b) How does one know whether the "tug-back" of the cone is due to the binding in the most apical portion or to binding laterally, somewhere short of the apical foramen?



A B

Fig. 24.17. **A**. The cone must not fold over. **B**. The cone must not twist.



A

B

Fig. 24.19. **A**. Intraoperative radiograph of the cone fit in a lower third molar: the canals are narrow and slightly curved; therefore, the cones are shortened by a fraction of a millimeter. **B**. Postoperative radiograph.

Obviously, if one is confronted by the latter situation and the tip of the cone is of lesser diameter than the apical foramen, once the friction is overcome in the compaction phase the cone will be pushed beyond the apex and will stop only when its body is entrapped by the apical foramen.
It is therefore necessary to determine the site of the "tug-back". This can be done by taking another cone of smaller size (less tapered) and gradually shortening it until it also exhibits tug-back.

The lengths of the two cones (the first more tapered, for example a medium, the second thinner, for example a fine-medium) are then compared. If the two lengths are identical and their apical diameter are the same, the two "tug-backs" are at the same depth and thus one can confidently use the more tapered cone, confident that its retention is in the most apical portion and therefore will not protrude beyond the apex.

On the other hand, if the two lengths are identical but the medium cone has a smaller diameter as compared to the fine-medium (Fig. 24.20), this means that the medium has a lateral, instead of apical, tug-back.

The choice of the master cone (which is also when the adequacy of the shaping is assessed) can present other problems:

a) The cone has no "tug-back". This occurs when the cone is too thin for the preparation. It must be shortened more; otherwise, one must advance to a larger cone (e.g., medium rather than fine-medium). By selective removal of different amounts of the apical tip of a gutta-percha cone, one gradually obtains cones of different size (still with the same taper) that can easily conform to canals of different size. The same fine-medium cone shortened slightly can conform to a narrower canal; if shortened more, it can serve to obturate a wider canal.
b) The cone is bent on withdrawal (Fig. 24.17 A). Evidently, the cone was bent on entry into the root canal. To prevent this, it suffices to check the entry of the cone into the canal opening with a mirror. Bending of the cone is a drawback that can occur not only at the beginning, while one is fitting the cone in the canal, but also in the much more important subsequent phases, such as the introduction of the cone at the beginning of the true compaction phase. It is important that one realize immediately that the hindrance has occurred, so as not to risk compromising all the work. The notch made previously on the gutta-percha cone with the cotton pliers is useful to this end, as it informs one of the proper descent of the cone within the canal. Indeed, bending impedes the cone's advance to the same prior marked length.
c) The cone is twisted on withdrawal (Fig. 24.17 B). This means that the tip of the cone has hit against dentin mud that has accumulated in the canal or against a ledge left behind during preparation. In

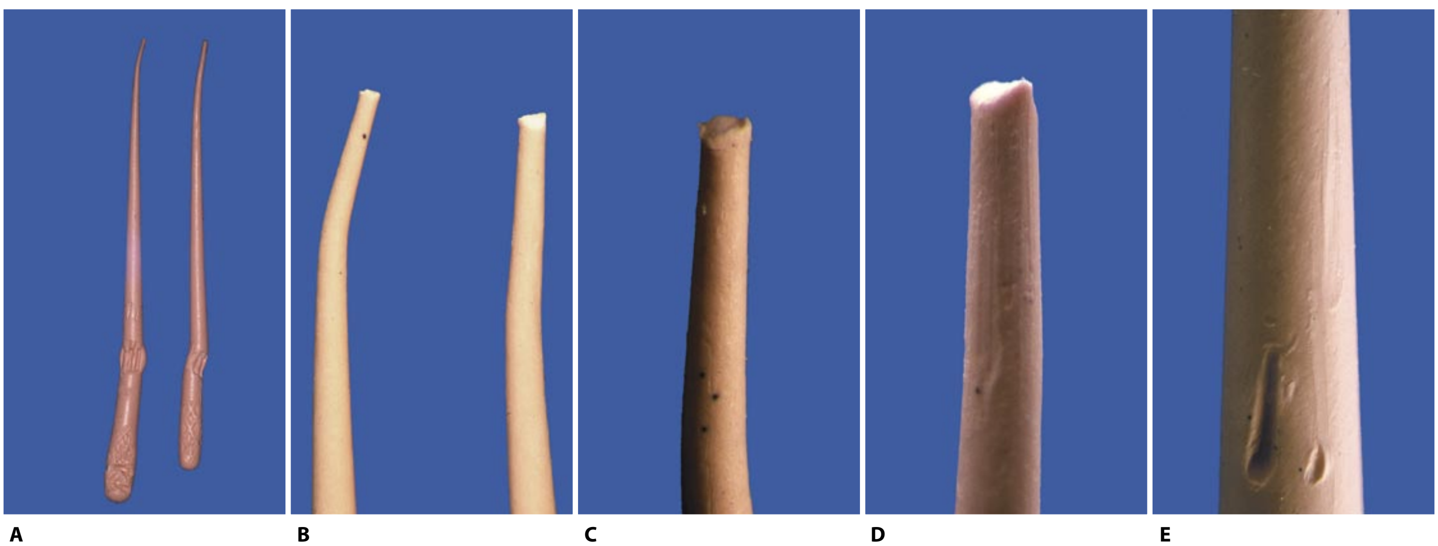


Fig. 24.20. **A.** On the left the Medium cone and on the right the Fine-Medium cone: they both reach the working length and they both have a good tug back: which one should we select? Note that the cone on the right has more cut off. **B.** The two cones at higher magnification. **C.** The tip of the Medium cone as seen at 64 magnifications. **D.** The tip of the Fine-Medium cone as seen at 64 magnifications: the tip diameter is bigger and the cone presents some streakings in the apical few millimeters, because it was in contact (tug back) with the dentinal walls. Those streakings are not evident on the Medium cone. It is obvious, therefore, that the right cone to be used is the one with less taper (Fine-Medium), which has an apical tug back and a larger diameter tip. **E.** The coronal site of the tug back of the Medium cone is evident.

both cases, it is advisable to put down the gutta-percha cone and again take up the sodium hypochlorite and files to re-shape that segment of the root canal. Fitting the cone is the best test to check if the root canal has been shaped properly.

In summary, the gutta-percha cone must be shortened so that its apical diameter is of the same size as the apical foramen. For this purpose, the instrument designed by Maillefer and shown in Fig. 24.15 is very useful. The cone should now be fitted to the working length, should have adequate tug back and should be checked radiographically: then, after being shortened about half a millimeter, it is ready for obturation.

If the canal preparation has been made using the Nickel Titanium instruments GT Rotary Files, the cone fit is much easier and the clinician will choose the cone corresponding to the taper developed in the root canal. For this purpose, instead of the non-standardized cones, the operator will use the GT cones or the Autofit gutta-percha cones, which are named by their taper (Fig. 24.21).

Radiographic control of the cone fit

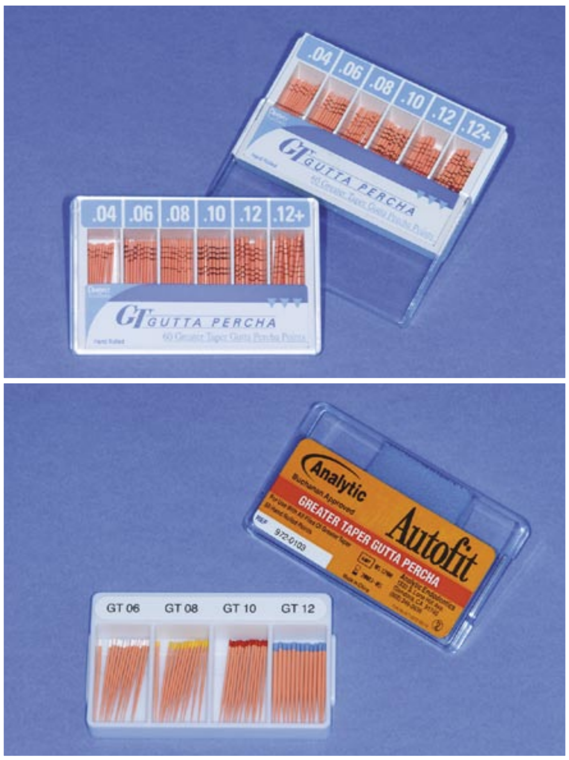
When the cone has been shown to descend to the desired depth without either bending or twisting and to have sufficient tug-back, it is re-inserted into the canal and a radiograph is obtained.

In a multirooted tooth, the radiograph is performed with the cones inserted into the various canals, orienting the X-ray beam in such a way as to prevent superimposition of the roots.

If one or more apices are not well demonstrated in the radiograph, one removes those cones whose placement is known to be correct, and a new radiograph is obtained.

One should not proceed to obturation if the radiograph does not give precise information regarding the position of the cones.

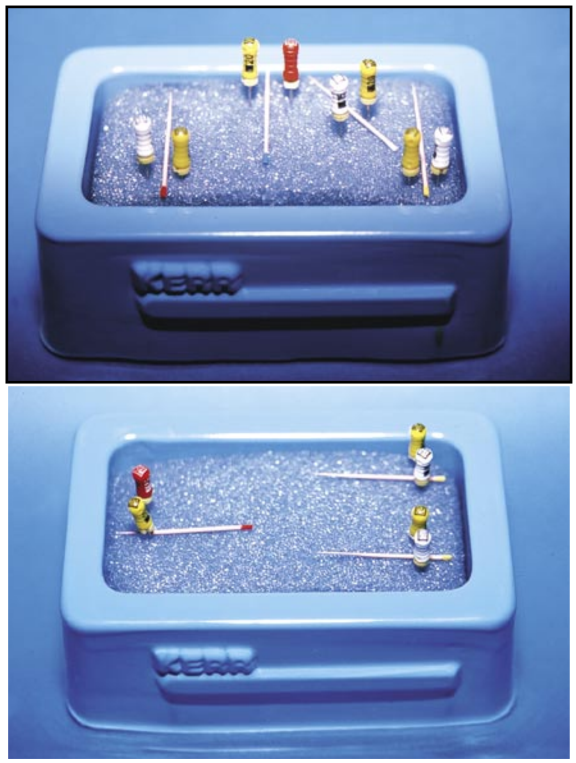
Following the radiographic control of each cone, which has been notched with the cotton pliers at the reference point, it is shortened about half a millimeter, then it is placed on the sponge next to the last apical file of the respective canal (Fig. 24.22).



A

B

Fig. 24.21. **A**. GT gutta-percha cones **B**. Autofit gutta-percha cones. They are no more named by their size but by their taper.



A

B

Fig. 24.22. After radiographic verification of the cone fit, the cones are removed from the root canals and placed on the sponge, each next to the apical files of the respective canal. **A**. Cones for an upper right first molar. **B**. Cones for a lower molar.

Prefitting of pluggers

The pluggers must be prefitted into the canal to determine the depth to which they can be introduced without touching the dentinal walls. The essence of the technique is to capture the maximal cushion of softened gutta-percha and to compact it vertically.[42] One always begins with a sufficiently wide plugger, which descends in the coronal one third of the canal (e.g., a # 10); one then advances to those of smaller size. If the plugger has been supplied with a rubber stop, the instrument is introduced into the canal and the stop is positioned just before the instrument touches the dentinal walls (Fig. 24.23 A). One then selects a second plugger (e.g., a # 9) that descends into the middle one third, again adjusting its rubber stop (Fig. 24.23 B). Finally, one advances prefitting a third, narrower plugger, which descends into the apical one third until about 5 mm from the apical foramen (e.g., a # 8 or 8½), and its stop is also adjusted (Fig. 24.23 C). If one used a plugger of smaller size to compact a wide surface of gutta-percha, the instrument would sink into the heat-softened material without exerting any pressure (Fig. 24.24).

In contrast, a wide plugger captures the largest amount of gutta-percha, compacting it not only apically but also, without any force, laterally (Fig. 24.25).

The pluggers must never touch the dentinal walls, because if they did so they would no longer exert any pressure on the gutta-percha, while they could cause a root fracture by their wedging action.

Preparation of the sealer

It has already been stated that the sealers of choice for this technique are Pulp Canal Sealer E.W.T. (Kerr), Pulp Canal Sealer (Kerr) and Argoseal (Ogna), since they best meet the requirements discussed above.

Commercially, the Extended Working Time Kerr Sealer comes in a bottle of powder and a bottle of liquid. The other two sealers come in the form of predosed capsules. The manufacturers recommend that each capsule be dissolved in a drop of liquid.

A study by Casanova[9] has, however, demonstrated that an increase of the powder/liquid ratio diminishes the solubility and resorbability of the sealer without affecting its fluidity and thus its capacity to spread as a microfilm. It is therefore advisable to prepare two small capsules of powder on a glass plate (Fig. 24.26). At least two-thirds of the powder is dissolved in a drop of liquid, so as to obtain a uniform, creamy mixture. Just-prepared sealer must be viscous enough to make at least a 2 cm "string" (Fig. 24.27). The powder remaining on the plate can be applied to the tip of the plugger to prevent the heat-softened gutta-percha

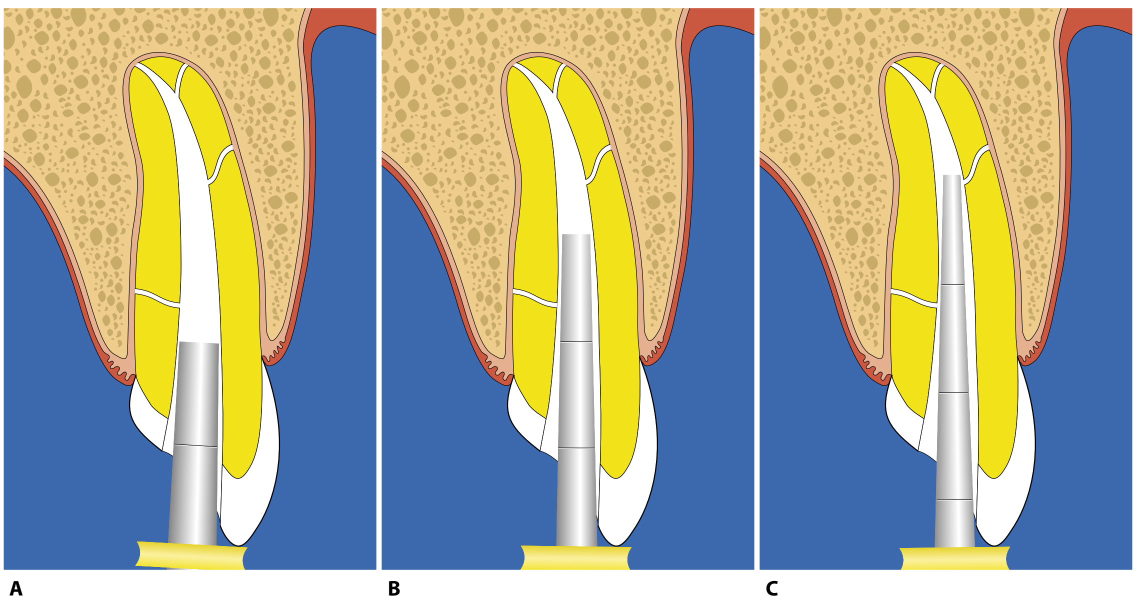


Fig. 24.23. **A**. Prefitting of a # 10 plugger. The rubber stop was positioned immediately before the tip of the instrument came into contact with the dentinal walls. **B**. Prefitting of a # 9 plugger. **C**. Prefitting of a # 8 plugger: its working depth is about 5 mm from the apical foramen.

cone from adhering to it; this reduces the risk of its being extracted from the root canal.

The prepared sealer must then be introduced into the root canal in small amounts. This can be done with the help of a Lentulo's spiral introduced in the coronal two-thirds and worked by hand (if mounted on a low speed handpiece, one loses control of the amount and site of the cement deposited). Alternatively, it can be carried with a large reamer (Fig. 24.28) introduced as far as the middle third of the canal and turned counter-clockwise. The instrument tends to withdraw from the canal and to deposit the drop of cement held among its spirals onto the dentinal walls. In this way, a small amount of cement is deposited in the

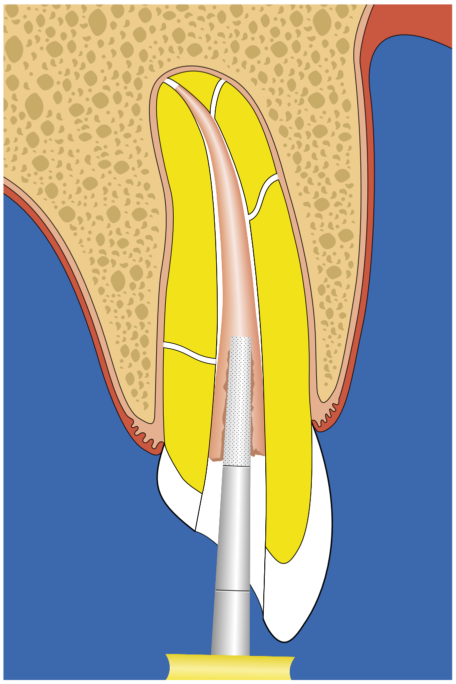


Fig. 24.24. The small plugger used in a wide section of the root canal does not compact at all but simply sinks into the heat-softened gutta-percha.

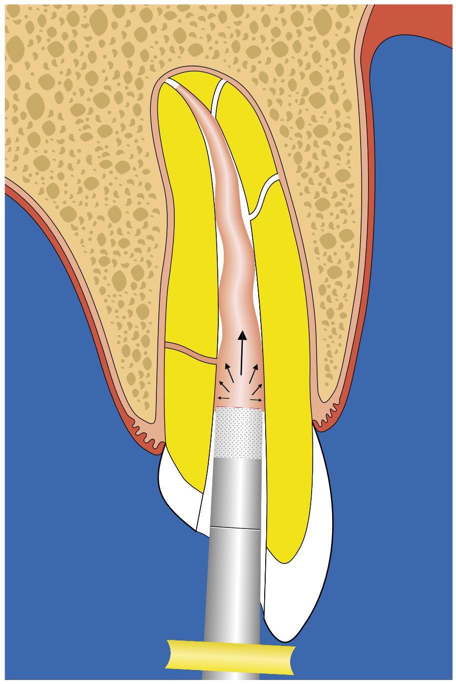


Fig. 24.25. To be effective, the plugger must capture the maximum cushion of warm gutta-percha. Thus, its size must always be proportionate to the section of the canal where it is working.

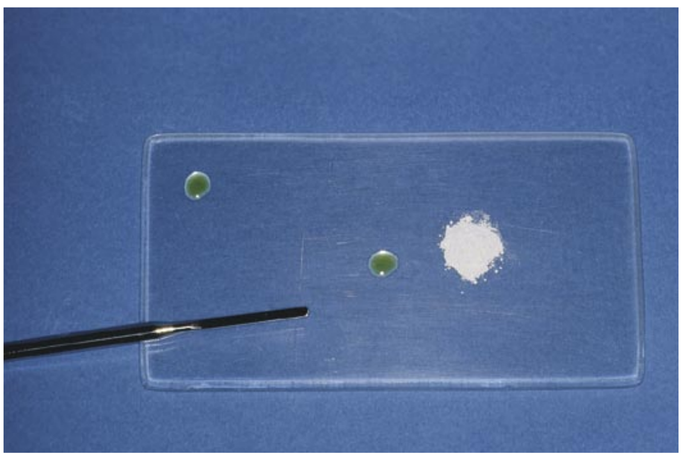


Fig. 24.26. On a sterile glass sheet, the assistant prepares a little amount of powder and two drops of liquid, one of which is kept in reserve. The dentist then mixes the powder and liquid so as to achieve a mixture of the desired consistency.

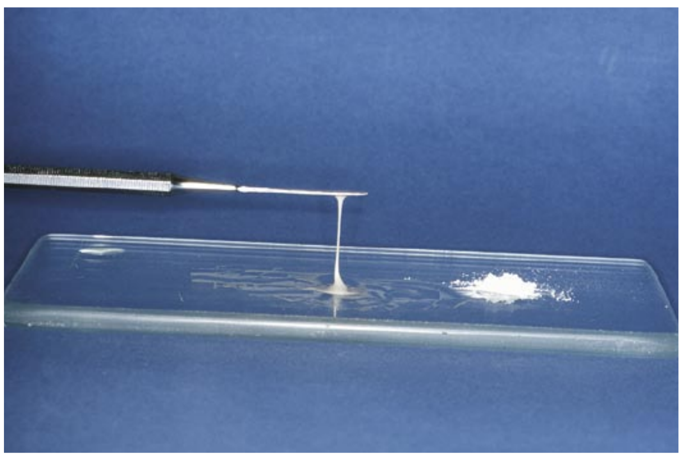


Fig. 24.27. Properly prepared sealer must not "drip", but must make at least a 2 cm "string".

Fig. 24.28. The simplest and safest way to transfer the sealer from the plate to the root canal is to use a file of a larger size with respect to the last apical file.

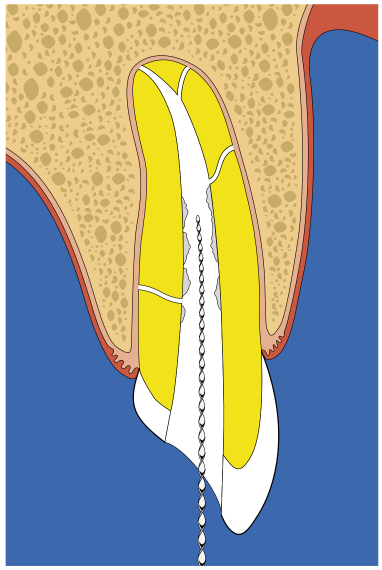


Fig. 24.29. The coronal and middle thirds of the canal are coated with sealer carried by a file rotating counter-clockwise.

coronal and middle thirds of the canal to a depth of about 4-5 mm from the apical foramen (Fig. 24.29).

It is not advisable to use a great deal of cement or to place it more deeply, since the gutta-percha cone could then act as a piston and cause unwanted overfilling.

SEALER AND MASTER CONE PLACEMENT

The cone, which after the radiographic control was shortened and placed on the alcohol-moistened sponge next to its respective apical file, is dried with a sterile gauze. Its apical 4-5 mm are coated with a thin layer of sealer (Fig. 24.30). Another easier and faster method to carry the sealer into the root canal is to coat the entire length of cone with sealer. This is then placed in the canal opening and, with small pushes, made to slide slowly and carefully to the maximal depth designated by the notch.

Fig. 24.30. The sealer is transferred to the apical third of the root canal on the tip of the cone on which a small amount is deposited.

The slow, careful introduction of the cone into the canal causes the air and any excess sealer apical to the cone to exit laterally and coronally, without creating any increased pressure or issuance of sealer into the periapical area.

If in its coronal third the canal has a particularly elliptical shape, an auxiliary cone is introduced alongside the cone just introduced (Fig. 24.31). This is not so much to condense it laterally to the first one, as to have a greater mass of gutta-percha to compact apically.

DOWN-PACKING

The assistant hands the heat-carrier to remove the portion of gutta-percha extruding into the pulp chamber. The heat-carrier may be an old spoon excavator heated by a flame or the tip of the Touch 'n Heat instrument (Fig. 24.32).

The heat-carrier is returned to the assistant, who at the same time hands the wider prefitted plugger (after having powdered its tip with sealer powder to prevent adhesion to the tacky gutta-percha) to begin the vertical compaction (Fig. 24.33).

The plugger (for example, a # 10) is returned, while the heat-carrier is handed back (Fig. 24.34). This is introduced for 3-4 mm into the gutta-percha cone (this also must not touch the dentinal walls), where it remains for a fraction of a second and is then removed. In actual practice, the probe of the Touch'n Heat unit is introduced into the orifice, started and allowed to plunge 3-4 mm into the coronal most extent of the gutta-percha.[42] The heat-activating element is then released and after hesitating momentarily, the cooling instrument is removed, along with an adhered bite of gutta-percha (Fig. 24.35).

In this manner, the gutta-percha is heated around the heat-carrier and about 3-4 mm apically (no more, because gutta-percha is not a conductor of heat[18]). When the instrument is withdrawn from the root canal, simultaneously a bite of gutta-percha has remained attached to it and is then removed (Fig. 24.36).

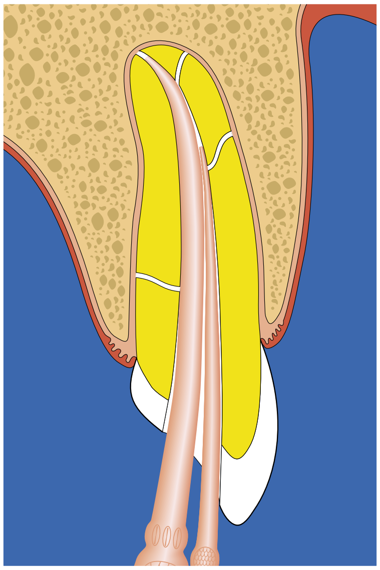


Fig. 24.31. In very wide or elliptical canals, it is advisable to introduce a supplemental cone(s) alongside the master cone for added bulk of gutta-percha to compact apically.

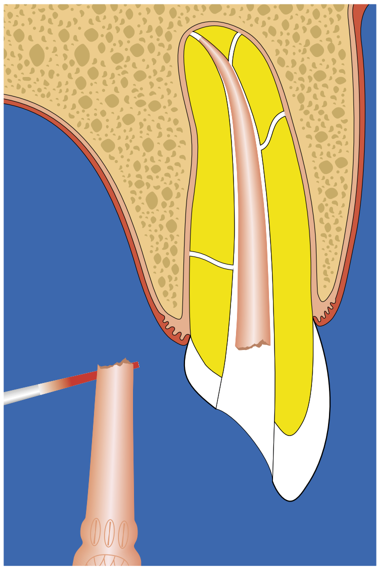


Fig. 24.32. With an old spoon excavator heated on a flame or with the tip of the Touch 'n Heat instrument, the gutta-percha that protrudes into the pulp chamber is seared off.

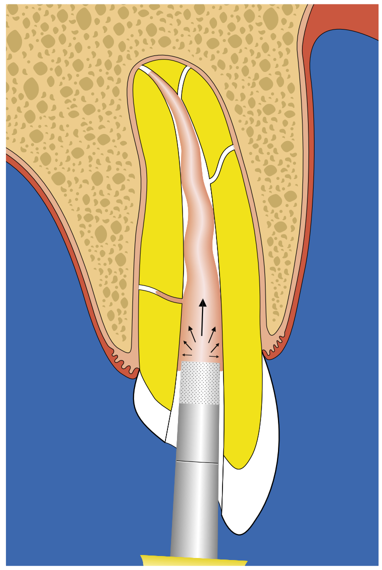


Fig. 24.33. A # 10 plugger (whose tip is powdered with left-over sealer so that the gutta-percha cone does not attach to it) begins the vertical compaction of the gutta-percha just heated by the preceding heat carrier.

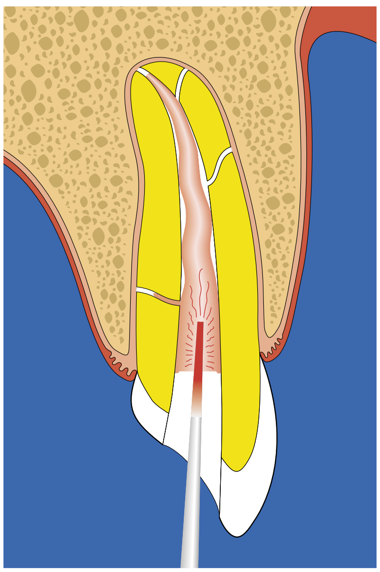


Fig. 24.34. The assistant returns the heat-carrier, which is introduced into the center of the gutta-percha cone in the root canal.

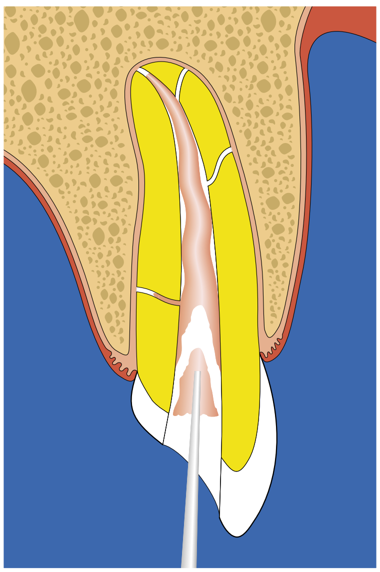


Fig. 24.35. The heat-carrier is heating the gutta-percha apically to its tip and removes the surrounding material from the canal.

Fig. 24.36. The heat-carrier is withdrawn, carrying the cooled gutta-percha around it. This way, the level of the next compaction will be more apical.

The heat-carrier is returned to the assistant, who cleans it of all traces of gutta-percha and simultaneously hands the plugger, which is used to compact and push apically the gutta-percha that has just been heated in the root canal (Fig. 24.37).

We always begin with the widest prefitted plugger, since as already suggested, we want to capture the maximum cushion of softened gutta-percha with appropriate pluggers and to gradually move the entrapped material toward the apex.[42] If we begin with a narrower plugger, it would penetrate the gutta-percha softened by the heat-carrier, without exerting any pressure and without compacting it effectively.

The force exerted by the plugger should be delicate but sustained and firm. Excessive force is not required. The work is generated by the wrist, not the elbow, and certainly not the shoulder.

If, after having given the first stroke to the central mass of the cone, we sense that the plugger is sinking into the gutta-percha and leaving traces laterally, we must attempt with light strokes to direct the traces of gutta-percha left on the walls toward the center of the root canal. In this way, the working level is kept relatively flat and homogeneous; this ensures good compaction of the mass.

The plugger is then returned to the assistant, who hands back the heat-carrier.

The instrument is again introduced into the canal to a depth of 3-4 mm and is removed once again covered with gutta-percha (Fig. 24.38). It is important that each time the heat-carrier enter the canal, becomes hot enough to transfer heat to the gutta-percha mass, and that after a short hesitation it is withdrawn relatively quickly, to prevent the gutta-percha from "freezing" on the instrument, which would cause inadvertent removal of the entire gutta-percha cone at an early stage of the compaction process. Once compaction has proceeded more deeply into the canal, it is impossible to remove the gutta-percha involuntarily in this way.[45]

The assistant then hands the same prefitted plugger, which will continue to be used until the rubber stop indicates that it is coming in contact with the dentinal walls. At this point, always alternating it with the heat-carrier and always with the aim of capturing the maximum cushion of warm gutta-percha in that section of the root canal, we ask the assistant to hand the plugger of smaller size, which will continue to compact the heated gutta-percha until it also reaches the maximal limit of its working depth (Fig. 24.39). A new introduction of the heat-carrier (Fig. 24.40) will then remove another bite of gutta-percha (Fig. 24.41), moving more apically the level of compaction. Now the assistant will hand the smallest plugger, to compact the softened material in the most apical portion of the root canal (Fig. 24.42).

What is happening now within the root canal during this cyclic use of the heat-carrier and pluggers? Three very important things:[45]

1. From the very beginning, the force is exerted in a "closed" space where significant hydraulics is produced. Coronally, the plugger of adequate size exerts its pressure against the maximal amount of heat-softened gutta-percha that, compacted, will make immediate contact with the dentinal walls, while at the other end the cone, by virtue of its "tug-back", occludes the apical foramen. Thus the force is dissipated in a closed environment and the hydraulic pressure that develops within causes the sealer and the heat-softened gutta-percha to fill all the available spaces in a true corono-apical "wave of condensation".
   The more coronal lateral canals are filled first, then gradually as the condensation wave moves apically, those of the middle third of the root and finally those of the apical third and the delta. This hydraulic pressure is absent in the lateral condensation, since in that technique the condensation never occurs in a "closed" space and the force applied to the gutta-percha is transmitted to the sealer, which finds an easy outlet coronally. This is one of several reasons why, with the lateral condensation technique, it is much more difficult to achieve filling of the lateral canals, even with sealer alone.
2. The working level of compaction of the gutta-percha moves increasingly apically for two reasons. The first is that the gutta-percha mass softened and vertically compacted in the cone shaped canal automatically assumes a lateral component of forces; this follows routine laws of physics and requires no lateral direction of the instrument on the part of the operator.[45] The second reason is that each introduction of the heat-carrier in the root canal is followed by the removal of a certain amount of gutta-percha, which remains attached to the tip of the instrument as it begins to cool. For these two reasons, the wave of condensation and the working level of the pluggers are displaced increasingly apically, so much so that at a certain point it becomes necessary to advance to the plugger of narrower size.
3. The temperature of the apical gutta-percha gradually increases by few degrees above body temperature. As already suggested, gutta-percha is not a con-

ductor of heat, so that it is wrong to think that after the first or second application of heat at the level of the coronal third, the temperature of the gutta-percha of the apical third will rise in equal measure. Studies performed with the help of thermocouples introduced into the root canal[17] have demonstrated that the apical gutta-percha becomes moldable at a temperature 3-7°C above body temperature and that it is impossible to elevate the temperature of this gutta-percha more than 9°C above the initial temperature, even if one attempted to do so deliberately.[17]

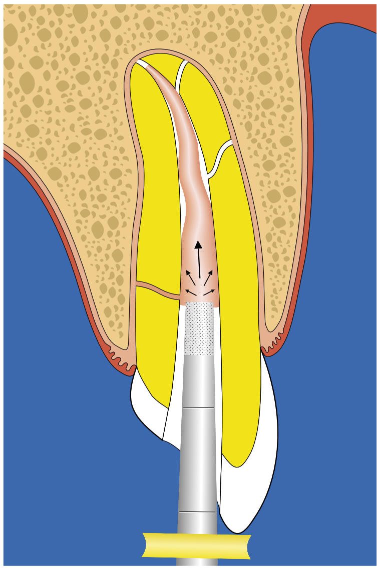


Fig. 24.37. The # 10 plugger repeats and completes the vertical compaction process in the coronal third. Once the rubber stop is approaching the reference point, it is time to select a plugger of slightly smaller diameter, like the # 9.

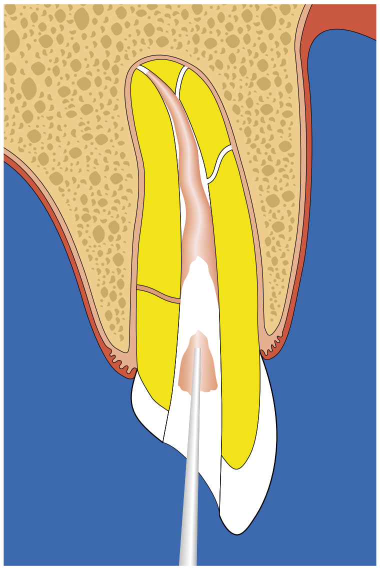


Fig. 24.38. The assistant returns the heat-carrier, which is activated for just one second once it is in contact with the gutta-percha inside the root canal. It is then inserted directly into the central portion of the gutta-percha to a depth of 3-4 mm and quickly inactivated and withdrawn while it is cooling, so that at the same time it removes another bite of material from the root canal.

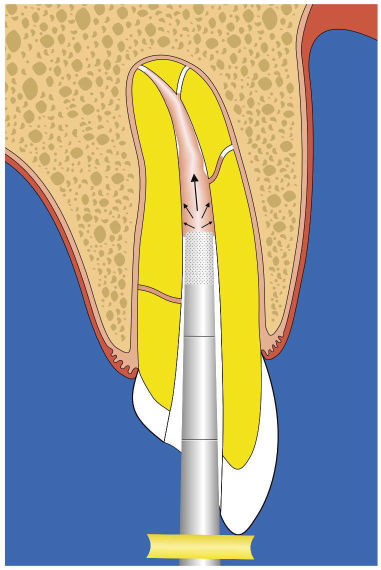


Fig. 24.39. The # 9 plugger has completed its vertical compaction to its maximal working depth.

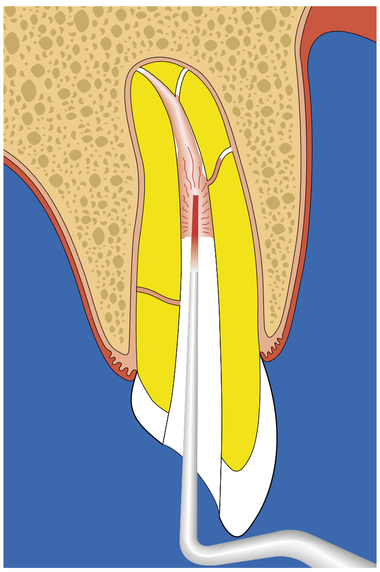


Fig. 24.40. A new introduction of the heat-carrier is softening the gutta-percha in the apical one third.

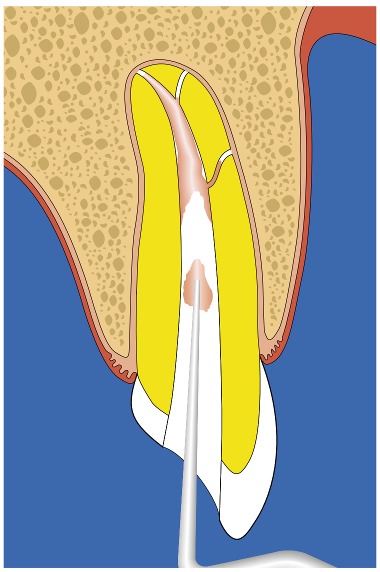


Fig. 24.41. Another piece of gutta-percha has been removed. Now it is time to use the smallest plugger, # 8.

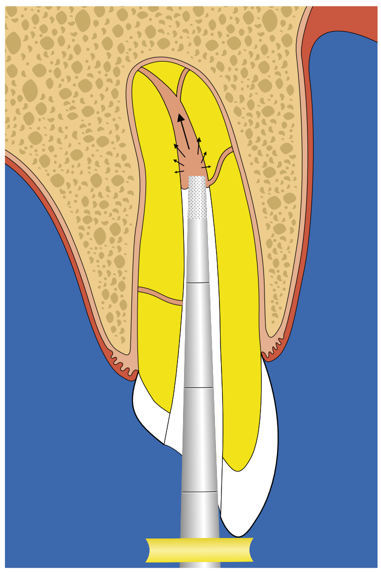


Fig. 24.42. The # 8 plugger has advanced, compacting about 5 mm from the canal terminus.

If we analyze the thermal profile of gutta-percha in the apical one third of the root canal (Fig. 24.43), once the heat-carrier and then the narrower plugger have descended to a depth of about 5 mm from the apical foramen, we note that the thermal increase occurs gradually in concomitance with the various applications of heat, that the gutta-percha has become moldable at a temperature 3-7°C above body temperature, and finally that, if heat is not intentionally added, it returns to body temperature and will resist further movement beyond the terminus of the canal preparation.[6,17]

Apical control of the obturation is thus excellent, since the gutta-percha at the apex is never molten.

Furthermore, it is not necessary – indeed, it is contraindicated – to descend further apically with the heat-carrier to heat the gutta-percha 2-3 mm from the apical foramen:[3] overheating and excessively plasticizing the apical gutta-percha increase the probability of gutta-percha extrusion beyond the terminus of the preparation.[44]

Stopping at 5-6 mm is more than sufficient to obtain an effective sealing or "corkage" of the canal preparation, to ensure adequate, controlled softening of the apical gutta-percha, so as to achieve filling of the small lateral canals (Fig. 24.44) or of the apical delta (Fig. 24.45) with gutta-percha or a mixture of sealer that surrounds the gutta-percha.

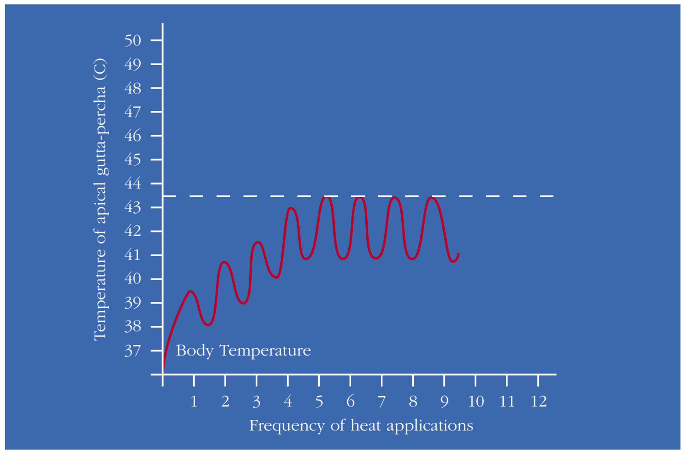
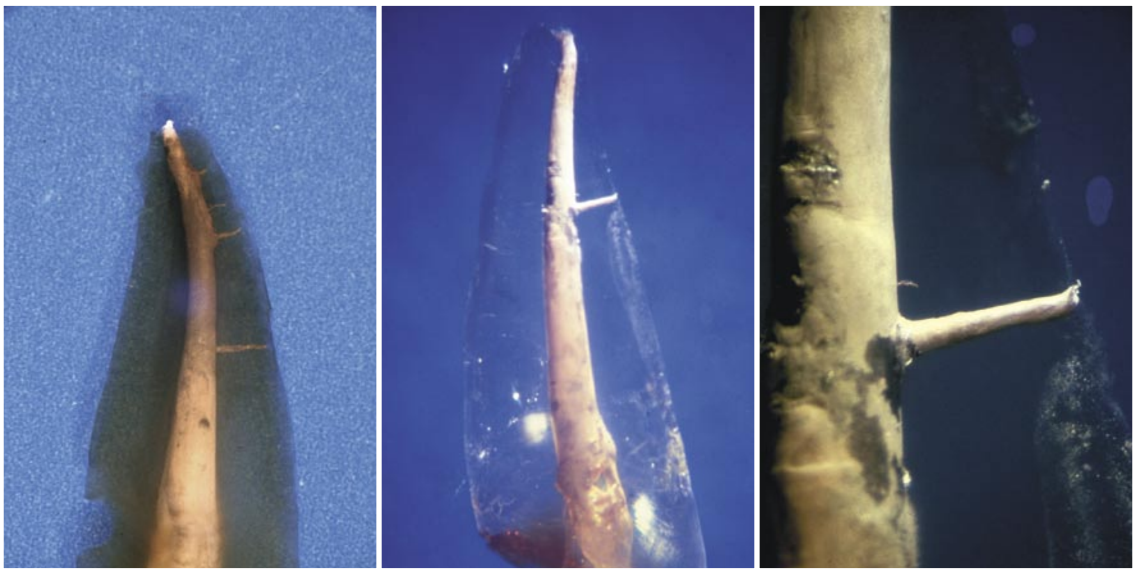
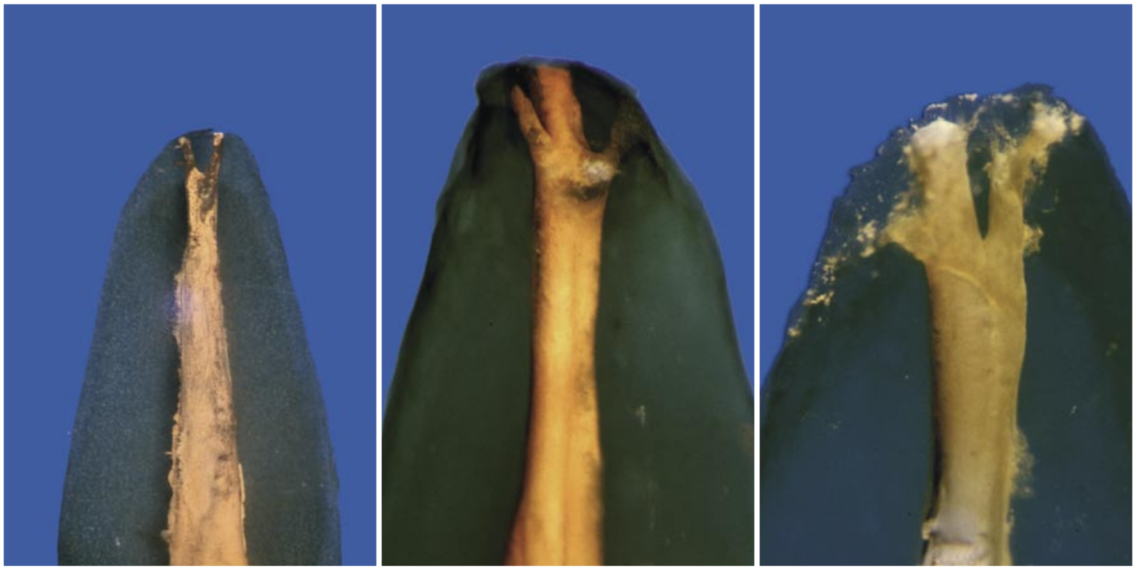


Fig. 24.43. Thermal profile of gutta-percha in the apical portion of the canal preparation (H. Schilder[41]).



A **B** **C**

Fig. 24.44. **A**. An endodontically-treated upper central incisor extracted for periodontal reasons and clarified. Four lateral canals filled mostly with gutta-percha are evident. In this case also, the compaction halted 5 mm from the canal terminus. **B**. Upper cuspid endodontically treated in vitro and then clarified. A lateral canal is present, about 4 mm from the apical foramen, completely filled with gutta-percha. Heating and compacting was carried up to 5 mm from the terminus. **C**. The same at 64 magnifications.



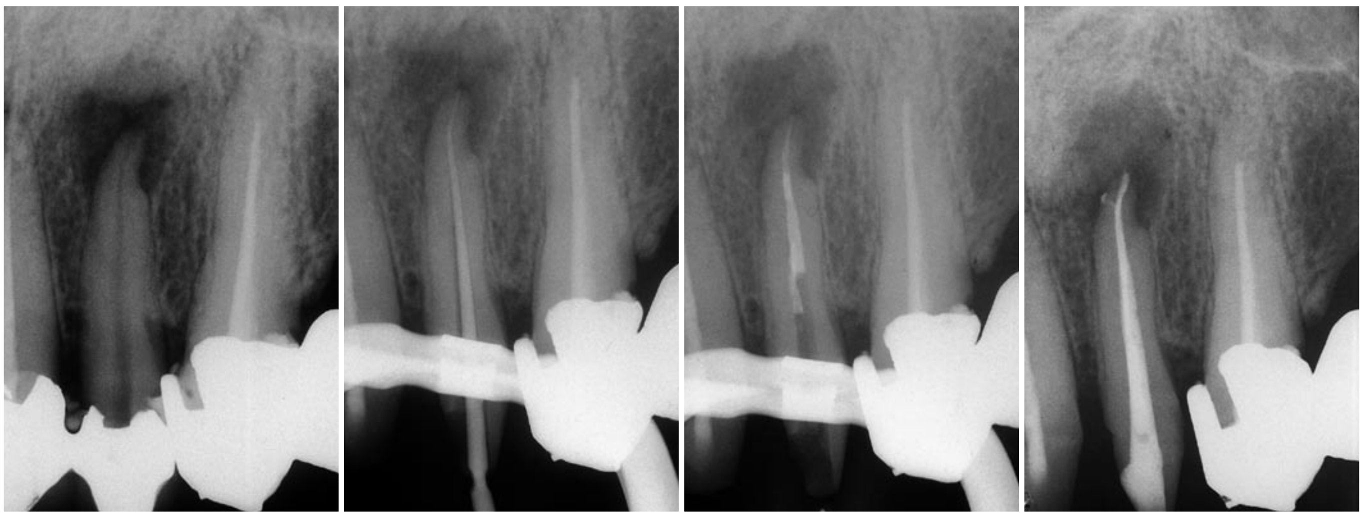
A B C

Fig. 24.45. **A**. The clarified root demonstrates a small apical bifurcation filled with gutta-percha and sealer. The compaction occurred 5 mm from the canal terminus. **B**, **C**. Other examples of apical delta mainly filled with gutta-percha, heated and compacted about 5 mm from the end of the canal preparation (Courtesy of Dr. T. Fondi).

