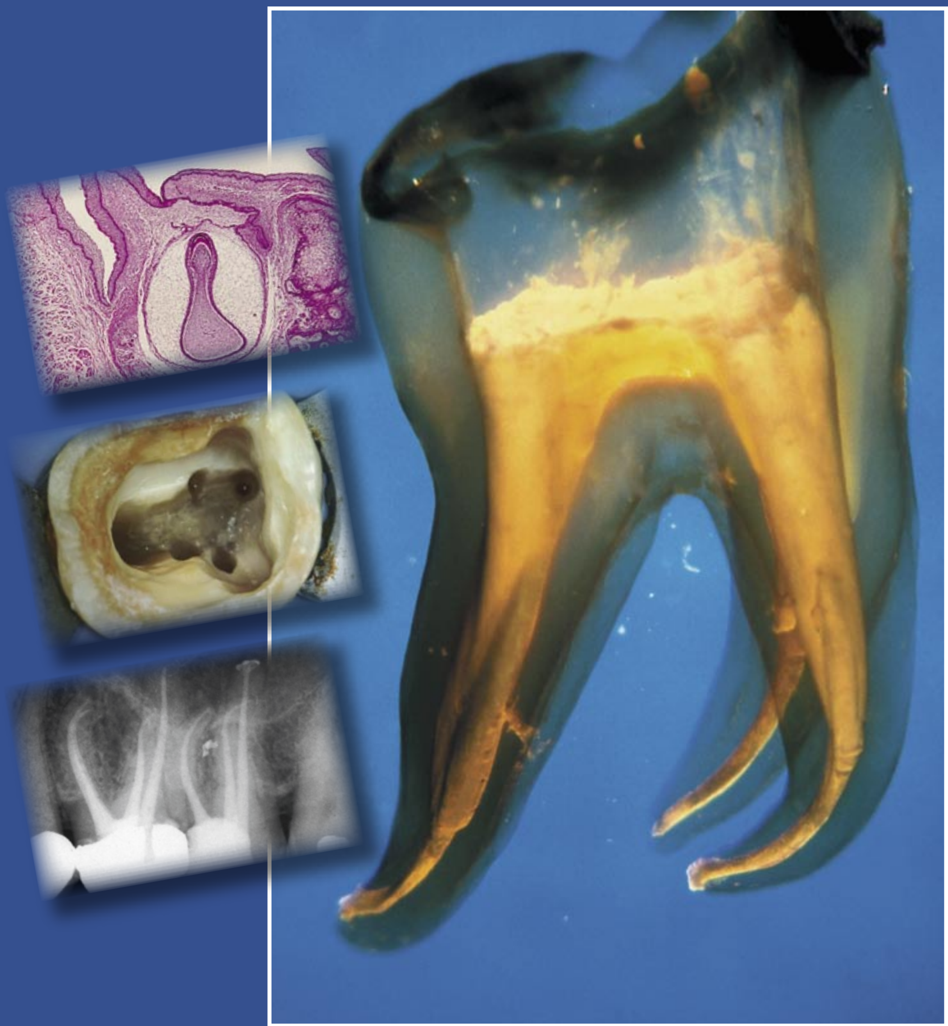
Arnaldo Castellucci MD, DDS

Endodontics

Volume 1



Foreword

John D. West, DDS, MSD

IL TRIDENTE
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NEW ENGLISH EDITION

1

A Brief History of Endodontics

Arnaldo Castellucci

The history of Endodontics begins in the 17th century. Since then, there have been numerous advances and developments, and research has proceeded continuously.

In 1687, Charles Allen, describing the techniques of dental transplants, wrote the first English-language book devoted exclusively to the field of dentistry.[5] At that time, necessity was the mother of invention: experimenting with new techniques, materials, and instruments, even though very rudimentary, the aim of Endodontics has been to relieve pain, maintain exposed pulp, and preserve teeth. Often, these attempts were successful.

Advances in the field of Endodontics have since continued without pause, but especially after Pierre Fauchard (1678-1761), considered the founder of modern dentistry, who in his textbook "Le chirurgien dentiste" precisely described the dental pulp [3] and dispelled the legend of the "tooth worm," which had been considered the cause of caries and toothaches since the time of the Assyrians.[16]

In 1725, Lazare Riviere introduced the use of oil of cloves for its sedative properties.[12]

In 1746, Pierre Fauchard described the removal of pulp tissue.

In 1820, Leonard Koecker cauterized exposed pulp with a heated instrument and protected it with lead foil.

In 1836, Shearjashub Spooner recommended arsenic trioxide for pulp devitalization.

In 1838, Edwin Maynard of Washington, D.C. introduced the first root canal instrument, which he created by filing a watch spring.

In 1847, Edwin Truman introduced gutta-percha as a filling material.

In 1850, W.W. Codman confirmed that the aim of pulp capping, which had already been proposed by Koecker in 1821, was to form a dentin bridge.[14]

In 1864, S.C. Barnum of New York prepared a thin rubber leaf to isolate the tooth in the course of filling.[7] Together with G.A. Bowman, he introduced the rubber dam clamp forceps in 1873.[1]

In 1867, Bowman used gutta-percha cones as the sole material for obturating root canals.[11]

Also in 1867, Magitot suggested the use of an electric current to test pulp vitality.[18]

In 1885, Lepkoski substituted formalin for arsenic to "dry" the non-vital pulp stumps left in the root canals after excision of the coronal pulp to prevent their decomposition.[4]

At the end of the century, prosthetic restorations, including the Richmond or Davis crown, became increasingly popular. Since they required the use of canal posts, they created an ever greater need for endodontic therapy.

In 1891, the German dentist Otto Walkhoff introduced the use of camphorated chlorophenol as a medication to sterilize root canals.

In 1895, and more precisely in the evening of November 8 in his laboratory in the Bavarian city of Wurzburg, the scientist Konrad Wilhelm von Roentgen accidentally discovered a new form of energy that had the ability to penetrate solid material. Because of their unknown nature, he decided to call these rays "X".[15]

A few weeks later Otto Walkhoff, a dentist in Brunswick, Germany, took the first dental radiograph, making a contribution to dentistry that almost equaled Roentgen's to medicine.[6] Roentgen's discovery of the X-ray has been ranked in importance with the discovery and development of anesthesia by Horace Wells and William Morton, both dentists, and the discovery of microorganisms and their role in disease by the likes of Pasteur and Lister.[13]

A true dental pioneer, C. Edmund Kells, is the one who quickly grasped the potential for applying Roentgen's discovery to dentistry and thereby forever changed the way dentistry would be practiced.[13]

In 1900, Price described periapical radiolucencies as "blind abscesses" and advised the use of radiography for establishing the diagnosis of pulpless teeth.[18]

In 1908, Dr. Meyer L. Rhein, a physician and dentist in New York, introduced a technique for determining canal length and level of obturation.[6]

About the same time, G.V. Black suggested a measurement control to determine the length of the canal and the size of the apical foramen, so that overfilling could be prevented.[4]

These are only some of the more important achievements of the pioneers of Endodontics, who made continual advances, with undoubtedly surprising results, considering their means and knowledge.

After 1910, when safe and effective local anesthetics were developed and radiographic machines, which were being perfected, came into wide use, one would have expected to see tremendous strides being taken to develop a safe and reliable system of endodontic therapy. Indeed, such advances would undoubtedly have occurred had the death knell of American dentistry in general and for endodontic treatment in particular not been sounded.

Several years before, in 1904, Frank Billings directed the attention of dentistry and medicine to the apparent relationship between oral sepsis and bacterial endocarditis.[4] Five years later, one of his students, E.C. Rosenow, developed the theory of "focal infection" in a study of the bacterial aspects of root canal therapy. He demonstrated that streptococci were present in many diseased organs and that they could cause infection at some distant site by hematogenous spread.[4]

Rosenow defined a "focus" as a well-circumscribed tissue containing pathogenic organisms. He distinguished two types of foci: primary, in the skin and mucosa, and secondary, which develop from the former by metastasis. He believed that organisms could migrate from an apical granuloma to reach peripheral organs and cause other diseases. The following di-seases could originate as a metastatic infection from chronic foci of infection such as pyorrhea alveolaris and alveolar abscesses: rheumatic fever, acute and chronic infectious arthritis, myositis, neuritis, endocarditis, myocarditis, pericarditis, phlebitis, peritonitis, meningitis, nephritis, appendicitis, cholecystitis, gastric and duodenal ulcer, pancreatitis, thyroiditis, erythema nodosum, herpes zoster, osteomyelitis, pneumonia, septicemia etc.[8]

In the same year, 1909, Mayrhofer published a work linking the nature of pulpal infection with specific microorganisms. The results indicated that streptococ-

Fig. 1.1 Dr. Alberto Castellucci in his private office in 1938.

ci were present in about 96% of the cases studied.[17] In October of that year, William Hunter, an English physician and pathologist, gave a lecture on focal infection at the University of Montreal. Its impact was such that for more than twenty years it blocked not only research in and the teaching of Endodontics, but more importantly its practice. His lecture, "The Role of Sepsis and Antisepsis in Medicine", also was published a year later in a respected medical journal of the time, the *Lancet*. Hunter was harshly critical of dentistry (particularly against prosthetic dentistry); indeed, he claimed that gold crowns were "a mausoleum of gold over a mass of sepsis". Although Hunter's concern was particularly directed more toward the septic conditions found around poorly constructed prosthetic restorations, it was widely interpreted as an indictment of the pulpless tooth.[8] "The worst cases of anemia", said Hunter, "gastritis, colitis, of obscure fevers of unknown origin, of purpura, of nervous disturbances of all kinds, ... of chronic rheumatic afflictions, of kidney disease, are those which owe their origin to (or are gravely complicated by) the oral sepsis produced, in private patients, by these gold traps of sepsis".[10]

It was therefore believed that all systemic diseases could be cured by the extraction of teeth. Consequently, for almost 40 years, American dentists continued to extract any devitalized teeth, while the more timorous extracted even vital teeth with some restoration, large filling, inlays, crowns, or bridges.

The theory of focal infection therefore reigned for many years, counting an enormous number of followers. Some of them feared the effects of focal infection itself, but others were simply tired of performing root canal therapy, a very difficult, meticulous, and poorly remunerated task.

Fortunately, a small group of dentists did not stop, but rather sought to improve their current procedures by using aseptic techniques, bacteriological and histological methods, and X-rays for diagnostic purposes. This group included men like Coolidge, Johnson, Reihn, Callahan, Grove, Prinz, and others. Mainly because of their efforts, the principle of preserving the pulpless tooth survived.[1]

It was not until the late 1940s or early 1950s that the cumulative laboratory research and clinical evidence was sufficient to confirm that the devitalized tooth did not play a role in the causation of systemic disease. Thus the theory of focal infection fell and faith was restored in endodontic treatment.[10]

Owing to the efforts of these researchers, patients today can be assured of predictably reliable and safe endodontic treatments, the success rate of which, as perhaps in no other branch of medicine, approaches 100%. Thanks to them, the number of people who specialize in Endodontics today is very high and continues to rise and Endodontics has assumed its precise role in the field of dentistry. In many foreign universities, and hopefully soon also in Italy, Endodontics is a distinct discipline, distinguished from restorative dentistry by its own curriculum.

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2

Embryology

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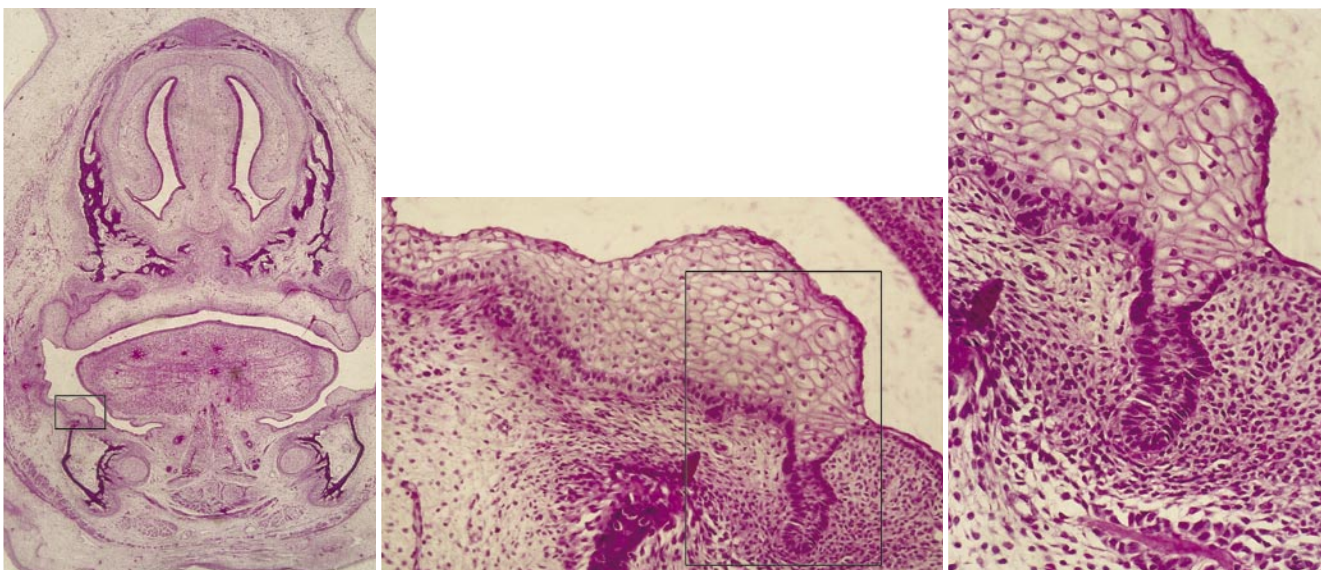
Because of its numerous clinical, including endodontic, implications, several fundamental points regarding the embryology of the tooth and its supporting structures will be discussed. For histological aspects, the reader is referred to existing sources.

CROWN FORMATION

The teeth begin to form about the sixth week of intrauterine life. The process is manifested by a thickening in the basal layer of ectodermal cells that cover the primitive oral cavity, or stomodeum.[9] This thickening is called the "dental lamina." It assumes the shape of a horseshoe, extending the length of the future dental arches. It comprises cells that proliferate at a more rapid rate than do the adjacent epithelial cells. At a certain point, at predetermined sites on the dental lamina, each corresponding to the ten deciduous maxillary and ten manidibular teeth, further cellular proliferation takes place, forming small protuberances (Fig. 2.1).

The protuberances do not form simultaneously throughout the dental lamina, but rather begin anteriorly, first in the mandibular, then in the maxillary regions. The posterior ones then develop, at points which correspond to the future deciduous teeth. As the protuberances proceed to enlarge, they remain associated with the dental lamina, differentiate, and depending on the stage, they assume peculiar forms called "bud," "cap," or "bell". These terms serve descriptive purposes only; they represent three moments of a slow evo-

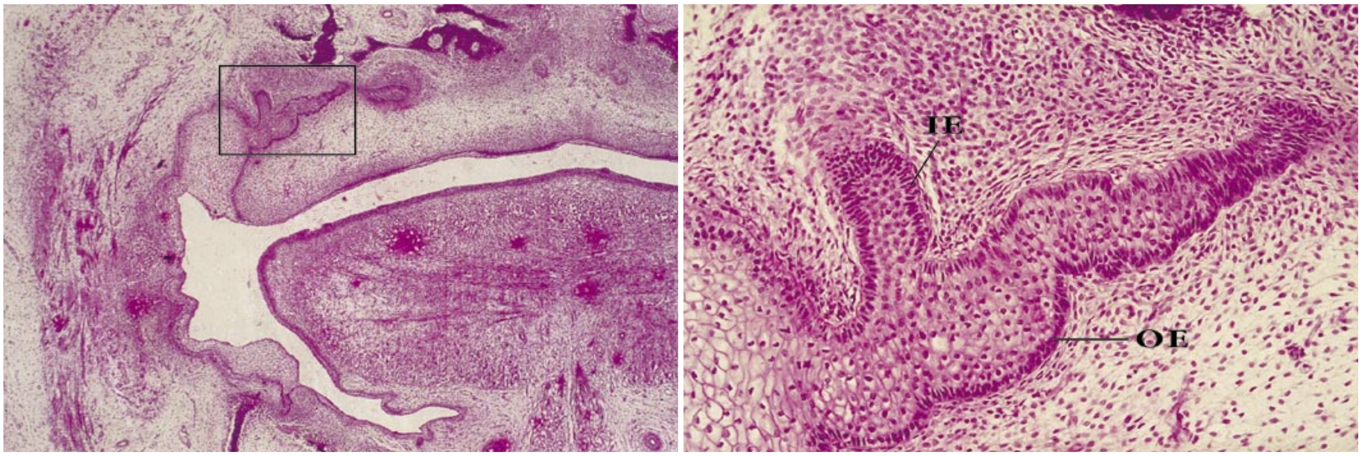


A B C

Fig. 2.1. Frontal section through head of a human 10-week embrio. **A**. x20. **B**. x200. **C**. x250. The "tooth bud stage": the epithelial cells of the dental lamina proliferate and begin to deepen in the underlying mesenchyme (Courtesy of Prof. A. Bloom, Boston University).

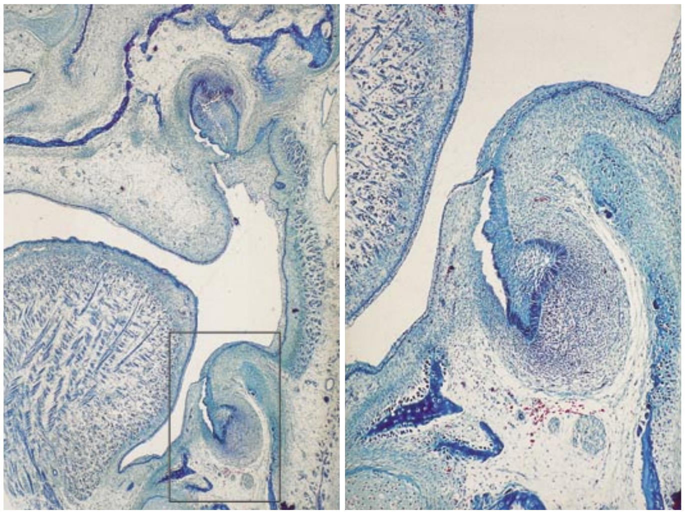
lution in which, by means of a continuous and gradual proliferation of cells, the teeth begin their slow, progressive formation.

Very early in the "tooth bud stage", which represents the primordia of the enamel organ,* two types of epithelial cells differentiate. One covers the internal surface of the bud, the other the external surface; they are the "inner epithelium" and "outer epithelium", respectively, of the enamel organ (Fig. 2.2). Concurrently, there is marked proliferation of the mesenchymal cells which face the inner epithelium of the enamel organ, from which the "dental papilla" (Fig. 2.3) will derive. This mesenchymal proliferation tends to dip within the epithelial proliferation (Fig. 2.4), which in turn circumscribes it during its growth. In this way, the process proceeds to the "cap stage" (Fig.



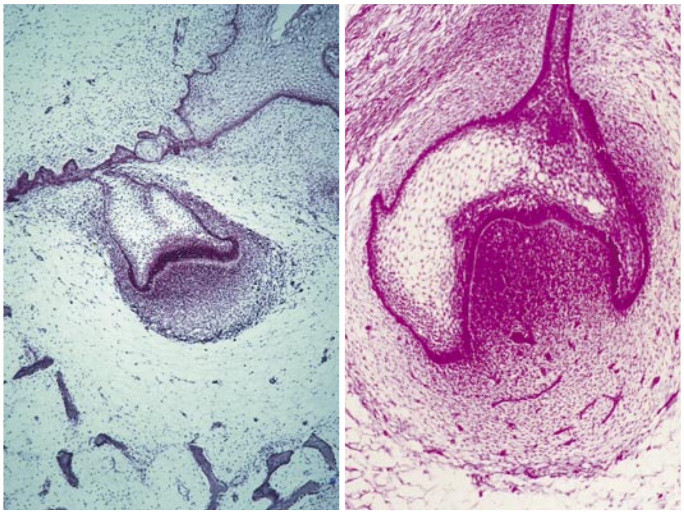
A B

Fig. 2.2. Frontal section of a human 10-week embrio. **A**. x40. **B**. x200. The inner epithelium (IE) and the outer epithelium (OE) have begun to develop within the enamel organ. Progression toward the "cap stage" has begun (Courtesy of Prof. A. Bloom, Boston University).



A B

Fig. 2.3. Frontal section of a human 10-week embrio. **A**. x40. **B**. x100. "Cap stage": proliferation of the mesenchymal cells facing the inner epithelium of the enamel organ (Courtesy of Prof. A. Bloom, Boston University).



A B

Fig. 2.4. **A**. x100. The dental papilla extends toward the interior of the enamel organ. **B**. x120. The enamel organ encloses the dental papilla, while the dental sac is organizing around it (Courtesy of Prof. A. Bloom, Boston University).

(*) A.R. Ten Cate [13] correctly notes that the term "enamel organ" is imprecise, inasmuch as it is too limiting; he prefers to call this structure the "dental organ". Indeed, it has several functions, as will be shown in the course of this chapter: apart from forming enamel, it is responsible for determining the shape of the crown, induces the differentiation of the odontoblasts, and thus directly initiates dentin formation and finally establishes the dento-gingival junction. Nonetheless, to avoid confusion, the universally-accepted old terminology will be employed.

2.5). By this point, the outer epithelium of the enamel organ, which is comprised of cuboidal cells that line the convexity of the "cap", and the inner epithelium of the enamel organ, which comprises cylindrical cells that line the concavity of the "cap", are well differentiated.
At a slightly more advanced stage (though still in the "cap stage"), a third type of epithelial cell differentiates between the outer and inner epithelia. It is sparsely distributed; the cells are distantly situated from one another because of the accumulation of a large amount of intercellular fluid. The presence of anastomoses forming the so-called "stellate reticulum" or "enamel organ pulp" accounts for their stellate shape (Fig. 2.6). Meanwhile, beneath the enamel organ, proliferation in the mesenchymal layer leads to organization and condensation to form the "dental papilla" (Fig. 2.7).
Concomitant with the development of the enamel organ and the dental papilla, the mesenchyme surrounding these two formations also condenses and organizes to form the "dental sac" (Fig. 2.8).
The following derive from the formations that we have listed up to this point:
The enamel prisms and therefore all the enamel of the dental crown derive from the inner epithelium of the enamel organ. They are therefore of ectodermal origin.
The odontoblasts and thus the dentin and dental pulp derive from the dental papilla. They are therefore of mesenchymal origin.
The periodontal tissues, comprising the periodontal ligament, cement, and alveolar bone derive from the dental sac. They are also of mesenchymal origin.[13]
The "bell stage" follows the cap stage. In this stage, the epithelial invagination deepens and tends increa-

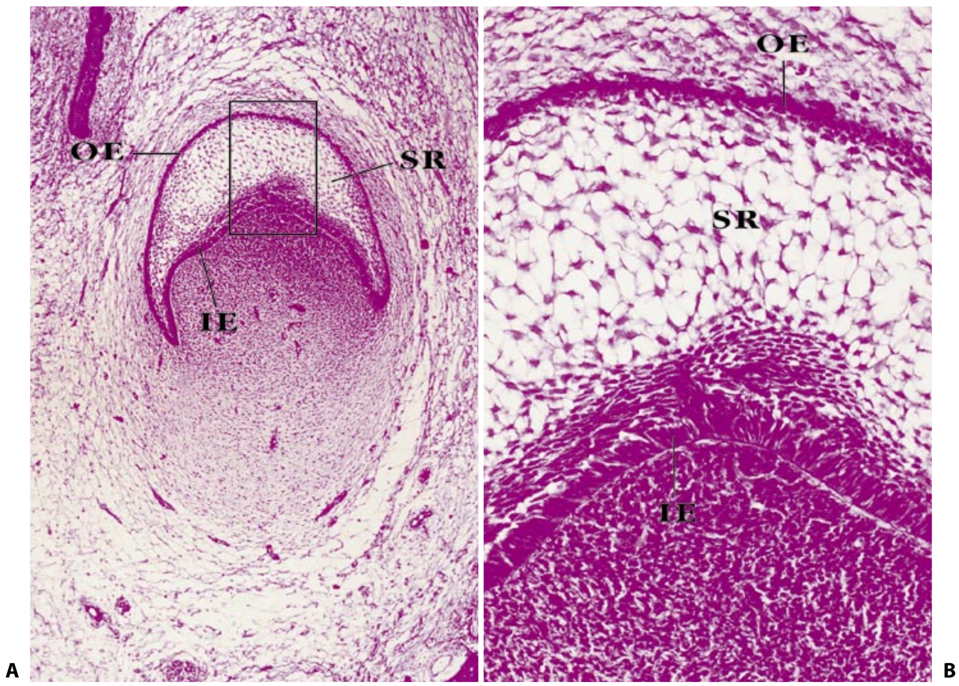


Fig. 2.5. **A**. x100. The enamel organ begins to surround the underlying dental papilla. **B**. x300. The framed area in Fig A. at a higher magnification. Between the inner epithelium (IE) and outer epithelium (OE) of the enamel organ, the stellate reticulum (SR) is starting to differentiate (Courtesy of Prof. A. Bloom, Boston University).

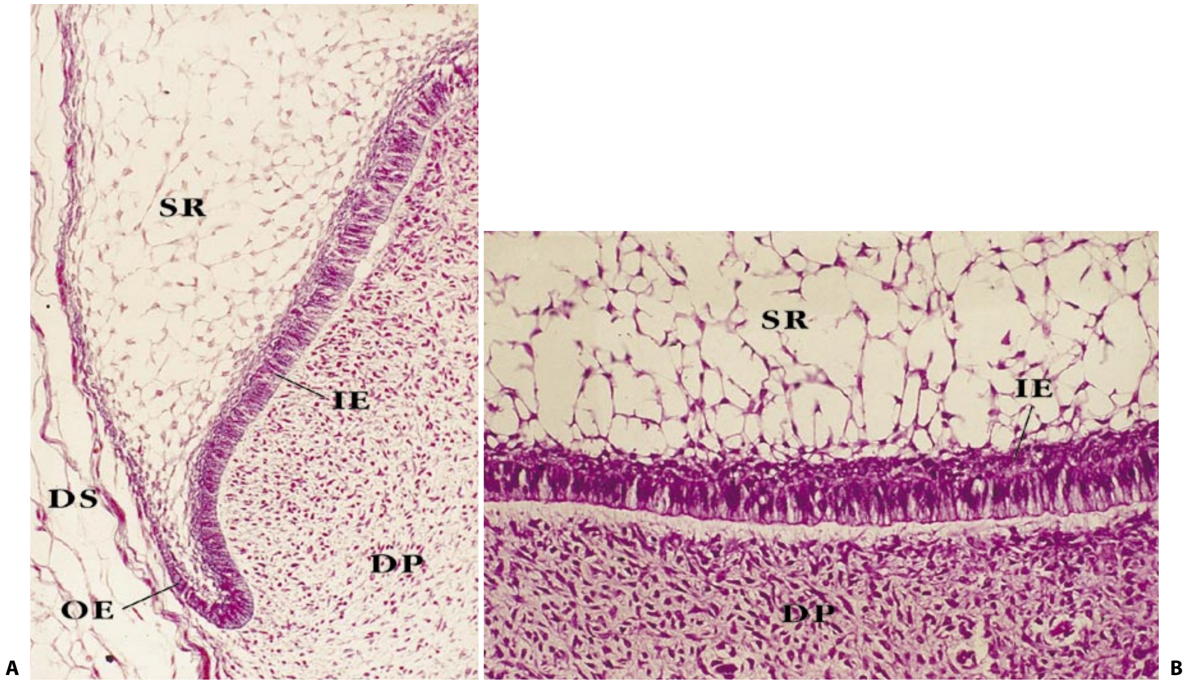


Fig. 2.6. **A**. x250. Cap stage: DS, dental sac; OE, outer epithelium of the enamel organ; SR, stellate reticulum; IE, inner epithelium of the enamel organ; DP, dental papilla. **B**. x280. SR, stellate reticulum; IE, inner epithelium of the enamel organ; DP, dental papilla (Courtesy of Prof. A. Bloom, Boston University).

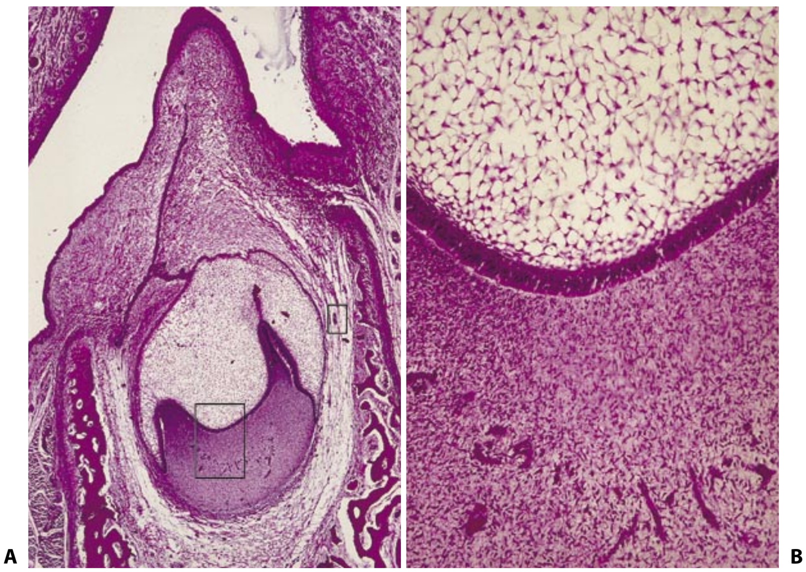


Fig. 2.7. **A**. x40. The formation of blood vessels within the dental papilla is becoming evident. **B**. x250. The bigger framed area in Fig A. at a higher magnification. From top to bottom: stellate reticulum, inner epithelium, and dental papilla with developing blood vessels (Courtesy of Prof. A. Bloom, Boston University).

Fig. 2.8. x400. The smaller framed area in Fig. 2.7. A at a higher magnification. Connective fibers and vessels of the dental sac at the periphery of the enamel organ (Courtesy of Prof. A. Bloom, Boston University).

singly to surround the underlying dental papilla (Fig. 2.9). When this epithelial deepening arrives at the point corresponding to the future cementoenamel junction, the future shape of the crown of the tooth is already delineated, and the dentinoenamel junction can just be identified.

At this point (Fig. 2.10), the dentin begins to form from one side and the enamel from the other. In fact, the cells of the inner epithelium of the enamel organ (Fig. 2.11) induce the "odontoblasts" to differentiate in the underlying mesenchymal cells. Leaving behind cytoplasmic extensions,[11] or Tomes' processes, as they migrate in a centripetal direction, these cells produce dentin. The presence of these processes accounts for the tubular appearance of the dentin (Fig. 2.12). The odontoblasts progressively move toward the pulp while they deposit dentin, and later these cells will cover the pulp cavity (Fig. 2.13).

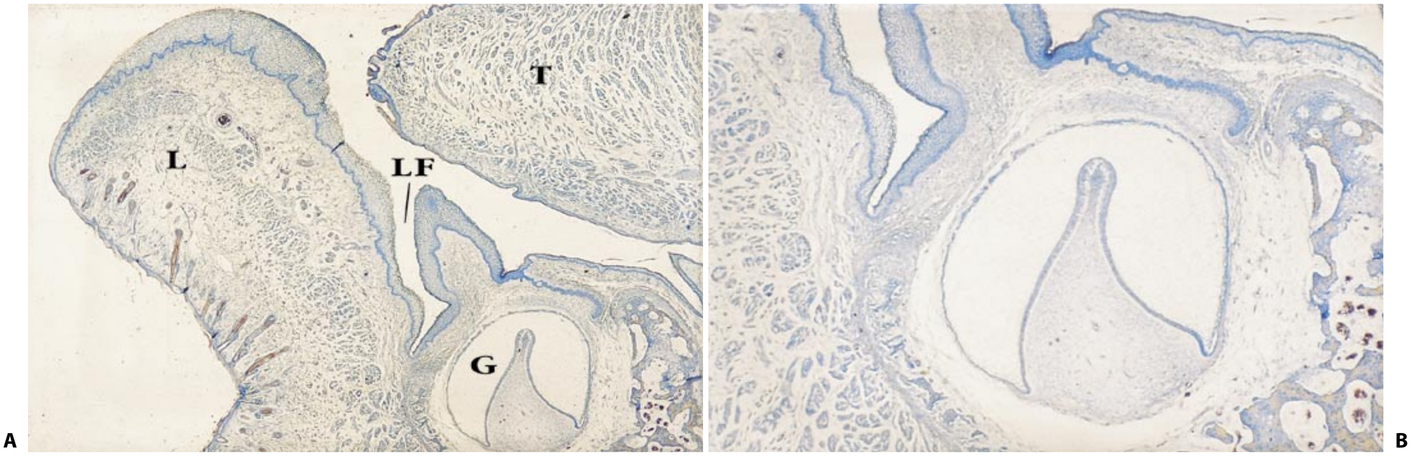


Fig. 2.9. Sagittal section of a human 18-week embrio. **A**. x25. T, tongue; L, lip; LF, lingual fornix; G, tooth germ at the "bell stage". **B**. x40. "Bell stage". The epithelial invagination begins to surround the underlying dental papilla and suggests the future cementoenamel junction (Courtesy of Prof. A. Bloom, Boston University).

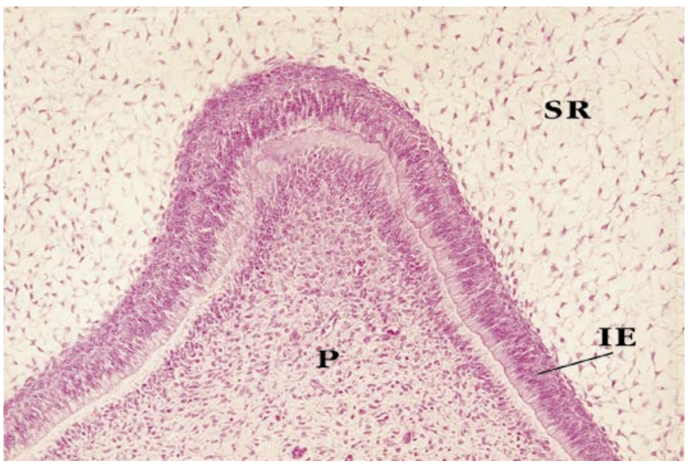


Fig. 2.10. x250. The formation of hard dental tissues has just begun. SR, stellate reticulum; IE, inner epithelium; P, dental papilla (Courtesy of Prof. A. Bloom, Boston University).

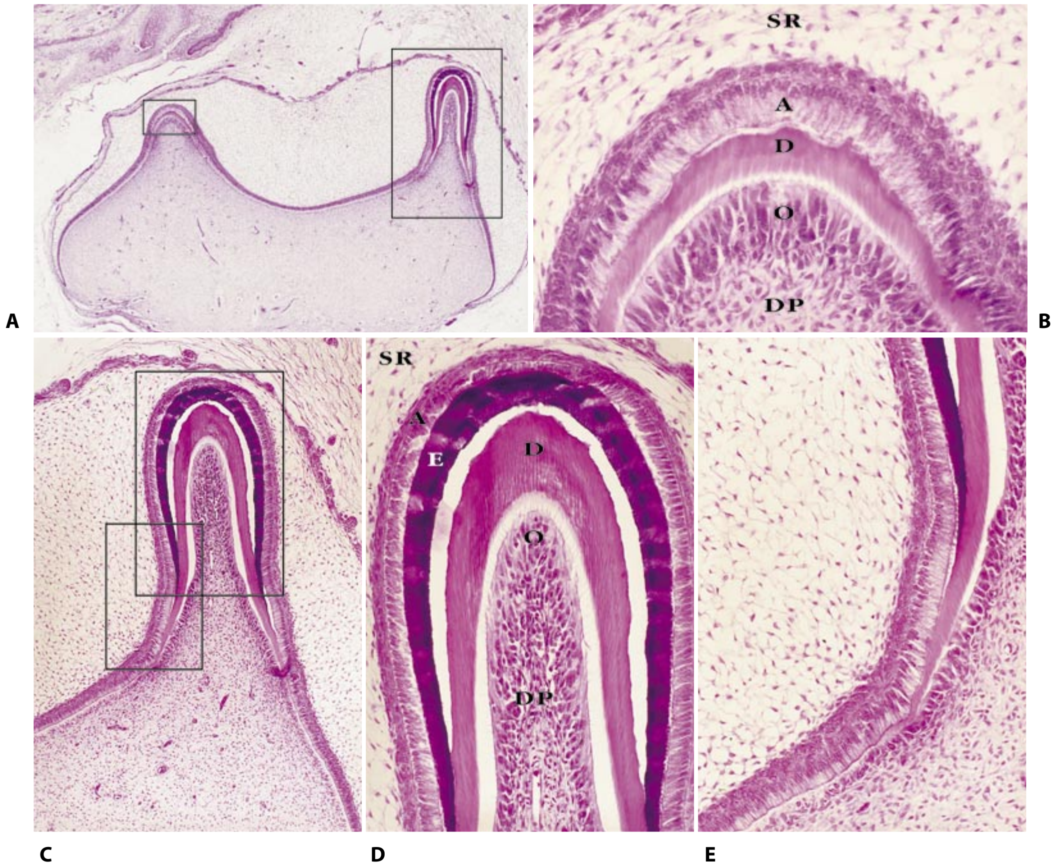


Fig. 2.11. **A**. x35. Deciduous molar at the bell stage. The deposition of the hard dental tissues, enamel, and dentin has started. **B**. x400. Higher magnification of the framed area on the left. The tubular structure of the dentin is becoming evident. From top to bottom, the following are identified: stellate reticulum (SR), inner epithelium already differentiated into adamantoblasts (A), dentin (D), odontoblasts (O), and dental papilla (DP). **C**. x100. Higher magnification of the framed area on the right. The deposition of hard tissue is at a more advanced stage and is proceeding downward from the top of the bell. **D**. x250. Higher magnification of Fig. 2.11C: stellate reticulum (SR), adamantoblasts (A), enamel (E), dentin (D), odontoblasts (O), and dental papilla (DP). The spaces between the enamel and dentin and between the dentin and odontoblasts are artefacts. **E**. x250. The deposition of enamel and dentin proceeds in the direction of the future cementoenamel junction (higher magnification of Fig. 2.11C) (Courtesy of Prof. A. Bloom, Boston University).

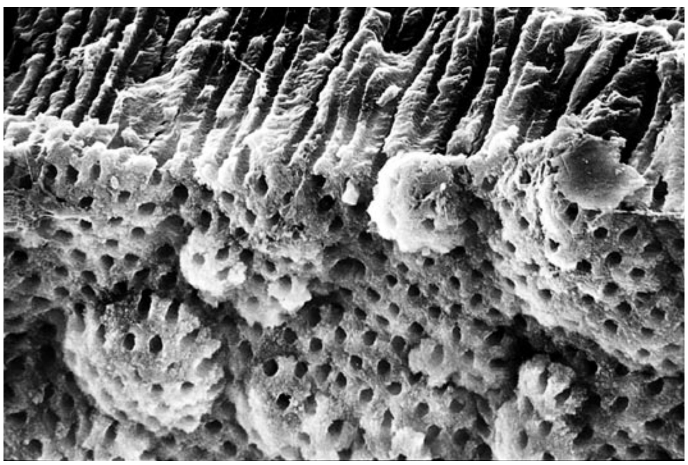


Fig. 2.12. Scanning electron micrograph showing mature human dentin (x1000). Note the typical tubular appearance of the dentin and the calcospherites of the predentin.

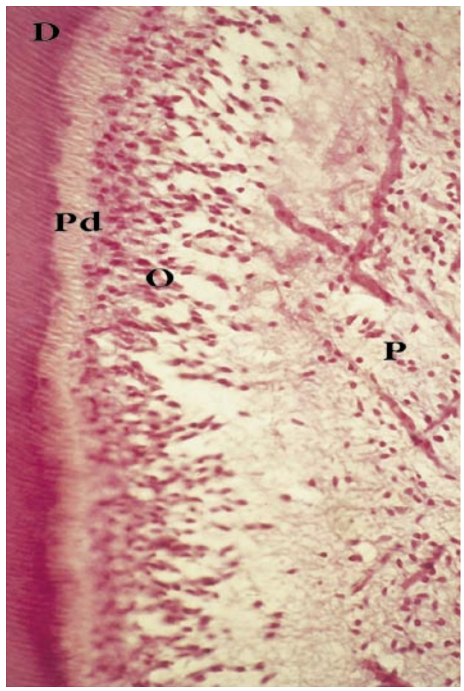


Fig. 2.13. Histologic section of the dental pulp. The odontoblasts cover the pulp cavity: pulp tissue (P) rich with fibroblasts and small vessels, odontoblast layer (O), predentin or noncalcified dentin (Pd), and calcified dentin (D) (Courtesy of Dr. N. Perrini).

At the same time, the "ameloblasts" differentiate in the inner epithelium of the enamel organ. They begin to move away from the dental papilla by migrating in a centrifugal direction, while producing enamel (Fig. 2.14). In chronological order, the first differentiated cells to appear are the "ameloblasts", which begin to differentiate at the level of the developing cusp tip or the incisal edge of the tooth. Differentiation then proceeds along the sides (Fig. 2.15) toward the base of the crown.[1,5,7] Immediately afterward, the mesenchymal cells of the dental papilla immediately adjacent to the newly-formed ameloblasts differentiate into elongate, cylindrical cells, the "odontoblasts".

The area in which these two cellular formations first appears is called the "growth center" of the tooth. It is the site at which the production of hard dental tissue begins. The first tissue to appear is the dentin, which is produced by the odontoblasts at the level of the papillary summit, and only after a thin layer of dentin has been laid down do the ameloblasts begin to produce the enamel matrix on top of it. This is a typical example of "reciprocal" induction, which emphasizes the interdependency between these two tissues: once the ameloblasts have differentiated, the inner epithelium of the enamel organ induces the differentiation of the odontoblasts, while the dentin for-

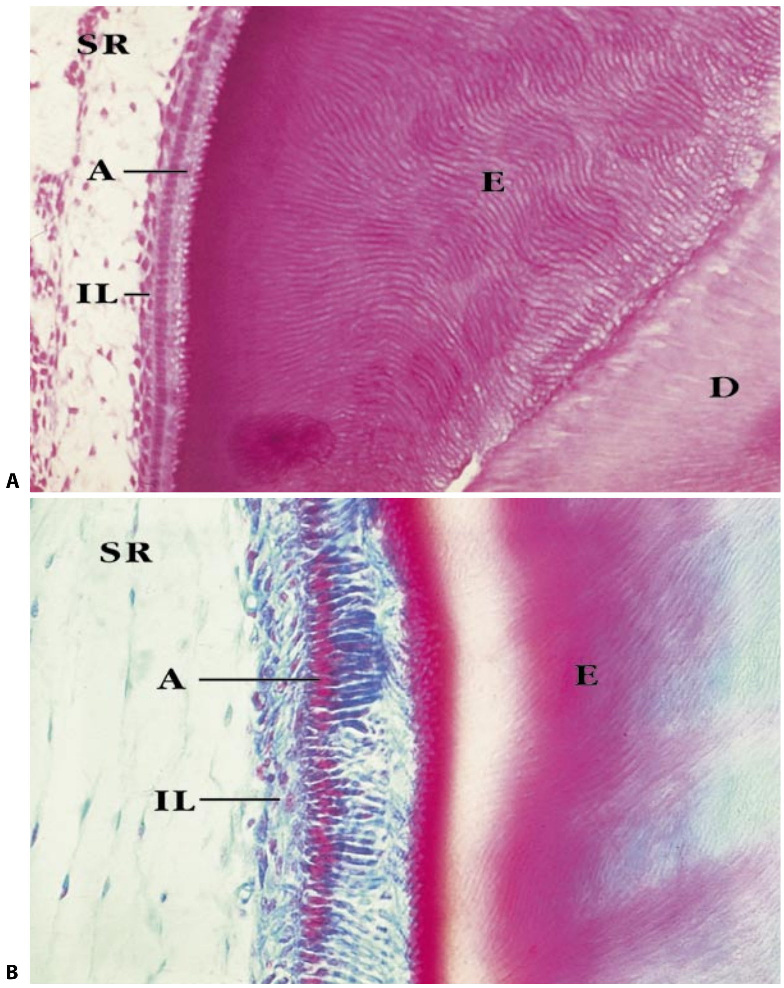


Fig. 2.14. **A**. SR, stellate reticulum; IL, intermediate layer; A, ameloblasts; E, enamel; D, dentin. **B**. SR, stellate reticulum; IL, intermediate layer; A, ameloblasts; E, enamel (Courtesy of Dr. R. Pontoriero).

med by the odontoblasts stimulates the ameloblasts to produce enamel.
At this point, it is important to emphasize that the formation process of the dentin and enamel is distinct from that of the body's other hard tissue, bone.[5] In contrast with the osteocytes, the cells that produce the hard dental tissues do not remain enclosed in the intercellular substance produced: there are no "amelocytes" or "odontocytes".
On the contrary, once the hard matrix of the dental tissues has been produced, the cells retreat from them, the ameloblasts toward the exterior and the odontoblasts toward the interior.
Once all the enamel of the dental crown has been formed and the tooth erupts, the ameloblasts die. Hence, the enamel is practically an inert mineralized tissue. Inasmuch as it is acellular, it is completely incapable of repairing lesions produced by caries, fractures, or other causes. It can only undergo a limited exchange of ions with saliva. In contrast, the odontoblasts do not disappear after the tooth has completely formed. Rather, they remain within the pulp cavity of the root canal, where dentin deposition continues for the entire life of the tooth, both spontaneously (secondary dentin) and under the influence of particular stimuli (tertiary dentin).

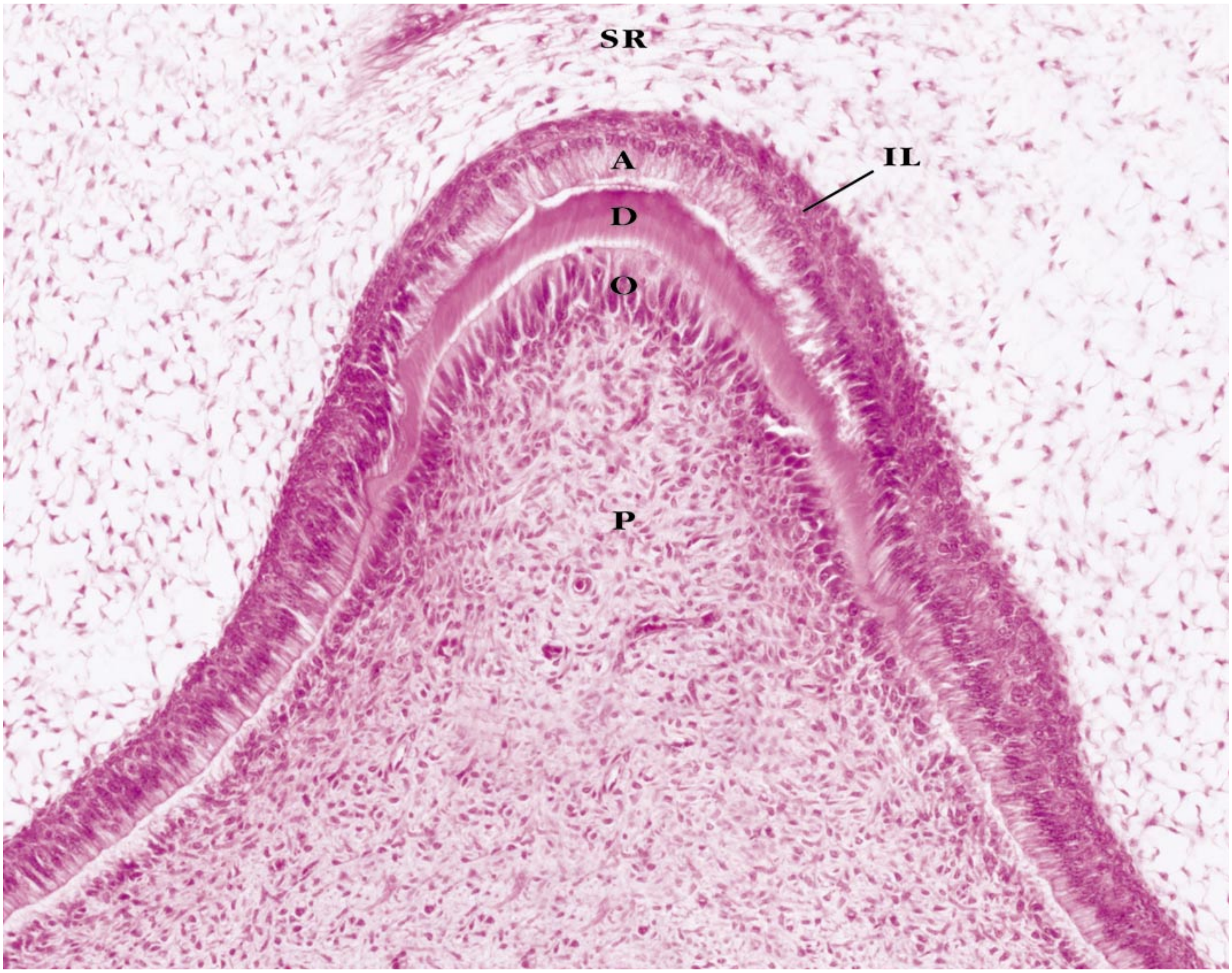


Fig. 2.15. x300. SR, stellate reticulum; IL, intermediate layer; A, ameloblasts; D, dentin; O, odontoblasts; P, dental papilla. Note that differentiation and the consequent deposition of hard tissues proceeds apically from the growth center (Courtesy of Prof. A. Bloom, Boston University).

ROOT FORMATION

At a more advanced stage, when enamel and dentin formation has reached the future cementoenamel junction, the dental root begins to form. The outer and inner enamel epithelia begin to proliferate, they come together and form a sort of diaphragm facing the interior of the structure which will become the pulp cavity or the root canal (Fig. 2.16). When the epithelial layers form this cellular diaphragm, the stage of formation of "Hertwig's epithelial root sheath" (Fig. 2.17) has been reached.

This root sheath does not extend along the entire length of the future root, nor does it grow to its free end toward the surrounding connective tissue, as had been erroneously believed in the past.[11] The diaphragm's position remains relatively stable during the development and growth of the root. The growth of the epithelium, which proliferates coronally ("Hertwig's vertical epithelial root sheath"), causes the formation and lengthening of the root, and finally the eruption of the tooth at this site [9] (Fig. 2.18).

While the epithelial diaphragm or "Hertwig's horizontal root sheath" is present throughout the forma-

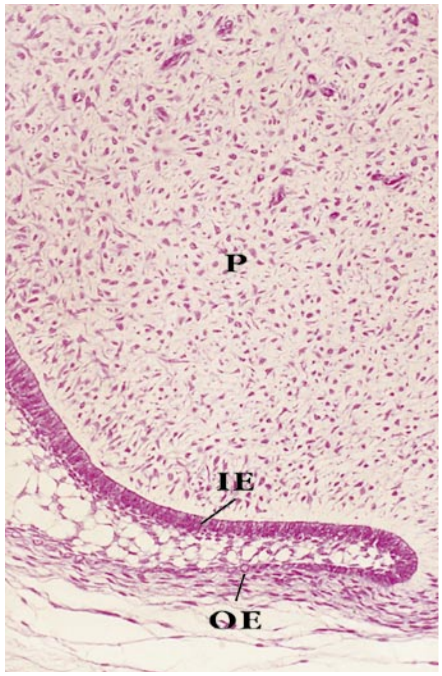
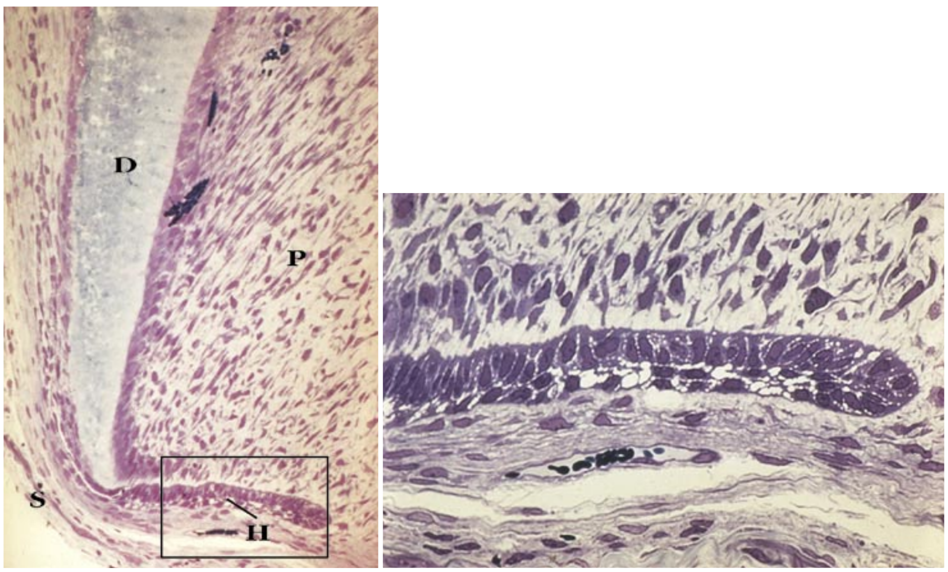


Fig. 2.16. x250. As the deposition of dentin and enamel proceeds, the inner epithelium (IE) and outer epithelium (OE) of the enamel organ come together and bend horizontally to form a diaphragm facing the dental papilla (P) (Courtesy of Prof. A. Bloom, Boston University).



A B

Fig. 2.17. **A**. x150. S, dental sac; D, dentin; P, dental pulp; H, Hertwig's epithelial rooth sheath. **B**. x400. Higher magnification of the framed area of Fig A. The cylindrical cells of the inner epithelium of the enamel organ are identifiable in the root sheath (Courtesy of Dr. R. Pontoriero).

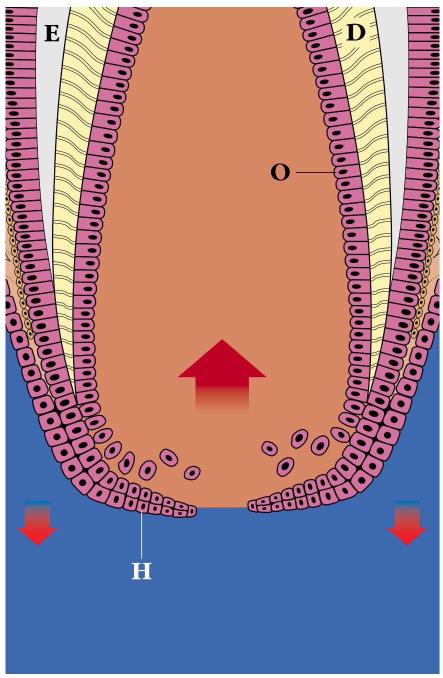


Fig. 2.18. Diagram showing the Hertwig's epithelial root sheath at the cervical region or base of the organ. E, enamel; D, dentin; O, odontoblasts; H, Hertwig's root sheath. The arrows indicate the root elongation (down) with the consequent tooth eruption (up) (Adapted from J.K. Avery).

tion of the root (Fig. 2.19), the presence of the vertical portion of Hertwig's root sheath is more limited. It induces odontoblastic differentiation, which initiates the formation of the radicular dentin. After this, the cells of Hertwig's vertical epithelial root sheath are dispersed (Fig. 2.20), become discontinuous, and partially disappear (Fig. 2.21). Only islands of cells, known as the "epithelial rests of Malassez", remain of the root sheath and may be found in the periodontal ligament (Fig. 2.22). In the adult, these epithelial cell rests persist next to the root surface within the periodontal ligament. Although nonfunctional, they are the source of the epithelium lining the dental cysts that develop in reaction to inflammation of the periodontal ligament.[13]

By the time the odontoblasts begin to form dentin, Hertwig's vertical root sheath has exhausted its function and begins to disappear. This process is spurred

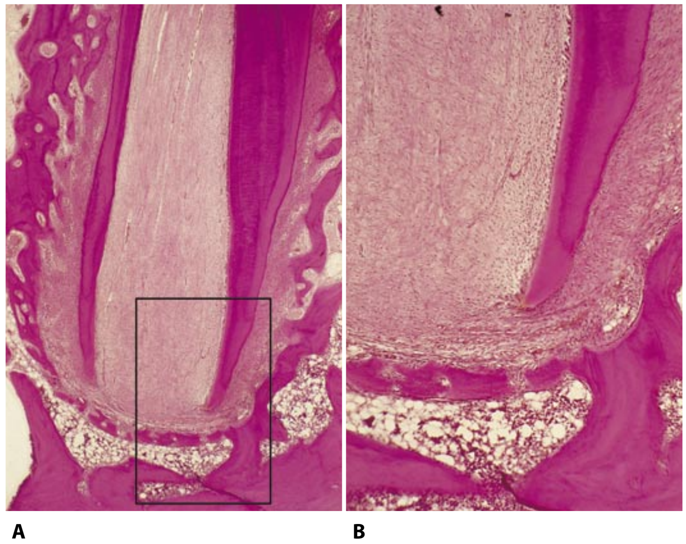


Fig. 2.19. **A**. x40. Developing root. **B**. x100. Detail. Hertwig's root sheath may be identified (Courtesy of Prof. A. Bloom, Boston University).

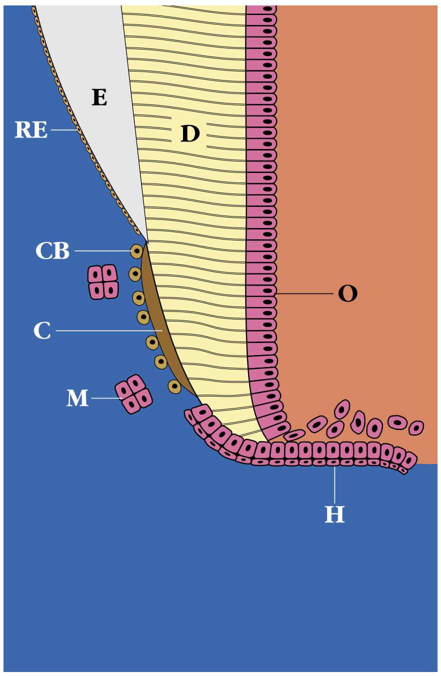


Fig. 2.20. Schematic diagram showing Hertwig's root sheath. Once the root dentin has been formed, the root sheath breaks up to allow the cementoblasts to deposit cementum over the newly formed dentin. Only scattered nests of epithelial cells, the epithelial rests of Malassez, remain of the sheath. At the same time the ameloblasts, once their function is exhausted, transform into cuboidal cells on top of the enamel (reduced enamel epithelium) which, at the moment of eruption of the tooth, fuse with the epithelium of the oral cavity. RE, reduced enamel epithelium; E, enamel; D, dentin; O, odontoblasts; C, cementum; CB, cementoblasts; M, epithelial rests of Malassez; H, Hertwig's epithelial root sheath (Adapted from J.K. Avery).

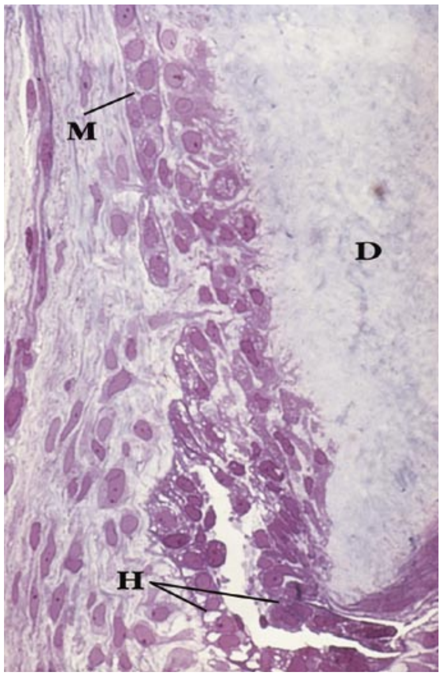


Fig. 2.21. x400. The cells of Hertwig's root sheath (H) break up into epithelial rests and partially disappear to be replaced by cementoblasts. D, dentin; M, epithelial rest of Malassez (Courtesy of Dr. R. Pontoriero).

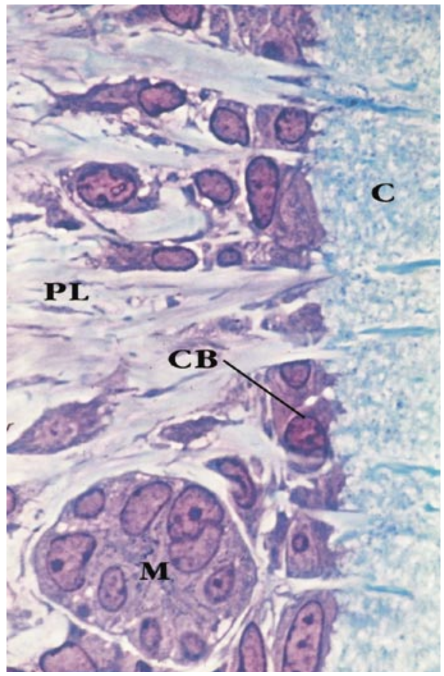


Fig. 2.22. x400. Epithelial rests of Malassez surrounded by fibers of the periodontal ligament. PL, periodontal ligament; M, epithelial rests of Malassez; CB, cementoblasts; C, cementum (Courtesy of Dr. R. Pontoriero).

by the fact that in the surrounding mesenchyme the newly-formed dentin concurrently induces the differentiation of the cementoblasts, which begin to deposit a layer of cementum on the surface of the dentin.

As already stated, not only the cementum, but also the periodontal ligament and the alveolar bone derive from the dental sac. In fact, the mesenchyme of the dental sac produces a large number of collagen fibers (to form the future periodontal ligament), as well as the organic matrix of the bone (alveolar bone) and the cementum (Fig. 2.23). This matrix is deposited around the previously formed collagen fiber bundles and subsequently mineralizes. This explains the presence of fibers embedded in the hard tissues at each end, bone (Fig. 2.24) and cementum (Fig. 2.25), where they are called Sharpey's fibers. The alveolar bone and the cementum develop around these fibers, thus anchoring the dental structure to the surrounding alveolar bone. The opposite does not occur; that is, fibers do not develop within the bone or already-formed cementum. In other words, if for some reason they are detached, the cementum must form so that the collagen fibers may be firmly reattached to the tooth.[5]

Fig. 2.24. Higher magnification of Fig. 2.23. On the left, Sharpey's fibers are identified within the bone; on the right, the periodontal ligament with osteoblasts (Courtesy of Dr. R. Pontoriero).

SINGLE- AND MULTIPLE-ROOT FORMATION

The horizontal diaphragm or Hertwig's horizontal root sheath may vary in shape, depending on whether the teeth are single- or multiple-rooted (Fig. 2.26). In fact, the diaphragm's shape determines the number of roots in a tooth. If the diaphragm remains in the shape of a collar, a single-rooted tooth will form. On the other hand, if two or three tongues of epithelium grow towards each other from this collar to bridge the gap and fuse, two or three diaphragms evolving independently from each other will form. They will either remain fused, forming fused roots or single roots with multiple canals, or separated, forming distinct roots in multirooted teeth.

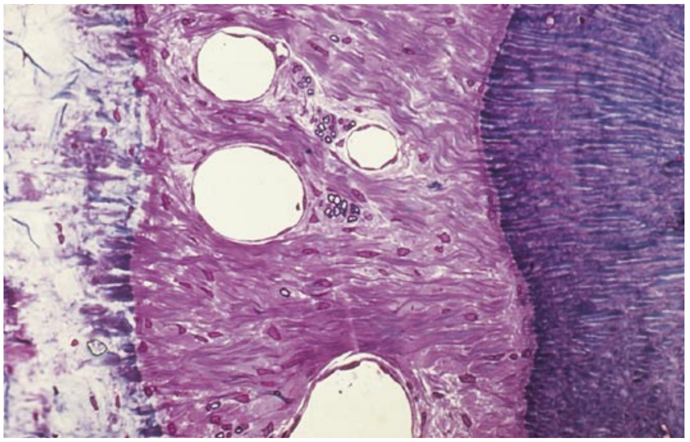


Fig. 2.23. The periodontal ligament. Alveolar bone (left), root (right). Blood vessels and nerve fibers may be identified in the ligament (Courtesy of Dr. R. Pontoriero).