REVERSE FILLING OR "BACK-PACKING"

Once the gutta-percha has been compacted to about 5-6 mm from the terminus of the preparation, a radiograph is obtained to verify that the gutta-percha has moved apically and sealed the apical foramen and that the obturation is well compacted (Figs. 24.46, 24.47).

At this point, it is necessary to fill in a backwards fashion the middle and coronal thirds of the canal, which were emptied during the previous phase of the obturation. This filling is achieved by introducing small pieces of gutta-percha into the root canal (Fig. 24.48), and then compacting and rhythmically heating them.



A B C D

Fig. 24.46. **A**. Preoperative radiograph of an upper left lateral incisor. **B**. Intraoperative radiograph of the cone fit. **C**. Radiograph of the apical compaction: the gutta-percha appears to be compacted for about 4 mm, then seems to fold. In the most apical portion, it has not been modified in the least. It is necessary to advance more apically with the heat-carrier and compact better. **D**. Postoperative radiograph: the obturation material now seems homogeneous and well compacted. A lateral canal has also been filled.

Fig. 24.47. **A**. Preoperative radiograph of a lower right second molar. **B**. Cone fit. **C**. Intraoperative radiograph of the apical compaction. The material seems to be homogeneous, but the obturation is slightly short. It is necessary to descend more apically (to 5 mm) with the heat-carrier and compact better. **D**. Postoperative radiograph: the small apical bifurcation has been filled.

Naturally, it is advisable to begin with small pieces, since one must introduce them into the deepest portion of the canal, and then to advance to medium-sized pieces in the middle third and to larger pieces in the coronal third.

An effective method for introducing the small pieces into the canal opening makes use of the heat-carrier. After slightly heating the apical gutta-percha, so that it can easily melt with the material we are going to introduce, the just-heated instrument touches a small piece of cut gutta-percha, which remains attached to the instrument. The piece is heated slightly, becomes sticky, and is therefore easy to apply to the canal opening (Fig. 24.49 A).

The assistant then hands the smaller plugger to push the piece apically (Fig. 24.49 B). With the heat-carrier, the piece is then re-heated (Fig. 24.49 C) and again with the same plugger it is compacted in such a way as to form a single mass with the previous apical gutta-percha (Fig. 24.49 D).

One proceeds by adding pieces of gradually increasing size, until the entire canal is completely filled (Figs. 24.49 E-H).

The use of large pieces in the deepest part of the canal can lead to the development of empty spaces in the final obturation. Even though they are of little importance, they indicate a lack of familiarity with the technique.[46] These empty spaces can develop even if streaks of gutta-percha or sealer are left on the dentinal walls during the previous phase of compaction.

The pieces of gutta-percha used in the back-packing phase may adhere to this material before fusing with the apical mass of gutta-percha, thus leaving empty spaces that interfere with the uniformity of the obturation (Fig. 24.50).

In the case of multirooted teeth, once the various canals have been filled, it is also necessary to obturate the pulp chamber floor with a pellet of flame-heated gutta-percha coated with sealer on the surface that will come into contact with the dentin (Fig. 24.51). This serves to fill any small accessory canals that may originate in the chamber floor and open in a bi- or trifurcation.

If not obturated, these small canals can cause inflammatory lesions in these areas.[4,25] This slightly flame-heated gutta-percha is compacted against the pulp chamber floor with a large amalgam condenser; then,

A

B

Fig. 24.48. **A**. The gutta-percha cones are cut into small, medium, and large pieces for "back-packing" of the apical, middle, and coronal thirds, respectively, of the root canal. **B**. The slightly heated heat-carrier transfers a small piece of gutta-percha to the canal orifice.

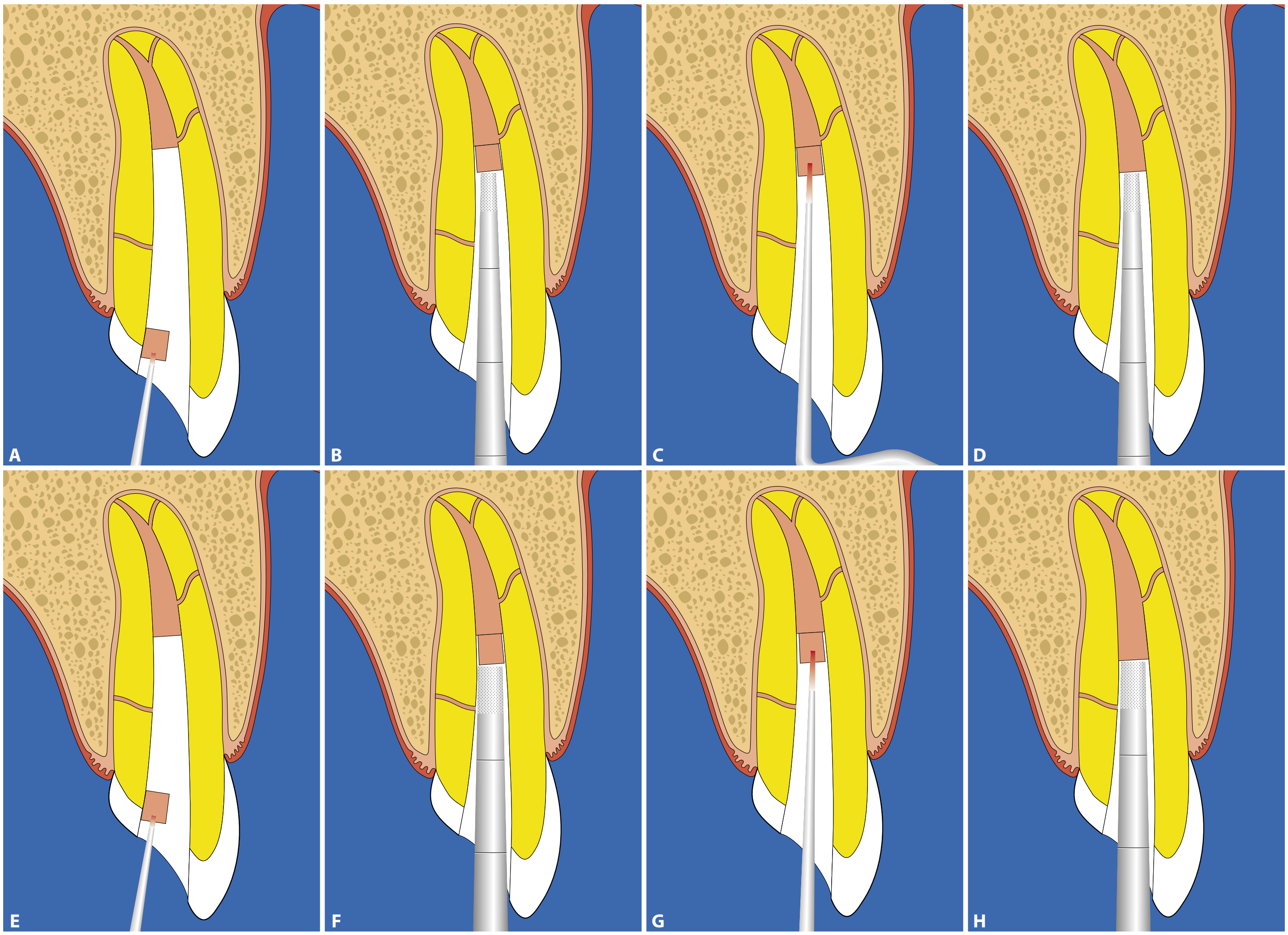
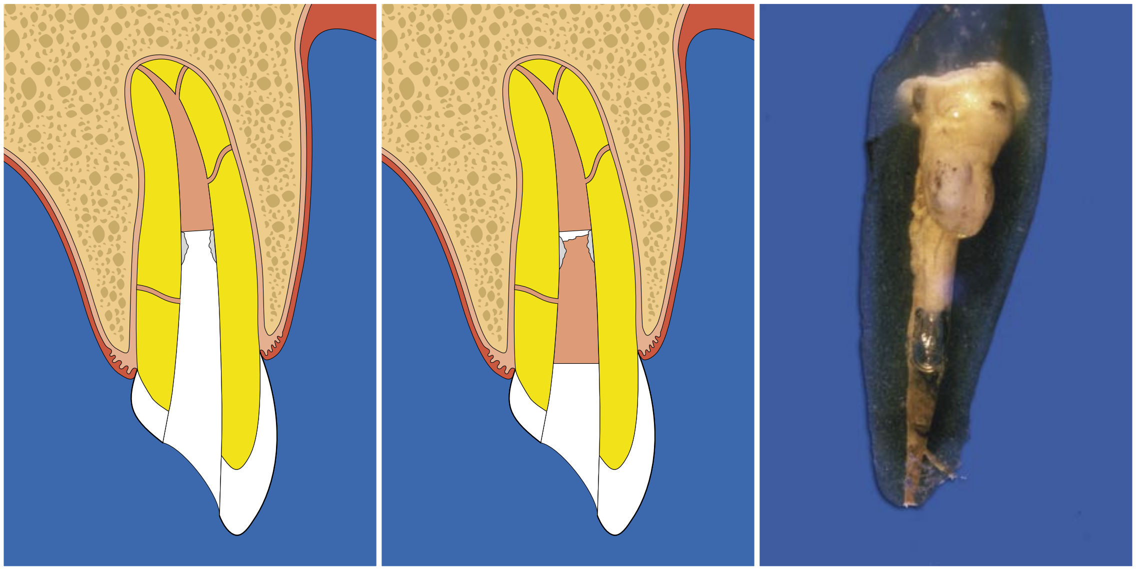
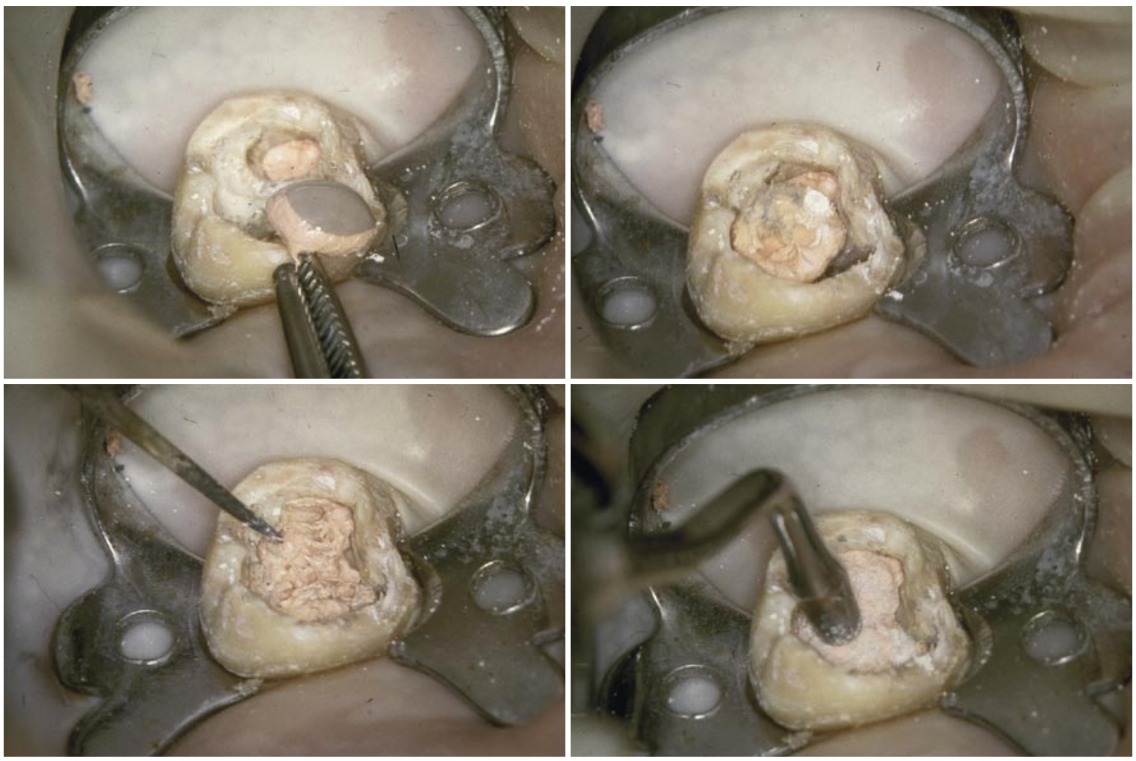


Fig. 24.49. **A**. The first piece is transferred by the heat-carrier to the margin of the access cavity. **B**. A # 8 plugger pushes the piece into contact with the gutta-percha that has already been compacted at the apical one third. **C**. The heat-carrier heats the piece without removing gutta-percha from the canal. **D**. The same # 8 plugger compacts the piece, which fuses with the rest of the apical gutta-percha. **E**. The heat-carrier now supports a medium-sized piece of gutta-percha at the margin of the access cavity. **F**. A # 9 plugger pushes it apically. **G**. The heat-carrier heats it without removing gutta-percha. **H**. The # 9 plugger compacts apically in such a way that it fuses with the gutta-percha present in the root canal.



A B C

Fig. 24.50. **A**. During the initial phase of compaction, the plugger can leave streaks of gutta-percha along the walls (grey in the illustration). They must be re-directed toward the center of the root canal. **B**. Forgotten streaks can create voids during the "back-packing" phase. **C**. A lower incisor endodontically treated in vitro, decalcified and made transparent. The compaction occurred 5 mm from the canal terminus, but the gutta-percha streaks left at 7 mm have caused a filling defect, which is visible as an air bubble. Note the complete filling of the lateral canal with gutta-percha about 2.5 mm from the apical foramen.



A B C D

Fig. 24.51. **A**. A mass of gutta-percha has been flame-heated and coated with sealer on the side that will be applied to the chamber floor. **B**. The mass has been compacted by a large amalgam condenser powdered with sealer. **C**. The heat-carrier re-heats the mass of gutta-percha. **D**. The large condenser completes the compaction of the material on the pulp chamber floor.

it is re-heated by the heat-carrier and re-compacted until it becomes a uniform mass (Figs. 24.51 B-D). As it will be described later, the pulp chamber of multirooted teeth ca also be filled with the thermoplastic gutta-percha of the Obtura.

If spaces are needed for posts, screw-posts, or other intracanal retentions, the endodontist can choose to terminate the obturation at the deepest point of the apical compaction or at any point of the reverse filling, or to complete the filling of the canal and then empty it by the necessary amount to allow introduction of the post.

At this point, it is necessary to discuss the different approaches to single- and multirooted teeth.

In the singlerooted tooth, one can terminate the "back-packing" when it is felt to be more opportune, since the lateral canals that may be present in the coronal or middle third have already been filled during the downpacking (Fig. 24.52).

Nonetheless, a strict understanding and collaboration between the endodontist and the dentist, who will later place the post, is necessary. Often, the latter does not use all of the space left for him, so that the canal remains half empty (Fig. 24.53).

In the case of a multirooted tooth, on the other hand, completion of "back-packing" and obturation of the pulp chamber is imperative, because of the presence of accessory canals on the floor, which can only be obturated in this phase.

In the front teeth, it is very important to limit the backfilling to about 2 mm below the gingival margin so as not to cause discoloration of the dental crown. Gutta-percha contains colorants that can cause unesthetic pigmentation (see Chapter 31).

A B

Fig. 24.52. **A**, **B**. The lateral canals that may be present are always filled during the downpacking.

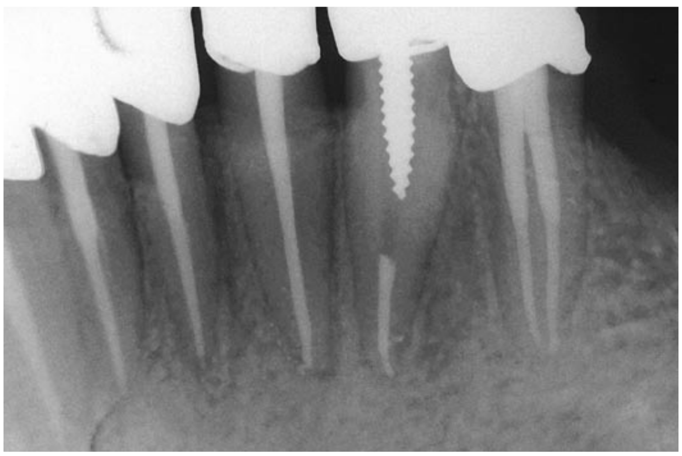


Fig. 24.53. The prosthodontist has not used the space (possibly excessive) that the endodontist had left him for a post in the root of the lower left canine.

"BACK-PACKING" WITH THERMOPLASTIC GUTTA-PERCHA

Using thermoplastic gutta-percha with the Obtura (Obtura Spartan) or with the Elements Obturation Unit (SybronEndo) (Fig. 24.54), the reverse filling of the canal can be performed in a similarly effective manner and with a significant saving of time. The procedure is much more rapid and comfortable, especially in multirooted teeth.

This procedure is performed by introducing the narrowest needle (# 23 or # 25) into the root canal, and squeezing the trigger of the gutta-percha gun gently but decisively, so as to feel the pressure of the gutta-percha, which pushes the operator hand coronally as it accumulates in the canal. After the introduction of a small amount of gutta-percha, it is compacted by the appropriately-sized plugger. It is then re-heated by the heat-carrier and compacted again (Fig. 24.55).

A B

Fig. 24.54. **A.** The Obtura III syringe (Obtura Spartan). **B.** The Elements Obturation Unit (SybronEndo).

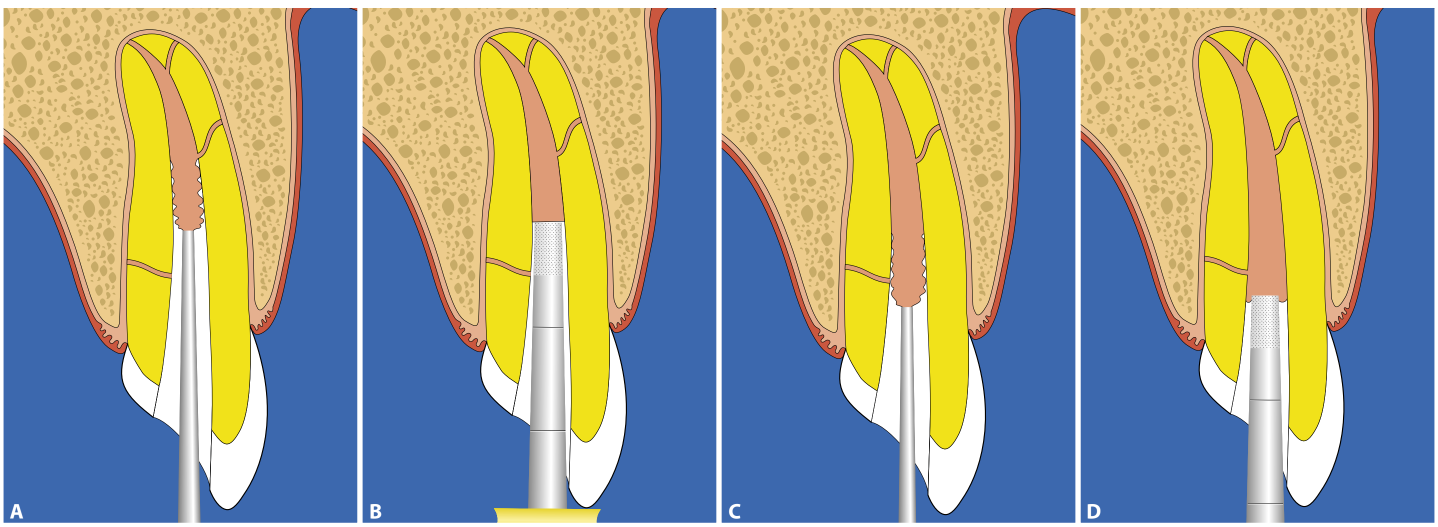
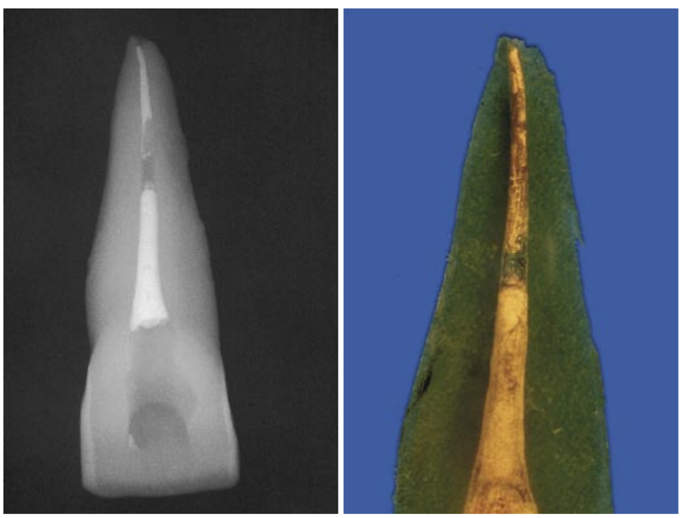


Fig. 24.55. **A.** The needle of the Obtura III touches and heats the apically compacted gutta-percha. Then a small amount of material is injected, in order to fill no more than 5 mm of space. **B.** The plugger previously used in the middle third (# 9) is now used to firmly compact the material until the gutta-percha is plastic. **C.** Five more millimeters of gutta-percha are injected in the root canal. **D.** The compaction is completed using the bigger plugger.

In general, with three successive introductions of material, "back-packing" of a canal is complete. It is always advisable to perform canal filling with thermoplastic gutta-percha in three or more injections (sectional technique), since better results are obtained in this way (without entrapping air bubbles) as compared to fillings performed in a single injection (single technique).[54] With the single injection it is very easy to leave voids.

According to Dr. Carl Nehammer (Lister House Endodontic Practice, London, UK), the trick to accomplishing a single-squeeze Obtura backfill without leaving voids is to slow down the process. Voids occur because the needle tip and the gutta-percha inside it are cooled when it comes into contact with the canal wall. The canal wall is 37°C and the needle tip is about 160°C (200°C at the heating chamber with a drop-off of heat toward the needle tip). When it touches the canal wall, the temperature of the sterling silver Obtura needle tip and the gutta-percha inside it immediately drops, often to non-plastic heat levels, thereby encouraging void formation. If the clinician simply places the needle in the canal and wait for five seconds before pulling the trigger, the needle will reheat itself and the gutta-percha inside it, as well as transmitting some of that heat to the canal wall. All of these thermodynamic events reduce the chances of leaving voids.[7]

As with the Obtura backfilling device, the Elements needle is placed in the canal for five seconds to heat the canal wall a bit, and the toggle switch is pressed while the needle is lightly held in place. After the extruded material fills the backfill space ahead of the needle, the needle will be felt to bump back. With the extremely tactile pencil grip, and the motor-driven extrusion, a light touch is easily maintained, thereby holding backpressure on the extruding material and eliminating void creation.[8]



A B

Fig. 24.56. **A.** Too rapid withdrawal of the needle from the root canal leaves empty spaces within. **B.** The same tooth after it has been made transparent. The empty space seems smaller than in the radiograph because of the small streak that partly conceals it.

It is important not to withdraw the hand during the injection with the syringe. Doing so may leave empty spaces (Fig. 24.56). It is advisable to let it be guided by the pressure of the material accumulating within the root canal.

Finally, in multirooted teeth, "back-packing" with thermoplastic gutta-percha can also be extended directly to the pulp chamber floor, since the gutta-percha issues from the instrument sufficiently thermosoftened as to be able to fill any accessory canals that may be present.

VERTICAL EXTENT OF THE THREE-DIMENSIONAL OBTURATION

Cemento-dentinal junction

As already suggested in Chapter 15, many authors, in agreement with Grove[19] (1929), maintain that the canal obturation must stop at the cemento-dentinal junction, which corresponds to the maximal apical constriction. The pulp tissue terminates at this point, and the tissue of the periodontal ligament begins. The walls are no longer made of dentin, but cementum.

In theory, this view is correct in that the apical constriction should ensure a good barrier to the filling material, which must maximally respect the periodontium. By obturating to this point, the root canal is obturated without invading the periapical tissues. Physiological closure of the root canal by the "great actors of the apex healing mechanism" is favored with the formation of cementum.[36]

In practice, however, things go differently.

As early as 1929, Coolidge[12] wrote that the site of the cemento-dentinal junction is so variable that trying to use it as a landmark is of little help to the endodontist. This junction often has unclear limits and can be found at different levels within the root canal (Fig. 24.57). The cemento-dentinal junction can even be found on the external surface of the root.[43]

Skillen[50] also emphasizes that it is histologically impossible to define a clear line of demarcation between the pulp on one side and the "periodontal membrane" on the other, so that it is also histologically impossible to find a point within the root canal where the pulpal tissue ends and the periodontal tissue begins (Fig. 24.58).

In agreement with Coolidge, Orban[35] states that from a practical point of view it is not possible to use the cemento-dentinal junction as a boundary of the endodontic obturation and that when it is identified, more often than not it is by chance.

One must also keep in mind that, also from a practical point of view, relying on tactile sensation to localize the cemento-dentinal junction as the site of maximal apical constriction can often be misleading. The maximal constriction of the canal lumen may be due to the presence of a narrowing of the canal (Fig. 24.59) or to a calcification that may vary in distance from the true end of the endodontium (Fig. 24.60).

In conclusion, for both histological and clinical-practical reasons, it is unfortunately not possible, however desirable, to exactly terminate the obturation each time at the cemento-dentinal junction.

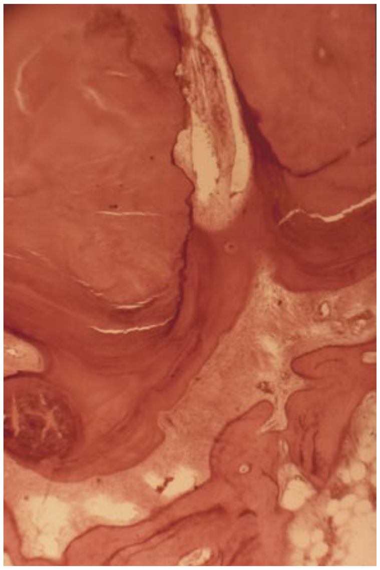


Fig. 24.57. The cemento-dentinal junction is difficult to locate, even histologically.

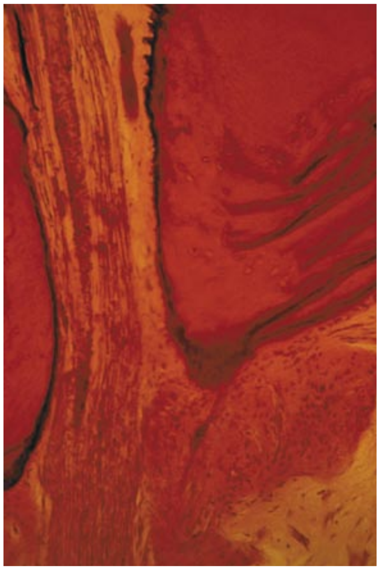


Fig. 24.58. The neurovascular bundle of the pulp has the same characteristics both before and after having crossed the apical foramen.

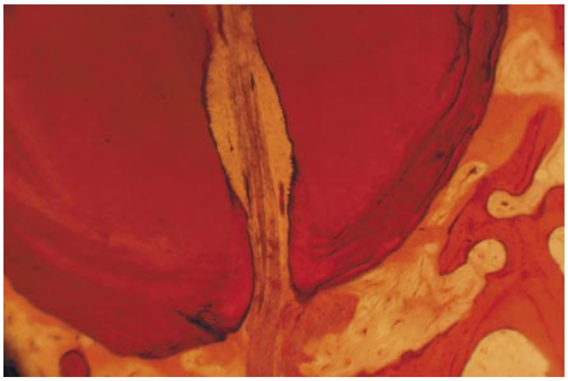


Fig. 24.59. The apical constriction in this case is due to a narrowing of the canal lumen, not to the cemento-dentinal junction.

Fig. 24.60. In this case, the apical constriction is due to the presence of a calcification distant from the cemento-dentinal junction, which is also difficult to identify.

Closure of the end of the root with radicular cement, however possible and desirable, is more easily demonstrable in experimental animals than in man (Fig. 24.61). What is more, it is not necessary for the health or function of the apical periodontium.[43]

Langeland[24] states that there are very few researchers who have histologically demonstrated closure by serial sections: which is often interpreted as biological closure of the apex is in reality the dentin of the wall of the root canal, which with respect to the section under examination, turned in another direction.

Still according to Langeland,[40] the deposition of calcified tissue into the pulp stump could not be considered a physiological process of healing: in general pathology calcification, except for the deposition of calcium salts during bone turn-over, is defined as "the deposition of calcium salts in dying or dead tissue".[41] Therefore, terms like "biological closure" or "physiological closure" do not appear correct, since they are phenomena which occur in the presence of inflammation.

Finally, in a recent article Ricucci and Langeland[40] say that the apical limit of canal instrumentation and obturation should not be the radiographic terminus of

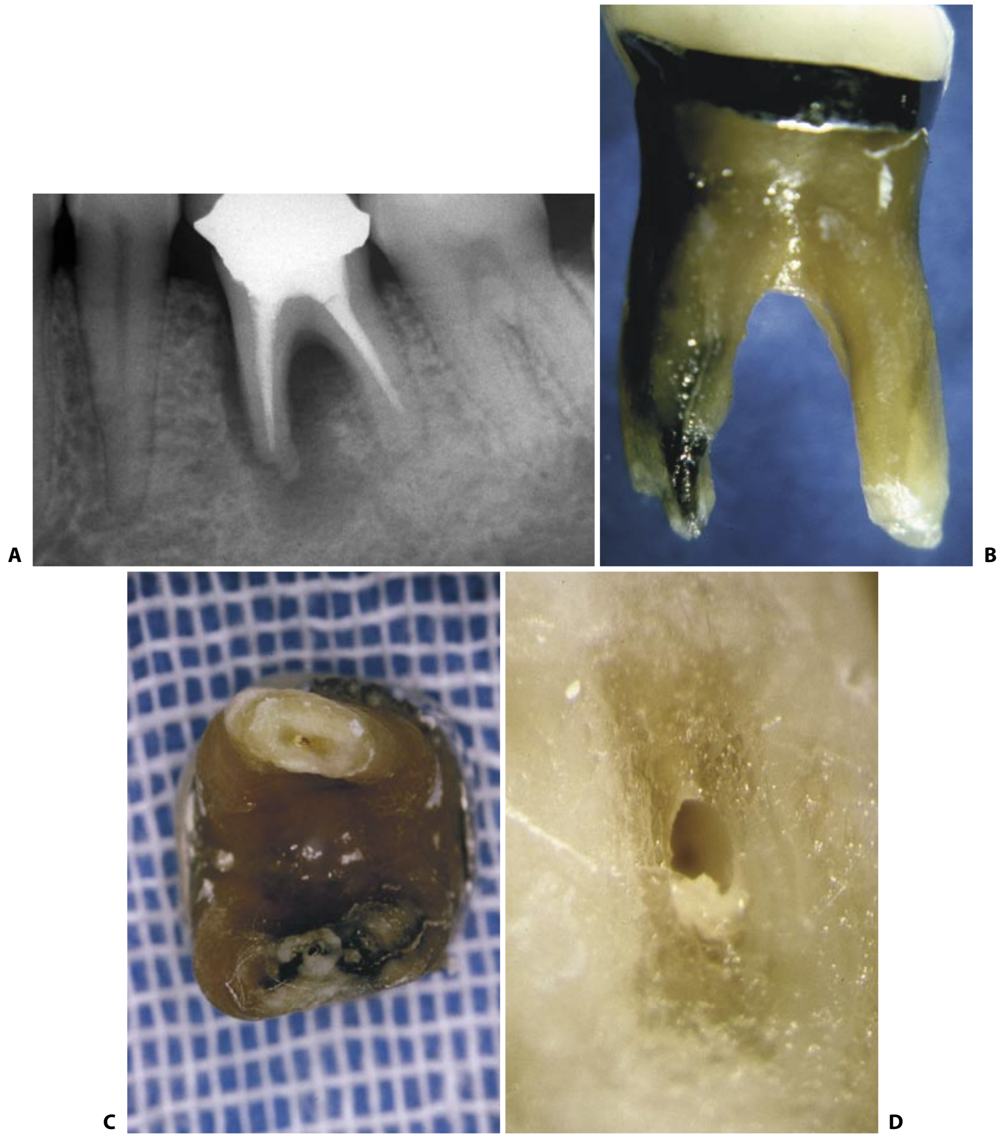


Fig. 24.61. **A.** The first lower molar of this patient has been treated endodontically with the lateral condensation technique, staying short of the radiographic apex, to let the "biologic" closure of the apical foramen happen by the "great actors of apical healing". The tooth has a vertical root fracture of the mesial root and therefore has to be extracted. **B.** The vertical root fracture is evident on the extracted tooth. **C.** The photograph is showing the apical foramina of the two roots. **D.** The foramen of the distal root at higher magnification: the foramen is still wide open and the unfilled portion of the root canal can act as a reservoir of bacteria and obviously cause an endodontic failure!

Fig. 24.62. In such a case, to terminate the instrumentation and obturation at the "constriction" means to remain 7 or may be even more millimeters short, since the calcification (which is a "constriction") is located coronally and will impede a more apical position of the instruments, to reach the "correct" working length.

the canal, nor should it be the cemento-dentinal junction or the distance of 1 mm from the radiographic apex, but rather the "apical constriction", the anatomical location of which cannot be clinically determined with accuracy (since the distance between the apical constriction and the radiographic apex is "non-measurable" and "ever-changing"), but it has been demonstrated[21] as far as 3.8 mm from the anatomic apex (!).

According to these authors, "the only way to localize the apical constriction is to have adequate radiographs, knowledge of anatomy and (*most of all!*) tactile sense, while apex locators are of no help". In other words, according to these authors, "the instrumentation and the obturation should terminate where the instruments stop" (*and they stop just because with their fingers the authors are not capable of moving them more apically!*) (Fig. 24.62). And all this in respect of the apical pulp stump, "which is always vital, even in presence of an apical lesion, and if it becomes necrotic, it will be removed by the periodontal circulation and by a foreign body reaction"(!).

On the other hand, many authors like Blaskovic et al.[5] and Olson et al.[34] say that the arbitrary rule that canal preparation should terminate 1 mm short of the radiographic apex is becoming increasingly unacceptable in modern endodontic therapy. This technique could result in instrumentation short of the true canal terminus, possibly leaving necrotic and infected debris behind and leading to treatment failure.

According to Schilder,[47] having three-dimensionally obturated a root canal as far as 0.5-1 mm from the radiographic terminus of the canal is in practice equivalent to having filled it completely. It is this that has led to the success of the therapy, more than respect for the "great actors of healing at the apex", as suggested by Pecchioni.[36]

In defining the apical region and to clarify the confusion in the literature, one must recall that the radiographic terminus of the canal refers to the point at which the endodontic instrument within the root canal radiographically encounters the external profile of the root. It is not to be confused with the anatomical apex, which represents the geometric vertex of the root, or with the radiographic apex, which represents the anatomic apex as seen on the radiograph. The endodontic or physiologic apex indicates the cemento-dentinal junction, which usually (but not necessarily) corresponds to the maximal point of narrowing of the canal lumen. The term apical foramen refers to the opening of the root canal on the external surface of the root (Fig. 24.63).

Radiographic terminus of the canal

Some authors claim that it is preferable to extend the obturation to the radiographic terminus of the canal, since this gives the greatest assurance of having obturated the entire root canal system, even if this sometimes leads to overfilling of few fractions of a millimeter beyond the apex.

Obviously, we all agree with Schilder that some very curved canals emerge in the roots at points that are not radiographically visible, several millimeters away from the anatomic apex. In these cases, obturation to the radiographic terminus of the canal is to be avoided, because this would entail considerable excess. In such exceptional cases, filling the root canal 0.5-1 mm short is also to be avoided, because the filling material would be equally in the periapical tissues (Fig. 24.64).

Nonetheless, these cases are the exception and not the rule, and they must be treated to the "electronic apex".

The successful outcome of cases obturated to the radiographic terminus of the canal (Fig. 24.65) is therefore due to the completeness and three-dimensionality of the obturation. The minimal overfilling is irrelevant, just as minimal underfilling is.

Sjogren et al.[49] looked at root canals filled short and long, with positive and negative culturing results in each group. They showed that high success rates were achieved regardless of long or short filling when the culture came back negative, but when the culture came back positive only the fully filled cases worked predictably. The authors theorized that success was achieved because the remaining bacteria were entombed in the canal. Infected or not (among the bacteria present at the time of root filling in cases that healed successfully, the authors of the study found Peptostreptococcus anaerobius, Actinomyces naeslundii, Fusobacterium nucleatum and Enterococcus faecalis), all of the cases worked when the canals were filled to or beyond the terminus! From this interesting study, we can conclude the following: because no one can insure sterility in any given root canal space, the surest chance of clinical success is gained when root canal systems, in all of their complexities, are filled to their full apical and lateral extents, even though that means that there may be surplus material beyond the confines of the root canal space. This is in agreement with the findings of Peters et al.[38] who demonstrated that the presence of a positive bacterial culture at the time of filling did not influence the outcome of treatment.

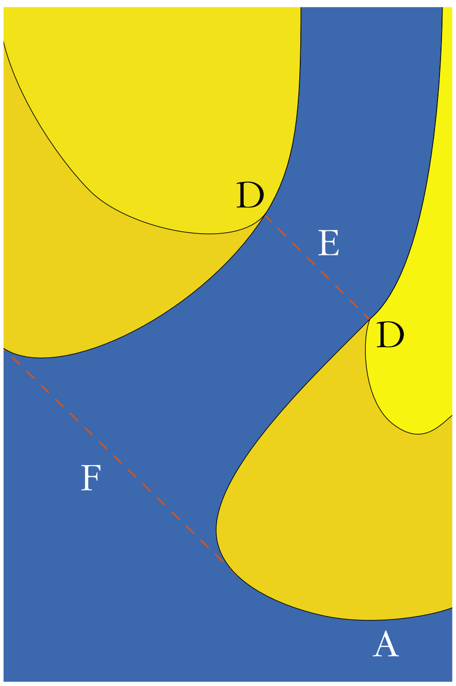


Fig. 24.63. A: Anatomic apex. F: Apical foramen. D: Cemento-dentinal junction. E: Endodontic apex.

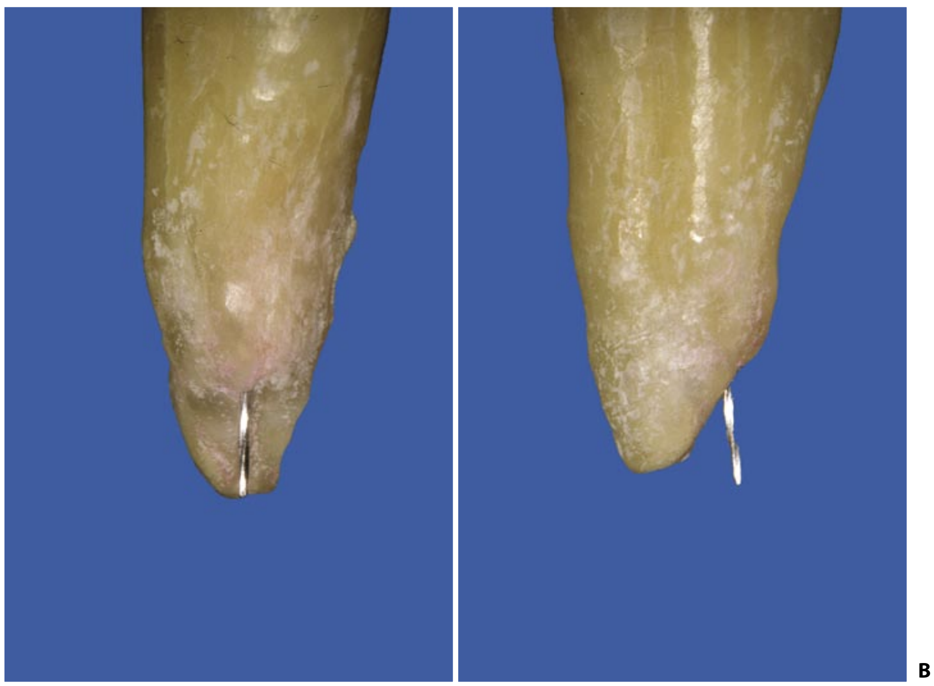


Fig. 24.64. The apical foramen of this lower premolar is not radiographically visible. Note the distance of the foramen from the vertex of the root. **A.** Buccal aspect. **B.** Mesial aspect.

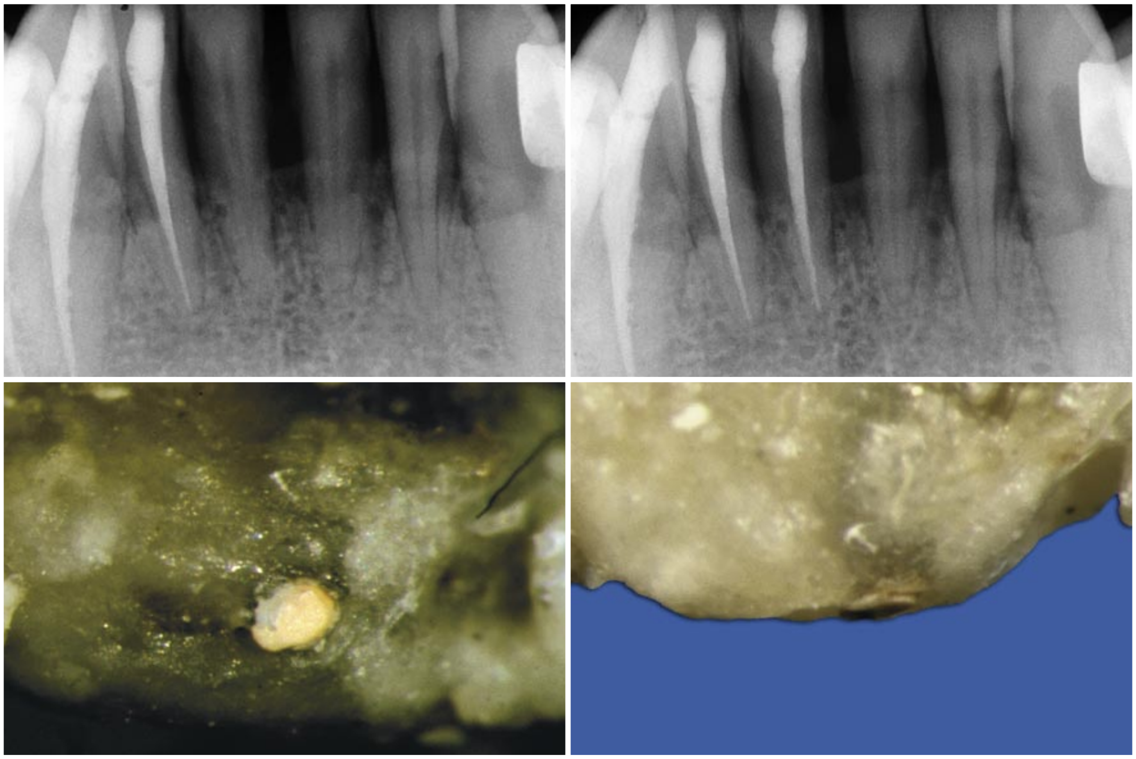


Fig. 24.65. **A**. Preoperative radiograph of a right lower central incisor requiring endodontic treatment for periodontal and prosthetic reasons. **B**. Postoperative radiograph: the obturation has been performed to the radiographic terminus of the canal. **C**. The tooth was extracted for periodontal reasons eight years later and was photographed under a stereomicroscope. Note the gutta-percha which seals the apical foramen without the least extrusion. **D**. The same apex photographed from another angle.

Especially in the case of necrotic teeth, Pecchioni[36] is also in favor of more complete filling than that performed to 0.5-1 mm from the radiographic apex, since one must avoid leaving gangrenous or infected débris or an empty space at the apical end of the root canal.

OVERFILLING AND OVEREXTENSION

At this point, it is necessary to make a distinction between over- and under-filling and between over- and under-extension.

Over and underextension refer only to the vertical component of the obturation beyond or short of the apical foramen.

Underfilling refers to an obturation that has been performed inadequately in all dimensions (e.g., a short and narrow silver cone in a longer and wider root canal, or a short obturation only in cement full of voids).

Overfilling refers to an obturation that has been performed in three dimensions in which a small portion of material extrudes beyond the foramen.

Therefore, the situation of a canal with a slight overfilling is quite different from that of a canal with a vertical overextension and an underfilling. In the former, the obturation fills the entire endodontium in its three dimensions and an excess of material issues from the apical foramen. In the latter case, the obturation material protrudes beyond the apex without sealing the apical foramen and thus without three-dimensionally obturating the root canal system.

The cause of failure in these cases is not the tip of the silver cone or of the gutta-percha that "pricks" the periodontium, but the fact that it does not seal the apical foramen. Surgery may be indicated, just to improve the apical seal of the root canal system (Fig. 24.66).

Ingle[23] states that in Endodontics one achieves a high success rate in spite of overfillings.

Weine[56] states that fortunately, since gutta-percha is so well tolerated by periapical tissue, only rarely is a post-treatment failure noted in conjunction with an overfilling. Most instances show no abnormal radiographic evidence (Fig. 24.67), and in some cases there is an actual amputation of the overfilling with phagocytosis of the extra mass (Figs. 24.68, 24.69).

Schilder[43] claims that he has never found a case of failure secondary to overfilling.