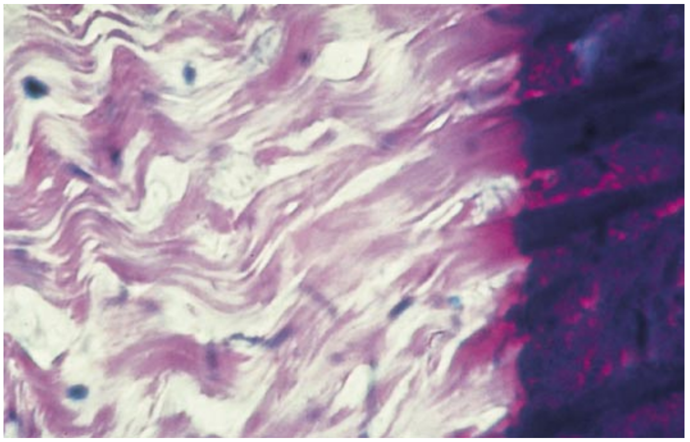


Fig. 2.25. Higher magnification of Fig. 2.23. On the left, the fibers of the periodontal ligament that continue as Sharpey's fibers (right) within the cementum (Courtesy of Dr. R. Pontoriero).

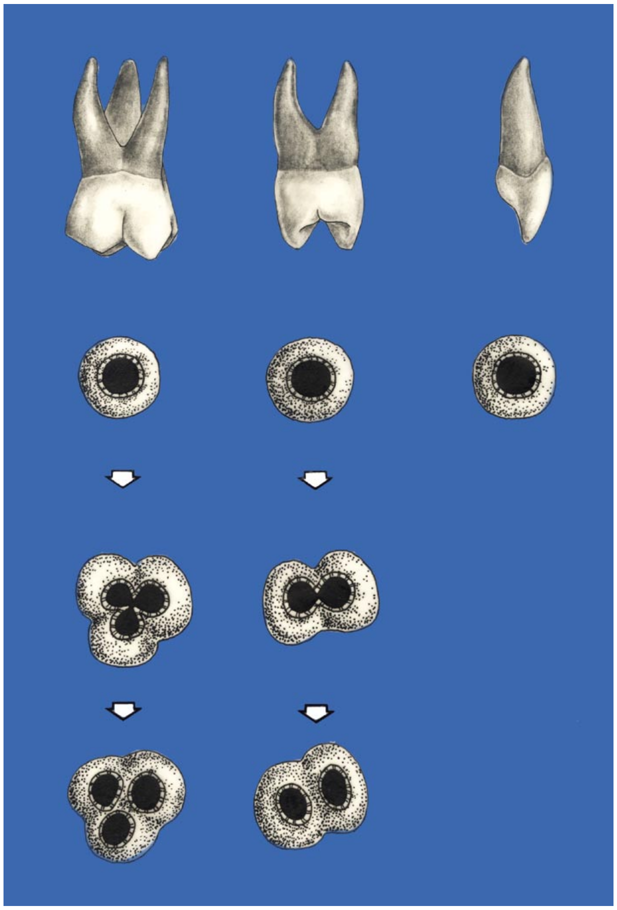


Fig. 2.26. Schematic diagram of the evolution of Hertwig's epithelial root sheath, which determines the formation of one, two, or three roots (Adapted from J.K. Avery).

THE FORMATION OF LATERAL CANALS

In some cases, small portions of Hertwig's vertical root sheath disappear before the odontoblasts have differentiated, and thus before dentin has been formed. A lateral canal will form at just such a point. This small island of "lack of cells" of Hertwig's root sheath, where odontoblasts do not differentiate and thus dentin does not form, is responsible for the lateral canal's formation (Fig. 2.27).

Weinmann [14] states that "the development of all the lateral branches of the root canals may be a defect of the epithelial root sheath of Hertwig which occurs during the development of the root because of the presence of a large, supernumerary blood vessel". As a consequence, if the continuity of the root sheath is interrupted before the formation of the dentin, a defect in the dentinal wall will occur. This defect may be also found in the floor of the pulp chamber of a multirooted tooth if the fusion of the tongue-like extensions of the epithelial diaphragm is incomplete due to the presence of a vessel.

Scott and Symons [10] concur that these aberrant openings are due to defects in the formation of Hertwig's root sheath, as a result of which the pulp remains in contact with the dental sac or periodontal tissue. They also believe that these openings in Hertwig's root

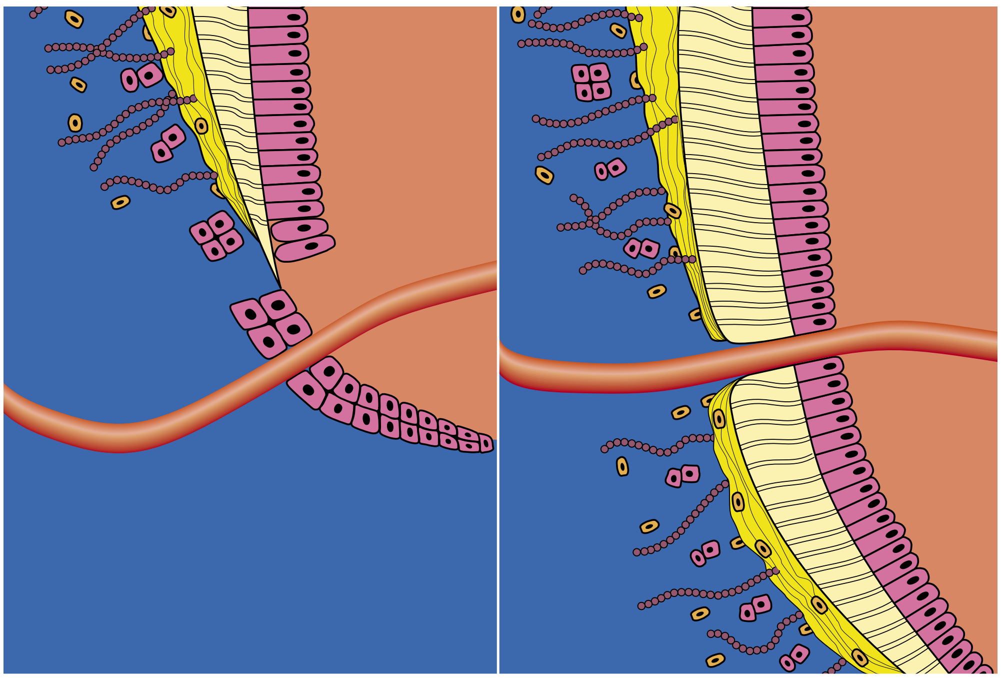


Fig. 2.27. Schematic diagram of the formation of lateral canals (Adapted from J.K. Avery).

sheath are probably due to the persistence of anomalous blood vessels reaching the pulp.

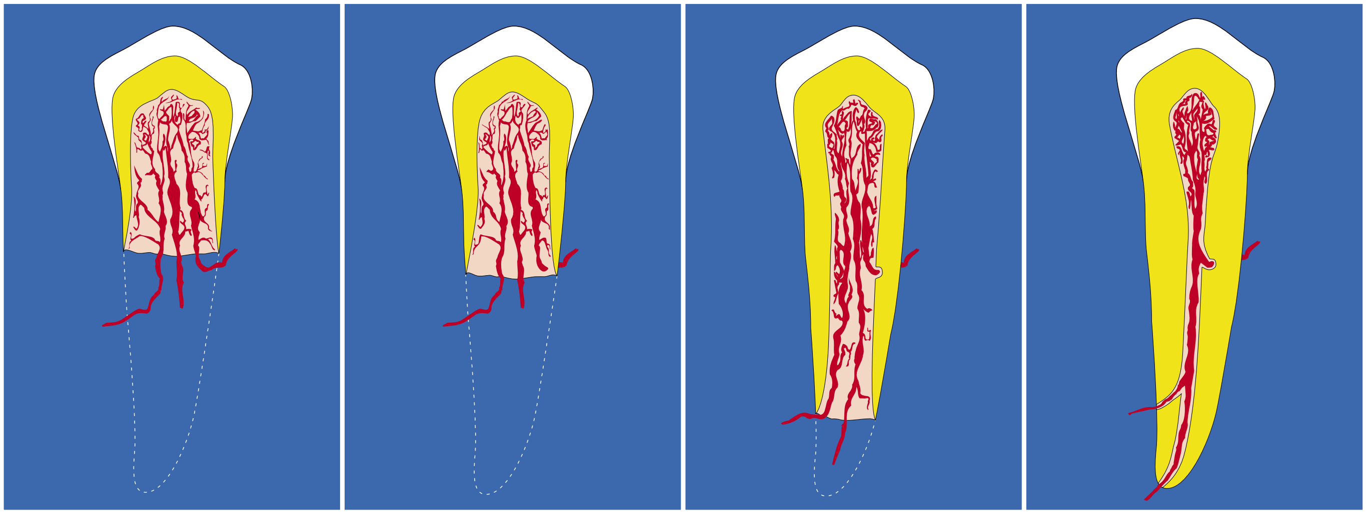
In studies of the vascularization of the developing tooth of the ape, Cutright and Baskar [2] have observed that a plexus of blood vessels develops in the area of the dental sac.

This plexus completely surrounds the enamel organ and the dental papilla.

As the tooth develops, this plexus feeds the enamel organ and sends branches into the developing papilla. Once the enamel has been formed, the plexus in the coronal zone degenerates, while the one which surrounds the root forms the periodontal plexus, which gives origin to the vessels that branch around the foramen and enter (or exit) the apical foramen.

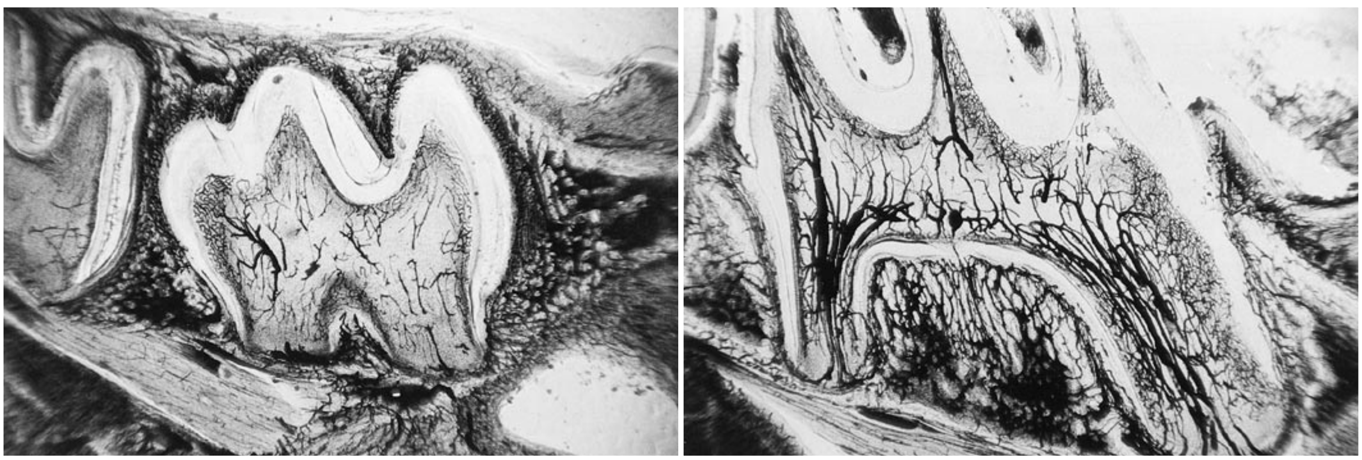
The formation of the lateral canals has been attributed to the entrapment within Hertwig's membrane of vessels of the periodontal plexus that course around and within the apex of the developing tooth (Figs. 2.28, 2.29).

To explain the high incidence of accessory canals near the tip of the root, Cutright and Baskar refer to



A B C D

Fig. 2.28. **A-D**. Schematic diagram of the formation of lateral canals at various root levels (Courtesy of Drs. C.J. Ruddle and M.J. Scianamblo).



A B

Fig. 2.29. **A**. Section of the developing third molar. Root formation has just begun (x25). **B**. Section of the developing third molar. Root formation is almost complete. The pulp and periodontium seem to share the same vascular source. The vessels that traverse accessory foramina in the apical, lateral, and bifurcation areas may be identified (x25). India ink perfusion (From Dr. M.J. Scianamblo, Post-Doctoral Thesis, Harvard University, 1977).

Kovacs' finding that once the tooth enters occlusion the tip of the root grows within the alveolar bone rather than growing outwardly.[6]
According to this theory, each time the vessels of the periodontal plexus are forced to curve apically and then coronally to enter the apex, there is a high probability that they will remain entrapped in Hertwig's root sheath and then be surrounded by dentin. The origin of the accessory canals in the furcation area of multirooted teeth is also attributed to vessels of the periodontal plexus that remain entrapped at points of fusion of the tongue-like extensions of the epithelial diaphragm.
In confirmation, Grove [4] has noted that no lateral canal can be found in the apical one third of immature teeth, while they are found in completely deve-loped teeth. Grove hypothesized that if all the vessels reached the pulp from a position directly opposite the foramen, only a single canal would form. If, instead, the vessels entered the pulp from different angles, multiple openings would develop; thus, an apical delta (Fig. 2.30) or lateral canals (Fig. 2.31) would occur.

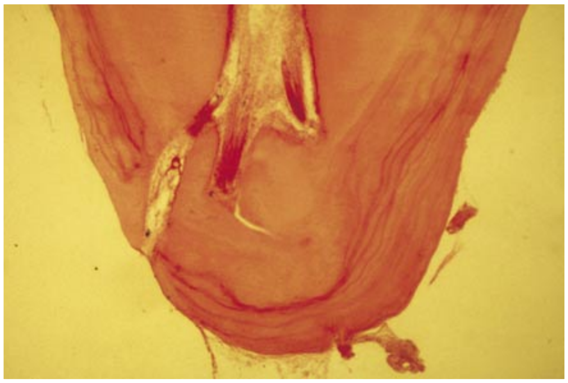


Fig. 2.30. x10. Histologic section of a root showing apical ramifications of the main root canal. (Courtesy of Dr. N. Perrini).

Fig. 2.31. Histologic section of a root showing a lateral canal. (Courtesy of Prof. A. Bloom, Boston University).

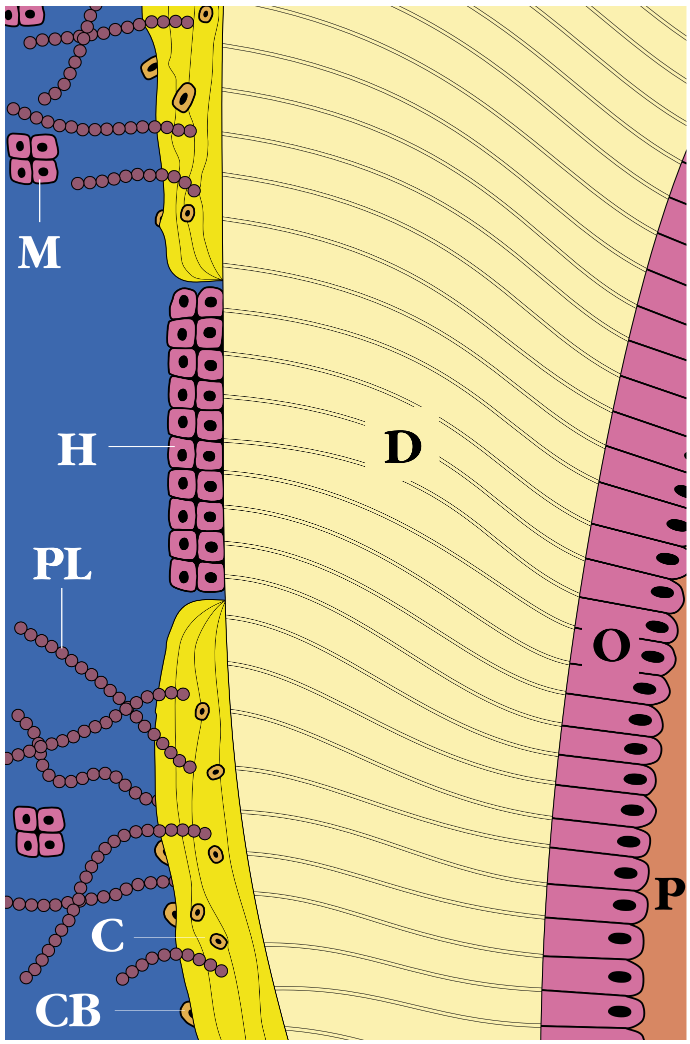


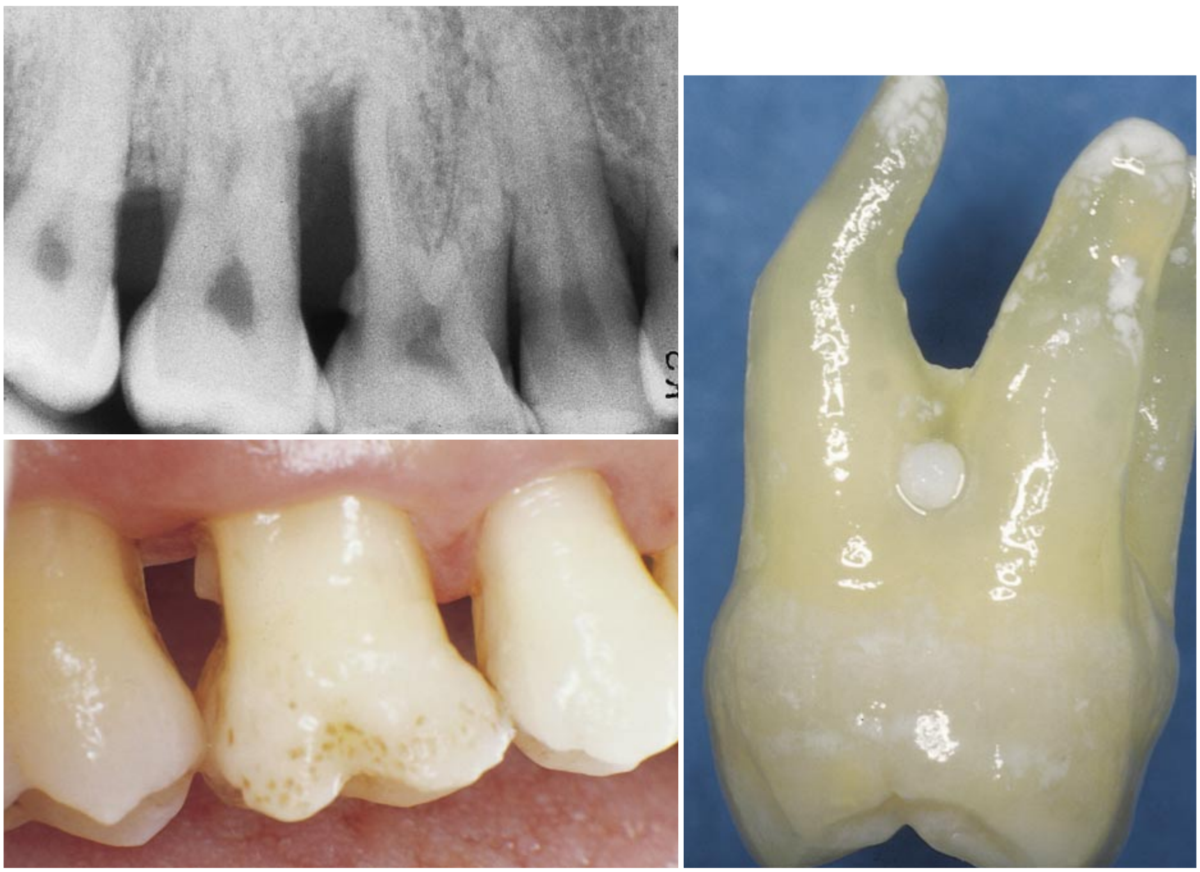
Fig. 2.32. Schematic diagram of the origin of an area of exposed dentin. H, root sheath cells fused to dentin; M, epithelial rests of Malassez; CB, cementoblasts; C, cementum; PL, fibers of the periodontal ligament; D, dentin; O, odontoblasts; P, pulp (Adapted from J.K. Avery).

EXPOSED DENTIN AND ENAMEL PEARLS

If the epithelial cells of the Hertwig's vertical root sheath do not degenerate after the dentin begins to form and remain adherent to the root dentin surface, they impede the differentiation of the cementoblasts and thus the deposition of cementum, since the mesenchymal cells of the dental follicle cannot come into contact with the newly-formed dentin.

This would result in areas of the root being devoid of cementum. These areas of exposed dentin may be found in any area of the root surface, but are particularly frequent in the cervical zone[1] (Fig. 2.32). They can cause cervical sensitivity if afterwards in the course of life, gingival recession occurs, and they can be significant in cases of external resorption after bleaching procedures.

The epithelial cells of Hertwig's vertical root sheath that remain adherent to the dentin can also differentiate into perfectly functional ameloblasts and produce enamel, producing so-called "enamel pearls", which are sometimes found in the furcation area of the permanent molars and are responsible for periodontal defects (Fig. 2.33).



A B C

Fig. 2.33. **A.** An enamel pearl is present on the distal aspect of this upper first molar in the furcation area between the distobuccal and the palatal roots. Note the periodontal involvement. **B.** Clinical aspect of the enamel pearl. (Courtesy of Dr. G. Ricci). **C.** The enamel pearl on an extracted tooth.

FUNCTION AND FATE OF DENTAL LAMINA

The dental lamina of each dental arch gives rise not only to the ten protuberances that through the different stages (bud, cap and bell stage) will finally form the deciduous teeth. During the bell stage, an epithelial proliferation of the dental lamina that develops at the point where it joins the enamel organ (*Gubernaculum dentis*) is already recognizable. It is directed lingually to each deciduous tooth and represents the primordium of the permanent tooth (Fig. 2.34). These buds of permanent teeth are identifiable around the twentieth week in utero by means of the permanent central incisor and around the tenth month after birth by means of the second premolar.[13]

The activity of the dental lamina finally ends with the formation of the primordium of permanent molars, which do not have precursors among the deciduous teeth. These germs form from the distal end of the dental lamina called "accessional dental lamina",[8] distal to the enamel organ of the second deciduous molar. When the jaws have grown long enough, the dental lamina proliferates distally beneath the lining epithelium of the oral mucosa into the mesenchyme.

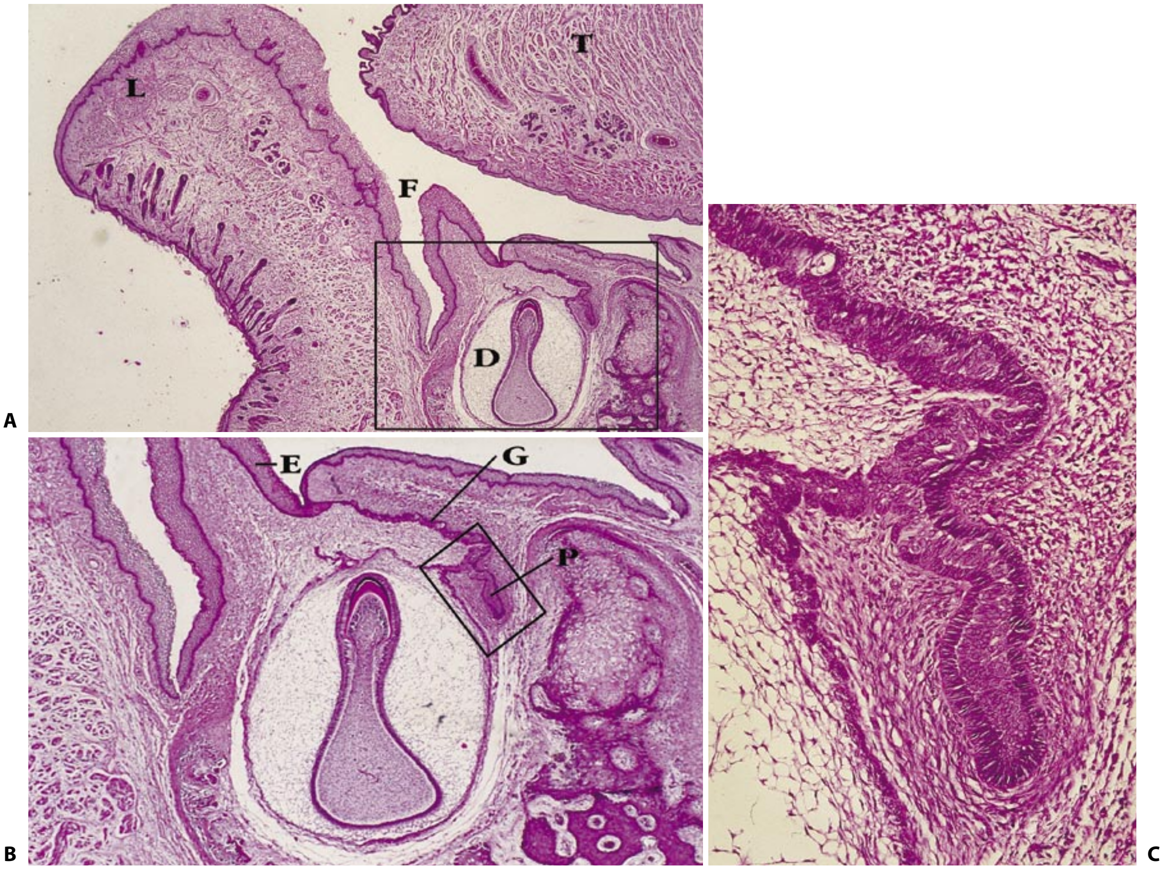


Fig. 2.34. Sagittal section of a human 20-week embrio. **A**. x25. T, tongue; L, lip; F, lingual fornix; D, deciduous tooth germ in the bell stage. **B**. x50. Higher magnification of the framed area in Fig. **A**. Note the lingual position of the primordium of the permanent tooth. E, oral cavity epithelium; G, gubernaculum dentis; P, primordium of the permanent tooth. **C**. x250. Higher magnification of the primordium of the permanent tooth (Courtesy of Prof. A. Bloom, Boston University).

Within this backward extension of the dental lamina, there subsequently occur cellular multiplications that, with the concomitant mesenchymal response, form the tooth germs of the three molars (Fig. 2.35). The germ of the first permanent molar begins to develop around the fourth month of intrauterine life, that of the second permanent molar around the first year of life, and that of the third permanent molar around the fourth or fifth year of life. The entire cycle of the dental lamina, therefore, begins at the sixth week of interauterine life and ends around the fourth or fifth year of life.

Aberrations in this developmental pattern lead either to dental agenesis (Fig. 2.36) or to the formation of supernumerary teeth (Fig. 2.37).

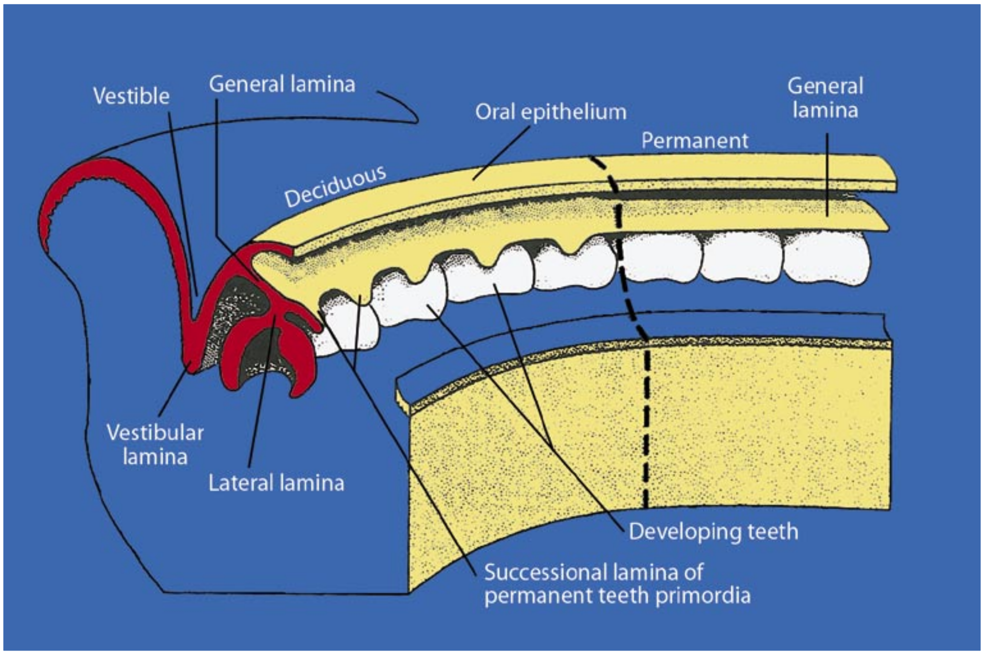


Fig. 2.35. Schematic diagram of the dental lamina and its distal extension in the lower right jaw, seen from the inside. The permanent molars arise directly from the distal extension of the dental lamina which grows backwards underneath the oral epithelium. This part is called the "accessional dental lamina" (Adapted from J.K. Avery).

Fig. 2.36. An example of agenesis of the two upper lateral incisors.

Fig. 2.37. An example of a supernumerary lower premolar.

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3

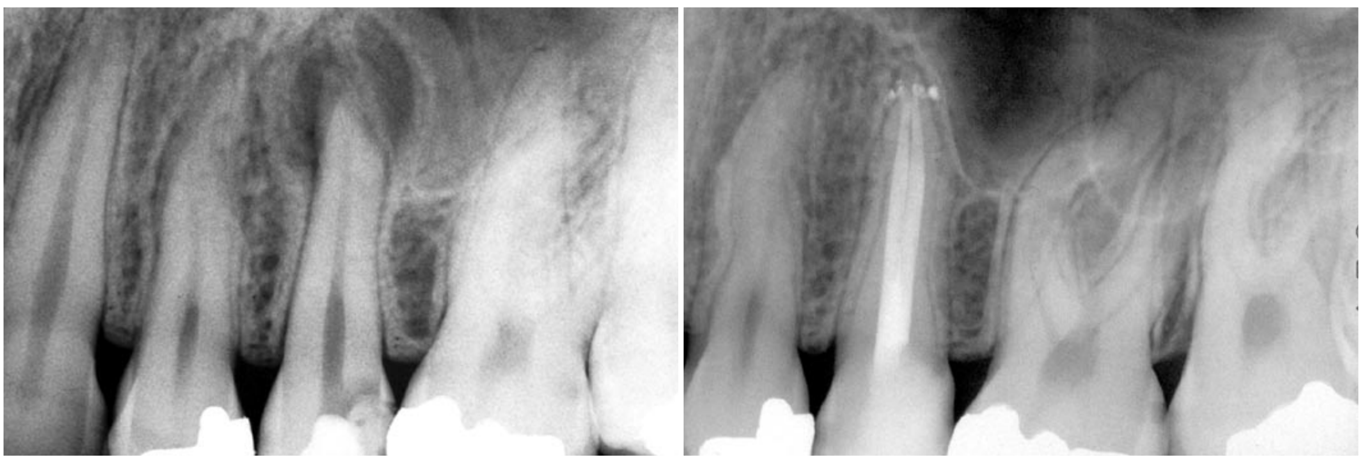
Definition, Scope, and Indications for Endodontic Therapy

Arnaldo Castellucci

Richard Bence[2] defines Endodontics as the specialty of dentistry concerned with the diagnosis and treatment of diseases and injuries of the pulp and periapical tissue. In its 1987 Quality Assurance Guidelines, the American Association of Endodontists defines this field as that branch of dentistry concerned with the morphology, physiology, and pathology of the human dental pulp and periradicular tissues. The scope of endodontic therapy encompasses the following:

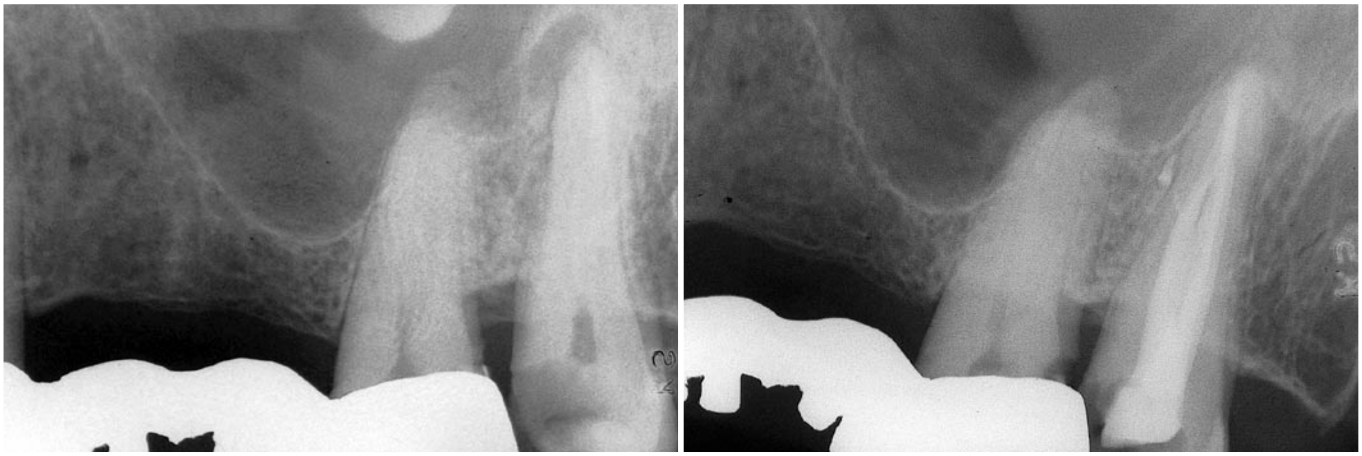
- differential diagnosis and treatment of oral pains of pulp and/or periradicular origin;
- vital pulp therapy, such as pulp capping and pulpotomy;
- root canal therapy, such as pulpectomy, non-surgical treatment of root canal systems with or without periradicular pathosis of pulpal origin, and the obturation of these root canal systems;
- selective surgical removal of pathological tissues resulting from pulpal pathosis;
- intentional replantation and replantation of avulsed teeth;
- surgical removal of tooth structures, such as in apicoectomy, hemisection, and root amputation;
- endodontic implants;
- bleaching of discolored teeth;
- retreatment of teeth previously treated endodontically;
- treatment procedures related to coronal restorations, by means of post and/or cores involving the root canal space.

It is important to note that the term "periapical" has been justly substituted by "periradicular": the diseases that affect the tissues beyond the pulp are not necessarily nor always limited to the zone closest to the apical foramen (Fig. 3.1), but may involve any other part of the root surface (Fig. 3.2), if not indeed the entire surface itself (Fig. 3.3). It suffices to consider the lesions that correspond to the lateral canals, which may be found at any level of the root surface, the combined endo-periodontal lesions, and the lesions that develop following vertical root fracture (Fig. 3.4).



A B

Fig. 3.1. **A.** Preoperative radiograph of the maxillary second premolar with a necrotic pulp and a periapical lesion. **B.** Eighteen-month recall.



A B

Fig. 3.2. **A**. Preoperative radiograph of the maxillary third molar with a necrotic pulp. Two radiolucencies are evident: a larger one in the periapical area and a smaller one on the medial aspect of the middle one third of the root. **B**. Twenty-seven months later. Note that the two radiolucencies have healed. The smaller one was sustained by a lateral canal.

A B

Fig. 3.3. **A**. Preoperative radiograph. Note the endodontic lesion between the first and second molars involving large portions of the radicular surfaces. **B**. Twentyfour months later.

Fig. 3.4. The radiolucency extends along the entire mesial aspect of the distal root. On extraction, the root was found to have a vertical fracture.

BASIC PHASES OF ENDODONTIC THERAPY

As described by Schilder,[30] Weine,[37] Bence,[2] and the entire modern literature, three basic steps of endodontic treatment can be identified: a) the diagnostic phase, in which the cause of the disease is identified and the treatment plan is prepared; b) the preparatory phase, in which, by cleaning and shaping the root canal, the root canal contents are removed and the root canal space itself is shaped to receive a three-dimensional filling; and c) the obturation phase, in which the root canal system is filled with an inert material to ensure a tight seal.

Success in Endodontics depends on following in strict sequence these three steps, which will be discussed in detail below.

INDICATIONS AND CONTRAINDICATIONS

All teeth can be treated successfully endodontically, which means that in theory there are no contraindications to such therapy, as long as the tooth is periodontally sound or can be made so, if its foramen or foramina can be sealed, independent of the approach that is chosen, that is, either the conservative, traditional, or non-surgical one (isolating the tooth with a rubber dam and approaching it by means of the access cavity), or the retrograde, surgical one (raising a flap and performing an apicoectomy with retrofilling)[29] (Fig. 3.5).

Superficially, therefore, it would seem that the only true contraindication might be advanced periodontal disease, aside from two other causes listed by Weine[37] which very often require the extraction of the tooth with a compromised pulp: the inability on the part of the dentist to perform the necessary work properly and the patient's inability to afford the fee of the procedure.

While even in these two circumstances, which represent relative contraindications, something could be done to save the teeth (an honest dentist who recognises his limits in such cases should send the patient to a capable endodontist, while, on the other hand, health insurance should be guaranteed to all citizens in any civilized country), far advanced and untreatable

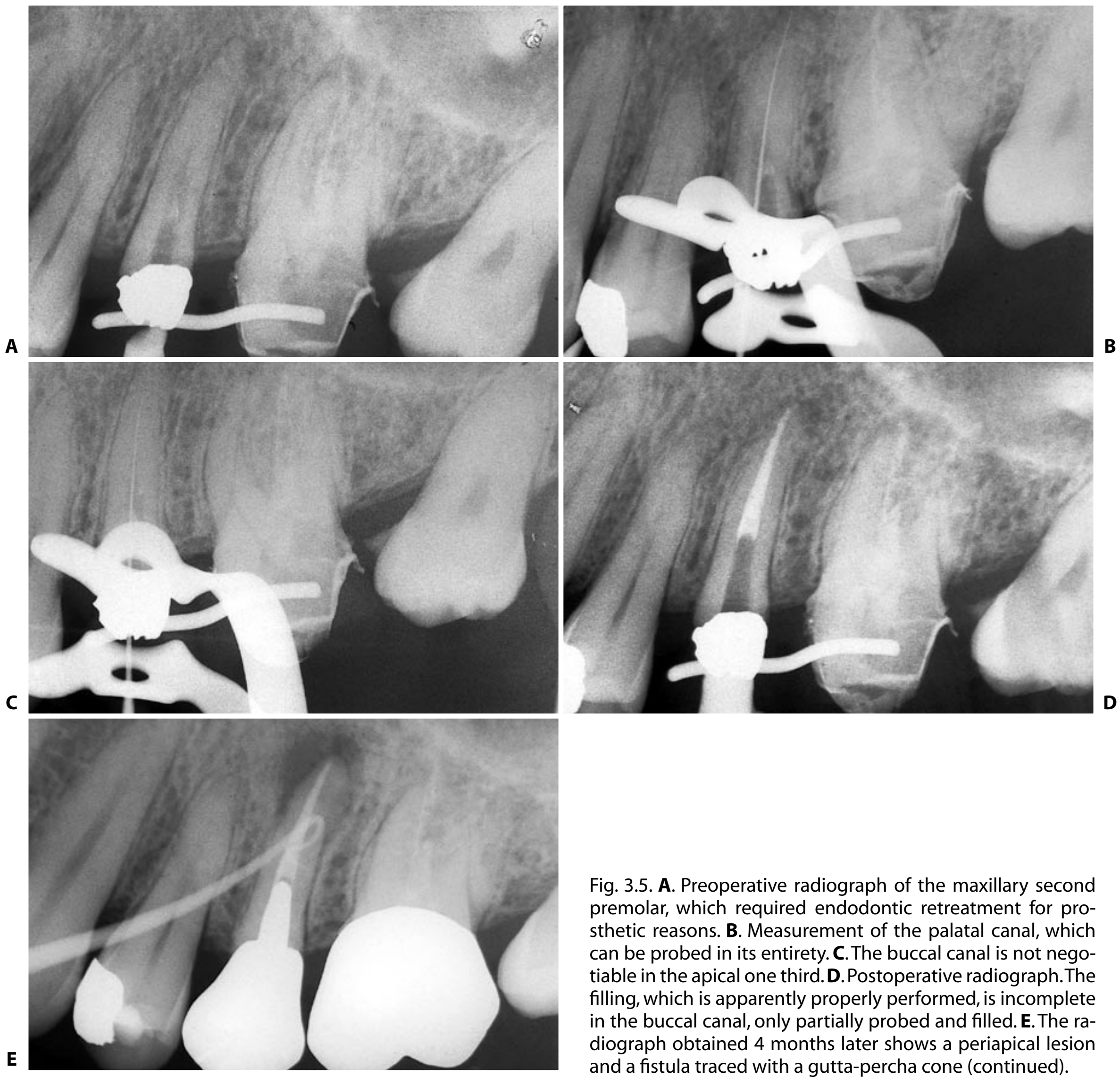
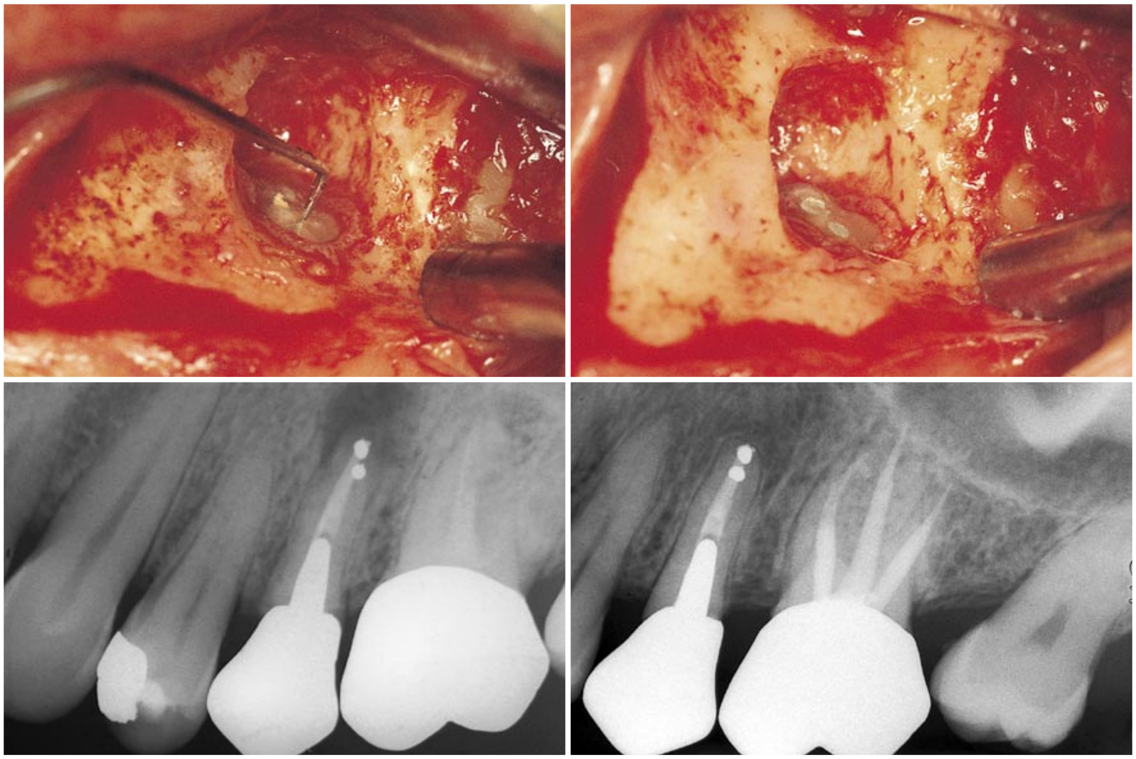


Fig. 3.5. **A**. Preoperative radiograph of the maxillary second premolar, which required endodontic retreatment for prosthetic reasons. **B**. Measurement of the palatal canal, which can be probed in its entirety. **C**. The buccal canal is not negotiable in the apical one third. **D**. Postoperative radiograph. The filling, which is apparently properly performed, is incomplete in the buccal canal, only partially probed and filled. **E**. The radiograph obtained 4 months later shows a periapical lesion and a fistula traced with a gutta-percha cone (continued).



F G H I

Fig. 3.5. (continued) **F**. A flap has been raised, the lesion has been excised, and the apex has been bevelled to allow retrofilling. The probe demonstrates the patency of the buccal canal, which had been left partially untreated. **G**. Two amalgam retrofillings have been made. **H**. Postoperative radiograph. **I**. Healing after 30 months.

periodontal disease is an absolute contraindication. Nevertheless, analyzing the problem further and taking into consideration separately the two therapeutic approaches, non-surgical and surgical, in the former there are some true indications and some contraindications, which may be distinguished as true and false.

True Contraindications

– *Insufficient periodontal support*. In the patient's first visit during the diagnostic phase and treatment planning, an extremely important instrument must never be missing from the "diagnostic tray": the periodontal probe, both straight and for bifurcations (Fig. 3.6). If the tooth has lost too much periodontal support or if it is excessively loose, there is no point in proceeding. The pulp may still be vital and the patient may present because he is sensitive to heat and cold.

  Nonetheless, it is pointless to treat endodontically a tooth than is no longer periodontically salvageable.

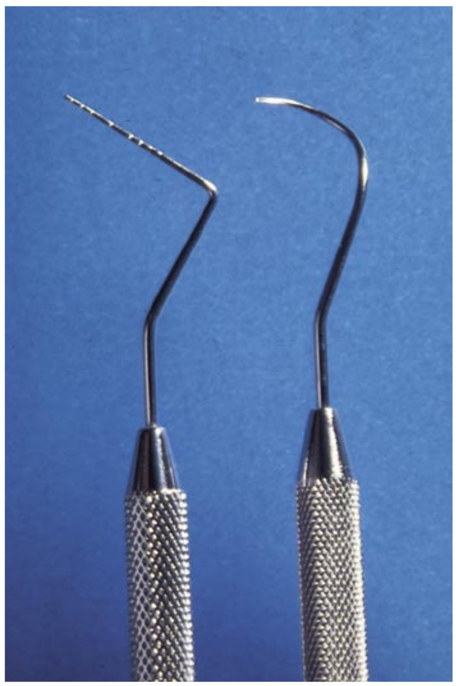


Fig. 3.6. Periodontal probes. Straight (left) and curved for bifurcations (right).

In these cases, tooth extraction is advisable (Fig. 3.7A).

– *Inadequate crown-root ratio*. In some situations, the tooth still has minimal mobility, but the crown-root ratio is so unfavorable that extraction is advisable (Fig. 3.7B).
– *Caries of the root and caries of the bifurcation* (Fig. 3.8). In some cases, teeth with caries of the root or bifurcation can be successfully treated with a combined endodontic, periodontal, and possibly orthodontic therapy. A careful evaluation of certain factors, such as the patient's motivation and the strategic importance of the tooth or of the roots from a prosthetic point of view, but above all the condition of the periodontium of the residual healthy tooth structure (more or less favorable crown-root ratio), will point to one therapy or the other.
– *Internal resorption with perforation* (Fig. 3.9). Extensive internal resorption with perforation may be a contraindication to root canal therapy (Fig. 3.10). However, even extensive internal resorption with perforation can sometimes be treated successfully with calcium hydroxide, as suggested by Frank and Weine.[8] In this case, one would have to keep in mind the fragility of the tooth, of which the patient must also be warned, as well as the possibility of restoring the crown in an adequate and predictable manner.
– *Vertical root fracture* (Fig. 3.4). The only instrument that may be used in this circumstance is the extraction forceps, as there is still no other form of therapy.
With the aim of saving even these teeth, some authors have suggested sophisticated treatments, including circumferential root wiring, "zipper" amalgam implants,[37] and reapposition of the two fragments by screwing.[10]
In any case, they represent desperate attempts destined either to succeed only temporarily or to fail immediately. The diagnosis of vertical fracture of the root will be discussed in detail in the chapter on endodontic-periodontal relationships.

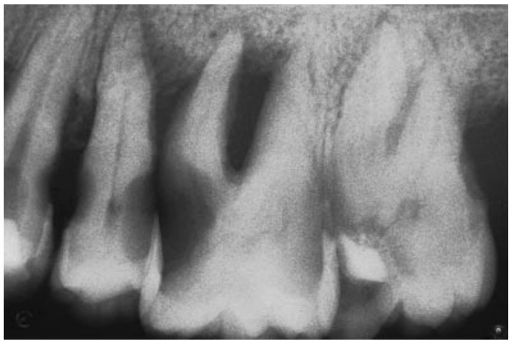
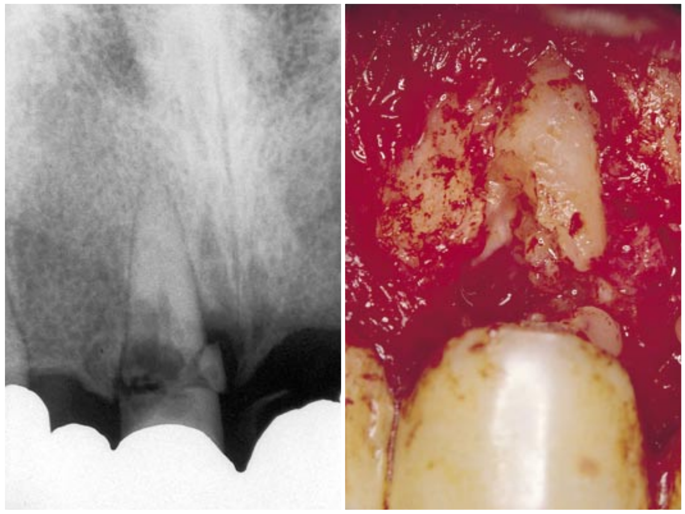

A

B

Fig. 3.7. Inadequate periodontal support and an unfavorable crown-root ratio are contraindications to endodontic treatment of the lateral incisor (**A**) and of the second premolar and first molar (**B**).

Fig. 3.8. Extensive caries of the bifurcation of the mandibular first molar required tooth extraction.

Fig. 3.9. The contraindication to endodontic therapy of the second premolar is obvious in this case.



A B

Fig. 3.10. **A**. Internal resorption with perforation in the maxillary central incisor. **B**. Intraoperative photograph of the radicular defect.

False Contraindications

Some authors consider the following clinical-pathological situations as indications for endodontic surgery and therefore contraindications to conservative therapy. Actually, before undertaking a surgical approach, it is always advisable, if not indeed mandatory, to perform or at least to attempt a conservative, non-surgical therapy. Only in the case of failure should one feel justified in intervening surgically, and the contraindication to nonsurgical endodontics will become an indication for a surgical treatment.

– *The presence of broken instruments*. A fractured instrument can sometimes be removed from the root canal space, allowing a nonsurgical endodontic retreatment (Fig. 3.11). With the use of the surgical operating microscope the removal of broken instruments is a lot easier and more predictable. In other cases, it is only possible to bypass the fragment with fine instruments to clean, shape, and fill the

A  B

Fig. 3.11. **A**. Preoperative radiograph demonstrates the presence of a large fragment of an endodontic instrument (Hedstroem's file) that fractured in the coronal and middle one third of the root of the maxillary first premolar. Radiopaque material is also present in the periapical tissues. **B**. Twenty-four months later: the fractured instrument has been removed, the material beyond the apex has been resorbed, and the periapical lesion has healed.

portion of the root canal situated apically to the tip of the fractured instrument, without however achieving its removal (Fig. 3.12). When a broken instrument is present in the root canal, it is not so important to remove it, even if this would impress the patient, who for his part does not appreciate the idea that a foreign body has been left (sometimes unbeknownst to him) by the preceding dentist.
In such a case, success depends on the possibility to negotiate the apical portion of the canal beyond the broken fragment, to remove the infected contents and then to seal the apical foramina of the root canal system.
If in the course of cleaning and shaping, the broken fragment is dislodged and removed from the canal, so much the better. If not, the small fragment will remain entrapped in the filling material without in any way diminishing the success of the endodontic treatment.
Only when the fractured instrument blocks the access to the more apical portions of the root canal is endodontic surgery indicated. In this case, the sole access to the apex will be through a flap (Fig. 3.13).
The problem of fractured instruments will be more thoroughly discussed in the chapter on retreatment.

– *The presence of califications*. Also in this case, the presence of a very calcified root canal could appear as an indication for a retrofilling. However, surgery is indicated only after attempts for a conservative treatment have failed. Many cases that initially seem untreatable by non-surgical means on radiographic examination, later turn out to be amenable

A B C D

Fig. 3.12. **A**. An instrument has fractured within one of the two root canals of the mesial root. **B**. A # 10 file is bypassing the fragment, which however is not removed from the root canal. **C**. Postoperative radiograph: the fragment is no longer recognizable because it is surrounded by filling material, but it is still present within the root canal. **D**. Twenty-four months later.

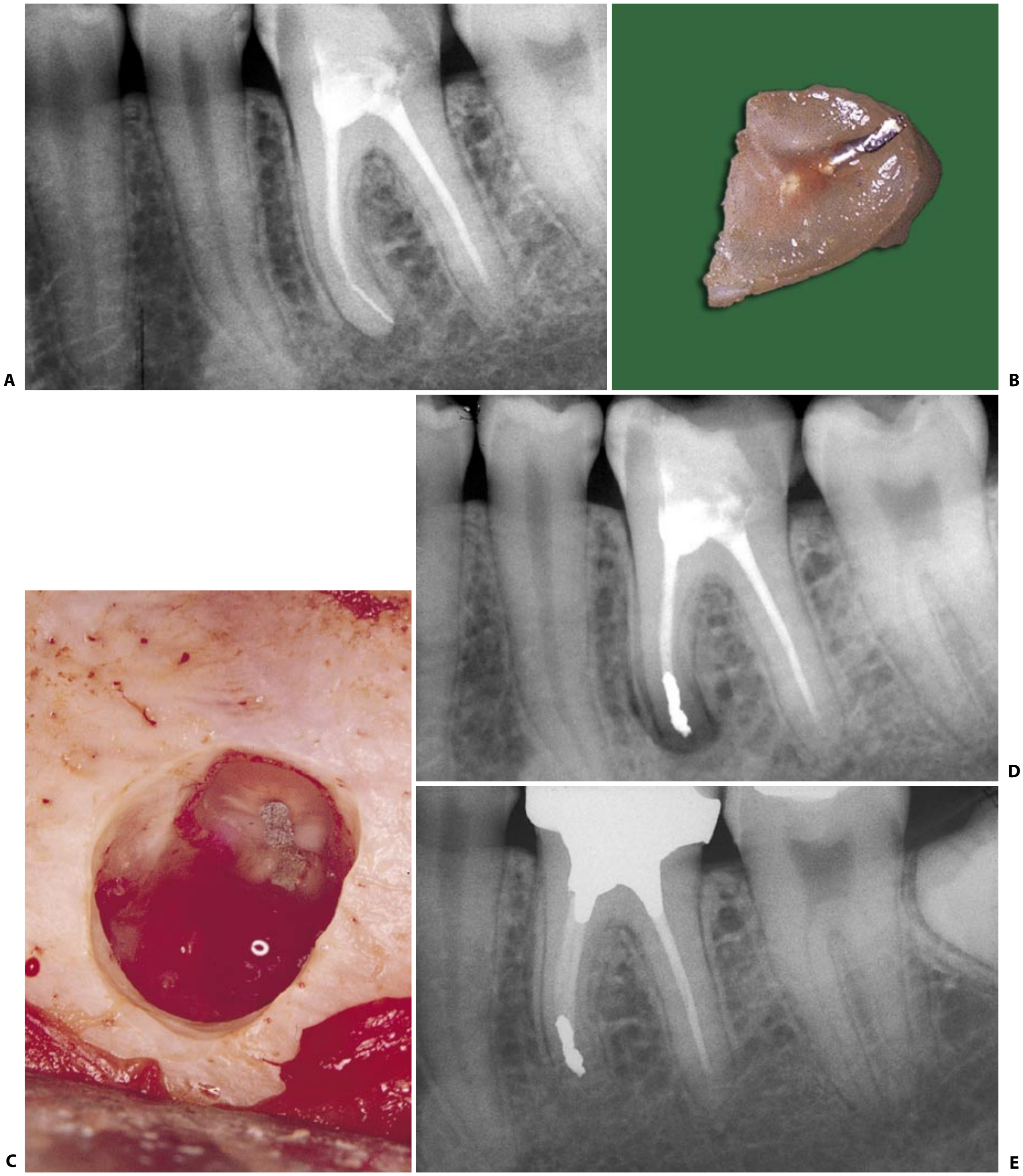


Fig. 3.13. **A**. Preoperative radiograph of the mandibular first molar showing a fragment of a broken instrument at the apex. **B**. Sectioned apex containing a fragment of Hedstroem's file. **C**. The root has been bevelled and the two canals filled with a single amalgam filling. **D**. Postoperative radiograph. **E**. Eighteen months later.

to conventional therapy: the root canals may be negotiated, although not without difficulty (Figs. 3.14, 3.15). The use of the surgical operating microscope is very helpful in finding and negotiating calcified root canals. As it will be discussed later on, the pulp tissue gets inflammed, calcifies, and dies in a coronal-apical direction, therefore even the most calcified root canal is almost always negotiable in the apical one third.

– *Anatomical difficulties*. Highly pronounced curvatures can sometimes discourage the endodontist, so much so that he may recommend retrofilling, possibly even extraction (Fig. 3.16). Indeed, Weine[37] states that, even if canals with pronounced curvatures can sometimes be treated successfully, the best approach is extraction, unless the tooth is of great strategic importance. He claims that such teeth require two or three times the normal working time

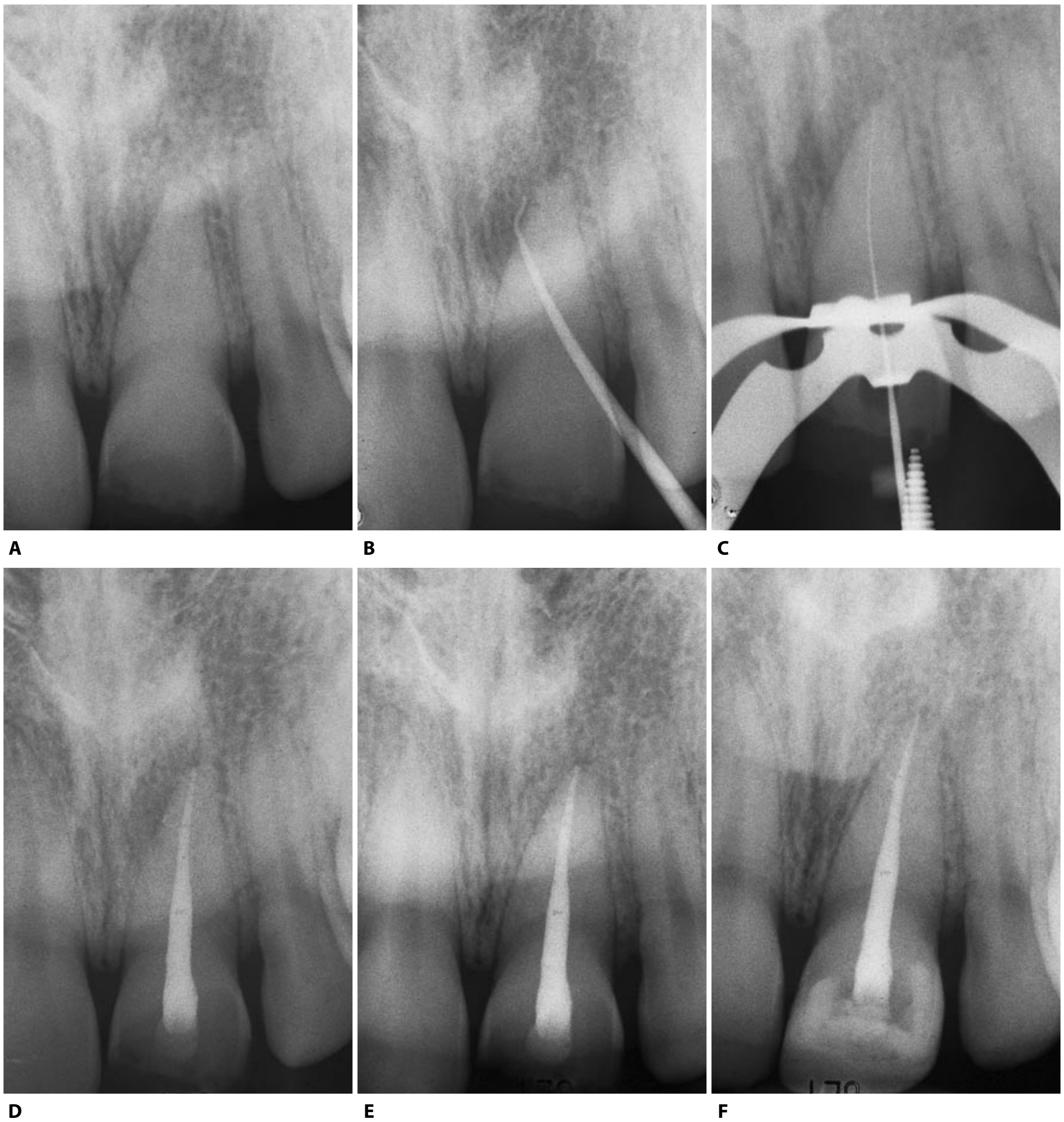


Fig. 3.14. **A**. Preoperative radiograph of a nonvital upper left central incisor. The pulp chamber and the root canal seem to be completely calcified. Note the width of adjacent root canals. **B**. A gutta-percha point has been introduced in the fistulous tract. **C**. Using the surgical operating microscope, the patency of the root canal has been found in the apical one third. **D**. Postoperative radiograph. **E**. Six month recall. **F**. One year recall.

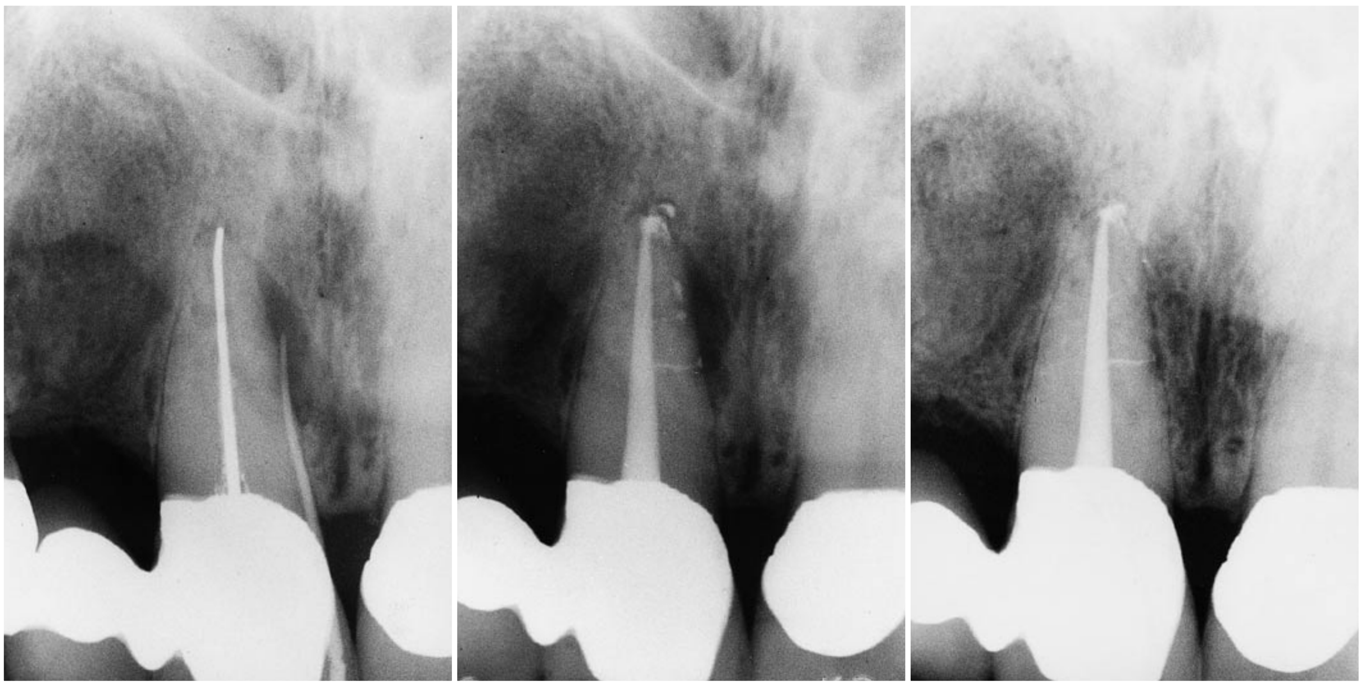
Fig. 3.15. **A**. Preoperative radiograph of the maxillary first molar, from which the mesiobuccal root has just been removed for periodontal reasons. **B**. The access cavity having been created, the rubber dam has been removed so that the clamp would not interfere with the radiographic examination of the canal orifices, which was performed with the help of an endodontic probe. **C**. An 06 file has been introduced in the distobuccal canal after the palatal canal had been found, cleaned and shaped. The rubber dam clamp has been removed to better check radiographically the course of the canal. The instrument handle has been secured with dental floss to the pincers of the patient's bib **D**. The dam has been repositioned and the therapy is completed in the traditional manner. **E**. Postoperative radiograph. **F**. Four-year recall.