Those cases that are labelled failures because of the presence of material beyond the apex are actually cases of underfilling with vertical overextension of the obturation and the failure depends on the presence of bacteria left inside the root canal system which has not been three-dimensionally obturated.[27] In the literature it has been widely demonstrated that the major factors associated with endodontic failures are inadequate root canal debridement or incomplete root canal seal,[16,26,32] while the apical extent of root canal fillings is not a determining factor.[22,48,49]

The excess material beyond the cemento-dentinal junction plays no role in healing[13,20] and can be considered irrelevant. It should be avoided, because it is unnecessary and because it may bother the patient at the time of obturation.[43]

Exclusive clinical research on the influence of the excess material on the treatment failure cannot be

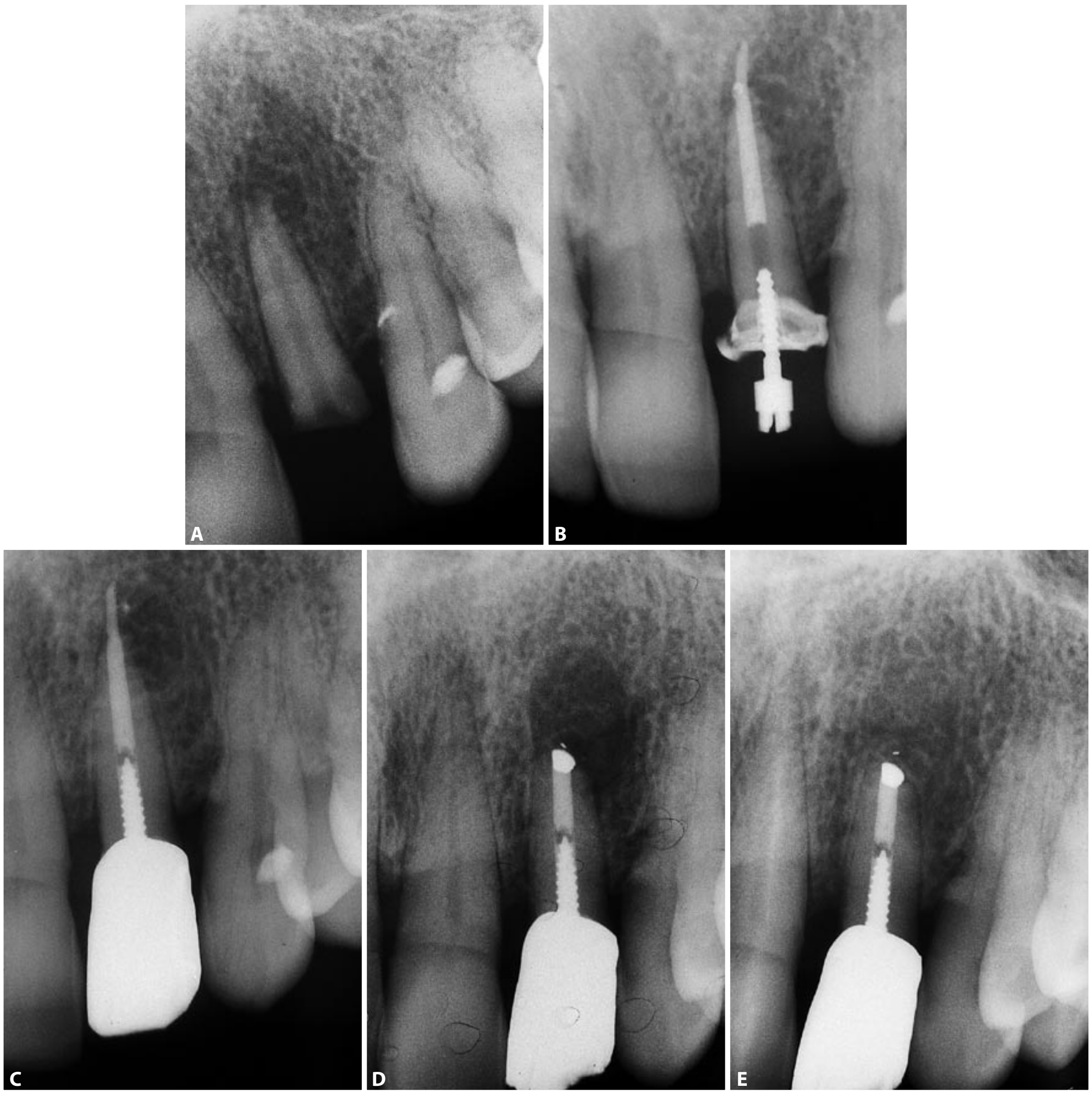


Fig. 24.66. Excess material is an indication for surgical treatment only if it does not seal the root canal system. In this case, more than removing the excess, the procedure is aimed at improving the seal by a retrograde approach. **A.** Preoperative radiograph of an upper left lateral incisor. Note the cylindrical preparation of the canal. **B.** Postoperative radiograph: because of the type of preparation and the preceding apical over-instrumentation, the gutta-percha cone has slid beyond the apex and for fear of pushing it further it has not been compacted adequately. Although it protrudes beyond the apex, this gutta-percha cone does not seal. The obturation is overextended, but the root canal is underfilled. **C.** After 24 months, the lesion has increased and a fistula has developed. Now there is the indication for a retrograde filling. **D.** Postoperative radiograph. **E.** Two years after the surgical procedure.

Fig. 24.67. Radiograph of the upper left central incisor, reimplanted after traumatic avulsion 3 years before. The root has had a replacement resorption. The gutta-percha radiographically appears to be in direct contact with bone and there is no radiographic evidence of inflammation.

taken into consideration, since they exclude too many variables regarding the cleaning and shaping of these root canals and the true three-dimensionality of their obturation.

Histologic studies on experimental animals by Deemer and Tsaknis,[13] and by Tavares et al.[53] have demonstrated that gutta-percha is perfectly tolerated by the surrounding tissues. Their results agree with those of Schilder[44] on human specimens.

Gutierrez et al.[20] have also demonstrated in experimental animals that gutta-percha in contact with the tissues and tissue fluids disintegrates and is subsequently removed by macrophages. This corresponds to the clinical phenomenon noted in the periapical region of human teeth.

Bergenholtz et al.[2] state that in the case of overfillings the filling material per sé is not necessarily the immediate cause of failure. Gutta-percha, both in vitro in cell cultures,[51] and in in vivo implants in experimental

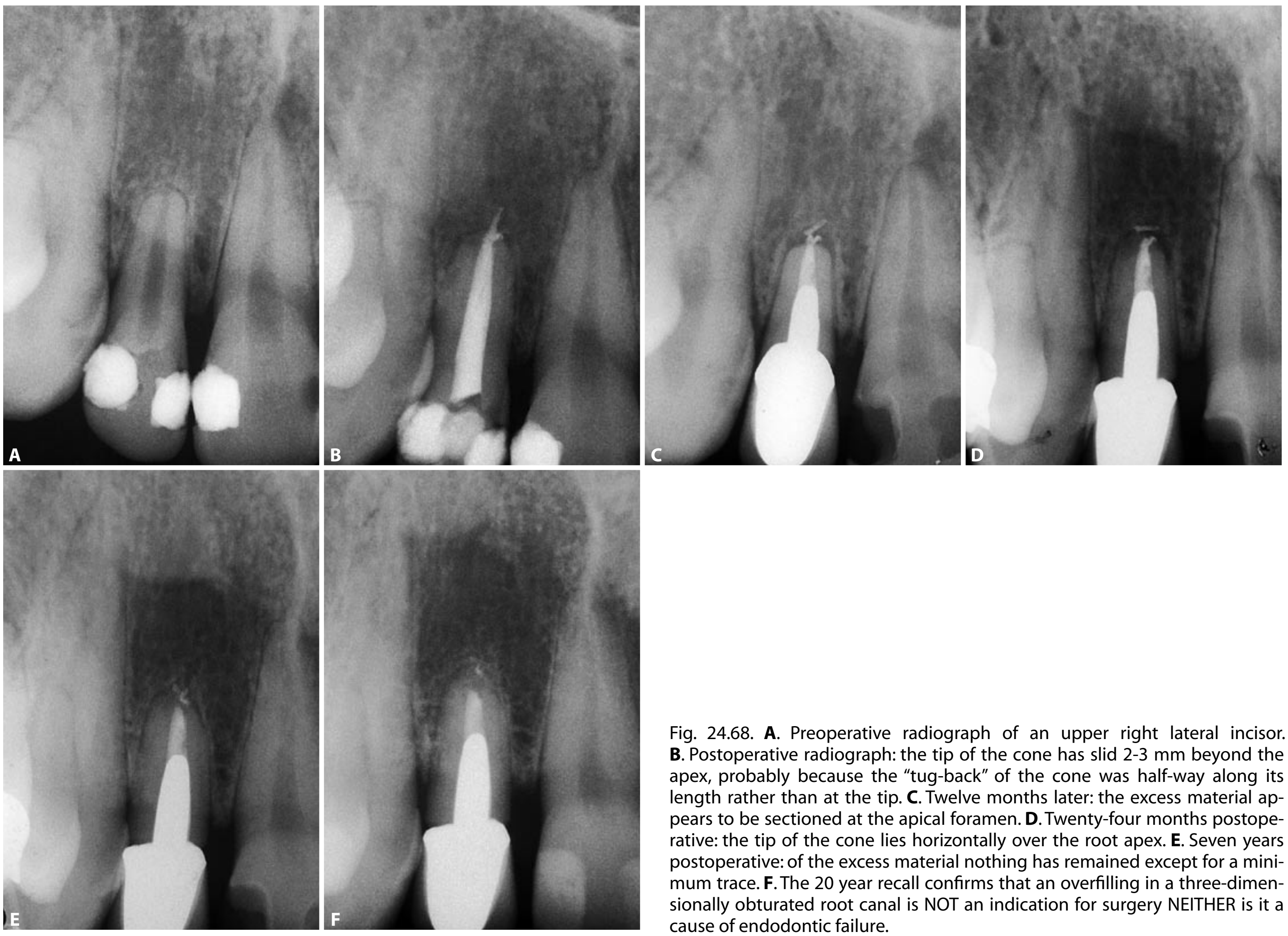


Fig. 24.68. **A**. Preoperative radiograph of an upper right lateral incisor. **B**. Postoperative radiograph: the tip of the cone has slid 2-3 mm beyond the apex, probably because the "tug-back" of the cone was half-way along its length rather than at the tip. **C**. Twelve months later: the excess material appears to be sectioned at the apical foramen. **D**. Twenty-four months postoperative: the tip of the cone lies horizontally over the root apex. **E**. Seven years postoperative: of the excess material nothing has remained except for a minimum trace. **F**. The 20 year recall confirms that an overfilling in a three-dimensionally obturated root canal is NOT an indication for surgery NEITHER is it a cause of endodontic failure.

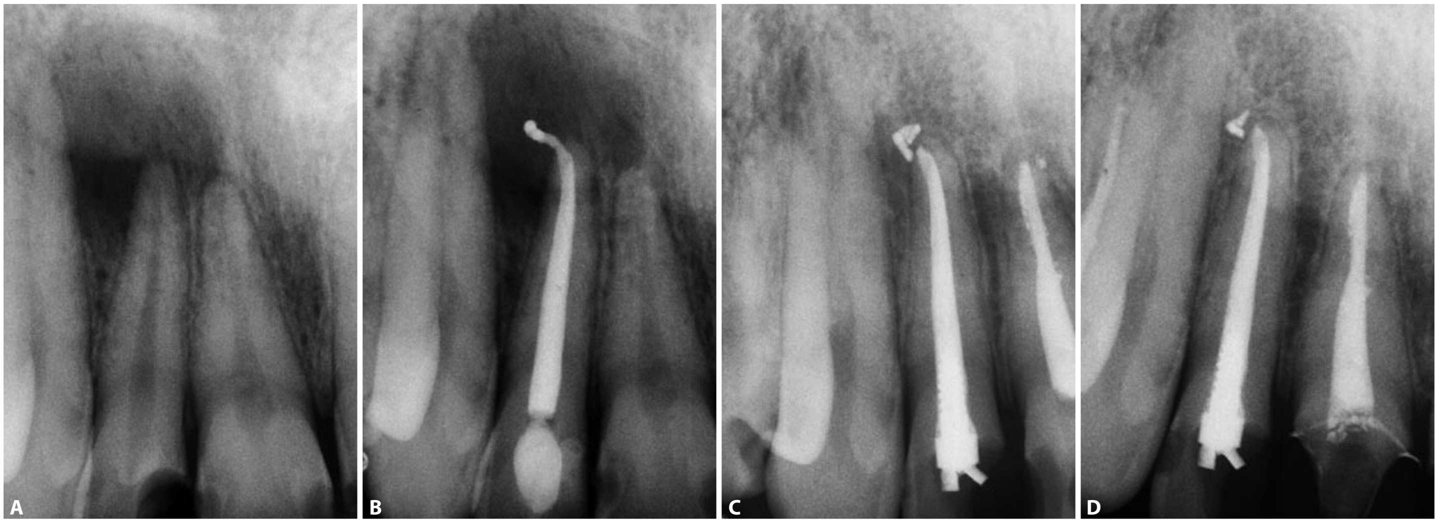


Fig. 24.69. **A**. Preoperative radiograph of an upper right lateral incisor. **B**. Postoperative radiograph. Note the gross excess of gutta-percha, which protrudes beyond the apex by almost 3 mm. **C**. Two-and-a-half years later. The lesion has healed and the excess appears to be sectioned. **D**. Five years later.

animals,[14,52] has been shown to be compatible with living tissues. Recent radiographic studies have showed that given time, the extruded canal filling materials would be removed from the periradicular tissues.[1,22] Consequently, the factors that impede healing in cases of overfilling are to be investigated elsewhere.

Regarding the greatly feared foreign body reaction around the excess material, Yusuf[58] in his recent article has demonstrated inflammation around the small pieces of dentin and cement found beyond the apex in the granulation tissue, where they act like a foreign body. In contrast, small pieces of amalgam or other canal obturation materials were usually associated with a fibrous reaction and encapsulation, without active inflammation.

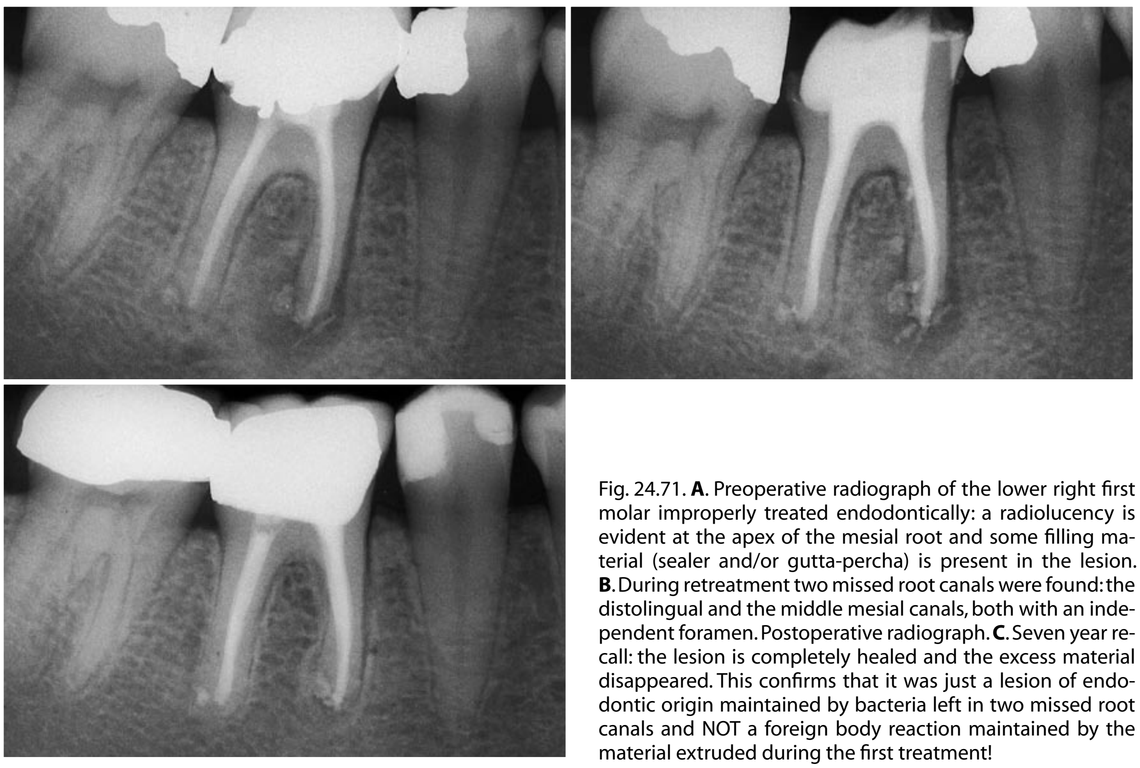
This is further confirmation of the tissue tolerance of canal filling material. Thus, accidental overfilling of a properly cleaned, shaped, and three-dimensionally filled canal is not an indication for surgical removal of the excess (Figs. 24.70, 24.71).

If this is true for the excess of gutta-percha, it is even more when the excess is made with sealer which, for Pulp Canal Sealer, it has been demonstrated to have good biocompatibility. Pertot et al.[37] in experimental animals have demonstrated that 12 weeks after the root canal sealer was implanted into the mandibular bone, macrophages, lymphocytes and plasma cells were no longer present (Fig. 24.72). In most cases, new bone was observed in direct contact with the sealer. The absence of an even moderate inflammatory

Fig. 24.70. **A**. Preoperative radiograph of the lower right first molar improperly treated endodontically: the distal canal is underfilled and each of the mesial canals have a gutta-percha cone overextending in the periapical tissues. **B**. Intraoperative radiograph: the attempt to remove the gutta-percha from beyond the foramen failed (Continued).

C D E

Fig. 24.70. (Continued) **C**. Postoperative radiograph: the two cones are still present in the lesion. **D**. Seven month recall. **E**. Three year recall: the lesion is completely healed and the two gutta-percha cones completely disappeared. The radiolucency was obviously a lesion of endodontic origin maintained by bacteria left in the root canal system and NOT a foreign body reaction, maintained by two pieces of gutta-percha!

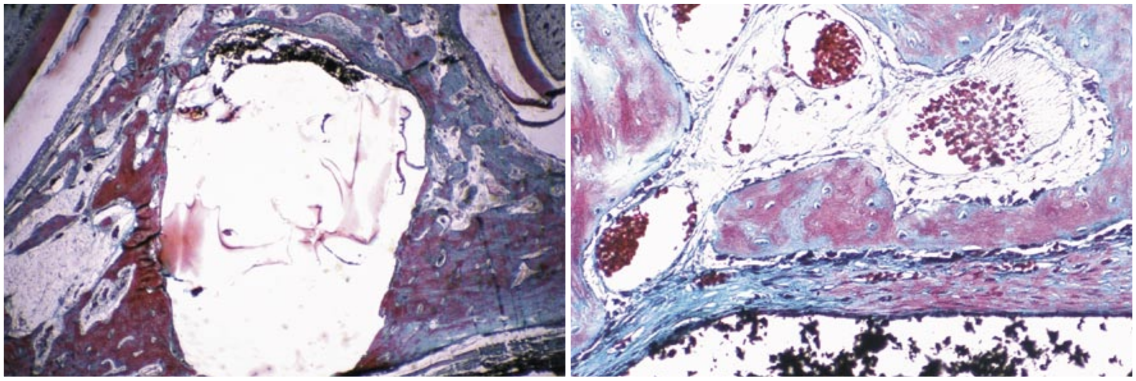


A B C

Fig. 24.71. **A**. Preoperative radiograph of the lower right first molar improperly treated endodontically: a radiolucency is evident at the apex of the mesial root and some filling material (sealer and/or gutta-percha) is present in the lesion. **B**. During retreatment two missed root canals were found: the distolingual and the middle mesial canals, both with an independent foramen. Postoperative radiograph. **C**. Seven year recall: the lesion is completely healed and the excess material disappeared. This confirms that it was just a lesion of endodontic origin maintained by bacteria left in two missed root canals and NOT a foreign body reaction maintained by the material extruded during the first treatment!

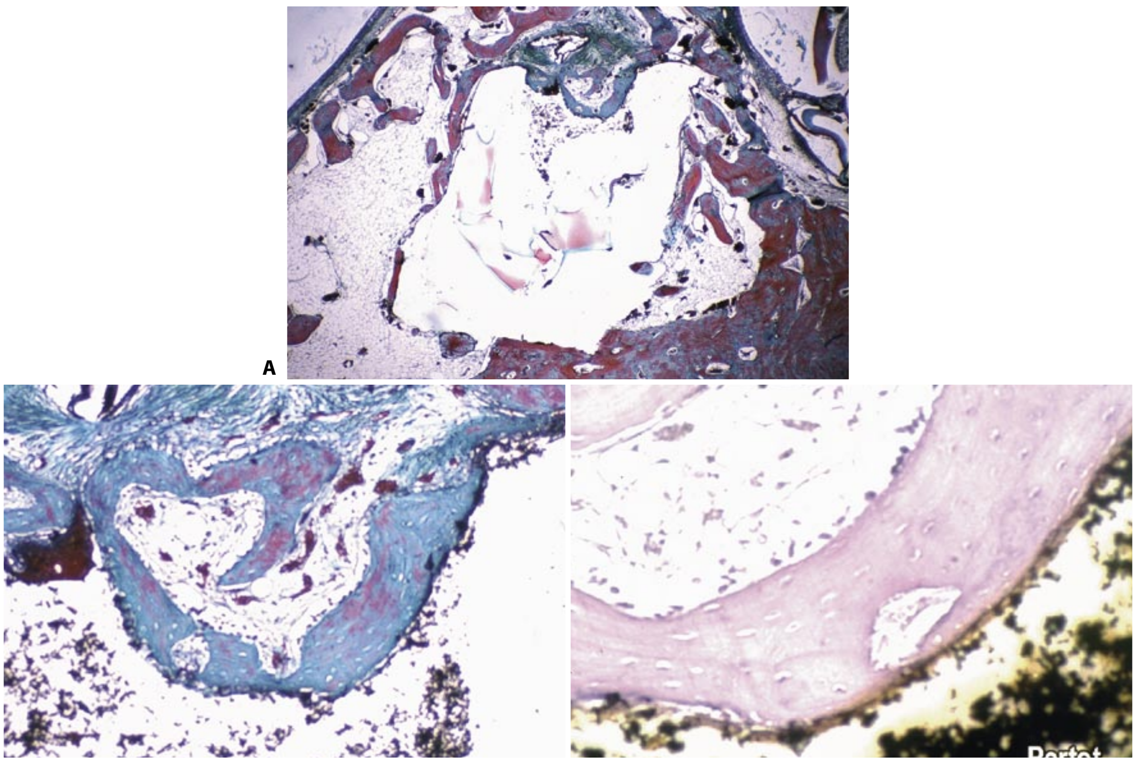
reaction at 12 weeks seemed to indicate that the reported in vitro toxicity of the freshly mixed sealers[28-30] decreases and disappears with time (Fig. 24.73).

If we can accept the material that protrudes beyond the apical foramen by many millimeters in cases of endodontic implants, even more so can the fraction of a millimeter of gutta-percha that may accidentally protrude beyond the apex in a three-dimensionally filled canal be accepted (Figs. 24.74, 24.75).



A **B**

Fig. 24.72. Osseous reaction to implanted Pulp Canal Sealer at four weeks. **A**. Normal bone marrow spaces (Original magnification: x 5. Masson's Trichrome). **B**. Layer of fibrous connective tissue between Pulp Canal Sealer and bone, without evidence of inflammatory cells. Normal appearance of the bone with living osteocytes and borded by a layer of osteoblasts (Original magnification x25. Masson's Trichrome) (Courtesy of Dr. Wilhelm-Joseph Pertot).



A **B** **C**

Fig. 24.73. Osseous reaction to implanted Pulp Canal Sealer at 12 weeks. **A**. Normal bone marrow spaces with new-bone ingrowths into the implant (Original magnification x5. Masson's Trichrome). **B**. New-formed bone is in direct contact with Pulp Canal Sealer without fibrous interposition or inflammatory cells (Original magnification: x10. Masson's Trichrome). **C**. Normal appearance of new-formed bone with living osteocytes and normal bone marrow (Original magnification x50. Hematoxylin-eosin) (Courtesy of Dr. Wilhelm-Joseph Pertot).

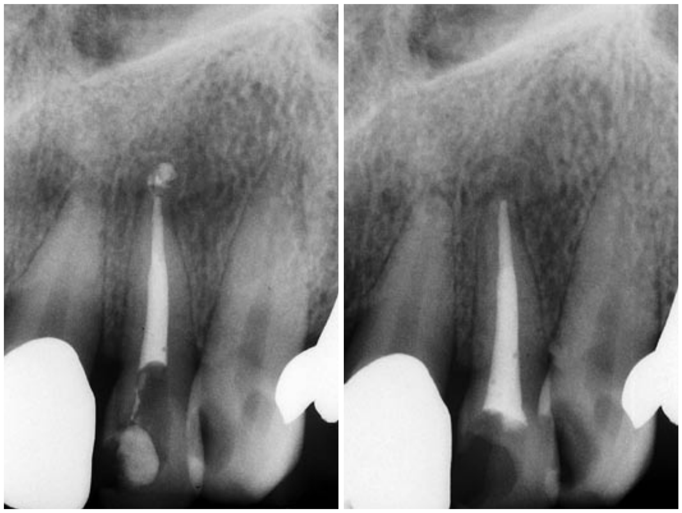

A B

Fig. 24.74. **A**. Postoperative radiograph of an upper left lateral incisor. **B**. Seven months later: the excess sealer has disappeared.

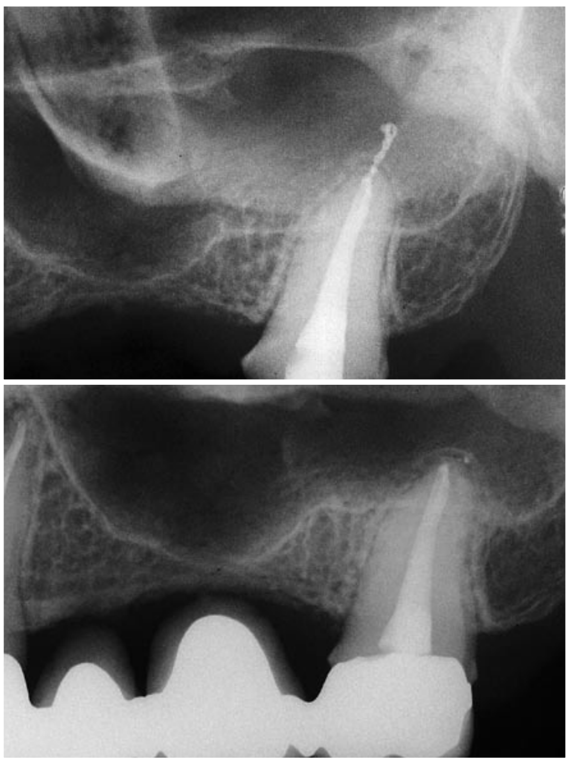

A
B

Fig. 24.75. **A**. Postoperative radiograph of an upper left second molar. **B**. Eight months later: the excess material is no longer present.

OBTURATION OF COMMUNICATING AND CONFLUENT ROOT CANALS

When we perform an obturation of two canals that lie in the same root and each time we suspect the presence of communications between canals of two different roots, we must obturate the two canals simultaneously.[10] This prevents the obturating material introduced into the first canal during the compaction procedure from passing retrograde into the second canal through the natural communication, hindering proper filling of the latter (Fig. 24.76).

However, the approach is different:

a) in the case of two canals merging to a single foramen (Fig. 24.77)
b) in the case of two canals communicating, with independent apical foramina (Fig. 24.78).

a) In the case of two canals merging into a single foramen (Figs. 24.79 A, B), the endodontist very often recognizes the convergence only when the radiograph of the cone fit is obtained. Individually, the cones advance unhindered to the desired maximal depth, but when they are placed simultaneously in the various canals, they advance only alternately (Figs. 24.79 C, D): in the mesial root of a lower molar, for example, if the buccal descends, the lingual remains short and vice versa.

This is clear proof that the two canals merge together, and only one of the two cones can be engaged at the apical foramen. The endodontist must thus decide which of the two it is preferable to advance to the apex; it should be the one which has better "tug-back" and that is found in the straighter and easier canal to obturate. The other is then shortened so that it touches the other cone.

As already described on Chapter 15, nonetheless, it is preferable to diagnose the confluence of two canals at a common apex as early as possible to prevent useless over-instrumentation and transportation of the apical foramen, which could occur as a result of cleaning and shaping it twice from two different directions.

At the time of compaction, each of the two cones must be inserted in its canal (SIMULTANEOUS INTRODUCTION), but the compaction must proceed with the cone that has been positioned at the foramen (ALTERNATE COMPACTION). For the sake of convenience, this will be called the "first canal". Only after the successful obturation of the apical third of this canal has been confirmed radiographically (Figs. 24.79 E, F) (the gutta-percha has moved

A B C D

Fig. 24.76. **A**. Preoperative radiograph of a lower left second molar. **B**. Radiograph to verify the working length of the # 20 file at the radiographic terminus of the mesiobuccal canal. **C**. Intraoperative radiograph of the apical condensation of the distal canal: the material has refluxed in a retrograde manner into the mesiobuccal canal through the confluence, which was undetected. The material was then removed and the obturation completed by compacting the gutta-percha simultaneously in the three canals. **D**. Postoperative radiograph.

Fig. 24.77. The mesial canals of this lower first molar obturated by the Schilder technique converge at a common apex.

Fig. 24.78. The two canals of this lower canine have independent foramina but communicate at two different levels.

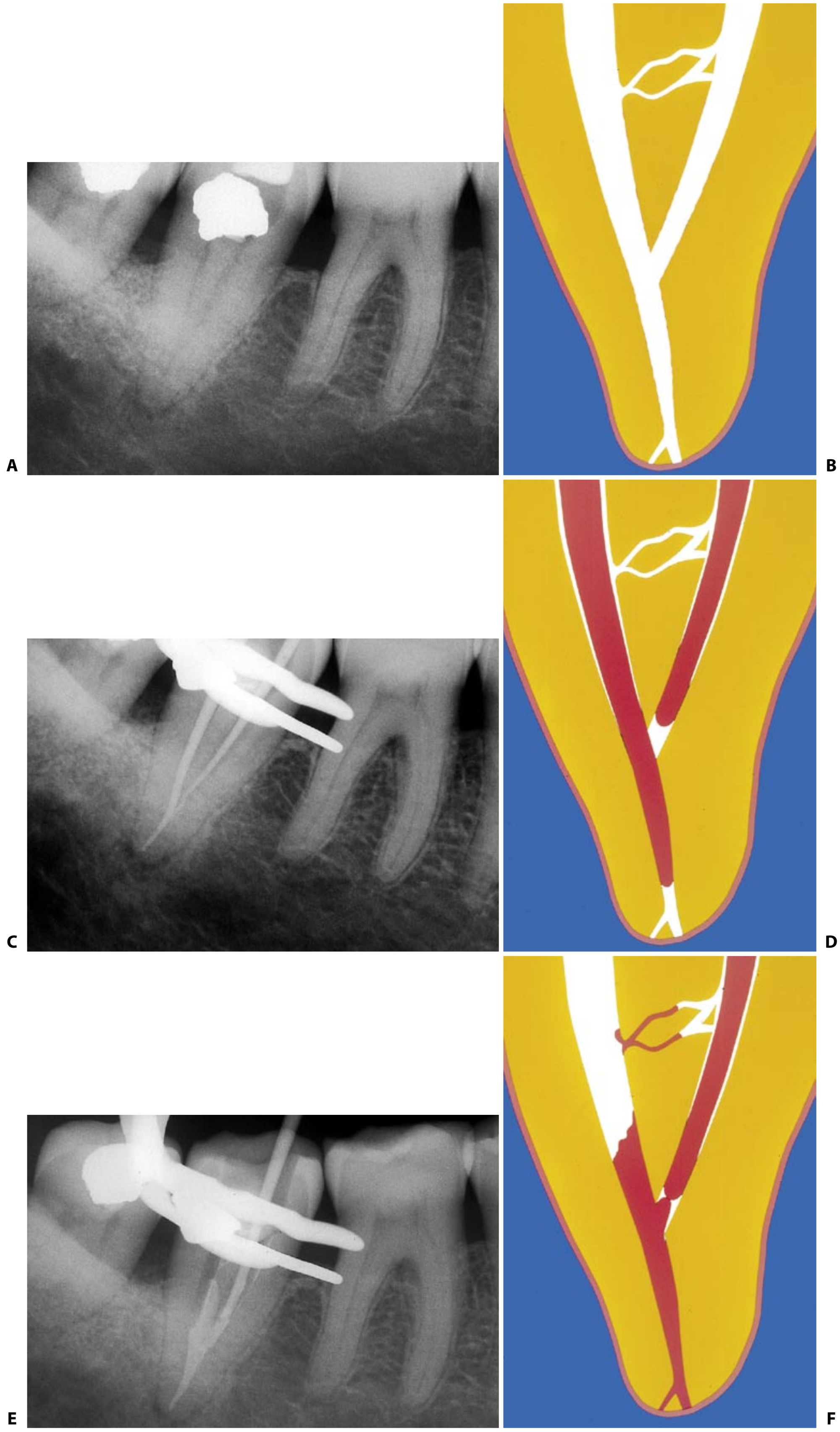


Fig. 24.79. **A**. Preoperative radiograph of a lower right second molar. The tooth shows a single root with only two root canals, one distal and one mesial, which converge at a common apex. **B**. The drawing represents the root of figure A. **C**. Radiograph of the cone fit: the distal cone descends to the end of the preparation, while the mesial stops against the preceding one. **D**. Schematic drawing. **E**. Radiograph of the apical condensation of the distal canal: note that the mesial cone has been introduced into the canal but has not yet been compacted. It will be compacted after this radiograph has been checked for the distal canal. **F**. Schematic drawing (continued).

apically and the obturation appears compacted), can the operator proceed with the compaction of the second cone of gutta-percha that will be pushed, heated, and compacted against the gutta-percha of the first canal (Fig. 24.79 G). If, instead of using this important trick, we perform the simultaneous downpacking in the two canals, we can find ourselves in the situation of a short apical obturation (because the gutta-percha of the first canal was not pushed sufficiently apically) and the impossibility of advancing this mass of gutta-percha further because the cone of the second canal has already been compacted against the first one (Fig. 24.80). This technique of downpacking must always be applied in the mesiobuccal root of the upper molars, after one has ascertained the presence of the me-


G


H


I

Fig. 24.79. (Continued) **G**. The compaction has been completed also in the mesial canal. **H**. Postoperative radiograph: note the extent of the confluence and its complete filling after compaction of the cone of the mesial canal. **I**. Two year recall.

Fig. 24.80. The simultaneous compaction of two cones could impede the correct compaction of the cone fitted to the terminus of the canal.

siopalatal canal (MB2) and its convergence in the mesiobuccal canal (MB1) (Fig. 24.81).

b) In the case of canals that communicate half-way along their length (obviously, this communication cannot be diagnosed, but must always be suspected in the two canals of the same root) but that flow into independent foramina, we must not only simultaneously perform the introduction of the two cones (as in the preceding case), but also their compaction (SIMULTANEOUS COMPACTION). This serves to prevent obstruction, with material that flows there retrograde, of one of the two canals and to have simultaneously good apical control of the obturation in the two distinct foramina. The communication will be filled in more or less equal parts by the gutta-percha of the two cones (Fig. 24.82). This technique of obturation must be applied any time one suspects communications, even among roots that appear to be independent (Fig. 24.83).

As previously indicated, if we want to know early whether there is a convergence of two canals, since this could influence one's approach (for example, the mesiopalatal canal of an upper molar sharing an apex with the mesiobuccal canal can be enlarged less with less risk of weakening of the root), we can make recourse to this small trick: the gutta-percha cone is placed in the canal that has just been prepared, and a small instrument (# 08 or # 10 K file) is introduced into the other canal we wish to determine whether its apical foramen is independent or not. If the foramen is shared, the file, working in the canal, will leave its impression on the gutta-percha cone. In this way, it is

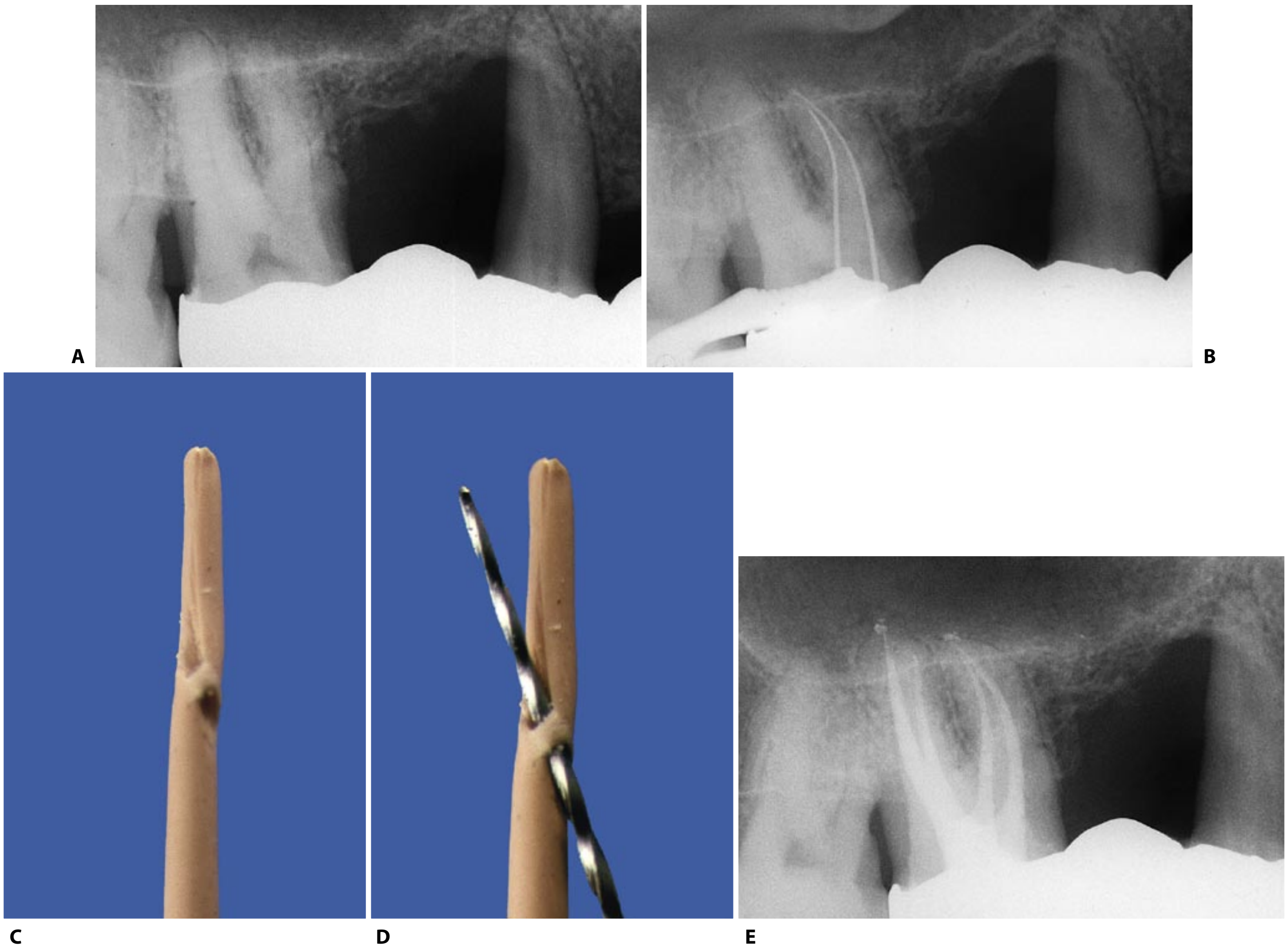


Fig. 24.81. **A**. Preoperative radiograph of an upper right first molar. **B**. Two files have been introduced to radiographically document the confluence between the mesiobuccal and mesiopalatal canals. **C**, **D**. Clinical confirmation of the confluence: the instrument introduced in the mesiopalatal canal, which was yet to be prepared, has traversed the gutta-percha cone introduced in the mesiobuccal canal, which had just been prepared. **E**. Postoperative radiograph.

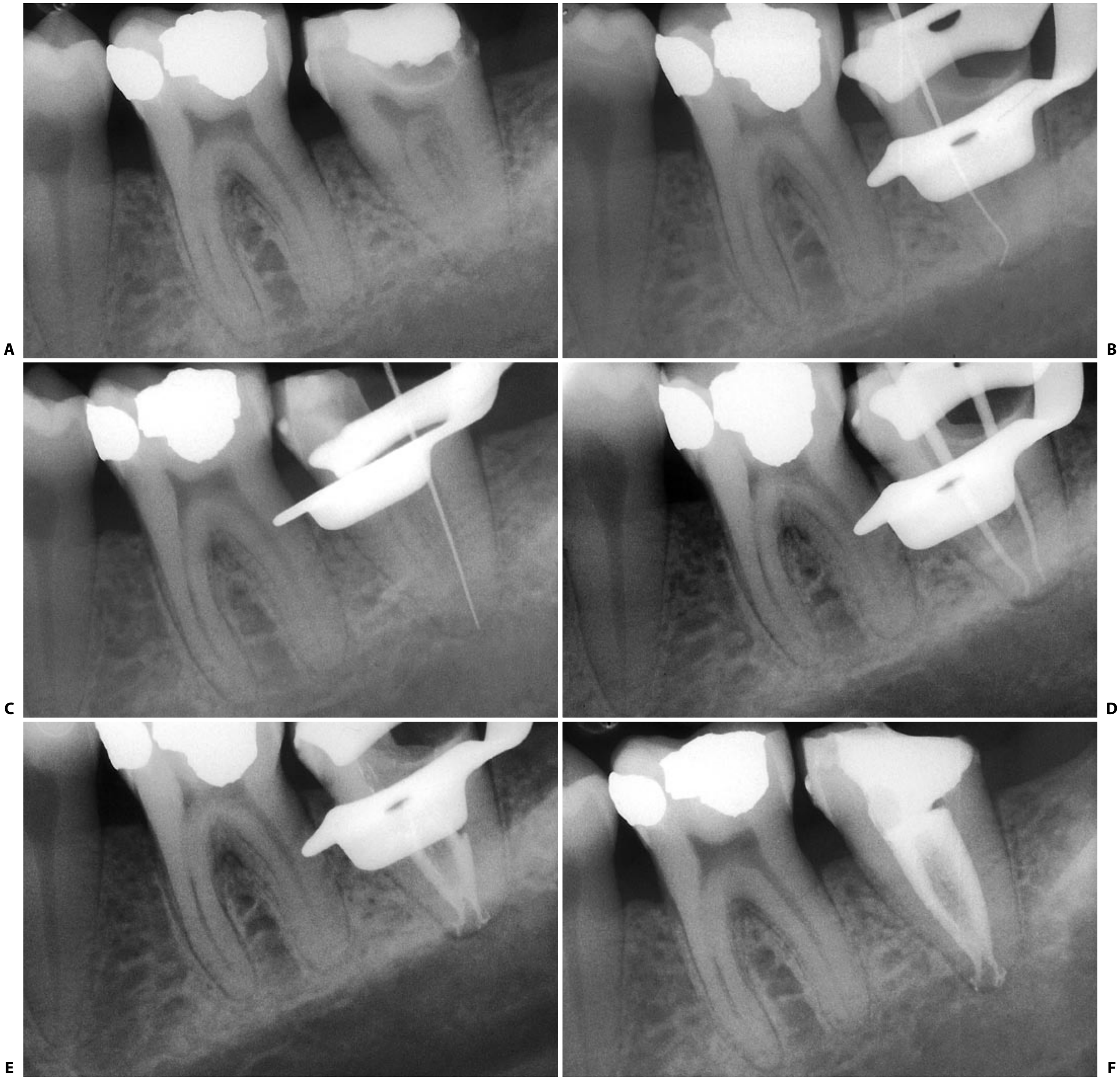
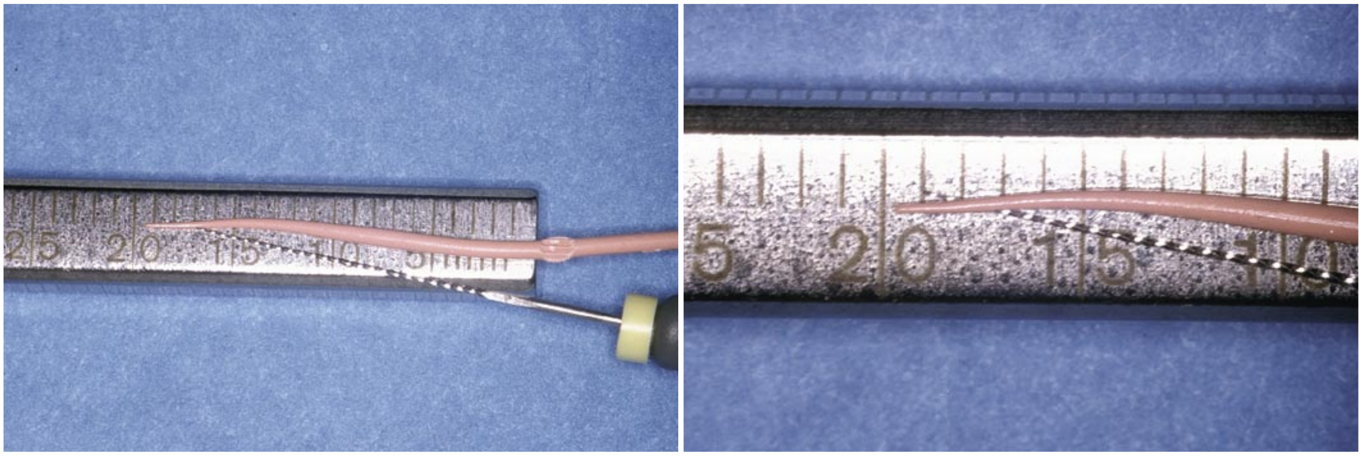


Fig. 24.82. **A**. Preoperative radiograph of a lower left second molar: the tooth has fused roots. **B**. Radiograph of a # 20 file at the radiographic terminus of the only mesial canal. **C**. Radiograph of the # 20 file at the radiographic terminus of the distal canal. **D**. Radiograph of the cone fit: the canals have independent foramina, but because they are in two fused roots, simultaneous compaction was performed, as the presence of communications was suspected. **E**. Radiograph of the apical condensation: note that filling of the communication at 2-3 mm from their respective foramina has been performed. **F**. Postoperative radiograph.

Fig. 24.83. **A**. Preoperative radiograph of a lower right second molar: the two roots seem to be separated by a bifurcation and fused at the apices. **B**. Intraoperative radiograph of the cone fit. Because the presence of communications was suspected, simultaneous compaction was performed. **C**. Radiograph of the apical condensation. **D**. Postoperative radiograph. **E**. Two year recall.

possible to determine whether there is a confluence and at how many millimeters from the foramen it is located (Fig. 24.84).

In this author's opinion, the introduction of two instruments into the two canals with the aim of demonstrating a possible confluence is not free of risks or false responses. If the canals are narrow, we can cause fracture of one of the two instruments. If a canal has already been prepared and thus can receive a larger instrument, the small instrument introduced in the other canal can pass between the spirals of the preceding instrument and the dentinal walls, arriving equally at the foramen and concealing in this way the tactile sensation of the confluence.



A B

Fig. 24.84. **A**, **B**. From the impression left on the gutta-percha cone it is possible to know that two canals are confluent and also the distance between the foramen and the confluence: the working length of the confluent canal will be the point were they merge together.

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25

The Continuous Wave of Condensation Obturation Technique

L. Stephen Buchanan

THE PREDECESSORS

During the 1980's, the Vertical Condensation Technique[4] (Fig. 25.1) was significantly improved through the introduction of two electronic devices: the Touch-and-Heat electric heat carrier by Analytic Technology and the Obtura gutta-percha gun by Obtura Corp. These devices helped to make 3D warm gutta-percha obturation more accessible to clinicians at all skill and experience levels.

Fig. 25.1. Mandibular molar with severe multi-planar curvatures in the mesial canals as well as an abrupt apical curvature in the distal canal. When this case was done in 1979 there was only one technique that could have successfully shaped these root canals without ledging, ripping, or transportation—the Serial Step-Back Schilder Technique.

The Touch'n Heat electric heat carrier

Introduced in 1981 by Johan Masreillez of Analytic Technology, the Touch'n Heat electric heat carrier was faster, better, and safer than flame-heated heat carriers. While flame-heated heat carriers required five to 10 seconds to be adequately heated in a Bunsen burner flame, the Touch'n Heat required one-half second to reach full temperature. More importantly, while a flame-heated carrier cools every second after its removal from the flame, the electric heat carrier could generate heat for an indefinite period of time, giving the doctor more control over the procedure. In addition to speed and control, the Touch'n Heat provided greatly enhanced safety and consistency of result to warm gutta percha obturation.

Dentists could then be passed a cold electric heat carrier, touch its button while taking the instrument into a root canal, and have full heat at the tip of the heat carrier before it touched the apical mass of gutta-percha. Other safety features included the elimination of an open flame in the operatory and the fact that, four seconds after releasing the switch, the heat carrier was safe to touch with gloved fingers.

For the first time, dentists had complete control of the duration of heat applied, allowing more adequate thermo-softening of gutta-percha, less likelihood of pulling the cone out of the canal attached to the heat carrier, and far less chance of burning the doctor, assistant or patient. Rather than being an incremental improvement over flame-heated heat carriers, the electric heat carrier was an evolutionary step forward in the heating and compaction of gutta-percha into root canal systems.

The Obtura III gutta-percha gun

The introduction by Unitek, in 1982, of the Obtura warm gutta-percha gun (now manufactured and sold by The Obtura Corporation) simplified the most difficult aspect of Schilder's Vertical Condensation Technique, the back-fill. With two or three "squirts" of warm gutta-percha from an Obtura Gun and vertical condensation of each aliquot, the backfill took less than a minute per canal with remarkably infrequent voids. With this new technology, a technique that previously took 45 minutes to an hour could be accomplished more effectively in 15 to 30 minutes; the same time required to do a thorough job of lateral condensation.

The one-shot birth of the continuous wave of condensation technique

Developed in 1987, the Continuous Wave of Condensation Obturation Technique was born out of my desire to simplify warm gutta-percha downpacking. After using the a Touch'n Heat electric heat carrier for two years, I enlisted Johan Masreillez of Analytic Technology (now owned by SybronEndo) to prototype electric heat pluggers which had the same taper as the non-standardized gutta-percha cones I was using at the time. My hope was that we could make a series of variably-tapered electric heat pluggers that could replace three to five vertical condensation pluggers and a heat carrier with a single instrument.

Johan sent the first .08-tapered prototype to me a month later. I prefit the electric heat plugger to its binding point in the canal, adjusted a stop I had placed on it to the reference point, put it into my Touch'n Heat handpiece, pushed the plugger against the cemented master cone, and hit the button. The plugger immediately moved into the canal and within two seconds I let off the switch, gliding to a halt just short of the binding point. I fired a one-second burst of heat to separate the plugger from the apical mass of condensed gutta-percha and pulled the plugger out.

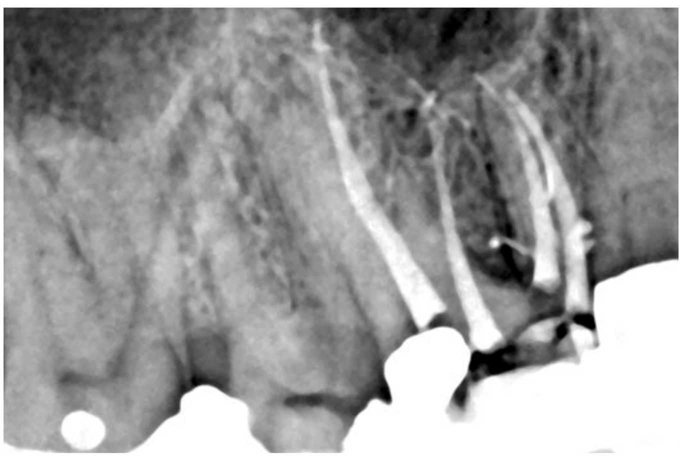


Fig. 25.2. Maxillary molar with a significant lateral canal filled off the MB2 canal. This was the first case filled with an electric heat plugger and the Continuous Wave of Condensation obturation technique.

The first-time result was ideal apically and a large lateral canal was filled as well (Fig. 25.2). Initially, I was suspicious—I had a hard time believing that a two-second downpack could ever fill anatomic complexities as well as the Vertical Condensation Technique (with its 5-7 hydraulic waves moving sealer and warm gutta-percha through a root canal system over a time frame of 2-3 minutes). I finally understood how well it worked after I saw slow-motion video footage, shot through a microscope, of a Continuous Wave Electric Heat Plugger moving through gutta-percha and sealer in a plastic block.

The conceptual basis for the continuous wave of condensation technique

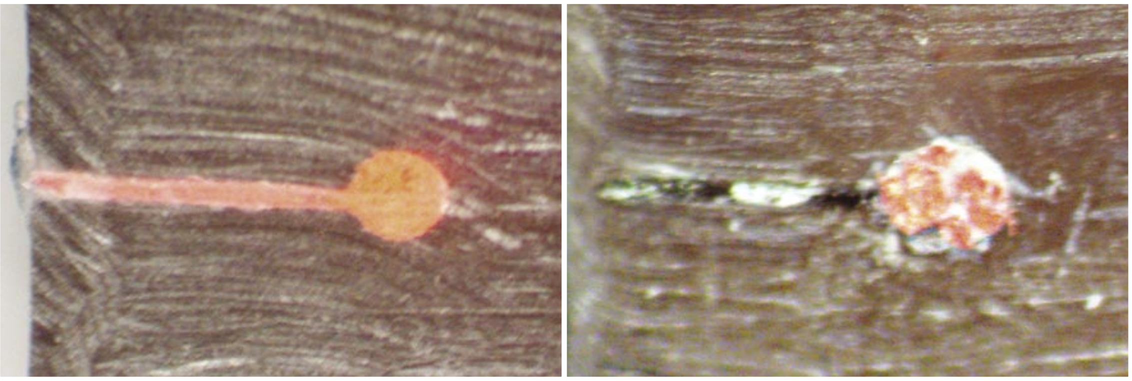
What I saw was the streaming effect that develops between the electric heat plugger and the canal wall as the plugger penetrates the canal, simultaneously warming and displacing gutta-percha along its length. The plasticized gutta-percha is primarily moved in lateral and coronal directions during its displacement as the electric heat plugger drives through the center of the gutta-percha mass in the canal. That is why it is considered to be a *Centered Condensation* obturation technique, as are the carrier-based obturation methods that use Thermafil and GT Obturators. Surprisingly, the sealer acts as a lubricant, helping the softened gutta-percha slip through the canal space.

This technique is called the *Continuous Wave Technique* because it allows a single tapered electric heat plugger to capture a wave of condensation at the orifice of a canal and ride it, without release, to the apical extent of downpacking in a single, continuous movement. This is in contrast to heating and packing the gutta-percha through three, four or five interrupted waves of condensation in the Vertical Condensation Technique. Because these tapered pluggers move through a viscosity-controlled material into a similarly-tapered canal form, the velocity of the thermo-softened gutta-percha and sealer moving into the root canal system actually accelerates as the downpack progresses (Figs. 25.3 A, B).

Interrupted waves of condensation build a pressure wave that is lost each time the gutta-percha cools, starting and stopping its movement into canal irregularities. Techniques using multiple waves of condensation may provide only a single chance at filling a cervically-positioned lateral canal since it is limited to deforming the gutta-percha 4 mm's apical to the plugger position and because the second wave of condensation starts with the removal, by the heat carrier, of gutta-percha adjacent to that lateral canal. The Continuous Wave technique provides the obturation potential to fill lateral canals at the orifice level throughout the downpack because of its centered position within the gutta-percha, simultaneously condensing it with the full length of the plugger (Figs. 25.4 A-C). This has been confirmed by many research studies but was best shown in post-obturation sagittal dissections by Sharp[5] and Carr.[3]

Several researchers have also studied the thermodynamics of the Continuous Wave Technique using the System-B Heat Source and the consensus is that the CW Technique, even when used for 12 seconds (three times the recommended four-second downpack/heating time), was safe to the periodontal ligament.[1]

Perhaps the most succinct explanation of the effi-



A B

Fig. 25.3. **A**. A cross-sectioned plastic block with simulated primary and lateral canals filled with the Continuous Wave Obturation Technique. The cross-sectioned primary canal is shown to have a thin layer of lealer between the simulated canal walls and the homogeneous gutta percha core, and the longitudinally-sectioned lateral canal was filled with the same sealer and gutta percha arrangement despite its four millimeter length. The downpack time was 1.2 seconds. **B**. A cross-sectioned plastic block with simulated primary and lateral canals filled with Lateral Condensation of Cold Gutta Percha. Note the lack of homogeneity of the gutta percha and the relatively large amount of sealer between the still-round gutta percha accessory points. The simulated lateral canal has neither gutta percha nor sealer in it, typical of this technique. Lateral Condensation of warm gutta percha is much more capable of creating a dense central core of gutta percha as well as filling root canals irregularities.

A B C

Fig. 25.4. **A**. Pre-operative radiograph of a lateral incisor with a periradicular lesion that has formed and extended around the circumference of the root—form osseous crest to osseous crest. Very suggestive of root fracture, however the attachment apparatus was intact—there were no abnormal pocket depths. The tooth was accessed while the patient was on vacation (not my access preparation). **B**. Post-operative radiograph showing a complex root canal system with five portals of exit symmetrically positioned relative to the asymmetric lesions of endodontic origin. Occam's Razor would suggest a cause and effect. Patient's treatment time was one hour, my time in the case was 18 minutes. **C**. Recall radiograph showing healing at six months post-op.

cacy seen in centered condensation techniques is that they are just the inverse of the very effective three-part impression systems. The hard impression tray is intended to push the heavy-bodied material against the teeth and gingival tissues, which pushes the light-bodied material picks up the detail around those structures. With centered condensation, the plugger or carrier functions as the tray does, by pushing the heavy-bodied gutta-percha through the larger primary and accessory canal spaces, which pushes the thin-bodied sealer into the smallest extents of the root canal system.

Instruments and devices

The centerpiece of the Continuous Wave of Condensation Technique is the set of CW Electric Heat Pluggers (Fig. 25.5). Designed by Johan Masriellez, they are made of tapered, hollow stainless steel tubes that have insulated copper wires soldered to their tips. The electric current from the heat source (Touch'n Heat, System-B Heat Source, or System-B/Elements Obturation Device—Fig. 25.6) enters the CW Electric Heat Plugger through the copper wire, relatively unimpeded, and then moves through the stainless steel tube to ground back in the heat source unit. Because the stainless steel tube is more resistive to electric current than the copper wire inside it, heat is generated when the current moves through the transition point between copper and stainless steel. This is why the very tip of the CW Electric Heat Plugger heats first and also why full heat can be reached within 0.5 seconds after activating the handpiece switch.

The CW Hand Pluggers (Fig. 25.7) are an important part of the CW Technique as the filling material must be condensed by hand near the orifice as well as at the apical extent of the downpack. Each of them has two plugger ends, one rigid stainless steel end

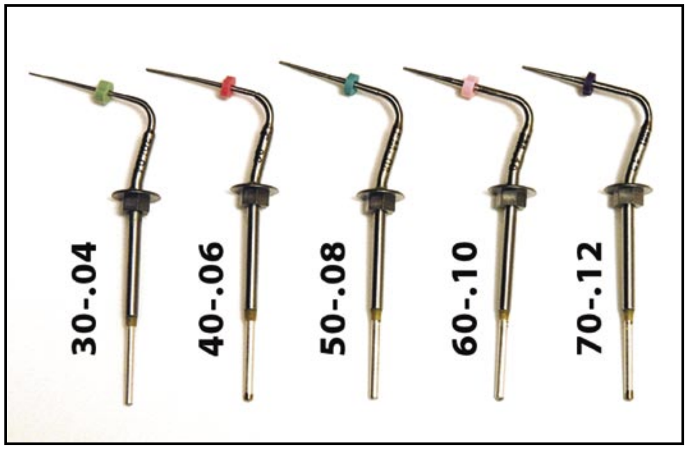
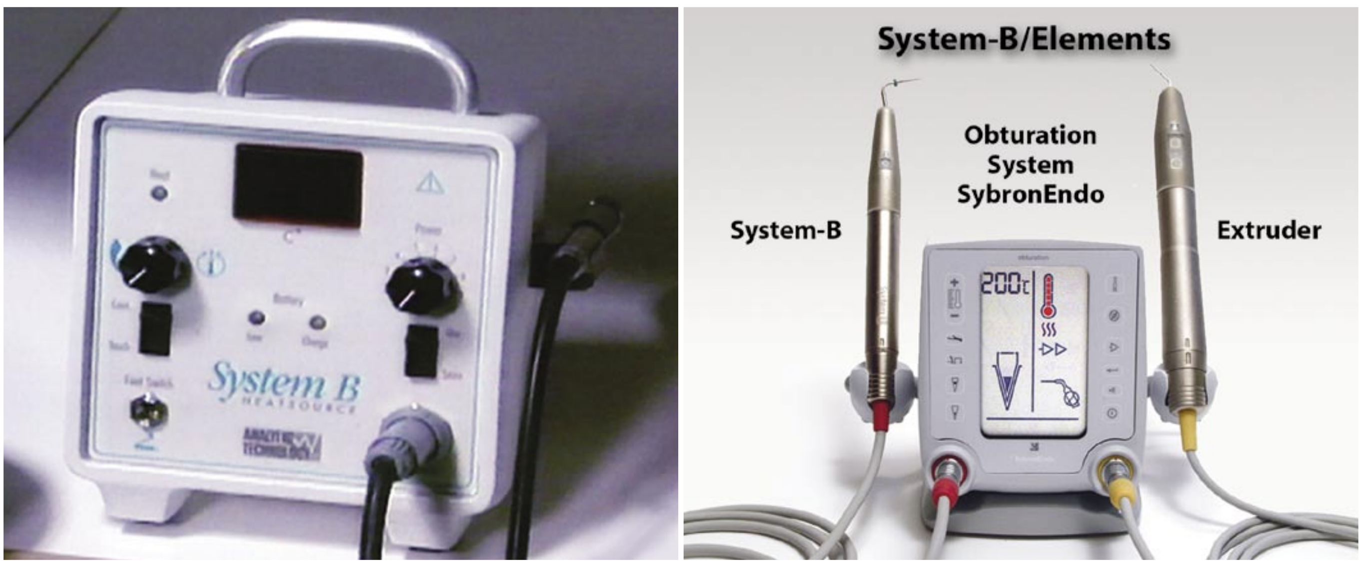


Fig. 25.5. Continuous Wave electric heat pluggers in sizes 30-.04, 40-.06, 50-.08, 60-.10, and 70-.12 (ISO tip diameter-taper in mm/mm). Each of these electric heat pluggers are hollow stainless steel with insulated copper wire soldered at their tips. The current comes in through the low-resistance copper wire and runs to ground through the high-resistance stainless steel, thereby generating heat at the tip of the plugger first. The dissimilar metals connected at the plugger tip act as a thermistor, the mechanism that provides dynamic control of heat generated.

A



B

Fig. 25.6. A. System-B Heat Source with quick-disconnect handpiece cord, temperature control knob and rechargeable battery. B. System-B/Elements Obturation Unit with redesigned System-B Handpiece and added Extruder.

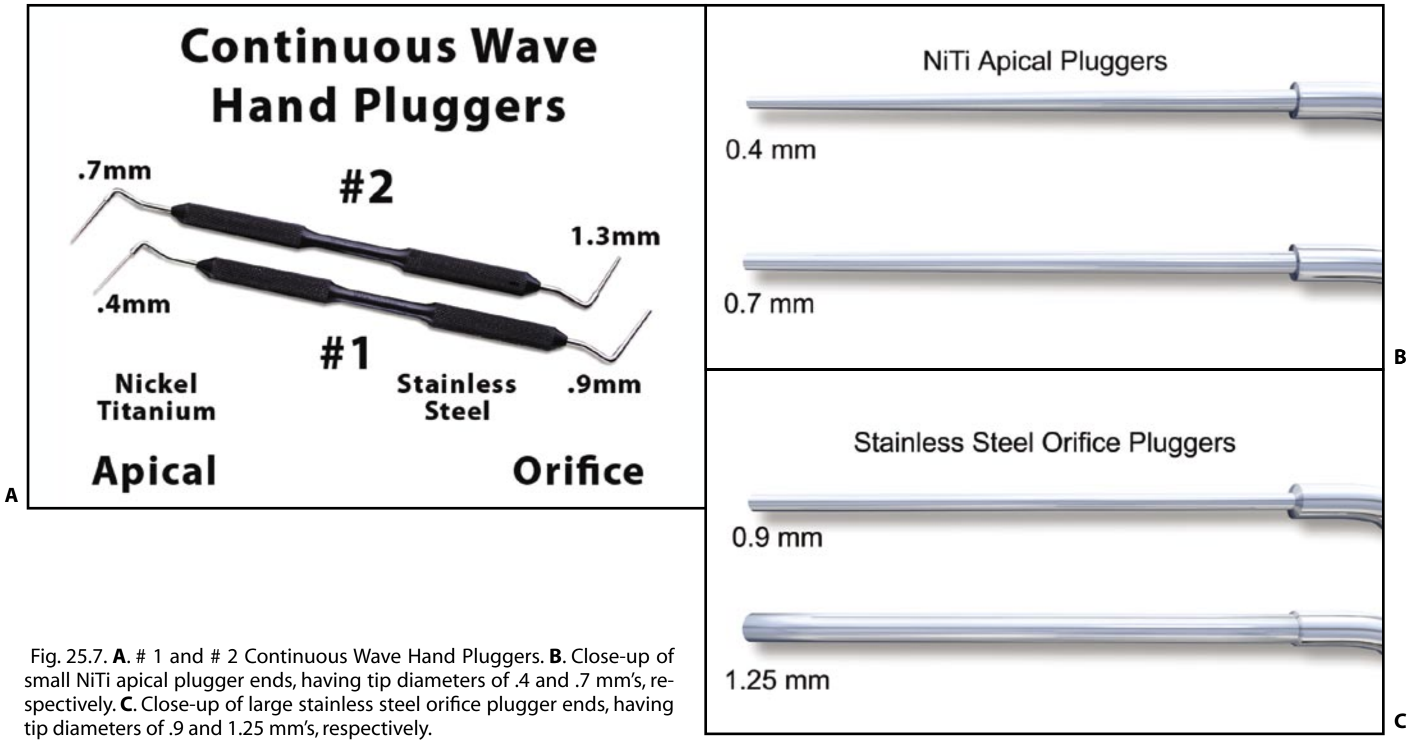


Fig. 25.7. **A**. # 1 and # 2 Continuous Wave Hand Pluggers. **B**. Close-up of small NiTi apical plugger ends, having tip diameters of .4 and .7 mm's, respectively. **C**. Close-up of large stainless steel orifice plugger ends, having tip diameters of .9 and 1.25 mm's, respectively.

for working at the orifice level and the other one nickel titanium so it can flex around canal curvatures to condense the apical mass of filling material after the electric heat plugger is removed. The # 1 size CW Hand Plugger has a .4 mm diameter at the nickel titanium end and a .9 mm diameter at the Stainless Steel end, the # 2 size CW Hand Plugger has a .7 mm diameter at the nickel titanium end and a 1.25 mm diameter at the stainless steel end. Recently added, there is a new # 0 size with a .2 mm diameter at the nickel titanium end and a .75 mm diameter at the stainless steel end.

The engine that drives the CW Pluggers is one of the electronic units mentioned before, a Touch'n Heat, a System-B Heat Source, or the new System-B/Elements Obturation Device—all of them, like the CW Pluggers, are made by SybronEndo.

The System-B heat source

In 1989, after the Continuous Wave of Condensation Technique had become popular with endodontists who were trained in the Vertical Condensation Technique, Johan asked me if I would look at a second-generation heat source he had designed to use in medical operating rooms for electric heat cautery. It was immediately obvious that this new unit would be a distinct improvement over the Touch'n Heat, which only had a power setting, as it had a temperature setting and could control the amount of heat delivered to the plugger tips. In addition, it had a quick disconnect plug at the end of the handpiece cord so that the handpiece and cord could be placed into an autoclave bag to improve infection control procedures.

When the CW Pluggers are driven by the Touch'n Heat device, the CW Technique requires intermittent switching of the current to slow down the speed of downpack. Using a preset temperature on the new heat source allowed the downpack to occur in a more controlled manner with less training. Johan and I decided to name it the System-B (for Buchanan) Heat Source and the simplification of the CW Technique propelled sales of the device into the domestic (US) general dentist marketplace and to the rest of the endodontic specialist market world-wide.

The System-B/Elements obturation device

In 2004, the next generation of heat source, the System-B/Elements Obturation Device, was introduced to the market after significant redesign and improvements. The most notable change was the addition of an inline, motor-driven gutta percha extruder to the unit, however, the System-B Handpiece and

CW Plugger set was greatly improved as well. Both the System-B and Extruder Handpieces were designed with removable, autoclavable stainless steel sheaths to allow for ideal infection control procedures, both of the handpiece cords were fitted with medical-grade quick-disconnect plugs, and both of the handpieces are driven by a single electronic control unit.

The CW Pluggers lock into the System-B Handpiece without needing to be cinched down by a collet, and the handpiece switch is much improved over the spring switch on the previous device. The control unit has a safety-interrupt program that stops heat delivery after four seconds to prevent overheating of the tooth, turning on again if the handpiece switch is let off and pushed again. The System-B Heat Source is designed to automatically recognize and drive nickel titanium CW Pluggers, as well as a new set of soft tissue heat cautery tips. The CW Plugger geometries have been improved by varying their tip diameters to be smaller in the narrower taper sizes, larger for the greater taper sizes, and there is a new 30-.04 CW Plugger size for narrow curved canals.

The Extruder is a big improvement over hand-operated gutta percha guns for several reasons. First, because it is inline in form, it can be placed (like the System-B Handpiece) upright in a standard handpiece hanger on the dental unit or cabinet. Second, the needle, which is pre-bent by the factory, and the gutta percha are inserted into the Extruder in a single-piece cartridge that has its own plastic attachment nut. The cartridge concept eliminates the need to clean the internal parts of the Extruder after each use and ensures that the needle will not blow apart in the middle of the backfilling procedure. These cartridges are available with 20, 23, and 25 gauge needles, with soft or firm viscosity gutta percha or even with RealSeal (Resilon) instead of gutta percha.

The biggest improvement of the System-B/Elements Heat Source Control Unit is that one unit drives both the System-B as well as the Extruder saving quite a bit of counter or shelf space in the operatory. The unit has hanger bars on either side with handpiece hangers that can be removed and attached to a hanger bar on a dental unit or cabinet for optimizing ergonomics in the operatory.

The left side of the menu-driven control panel on the base unit selects operations of the System-B Handpiece for electric heat testing of pulps, electric heat cautery, high-heat downpacking and low-heat downpacking. On the right side of the menu panel are the controls for the Extruder, including the start button for the heating of the Extruder cartridge, program selection for the extrusion of gutta percha or RealSeal, speed settings for the Extruder, retraction of the Extruder piston, and audio settings for both sides of the device.

While the redesign of the System-B was overdue by three or four years, this dramatic upgrade more than makes up for the wait. There is no other device on the market that does so many different functions so well.

PROCEDURES

Conefitting

Like the Vertical Condensation technique from which it is derived, the Continuous Wave Technique requires good canal shape and meticulous gutta-percha conefitting.[2] The apical constricture must be at the terminus of the canal, with a smooth, consistent taper behind it. The cone must be binding the canal wall in its last 1 mm, and be fit to full length before paper point length confirmation and cutback of 0.5 mm from that length, prior to cementation of the master cone.

Plugger fitting

Once conefit has been accomplished, a CW Electric Heat Plugger is selected with a taper matching the taper of the cone that was fit. The CW Electric Heat Plugger Set has two size designations; one corresponding to non-standardized gutta-percha points sizes (Fine, Fine-Medium, Medium, and Medium-Large), the other describing the size of the file taper used to finish the canal prep (.06, .08, .10, and .12), respectively. Consequently, when you have fit either non-standardized or standardized tapered shapes of gutta-percha points, you automatically know which Continuous Wave heat plugger to try in first.

Before inserting the CW Plugger into the System-B Handpiece, the plugger is pushed into the canal. Because they are made of dead soft stainless steel, pushing and wiggling the plugger causes it to be bent by the canal to fit that canal's curvature. Once its most apical binding point is reached, adjust the stop on the plugger to the reference point of that canal (Fig. 25.8) and remove the plugger. The larger sizes (M-.10 and ML-.12) may require bending with EndoBender pliers (SybronEndo) when used in curved canals.

It is important to hold the prefit plugger next to the prefit gutta-percha point so that the plugger stop is adjacent to the pinch mark on the shank of the cone. This shows how close the plugger fits to the end of the canal. Ideally, the plugger tip should be within 4-6 mm of the cone tip and canal terminus (Fig. 25.9). If the plugger fits too close to the end of the canal it could cause an overfill, if the plugger doesn't fit close enough to the end of the canal there could be a less than ideal movement of gutta percha in the apical region of the canal.

A canal with large preparation diameters in the body and/or apical region (in the GT System of instruments that would include shapes made by 40 Series and .12 Accessory GT Files) may sometimes allow overly deep introduction of CW Pluggers (Fig. 25.10 A). The gutta percha cone is softened about 3 mm's ahead of the tip of electric heat pluggers, so downpacking with a heated CW Plugger closer than four millimeters to the terminus of the canal could soften the tip of the gutta percha cone allowing it to squirt through the apical resistance form and result in overextension of gutta-percha. Prefitting the plugger and comparing it to the cone fit in that canal will reveal this situation which is simply resolved by shortening the stop so as to end the downpack four mm short of length (Fig. 25.10 B). As an aside, big canals like these are most easily filled with a single cone backfill (see later).

Difficulties in achieving adequate plugger depth in canals of average length are usually due to insufficient

Fig. 25.8. Dead-soft Continuous Wave electric heat plugger fit to its binding point in the shaped canal. The stop has been adjusted to the reference point for that canal. In curved canals simply rocking the smaller CW pluggers into the canal will cause the canal to ideally bend them to those curves.

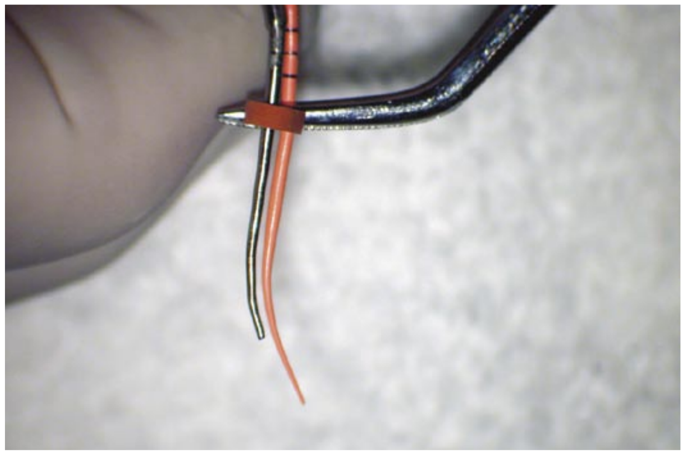
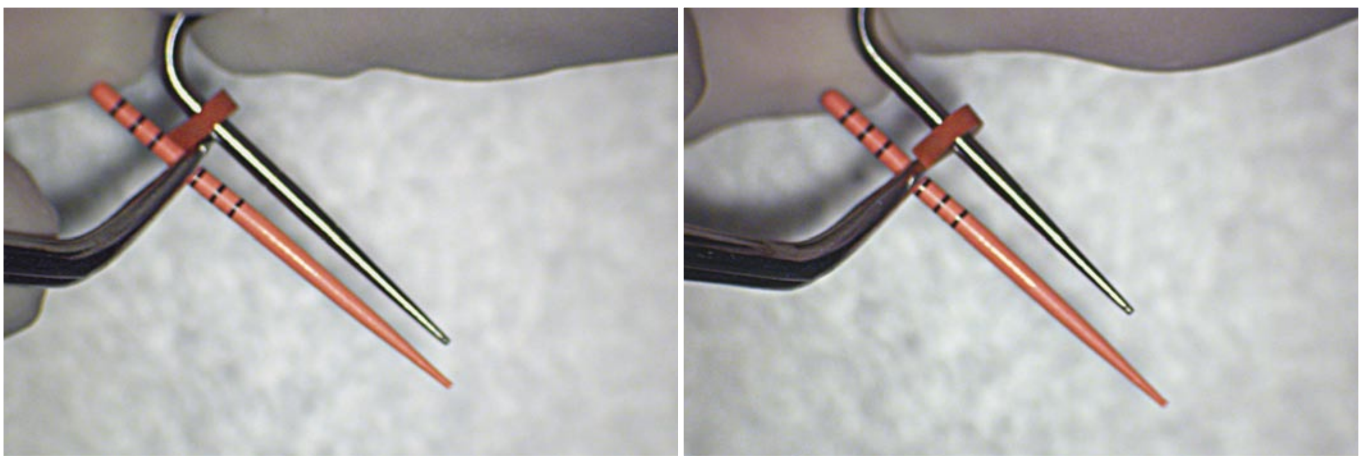


Fig. 25.9. Pre-fit plugger held against pre-fit master cone, its stop adjacent to the pinch mark on the cone, an accurate representation of where the plugger will fit in its most apical position in the canal. In this instance the depth, 4-6 mm's short of full length, is ideal.

A



B

Fig. 25.10. **A**. Plugger/cone comparison often seen with large canal shapes. The plugger is shown to fit within 2 mm's of full length, the set-up for an overfill when the plugger softens the tip of the cone and it extrudes past the terminus of the canal. **B**. Stop shortened to end the downpack at least 3.5 mm's short of full length.

deep shape in the canal preparation (inadequate enlargement 3 mm to 4 mm shy of the terminus). Using a variably-tapered shaping file (such as a GT File) to finish the shape or multiple recapitulations of serial shaping routines will ensure that adequate deep shape has been created. Sometimes insufficient plugger depth is due to severe curvatures in the coronal half of the canals. In that case just drop down one plugger size, push it to the binding point, and check the length again.

In a long single-rooted tooth, a preparation that is conservative of coronal tooth structure (such as a 20-.10 GT File shape) will have some coronal parallelism. If a CW Plugger is fit matching the apical taper in this case, it will prematurely bind short of ideal length (Fig. 25.11). Simply dropping down in taper size until the plugger tip reaches optimal length will allow ideal apical condensation. When fitting continuously tapered non-standard gutta percha points, the cone size will accurately delineate the appropriate CW Plugger size.

Downpacking

Once cone fit and plugger fit has been accomplished, paper points are used to dry the canals and to confirm their lengths. The master cones are adjusted in length if necessary and are cemented in place (Fig. 25.12). The stage is set for a Continuous Wave Downpack.

The high heat downpacking procedure can be done with a Touch'n Heat, a System-B Heat Source, or a System-B/Elements Obturation Device. The Touch'n Heat is set to "Intermittent" rather than "Continuous" mode, the power setting must be set on "10", the highest level. The System-B Heat Source is also set to "Intermittent" mode and "10", but in addition, the temperature control knob is dialed to produce around "200" (degrees Celsius) on the unit's display.

This preset temperature can be finessed to lower temperatures for smaller pluggers since they heat up quicker, and to higher temperatures for the larger pluggers. Those settings are 185° for the .04 and .06-F sizes, 220° for the .10-M size and 240° for the .12-ML size, but again, just setting it at 200° will work just OK for most canals. The System-B/Elements device is simply turned on, the "High Heat Downpacking" icon is pushed, and because of this unit's more robust power supply and controls, a very consistent amount of heat will be delivered regardless of the plugger size.

Since the two System-B devices have a temperature control feature, the downpack is done with the same continuous movement through the canal. Downpacking with the Touch'n Heat is different because it has no temperature feedback system, so the clinician must, as apical pressure is placed on the plugger, intermittently hit the handpiece switch each time the plugger stops its apical movement through the canal, to again move the plugger through the gutta percha in a controlled manner. On the high power setting, a single movement through the canal may cau-

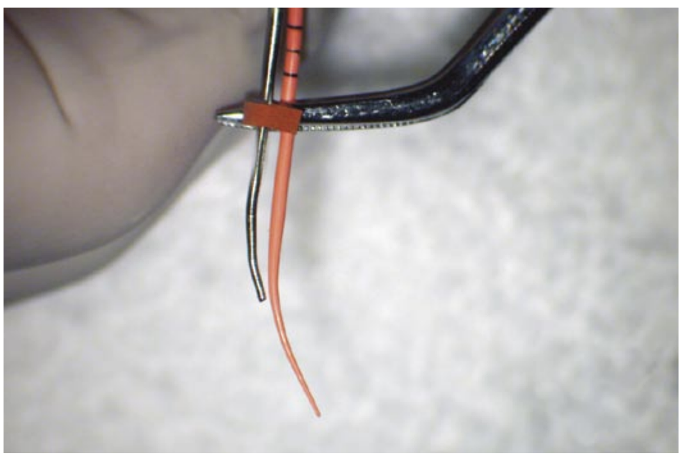


Fig. 25.11. Pre-fit CW plugger held against master cone, much too short of full length. This is usually in a long, narrow curved canal. Try a smaller plugger in the canal, enlarge the shape of the preparation, or use a carrier to obturate it.

Fig. 25.12. After paper points are used to confirm canal length, the master cone is adjusted to be 1/2 mm short of that length. Always believe the paper points. The cone is buttered with sealer and is slowly placed into the canal. The downpack is good to go.

se an extremely short downpack time (0.5-1.0 sec) unless the canal is quite long. Using a lower power setting on the Touch'n Heat is not recommended when filling small canals as the separation burst of heat will be inadequate and the cone will be pulled out on the heat plugger.

The high heat downpack with either of the System-B devices goes as follows:

Sear the cone at the orifice with the tip of the preheated CW plugger and remove (Fig. 25.13).

Use the larger end of the CW hand plugger to compact the softened gutta-percha at the orifice. Place the cold CW plugger against the gutta-percha.

Hit the System-B handpiece switch and the plugger will immediately move down the canal. With one finger on the switch, drive the heated plugger through the downpack (Fig. 25.14 A, B) until it is 3-4 mm shy of its binding point—release the switch but maintain firm apical pressure on the plugger (Figs. 25.14 C).

Ideally, the CW Plugger will slow and stop about 1 mm short of the binding point. With finger still off the switch, maintain apical pressure for a sustained 10-second push. This will take up any shrinkage that might occur upon cooling of the apical mass of gutta-percha ahead of the plugger.

While still maintaining apical pressure on the plugger, activate the switch for a full 1-second period, release the switch and pause for another full second and withdraw the plugger (Fig. 25.15). Note the surplus gutta-percha luted to its surface. If you suspect that you've pulled the gutta-percha cone out of the ca-

Fig. 25.13. CW electric heat plugger is switched on and used to sear the done off at the orifice or CEJ level.

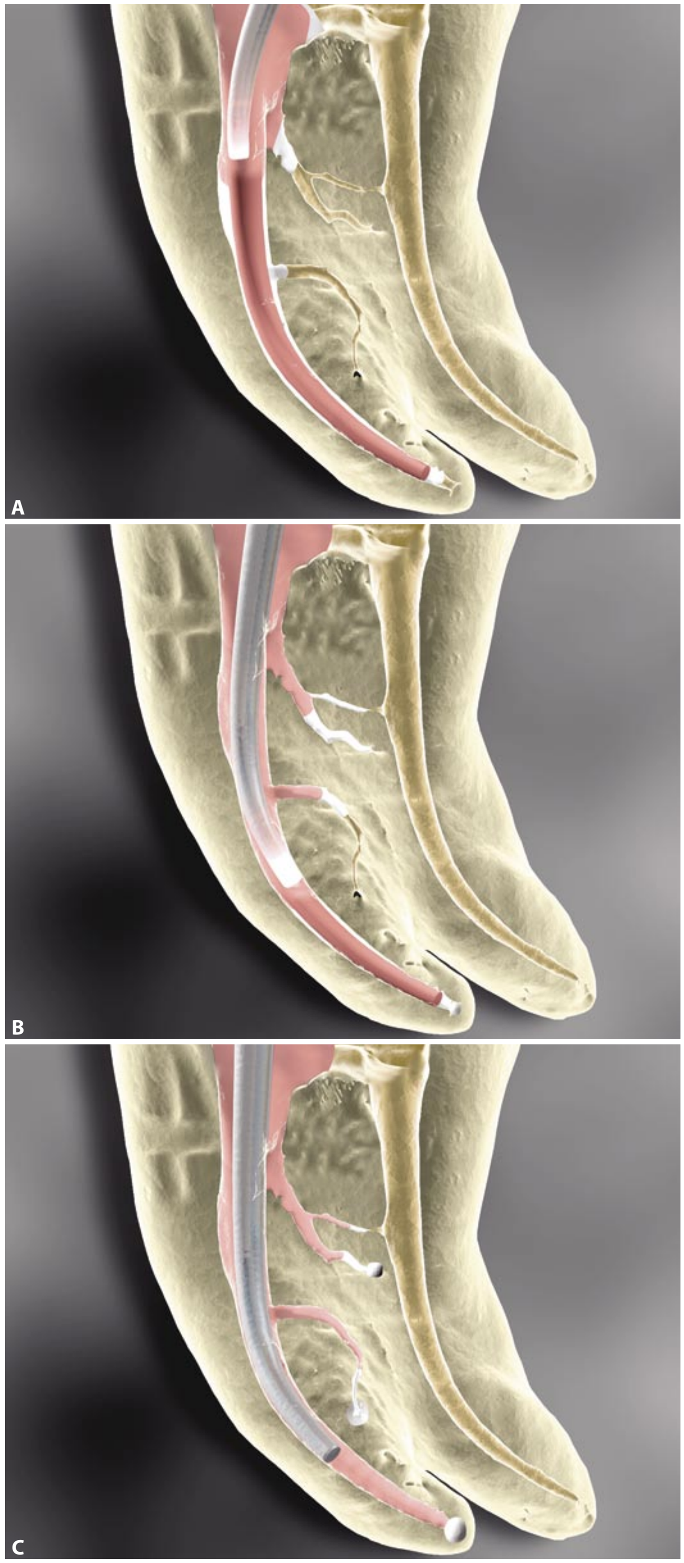


Fig. 25.14. **A**. CW plugger is pressed against the gutta percha at the CEJ level and is switched on, causing the plugger to immediately move into the canal. **B**. Pay very close attention as the downpack in a 20 mm canal may only take two seconds before the switch must be released. **C**. 2-3 mm's short of the plugger's binding point, release the switch but maintain apical pressure on the cooling electric heat plugger as it glides to a halt 1 mm from that binding point.

nal, simply touch the end of the plugger—if you feel its metal tip you obviously didn't pull it out. Use the small NiTi plugger end to condense the cooling apical mass of gutta-percha into the apical preparation as it sets (Fig. 25.16). Creating a flat surface here is crucial to avoiding the void during backfilling.

If this small hand plugger tip is buried in the apical mass of warm gutta-percha, it will create a narrow tubular space-virtually impossible to backfill without a void resulting.

Fig. 25.15. After holding a sustained apical condensation force for five seconds, switch on the heat for at least one full second, pause for one second, and retrieve the plugger with surplus gutta percha attached.

High heat downpacking difficulties

If you have pulled the cone out at the end of the downpack (Fig. 25.17), straighten it on the plugger, confirm that the Power Setting is correct (the # 10 setting for the Touch'n Heat or System-B Heat Source, or when using the System-B/Elements unit that the "High Heat Downpack" icon is selected) and replace the gutta percha cone into the canal. While applying apical force to the plugger, do the separation burst again, confirming it to be at least 1 second, pause for a full second after releasing the spring switch, and withdraw the plugger again. Causes of this problem: low power setting, too short of a separation burst of heat, poor cone fit, or a very large canal diameter.

In a large canal case, when a post space is needed, it is sometimes necessary to place the small end of a CW Hand Plugger alongside the CW Heat Plugger to hold the apical mass of gutta percha in place as the heat plugger is withdrawn with the surplus gutta-percha. In most cases a post space is not necessary and a low heat downpack with a single cone backfill is the simplest CW method.

On occasion, after applying the separation burst of heat and withdrawing the plugger, the plugger will come out clean, without any gutta-percha sticking to it. This is OK, it often occurs in single rooted premolars that have big buccal and lingual fins off the primary canals which mechanically lock the surplus gutta-percha into the canal (Fig. 25.18). If a post space is

Fig. 25.16. #1 CW plugger—the .4 mm NiTi end condensing the apical mass of gutta percha into the apical resistance form until it has cooled and set. Take care to create as flat an interface as possible at the coronal extent of the apical mass—this will radically reduce the chances of a backfill void.

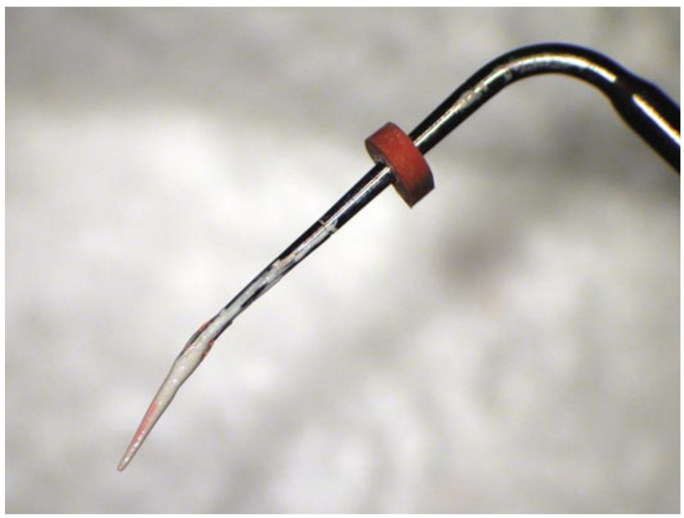


Fig. 25.17. Plugger with master cone luted to its tip. If this happens, just place the gutta percha cone back into the preparation. Unless the tip has been mangled, the cone will go back to its pre-fit position in the canal. Then do a longer, 2-second separation burst of heat, wait a second, and withdraw the plugger—the cone should stay where you put it.

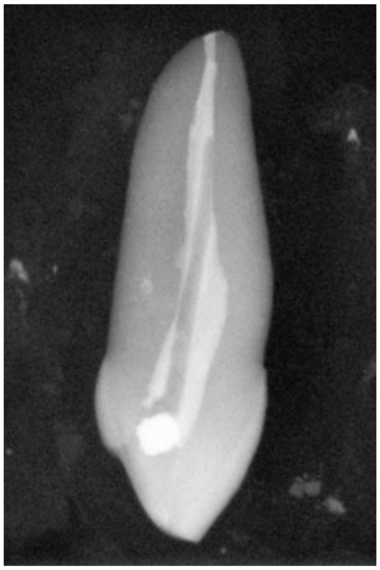


Fig. 25.18. Mesial view of canine canal exhibiting significant buccal and lingual canal fins that have mechanically locked the gutta percha into the canal despite the separation burst. A single-cone backfill is best here, if a post is needed the post drill can easily cut a post space, leaving gutta percha in the fins.

needed, use the post space drill to cut out any gutta percha in the way of post placement. If a post space is not needed place a backfill cone, with sealer on it, in the space left by the plugger.

At the end of the high heat downpack, if you need a post space, no backfilling is needed. If not, you can backfill either with the Extruder side of the Elements/System-B device or the Obtura III Gun.

Low heat downpacking

In medium and large canals where a post space is not needed, the low heat downpack with the single cone backfill is the easiest and quickest CW obturation method. It greatly simplifies the downpacking process as there is no plugger fit necessary and no separation event to finesse, and it makes the backfill a slam-dunk as it is nearly impossible for a void to be left during the backfill. In fact, when a void is caused during a syringed gutta percha backfill, doing a low heat downpack to the void with a straight plugger and a single cone backfill is a very predictable fix of a frustrating problem.

The high heat downpack in small canals is more ideal as it allows prefit, prebent CW Pluggers to downpack deeper into the canal, more ideally molding the gutta percha in the apical region of the canal. However, for beginners to the CW Technique, the low heat method is a good place to start. The technique is as follows:

Plugger fitting is not necessary. The System-B Heat Source power control is set on "10" and the temperature is set to 100°C or if using the System-B/Elements unit the "Low Temperature Downpack" icon is pushed. The master cone is cemented into the canal, the cold CW Plugger is positioned at the orifice level with apical pressure, and the handpiece switch is pressed.