Fig. 3.16. First upper molar with an endodontic anatomy that makes the clinical approach extremely difficult.

for enlargement and filling, cause a great deal of frustration, and are frequently treatment failures. In contrast, the same amount of time spent on a prosthetic replacement will usually afford a better final result.

As a matter of fact, one need not be so pessimistic. The motivated patient will appreciate the time spent in treating his or her tooth, especially if, a precise treatment plan having been established, he or she is apprised from the beginning about the difficulty that the case presents. With patience, a good supply of very fine instruments, and a good canal preparation technique, even the most difficult cases can be treated; thus the number of cases will be reduced that on a superficial examination may have been judged untreatable. However, one must recall that "untreatable by conservative means" does not mean "indication for extraction" and thus prosthesis: before using forceps for extracting teeth, it is well to attempt surgical Endodontics.

– *Difficulty of retreatment*. The presence of a silver cone within a root canal, the crown of which is covered by a gold-ceramic prosthesis (Fig. 3.17) does not per se indicate the need for surgical interven-



A B C

Fig. 3.17. Nonsurgical retreatment of the maxillary central incisor, which has already been treated with a silver cone. The mesial radiolucency is a contraindication to the surgical approach. **A**. Preoperative radiograph: a gutta percha cone has been introduced into the fistula and reaches the lesion on the side of the root. **B**. The postoperative radiograph shows that the lesions had been maintained by three lateral canals that had not been filled. **C**. The one-year recall shows the healing (Courtesy of Dr. C. J. Ruddle).

tion. This is especially true if the root has a lateral lesion of endodontic origin, securely supported by the presence of lateral canals that are untreated and difficult, if not impossible, to seal surgically. In such cases, apicoectomy with retrofilling of the main canal is contraindicated. It would lead to certain failure, leaving numerous unsealed portals of exit below. Nonetheless, in such cases a proper treatment plan must consider the opening of an access cavity in the prosthesis, the removal of the old obturating material and the three-dimensional filling of the root canal system, so as to seal all the portals of exit.

– *Size of the lesion*. Many authors, including Harnish,[14] Grossman,[12] and Tay et al.[34] are still convinced that if a lesion is very large it is almost certainly a cyst, and thus cannot heal unless excised in its entirety.
  Indeed, Harnish writes that, given that the distinction between a granuloma and a cyst is extremely difficult on the basis of clinical and radiographic criteria, "it is well to make extensive use of apicoectomy". "The smaller the radiographic image, the more likely it is that the diagnosis of granuloma is correct". In support of his claim, Harnish reports a study by Lalonde[17] which demonstrated that periapical lesions from 0 to 1 cm^2 in area represented granulomas in 70% of cases and cysts in 30%; those from 1 to 2 cm^2 represented granulomas in 40% of cases and cysts in 60%; and 100% of those greater than 2 cm^2 were cysts. "The differential diagnosis between granuloma and cyst is important", continues Harnish, "inasmuch as the treatment of granulomas can be attempted through proper canal treatment. The granuloma, however, containing epithelial tissue that may lead to the formation of apical cysts, is generally considered an indication for intervention (i.e., apicoectomy), since the removal of the epithelium eliminates the possibility that a cyst will form".

Among the indications for apicoectomy, Grossman[12] lists first the extensive destruction of the periapical tissue, bone, or periodontal ligament that involves one-third or more of the root apex, and second the root apex involved in a cystic condition.

Tay et al.[34] have demonstrated that the success of conservative endodontic therapy diminishes with increased size of the periapical lesion.

Contrary to these authors' claims, it can be stated with the support of extensive evidence in the literature and clinical experience based on thousands of cases that the size of the lesion has no bearing on its healing.

Once it has been confirmed that the lesion, large or small, limited to only one apex or involving the apices of adjacent teeth, is a lesion of endodontic origin, it is practically impossible to distinguish between a granuloma and a cyst on the basis of radiography alone,[1,4,13,19,25,26,28,33,36,38] even though the literature may suggest a correlation between increasing lesion size as demonstrated by x-rays and the incidence of cysts.[20] Furthermore, since it has no bearing on therapy, the distinction is practically pointless; its value is only academic and can be confirmed only by electrophoretic [22,23,25] or histological examination.

Even with histologic techniques, however, it is impossible to provide precise statistics, because there are numerous intermediate forms. Thus, if the presence of epithelial cells is used to distinguish between the two, one arrives at the easy conclusion that all lesions are cysts.

The presence of epithelium in periradicular inflammatory lesions is a consistent finding, so much so that it is the rule to find nests of epithelial cells (the epithelial rest of Malassez, which remain after the disappearance of Hertwig's root sheath) in the periodontal ligament of a healthy tooth.

A study by Bhaskar[5] confirmed by Lalonde and Luebke,[18] showed that the percentage of periapical radiolucencies classifiable as cysts is close to 45%. It is logical, therefore, to conclude that many cysts heal after nonsurgical endodontic therapy, since the success rate of clinical endodontics is much higher than just 55%! Furthermore, even though a surgical endodontic procedure is planned, the root canal system has to be three-dimensionally cleaned, shaped, and obturated first any how, therefore the non-surgical therapy has nothing to loose![38]

From a practical point of view, the distinction between a granuloma and a cyst is completely useless, since they are two different histologic aspects of the same lesion. Their (endodontic) etiology is the same, and they require the same (endodontic) therapy (Fig. 3.18).

The endodontist must therefore not be alarmed by the size of the lesion or the presence of epithelium, which will surely always be variably present. Instead, he must focus his attention on the etiology (i.e., whether the lesion is of endodontic origin), since the therapy in either case is the same.

According to Lalonde,[17] the surgical treatment is justified only when conservative endodontic treatment has failed (for reasons independent of the lesion's biology). The purpose of such intervention is to improve the apical seal that had been imperfectly comple-

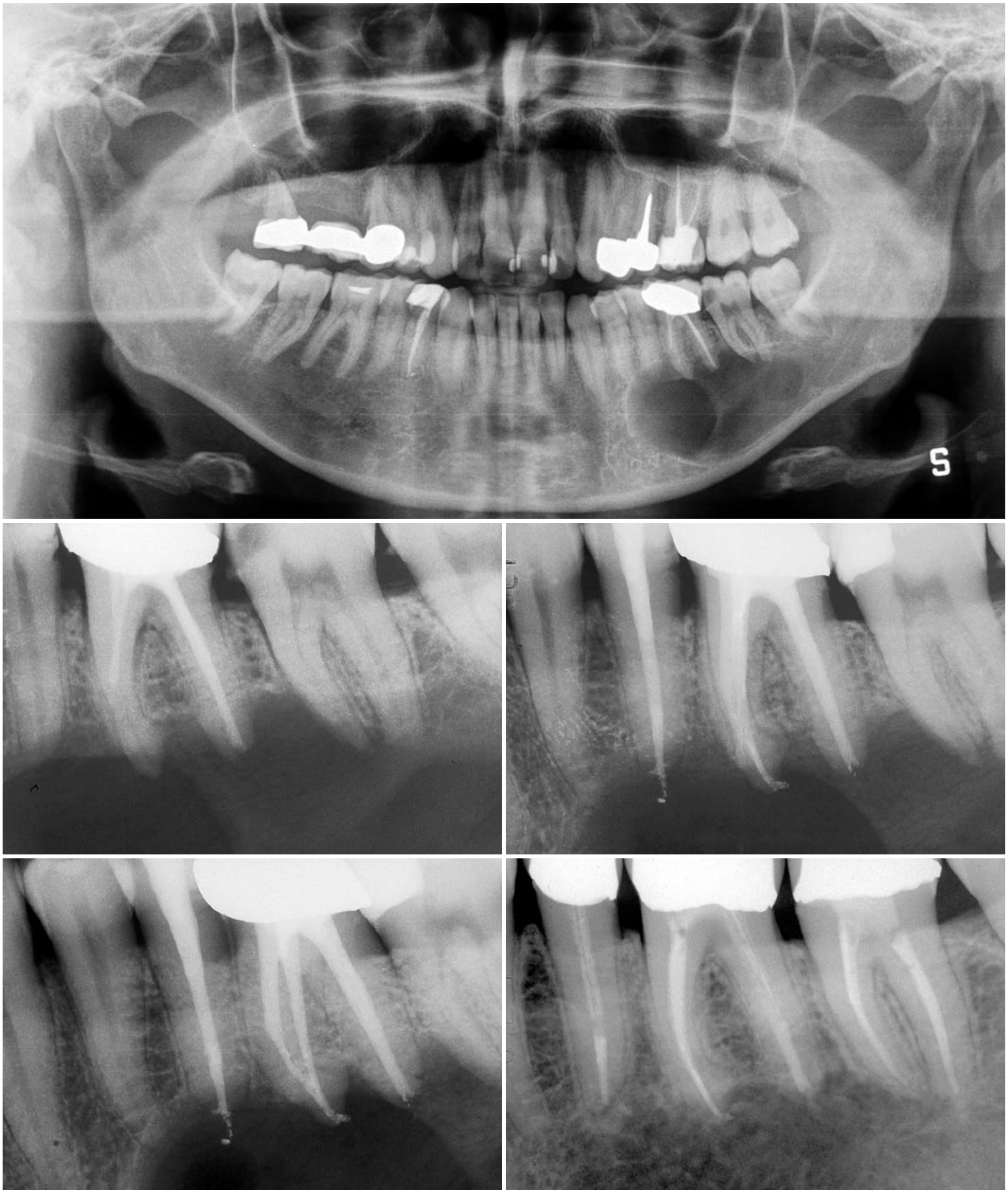


Fig. 3.18. **A**. The panoramic radiograph shows the presence of a large cyst involving several teeth, from the first premolar to the second molar. The first premolar tested vital, the second premolar had a necrotic pulp, the first molar needed a retreatment and the second molar had a pulp exposure. **B**. The preoperative radiograph shows the radiolucency of the lesion. **C**. Postoperative radiograph after nonsurgical treatment. **D**. Another postoperative radiograph with a different angulation shows the root canal anatomy. **E**. 24 months recall. Why do oral surgeons still insist that it is important to remove the cystic wall?

ted by the conservative approach (Fig. 3.19). The large cystic lesion is removed during the intervention, but only partially, for reasons of visibility and surgical access, and it is not necessarily removed in toto, for fear that the lesion will re-form: in this way, one avoids damaging important adjacent anatomical structures (the mental nerve, inferior alveolar nerve, floor of the maxillary sinus, and nasal fossa) and having to devitalize adjacent teeth.[15,26]

Today, most North American oral surgeons concur in not curetting the lesion, since this is considered a malpractice risk.[31]

Another reason why some authors are convinced of the need for surgical removal of cysts is the fear of so-called "residual" cysts. According to these authorities, if the lesion is not excised down to the last epithelial cell, it will re-form, since it has the potential of a self-sustaining lesion.[32]

In 1950, Grossman [11] wrote: "root canal therapy is contraindicated in teeth with a cyst, since the cyst will continue to develop unless its epithelial wall is surgically removed in its entirety". Contradicting this theory is the fact that apical cysts heal spontaneously after conservative endodontic therapy.[6,24]

In the author's opinion, one may accept the theory of residual cysts, but one must keep in mind that their extreme rarity does not justify a surgical intervention in the case of every radiolucency that suggests a cyst. It would be sheer folly to do so in every case.

It remains to be proved that the so-called "residual cysts" are persistent lesions of endodontic origin after dental extraction or following apicoectomy not followed by scrupulous curettage of the alveolar bone. In fact, there are not only odontogenic cysts, but many other pathological varieties that can present as cysts in edentulous zones: it would be too simple to list all such entities as residual cysts (Fig. 3.20).

On the other hand, if a careless curettage were enough to cause the number of residual cysts to increase, one would expect that such lesions would be very frequent, given the widespread "malpractice" everywhere. Fortunately, this is not the case.

Finally, one might be faced with cysts or, even better, with residual infections, but frequently (if not always) such infections are due to the presence of an apical fragment left in the alveolus after an extraction perfor-

A B C D

Fig. 3.19. **A**. Preoperative radiograph of the maxillary central incisor, which has been previously treated endodontically. A large, probably cystic lesion, possibly sustained by the irritant matieral beyond the apex, is present. **B**. Postoperative radiograph after nonsurgical retreatment. **C**. Postoperative radiograph following apicoectomy with retrofilling, performed because of persistent symptoms. In the course of the procedure, performed only to improve the apical seal and remove the irritant material, the cystic wall has been *intentionally* left in place, so as not to compromise the vitality of the adjacent tooth. **D**. Four years later. The vitality of the cuspid has been preserved. The radiolucency between the two apices does not indicate treatment failure, but rather represents healing with an *apical scar*, a typical outcome of the treatment, nonsurgical or surgical, of large lesions.

med hurriedly, rather than to a careless apical curettage (Fig. 3.21).
Alternatively, they may be due to the presence of a concretion of tartar that has fallen into the bleeding alveolus during tooth extraction, or to the presence of a bony sequestrum.
That which is left behind in these cases is not so much the epithelium that covers the lesion, so much as a closed system containing bacteria and toxins. Because it is impenetrable to the organism's defense mechanisms, the pathogens continue their pathogenic action undisturbed. One must therefore conclude that the lesions named as "residual cysts" are lesions of unknown etiology.

Fig. 3.20. **A**. Mandibular first premolar during apexification. **B**. Six months later, a cyst is developing in the adjacent zone which is edentulous for the agenesis of the second premolar. **C**. Nineteen months later the cyst is still growing. **D**. Two years later, the cyst has reached a considerable size. **E**. Healing one year after surgical excision of the cyst. A histological examination confirmed that it was a keratocyst in a patient with Gorlin's syndrome. **F**. Three year recall.

A B C D

Fig. 3.21. **A**. The preoperative radiograph of the mandibular second molar shows the presence of a "residual infection" in the zone in which one year prior a necrotic first molar had been extracted. **B**. A radiograph of the apical area shows that the entire mesial root has fractured during the extraction and then was forgotten in the alveolus. It is evident what this infection is a "residual" of. **C**. Radiograph following surgical root extraction. **D**. Healing of the lesion two years later.

True Indications

Apart from the true contraindications discussed above, all teeth that have pulp and/or periradicular pathology are excellent candidates for endodontic treatment.[2,37] Furthermore, root canal therapy is indicated in many other situations that in the literature are described as contraindications on account of the general condition of the patient:

– *Age*. There are no age limits for this type of therapy. If even the youngest baby cooperates, either spontaneously or by sedation, he is an optimal patient.

  The elderly patient can be treated like any other patient, as long as one keeps in mind that his root canals are thinner because of the deposition of secondary dentin; thus, probing can be difficult. In addition, the healing process is slightly slower in comparison with young patients.

– *The patient's general state of health*. Very frequently, one hears that the gravely ill patient cannot undergo endodontic therapy. In fact, the contrary is true: it is much easier and safer for the patient to undergo endodontic treatment than a dental extraction. For example, one does not run any risk in treating a patient with a history of rheumatic fever, since such a patient can be given antibiotic prophylaxis.[3] Extraction, in contrast, leads to much greater bacteremia.[7,27]

  Patients with heart disease may be treated without concern. Many endodontic treatments may be done without anesthesia, and when it is necessary it may be used without a vasoconstrictor. As long as their disease is well-controlled, diabetic patients respond well to therapy, although they heal more slowly. There is no reason not to perform endodontic treatment on a patient with leukemia or terminal cancer. Such patients should live their last months of life without toothaches. For them, as for patients with hemophilia or hemorrhagic purpura, it is undoubtedly less traumatic to undergo a root canal treatment than an extraction.

– *Pregnancy*. Postponing treatment to at least the second trimester is advisable. Is is inadvisable to perform it during the first, both because the patient cannot receive radiation, and because this is the most delicate period, during which the highest percentage of abortions occurs, and it would be very unpleasant to be unjustly blamed for a miscarriage by the patient, who may have had to interrupt the pregnancy for other reasons.

If a toothache arises during the first trimester, it is advisable to temporize with medications, use anesthetics without a vasoconstrictor, and avoid radiography for canal measurements, possibly making use of electronic apex locators.
There are no contraindications to root canal therapy in the last trimester,[16] as long as the patient can sit for an extended period of time in the dental chair. Nonetheless, the author prefers to postpone everything until the patient has carried the pregnancy to its end, especially for medico-legal considerations (see Chapter 5).

This is the case when a tooth requires a post to give more retention to the reconstruction. It is the case when "overdentures"[20] are anchored to teeth, or when roots are treated and retained only under complete dentures with the sole aim of not resorbing the alveolar crests. Finally, it is the case when teeth are prophylactically treated by endodontic means to prevent certain pulp compromise following prosthetic preparation (Fig. 3.22), or when a root must be removed for periodontal reasons. These are all cases of so-called "strategic Endodontics" (Figs. 3.23-3.27).

Strategic Endodontics

Frequently, endodontic therapy may also be necessary in teeth that have no pulp or periradicular compromise.

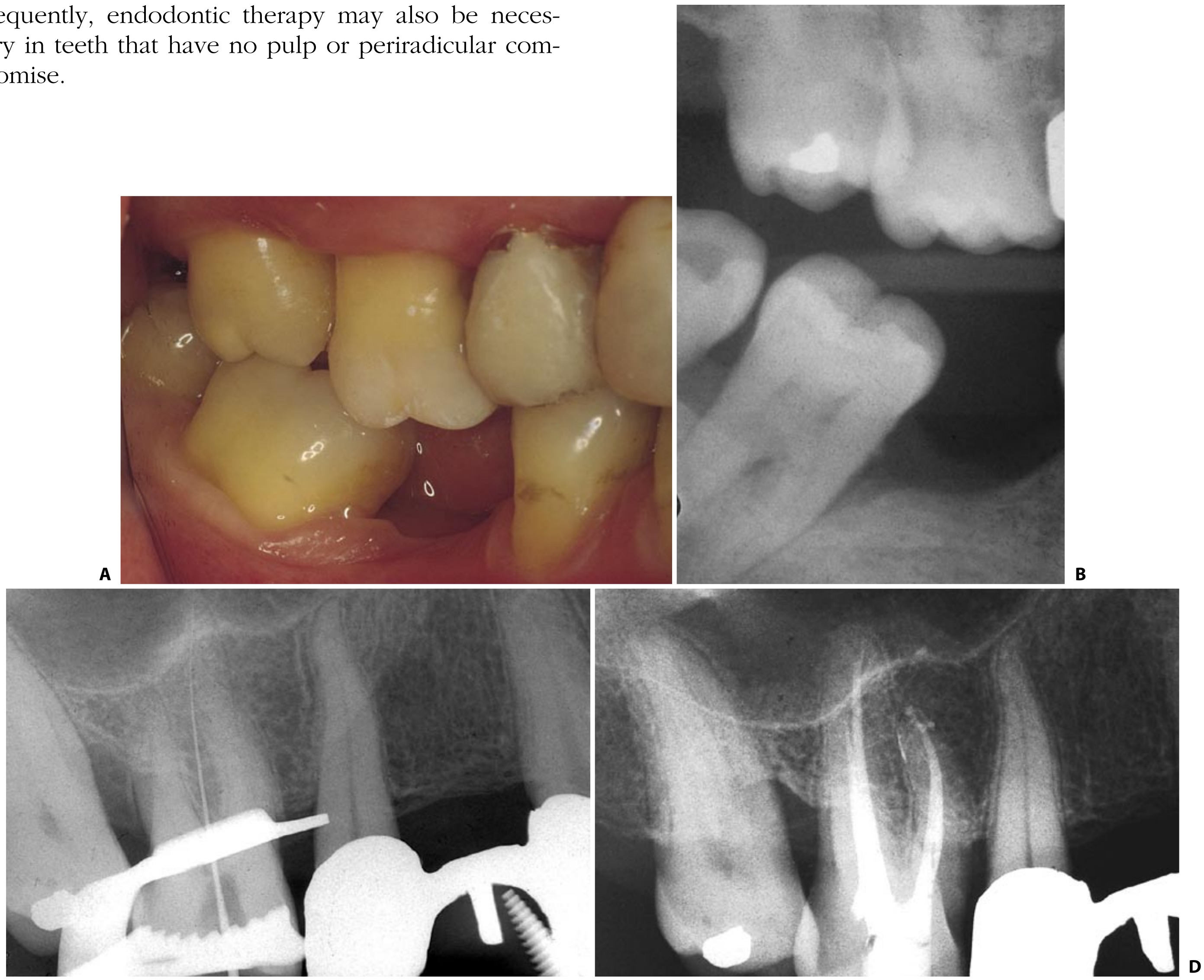
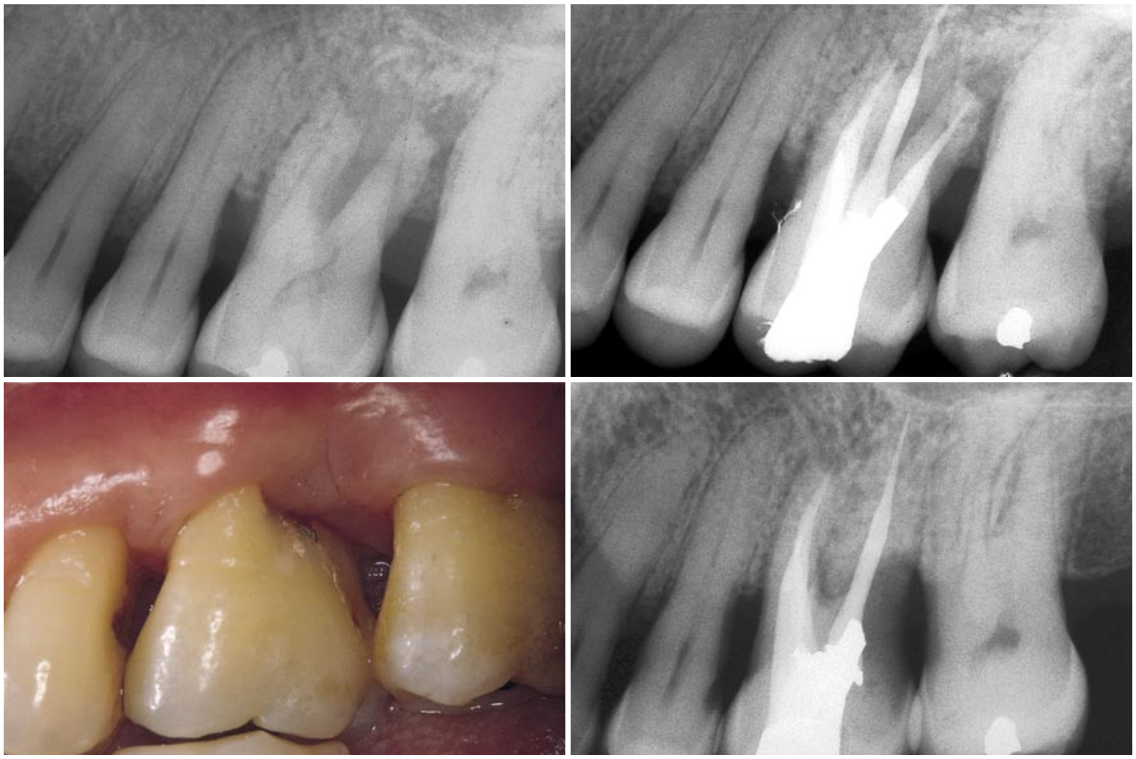


Fig. 3.22. **A.** The maxillary first molar, because of its significant extrusion, must be treated endodontically before prosthetic treatment. **B.** Bitewing radiograph. **C.** Intraoperative radiograph. **D.** Postoperative radiograph.



A B C D

Fig. 3.23. **A**. Preoperative radiograph of the maxillary first molar. The tooth must undergo amputation of the distobuccal root for periodontal reasons and therefore must first be treated endodontically. **B**. Postoperative radiograph. The access cavity has been obturated with amalgam and a pit has been made in the root, which must be amputated. **C, D**. Clinical and radiographic appearance two years later.

A B C D

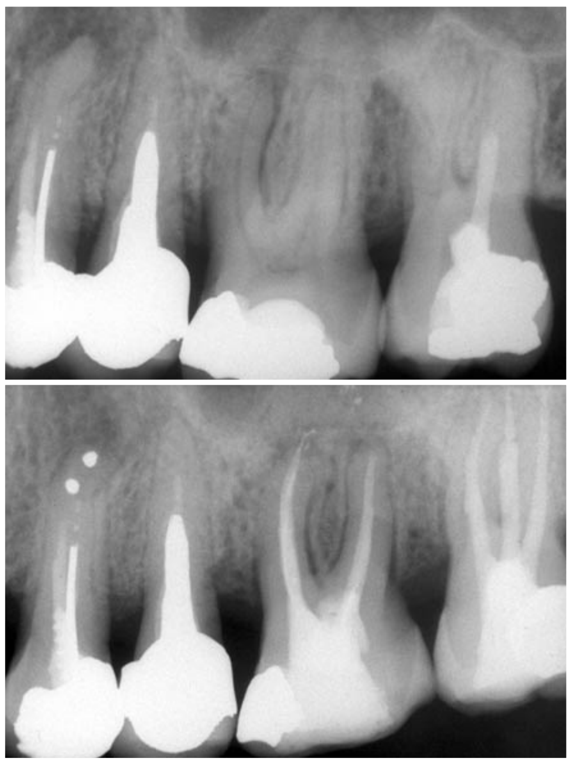
Fig. 3.24. **A**. Preoperative radiograph of a mandibular first molar with severe periodontal disease. **B**. During the periodontal procedure, it is decided to amputate the mesial root. **C**. Postoperative radiograph after endodontic therapy. **D**. Eighteen-month recall.

A B C D

Fig. 3.25. **A**. Preoperative radiograph of a lower left first molar, with furcation involvement of periodontal origin. The molar has to be bicuspidized, therefore it has to be treated endodontically first. **B**. Post-operative radiograph. **C**. Fourteen month recall. **D**. Four year recall.

A B

Fig. 3.26. **A**. Preoperative radiograph. The lower first molar has a furcation involvement of periodontal origin and needs to be endodontically treated in order to be bicuspized. **B**. 16 month recall.



A B

Fig. 3.27. The palatal root of this first upper molar has to be removed, therefore the tooth needs to be endodontically treated. **A**. Preoperative radiograph. **B**. 12 month recall.

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4

Diagnosis in Endodontics

ARNALDO CASTELLUCCI

As already stated, the first step in properly performing therapy is making an accurate diagnosis, in order to prepare an adequate treatment plan.
The dentist must collect some data from the patient and simultaneously perform numerous tests and examinations. By combining the subjective and objective information, one can arrive at the correct diagnosis.

SUBJECTIVE INFORMATION

Medical history

Although practically speaking there are no systemic contraindications to endodontic treatment, one must nonetheless ask the patient to complete and sign a short, updated, and comprehensive form (Tab. I) that provides the dentist with information about the general medical status of the patient.[6] Apart from its medico-legal importance, it is important because it may influence the therapy to some degree.
For instance, if the patient had a prosthetic heart valve replacement, a history of rheumatic fever, or a malignancy requiring chemotherapy or radiotherapy, the endodontic treatment will have to be performed with antibiotic prophylaxis.
In other cases, such as patients with hepatitis, herpes, or AIDS, it is not only the patient who must be protected from infections, but also the dentist and the staff. In such cases, the dentist and the assistants are urged to protect themselves with rubber gloves, face masks, and protective eye shields, which on the other hand is advisable to use routinely.
If the patient is under treatment for other reasons and there is concern regarding drug interactions or if one needs information that the patient is unable to provide, it is always prudent to consult with the patient's physician.

Dental history

Frequently, patients spontaneously offer their dental complaints; in other cases, the dentist must guide them by asking precise questions and listening carefully to their answers.
The aim of the dental history is to determine:
– why the patient has sought the attention of a dentist;
– whether he has recently had any dental treatment that may influence the condition of the pulp;
– when the problem began;
– whether there are factors that positively or negatively influence his presenting complaint, such as heat, cold, pressure, or mastication;
– the frequency of the problem;
– whether there is pain; and if so, its location (whether the patient can identify the area of the responsible tooth, or whether the pain is diffuse), its origin (spontaneous or provoked), its reproducibility (whether the symptoms can be reproduced), its character (sharp, dull, lingering, or throbbing), its duration (continuous or intermittent), and whether it is postural (whether the pain occurs in the evening, when the patient is recumbent).

The dentist must carefully consider all the information that the patient provides, since this information alone sometimes suffices to formulate a general diagnosis, even before collecting objective information and performing other tests. However, the diagnosis must be confirmed with other tests.
On the other hand, the dentist must on occasion sift through a mountain of information that the patient sometimes provides. He must not overvalue such data, especially if the patient recounts as his present complaint a variety of symptoms that have occurred over the course of weeks or months. With some exceptions, certain symptoms cannot coexist, and thus the

Last Name____________________ First Name ____________________

Date of Birth __________ City of Birth ____________________ State __________

Home Address____________________ Telephone__________

Profession______________________________

Work Address____________________ Telephone__________

Referred by ______________________________

Address____________________ Telephone__________

Medical-Endodontic History

1) Are you under the care of a physician for a medical condition? Yes ☐ No ☐
   If yes, please specify ____________________
2) Have you been hospitalized in the last twelve months? Yes ☐ No ☐
3) Do you take any medications? Yes ☐ No ☐
   If yes, please specify ____________________
4) Are you allergic to any medication, such a penicillin, novocaine, codeine, adrenaline, or aspirin? Yes ☐ No ☐
   If yes, specify ____________________
5) Have you ever had any of the following diseases: Yes ☐ No ☐
   ☐ tuberculosis ☐ hepatitis ☐ heart attack ☐ epilepsy
   ☐ rheumatic fever ☐ angina ☐ hypertension ☐ diabetes
   ☐ bleeding disorder ☐ other? ____________________
6) Do you smoke? Yes ☐ No ☐
7) Do you have a toothache? Yes ☐ No ☐
8) Can you identify the tooth responsible of your pain? Yes ☐ No ☐
9) Underline the following causes of pain:
   ☐ heat ☐ cold ☐ sweet ☐ pressure.
10) When did the pain or swelling begin?____________________
11) Have you had an accident involving the teeth? Yes ☐ No ☐
    When? ____________________
12) Are you pregnant? Yes ☐ No ☐
    If yes, how many months?____________________

Root canal or devitalization therapy consists in the treatment of a tooth that otherwise would be extracted.
To be well performed, it must be done in a careful manner, so several intraoperative radiographs will be required.
Although root canal therapy has a very high success rate (close to 100%, as in perhaps no other medical or surgical therapy), it cannot be guaranteed. Rarely, a tooth that has undergone root canal therapy may require retreatment, surgical treatment such as apicoectomy, or even extraction. It is therefore very important to check the endodontically treated teeth periodically with radiographic and clinical examinations. Once the treatment is finished, it will be necessary to undergo at least four check-ups six months apart at no charge, since they are included in the treatment.

Date__________ Signature____________________

Table I. Example of a form to be completed and signed by the patient regarding his medical and endodontic history.

patient may, without realizing it, confuse the dentist rather than enlightening him or directing him toward the correct diagnosis. It is the dentist's responsibility to distinguish important symptoms from negligible or remote ones and to investigate further the recent dental history, without being misled by the past dental history. If a patient comes to the office indicating as the cause of his problem an obviously carious tooth, hopefully the only one affected by caries in that hemiarch, there is no need to linger on the dental history. Rather, it is preferable to use this time to eliminate the patient's suffering.

OBJECTIVE INFORMATION

Examination

The first quality to assess is facial symmetry. Asymmetry might indicate edema of dental origin or the consequence of trauma. During the external inspection, cutaneous fistulae are sought.

With the help of a dental mirror and a probe, an intraoral examination of the soft and hard tissues follows the extraoral inspection.