The plugger immediately, but relatively slowly, will move into the canal. When the desired depth or the binding point is reached, the handpiece is switched off but the apical pressure on the plugger is maintained for five to ten seconds to allow the plugger to cool. When using the System-B/Elements System, a clicking sound will be heard five seconds after release of the handpiece switch and a double click after ten seconds.

While maintaining apical pressure on the plugger, the handpiece is rotated to break the plugger loose from the condensed gutta percha in the canal. After two or three rotations with apical pressure a light coronal backpressure is exerted on the plugger as it continues to be rotated. The plugger will slowly ease out of the canal, leaving the condensed filling material in the canal with an impression of the plugger in it center.

Backfilling can be accomplished very simply by placing a sealer-coated Autofit Backfill Cone (SybronEndo) in the space vacated by the plugger. After turning the temperature setting to 200°C or selecting the High Heat Downpack icon the backfill cone is seared off at the orifice, and the larger end of the hand plugger is used to finish the backfill by firmly condensing it at the orifice.

Backfilling with a warm gutta-percha syringe

Backfilling is the least important part of the Continuous Wave Technique, as all of the portals of exit (that were cleaned out) from the root canal to the root surface have already been sealed during the downpack, but it can be a challenge for beginners to accomplish without leaving a void. One of the easiest CW cases is the canal fill that will be followed by placement of a retentive post, because no gutta percha backfill is necessary. However, for most teeth, a post is unnecessary so backfilling must be learned as a routine part of Continuous Wave Obturation.

Obtura gun backfilling

After you have completed the downpack and are ready to begin your backfill, make sure that you allow the Obtura needle to heat to a full 200°C, and test the flow by extruding a short string of gutta-percha before you place the needle in the backfill space.

The art of using the Obtura Gun to backfill without voids is to be patient. Wait for 5-6 seconds after inserting the needle (23 gauge) into the canal before pulling the trigger to syringe gutta-percha into the backfill space and you can avoid the void. If you pull the trigger shortly after binding the needle in the canal you will most certainly create a void as the 37°C canal wall chills the 150°C needle to 100°C, and the gutta-percha inside it cools as well and rolls out of the needle semi-solid.

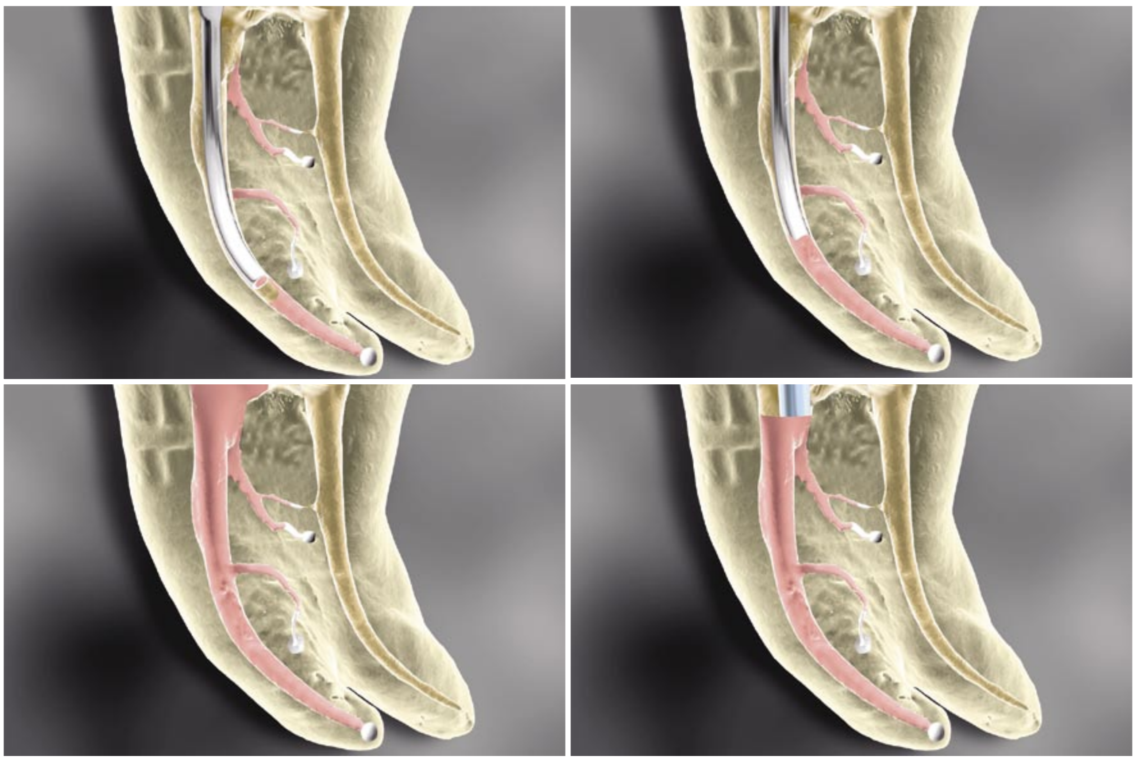
When you place the needle in the canal and pause for five seconds, heat is rapidly conducted down the sterling silver needle, reheating the needle and the gutta-percha inside it, as well as the canal walls around the needle (Fig. 25.19 A). At that point, the syringed gutta-percha is able to flow more effectively against the canal walls and the apical mass of gutta-percha, thereby preventing a void.

After 5 seconds pull the trigger *firmly*, and hold that pressure until the needle starts to back out of the canal (Fig. 25.19 B). Hold the needle in with the same backpressure, but reduce the force on the trigger so that the backfill takes about 10 to 15 seconds (Fig. 25.19 C). At this point, it's important that you resist the temptation to pull the gun out the canal... let the extruded gutta-percha push the needle out.

Once the needle has been pushed back to the orifice level, pause for another 5 seconds, and gently remove the needle, using a circular motion as you lift it out of the canal. Using the fat end of the appropriate CW hand plugger, give the soft gutta-percha at the orifice a *very firm*, *sustained* condensation push (Fig. 25.19 D). Be aware that you can eliminate a void 4mm's below the orifice if you apply enough pressure here.

However, when in canals with significant curvature in the coronal half of the canal, I usually place and condense a small aliquot of gutta-percha deep in the backfill space before filling the remaining space to the orifice.

Avoid backfilling the pulp chamber with gutta-percha. Backfilling into this region reduces the conden-



A B C D

Fig. 25.19. **A.** Needle inserted to binding point in backfill space, short of condensed apical mass of gutta percha. It is critical that the needle is held in place for at least five seconds before beginning extrusion. **B.** The needle is held in the canal as the extruded material flows into the backfill space ahead of the needle. As soon as that canal space is filled, the needle will be felt to "bump back". **C.** It will take about five to ten seconds to backfill to the CEJ or orifice level. **D.** The stainless steel end of the CW Hand Plugger is used to firmly condense the gutta percha at that level.

sation efficacy at the orifice level, reducing the possibility of removing a void below there. Furthermore, backfilling into the pulp chamber reduces the apical extent of coronal seal provided by the bonded build-up, increasing the chances of coronal leakage in the future. More ideal is to end the backfill 1 mm short of the orifice level or the CEJ. Ideally the corono-radicular build-up extends 1 mm past the orifice level. Long term, this is most secure as the tooth could decay off to the gum line without affecting the long-term success of the root canal therapy.

System-B/Elements Extruder backfilling

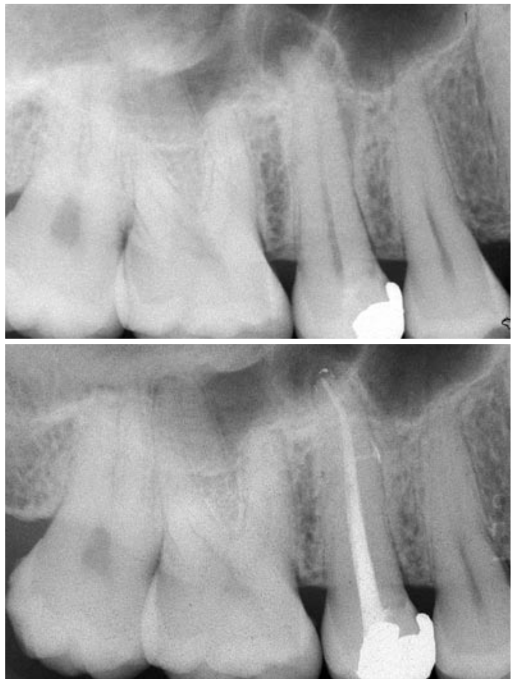
The backfilling technique used with the Elements Extruder is very similar to Obtura backfilling, in terms of the five second wait time and the light apical pressure that is held on the needle to eliminate void production. The main differences are in the Extruder's design and function.

The tip cartridge (23 gauge needle with heavy body gutta percha) is placed in the end of the Extruder, the heat switch on the upper right of the System-B/ Elements control panel is pressed, and in just 25 seconds it is heated to operating temperature as signified by the thermometer icon on the display. It is important to "prime" the needle by pressing the forward high-speed end of the toggle switch on the Extruder handpiece until warm gutta percha comes out of the needle tip. You are now ready to backfill.

The needle is placed in the backfill space to its binding point and after the same five-second wait, the slower speed back end of the toggle switch is pressed. After a number of seconds, the needle will be felt to bump back by the extruded gutta percha. When the needle tip reaches the orifice level the switch is released, the needle is removed, and the large end of the CW Hand Plugger is used to firmly condense the material at the orifice.

CONCLUSION

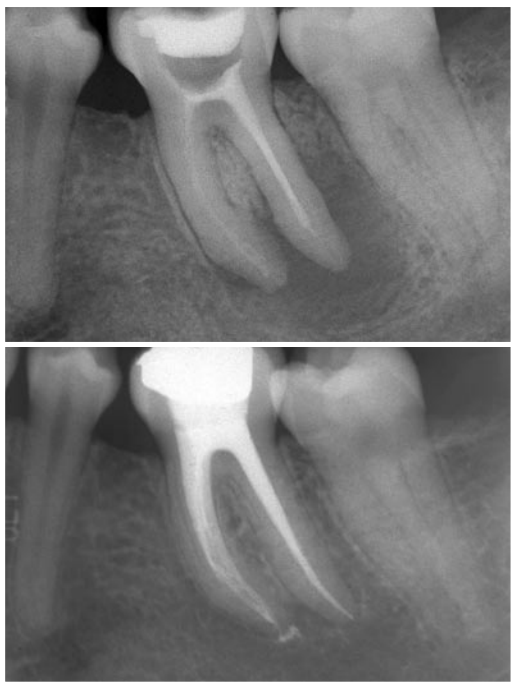
The Continuous Wave of Condensation is currently the state-of-the-art filling technique among Endodontists around the world. It is used in virtually every post-graduate endodontic training program in the United States, has been used by thousands of general dentists since 1990, and the recent introduction of the System-B/ Elements Obturation Unit has made every part of the technique easier. It is a fact that regardless of the complexity of the root canal system being treated, if you can clean it—you can three dimensionally fill it in seconds with the CW method (Figs. 25.20-25.23).



A

B

Fig. 25.20. **A**, **B**. Pre-op and 24 month recall radiographs of an upper premolar filled with the Continuous Wave of Condensation. Note the multiple lateral canals filled in the apical thirds of these curved canals despite the narrow coronal GT File shapes (Courtesy of Dr. A. Castellucci).



A

B

Fig. 25.21. **A**, **B**. Pre-op and 24 month recall radiographs of a lower molar filled with the Continuous Wave of Condensation (Courtesy of Dr. A. Castellucci).

A B C D

Fig. 25.22. **A-D.** Post-operative radiographs of cases shaped with the GT Files and filled with the Continuous Wave of Condensation (Courtesy of Dr. A. Castellucci).

Fig. 25.23. The extracted tooth has been treated by a student during a hands-on course and has been filled with the Continuous Wave of Condensation (Courtesy of Dr. A. Castellucci).

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26

The Thermafil System

Giuseppe Cantatore, W. Ben Johnson

The Thermafil Obturation Technique was derived from an original idea by Dr. W.B. Johnson who first described it in an article published in the Journal of Endodontics in 1978. Commercialized in the beginning of the 90's, the first Thermafil obturators were similar to steel K files with the file covered in a uniform layer of gutta-percha; this was then heated in the blue part of the bunsen burner flame (the coldest part) and then placed in a canal already filled with sealer and sectioned at the level of the pulp floor. However, the final obturation was characterized by the presence, in the center of a sealer and gutta-percha layer, of a solid steel core that could cause operative difficulties in post placement and especially in retreatment. After about ten years of first appearing on the market, currently Thermafil obturators are completely modified and form an intergral part of a complete and sophisticated system of root canal obturation that, when used correctly, can give optimal results.

COMPONENTS OF THE THERMAFIL OBTURATION SYSTEM

Thermafil obturators

The Thermafil obturator consists of two parts, the carrier and the gutta-percha (Fig. 26.1).[6,10,12,28]

The carrier (Fig. 26.2) is similar to a manual endodontic instrument without the blades, made from a special radio-opaque plastic; it is distinguished by a coloured grip and a 25 mm extention with a groove along its length which has two functions:

- to increase the flexbility of the carrier while reducing its mass
- to facilitate retreatment by creating a space between the carrier and canal walls.

Along the shaft and grip at 18, 19, 20, 22 and 24 mm from the tip, there are circular reliefs, which are a useful reference to check the penetration of the obturator (Fig. 26.2).

The colour of the grip indicates the diameter of the carrier tip using the ISO classification. The plastic of the carrier is a derivative of polysulfone perfectly inert and biocompatible if it should accidentally come into contact with the periapical tissues;[22,25] its flexibility allows it to adapt as well to very curved canals with maximum ease. The Thermafil obturators are available in two different versions based on the characteristics of diameter and taper:

- Classic Obturators, are available in 17 sizes with the tip diameter from 0.20 to 1.40 mm with taper between 4 and 5% (Fig. 26.3). These obturators are very versatile: the variety of diameters at the tip infact allow their use in most variations of endodontic anatomy while their taper adapts to the canal preparation obtained with the use of most Nickel-Titanium instruments currently commercially available.
- GT Thermafil Obturators were introduced by L.S. Buchanan to complement the GT Endodontic files. The GT Thermafil corresponds exactly to the GT

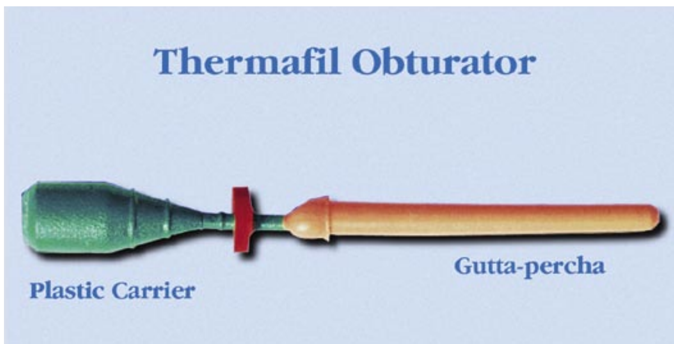


Fig. 26.1. Thermafil Obturator: The carrier in plastic is roughly wrapped in gutta-percha for about 16 mm.

rotary files with the only exception that the carrier taper is slightly less than that of the GT file to prevent contact of the carrier with the canal walls and to leave space for the flow of gutta-percha and sealer (Fig. 26.4). The GT Thermafil are available in the following four series (Fig. 26.5):

- series 20 consisting of 4 obturators with taper .04, .06, .08 and .10 with the tip diameter of 0.20 mm and a maximum diameter of 1.00 mm
- series 30 consisting of 4 obturators with taper .04, .06, .08 and .10 with the tip diameter of 0.30 mm and a maximum diameter of 1.00 mm for the GT Thermafil 30 .04, .06 and .08 and 1.25 for the GT Thermafil 30 .10
- series 40 consisting of 4 obturators with taper .04, .06, .08 and .10 with the tip diameter of 0,40 mm and a maximum of 1.00 mm for GT Thermafil 40 .04, .06 and .08 and 1.25 mm for the GT Thermafil 40 .10
- large series consisting of three obturators: 35 .12 with tip diameter of 0.35 mm and maximum diameter of 1.25 mm, 50.12 with tip diameter of 0.50 mm and maximun of 1.50 mm, and 70.12 with tip diameter of 0.70 mm and maximum diameter of 1.50 mm.

Fig. 26.2. Plastic carrier characterized by a longitudinal groove and circular reliefs which are depth reference points to check depth of insertion of the obturator. There is also a rubber stop.

Fig. 26.3. The classical Thermafil obturators are available in 17 sizes and in packs of 6 or assorted sizes for anterior and posterior teeth.

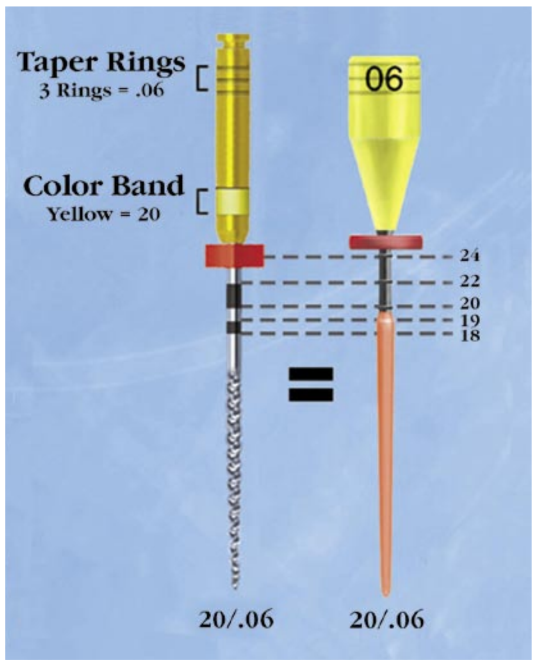


Fig. 26.4. The GT Thermafil obturators are available in 4 series perfectly corresponding to the taper and diameter of the GT Rotary file.

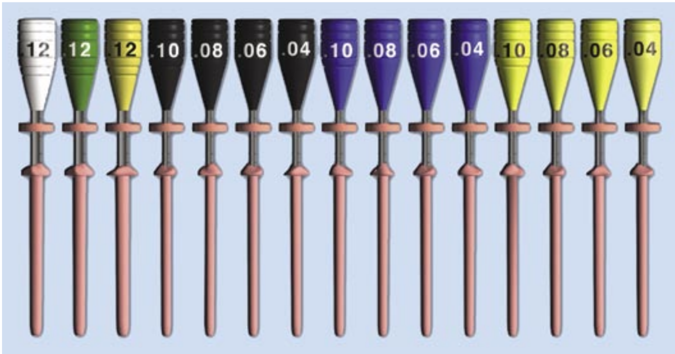


Fig. 26.5. Complete series of GT Thermafil Obturators.

The GT Thermafil obturators are ideal for obturating canals prepared with GT files because of the perfect proportionality between canal taper and carrier that allows an optimization of the condensation forces.[12] While the GT Thermafil .08 and .10 can only be used together with a preparation carried out using the corresponding GT rotary file, those with taper .04 and .06 can also be used in canals prepared with other instruments such as ProFile, Quantec, RaCe, K3, Hero etc.

The Thermafil gutta-percha

The Thermafil gutta-percha covers the carrier for approximately 16 mm overextending the tip by about 1 mm; hard and friable in the solid state, when heated it becomes sticky, shiny and swollen, assuming excellent adhesive and flow characteristics.[7,8] Because of its properties, in particular the low viscosity (Fig. 26.6), the Thermafil gutta-percha was initially considered an Alpha gutta-percha compared to the Beta gutta-percha of conventional cones, elastic and malleable in the solid state but more viscose and less adhesive once thermoplasticized.[9,42] However the fusion temperature analysis[42] for Thermafil gutta-percha shows a fusion temperature of about 56°C, that is a good 14°C less than the fusion temperature of 70°C indicated for Alpha gutta-percha[9,42] (Fig. 26.7). Furthermore the Thermafil gutta-percha, once plasticized, resolidifies after 1.5 minutes reassuming the initial characteristics of friability and hardness (Fig. 26.8); reheated once again does not show any changes in physical properties, on the contrary the true Alpha gutta-percha, brought to fusion temperature, shows irreversible changes of the cristalline reticulum, losing part of its characteristics.

Subjected to nuclear magnetic resonance (1H-RMN and 13C-RMN),[9] the Thermafil gutta-percha showed (Fig. 26.9):

– a repeatable crystalline unit of polyisoprene trans typical of all gutta-percha cones (beta type) with identical positions of the C and H atoms.[1,4]
– peak graphs perfectly superimposable over those obtained from Beta gutta-percha.

To summarize then, Thermafil gutta-percha is not a stereo isomeric crystalline Alpha form but it presents identical to Beta gutta-percha in cone form and can therefore correctly be defined chemically, as Beta

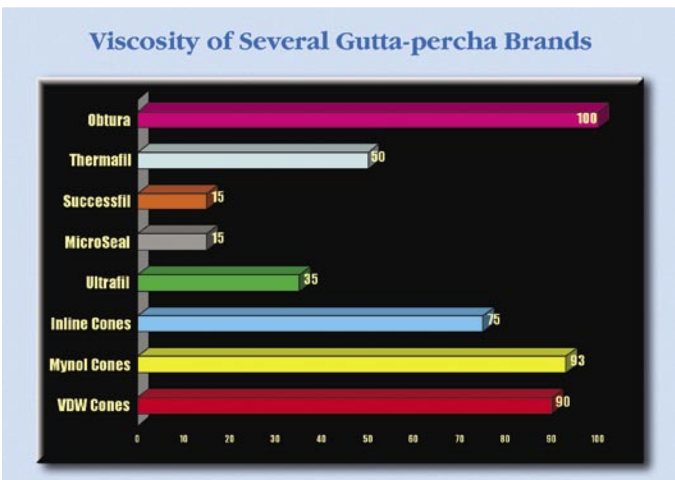


Fig. 26.6. Various viscosities of dental gutta-percha;[42] the Thermafil gutta-percha showed intermediate values between the gutta-percha of very low viscosity (similar to Ultrafil gutta-percha) and those with high viscosity (generally Cone and Obtura gutta-percha).

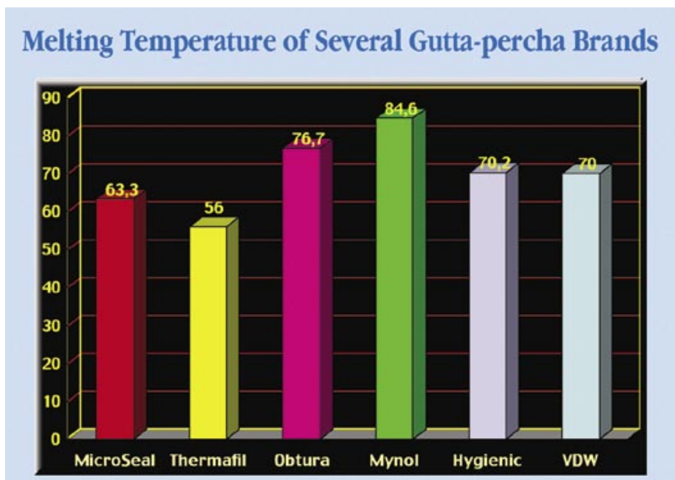


Fig. 26.7. Fusion temperatures of various dental gutta-perchas;[42] the Thermafil gutta-percha has a fusion temperature of around 56°C ie. 14°C less than the fusion temperature of Beta gutta-perchas.

gutta-percha but with the physical behaviour of the Alpha type.

With the aim of checking if the physical properties of the Alpha type were dependant on the variation of the percentages of the components, for example, high content of pure polymer, the Thermafil gutta-percha was subjected to an elementary[42] chemical analysis demonstrating however C, H and O content and a C/H relationship (proportional to the concentration in pure gutta-percha) similar to that of Beta gutta-percha[42] (Fig. 26.10).

The only way to explain the properties of Thermafil, is to confirm physical changes that occur during the production phase, most probably during the "chewing" phase when the natural gutta-percha is treated to make it suitable for dental use or during the "vulcanisation" phase when the gutta-percha is mixed with other components like zinc oxide, barium sulphate, wax, colourants etc.[8,10] SEM studies seem to confirm the hypothesis that Thermafil gutta-percha subjected to thermo "physical and or mechanical treatment" shows a very fine and homogenous reticular structure in which it is difficult to distinguish the different components. On the contrary gutta-percha in cone form reveals an inferior level of component amalgamation (Figs. 26.11 and 26.12). At the molecular level the physical treat-

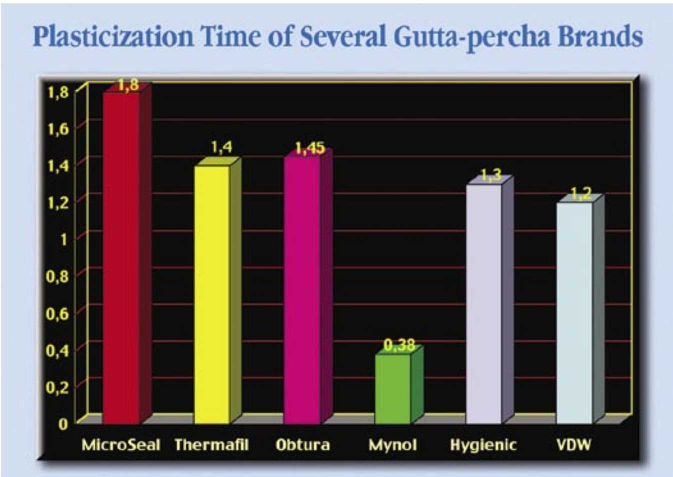


Fig. 26.8. Plasticization times of various dental gutta-perchas;[42] Thermafil gutta-percha once heated remains plastic for about 1.5 minutes.

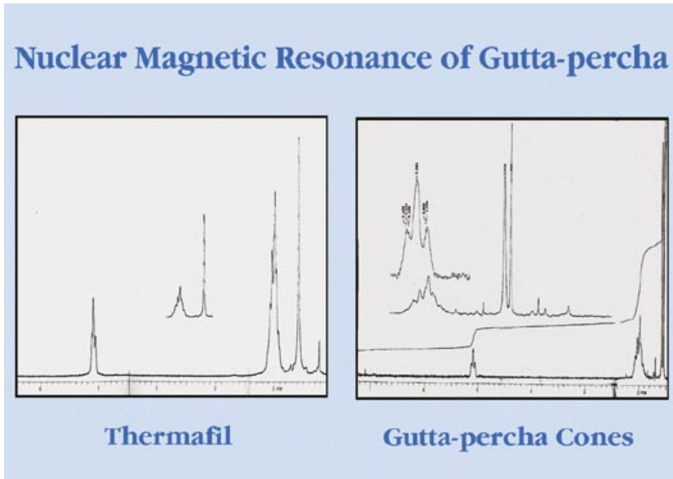


Fig. 26.9. Nuclear magnetic resonance of Thermafil gutta-percha and cone gutta-percha.[9] The two gutta-perchas exhibit graphs with similar peak values that both correspond to the repeatable cristollographic unit 1.4 polyisoprene trans typical of Beta gutta-perchas.

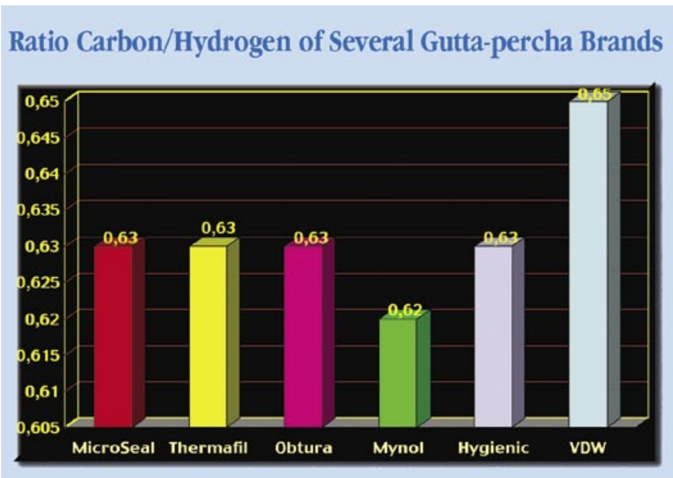


Fig. 26.10. The C/H ratio of various types of dental gutta-perchas [42] proportional to the concentration in pure gutta-percha; Thermafil gutta-percha exhibits a C/H ratio identical to Beta gutta-perchas.

Fig. 26.11. Cone gutta-percha, as seen directly with an SEM reveals a poor amalgamation between the various components (SEM x5000).

ment brings about a fragmentation of the long polymer chains as is demonstrated by preliminary results from our research in which different types of gutta-percha underwent two tests, infrared-spectroscopy and gel-permeation chromatography, used to evaluate the effects of the degradation process and the molecular weight of complex polymers.[37,43]

The infrared-spectroscopy indicated that the Thermafill gutta-percha has a molecular structure less intricate than that of typical Beta gutta-percha and is more susceptible to ozone degradation, as is shown by the many peaks corresponding to the splitting of the double bonds trans -C(CH^3)=CH seen in the 750-960 cm^{-1} region and to the consequent freeing of the carbon groups in the 1700 cm^{-1} region (Fig. 26.13). The molecular fragmentation of the Thermafil gutta-percha chains was confirmed by the gel-permeation chromatography results which showed, in the area of light and very light molecular weights, higher and wider peaks than that of beta-phase gutta-percha[10,37,43] (Fig. 26.14)

The Alpha type behaviour of the Thermafil gutta-percha thus depends on the physical treatment that is able to degrade the long policarbonaceous chains freeing low molecular weight fragments responsible for the low viscosity and adhesivety of the polymer as well as its capacity to penetrate the dentinal tubules.[8,10,44]

The penetration capacity of Thermafil gutta-percha was evaluated comparatively in two SEM studies on extracted teeth obturated using thermafil with and without sealer:[8]

– SEM analysis of specimens obtained by fracture and prepared with the "critical point" technique. This type of investigation allows one to directly observe the gutta-percha in the dentinal tubules and is useful for measuring penetration depth (Fig. 26.15); however, the technique is difficult to carry out due to the risk of artefacts and the difficulty of obtaining fractures which include filled tubules.[8]
– SEM analysis of specimens obtained by complete decalcification of the dental tissues which are then removed in an atraumatic manner[8] (Fig. 26.16). In this way the obturations can be directly observed with the SEM (Figs. 26.17, 26.18). This type of investigation is simpler to carry out and allows an evaluation of the number of filled tubules over a large surface area; the risk of artefacts is however still present during the setting up of the preparations.

Both methods showed Thermafil gutta-percha to have an elevated capacity of tubular penetration with depth of fill and number of tubules filled.[8] The penetration capacity does not appear to be influenced by the presence of cement which seems to combine with the gutta-percha into a type of "cemento-percha" with a high sealing capacity in which it is impossible to distinguish, at least with the SEM, the two original components (Figs. 26.19, 26.20).

The actual clinical importance of obturating the dentinal tubules with gutta-percha has not yet been demonstrated; it is certainly responsible for a reduction in the dentinal permeability to bacteria and their toxins[44] and therefore for an increased hermetic seal of the canal obturation.

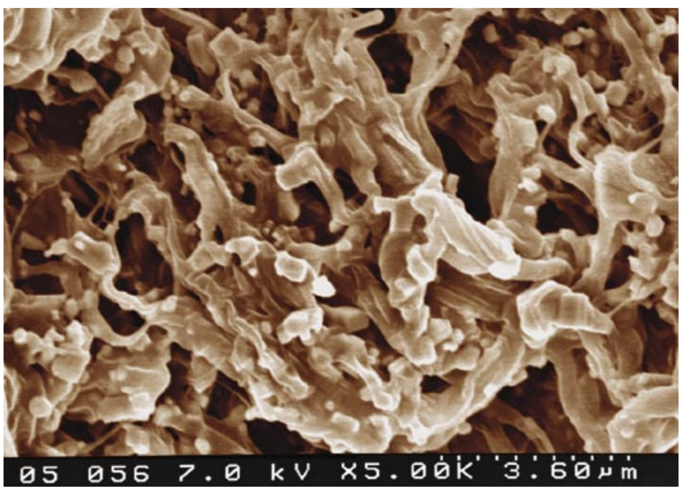


Fig. 26.12. Thermafil gutta-percha exhibits a good amalgamation between the various components with a very fine reticular structure (SEM x5000).

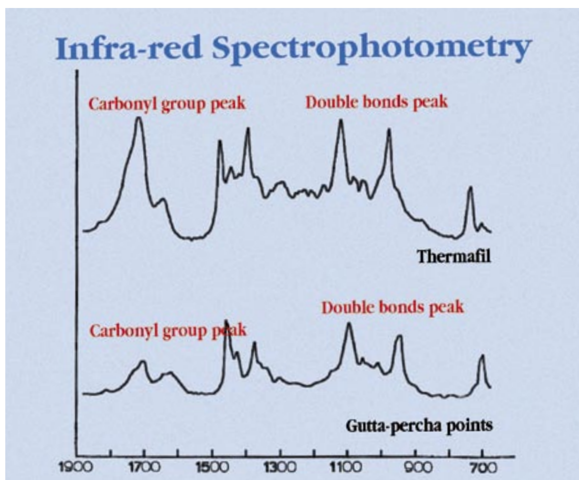


Fig. 26.13. Examination of the Thermafil gutta-percha spectrogram exhibits a molecular structure simpler than cone gutta-percha, as demonstrated by the wide peaks corresponding to the scission of the double trans links, inversely proportional to the complexity and molecular weight of the polymer.[10]

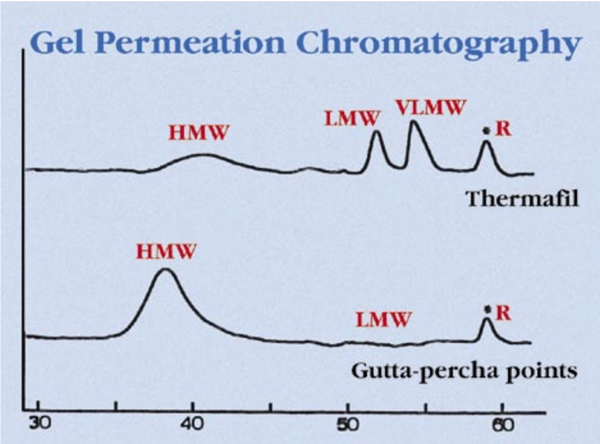


Fig. 26.14. Examination of the Thermafil gutta-percha chromatogrammes exhibits wide and high peaks in the regions of low molecular weights (LMW) and very low (VLMW). By contrast the cone gutta-percha exhibits a high peak in the region of high molecular weights (HMW).

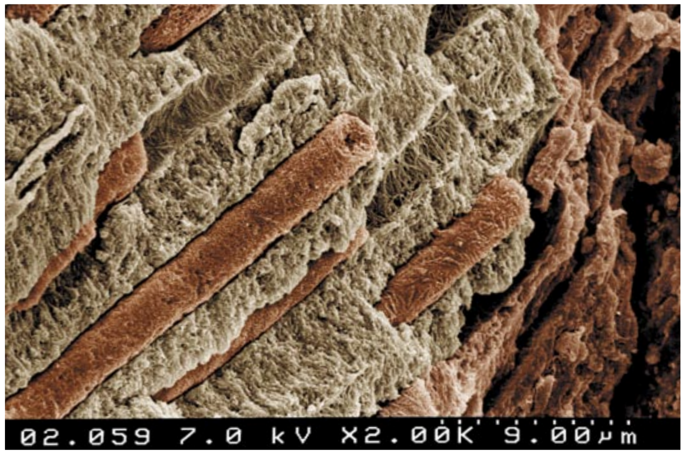


Fig. 26.15. Scanning Electron Micrograph carried out on extracted teeth which were obturated with Thermafil without sealer then fractured and prepared with "critical point" technique (SEM x1000). The penetration of Thermafil gutta-percha in the dentinal tubules is evident.

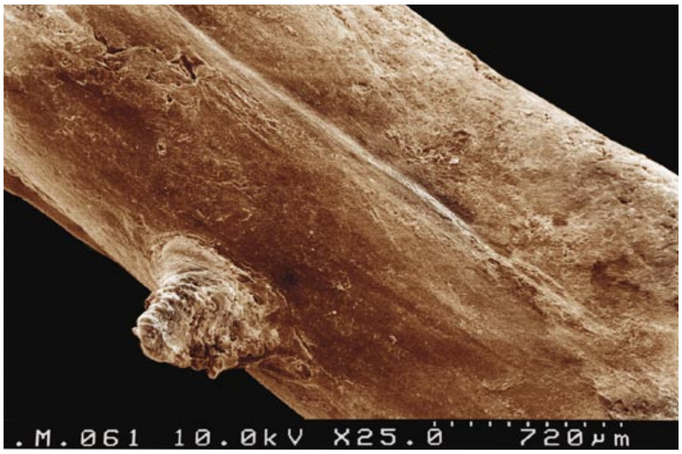


Fig. 26.16. Thermafil obturation obtained after decalcification and the removal of the dental tissues. Note the penetration of the gutta-percha in a lateral canal (SEM x25).

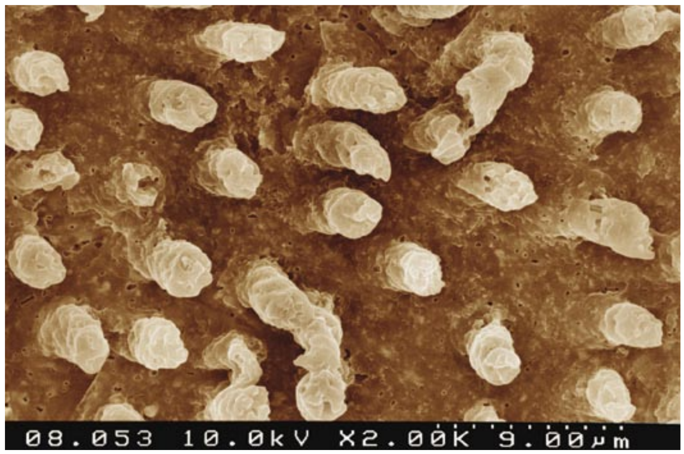


Fig. 26.17. The examination of the surface of Thermafil obturations at higher magnification shows the presence of numerous microprojections corresponding to the imprint of the dentinal tubules in the gutta-percha (SEM x2000).

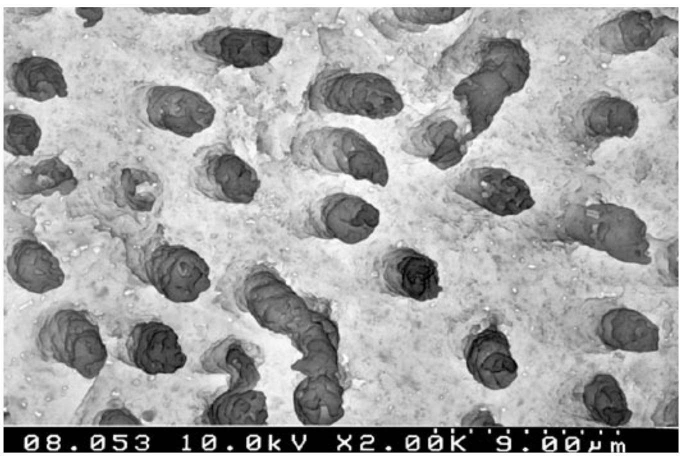


Fig. 26.18. The same image in Fig. 26.17 digitally turned shows a typical dentine structure. In this way the tubular penetrations of the Thermafil gutta-percha is illustrated without possible errors (SEM x2000).

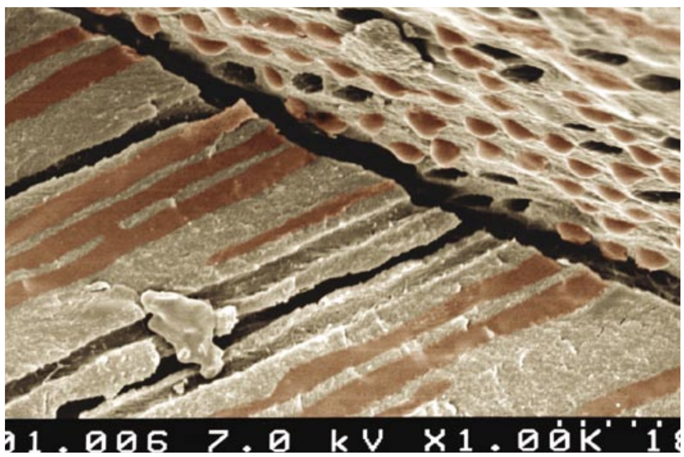


Fig. 26.19. Scanning Electron Micrograph of an extracted tooth obturated using the Thermafil technique and sealer. The sample was obtained by fracture and the examination of the dentinal walls shows numerous dentinal tubules filled in their depth with guttapercha (SEM x1000).

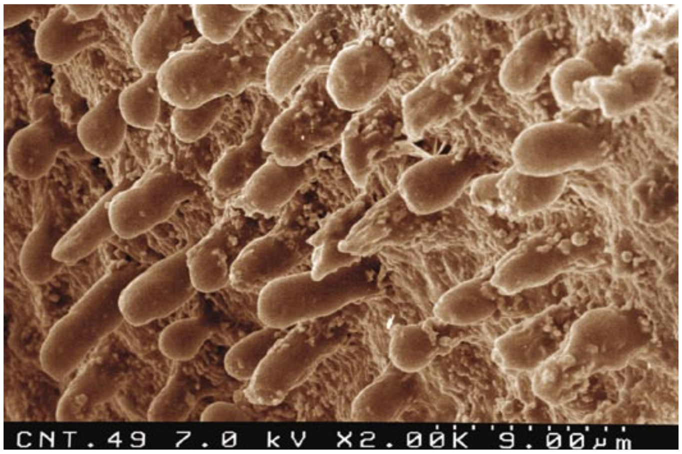


Fig. 26.20. Scanning Electron Micrograph of an extracted tooth obturated with Thermafil gutta-percha and sealer. The sample was obtained by fracture and surface examination of the guttapercha reveals the presence of numerous microprojections corresponding to the penetration of the polymer into the dentinal tubules (SEM x2000).

Size verifiers

The size verifiers are available in 12 sizes with tip diameters 0.20 to 0.90 mm and taper of 5%. Made from nickel titanium, they are similar to hand Profiles in that their tip is non cutting and the blades show the typical radial lands (Fig. 26.21). The size verifiers are used by inserting them in a canal and checking their positions with a radiograph; as their taper is 5% which is slightly greater than that of the carrier, which is 4%, they are considered verifiers of the canal dimension thereby aiding the selection of the correct Thermafil obturator.[6,12] For example, if the canal preparation is terminated with an apical diameter of 0.25 mm, one tries a # 25 verifier; if this reaches the working length with ease and without interference, we have the certainty that the canal has the correct taper to accept # 25 Thermafil obturator.[6,12]

Since the verifiers have blades that cut, small adjustments can be made to the preparation; conversely if their insertion seems difficult then the whole canal preparation sequence should be repeated.[6,12] The size verifiers are not currently available for GT Thermafil and in these cases the last GT file used to working length will act as verifier, given the perfect correspondence between the taper of the GT file and the GT obturator carrier (Fig. 26.22).

Finally one should note that the same obturator carrier can be used as a verifier once the gutta-percha has been removed; the advantages of these plastic verifiers are, in our opinion, multiple:[6,12]

- can be used also for GT Obturators;
- they exactly verify the adaptation of the carrier to the canal anticipating what will happen at the moment of obturation;
- they do not cut, therefore do not produce dentinal smear layer and no further rinsing with EDTA or hypochlorite is required.[11]

Fig. 26.21. Nikel Titanium verifiers for classic Thermafil obturators.

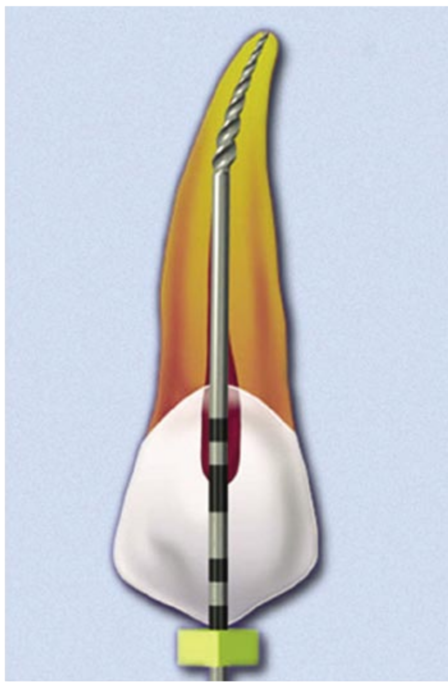


Fig. 26.22. With GT Thermafil, the last GT apical working file acts as the verifier.

ThermaPrep Plus Oven

The Thermaprep oven enables one to thermoplasticize two Thermafil obturators in a few seconds (Fig. 26.23). It only requires inserting the obturators in the necessary inserts, selecting the diameter of the obturator, start the heating and in a few seconds the thermoplasticization of the gutta-percha is complete. Anyway, once the obturators have been removed from the oven, one has to check that the gutta-percha appears swollen, shiny and sticky, in other words, ready to use; if not it is worthwhile repeating the heating cycle.

Fig 26.23. The ThermaPrep Plus Oven for thermo-plastisizing the Thermafil obturators.

Therma-cut burs

The Therma Cut are steel burs for use with a high speed handpiece and are used to section the obturator after insertion in the canal. Available in 4 diameters, 25 mm long, they are tapered fissure burs with a perfectly smooth spherical and non cutting tip (Fig. 26.24). Used dry and in contact with the obturator it sections it instantly, at the canal orifice level, with the heat generated through friction. Alternatively it is possible to section the obturator with the heat generated by the Touch'n Heat or System-B.

Fig. 26.24. Therma-cut burs for sectioning Thermafil obturators after placement in the canal.

Post space burs

These are steel burs that are useful for rapidly preparing post space in a root canal obturated with the Thermafil system. Available in 2 diameters 25 and 31 mm long, the post space burs have a tapered fissure shape, rounded tip perfectly smooth and without blades; however they have two transverse grooves along the bur shank which are useful for removal of debris (Fig. 26.25). The post space burs are used dry, placed in contact with the carrier at the level of the canal orafice; the heat generated by the friction assures the removal of both carrier and gutta-percha, with reasonable precision, to the desired depth (see "Preparation for Post Space in a Thermafil Obturation").

Fig. 26.25. Post space burs to prepare the space for the post in canals obturated with Thermafil.

OPERATIVE SEQUENCE FOR A THERMAFIL OBTURATION

Canal preparation

The ideal canal preparation for a Thermafil obturation must allow an easy insertion of the carrier leaving sufficient space for the flow of sealer and gutta-percha (Figs. 26.26 A, B).[6,12]

The taper of the canal as well should be proportionally larger than that of the carrier to optimize the condensation by creating a wedging effect between the carrier and the canal walls.[6,12]

If one uses the classic thermafil obturators with carriers that have a .04 (4%) taper, the final conicity of the canal should be between .05 and .06 (5-6%) easily obtained with many of the nickel titanium instruments available commercially like Profile .06 (Dentsply-Maillefer®), Quantec (SybronEndo®), Hero 6-4-2 (Micro Mega®), K3 (Kerr®), RaCe (FKG®) etc.

In the case of GT Thermafil the correct canal taper is determined by the last apical working GT File. If one immagines for example completing the preparation with a GT File 20.10, the definitive taper will be 10%, perfect to accept the corresponding GT Thermafil 20.10 which has a carrier with a taper slightly less (about 9%) to optimize the wedge effect and allow space for the gutta-percha.

Obturator selection and preparation

The easiest way to select a correct Thermafil obturator is to use the bared plastic carriers. Indeed the size of the Thermafil obturator to be used will correspond to the plastic carrier that, when introduced into the root canal, binds 1 mm shorter than the working length. By keeping the tip of the plastic carrier shorter than the working length, one will allow gutta-percha and sealer alone to fill the apical area thus incresing the hermeticity of the apical seal as recently demonstrated in an "in vitro" study.[45] Position and adaptation of the plastic carrier inside the root canal will be then checked by a radiograph and the carrier working lenght will be transferred on a Thermafil obturator of corresponding size. Since the amount of gutta-perchaexceeding the tip of the plastic carrier is variable, it has been advised[45] to remove a portion of this gutta-percha until the tip of the plastic carrier becomes visibles, thus obtaining obturators covered by a costant amount of gutta-percha and, at the same time, reducing the risk of apical extrusion of the obturating material (Fig. 26.27)

Pre-obturation irrigation

With the aim of improving the sealing capacity of the Thermafil gutta-percha and especially its penetration of the lateral canals and the dentinal tubules it is

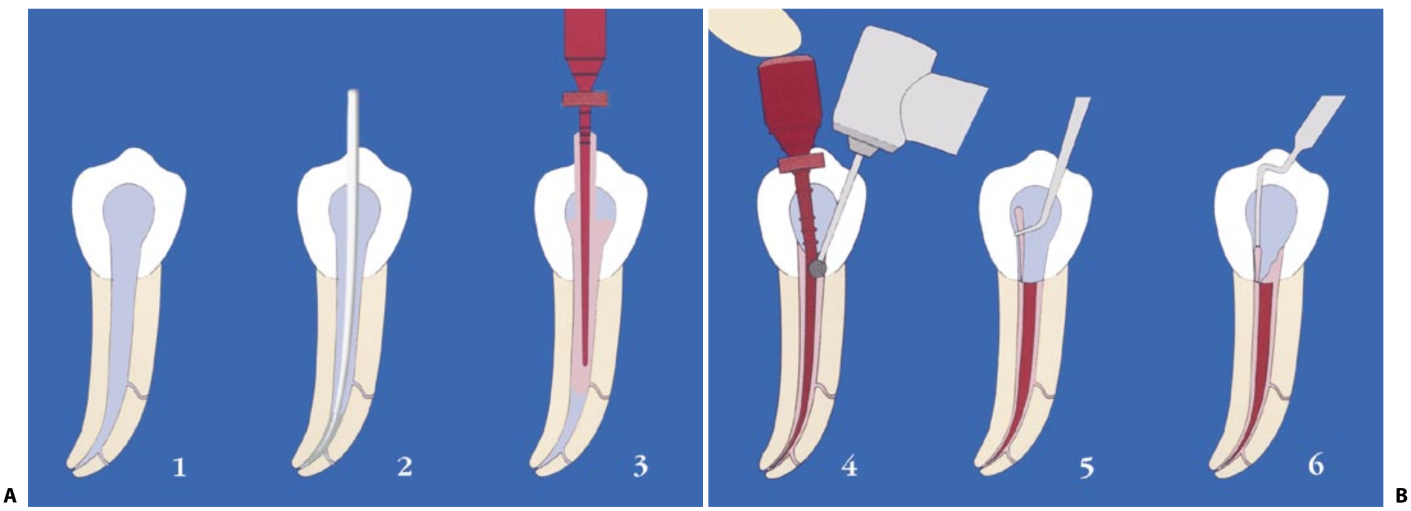
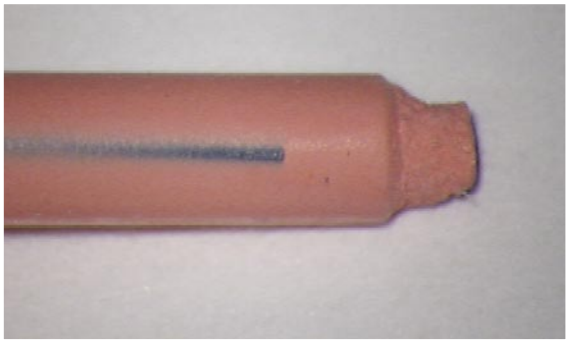
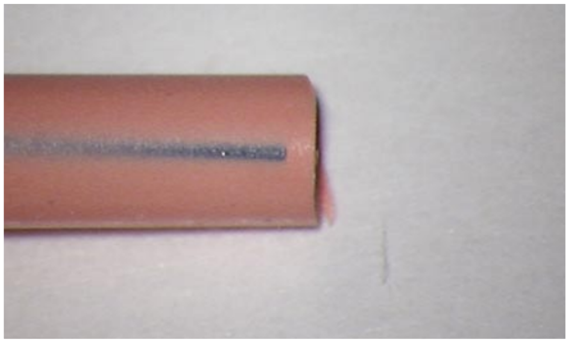


Fig. 26.26. **A.** Operative sequence for Thermafil obturation. In the shaped and dried canal (**1**), one places a very small amount of sealer using a paper point (**2**). One then slowly inserts the obturator (**3**). **B.** After waiting a few seconds the obturator is sectioned using a Therma-cut bur (**4**). Where necessary it is possible to increase the mass of gutta-percha coronally by adding accessory cones and manually condensing them (**5**, **6**).



A



B

Fig. 26.27. The Thermafil before (**A**) and after (**B**) removing the gutta-percha apical to the carrier tip.

advisable to dedicate a few minutes to a “final” irrigation which should be carried out immediately prior to obturation, after completion of canal preparation, using the following operative sequence:[11]

– rinse the canal with 8-10 cc of 10-15% EDTA carried to the apical third with a 30 gauge Endodontic needle, activating the solution subsequently with # 15 K-File mounted in an ultrasonic handpiece and placed passively 1 mm short of working length; the solution must be left to act for a total of about 5 minutes
– rinse with 10 cc of 5% sodium Hypochlorite activating the solution with ultrasonic files as was done for the EDTA
– re-rinse with saline solution and then absolute alcohol (optional)
– complete the drying of the canal using sterile paper points
– it should be remembered that pre-obturation rinsing does not replace the usual rinsing carried out during canal preparation (Figs. 26.28-26.30).

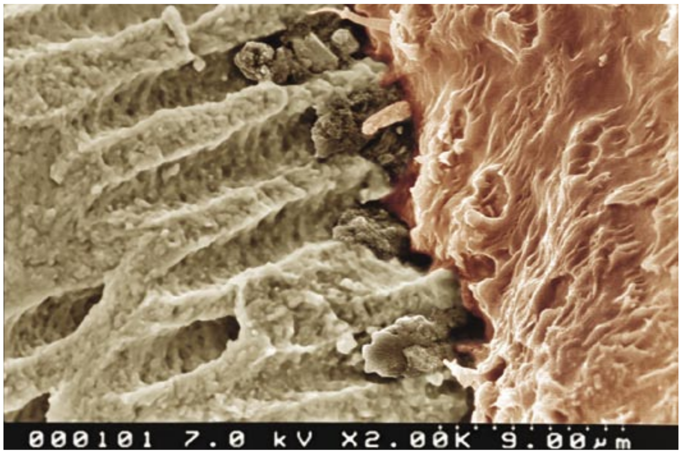


Fig. 26.28. The incomplete removal of the dentinal smear layer deters the penetration of the heated gutta-percha into the dentinal tubules thereby reducing the hermeticity of the obturation (SEM x2000).

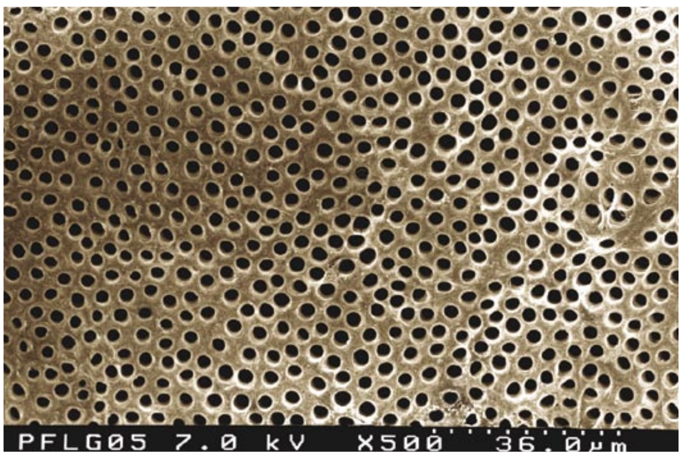


Fig. 26.29. Scanning Electron Micrograph of the canal walls which have been subjected to an efficient sequence of preobturation irrigation. The orifices of the dentinal tubules are patent and cleaned. There is no trace of smear layer (SEM x500).

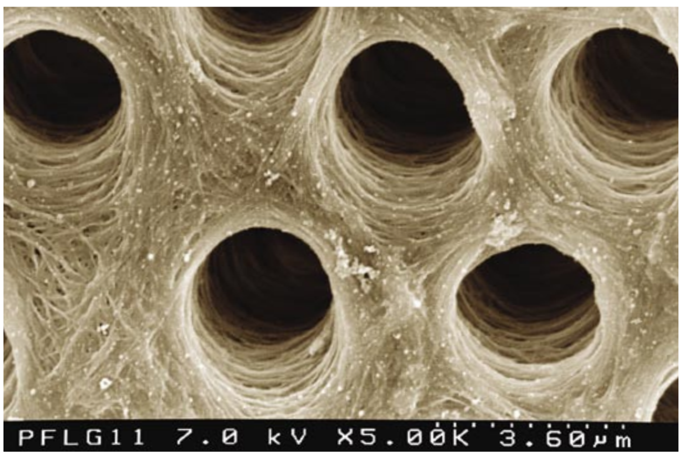


Fig. 26.30. A higher magnification of fig 26.29 shows the degree of cleanliness obtained and the aspect of the intertubular dentine which doesn't show signs of decalcification as a result of the irrigating solutions used (SEM x5000).

Sealer placement

The Thermafil technique relies almost completely on the gutta-percha for a hermetic seal; the use of an excessive quantity of sealer is not only unnecessary but could be damaging, by increasing the risk of overfilling.[6,12] One places a small amount of sealer in the canals adapting it to the walls and eliminating the excess with a paperpoint until it is reduced to a paper thin covering layer. All zinc oxide eugenol endodontic sealers that have medium to long working times like Pulp Canal Sealer (Kerr®) type EWT or the resin polymer AH+ or TopSeal (Dentsply®) can be used with the Thermafil system; the consistency of the sealers should be quite thick, similar to molten gutta-percha.

Notwithstanding the properties of Thermafil gutta-percha, the use of sealer cannot be avoided without risking loss of the hermetic seal of the obturation.[4,27,40,58]

Obturation

The selected obturator heated in a ThermaPrep Plus Oven is slowly introduced into the canal with small clockwise/counter-clockwise movements until it reaches its final position; after 8-10 seconds one sections the obturator with a Thermacut bur keeping it in position with light pressure. The use of these burs enables one to section the carrier with maximum precision and without disturbing the apical seal. During the period (1.5 minutes) that the gutta-percha remains plastic it is possible to carry out small adjustments to the coronal part of the obturation such as elimination of excess gutta-percha or addition of auxiliary cones where endodontic anatomy requires it (C-shaped canals or those with irregular cross section).[6,12]

During insertion of the obturator the patient may experience pain, even quite intense, because of pressure on the periapical tissues by the air in the canal being compressed by the heated gutta-percha. The use of a light anaesthesia prevents the risk of this pain which anyhow tends to disappear spontaneously after a few minutes; the patient should be informed of the possibility of feeling some pain and assured that it is "normal".[6,12] The sequence of a Thermafil obturation provides for a minimun of four radiographs (Fig. 26.31): diagnostic, working length, verifier and post operative.

If problems occur during the operative sequence (early cooling of the gutta-percha, impossibility of reaching working length etc), an extra radiograph should be taken before sectioning the carrier; in case of an error it is easier to remove it and repeat the obturation.

Post endodontic restoration

Following obturation it is advised to place a provisional restoration and to reappoint the patient for the post endodontic restoration[6,12] (see "Preparation for Post Space in a Thermafil Obturation"); this allows ti-

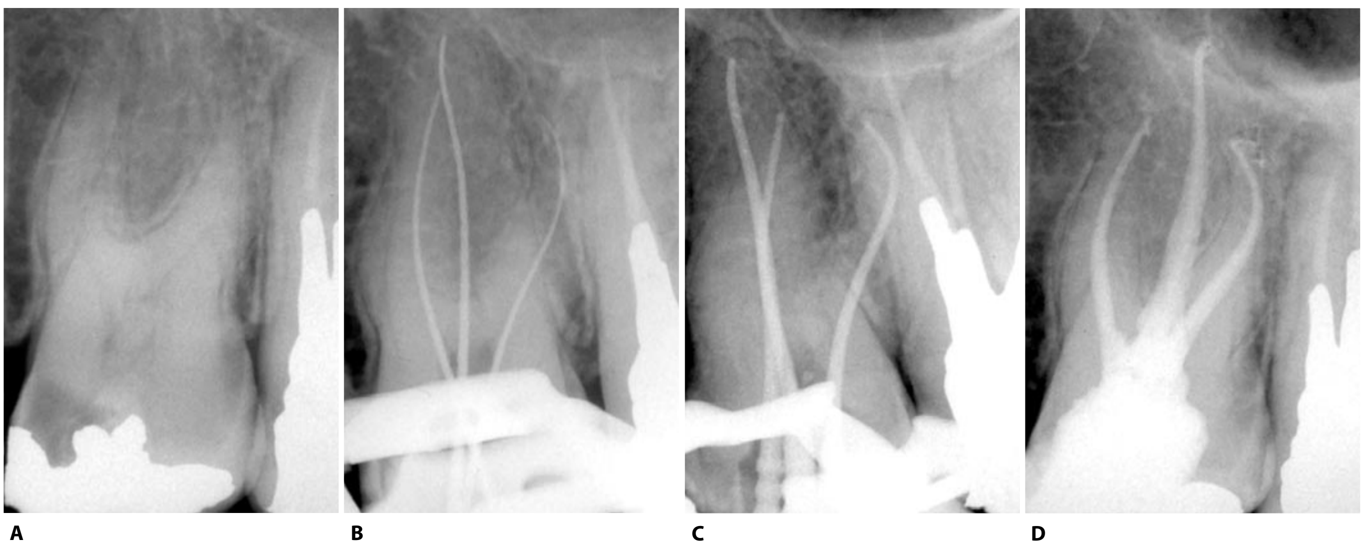


Fig. 26.31. To correctly carry out a Thermafil obturation at least four radiographs are required. **A**, **B**. Diagnostic and working length determination. **C**. Plastic verifier radiograph. **D**. Post-operative radiograph.

me for the sealer to set completely which in the case of resin polymers could be some hours.

Post operative sequelae

The patients should be advised of the possibility that they may have light-moderate pain due to air compression post-operatively which will disappear after 2-3 days and is easily managed with commonly used analgesics. Pain that persists for more than one week is generally due to an error in the preparation stage of the canals (over or under- instrumentation) or obturation (overfilling).

HERMETIC SEAL AND QUALITY OF THERMAFIL CANAL OBTURATION

The quality of a canal obturation technique is evaluated according to the capacity to three dimensionally fill the endodontic system, adaptation to the canal walls without gaps and the prevention of bacterial micro infiltration coronally and apically.

Flow and filling capacity

The flow of Thermafil gutta-percha and the accompanying sealer obeys the law of Hagen-Poiseuille[6,12] (Fig. 26.32) and is therefore directly proportional to the canal radius and size of condensation force, while being inversely proportional to the viscosity. A continous tapered preparation with a constant and progressive reduction in radius, favours an adequate flow of the gutta-percha, while an irregular canal preparation with sudden reductions in radius are responsible for slowing the gutta-percha flow.

The condensation forces that develop during Thermafil obturation are less than those produced during lateral condensation, vertical condensation and System-B;[5] it is however possible to optimize these forces by giving the canal the taper corresponding in scale to that of the carrier (eg., a .06 canal and a .05 carrier). The wedge effect that occurs, together with the low viscosity gutta-percha, favours the penetration of the latter into the lateral canals and dentinal tubules (Fig. 26.33).

The ability of Thermafil gutta-percha to penetrate the dentinal tubules was discussed previously; its capacity to obturate the lateral canals was shown to be equal to that of vertical condensation and System-B, but significantly superior to that of lateral condensation, warm lateral condensation and Obtura[18,26] (Figs. 26.34-26.37).

Adaptation to the canal walls

The relationship between gutta-percha, sealer, carrier and canal walls of Thermafil obturations has been the subject of numerous "morphological" stu-

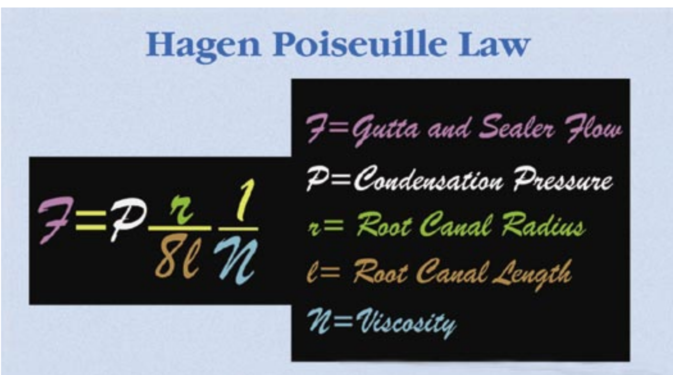


Fig. 26.32. The Hagen Poiseuille Law which regulates the flow of the complex polymers such as guttapercha. The flow is directly proportional to the condensation forces and to the radius of the canal, while it is inversely proportional to the viscosity of the plasticized gutta-percha.

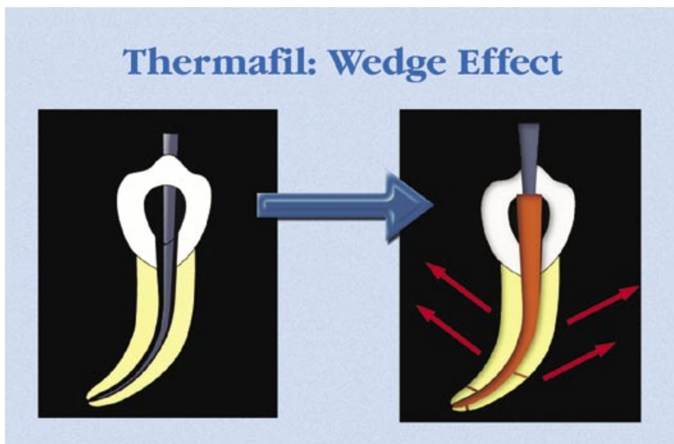


Fig. 26.33. The wedge effect serves to optimize the condensation forces during the Thermafil obturation, reducing the apically directed forces, to the advantage of the lateral forces which are directed against the canal walls. To optimize the wedge effect it is necessary that the taper of both carrier and canal should be proportionally similar.

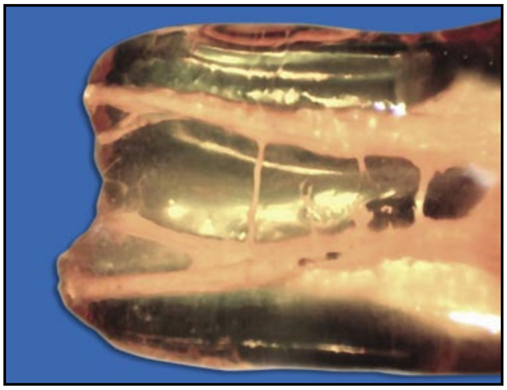


Fig. 26.34. In this second maxillary premolar the buccal canal (above) has been obturated with a Themafil # 35 while the palatal canal (below) was obturated with the System B technique. Both techniques appear to show the same capacity to three dimentionally fill the complex endodontic anatomy.

A B C D

Fig. 26.35. **A**. Endodontic treatment of a lower right first molar with a necrotic pulp and a substantial periapical lesion associated with the mesial root. **B**. Working length radiograph. **C**. One should note the presence of a large lateral canal in the mesial root which opens directly in the periradicular lesion. **D**. The 15 month recall reveals good bone healing.

A B C

Fig.26.36.Endodontic treatment of an upper left second molar.**A**.Working length determination in the two mesio buccal canals. **B**. Plastic verifiers radiograph. **C**. Post-operative radiograph with a large lateral canal associated with the palatal root.

A B

Fig. 26.37. **A**. Endodontic treatment of an upper left first molar. **B**. Postoperative radiograph after obturation with standard Thermafil reveals a complex canal system associated with the palatal root.

dies.[1,2,12,28,30,36,39,41,60] In particular subjects studied were:
- complete adaption of the obturations to the canal walls
- amount of sealer present at various levels
- amount of gutta-percha present at various levels
- phenomena of "bared carrier" (ie. carrier without gutta-percha)
- phenomena of "touching carrier" (ie. carrier in contact with canal walls).

The results of these studies showed that the Thermafil technique has a good ability to completely adapt to the canal walls that is comparable to other methods like vertical and lateral condensation[60] (Figs. 26.38, 26.39). The amount of sealer present always appears minimum while the amount of gutta-percha varies depending on the type of canal preparation used. In a canal correctly prepared the gutta-percha has sufficient space to flow and covers the carrier with a uniform layer. The contrary in fact occurs in a canal with a taper equal to or less than that of the carrier. The gutta-percha not having space to flow, is torn from the carrier and forced coronally (phenomena of the bared carrier).[6,12] The difficulty of obtaining an adequate taper in long and curved canals explains the increased incidence in these cases of "the bared carrier".[12,28]

With regard to the position of the carrier relative to the canal walls one can distinguish two clinical situations:
- well centered carrier at all levels, uniformely surrounded with gutta-percha without any contact with the canal walls. This situation is found in straight canals and those which are round in cross section[28,36] (Fig. 26.40)

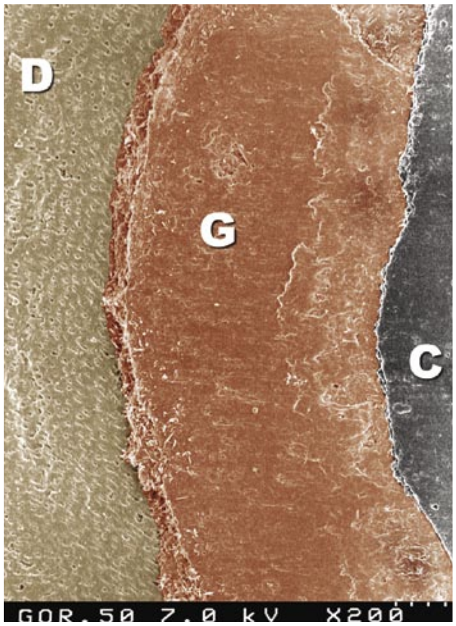


Fig. 26.39. The higher magnification of fig. 26.40 shows a good adaptation of the Thermafil gutta-percha to the canal walls; neither gaps nor spaces are visible at the contact surface between dentine and gutta-percha or gutta-percha and carrier.

- eccentrically positioned carrier, with thinning of the covering gutta-percha layer to the point of the plastic having contact with the canal walls (touching carrier). This situation one notes most often in curved and long canals as well as canals with irregular cross section (elyptical, kidney shaped, C shaped) and should be most frequent in the coronal and middle third; in the apical third the carrier positions itself centrally[28,30,36] (Fig. 26.41).

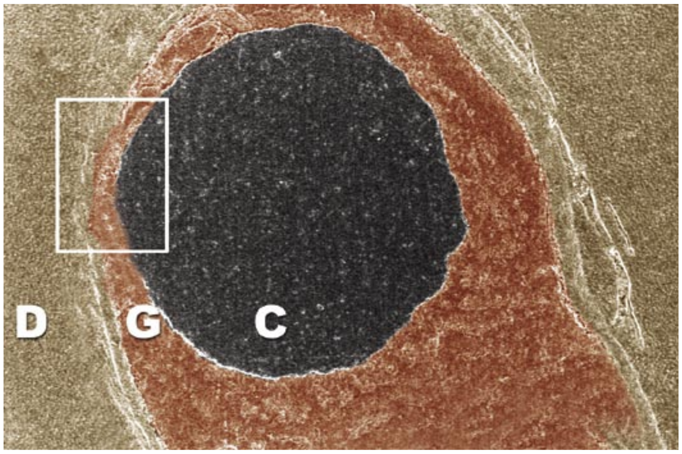


Fig. 26.38. Scanning Electron Micrograph of an horizontal section of the Thermafil obturation photographed using the replica technique to reduce the risk of artefacts. It is possible to observe the dentine (D)-gutta-percha (G)-carrier interfaces (SEM x30).

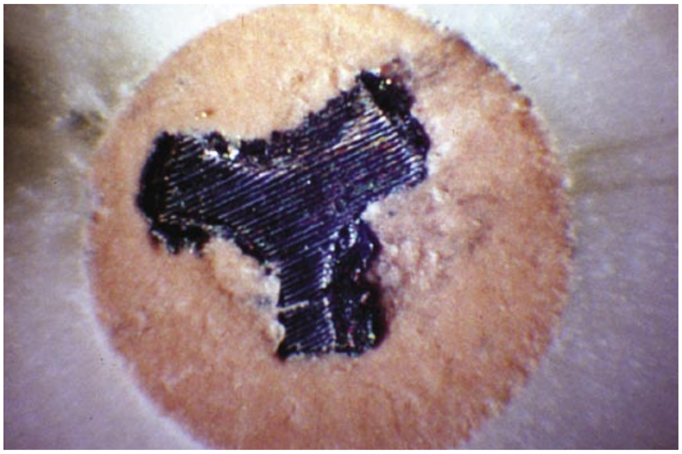


Fig. 26.40. Horizontal section of a Thermafil obturation which has been photographed using stereo-microscope (x12). The carrier appears well centered and surrounded by gutta-percha, and contact points between carrier and canal wall are not present. This situation presents more frequently in straight canals and canals with a round cross section.

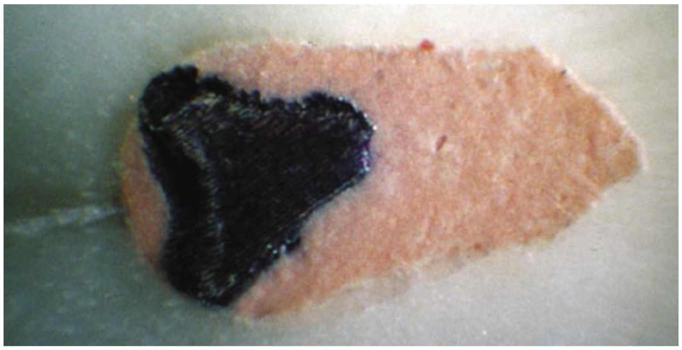


Fig. 26.41. Horizontal section of a Thermafil obturation which has been photographed with stereo-microscope (x12). The carrier appears in an eccentric position in the canal space and contact areas between carrier and dentinal walls are present. This situation most frequently presents in curved or in elliptical canals.

Summarizing one must distinguish between "bared carrier" phenomena and the "touching carrier" phenomena.

The basic cause of the bared carrier is an error in canal preparation with an obturation that relies principally on the rigid plastic of the carrier for a hermetic seal. In the case of the touching carrier phenomena the contact of the plastic with the walls is limited and localized coronally while the apical obturation relies solely on gutta-percha and sealer. That the limiting contact with the canal wall does not alter the hermetic seal of the Thermafil obturation has been demonstrated by apical microinfiltration studies discussed below.

Checking coronal infiltration

The prevention of coronal bacterial micro-infiltration, the cause of numerous endodontic failures,[59] is obtained with a restoration capable of hermetically sealing the access cavity and other portals of entry such as the dentinal tubules. The loss or absence of hermetic sealing by the coronal restoration allows the saliva to come into direct contact with the canal obturation; the risk of endodontic contamination is a direct function of the time of exposition to the saliva as well as the quality of the hermetic seal by the endodontic obturation. The coronal micro-infiltration tests using dye indicators (indian ink), seem to indicate that Thermafil behaves better than cold lateral condensation especially in the short term results whereas after four months the two techniques tend to show the same results.[53,54,57] Comparing other techniques based on thermoplastic gutta-percha, Thermafil shows better results than the Ultrafil technique but worse than vertical condensation.[24,57] Instead with the bacterial micro-infiltration tests vertical condensation and Thermafil have similar results assuring a coronal seal superior to that of lateral condensation especially after smear layer removal and when carried out with a resinous sealer.[57]

In brief, warm gutta-percha that is compacted vertically is able to delay coronal bacterial infiltration more than cold compacted gutta-percha. Delay but not prevent; infact no technique is able to produce a seal that prevents saliva contamination beyond 30 days.[56] The possible solutions are:

1) place a post in the canal cemented with a composite that, with the new dentine adhesives, is able to seal the coronal third hermetically
2) remove a few millimetres of the obturation and fill the space thus created with Cavit, IRM, Super Eba or a composite cement using a dentine adhesive.[17,47]

Hermetic apical seal

The capacity to hermetically seal the apical third, where more than 90% of all endodontic anatomical complexities are found,[38] is the most important criteria for evaluating a canal obturating technique and has been the object of research using the most varied methodology of which we note:

– Infiltration of colourants. Commonly used, it is based on immersion of the root in a dye like methylene blue, prussian blue, eosin or china ink. Normally only the apical third is in contact with the dye while the rest of the tooth is isolated with silicone or varnish. The infiltration can be either passive, obtained by simple immersion in the dye at atmospheric pressure or with a vacuum, or active, by forcing the dye into the tooth under pressure or by centrifuge.[49,50] The root is than sectioned vertically or even diaphanized for the measurement of the microleakage using an optical microscope.[28]
– Liquid infiltration. More complicated than the preceding test, it requires the positioning of the tooth in a soft silicone tube connected to a vessel containing liquid under pressure (generally a saline solution with various added substances). In practice, the fluid is forced via the apex along the interface between the canal wall and obturation; its movement and the volume of the liquid filtered are direct

functions of the penetrability of the canal and thus the hermetic seal of the obturation.[48]

- Electrochemical method. The tooth is positioned with the apical portion in an electrolytic solution. Using two electrodes in platinum, one immersed in the solution and the other in the coronal access of the tooth, the impedence is measured by passing an electric current through the tooth. The impedence is a function of the liquid absorption via the gaps that are present between the dentine and the obturation.[48-50]
- Infiltration with resin. The roots are submersed in a resin type resorcinol-formaldehyde for 5 days at 5°C and then sectioned horizontally at various levels. The sections are evaluated using an optical microscope to see how much resin has penetrated the canal to fill the gap that exists between the obturation and dentine.[32]
- Radio-isotopes. The roots are immersed in a solution containing radioactive isotopes (Iodine, Ca[45] or S[35]) capable of emitting beta and gamma radiation which can be registered using autoradiography techniques or a gamma counter.[31]

All these techniques used to evaluate the Thermafil technique resulted in the following conclusion:

- Thermafil obturations, notwithstanding the excellent characteristics of its gutta-percha, needs sealer or otherwise a drastic increase in microleakage results. The role of the sealer is twofold: it lubricates the canal walls aiding in the flow of the gutta-percha which otherwise tends to adhere to the dentine and also compensates for the cooling contraction of the gutta-percha that occurs.[32,40,58] The characteristics of the sealer do not seem to influence the quality of the obturation; with all the sealers tested, such as TopSeal®, Kerr's sealer,[4] AH-26,[27] Ketac Cem® and zinc oxide,[58] all produced similar results.
- The Thermafil obturations are superior to that of the lateral condensation technique because of their apical hermetic seal. The major part of the research confirms these results,[14,16,19,20,29,30,31,32,41,46,55,60] with the exception of some studies from the early 90's, a time when Thermafil was neither well known nor perfected.[13,39]
- Compared to warm vertical condensation and System-B, the Thermafil technique behaves equally well; the differences between the three methods are not statistically significant.[4,21,49,50]
- The Thermafil obturations demonstrate better hermetic seal than than obtainable with Obtura and the Ultrafil technique as it was expected, due to the variability and poor predictability of these two obturation techniques.[16,18,27,49,50]

PREPARATION FOR POST SPACE IN A THERMAFIL OBTURATION

The preparation for the post space (dowel space) in cases where Thermafil has been used does not require more time than it would to remove gutta-percha from a canal obturated using lateral or vertical condensation, as long as adequate methods are used.[6,12] Furthermore, the difficulty depends on the presence of the plastic carrier, and one would prefer a technique which is able to remove it with ease and precision. The ideal method for cutting the carrier is with a heat source; it is possible to use the Touch'n Heat or System-B tips, however the most economical and effective solution is to use the appropriate "Post Space Burs®" (Fig. 26.25). The Post Space Burs are non cutting and are able to remove the carrier to the desired depth through the frictional heat generated during rotation. Their effectiveness is maximized by not using water coolant, however they can also be used with water spraying if one is concerned about overheating the dentine during contact with the canal walls. The operative sequence is really simple: one locates the carrier at the canal orifice and placing the bur in contact, start high speed rotation with light pressure; the bur easily penetrates the canal plastifying the carrier and pushing the debris coronally[6,12] (Fig. 26.42). It is advisable to measure the working length accurately to

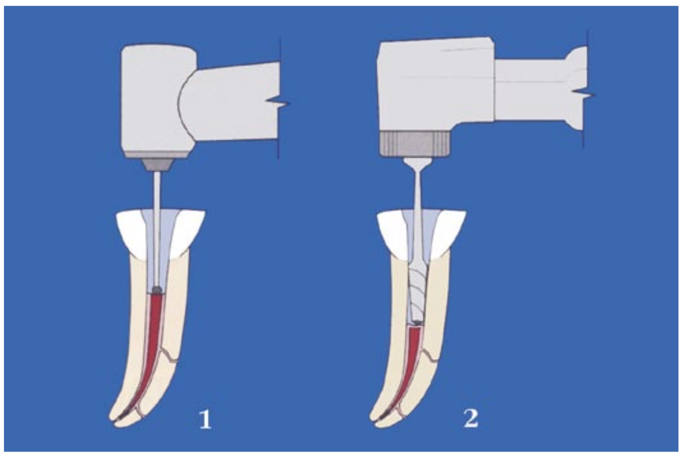


Fig. 26.42. The post space preparation in a Thermafil obturated canal can be completed with Post Space Burs (Dentsply-Maillefer) (**1**) or with burs contained in the Pro-Post kit (Dentsply-Tulsa Dental) (**2**).

avoid removing too much obturation, thereby compromising the apical seal; it is better to progressively remove the carrier until an adequate depth is reached to position the post. The Post Space Burs are restricted to removing the carrier and part of the gutta-percha, therefore it is necessary to complete the detersion and preparation of post space using calibrated burs.[6,12] As an alternative to Post Space Burs it is possible to utilize Pro Post steel burs by "Dentsply Tulsa Dental®" available in 4 diameters for use with a blue ring contra angled handpiece. The Pro Post Burs are able to section the carrier thanks to a bevelled tip that is very efficient and agressive[6] (Fig. 26.43). It isn't advisable to use Gates or Largo type burs, as they have non cutting tips and are therefore not very effective.[6] Ultimately, some authors have questioned whether it is opportune to prepare the post space immediately after obturation or rather postpone it to a successive appointment. Even though there is no evidence that demonstrates the risk of apical seal loss following immediate preparation of the post space,[15,51-53] we still prefer to delay post placement at least for a day: the complete setting of the sealer and the "stabilization" of the whole obturation allows one to work with increased neatness and security (Figs. 26.44, 26.45).

RETREATMENT OF THERMAFIL TREATED TEETH

The first Thermafil commercially sold were characterized by a metallic carrier in steel or titanium which caused problems with both sectioning of the obturator as well as with post placement, and especially in retreatment.[28] Considering the similarity of the metallic carrier with a root canal instrument, the retreatment situation was similar to that of a fractured instrument with analogous difficulties such as long working time and uncertain outcome.

The advent of the plastic carrier represented a major upgrade for the Thermafil system, making sectioning of the carrier, preparation of the post space and retreatment much simpler even for dentists not specialized in this area.[64] The retreatment of Thermafil cases can be done with the use of physical (heat), chemical (solvents) and mechanical (root canal instruments) means. With the function of making retreatment easier, the carrier has a longitudinal groove which creates a space between the canal wall and the plastic in which an instrument for removal can be passed. Among the numerous methods recommended for retreatment are:

– *Solvents for plastics and gutta-percha*.[33,64] Chloro-

Fig. 26.43. Scanning Electron Micrograph of the tip of a pro Post Bur (Dentsply-Tulsa Dental); the oblique cut of the tip is very aggressive and is able to cut and remove the carrier with precision.

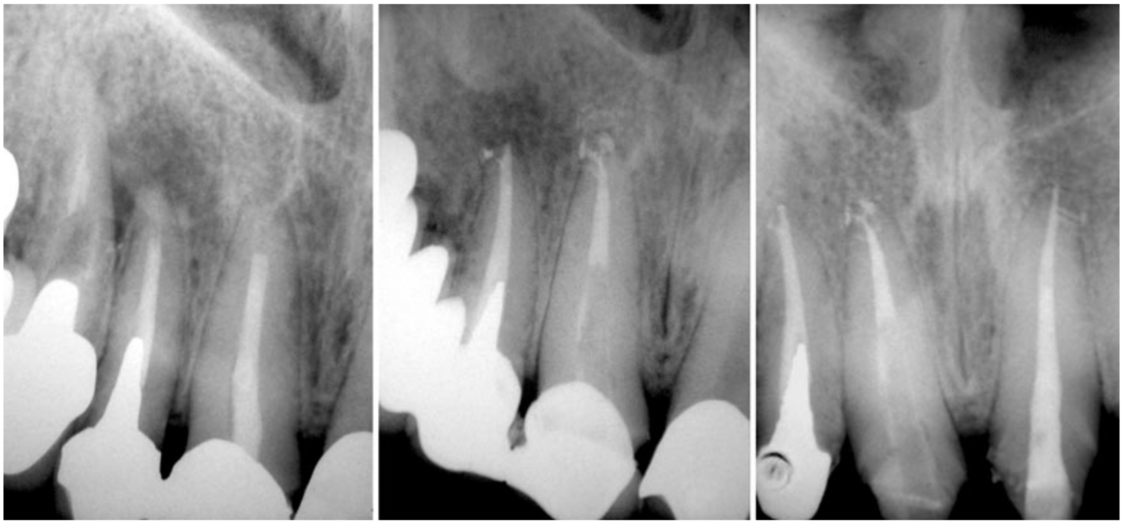


Fig. 26.44. **A**. Endodontic retreatment of the upper right lateral and central incisors. **B**. Post-operative radiograph; in the central incisor a carbon fiber post has been inserted. **C**. One year recall, after retreatment of the upper left central incisor and before cementation of new prosthesis. Note the healing of the periapical lesion of the lateral incisor and the presence of numerous lateral canals in all the treated teeth.

Fig. 26.45. **A**. Pre-operative radiograph. **B**. Working length with plastic verifier. **C**. Post-operative radiograph after restorative reconstruction with a fiber post in the palatal root.

form, dimethylformamide, xilene, eucalyptus oil and halothane have all been used without any significant statistical difference between them. The penetration of the solvent in the canals can be aided with the use of small K Files.

– *Hand instruments with solvents*. H files on their own[23] or alternating with K files[3] can be used: the use of solvents (chloroform or xilene) have the function of aiding penetration of the hand instruments which carry out the major work.
  The time required for a retreatment using this method depends on the operator ability and the tooth involved; the time quoted in the literature varies from about 6[3] to about 12 minutes[23] similar to that required to retreat a tooth obturated using lateral condensation.
– *Gates Glidden and chloroform (Imura)*. The time using this method for retreatment of Thermafil is similar to that for retreating a lateral condensation case. The two techniques are similar regarding the amount or residual gutta-percha remaining in the canals.
– *Heat (red-hot spreader, Touch'n Heat) plus solvents.* The average time reported for a Thermafil retreatment with this method according to Wilcox[61,62] is about 6 minutes as opposed to 5.3 minutes necessary for retreating a canal closed using lateral condensation.
– *System-B*: Using a technique based on the use of System-B pluggers, Wolcott reported retreatement times of only 1.8 minutes as opposed to 3.6 minutes for the solvent and hand instrument method.[63] It is worth noting that retreatment times can vary enormously depending on the canal being treated; it is difficult to immagine that one could retreat a canal, in less than 2 minutes, that is very long and/or curved even with the use of the finest System-B tips, due to the limited flexibility and a tip diameter of 0.5 mm.
– *Ultrasonic tips*. Small and flexible ultrasonic tips coated with diamond or zirconium can be successfully used to retreat Thermafil cases. The heat generated by the ultrasonic waves will easily soften the plastic carrier, thus allowing the penetration of the tip up to the apical one third. After a few seconds one can remove the tip thus obtaining a hole inside the carrier; this hole can be used as a pathway for hand or rotary instrument that will complete the removal of the carrier.
– *Rotary instruments*: this method requires a working time generally not exceeding 5-6 minutes.[6,12] The instruments used must be sufficiently flexible and resistant to torsional tress; in our opinion the most suitable are the Profiles 25 .06 or the Protaper Finisher F1 that offer a good compromise between flexibility and strength.
  The rotational speed must not exceed 300 rpm, and the maximum torque not more than 2-2.5 newton/cm. The instrument initially during rotation must be limited to gutta-percha removal, then progressively proceed deeper using the longitudinal groove present on the surface of the carrier, ultimately loosening it and removing it from the canal[6,12] (Fig. 26.46).

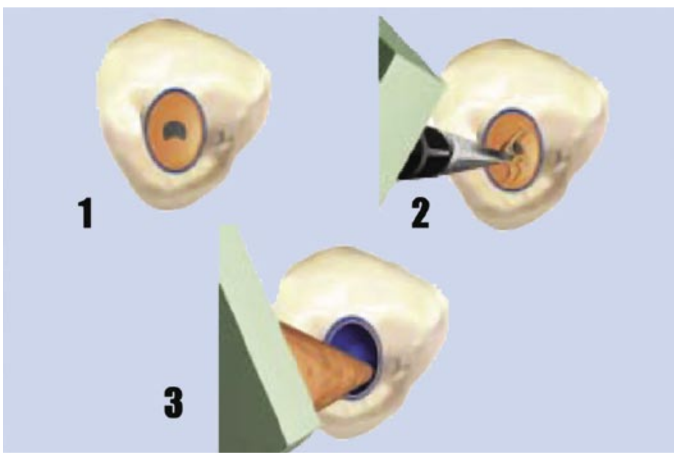


Fig. 26.46. To retreat a Thermafil case the longitudinal grooves can be utilized which are present on the carrier (**1**). The endodontic instruments to be used, preferably mechanical ones, will progressively proceed deeper between the carrier and the canal wall (**2**) until the carrier is freed from the gutta-percha and removed from the canal (**3**).

ADVANTAGES OF THE THERMAFIL SYSTEM

Rapid learning curve

Rapidity in learning the technique as well as consistent results are the keys that explain the success of the Thermafil System. Only a short course of a few hours is necessary to enable dentists with limited experience to successfully complete their first obturation; one must remember though that the quality of the results obtained rigorously depends on the canal preparation and scrupulous attention to all the steps.[12]

Conservative canal preparation

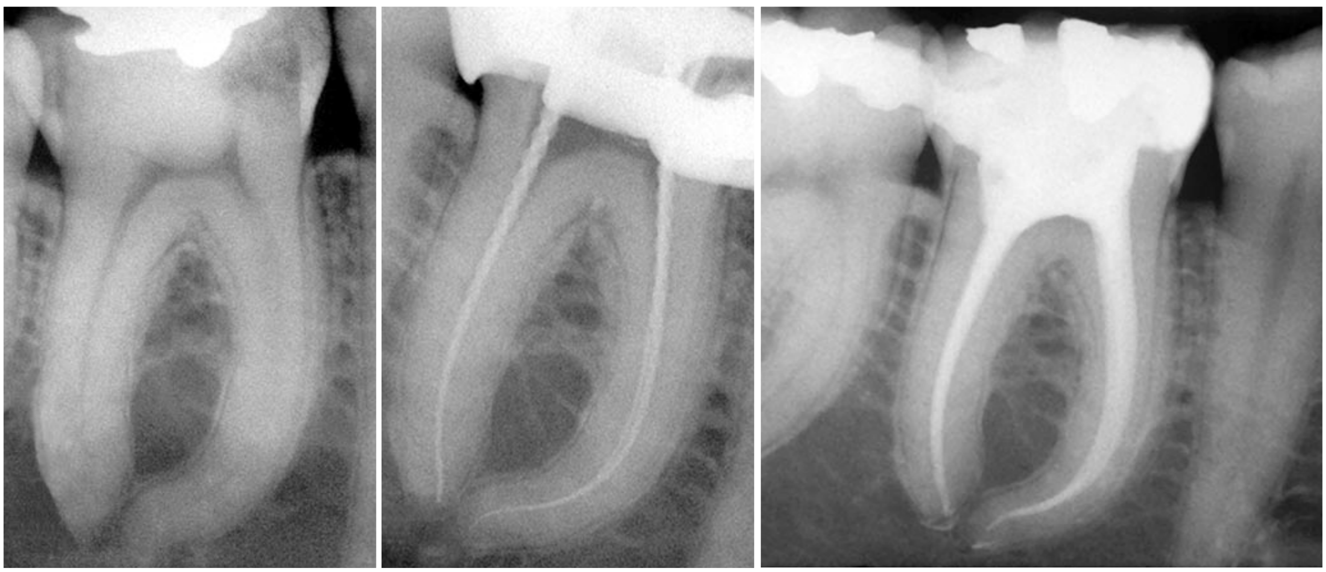
The canal diameters necessary to carry out Thermafil obturations are less than those for other techniques based on heated gutta-percha such as System B or vertical compaction. For example in a canal that is 16 mm in length (with total tooth length of about 25 mm), curved and calcified, the minimum diameter necessary to place a fine System B tip within 4 mm of the apical foramen is 0.55 mm at D_4, 0.80 at D_8, 1.05 mm at D_{12} and 1.30 mm at D_{16}. Allowing an apical preparation limit of 0.25 mm, it would be necessary to have a canal taper of 8% to obtain the correct diameter. On the other hand, when choosing GT Thermafil .04, one can limit the shaping of the canal to 4% with a notable saving of dental tissue and lower risk of errors. The precise required diameter for Thermafil 25/.04 would be 0.41 mm at D_4, 0.57 mm at D_8, 0.73 mm at D_{12} and 0.89 mm at D_{16}.