In examining the soft tissues, one must search for leukoplakia, precancerous or cancerous lesions of the oral cavity, fistulae, swelling or erythema, scars, and evidence of prior periapical surgery (Fig. 4.1). The pa-

A B C D E F

Fig. 4.1. **A** and **B**. Allergy to amalgam evident on the tongue and the lip. **C**. This lesion has been caused by the repeated biting of the lip by the patient, anesthetized with the inferior alveolar block. **D**. Osseous sequestrum, caused by the accidental injection of a carpule of chloroform (Courtesy of Dr. R. Becciani). **E**. Lesion at the labial commissure caused by incorrect use of laser (Courtesy of Dr. J. Colasanti). **F**. Scar of a previous periapical surgery.

tient's oral hygiene and the integrity of his dentition must also be assessed. Poor oral hygiene in a mouth with many missing teeth testifies to a patient who very likely will not appreciate the dentist's therapeutic efforts and thus does not deserve them. He will not know how to maintain in a state of good health the tooth that he asks the dentist to treat. A question that occasionally is worth asking oneself is: "If the patients don't care about their teeth, why should I care for them?" Nevertheless, it is the dentist's implicit responsibility to undertake every effort to motivate that patient.

In examining the hard tissues, after the assistant has dried the dental crowns with the help of a surgical aspirator, one searches for caries with the help of a small, sharp probe, and one checks for discoloration of the dental crowns, the condition of prior dental work, and the presence of cracks or fractures.

If one suspects a periodontal or a mixed periodontal-endodontic lesion, it is also necessary at this point to perform a careful examination with the help of periodontal probes, the straight probe for vertical defects and the curved one for horizontal bifurcation defects.

Percussion

The percussion test determines the presence of inflammation in the periodontal ligament, but gives no information about the state of health of the pulp. Percussion stimulates the proprioceptors of the periodontal ligament. The test can be used to diagnose an acute apical periodontitis, the consequence of pulp inflammation or result of occlusal trauma or periodontal disease.

Percussion is first performed gently with the right index finger (Fig. 4.2) (always beginning with the least suspect tooth so as not to frighten the patient), and then percuss the occlusal, buccal, and lingual surfaces with the handle of the dental mirror (Fig. 4.3). Gentle percussion of a tooth affected by an inflammatory process in the periodontal ligament will cause pain to the patient, while the dentist can appreciate the "cracked" sound arising from it.[34] A positive response to the percussion test is a sure sign of an inflammatory process involving the periodontal space, probably of endodontic origin. A negative response, on the other hand, is not a definite sign of good health, because chronic periapical inflammation is asymptomatic.

The percussion test is contraindicated when a crack and especially a coronal fracture is suspected (see Cracked Tooth Syndrome).

Fig. 4.3. Percussion test performed with the handle of the mirror.

Palpation

Palpation consists of the application of light digital pressure on the soft tissues of the oral cavity (Fig. 4.4). The right index finger is usually employed. Using a glove, it is lightly applied to the suspect area with a rolling motion. In this way, painful areas can be iden-

Fig. 4.2. Percussion test performed gently with the index finger.

Fig. 4.4. Palpation test.

tified because of the spread of inflammation from the periodontal ligament to the overlying periostium.
The test is most effective when it is performed simultaneously on the controlateral tooth for the purpose of comparison.[20]
This manoeuvre can help reveal apical periodontitis in the earliest phase. It is useful in delineating the limits of the inflamed and swollen area (e.g., an acute alveolar abscess) and then localizing the point in which to insert the scalpel for incision and drainage of the purulent exudate. In the case of an abscess, it may furthermore be useful to perform a bimanual examination using the two index fingers, to assess whether the underlying swelling is soft and fluctuant (Fig. 4.5).*

Fig. 4.5. Bimanual palpation to ascertain the fluctuance of the purulent exudate.

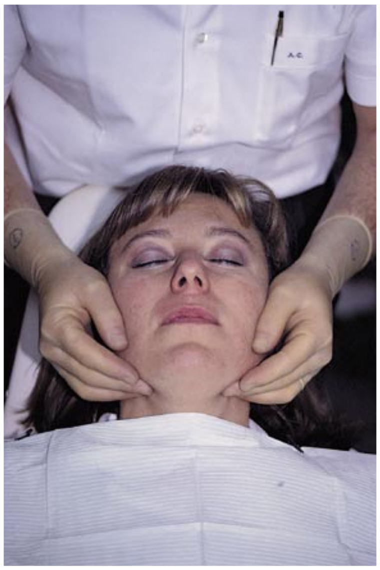


Fig. 4.6. Bimanual palpation to explore the submandibular lymph nodes.

Bimanual examination is also performed to investigate the condition of the submandibular or cervical lymph nodes (Fig. 4.6).
Finally, palpation can provide information about the mobility of the teeth and the presence of an apical fenestration or an alveolar fracture.

Radiographic examination

Radiographs are of fundamental importance for endodontic diagnosis. The dentist who tries to make a diagnosis without the support of a radiographic examination is like a blind man groping in the dark. One must nevertheless remember that radiography is a two dimensional representation of an object that exists in three dimensions. There is always the risk of an erroneous interpretation; hence, it must not be used as the sole diagnostic tool, but only in association with others. Furthermore, when examining multirooted teeth, it is always advisable to have at least three radiographs taken with different angulations. Obviously, radiography is of no help in assessing the vitality of pulp tissue. For example, a necrotic tooth will not cause apical radiographic abnormalities until the periapical pathology has destroyed the osseous trabeculae at their point of union with the cortical bone.[3,4,24,26,29] In spite of this the information radiography provides is substantial. This includes:
– the presence and extent of carious lesions
– the vicinity of dental restorations to the pulp tissues
– pulp caps
– pulpotomies
– pulp calcifications
– canal calcifications
– root resorptions
– periradicular radiolucencies (if there is a large radiolucency, it is necessary to take another radiograph that shows the entire limits of the defect)
– the origin of a fistulous tract (by introducing a contrast medium into the fistula, such as a gutta-percha cone)
– radicular fractures
– thickness of the periodontal ligament
– periodontal disease
– number of roots (following the outlines of the lamina dura) and canals
– the width of the pulp cavity
– the approximate length of the roots

(*) Fluctuance, from the Latin *fluctuo*, wave, refers to the wave-like movement of a liquid entrapped in a soft-walled space when light pressure is applied to one point of the wall, so that the finger applied at another point perceives a movement.[10]

– the thickness of the dentinal walls
– the degree of radicular curvature (if the curve lies on a mesiodistal plane)
– the degree of maturation of the radicular apices
– evidence of prior root canal therapy.

The preconditions of correct radiographic interpretation are good techniques in taking and developing the radiograph. The film should always show the entire tooth (from the crown to the alveolar bone surrounding the root apex), the entire periphery of the lesion and the examined tooth should always be centered.

The film must be positioned with the appropriate film-holding instruments and any free-handed positioning methods must be avoided. It must be properly developed and fixed, and it must be analyzed with a good light source, possibly with the help of a magnifying lens.

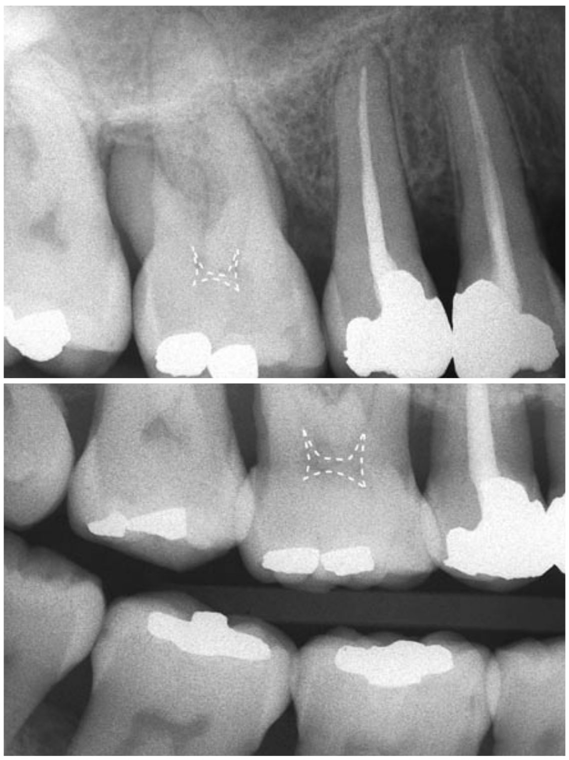
Very often, it is necessary to take two or even more diagnostic radiographs, changing the angle of the radiographic tube by a few degrees from one to the next. By carefully analyzing the radiographs, one can obtain a more three-dimensional view, and the roots or overlying anatomical structures can be better distinguished (see Chapter 5).

A bite-wing radiograph (Fig. 4.7) can also be useful for diagnostic purposes, as it provides more precise and less distorted information about the condition of the pulp chamber (e.g., deep caries, deep filling, direct capping, pulpotomy, calcifications).

It is important to keep in mind that not all periapical lesions are radiographically visible, as occurs with lesions that extend only within the cancellous bone. In fact, as already emphasized, the lesion must also involve the cortical bone to be visible radiographically.[12] Moreover, once the lesion appears on the radiograph, the true involved zone and the extent of osseous destruction are *always* greater than their radiographic appearance would suggest.[30]

The radiographic examination is therefore perhaps the most important diagnostic test; nevertheless, it must never be interpreted alone, but must always be confirmed by tests of pulp vitality. As not all radiolucencies represent endodontic lesions, it would be very easy to commit serious diagnostic errors (Figg. 4.8-4.19).

A



B

Fig. 4.7. **A**. Preoperative radiograph of the maxillary first molar. The pulp chamber seems very calcified. **B**. The bite-wing radiograph shows the true dimensions of the pulp chamber.

A B

Fig. 4.8. **A**. The radiolucency seems to involve primarily the apex of the lateral incisor, which responds normally to all the vitality tests. The central incisor, on the other hand, is necrotic. **B**. Twenty four months later.

A B C D E

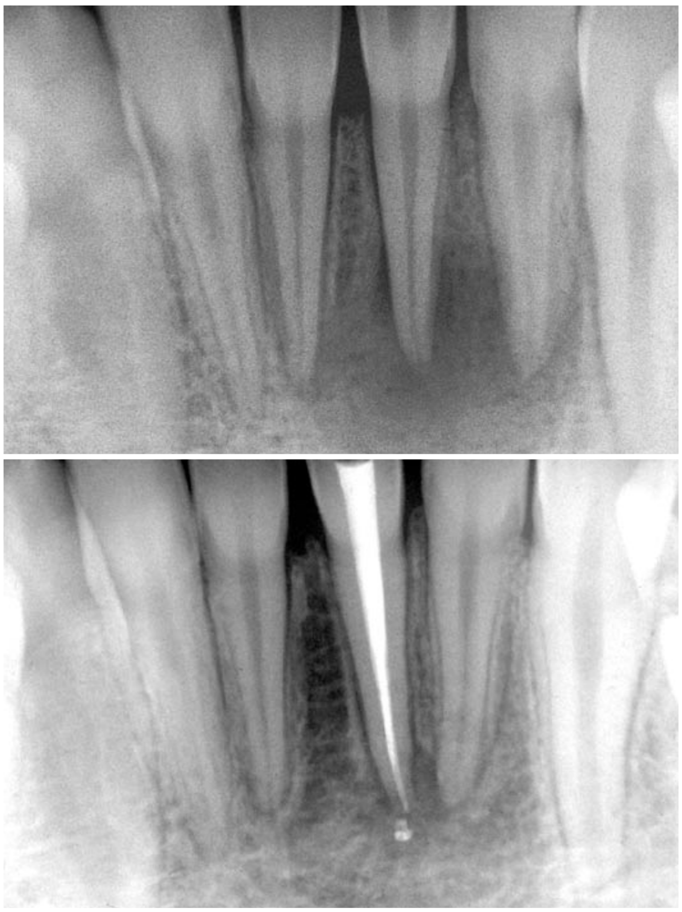
Fig. 4.9. The radiolucency seems to involve the central and lateral incisors. Both teeth test vital. The cuspid has a necrotic pulp. **A**. Preoperative radiograph. **B**. Six month recall. **C**. 12 month recall. **D**. 18 month recall. **E**. 24 month recall. The lateral incisor is still vital.

Fig. 4.10. The first mandibular molar has a furcation involvement. The tooth has a vital pulp and the patient has no periodontal desease in the other quadrants of his mouth. The radiolucency is not periodontal origin but rather is a primary endodontic lesion caused by the necrotic pulp of the second premolar. Its lesion is draining through the periodontal ligament of the molar, in the area of the furcation. **A**. Preoperative radiograph. **B**. Postoperative radiograph. **C**. 7 month recall. **D**. 4 year recall.

Fig. 4.11. **A**. Every tooth of this radiograph tests vital, therefore the apical radiolucencies are not lesions of endodontic origin. The patient has an adenocarcinoma of the maxillary sinus. **B**. The patient is referred for the root canal therapy of the first upper molar and his chief complaint is spontaneous pain radiated to eye and ear. The first molar needs a root canal therapy, but the tooth responsible of pain is the third molar, which is in pulpitis.

A B

Fig. 4.12.**A**. Two teeth seem to be responsible for the lesion: both the central and the lateral incisors. The lateral incisor responds normally to all vitality tests, while the central gives a negative response. **B**. 46 month recall. Note the complete healing of the lesion, while the lateral is still vital.



A B

Fig. 4.13. **A**. The lesion seems to involve the apices of three teeth, but the tooth responsible for the lesion is the lower left central incisor. The other two teeth respond normally to the vitality tests. **B**. Five months later: the lesion has already disappeared, and the adjacent teeth have obviously preserved their pulp vitality.

A B

Fig. 4.14. **A**. The preoperative radiograph shows a lesion that involves two apices, but only one of the two affected teeth has a necrotic pulp. **B**. Twenty-seven months later.


A B C D

Fig. 4.15. **A**. The maxillary first molar presents a radiolucency at the apex of the palatal root. The tooth responds normally to all the vitality tests, therefore, the lesion is not of endodontic origin. **B**. The palatal root of the same tooth has a deep pocket; thus, the radiographically visible lesion is of periodontal origin, and represents the roof of the deep infrabony pocket. **C**. Post-operative radiograph. The tooth has been treated endodontically in preparation for periodontal therapy, which involved the amputation of the palatal root. **D**. Two year recall.


A B

Fig. 4.16. **A**. The lateral incisor also seems to be responsible for the lesion involving the cuspid. The lateral incisor responds normally to all the vitality tests. **B**. 18 month recall after surgery. Note the complete healing of the lesion, while the lateral incisor is still vital.


A B

Fig. 4.17. **A**. The maxillary left central incisor presents a small, roundish radiolucency superimposed on the apex. Note the presence of the lamina dura, an index of health and integrity of the periodontal ligament. The tooth responds normally to all the vitality tests, hence the radiolucency cannot be interpreted as a lesion of endodontic origin. **B**. A second radiograph taken with a more pronounced mesio-distal angulation shows that the radiolucency is no longer related to the root apex, which evidently lies on a more buccal plane. The radiolucency can therefore be assumed to represent the incisor or nasopalatine foramen.

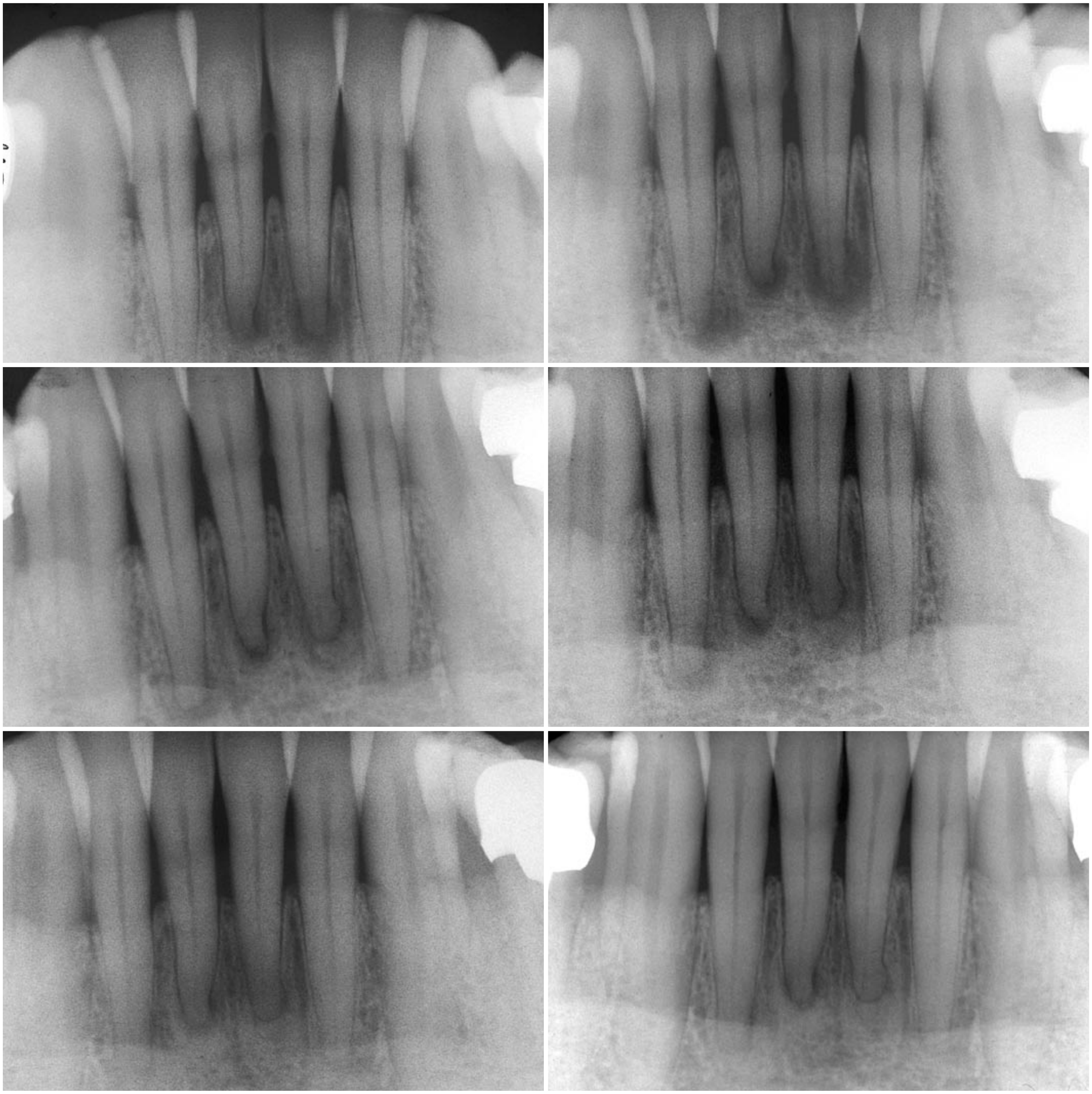


Fig. 4.18. **A**. The lower central incisors of this 45-year-old patient present with a periapical radiolucency. The two teeth respond normally to the pulp tests and are not in occlusal trauma. This represents a case of periapical dysplasia of the cementum or periapical osteofibrosis in the osteolytic stage. These lesions need only be diagnosed and require no intervention. **B**. Four years later, the lesion is now also involving the right lateral incisor. **C**. Seven years later, the lesions are in the second stage, with initial calcification of the fibrotic tissue. The pulps continue to respond normally to the vitality tests. **D**. 12 year recall. **E**. 18 year recall. **F**. 20 year recall.

A B C

D E

F G

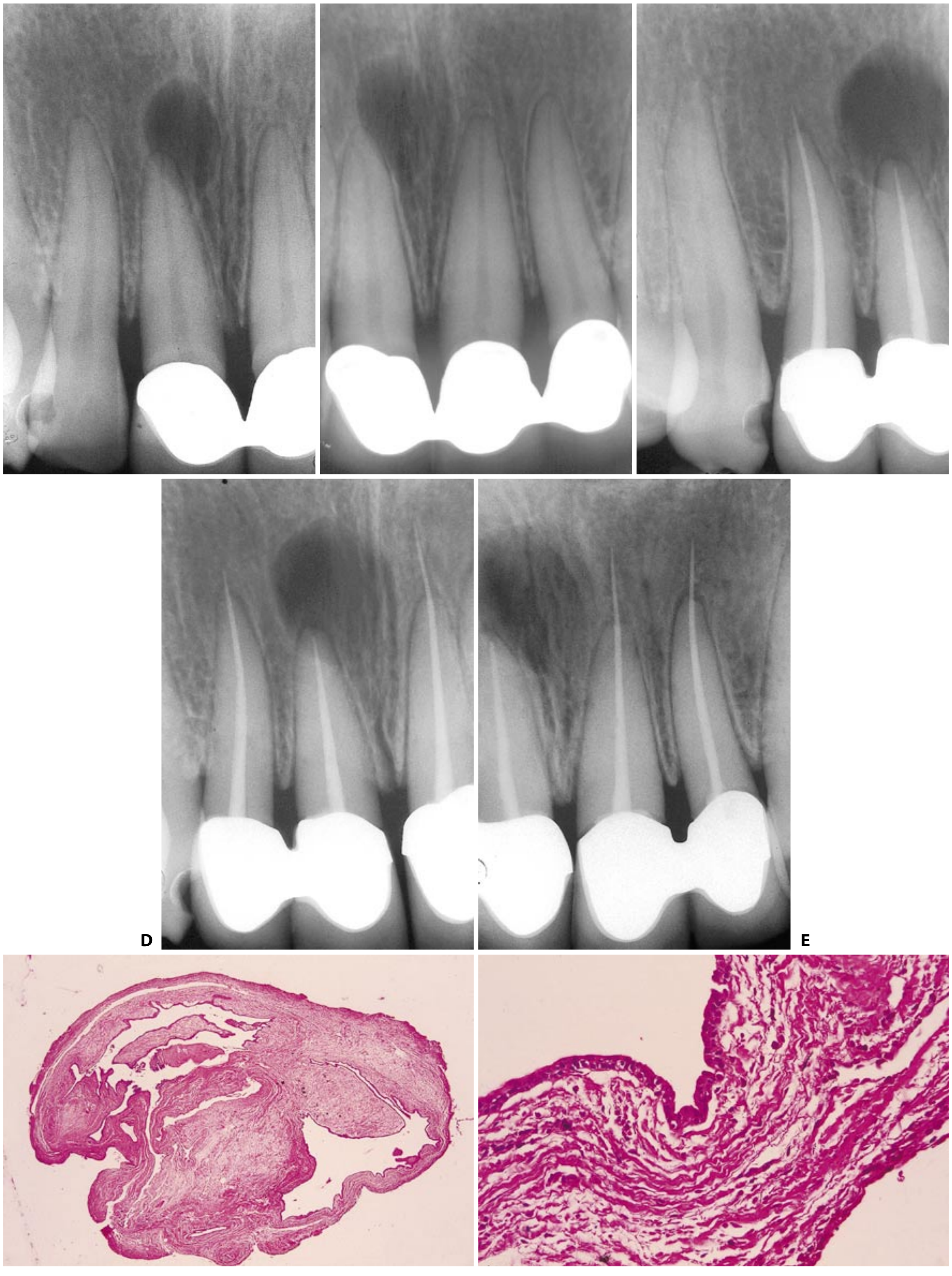


Fig. 4.19. **A**. The presence of an intact lamina dura around the apex of the maxillary right central incisor raises doubts about the endodontic nature of this radiolucency. **B**. A second radiograph taken with greater mesiodistal angulation reveals that the two structures, the apex and lesion, are on two different planes. The radiolucency is situated more palatally. **C-E**. The patient has been referred back several years later because of a palpable swelling in the palatine vault, which had not healed in spite of the endodontic therapy performed elsewhere! Once again, the two radiographs taken with incremental mesiodistal angulations show that the root apex and the lesion are unrelated. The periradicular lamina dura is still identifiable. This is a case of a cyst of the nasopalatine duct. **F**. Histologic appearance of the lesion (x25). **G**. Detail of the preceding figure (x400).

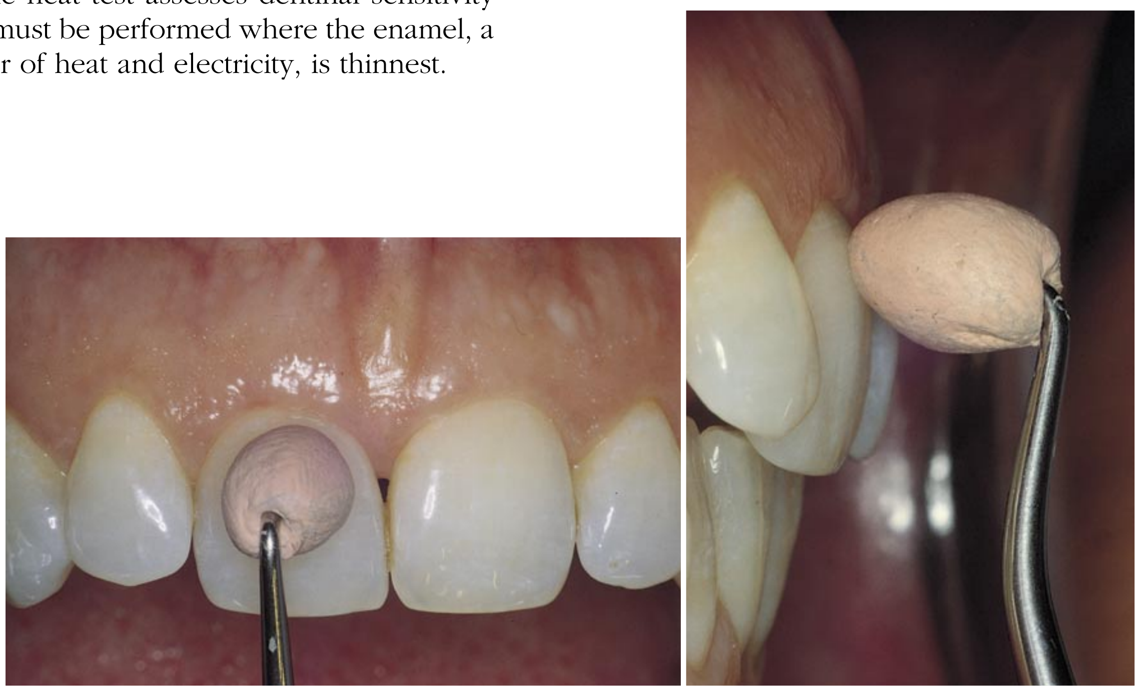
Thermal Tests

Heat tests provide the most reliable information regarding the health or degree of inflammation of the pulp. Patients frequently complain of pain following changes in temperature. A necrotic or inflamed pulp responds in a very different manner from a healthy pulp to thermal stimuli. Healthy pulp is normally sensitive to hot or cold stimuli, and this sensitivity will disappear shortly after the stimulus is removed. A necrotic or inflamed pulp, on the other hand, either does not respond or responds in an exaggerated and prolonged manner.

When performing tests that duplicate the patient's symptoms and thus reproduce their pain, one must first have the patient experience the response of a normal pulp before proceeding to test the suspect tooth or teeth. In other words, one must always begin from the least suspect tooth, so as to minimize the patient's natural anxiety. The teeth must then be dried and isolated with cotton rolls.

– *Heat test.* This is performed by heating a piece of gutta-percha wrapped around the handle of a spatula or an old instrument with a flame (Fig. 4.20). The gutta-percha is heated to the point at which it is nearly too hot to be touched, but no more than about 65°C. It is placed on the apical third of the buccal surface, where the enamel is thinnest (Fig. 4.21). Like the electric test, the heat test assesses dentinal sensitivity and therefore must be performed where the enamel, a poor conductor of heat and electricity, is thinnest.

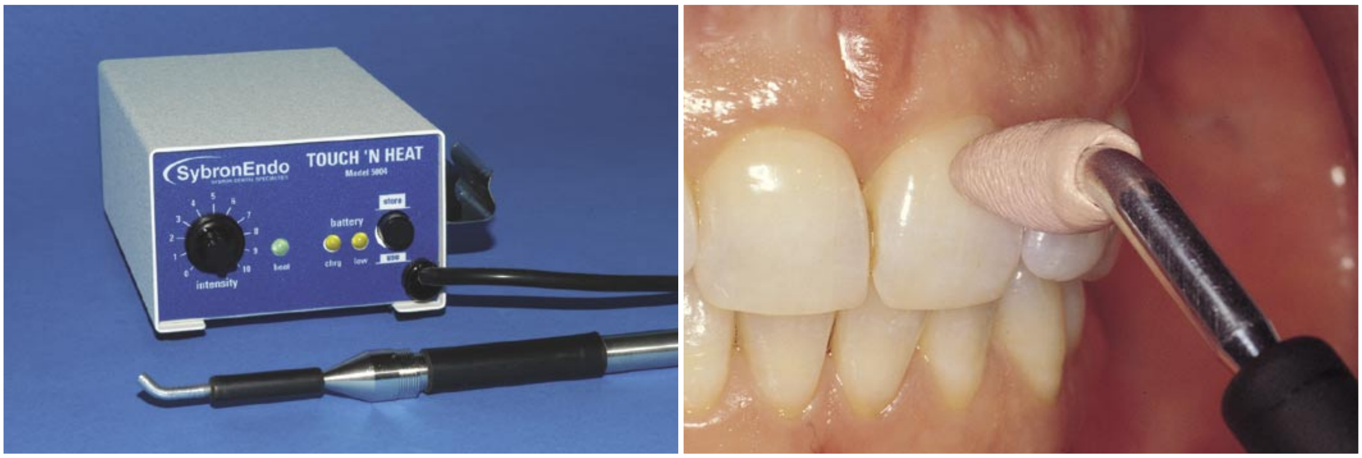
Fig. 4.20. Gutta-percha wrapped around the end of an instrument is heated by a flame to perform the heat test.



A B

Fig. 4.21. **A, B.** The heat test is performed by applying the warm gutta-percha to the cervical area of the tooth, where the enamel is thinnest.

The heat test can also be performed using the "Touch'n Heat" or the "System B" devices with the specially designed tip (Fig. 4.22).
To perform the heat test on teeth with full gold crowns, one can use a polishing rubber disk in a rotary handpiece revolving at a low speed, generating frictional heat against the metal. If the tooth is covered by a ceramic-metal crown, the test is performed at the lingual cervical area, where there is usually some exposed metal surface (Fig. 4.23).
Another method for performing the heat test in gold-ceramic-covered teeth is to irrigate the suspect tooth with very hot water, after the tooth has been isolated with the rubber dam. In this manner, more reproducible results are obtained, and heat is used in quantities sufficient to penetrate the crown.[36]
The response of a normal pulp to the heat test is evident and immediately recedes after the removal of the stimulus.
The patient should not feel any pain.
It must not be forgotten that when the heat test is performed to diagnosis pulpitis, one can produce an extremely strong radiating pain, which is throbbing and prolonged. Therefore, a means of relieving this pain, such as anesthesia or, more simply, cold water or an ice cube must be within reach.
Patients with intense pain of pulpal origin may be aware that cold reduces their discomfort and sometimes bring with them a glass of cold water for relief.[2,21]
– *Cold test*. This can be performed by spraying ethyl chloride on the cervical area of a tooth or on a cotton pellet held in pliers and then placing it at the cervical area of the dried tooth.[6] The second method is preferable, as ethyl chloride is a highly flammable anesthetic and potentially dangerous. A better and simpler method is to use sticks of ice, as Weine suggests.[33] They can be produced by filling with water the di-



A B

Fig. 4.22. **A, B.** The heat test can also be performed with the "Touch'n Heat" device manufactured by SybronEndo, using the specific tip.

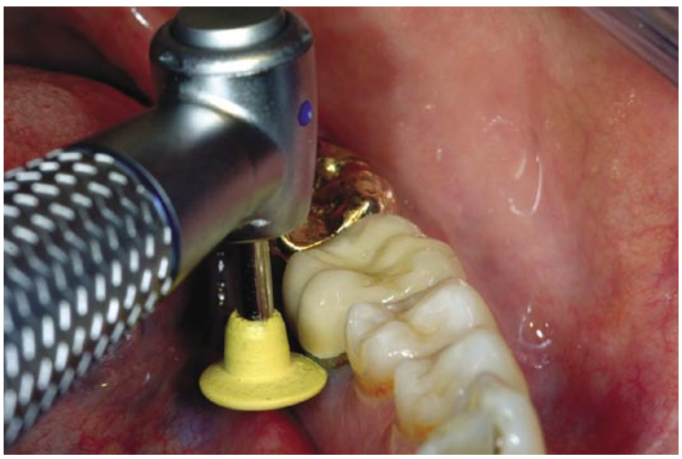


Fig. 4.23. A rubber disc generates frictional heat on the metallic border, and this can be used to perform the heat test on a full crown tooth.

sposable anesthetic needle holders and placing them in the freezer compartment of the refrigerator, where they remain ready for use. When needed, the top of the plastic container is removed, leaving a stick of ice about 3 cm. long, which will more than suffice for testing the teeth of an entire quadrant (Fig. 4.24).
Also for this test, the teeth must be dried and isolated with cotton rolls. While the ice is applied, the assistant should aspirate the cold water of the melting stick, which, dripping on the adjacent tooth, could yield a false positive response. If there is concern about not having a precise response from the patient and the test must be repeated in a more selective manner, a rubber dam can be used to singly isolate the teeth to be tested and immerse them in cold water (Fig. 4.25).
The response of a normal pulp to cold stimulus is identical to that to a hot stimulus: the pulp has no specific receptors, and the neural fibers in the pulp transmit only the sensation of pain. The patient should not feel pain, but only a moderate sensation, which recedes immediately after the removal of the stimulus. If the responses to the thermal tests, hot or cold, deviate from a simple moderate response, for example pain that is slow to resolve even after withdrawal of the stimulus, very acute pain, or no response at all, the pulp that has been tested is not healthy, but variably inflamed. The lack of response may suggest either a necrotic pulp or a false-negative response due for example to excessive calcification, an immature apex, recent trauma, or patient premedication.[6]

A  B

Fig. 4.24. **A**. Ice sticks can be made using the plastic needle holders. **B**. The cold test is also performed on the cervical area of the tooth, where the enamel is thinnest. The teeth are dried and isolated with cotton rolls. The test is performed while the assistant aspirates the water produced by the melting ice stick so as not to have false-positive responses from the adjacent teeth.

A  B

Fig. 4.25. **A, B**. For a more selective response, the tooth may be isolated with a rubber dam and then completely immersed in iced water.

Electric pulp test

This test is performed with an instrument that can electrically stimulate the neural elements within the pulp. Consequently, the responses suggest the presence or absence of such neural fibers, but they will not provide any information about the status of the blood supply of the pulp, which would be very useful to know and on which alone pulp vitality depends.

In other words, this test can distinguish whether the pulp is vital or necrotic, but it provides no information about the type of pulp vitality, whether the pulp is alive and healthy (i.e., vital) or whether it is viable but diseased.[6,8,21] Furthermore, because of the possibility of false-positive or -negative responses, this test must always be used in association with other pulp tests or to corroborate what other tests have indicated.

A very reliable and easy-to-use device is the digital one produced by SybronEndo (formerly known as Analytic) (Fig. 4.26), which has various advantages as compared to similar instruments.[8,10,11,14,15,16] It is battery operated and thus easily portable from one operatory to another without requiring an electrical outlet. Once dental contact is made using a conductive gel (tooth paste), the intensity of the current increases, always starting at zero current; thus, there is no danger of shocking the patient, which would provoke a sudden and unexpected pain. The current automatically increases without advancing any manual rheostat. Even the contact is automatically established, so that it is not necessary to turn on any switches. The rate of increase of the intensity of the current transmitted to the tooth can be regulated; thus, if the patient is anxious or if an early response is expected, one can set the switch to a minimal level. If the patient or the dentist's hand moves involuntarily and causes loss of contact between the tip of the instrument and the tooth for a few seconds, the instrument resets and begins at the level at which the contact was lost as soon as contact is reestablished. If contact is interrupted for several seconds, for example in the time required to pass from one tooth to another, the electric pulp tester automatically resets and starts again from zero, although on the digital read-out the value of the preceding measurement is still visible. At the end of use, the instrument turns itself off automatically, so there is no risk of discharging the batteries. When the batteries begin to lose their charge, a small illuminated signal appears between two numbers of the digital scale, so they can be promptly recharged.

The instrument's scale ranges from 0 to 80 (Fig. 4.26), and the range in which the teeth generally respond is around 20 for the incisors and cuspids, 30 for the premolars and 40 for the molars.

As long as the instrument is functional, it is necessary to establish a physical contact between the dentist and the patient, for example by touching the cheek with the hand holding the mirror used as a retractor. Otherwise, the pulp tester will not function. If the dentist is wearing rubber gloves, the patient must touch the metal portion of the instrument handle with a hand[1,5,17,32] in order to complete the electric circuit (Fig. 4.27).

The teeth to be tested must be isolated with cotton rolls and dried. Contact between the tooth and the instrument tip must be established with a conductive

Fig. 4.26. Electric pulp tester by SybronEndo.

Fig. 4.27. If the dentist wears rubber gloves, contact must be established between the patient's hand and the metal of the instrument handle.

gel (Fig. 4.28). Toothpaste is acceptable, but it is better to use the appropriate gel provided by same manufacturer or even electrocardiogram gel. Like the other tests discussed above, this test also must first be performed on teeth known to be healthy, to insure that the patient understands the response of a normal pulp and thus reduce his or her fear. If there are doubts about the responses that the patient gives, it is prudent to perform the test on the controlateral healthy tooth. Since the response is subjective and can vary slightly from one moment to another, the test must be repeated several times and the average recorded in the chart.

The patient's first sensation is a very faint one. It can be described as a slight tingling or a slight sensation of heat. At a certain point, if the instrument is left in contact with the tooth, the patient feels a pain that slowly becomes unbearable, but if at the first tingling the patient raises a hand, the dentist can interrupt the circuit and the patient will feel no more discomfort. If the dentist is wearing rubber gloves, it is enough for the patient to release the metal part of the probe to interrupt the circuit and thus the stimulus.

As for the thermal tests, the electric test must also be performed at the point at which the enamel, a poor conductor of electricity, is thinnest, since the sensitivity of the pulp-dentinal organ is being tested.

Nonetheless, the instrument tip must be applied at the cervical area, paying attention to avoid contact of the electrode or conductive paste with the gingival tissue or with any restoration, since that would cause a false response.

Fig. 4.28. The electric test is also performed where the enamel is thinner, with the interposition of a conductive gel, after the tooth has been dried and isolated with cotton rolls.

If there is periodontal disease with gingival recession, it can be applied to the exposed dentin, thereby eliciting a more rapid response.

In the teeth of elderly patients, there are sometimes false negative responses due to extensive pulp calcification. These teeth are frequently abraded on their occlusal surfaces, with exposed, sclerotic dentin no longer covered by enamel. In such cases, one can perform the test by applying the instrument to the abraded surface, in such a way as to establish direct contact with the dentin, no longer mediated by the enamel.

The electric test of pulp vitality must not be used in patients with pacemakers because of the potential interference.[36]

The responses that the electric test of pulp vitality provides are usually reliable, especially if they are obtained with a reliable instrument. Nonetheless, false readings can sometimes occur. One false-positive response occurs in the case of a necrotic pulp, a false-negative response in the case of a vital pulp.

Causes of false-positive responses:[6]

1) Rather than touching the enamel at the cervical area, the electrode or the conductive paste touches the gingiva or a large amalgam filling, and the current is transmitted through the periodontal ligament.
2) The patient is anxious and states that the shock is felt before the current has begun to flow.
3) Liquefaction necrosis: the current is transmitted to the periodontal ligament through the fluid present in the root canal, but is felt only at the highest range. The patient may feel some tingling when the intensity of the current reaches about 60, but he feels no increase of the tingling and no pain if the instrument remains in contact until the highest range is reached. The control test performed on the controlateral vital tooth establishes this diagnosis easily.
4) The tooth is not dry or well isolated.

Causes of false-negative responses:

1) The patient is premedicated with a large quantity of analgesics, narcotics, alcohol, or tranquilizers.
2) Contact with the enamel is inadequate, either because there is little conductive paste or because a composite restoration is being touched. In these cases, however, the electric tester does not even begin to work.
3) The tooth has recently sustained trauma. In this case, the pulp nerve fibers are in shock and the normal response will not return for 30 to 60 days.[33]
4) The canal is heavily calcified.

5) The batteries are discharged or the device has not been turned on (but this also cannot occur with the Sybron Endo instrument, since as already stated, it is easy to know when the batteries are about to discharge and nevertheless the instrument continues to function. Furthermore, there is no switch, since the device turns on automatically as soon as contact is established and the circuit is completed).
6) The tooth is newly erupted and the apex is immature.
7) There is partial necrosis: although the pulp is still partially alive, it may appear totally necrotic with the electric test.
This last circumstance may give rise to some doubts. How will a multi-rooted tooth with necrotic pulp in one canal and vital pulp in the others respond to the electric test? The answer to this question is quite simple if one keeps in mind two very important facts:
a) diseases of the pulp proceed in a coronal-apical direction,[28] while pathological processes begin in a pulp horn. From here the pathology that leads to pulp necrosis propagates to the pulp of the chamber and then to the pulp of the root canal.
b) when the electric pulp test is performed, the pulp of the pulp chamber is actually being tested.
In this case, if the pulp of one canal is necrotic, all the overlying pulp – i.e., the pulp of the chamber – has also become necrotic. Consequently, the response of the tooth to the electric test will be negative and the tooth will therefore be considered to all effects a necrotic tooth: the opening of the access cavity and the cleaning and shaping of the necrotic root canal without any need for anesthesia. If, in beginning to treat the other canals, one discovers that the pulp there is still vital, then and only then does one resort to anesthesia.
There is only one case in which one can have a positive response to the electric test in a tooth like the one just described. This is the case in which the pulp cavity has a large calcification and the roof and floor are merged, so that the chamber is literally divided into two separate portions: one mesial or mesiobuccal, for example, and one distal or distopalatal.
In a case such as this (Fig. 4.29), the electric pulp test performed on the distobuccal or palatal area will yield

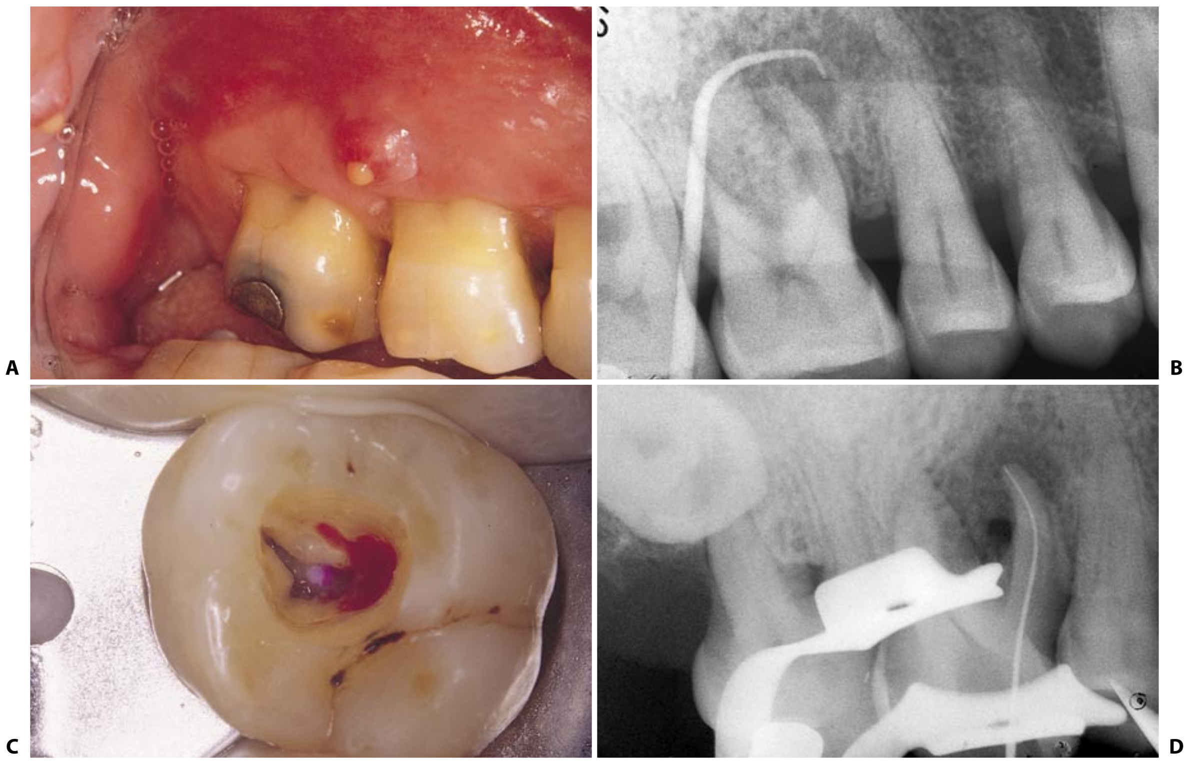


Fig. 4.29. **A.** A fistula is present in the alveolar mucosa between the maxillary first and second molars. **B.** The gutta-percha cone introduced into the fistula reaches the mesiobuccal root, which has a periapical lesion. The electric test performed at the distobuccal root gave a positive response, while the responses were negative at the mesiobuccal. **C.** The access cavity has been made without anesthesia, and once the calcifications in the pulp chamber were removed one could appreciate the presence of vital, bleeding pulp both in the palatal and distobuccal canals. **D.** Without anesthesia, MB1 and MB2 have been cleaned and shaped, and then under anesthesia a pulpotomy has been performed at the orifice of the other canals (continued).

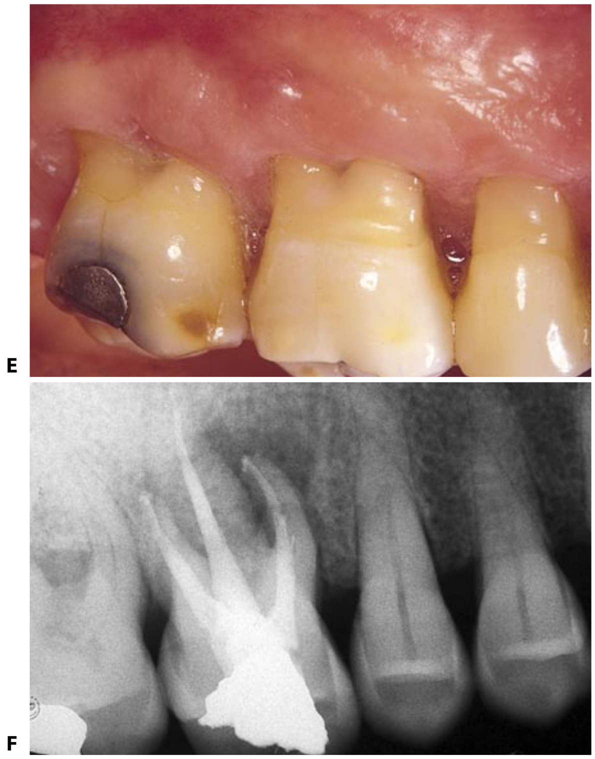


Fig. 4.29. (continued) **E**. One week after the first visit, the fistula appears to be already closed and healing. **F**. With anesthesia, the palatal and distobuccal canals were then prepared. In a subsequent visit, they were filled along with the others.

a positive response, while at the mesiobuccal it will give a negative response.
If it is necessary to perform the electric test on a tooth covered by a full crown, it can be performed with the appropriate mini-tip by placing it between the border of the prosthesis and the gum. This technique, however, does not always yield precise responses, since it is inevitable that at least the conductive paste touches both the metallic border and the gum. Or, if it is still necessary, the electric test can be performed after the cavity test.

Cavity test

When the responses of the other tests are questionable or when it is not possible to perform them (e.g., because the teeth are completely covered by full crowns), one should proceed with this test, which is undoubtedly the most reliable of all and immediately erases any doubt.
The test is performed by preparing a small cavity on the occlusal surface of the posterior teeth or on the palatal and/or lingual surfaces of the anterior teeth, using a small round bur mounted on a high speed handpiece, obviously without anesthesia. In this way, once the thickness of the prosthetic restoration, and possibly the enamel (if it has been left) has been removed, the bur will stimulate the dentin and the patient will experience a sudden but slight pain. This will confirm the vitality of the pulp (Fig. 4.30).
If at this point there is enough space, for further confirmation the other tests, including the electric test, can be performed through the small opening. If the tests are positive, the cavity will be filled, just like any class I cavity.
If, instead, the bur continues until it reaches the pulp chamber without the patient feeling any symptoms, the suspicion that the pulp was necrotic was well founded. The small opening made to perform the cavity test can then be enlarged and transformed into an access cavity.
This test is particularly useful when there are lesions of dubious etiology (endodontic vs periodontal) on teeth with full crowns, as it will be discussed in the chapter on perio-endo relationships.

Anesthesia test

In the rare situation in which all the tests discussed are inconclusive to establish the diagnosis, we can make recourse to the use of selective anesthesia. For instance, in the case in which the patient has diffuse hemifacial pain without any sign indicating one particular tooth or another, one may anesthetize one hemiarch and check whether after several minutes the pain resolves. If this occurs, the opposite hemiarch can be excluded. If, on the other hand, the pain persists, one must perform anesthesia singly on the teeth of the opposite arch, hoping to finally anesthetize the responsible tooth.
There are disagreements on the area which one should begin to anesthetize. Weine[33] recommends beginning with the most mesial teeth, since the innervation of the palatal root of the posterior teeth arrives from the most posterior portions of the palate, through the greater palatine foramen, adjacent to the second molar. If the palatal injection were done here, the inflamed pulp of the palatal canal of any tooth anterior to the infiltration zone would be anesthetized.
Cohen,[6] on the other hand, states that the anesthesia of maxillary teeth should start with the most distal.
According to the author, as Bence also confirms,[2] the

A B C D E

Fig. 4.30. **A**. A fistula between the mandibular first and second molars is present. **B**. The radiograph demonstrates the absence of periapical radiolucencies and the presence of weakly radiopaque fillings in the crowns of the two molars. **C**. The fillings have been removed to allow the cavity test and other tests to be performed directly on the exposed dentin. Both teeth gave positive responses. A gutta-percha cone was then introduced in the fistula that seems to indicate the distal root of the first molar as the culprit. **D**. Occlusal surface of the molars with temporary fillings after having performed the cavity test. Note the presence of the fistula and the partially impacted third molar. **E**. Healing of the fistula after extraction of the third molar in dysodontiasis.

anesthesia test cannot identify the *tooth* affected by pulp pathology, but can only indicate whether a *zone* is responsible for the pain.

To make the anesthesia test more selective, one can use intraligamental injection, as Simon et al.[31] and Littner et al.[19] suggest, administering the anesthetic on the buccal side of each suspect tooth. If this type of anesthesia is performed correctly, the pain will resolve immediately. Littner et al.[19] suggest not to perform such anesthesia in the interproximal zone, where usually the intraligamental anesthesia is recommended, since doing so one could anesthetize the adjacent tooth as well and the test would lose selectivity (see Chapter 9).

Transillumination

Transillumination with fiber optics (Fig. 4.31) can be useful in the diagnosis of dental cracks or fractures. By illuminating the tooth laterally, a small dark line represents the crack. The best results are obtained after removal of preexisting dental restorations.

Bite Test

This test is indispensable for correct diagnosis of the cracked tooth syndrome. It is performed by making the patient bite a moist cotton roll with one pair of antagonists at a time (Fig. 4.32). This maneuver provokes minimal displacement of the fragments, a stretching of the odontoblastic processes, and then a sensation of pain (see Cracked tooth syndrome).

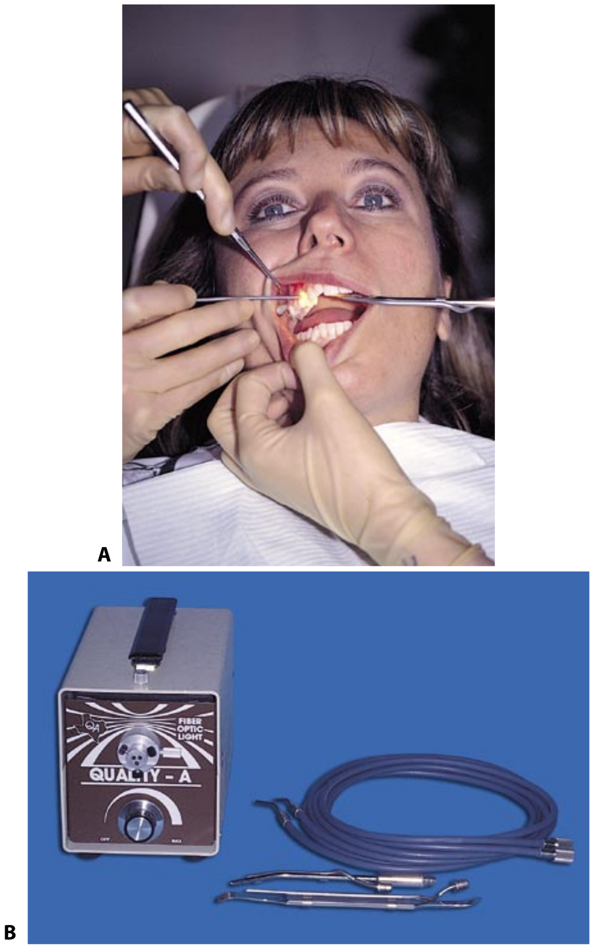


Fig. 4.31. **A.** Transillumination can be useful, for instance, to reveal a crack. **B.** Fiberoptics produced by Quality Aspirators.

Fig. 4.32. This test demonstrates the cracked tooth syndrome.

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5

Endodontic Radiography

ARNALDO CASTELLUCCI

In no other branch of dentistry does radiology play such an important role as in Endodontics.
The discovery of X-rays by Wilhelm Conrad Roentgen (Fig. 5.1) on the night of November 8, 1895 had such a profound impact on the entire medical world that it has come to be considered one of the most revolutionary achievements in the history of medical science.
In the field of Dentistry, Endodontics is surely the branch that has benefited most from this discovery, not only because of continual technical and technological improvements,[46] but mainly because the use of X-rays has brought dentists "out of the dark", allowing them to visualize areas not accessible by other diagnostic means.
Prior to this important date, dentists could only "attempt", with greater or lesser success, to reach a diagnosis and implement a therapeutic approach to endodontic problems.
The advent of the first oral radiography equipment (Fig. 5.2) permitted visualization for the first time of the changes that occur in the bone surrounding the apices of non-vital teeth, as well as the results of endodontic therapy.
In this way, Endodontics ceased to be simply an empirical pursuit; from that moment on, it became a scientific discipline.[28]
Today, the X-ray machine must be included among the dental equipment, especially in an endodontic

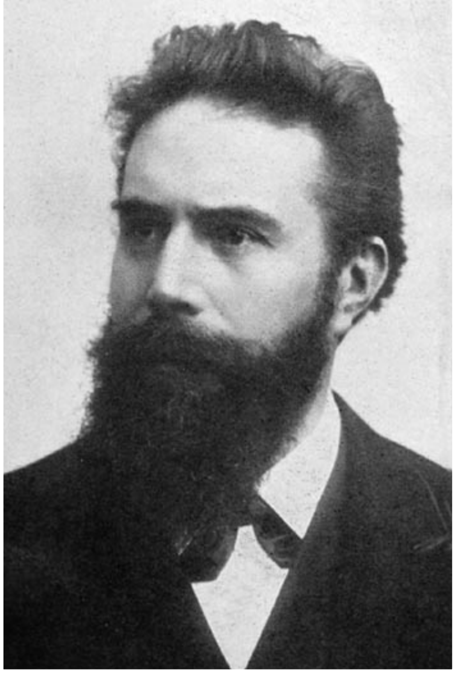


Fig. 5.1. Wilhelm Conrad Roentgen.

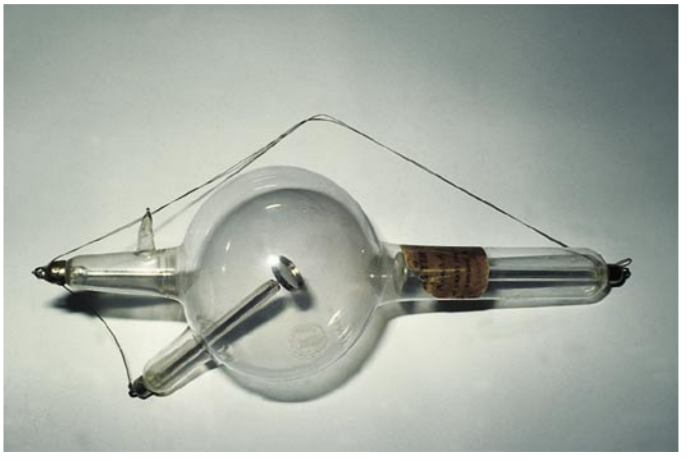


Fig. 5.2. One of the first tubes used at the turn of the century to produce X-rays.

practice. Having to work on the root canals of a patient without the help of this essential diagnostic apparatus is inconceivable.
In this chapter, we will discuss several fundamental principles of oral radiology. We will analyze the correct techniques of obtaining, developing and interpretating radiographs in Endodontics. We will not discuss the physical principles of ionizing radiation in detail, nor will we describe the biological effects of radiation itself; for a discussion of these topics, the reader is referred to the numerous radiology textbooks.

BASIC PRINCIPLES OF RADIOLOGY

X-rays are electromagnetic radiations. They have the same nature as visible light rays; like them, X-rays travel in a straight line until they are either absorbed or deflected. In contrast to visible light, however, they are not perceptible to the eye because of their short wavelength (10^{-10} to 10^{-6} cm).[8] Differences among the various types of electromagnetic radiation depend upon their wavelength. Starting with the longest wavelengths, electromagnetic radiation includes:

– Electric waves
– Radio, television, and radar waves
– Infrared rays
– Visible light rays
– Ultraviolet rays
– X-rays
– Gamma rays

Depending on its wavelength, which is measured in Ångström units (Å), electromagnetic radiation has variable capacity to pass through solid bodies. Rays with longer wavelengths have poor penetrating power. In contrast, those with shorter wavelengths, beginning with ultraviolet light, have increasing penetrating power. The wavelength of the X-rays used in oral radiography vary from 0.8 to 0.1 Å; thus, their penetrating power is greater than that of ultraviolet rays.[1]
Apart from the radiation's wavelength, the penetrating power depends on the atomic mass (density) of the object penetrated. Low-density objects are almost completely penetrated, while higher-density objects are penetrated to a lesser extent. Lead does not allow X-rays to pass at all; therefore, it is an optimal protective material against the harmful effects of X-rays.
If one examines X-rays passing through an object, one finds that a portion of them have been absorbed by the object, which therefore projects a "shadow", like an opaque body struck by a beam of light.
Just as bodies of varying opacity hit by light rays throw different shadows depending on their capacity to be traversed by luminous radiation, bodies of variable density struck by X-rays throw different shadows depending on their capacity to be penetrated by these electromagnetic radiations.
Because less dense bodies (e.g., soft tissues) are traversed to a greater degree, they throw lighter shadows, while denser bodies (e.g., bone) are traversed less and draw more radiation, for which reason they throw darker shadows. One must keep in mind, however, that because the radiographic image is a *negative*, the shadows appear to be reversed: soft tissues appear dark, while bone appears light.
In conclusion, the images produced by radiography represent the shadows that bodies of different densities project onto a film when placed in the X-ray's path.
Furthermore, a radiograph is a *two-dimensional* representation of *three-dimensional* structures. In other words, it is a fictitious image and never a real image [40] with all the consequences this implies. This is an extremely important concept that must never be forgotten.
In radiology, shadows corresponding to different anatomical structures situated on different planes are superimposed, with the consequent phenomena of summation and cancellation (e.g., one radiopaque body superimposed on a radiolucent one can hide the latter). Furthermore, like all shadows, radiographic images also are deformed to a certain degree with respect to the true dimensions of the body under examination. This deformation will be exaggerated more or less, according to the radiologic technique employed. The dentist must keep these factors in consideration during the clinical practice.

PRINCIPLES OF X-RAY FORMATION

X-rays are produced when electrons, accelerated by a high potential of tens of thousands of volts (or tens of kilovolts), strike a target at high speed (Fig. 5.3). To produce X-rays, the following are also required:

a) source of electrons,
b) high voltage to accelerate the electrons,
c) target that once hit by these electrons becomes the source of this radiation.

a) *Source of electrons*. The source is a tungsten filament (the cathode or negative electrode), which is enclosed within a glass-walled vacuum tube together with the anode (positive electrode). When an electrical current passes through the filament, heat is created and a “cloud” of electrons is produced. The electrons are reflected and directed toward the anode so as to strike the target. The number of electrons emitted by the element is measured in milliamperes, the Ampere being the unit of measurement of the intensity of the current, that is of the displacement of electrons.

b) *High voltage*. Since they have a negative charge, the electrons emitted by the filament are attracted to the anode, which has the opposite charge. The greater the anode’s positive charge, the more electrons travel toward it. Therefore, when a high voltage is established in the tube and the anode becomes strongly positive, the potential difference between the cathode and anode, (between the filament and target), increases at the same time; thus, the electrons are accelerated. High voltage is provided by a transformer that carries the current from 110 volts to a range of 60,000 to 90,000 volts (from 60 to 90 kilovolts or kVp).

c) *The target*. On the external surface of the anode, there is a small disc of tungsten, a metal that produces X-rays relatively efficiently and supports high temperatures without melting. The electrons, which are accelerated by the very large potential difference between the anode and filament, strike the target at an extremely high speed. As a result of this electron bombardment, the target surface emits X-rays. The anode is usually made of copper, to allow better dispersion of heat, which is created by the electrons at the target site. Only one per cent of the energy of the electron beam that strikes the target is transformed into X-rays. Ninety-nine per cent of the energy is transformed into heat, which the copper anode dissipates in the air, oil, or gas contained in the X-ray machine. The angulation of the target is very important, since it determines the size of the radiographic source (focal spot). It will be shown later that the more pointed the source the more defined the radiographic image and the sharper its margins (Fig. 5.4).

THE QUALITY OF THE RADIOGRAPH

The radiographic image is a graphic representation of the internal structures of an object placed in the path of the X-ray beam.

The principal aim of the radiographic examination is to obtain maximum differentiation of tissues on the

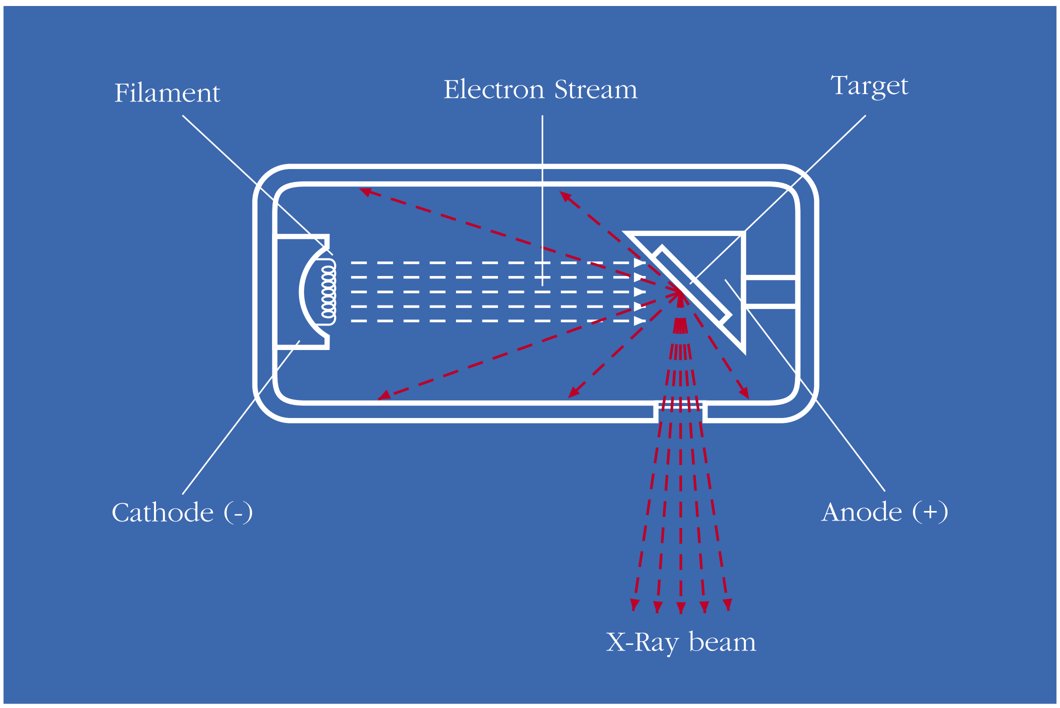


Fig. 5.3. Schematic diagram of a radiographic tube (adapted from P.W. Goaz, S.C. White, Oral Radiology, The C.V. Mosby Company, St Louis, 1982).

film.[1] This differentiation is achieved only when the film has certain degrees of the following four qualities, which determine the radiograph's visual and diagnostic qualities:

1. *Detail* is provided by sharp, well-defined borders in all the images of the radiograph (see the concepts of "umbra" and "penumbra" on pag. 73).
2. *Density* is the degree of blackening of the film and the amount of light transmitted through it.
3. *Contrast* consists of the difference between black, white, and the various shades of gray on adjacent areas of the same film.
4. *Distortion* causes changes in the *size* and *shape* of the radiographed object.