We are therefore confronted by significant differences that increase proportionally with the canal complexity; in very long and curved canals the choice of the Thermafil technique makes it possible to do a more conservative preparation with drastically reduced working time[12] (Figs. 26.47, 26.48).

Obturation of curved canals

Thanks to the flexibility and the cutting efficacy of the latest generation of endodontic instruments, the possibility of correctly shaping canals, even ones with severe curvatures has been considerably improved, however the obturation in these cases remains complex because of the difficulties of introducing spreaders and pluggers to the correct depth.[1,6] Faced with these difficulties the operator has two choices. Either to increase the diameter of the canal, thereby lengthening working time and increasing the risk of errors, or reduce the working depth of the spreaders and pluggers with the risk though of not adequately condensing and plasticizing the apical gutta-percha.[12]

The Thermafil System perhaps represents the best solution for the obturation of curved canals; infact



A B C

Fig. 26.47. **A.** Endodontic treatment of a lower right first molar characterized by both long and curved canals. **B.** Working length determination and obturation with standard Thermafil #30. **C.** Note that the preparation of the canal is conservative and respectful of the endodontic anatomy and of the canal diameters.

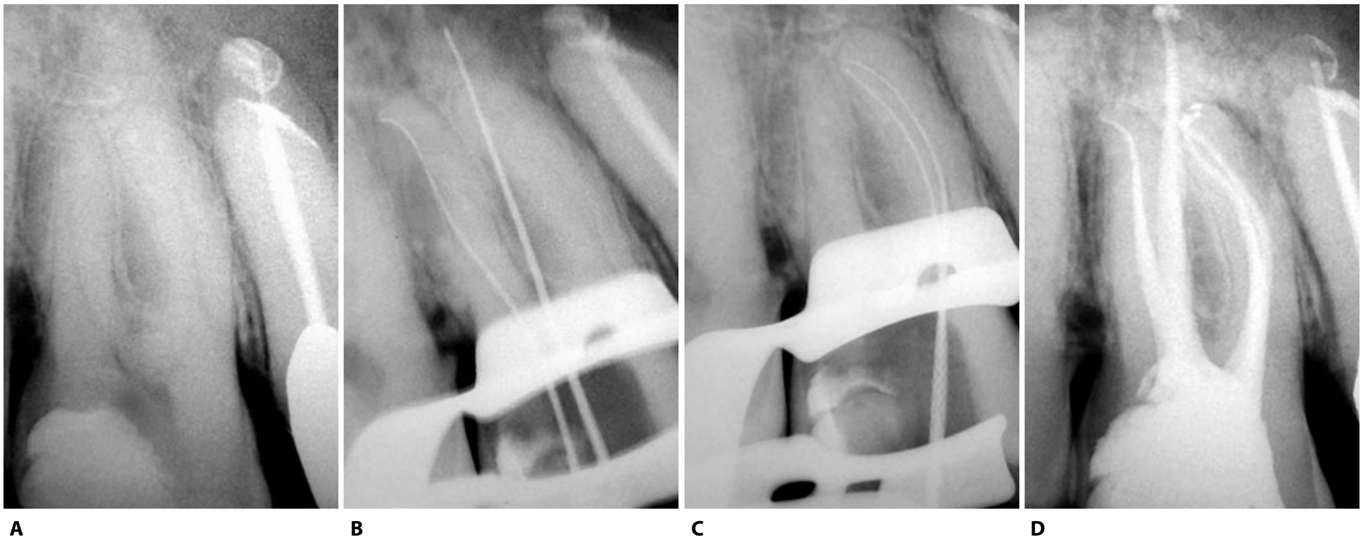


Fig. 26.48. **A.** Canal treatment of an upper right first molar with curved (in the mesial root) and calcified canals. The choice of Thermafil has enabled the preparation to be limited to 25.06 in the buccal roots with a notable saving of time and dental tissue. **B.** Determination of working length in the distal and palatal canals. **C.** Determination of working length in the two mesial canals. **D.** Post-operative radiograph.

the carrier is very flexible, easily adapts even to those curves which are more pronounced and for a correct introduction it requires limited canal diameters (see "Conservative Canal Preparation").[6,12,41] The use of Thermafil in curved canals presents only one complication, which is insiduous because it isn't recognisable from the radiographs: that is the stripping of the gutta-percha with direct contact between the plastic and the canal walls. A correct shaping of the canal and positioning of the carrier 1 mm short of working length will allow one to overcome this problem or to reduce its effect at the level of the apical hermetic seal (Figs. 26.49, 26.50).

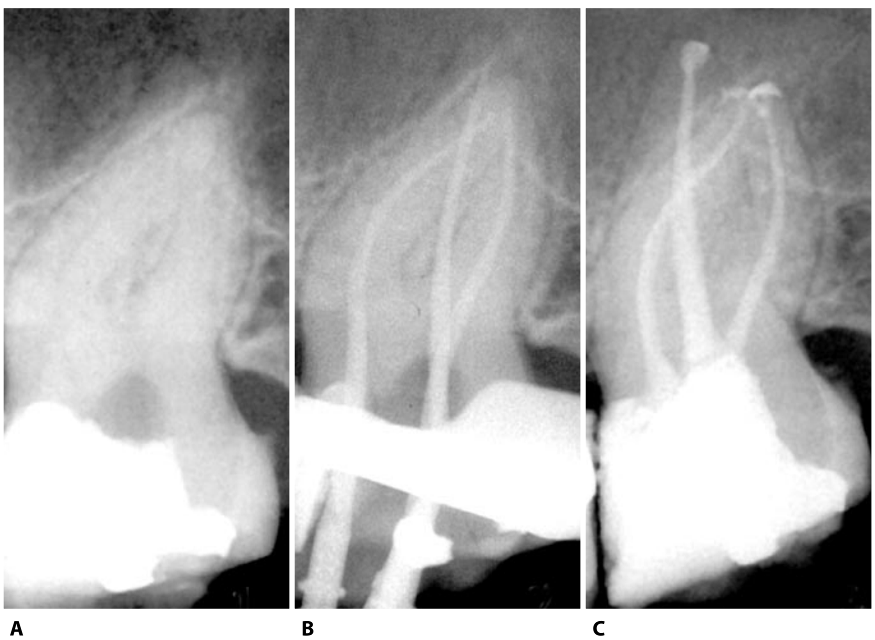


Fig. 26.49 **A.** Endodontic treatment of an upper left second molar with very curved roots. **B.** Working length and selection of Thermafil obturators using plastic carriers as verifiers. **C.** Post operative radiograph.

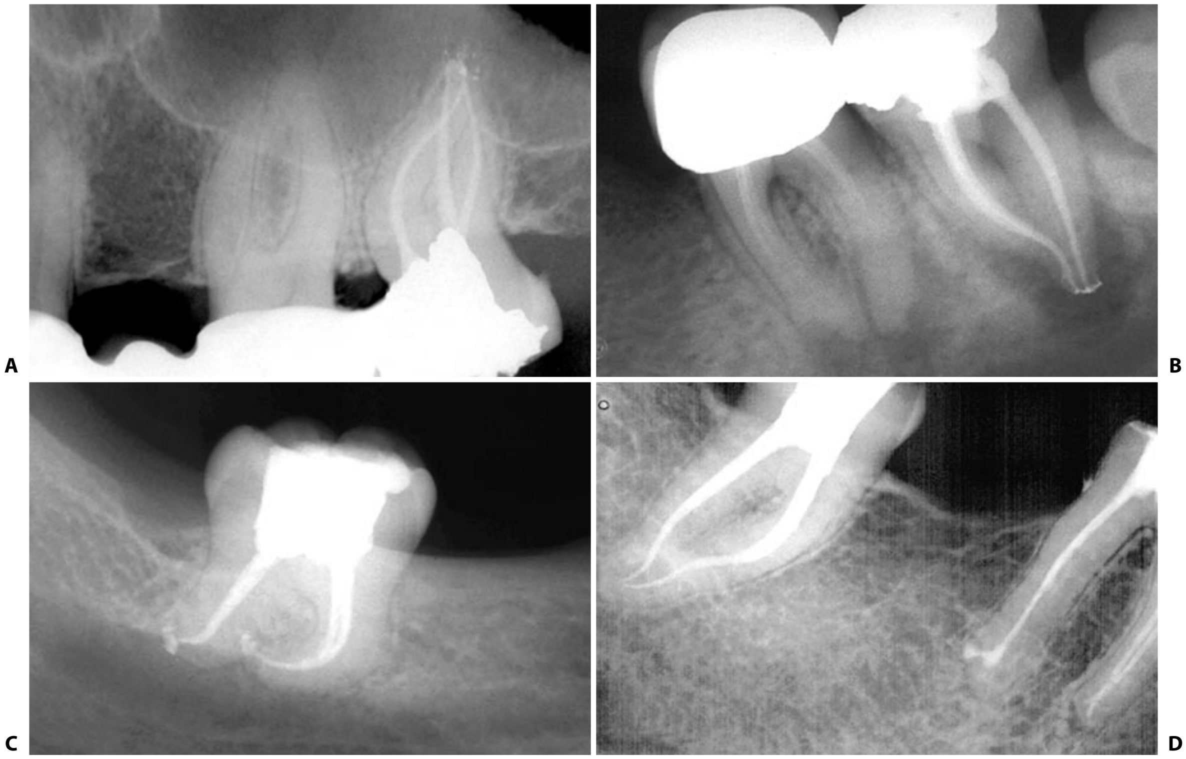


Fig. 26.50. **A-D**. Canal obturation of second (A, B) and third (C, D) molars all with severe curves. The Thermafil technique, in these cases, represents the optimal solution because of the flexibility of its carriers and the limited canal diameter necessary to correctly carry out the obturation.

Quality of the results

The quality of the results obtainable with the Thermafil technique has been discussed at length in "Hermetic Seal and Quality of Thermafil Canal Obturation".

DISADVANTAGES OF THE THERMAFIL SYSTEM

Complex use in presence of particular endodontic anatomy

The use of the Thermafil technique requires particular attention in the following endodontic anatomy cases:[12]

- *Very long canals*. Thermafil obturators have a length of 25 mm; their use in teeth with a corono-radicular length exceeding 26-27 mm can be difficult, and in some cases, impossible.[39]
- *Very short canals*. In very short canals (<10 mm) a good amount of the carrier remains outside the tooth and at times protrudes from the access cavity, thus making the obturation difficult.
- *Immature apices*. The Thermafil technique is not suitable for obturation of teeth with immature apices which require alternative treatment (generally apicogenesis or apical barrier technique with MTA).
- *Confluent canals*. In confluent canals during insertion of the first Thermafil there is a risk of reflux of gutta-percha and sealer into the second canal, with the loss of hermetic sealing of the obturation. This reflux must be prevented by inserting a carrier without gutta-percha in one of the two canals up to the point of confluence. After the obturation of the canal which has remained free, the carrier is removed and one proceeds with the second Thermafil which is inserted only up to the point of confluence (Figs. 26.51, 26.52).
- *Canals with bifurcations or trifurcations in the middle third*. In these cases the carrier of the first obturator mechanically hinders the introduction of the successive ones. At times it's possible to section the first carrier beyond the bifurcation point, thereby freeing the canal for the other obturator, but this operation is not always easily carried out. In these

cases its preferable to adopt alternative techniques such as the System-B, which allows one to insert, section and to condense the gutta-percha cones one at the time (Fig. 26.53).

Obturation of bifurcations or deltas at the apical third doesn't present a problem for the Thermafil technique since the quantity of gutta-percha and the forces of condensation are more than adequate to ensure that they will be filled (Figs. 26.54, 26.55).

A B C D

Fig. 26.51. **A**. Retreatment of a lower right first molar with a screw post in the distal root and a broken instrument in the mesial root. **B**. Once the screw post has been removed the instrument in the mesial root is by-passed and a working length radiograph is taken. The two mesial canals are confluent between the middle third and apical third. Radiograph with Thermafil verifiers. **C**. In the presence of merging root canals one must choose an obturator to insert at the working length and a second obturator to insert up to the point of convergence. Since the mesial root is delicate and fine it is preferable to by-pass the fragment which will then be incorporated in the mass of warm gutta-percha. **D**. Post operative radiograph. While the main canal is obturated (that is the canal in which the obturator will reach the working length) it is advisable to insert a carrier or a metal verifier in the second canal so as to avoid the reflux of gutta-percha resulting in the loss of hermeticity of the obturation.

A B

Fig. 26.52. Another example of the use of Thermafil technique in the presence of confluent canals. **A**. The radiographs with verifiers reveals the presence of two canals on the mesio-buccal root convergent between the middle third and the apical third. **B**. An obturator was selected to be inserted to full working length and a second obturator was inserted up to the convergence point. Post-operative radiograph.

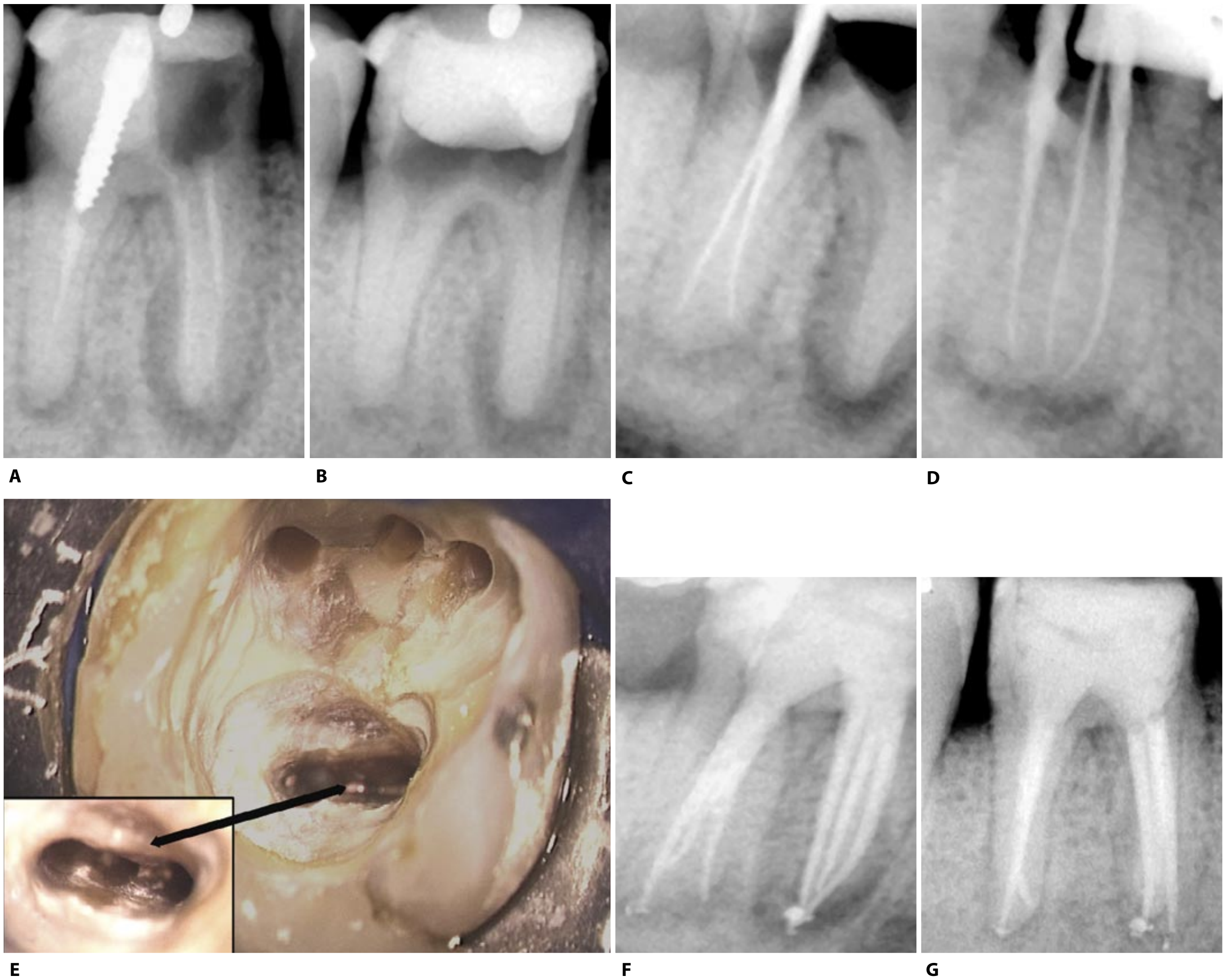


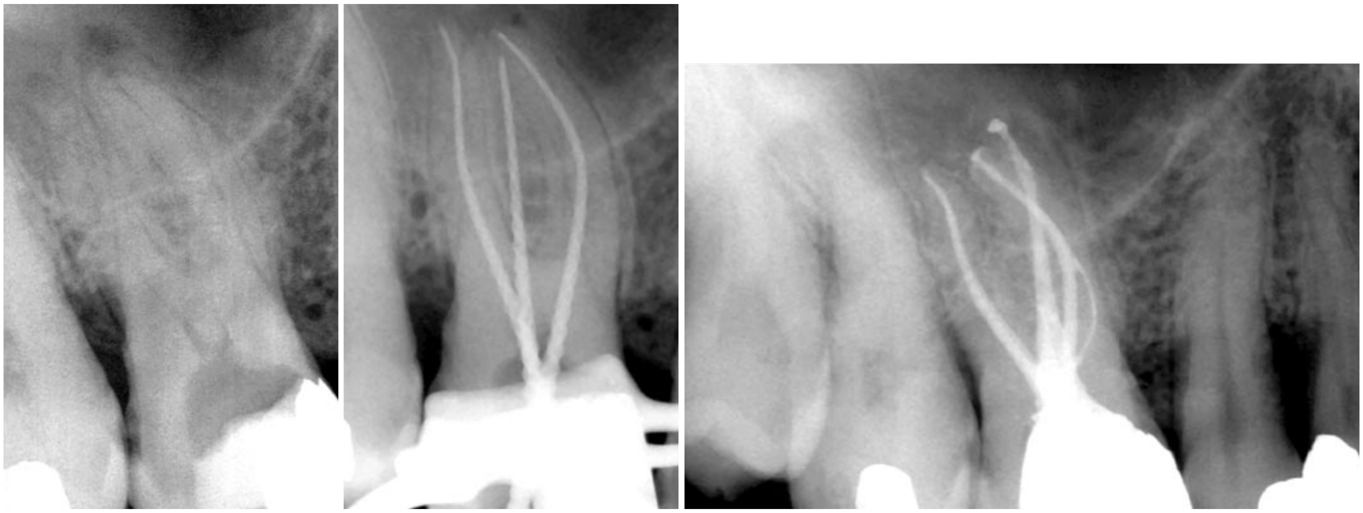
Fig. 26.53. **A**. Retreatment of a lower right first molar with a large peri-radicular lesion associated with the mesial root. **B**. Removal of the screw post, elimination of the old restorative material and calcium hydroxide medication. **C**, **D**. The radiographs taken to determine working length show the presence of two canals in the distal root and three separate canals in the mesial root. **E**. Careful microscopic examination identifies a third canal in the distal root. The presence of a common canal trunk and the closeness of the three orifices to each other makes the use of Thermafil difficult in the distal canal; it was decided to obturate the distal root using only gutta-percha (System B), filling the canals one at a time, removing the excess gutta-percha down to the orifice level each time. The backfill of the common trunk is completed using the Obtura gun. **F**. The three mesial canals were obturated with three Thermafil obturators. **G**. The one year recall shows good bone repair.

The risk of overfilling

In our opinion the risk of overfilling is the only true limitation of the Thermafil technique; that this risk exists is demonstrated by the scientific literature which points out that in the Thermafil technique there exists a tendency to extrude material beyond the apex, which is greater than that found in other obturation methods such as lateral and vertical condensation.[6,12,14,19,19,20,30]

This extrusion happens with a higher frequency in straight canals but this doesn't seem to affect the hermetic seal of obturations[14,28,30] and it doesn't impede the normal processes of periapical healing.[6,12] The extrusion becomes worrying if it is repeated too often and if the quantity of extrusion material is excessive. The causes of overfilling can be summarized as follows:[12]

– incorrect canal preparation (over instrumentation, insufficient taper of the walls, laceration of the api-



A B C

Fig. 26.54. **A**. Endodontic treatment of an upper right first molar with long (24 mm) and curved roots. **B**.Thermafil verifier. The mesial root appears to have only one canal. **C**. The post operative radiograph however shows the presence of a loop that was cleaned and filled thanks to an effective irrigation sequence and the flowability of the Thermafil gutta-percha.

A B C

Fig. 26.55. **A**. Endodontic treatment of an upper left first molar with particularly long roots (26 mm). **B**. Radiograph with verifiers. **C**. Post-operative radiograph. Note the complex apical anatomy in the mesial root perfectly filled with Thermafil gutta-percha.

cal foramen)
- excessive amount of sealer
- use of sealer with insufficient viscosity
- use of an obturator that is too small for the canal dimension
- obturator pushed too deep
- excessive amount of gutta-percha
- excessive force and velocity during insertion.

HOW TO ACHIEVE THE BEST RESULTS USING THE THERMAFIL TECHNIQUE

1) Choose an obturator with a carrier having slightly less taper than the canal and with the same diameter at its tip as the apical foramen.
2) Remember to carry out a pre-obturation irrigation.
3) Select a plastic carrier with a binding point 1 mm shorter than the working length and control its position and adaption with a radiograph.
4) Transfer the working length taken with the verifier to the obturator after cutting off the excess gutta-percha with a blade.
5) Check that the plasticization of the gutta-percha has occurred.
6) Use a sealer with medium-high viscosity and in small amounts.
7) Insert the obturator carefully and wait approximately 10 seconds before sectioning it.
8) If you suspect an error, take a radiograph before sectioning the carrier; it would then be easy, if necessary, to extract the obturator.
9) Defer the post-endodontic restoration to the successive appointment.
10) Carry out the obturation with anaesthesia or inform the patients that they may experience some pain.

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27

Microseal Technique

Vito Antonio Malagnino, Paola Passariello

At the end of the 70's the techniques of canal obturation which were considered correct and therefore able to seal the apex together with the whole endodontic system, were substantially two: warm vertical compaction and cold lateral condensation of the gutta-percha. Two techniques had created two different "schools" based on different biological principles: the school of warm vertical compaction which was in favour of the radical elimination of the organic content of the endodontic system and its substitution with an obturation that sealed the system, the school of cold lateral condensation which was in favour of the organism's ability to positively manage the terminal millimeter or millimeters (apical portion of the canal and lateral canals) of the endodontic system.

Corollary to this different approach was (and is) the different interpretation of an incidental overextension beyond the apex of the obturation: not a serious accident if accompanied by a seal for the vertical supporters,[2,6,18] "a grave error", always considered serious by the lateral supporters.[7,15,20-22]

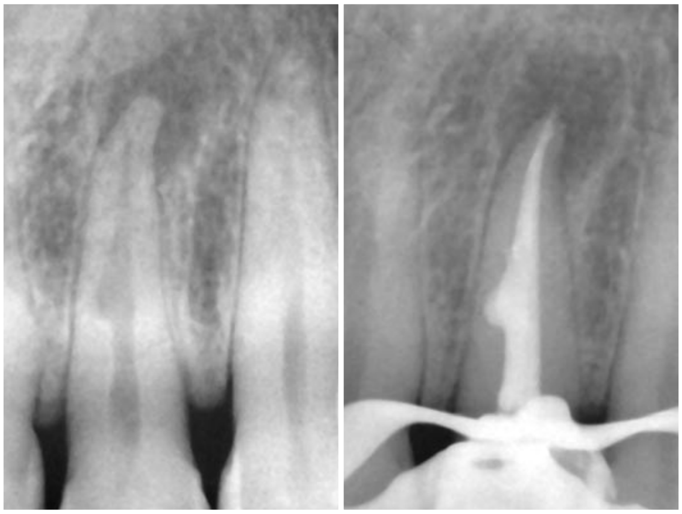
In this context (at the end of the 70's) a new obturation technique emerged called thermo-mechanical compaction or (with the name of the inventor) the "McSpadden technique". This technique depended entirely on the use of a new instrument which could condense the gutta-percha: the McSpadden compactor. This instrument had the design of an inverted Hedstrom file, that is, with the blades turned towards the tip instead of towards the shaft. The compactor mounted on a 1:1 contra-angled handpiece, was inserted in the canal next to a gutta-percha cone and made to rotate at 20,000 rpm.

The heat generated as a result of the rotational friction of the instrument caused the softening of the gutta-percha, which thanks to the blades of the instrument, was pushed towards the apex. This allowed the adaptation of the obturation material to the canal anatomy, and the three dimensional filling and seal of the endodontic system with gutta-percha.[1,5,9,11,17] This technique made no reference to either of the two above mentioned biological "philosophies" since it didn't require an "absolute" choice in this sense, even if it was a fact, that the efficient vertical and lateral thrust of the heated gutta-percha brought about a filling of all the available endodontic spaces.

Maintaining the basic concept unaltered, that is the concept of utilising a rotating instrument inside the canal to introduce and condense the thermo plasticized gutta-percha, the successive evolution of the thermo-mechanical compaction technique utilized the technical advances achieved in the endodontic field: the use of NiTi alloy and the new knowledge regarding the physico-chemical properties together with the resulting new methods of gutta-percha production.

The Multi Phase Technique[14,16] is a technique that in the early 90's combined the principle of thermo-mechanical compaction with the new materials; in fact it foresees the use of an instrument similar in design to the McSpadden compactor, but made out of Nickel Titanium with differing tip diameters and conicity, and of a particular gutta-percha defined as "Alpha Phase" which is pre-plasticized and then introduced into the canal with the rotating instrument. The distinctive characteristics of this type of gutta-percha by comparison to the traditional ones are: a lower point of fusion, a longer working time, less contraction during cooling down, adherence to the tooth surfaces.[4,12,13,19]

The most important clinical characteristic is however, represented by the higher fluidity: so if on the one hand it allows a better adaptation of the material to the endodontic irreguliarities with even the possibility to easily fill complex canal systems,[14] on the other hand it brings about a difficult vertical control of the obturation (Figs. 27.1-27.2).



A B

Fig. 27.1. Multiphase obturation technique. Canal obturation of an upper lateral incisor. **A**. The pre-operative radiograph shows the presence of internal root resorption. **B**. Post operative radiograph; canal obturation carried out with multiphase technique, which has allowed one to obtain an effective filling of the endodontic system with a single introduction of thermoplastic gutta-percha in a few seconds.

THE MICROSEAL TECHNIQUE

To utilize the advantages of a more fluid gutta-percha and reducing the risk of overfilling, an evolution of the multi phase technique has been proposed, which maintains unaltered the advantages of this obturation method, but in which the vertical control has been improved by the use of a master cone, which acts as an apical "cork" and which is positioned and condensed inside the canal before the introduction of the thermo-plasticized gutta-percha. This method is called the "microseal technique".

This technique utilizes cones of gutta-percha and pre -plasticised gutta-percha, both made with new generation high plasticity gutta-percha, as well as spreaders and thermo-mechanical condensers in NiTi capable of working in all the canal pathways. The presence of a master cone which engages the apex and whose physico-chemical characteristics allow integration with pre-heated gutta-percha enables a complete, but controlled filling of the endodontic space.

A B C D

Fig. 27.2. Multiphase obturation technique. **A**. Canal obturation of a lower second premolar; one notes the filling of a complex apical system with multiple exits. **B**. Canal obturation of a lower second premolar; the presence of a bifurcation at the level of the apical third of the canal is highlighted. **C**. Canal obturation of a lower second molar; one notes the obturation of a large lateral canal corresponding to a lateral lesion. **D**. Canal obturation of an upper second molar which presents buccal canals converging at the apex. The overfilling of the palatal canal highlights the difficulty of obturation depth control with the multiphase technique.

The Microseal Technique can be schematically subdivided into two phases:

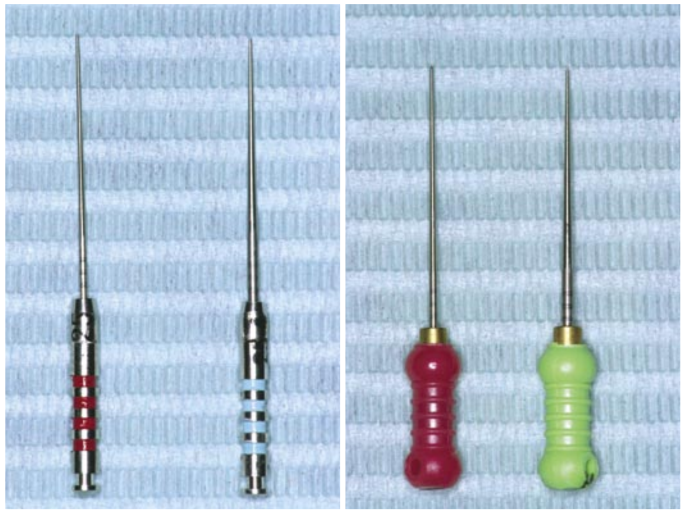
Phase 1: a gutta-percha cone is positioned at the apex and is cold compacted with a NiTi spreader.

Phase 2: the remaining endodontic space is filled with pre-plasticized gutta-percha carried with a condenser in NiTi.

This method provides for the use of:

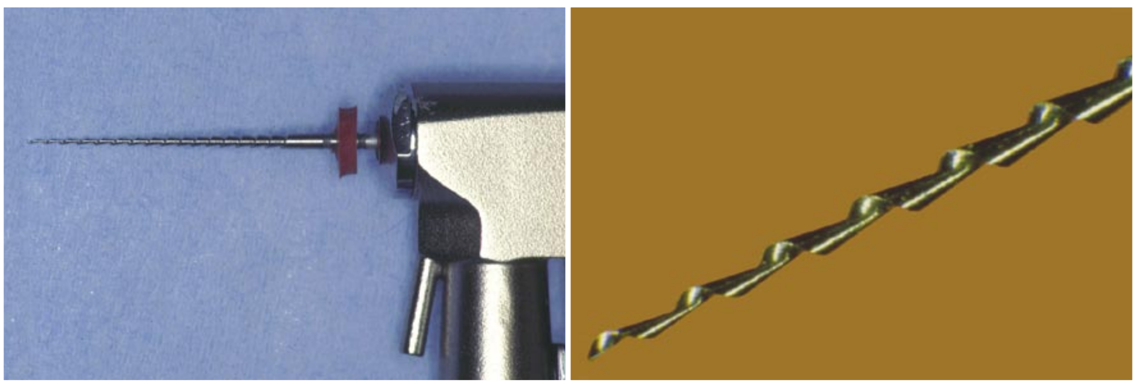
– microflow gutta-percha cones, with differing tip diameters and conicity .02 and .04 made from high plasticity gutta-percha (Fig. 27.3)
– spreaders in Nickel Titanium (manual or mounted on a micromotor, with a tip diameter of # 20 and # 25 and conicity .02 and .04) (Figs. 27.4 A-B)
– condensers in NiTi (Figs. 27.5 A-B) existing with conicity .02 and .04; the first (called condenser) available with tip diameters # 25, 30 and 35 (Fig. 27.6) and the second (called PacMac) with tip diameter # 25 and 45 (Fig. 27.7)
– microflow gutta-percha cartridges with a low fusion temperature (each one containing a dose which is sufficient for the obturation of 4-5 canals.) with physical characteristics similar to those of gutta-percha cone (Fig. 27.8)
– dispensing syringe for the gutta-percha cartridges (Fig. 27.9)
– Microseal heater to plasticize the gutta-percha contained in the cartridges (brings the gutta-percha to working temperature in 15 seconds and it has a pre-

Fig. 27.3. Microflow gutta-percha cones.



A B

Fig. 27.4. **A.** Mechanical spreaders in NiTi to be mounted on the micromotor at a low rotation speed. **B.** Hand spreaders in NiTi.



A B

Fig. 27.5. **A**. Condenser in NiTi: the instrument must be used mounted on a 1:1 handpiece. **B**. Condenser in NiTi: image of the working part viewed through a stereo microscope; one notes the inverse screw design of the blades.

heating time of about 1 minute from the moment of switching on) (Fig. 27.10).

To utilize the Microseal method, a specific canal shape is not required, but a preparation with continuous conicity is advised; furthermore it is best to carry out a specific apical preparation which allows the creation of a suitable stop for the master cone. Once a preparation with conicity of .05 or .06 and an apical diameter of # 25 has been reached via the shaping, to complete the instrumentation it is necessary "to finish off" the final apical millimeters; this means bringing an instrument # 30 and one of # 35 and conicity of .02 up against the apex, that is in the area between the apex and a millimeter from it; in this phase we suggest the use of hand instruments, a NiTi of .02 coni-

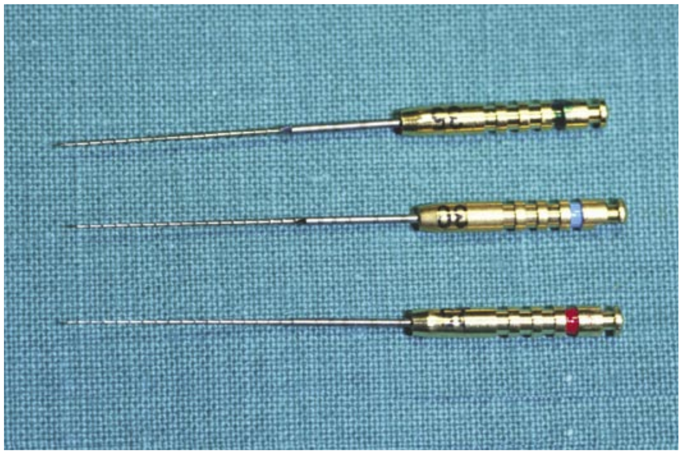


Fig. 27.6. The condenser with .02 conicity is available with # 25-30-35 tip diameter.

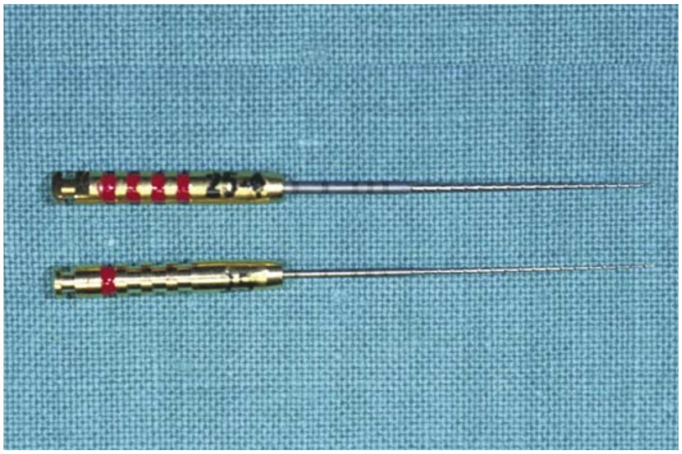


Fig. 27.7. The condenser with a #25 tip diameter is available with .02 and .04 (PacMac) conicity.

Fig. 27.8. Microflow gutta-percha cartridges.

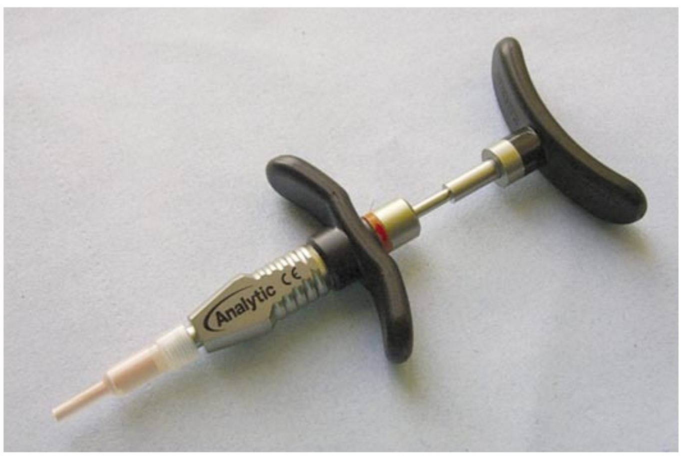


Fig. 27.9. Syringe dispenser for the gutta-percha cartridges.

Fig. 27.10. Microseal heater.

city used with a continual rotation movement. We are talking about an extremely easy and fast procedure; it allows the creation of a stop at the final millimeter of the canal in which the mastercone under force from the spreader can furthermore be engaged creating a type of “dynamic stop” (Fig. 27.11).

Particular care must be taken when the apex is more than # 25 (for intrinsic or iatrogenic reasons). In this case the instrument # 30 .02 will not have any difficulty in reaching the apex; to reach the apex one has to use instruments (of .02 conicity, manual and NiTi instruments) having an increasing tip diameter until an instrument is found which has difficulty in reaching the apex; at that point, using great care two instruments must be used which are of the next size up in diameter, thereby trying to obtain a dynamic stop which corresponds to the apical size. One has to return 2 or 3 times to the apical portion with the three preparation instruments; in these cases given the dimensions of the instruments it will not always be possible to bring the third instrument to exactly 1 mm from the apex. What is important is that the master cone be stopped with maximum engagement 1mm from the apex. This type of apical preparation (the dynamic stop) allows the involvement of the whole length of the canal in the preparation and in the obturation adhering to the principles of the “vertical school”.

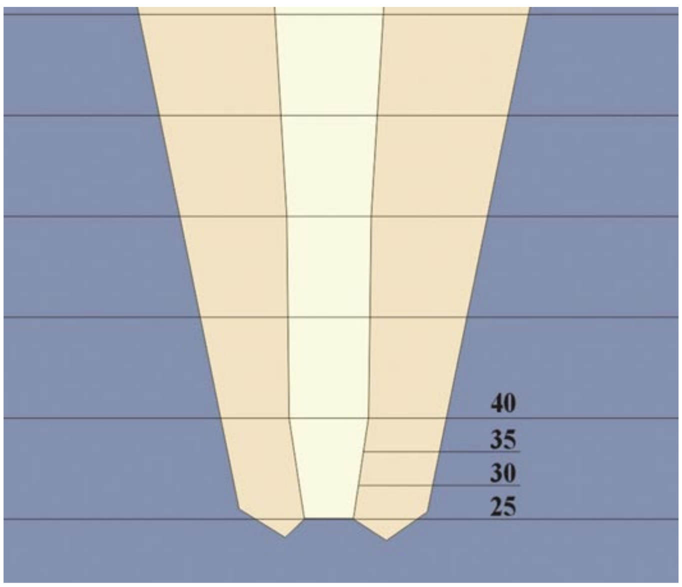


Fig. 27.11. Graphic representation of the apical finishing that is necessary for the Microseal Technique:“dynamic stop”.If the apical diameter is # 25 (canal conicity .05 or.06) a # 30 and a # 35 instrument with .02 conicity must be brought close to the apex and a # 40 instrument with .02 conicity must be brought to within a millimeter of the apex.

Phase 1

The first passage in the execution of the Microseal technique is the choice of a gutta-percha cone which is adaptable to the apical preparation; as we have mentioned, it has the function of occcluding the apex and therefore preventing the plasticized gutta-percha which was introduced with the rotating condenser, to flow beyond the apex. Therefore this cone must have a tip diameter and a conicity which allows it to come into contact with the canal wall, exclusively at the level of the last apical millimeter, leaving sufficient space for the second phase of the obturation. For this reason it is always advisable to use a cone of .02 conicity: cones of a higher conicity, could excessively reduce the space for the next phase.

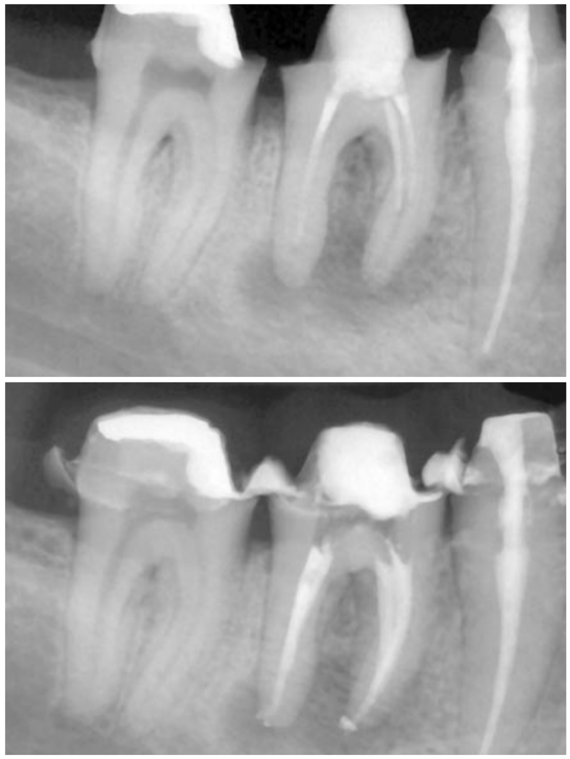
The Microflow master cone, according to the manufacturers, has the chemico-physical characteristics of the alpha phase gutta-percha and therefore it is endowed with higher plasticity. This allows one to obtain a better adaptation of the gutta-percha in the cold compaction phase and to create a single obturation mass with the pre-plasticized gutta-percha inserted during phase 2 of the obturation.

The choice and adaptation of the master cone to the apex is carried out according to established methods of the lateral condensation technique: one must seclect a cone which binds at about 1mm from the apex engaging the preparation, giving origin to the popular sensation of “tug-back”. In the canals with a # 25 apex, very often the correct cone will be a 35 or 40 with conicity of .02.

Particular care must be taken in the choice of the master cone in the cases with larger apical diameters. The rule, in all cases, is to look for the cone with a larger tip diameter that reaches 1 mm from the apex; when the apex has a larger diameter, after having found the correct cone (for example # 50) having tried and discarded a cone with a larger diameter (for example # 55), we suggest cutting 1mm off the tip of that cone and choose or discard it depending on whether or not it reaches up to 1mmn from the apex, ie exactly at the entrance of the apical preparation; in this way intermediate tip diameters (52-57 etc) will be obtained from those available thereby allowing one to be as precise as possible. In these cases the problem is to find the best possible seal while as far as possible to minimize the possibility of over extension of the obturation (Figs. 27.12-27.13). In particular cases which were resorbed, where a round preparation was not obtained, it is reasonable to hope, within certain

A B C

Fig. 27.12. Endodontic treatment of lower second molar. **A**. Preoperative radiograph: one notes a modest apical remodelling. **B**. Radiograph of cone fit: the position of the cone in the distal canal is incorrect. The cone must be shortened until tug-back is perceived with the cone 1 mm more coronally than the position in the radiograph. **C**. Postoperative radiograph: one notes a good apical control of the obturation.



A B

Fig. 27.13. Retreatment of lower first molar. **A**. Preoperative radiograph: one notes a modest apical remodelling due to the lesion. **B**. Postoperative radiograph: one notes a good apical control of the obturation.

limits, on the successive action of the NiTi spreader and in the second phase of the obturation with the introduction of the heated gutta-percha (Fig. 27.14). The correct positioning of the cone at the apex must therefore be radiographically verified (Fig. 27.15 A).

Once the canal has been dried, a small amount of cement is inserted in the coronal third (utilizing, for example a # 35 or # 40 paper point) (Fig. 27.16); the cement must have an elevated consistency. Its function is one of lubricating rather than of filling, which is necessary to allow the pre-plasticized gutta-percha to advance inside the canal. The recommended cement is a zinc-oxide eugenol cement according to the Rickert formula (such as Argo Seal, Ogna, Milano, Italy) that doesn't harden with heat.

The master cone is introduced (the last 3-4 mm of which has been smeared with cement) (Fig. 27.15 B) and then it is condensed by bringing a spreader up to within 2-3 mm from the apex (Fig. 27.15 C). The objective is to increase the apical adaptation of the cone and to press it along the canal walls creating the space for the introduction of the thermoplastic gutta-percha. To effectively carry out this procedure which is equivalent to a lateral condensation, mechanical and manual spreaders in Nickel Titanium have been made. The mechanical spreaders have to be mounted on low speed contra angled handpieces and allowed to rotate at about 300 rpm (the same speed as the NiTi instruments of preparation): the movement of insertion in continuous rotation, carried out following a wall of the canal, allows the spreader to approach to within 2-3 mm of the apex, exercising pressure on the cone; this considerably increases the tug-back resistence (Fig. 27.17). Similar results can be obtained with manual NiTi spreaders that have to be inserted in the canal and once these have begun to engage themselves between the cone and the canal walls, with delicate rotation continuing the progression up to the reachable depth, which will almost always be 2-3 mm from the apex.

The spreaders in NiTi can be found with different tip diameters and conicity; in the majority of cases we prefer to utilize an instrument with a # 25 tip diameter and .04 conicity. In the finer canals one can use a spreader with # 25 tip diameter and .02 conicity.

The spreaders in NiTi seem to be able to exercise

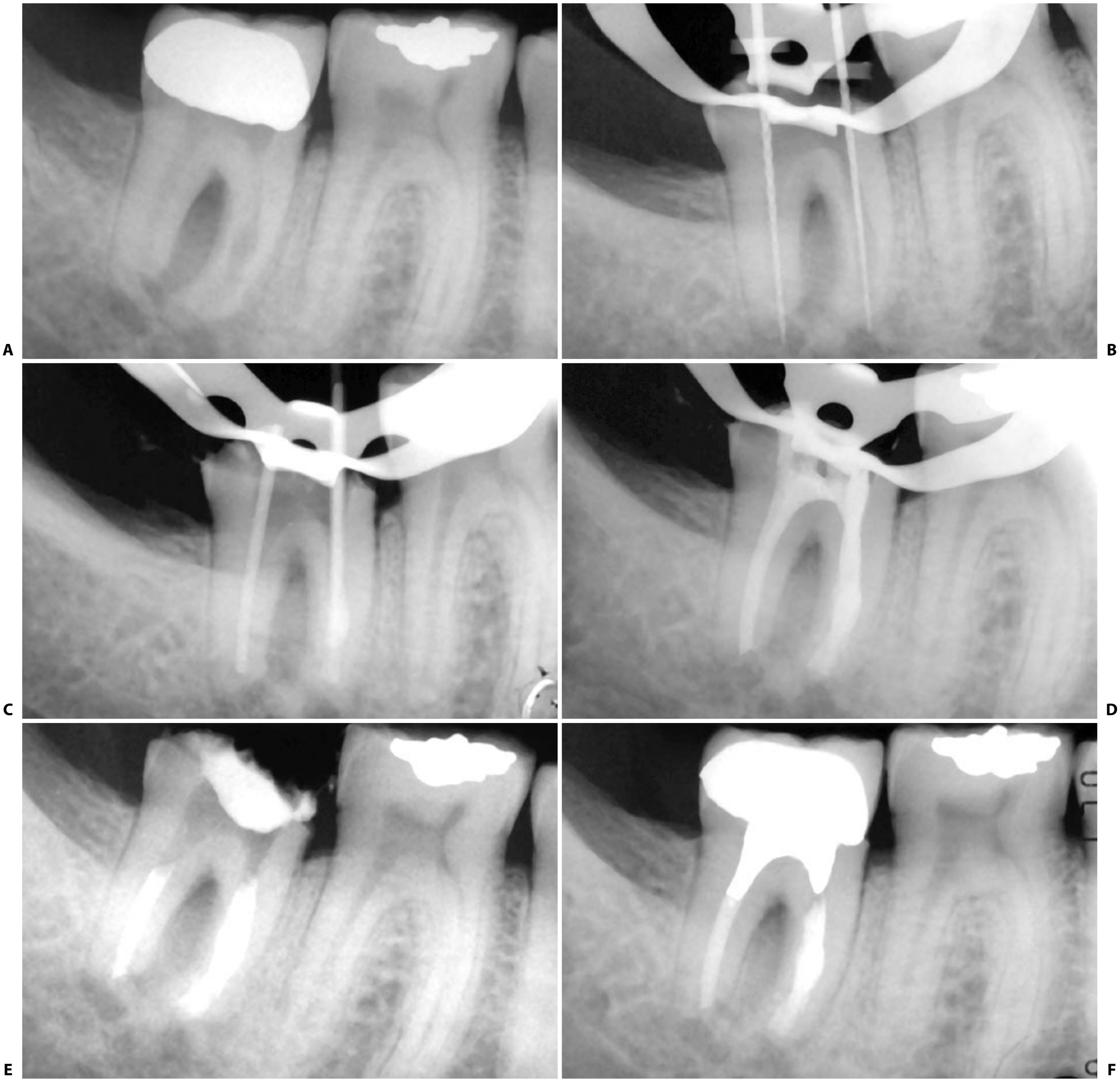
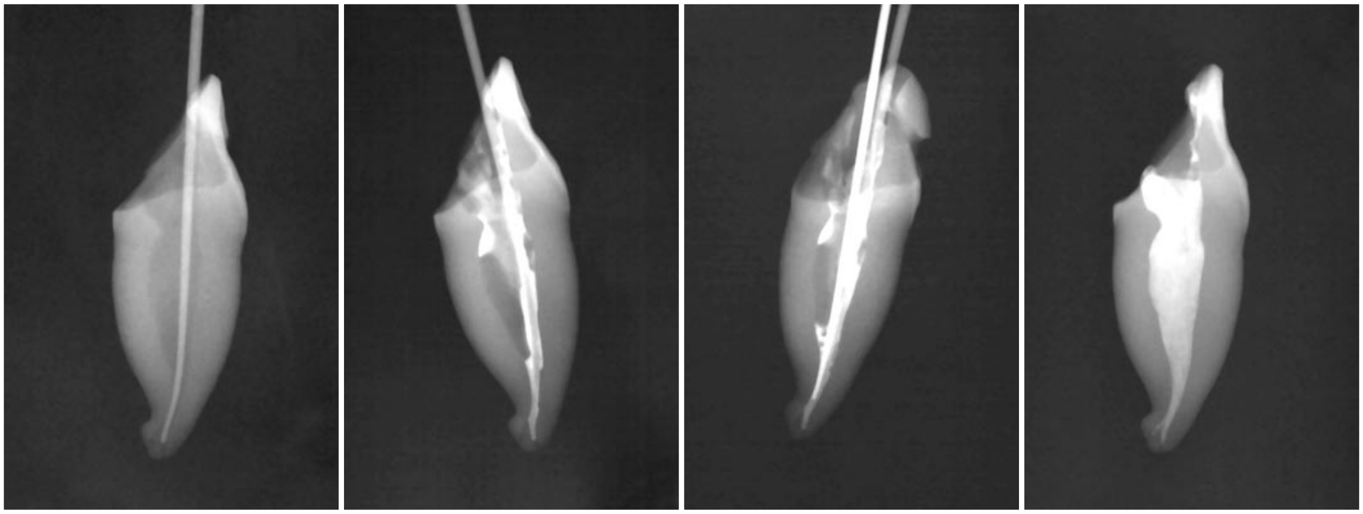


Fig. 27.14. Endodontic treatment of lower second molar. **A**. Preoperative radiograph: the tooth has undergone a direct pulp capping which has failed with the formation of a large area of internal resorption close to the apex with damage to the endodontic anatomy. **B**. The endodontic instruments underline the altered canal path with apical resorption. **C**. Radiograph of cone fit. **D**. Postoperative radiograph: obturation carried out with Microseal Technique. **E**. Three month recall. **F**. Six month recall.



A B C D

Fig. 27.15. Obturation with Microseal Technique carried out on an extracted tooth. **A**. Selection of mastercone; the correct positioning of the cone at the apex is checked radiographically. **B**. After having applied some cement in the coronal third of the canal, the mastercone its tip having been smeared with sealer is introduced in the canal. **C**. The master cone is condensed by bringing a spreader in NiTi up to 2-3mm from the apex. **D**. The root canal appears completely filled with a homogenous mass of gutta-percha.

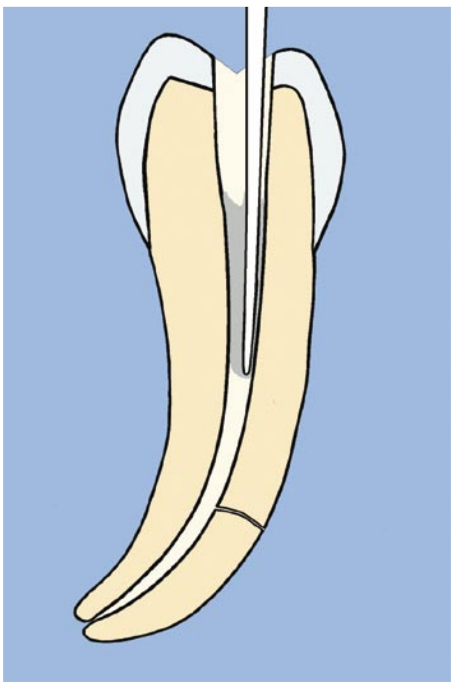


Fig. 27.16. Before positioning the master cone, a small amount of sealer is placed in the coronal third of the canal, utilizing a large paper point.

A

B

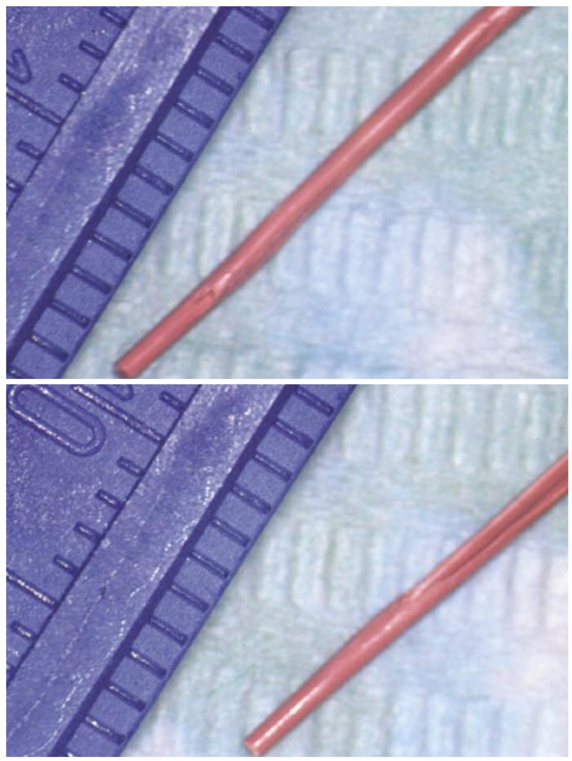


Fig. 27.17. **A**, **B**. Master cone modified by the condensing action of a mechanical spreader (continued).

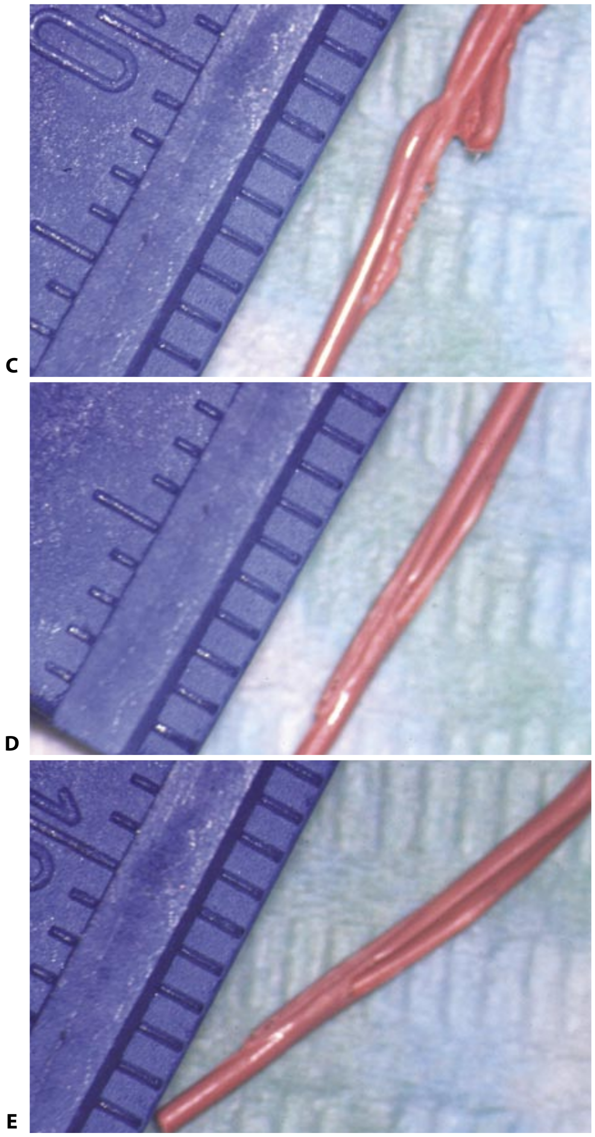


Fig. 27.17. **C-E.** (continued) Master cone modified by the condensing action of a mechanical spreader.

a more efficient lateral condensation action, by comparison to traditional steel instruments, since they are able to progress more easily in the apical direction even in curved canals, exerting less stress on the root walls.[21,22]

Phase 2

This phase consists of the introduction in the canal space, created by the spreader, of the pre-plasticized gutta-percha using the rotating compactor at a speed between 6,000 and 7,000 rpm.

Compactors are available with different tip diameters and .02 and .04 conicity; in the majority of cases, from our clinical experience it seems better to use an instrument with # 25 tip diameter and .04 conicity. In narrower canals it may be preferable to use a # 25 or a # 30 instrument with .02 conicity.

This phase commences with the application of the thermoplasticized gutta-percha on the NiTi compactor. The gutta-percha is plasticized by inserting a special dispensing syringe with a cartridge in the heater. The working part of the compactor, mounted on a 1:1 handpiece is introduced in the nozzle of the Microflow cartridge, containing the plasticized gutta-percha. Subsequently the instrument is slowly extracted from the cartridge, while one exerts a gentle and continuous pressure on the plunger of the syringe. The blades of the compactor must be covered by a layer of thermo-plasticized gutta-percha (Fig. 27.18). The compactor coated with plasticized gutta-percha is therefore introduced in the canal in the space left by the spreaders. The instrument must be inserted passively, without having activated the rotation (Fig. 27.19 A). Given that the compactor has the same tip diameter and the same conicity of the previously utilized spreader, it is able to reach the same depth: about 2-3 mm from the apex.

Then the rotation is started at a speed which was preset at about 6,000-7,000 rpm (Fig. 27.19 B). Thanks to the design of the instrument blades, the gutta-percha is pushed towards the apex; the impact of the gutta-percha against the canal walls causes a counter thrust on the compactor towards the crown. The operator must use a counterforce for 1-2 seconds against this movement of the exiting instrument maintaining it at a depth reached with the passive insertion: in this way the gutta-percha is forced to fill the endodontic

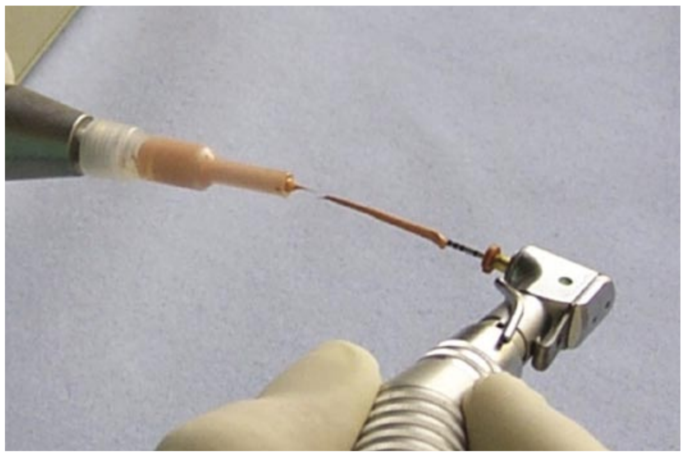
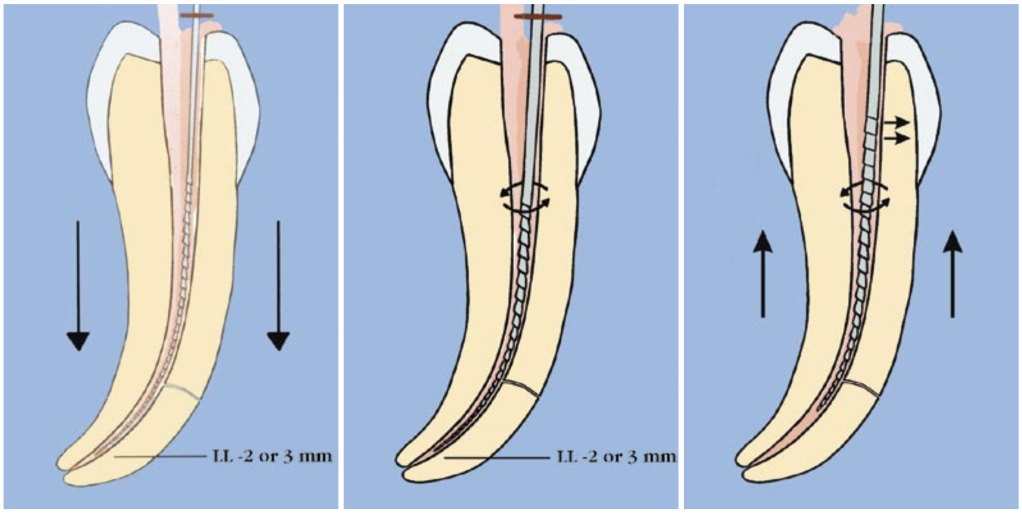


Fig. 27.18 The PacMac is coated with thermoplastic gutta-percha.

space, obturating any portals of exit, irregularities of the endodontic system or lateral canals. After about 1-2 seconds, with a gradual and continuous movement, one aids the instrument exit; during the exit the compactor must maintain a constantly light contact with a canal wall; this allows the gutta-percha to remain and be compacted within the endodontic system (Fig. 27.19 C); if this contact is not maintained the instrument has a tendency to extract the gutta-percha from the canal (Figs. 27.20-27.32).

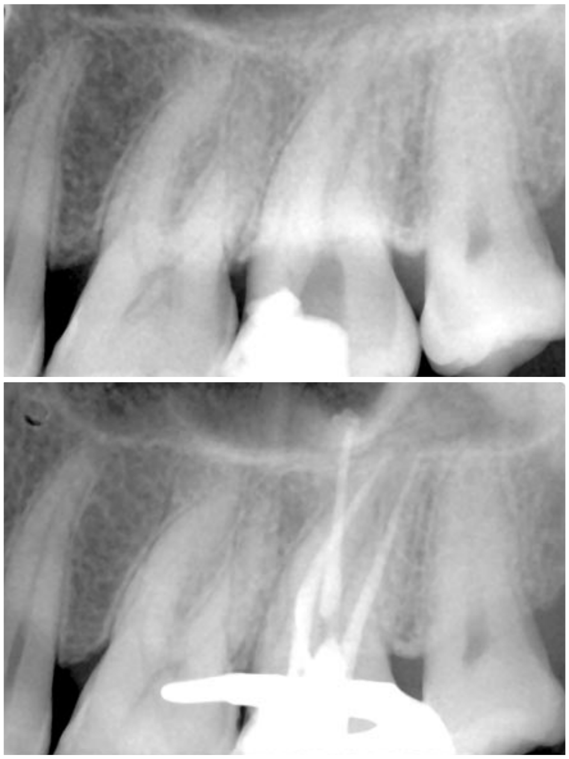


A B C

Fig. 27.19. **A**. The plasticized gutta-percha coated PacMac is introduced without rotation into the canal space left by the spreader after the condensation. **B**. The PacMac is allowed to rotate at a speed of about 6000 -7000 rpm. The instrument must be kept opposing the reverse thrust for about 2 seconds. **C**. The PacMac is extracted from the canal keeping it in a constant and light contact with one canal wall.

A B C

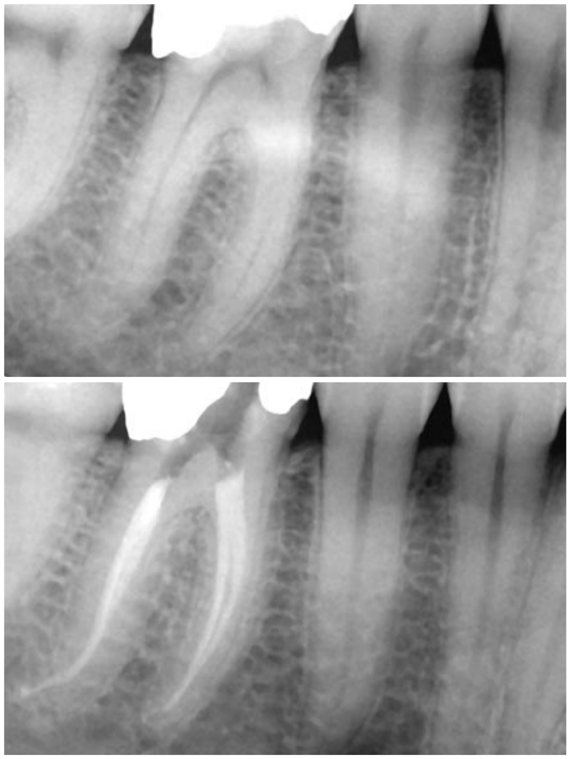
Fig. 27.20. **A**. Endodontic treatment of lower second molar. **B**. Intraoperative radiograph: the mesial root presents with a Weine type II endodontic anatomy. **C**. Immediate postoperative radiograph: the canal path appears maintained and the endodontic system appears well filled.



A

B

Fig. 27.21. **A**. Endodontic treatment of an upper second molar with long canals and a fairly regular course. **B**. The obturation with the Microseal Technique highlights the balance of the preparation and the correct preservation of the dentinal thickness.



A

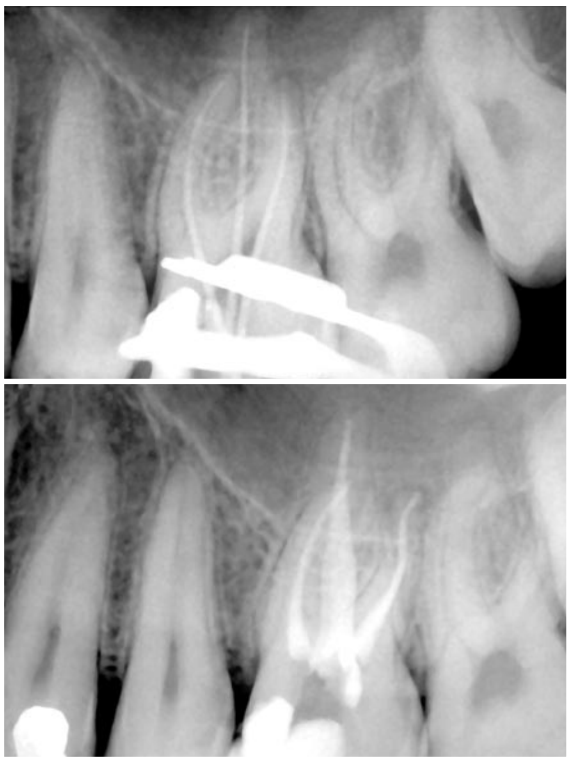
B

Fig. 27.22. Endodontic treatment of a lower first molar. **A**. Preoperative radiograph. **B**. Endodontic obturation carried out with the Microseal Technique highlights type II anatomy according to Weine involving both roots.

A

B

Fig. 27.23. Endodontic retreatment of a lower first molar with narrow and rather long canals. **A**. Preoperative radiograph. **B**. Postoperative radiograph. The obturation carried out with the Microseal Technique highlights the maintenance of the canal pathway which is particularly delicate in the apical third.

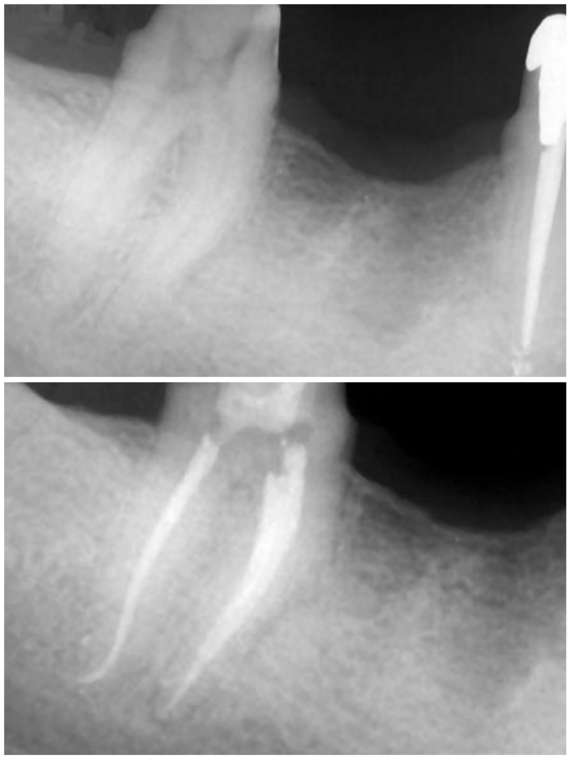


A

B

Fig. 27.24. Endodontic treatment of an upper first molar. **A**. Radiograph of cone fit. Correct positioning at 1mm from the apex. **B**. Postoperative radiograph: note the presence of a curvature of the apical third of the disto-buccal canal and the apical control of the obturation in all the canals.

Fig. 27.25. Endodontic treatment of an upper first molar. The canal obturation carried out with the Microseal Technique has allowed one to highlight the maintenance of the canal anatomy particularly with regard to the apical portion of the disto-buccal canal which presents a small distal curvature. In the palatal canal an apical system with multiple exits has been obturated.



A

B

Fig. 27.26. Endodontic treatment of a lower third molar. **A**. Preoperative radiograph. **B**. Postoperative radiograph: the obturation has been carried out with the Microseal Technique. The original anatomy has been maintained. Note the obturation of a lateral canal in both roots.

A

B

Fig. 27.27. Endodontic treatment of a lower second molar. **A**. Preoperative radiograph. **B**. Post operative radiograph: obturation carried out using the Microseal Technique: Note the preservation of the canal path and the respect for the dentinal thickness of the root, obtained using mechanical instruments in NiTi.

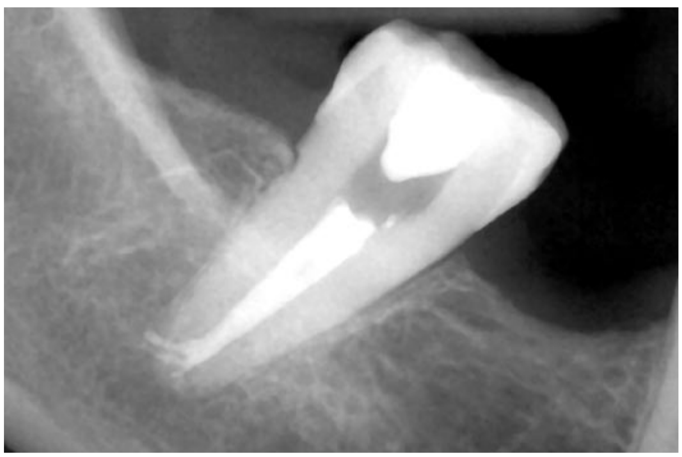
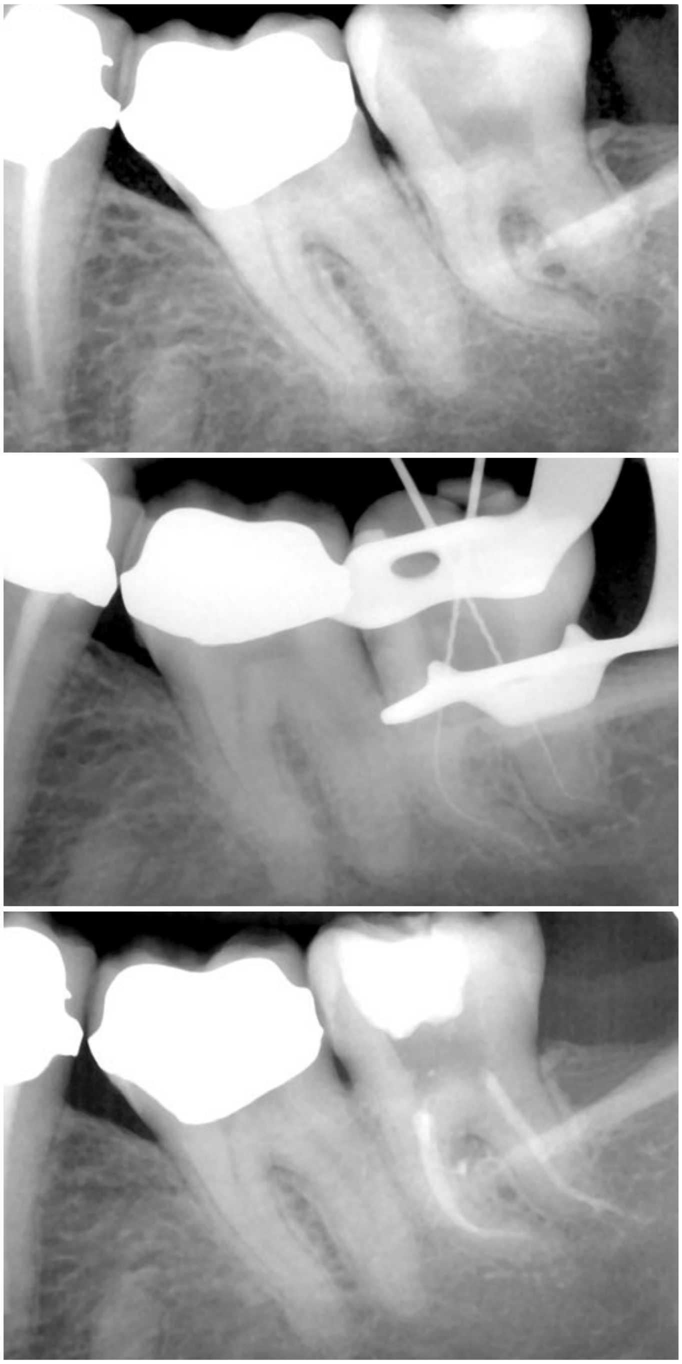


Fig. 27.28. Endodontic treatment of a lower third molar with a single canal and multiple apical exits, obturated with the Microseal Technique.

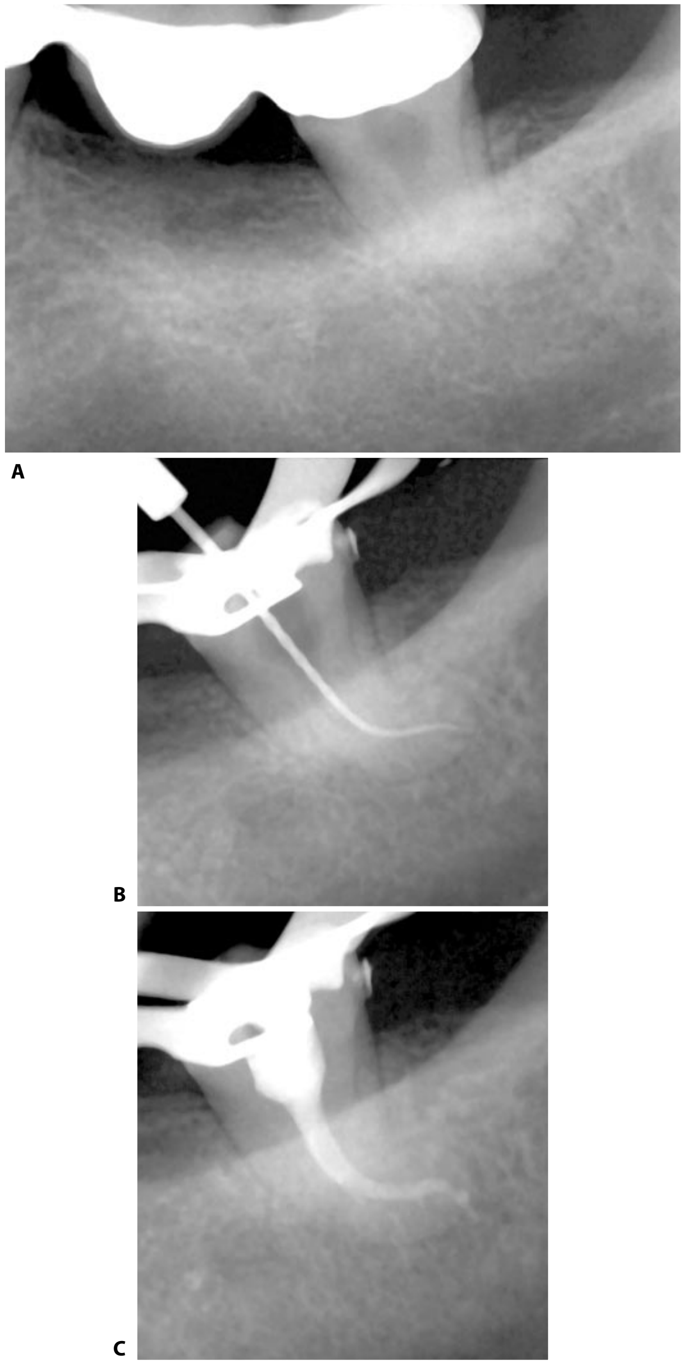


A

B

C

Fig. 27.29. Endodontic treatment of a lower third molar. **A**. The preoperative radiograph shows the presence of rather short roots and accentuated curvature as well as very narrow canals. **B**. Intraoperative radiograph. **C**. Postoperative radiograph: note the obturation of a lateral canal situated at the level of the coronal third of the mesial root. The fine thickness of the distal walls of the mesial canals have been respected. The obturation using the Microseal Technique was carried out using a # 25 tip diameter condenser with .02 conicity.



A

B

C

Fig. 27.30. Endodontic treatment of a lower third molar. **A**. Preoperative radiograph: the tooth presents with a single canal having a rather accentuated double curvature. **B**. Intra-operative radiograph. The canal preparation was carried out with NiTi instruments (Quantec Analytic, Glendora, CA,USA). **C**. Postoperative radiograph. For the obturation a condenser with .02 conicity and # 25 tip diameter was preferred because it was more flexible.

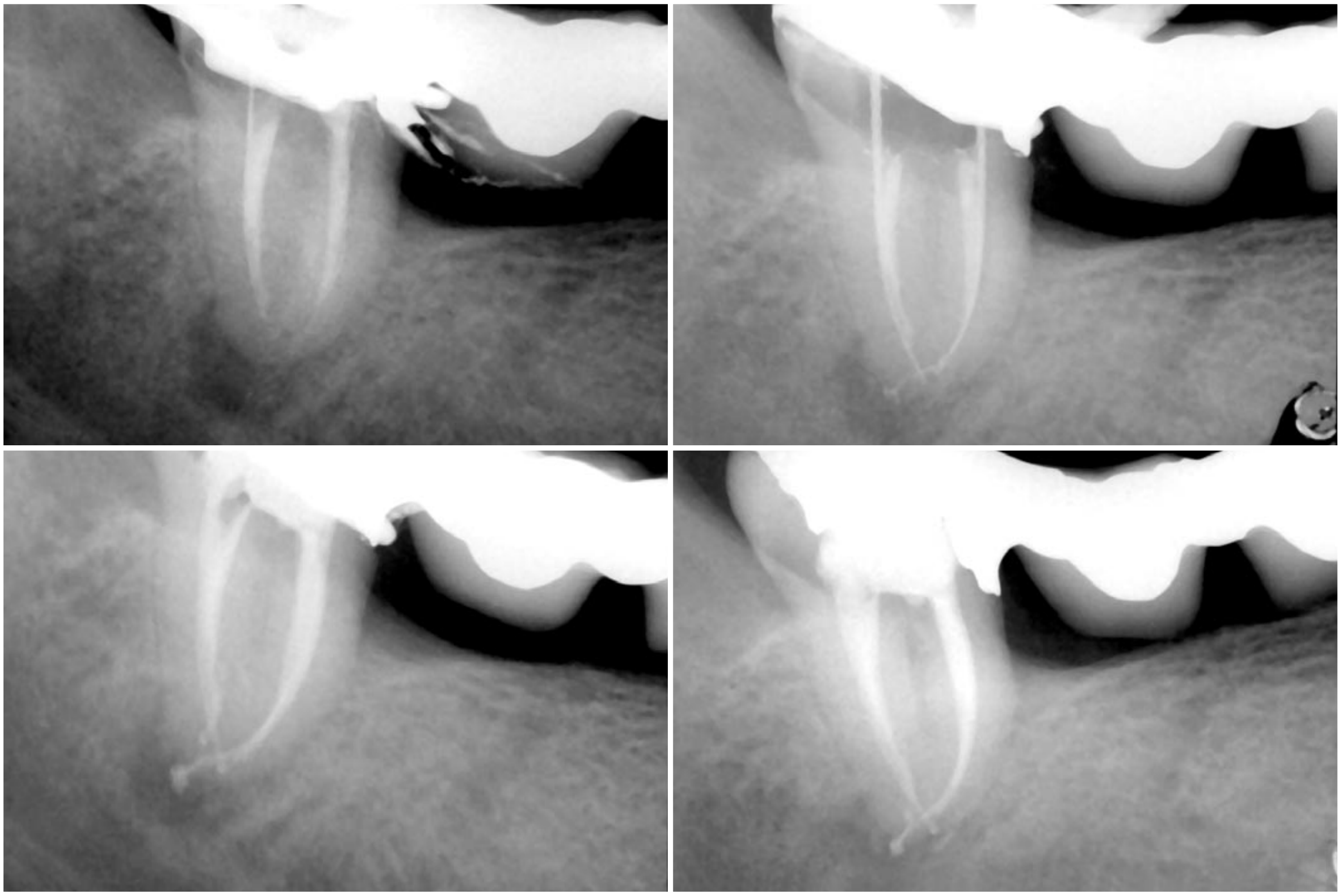


Fig. 27.31. Re treatment of a lower third molar. **A**. Intraoperative radiograph. **B**. A long, narrow and curved mesio-lingual canal is illustrated. **C**. Canal obturation carried out using the Microseal Technique. **D**. Six month recall.

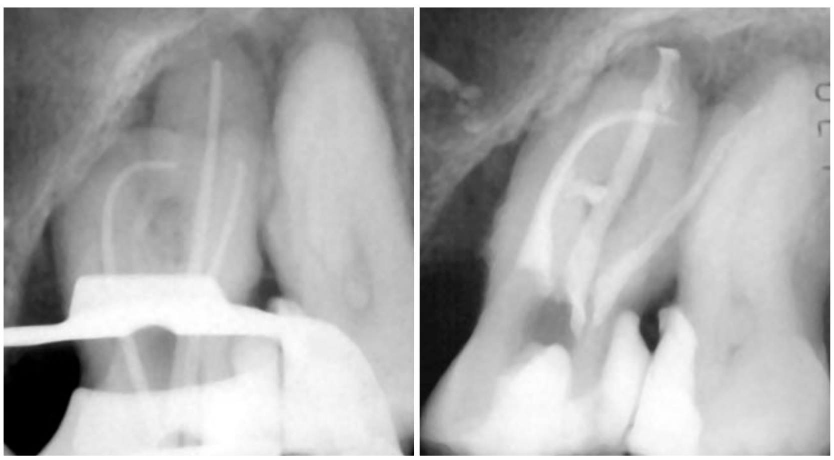


Fig. 27.32. Endodontic treatment of an upper second molar; the mesio-buccal root has a very accentuated curvature. **A**. Cone fit radiograph. **B**. Postoperative radiograph: obturation carried out using the Microseal Technique. One notes the obturation of a lateral canal in the middle third of the mesio-buccal root.

If in the post operative check radiograph an imperfect filling of the coronal portion of the canal is detected, it is possible to re-enter the gutta-percha mass with the spreader. This allows the creation of space for the insertion of more fluid gutta-percha with the compactor. This situation frequently presents itself in the coronal portion of larger canals, and therefore in these situations it is necessary to almost routinely carry out the second introduction of gutta-percha in the first few millimeters of the canal.

EXPERIMENTAL EVALUATION OF THE MICROSEAL TECHNIQUE

Materials and methods

An in-vitro study was carried out to study the three dimensional filling of the endodontic system and the adaptation to the canal walls of the Microseal Technique.

Ten single rooted human teeth were immersed in sodium hypochloride for a few minutes until the complete elimination of the periodontal ligament and subsequently preserved in a physiological solution.

For each tooth a buccal radiograph and a mesio-distal radiograph were taken so as to highlight the canal anatomy.

The preparation of the access cavity was carried out paying particular attention to the elimination of any coronal interferences. The shaping of the endodontic space was carried out using the Quantec Method.

During the canal instrumentation the canals were irrigated after each instrument with 2 mm of 5% sodium hypochlorite. At the end of the instrumentation the canals were further irrigated alternating for 3 times 17% EDTA solution and sodium hypochlorite that were kept in the canal for a minute after each irrigation.

Once the canals were dried, a Microflow gutta-percha cone having a conicity of .02 and having an adjusted tip diameter was chosen and adapted, so as to obtain the necessary tug-back; a check radiograph was carried out.

The cone was removed and the sealer was applied in the coronal two thirds. Then the cone was repositioned after having smeared the last 3-4 mm of the tip with sealer.

The master cone was condensed with a # 25 spreader in NiTi .04 conicity mounted in the handpiece (340 rpm), introduced into the canal up to 2-3 mm from the cone tip.

A PacMac (# 25 conicity .04) mounted on a 1:1 handpiece was coated with fluid gutta-percha and introduced without rotation into the space left by the spreader. The micromotor was then run at a speed of 6,000 rpm without applying any pressure on the instrument, but only resisting the thrust in the coronal direction for about 2 seconds. The rotating condenser was then made to slowly exit the canal, insuring a contact with one of the canal walls, so as to allow the gutta-percha to remain in the endodontic space.

Once the obturation of all the canals had been completed the teeth were radiographed in double projection. Later the specimens were made transparent. The crowns were covered in wax and then the teeth were immersed in a 5% nitric acid solution for 3 days renewing the solution daily. Once the complete decalcification was obtained (radiographically verified) the specimens were washed for 4 hours in running water and then they were dehydrated by immersing them in solutions with increasing concentrations of ethyl chloride (12 hours in alcohol at 80°, 2 hours in alcohol at 90°, 2 hours in alcohol at 96°). Finally the specimens were rendered transparent by putting them in methylsalicylate for about 2 hours.

RESULTS

Radiographic evaluation

The radiographic evaluation shows the obturations to be dense and homogenous, the gutta-percha shows a good adaptation to the endodontic morphology, determining a good filling of the irregularities of the canal system (Figs. 27.33 A, 27.34 A).

In 5 cases out of 10 some lateral canals were observed (Fig. 27.33 A); in one case multiple apical exits were noted (Fig. 27.34 A).

Observation using stereo microscope

Observation with the stereo microscope allows one to observe that gutta-percha and sealer are present at the apical level (Figs. 27.33B, 27.34 B).

In 5 cases out of 10 the obturation of lateral canals were observed (Fig. 27.33 B); in 1 case multiple exits were observed (Fig. 27.34 B).

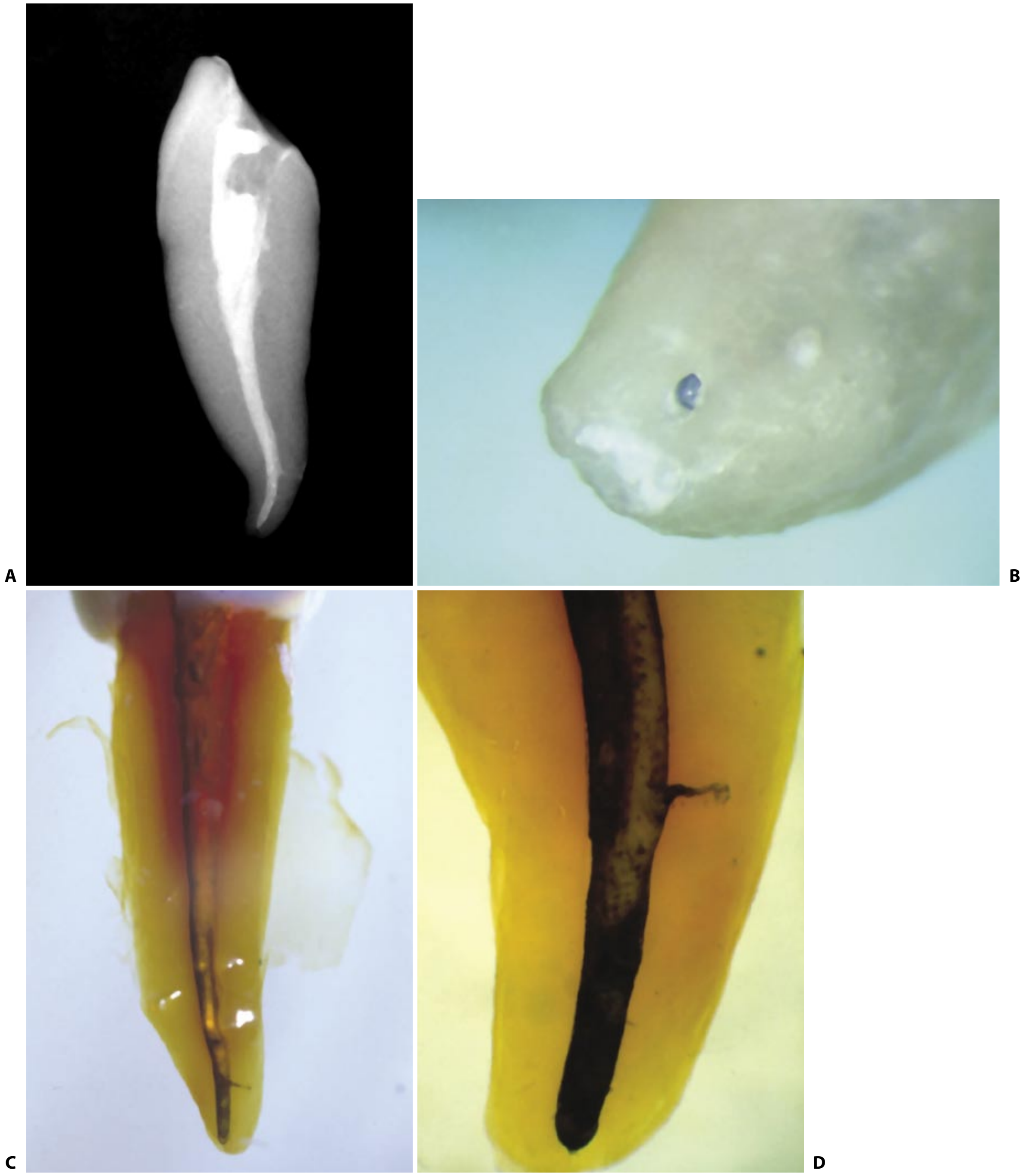


Fig. 27.33. In vitro evaluation of the Microseal Technique. **A**. Radiograph after the canal obturation: one notes that the root canal is completely filled by a homogenous mass of gutta-percha; at the apical third level a lateral canal was obturated. **B**. Stereomicroscope photograph of the apical area: one notes the presence of sealer which has extruded at the apical foramen and at exit of a lateral canal. **C**,**D**. The specimen after diaphanization: the obturation appears dense and homogenous and well adapted to the canal walls. The lateral canal in the apical third appears at least partially filled with gutta-percha.

Diaphanization

The analysis of the diaphanized specimens reveals that the canal obturations are made up of a single homogenous mass of gutta-percha, having a good adaptation to the irregularities of the canal anatomy (Figs. 27.33 C, D, 27.34 C).

In 5 cases out of 10 the obturation of a lateral canal was observed (Fig. 27.33 D); in 1 case multiple exits were observed (Fig. 27.34 C).

The lateral canals appear to be filled with gutta-percha and sealer.

A B C

Fig. 27.34. In vitro evaluation of the Microseal Technique. **A**. Radiograph after canal obturation. The obturation shows a good adaptation to the irregularities of the endodontic system and one notes the obturation of a complex apical system with multiple exits. **B**. Stereomicroscope photograph of the apical area: one notes the presence of sealer and gutta-percha which extrudes at various apical points. **C**. After diaphanization it is possible to observe that the obturation is dense and well adapted to the canal walls. At the apical level one notes the obturation of a complex apical system with multiple exits obtained with gutta-percha and sealer.

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Index
Volume 1 and 2

A

B

C

D

E

Q

R

S

T

U

V

W

X

Z