FACTORS CONTROLLING THE X-RAY BEAM

The X-rays emitted by the generating tube can be modified by the operator, depending on the needs of a given case.

This can be accomplished by:[1]

a) altering the conditions of tube operation:
   - Kilovoltage (kVp)
   - exposure time
   - milliamperage (mA)

b) manipulating the beam produced by the tube with:
   - filter
   - collimator
   - changes in the target-object distance

Kilovoltage

As already emphasized, this represents the potential difference between the cathode and anode, between the filament and the target. Increasing the kilovoltage increases the energy of each electron at the moment it strikes the target. This leads to increased efficiency of conversion of electron energy into X-ray photons, since there is an increase of both the number of photons generated, the mean energy of the photons and the maximum energy of these photons. High-energy photons (i.e., short wavelength) have a greater capacity to penetrate bodies, while photons of relatively low energy have a greater probability of being absorbed. In conclusion, higher kilovoltage produces an X-ray beam with higher energy and thus a greater capacity to penetrate bodies.

Keeping constant the exposure time and milliamperage, a radiograph taken with *low kilovoltage* will show

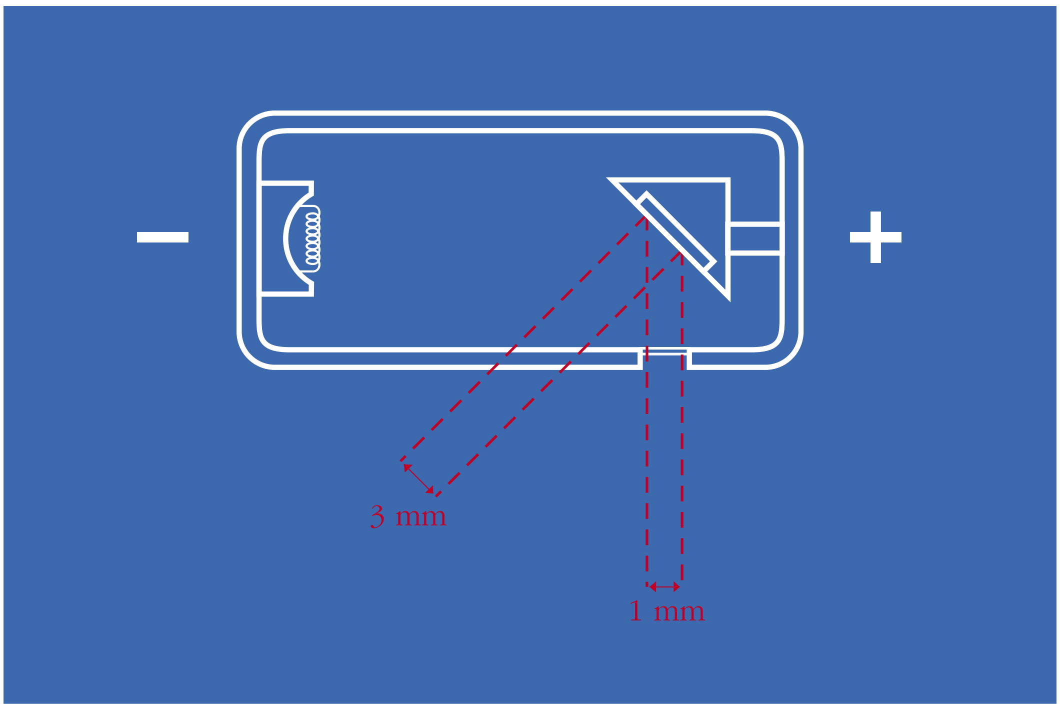


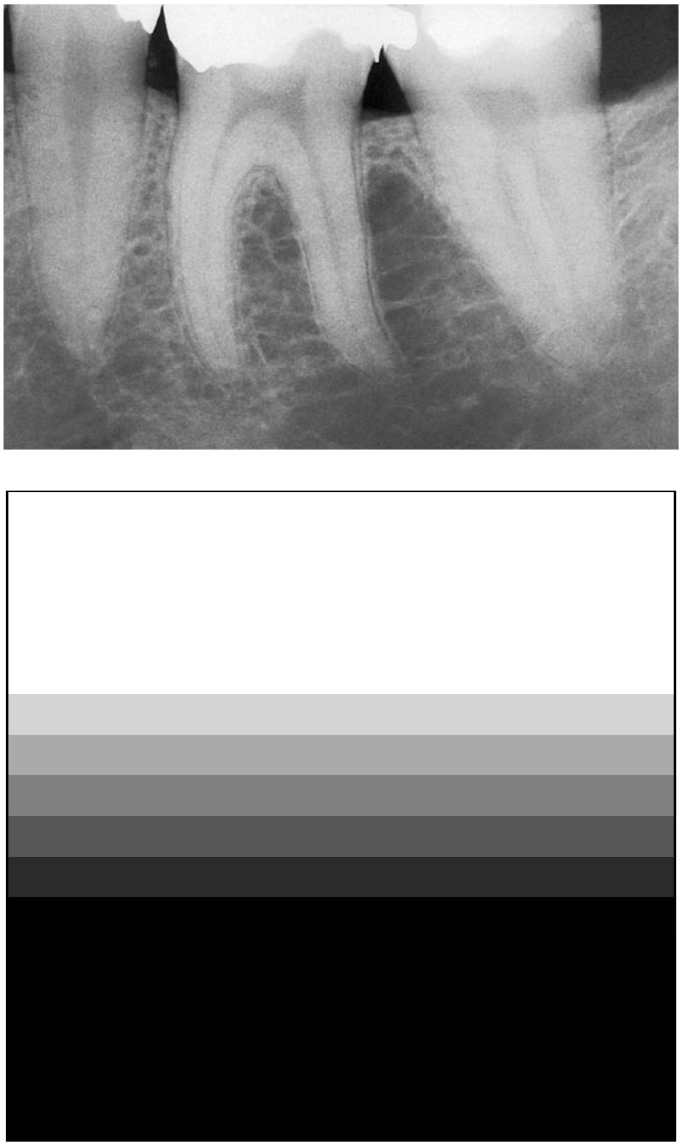
Fig. 5.4. Because the target is angulated, the radiographic source is much smaller than the real size and closer to the ideal size: punctiform (adapted from P.W. Goaz, S.C. White, Oral Radiology, The C.V. Mosby Company, St Louis, 1982).

high contrast, since the number of densities that comprise the image is relatively scarce on account of the poor penetrating power of the X-ray beam. This is also known as “short-scale contrast”, since the densities are very limited and pass abruptly from white to black, with little gray (Fig. 5.5).

On the other hand, a radiograph taken with *high kilovoltage* will show *low contrast*, since the number of densities that comprise the image are increased, owing to the greater penetrating power of the X-ray beam. This is known as “long-scale contrast”, since there are different densities in large numbers on the film, resulting in a more gradual passage from white to black, through a vast range of gray (Fig. 5.6). This increased density can be detrimental to the aesthetic quality of the image, but on the other hand it may reveal important information which the aesthetically more pleasing radiograph with greater contrast cannot provide.[47]

Dental radiographs are usually produced with kilovoltages ranging from 65 to 90 kVp.

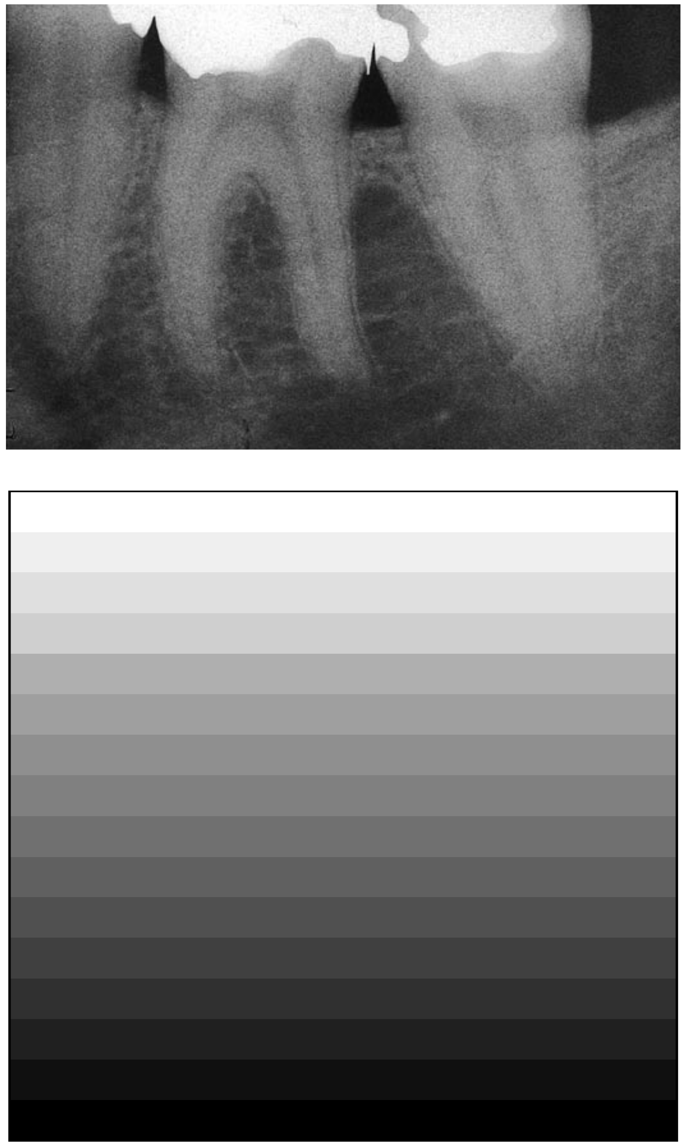
Some X-ray machines for dental use allow changes of kilovoltage (Fig. 5.7), but in most of them the kilovoltage is fixed. Nonetheless, if one has to choose among machines of different kilovoltages, it is better to choose those with higher values.



A

B

Fig. 5.5. **A.** Radiograph performed at 50 kVp. Note the image contrast. **B.** Short-scale contrast, typical of radiographs performed at low kilovoltage.



A

B

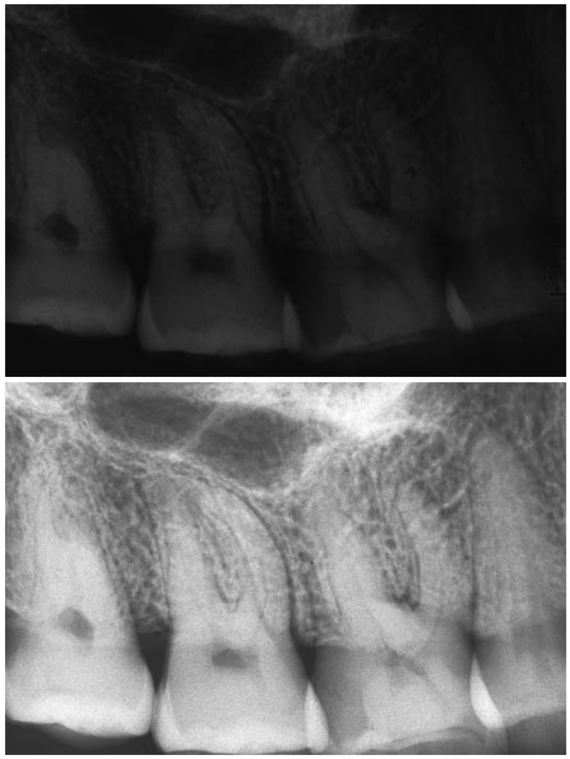
Fig. 5.6. **A.** Radiograph performed at 90 kVp. Note the lesser contrast as compared with the radiograph in the preceding figure. **B.** Long-scale contrast, typical of radiographs performed at high kilovoltage.

A B C

Fig. 5.7. Using the X-ray machine Planmeca (**A**), the operator can vary the kilovoltage, between 60 (**B**) and 70 (**C**) kVp.

Exposure Time

If the exposure time is doubled, while the milliamperage and kilovoltage are kept constant, the number of photons originated is also doubled; however, their energy remains unvaried. Therefore, in varying the exposure time, one simply varies the exposure quantity, which is to say the number of photons generated.
If one compares two radiographs taken with fixed milliamperage and kilovoltage, but varied exposure times, one notes that the radiograph taken with a longer exposure time is denser and appears darker, like the negative of an overexposed photograph (Fig. 5.8).



A B

Fig. 5.8. **A**. Radiograph performed with a long exposure time: it is dark because of overexposure. **B**. Radiograph of the same area, performed with the proper exposure time.

Milliamperage

The quantity of electrons emitted from the filament within the generating tube and striking the target is measured in milliamperes. It can be compared to the amount of water that passes through a tube. The ampere is a unit of measure of electron flow; a milliampere (mA) corresponds to 1/1000 of an ampere. Increasing the flow of electrons increases the flow of X-rays, resulting in increased radiographic density. If one compares two radiographs taken with fixed exposure times and kilovoltage, varying only the milliamperage, the film taken with a higher milliamperage will be denser, thus appearing darker.
Since exposure time and milliamperage both influence the radiographic density, they can be combined as a single factor known as milliampere-seconds (mAs).
In other words, radiographs of the same density can be obtained either by shortening the exposure time or increasing the milliamperage.
For example:

$$\left.\begin{array}{r} 4 \text{ mA x } 3.0 \text{ sec} = 12 \text{ mAs} \\ 8 \text{ mA x } 1.5 \text{ sec} = 12 \text{ mAs} \\ 12 \text{ mA x } 1.0 \text{ sec} = 12 \text{ mAs} \end{array}\right\} \text{constant density}$$

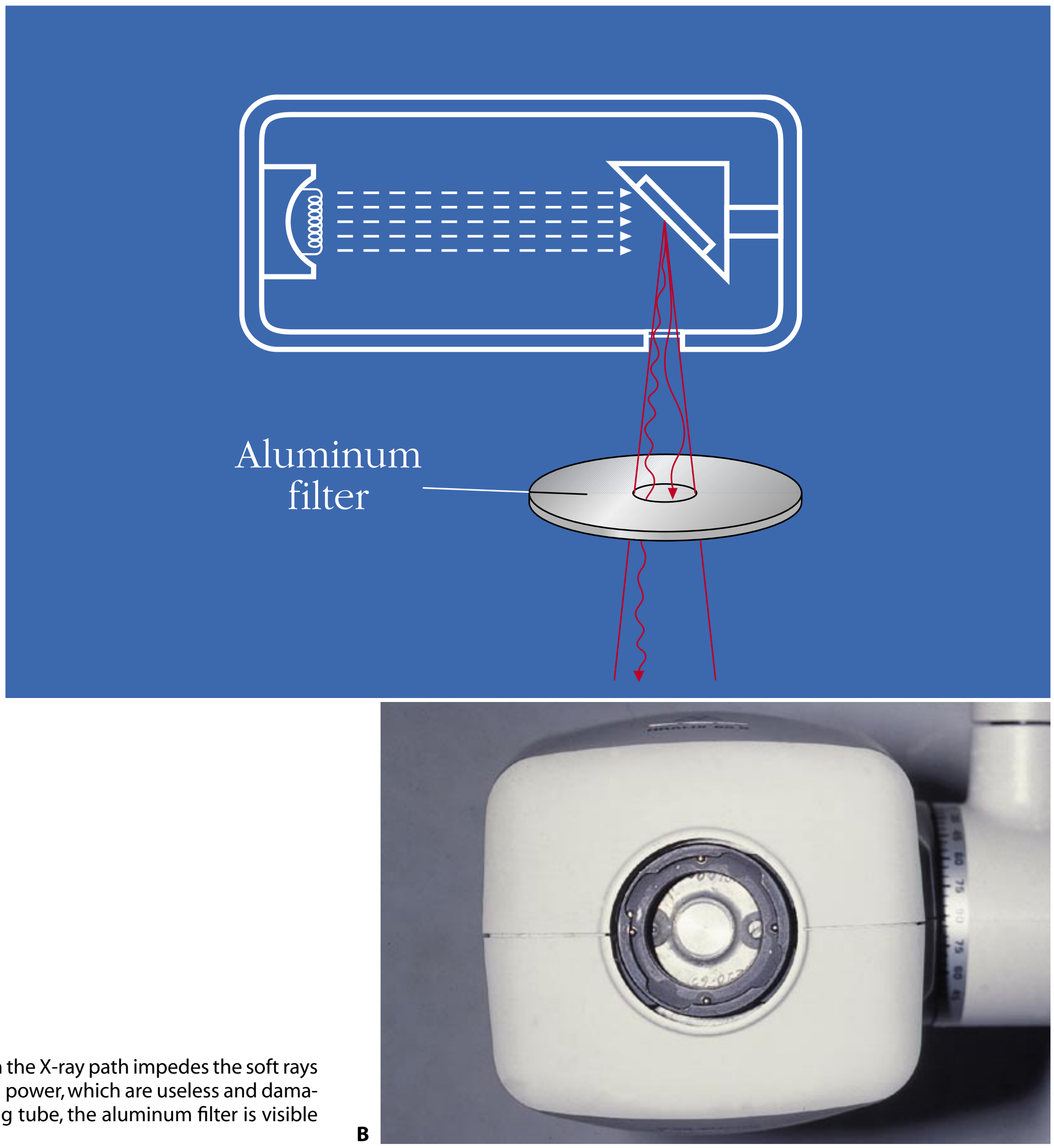
From this table, it is obvious that a high milliamperage is preferable to reduce the exposure time and thus to limit the patient's exposure to ionizing radiations.

Filter

The target struck by electrons emits X-rays of different wavelengths and thus different energies. Those with higher energy, which are capable of penetrating anatomical structures, are useful for radiologic diagnosis. Those with less penetrating power (long wavelengths) contribute to the patient's radiation exposure without giving any useful radiographic information. It is therefore obvious that, for the sake of patient safety, X-rays with less penetrating power and low diagnostic benefit must be eliminated from the beam. This can be achieved to some extent by interposing an aluminum filter in the path of the beam [26] (Fig. 5.9).

Collimator

When an X-ray beam penetrates the patient's tissues, some of the photons pass through and continue until they encounter the film on which the images are formed. Other photons which are absorbed by the tissues in turn generate a scattered radiation, which di-

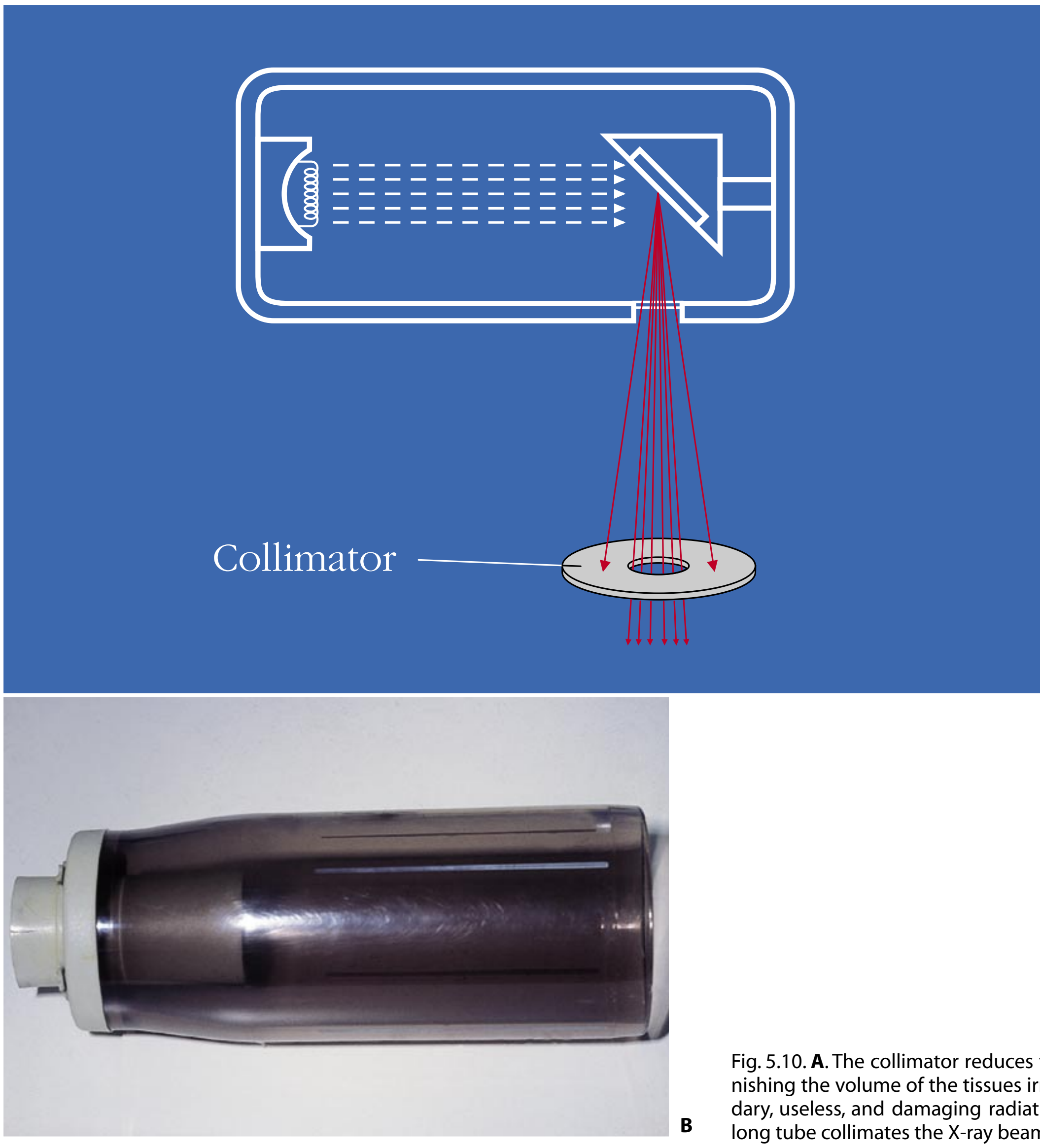


A

B

Fig. 5.9. **A**. The aluminum filter interposed in the X-ray path impedes the soft rays with long wavelength and low penetrating power, which are useless and damaging (continued). **B**. Disassembling the long tube, the aluminum filter is visible in the exit portal of the X-rays.

sperses in all directions. The scattered radiation that travel in the same direction as the original beam participate in the formation of the image on the film and therefore can have a certain diagnostic utility. The others, however, which travel in other directions yet can also reach the film, not only do not provide any useful information, but indeed cause deterioration of the image quality, causing a certain fogging or indistinctness.
It is therefore obvious that it is necessary to reduce to a minimum the formation of secondary diffuse radiation and block them from reaching the film, with the aim of eliminating as much as possible their damaging effect on image formation.
This can be achieved with the use of a collimator (Fig. 5.10).
Collimating the X-rays reduces the formation of scattered radiation. It is achieved by interposing a radiopaque barrier containing an aperture in the X-ray path.
The collimator, comprising a ring of highly absorptive material (lead) reduces the size of the X-ray beam (6 cm in diameter, see Fig. 5.94) and thus the volume of the irradiated tissues, from which the diffuse radiation originates.
The collimator thus reduces the exposure of the patient to ionizing radiations and improves the film quality.



A

B

Fig. 5.10. **A.** The collimator reduces the diameter of the X-ray beam, thus diminishing the volume of the tissues irradiated and thus the production of secondary, useless, and damaging radiation. **B.** The metallic tube visible within the long tube collimates the X-ray beam.

Target-Object distance

The intensity of a beam of X-rays at a certain point (measured in number of photons x cross-sectional area x unit of time) depends on the distance from the radiographic source.[26]
X-rays, like visible radiation, obey the inverse square law: for a given beam, the intensity is inversely proportional to the square of the distance from the source (Fig. 5.11).
If the distance between the X-ray source and object is doubled, the intensity of the radiation must be quadrupled; conversely, if the distance is halved, the intensity must be reduced to one-quarter.[38]
Changes in distance between the radiogenic source and patient therefore have a great effect on the intensity of the X-ray beam. If the patient's exposure must be kept constant, changes in this distance require corresponding changes in kilovoltage (kVp) or milliampere-seconds (mAs).[26]

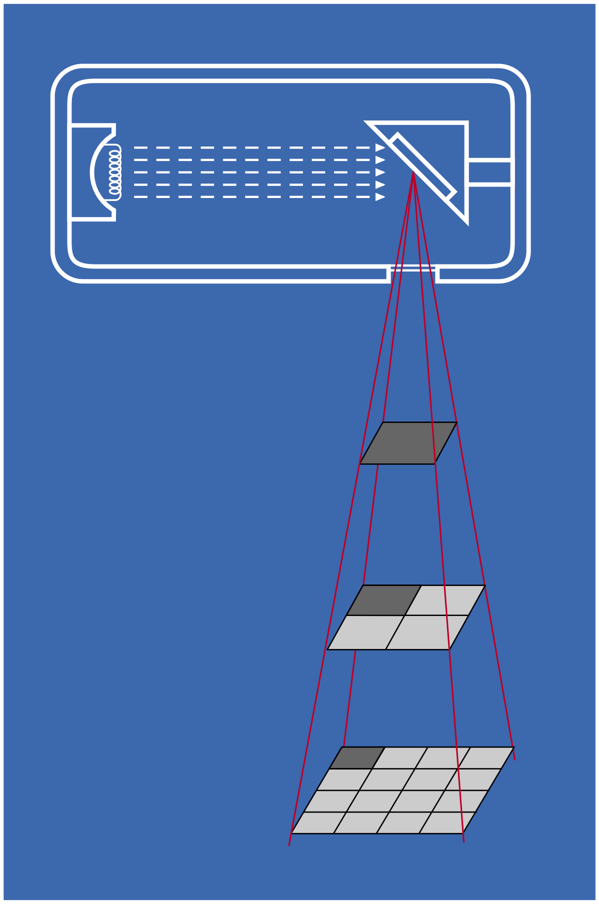


Fig. 5.11. The intensity of an X-ray beam is inversely proportional to the square of the distance (adapted from P.W. Goaz, S.C. White, Oral Radiology, The C.V. Mosby Company, St Louis, 1982).

BASIC PRINCIPLES OF IMAGE FORMATION

As already stated, the radiograph is a two-dimensional representation of a three-dimensional structure. Therefore, to get the greatest amount of information, one must examine one or more two-dimensional images in order to reconstruct mentally a three-dimensional image of the anatomic structures of interest. Obviously, that can be done only if the radiographs have been taken correctly.
One must understand certain principles of projection geometry, which regulate the formation of images to obtain well-defined radiographs, which are neither enlarged or distorted. It will be seen that the size and position of the focal spot, relative to the object and film, are important in determining the image clarity (sharpness and contrast), image magnification, and image distortion.

Image sharpness

"Sharpness" refers to the degree to which the smallest details of an object are reproduced on the radiograph. More specifically, it refers to the degree to which the boundary line between two zones of different density is well defined.[26]
Strictly related to this is the resolution, which refers to the extent to which it is possible to distinguish two small nearby objects as separate.
Sharpness and resolution are distinct but interdependent, since both qualities are influenced by the same parameters.
To explain these concepts, a light source, an object, and its shadow will be considered.
Consider the shadow of a human figure that is projected onto a wall when the sun is setting. In this case, the light source is so far as to be considered punctiform; thus the shadow that the figure projects on the wall is well-defined, without blurring. Since the light source is far away from the figure, which in contrast is extremely close to the wall, the projected shadow is the same size as the human figure and thus is neither enlarged nor distorted.
If, on the other hand, one considers the shadow that the same figure projects onto the same wall at the same distance when it is illuminated by a neon light placed only a few meters away, there is a great difference.
First of all, it lacks defined limits and is very blurred, since there is a gradual passage from the black areas

in the shadow to the clear zones in plain light, with an entire range of gray, typical of the zones in "mid light".
Furthermore, the size of the shadow is quite different from that of the original figure, since the shadow appears enlarged.
When a radiograph is taken, exactly the same considerations apply.
Since the radiographic source is not punctiform but, however small, still represented by a surface, each of its points will emit rays. Thus, the radiographed object will be struck by beams originating from different angles. The result will be a "shadow" without defined borders, but surrounded by blurred borders (the so-called "penumbra") (Fig. 5.12). The shadow zone is that area which does not receive "light" from *any* of the points of the radiographic source. The zone of the penumbra is that which does not receive "light" from *some* parts, but receives it from others. This causes a loss of image clarity, reducing the sharpness and resolution.
To reduce these drawbacks as much as possible, three factors must be modified:

1. The size of the focal spot. Just as the sun, which can be considered a "punctiform" light source, generates defined shadows, thus by making the radiographic source (i.e., the size of the target within the tube) as small as practical, one obtains radiographic images that are increasingly sharp and high in resolution (Fig. 5.13).
2. The distance between the focal spot and the object. By moving the radiographic source away, the angle of the cone of rays is reduced. Hence, the zone of the penumbra is reduced, with an increase of sharpness and resolution (Fig. 5.14).
   Further, moving the radiographic source away also leads to another advantage, that is to a lesser enlargement of the shadow with respect to the object's actual size, this being due to the fact that the rays that strike the object from far away are more parallel to each other.
   In practice, the increase of the distance between the focal spot and the object is achieved with the use of a long cone.
3. Distance between object and film. Bringing the film close to the object is equivalent to increasing the distance between the focal spot and the object. The results are exactly the same: an increase of sharp-

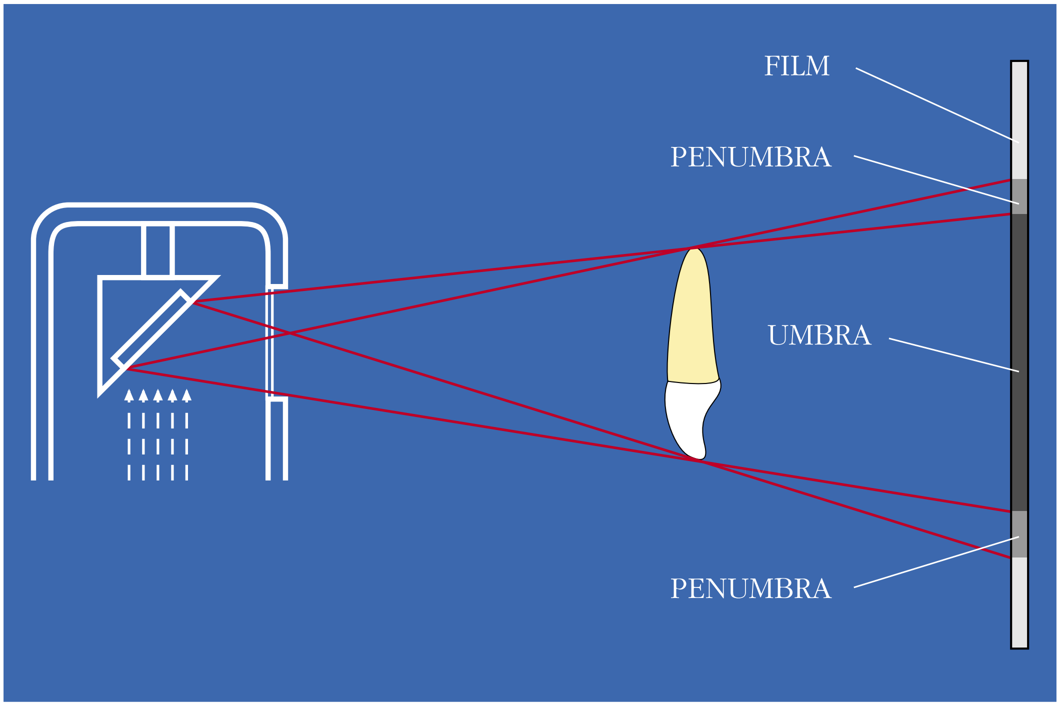


Fig. 5.12. The shadow zone receives no radiation from the points of the radiographic source. The penumbra zone receives radiation from some points, but not from others (adapted from P.W. Goaz, S.C. White, Oral Radiology, The C.V. Mosby Company, St Louis, 1982).

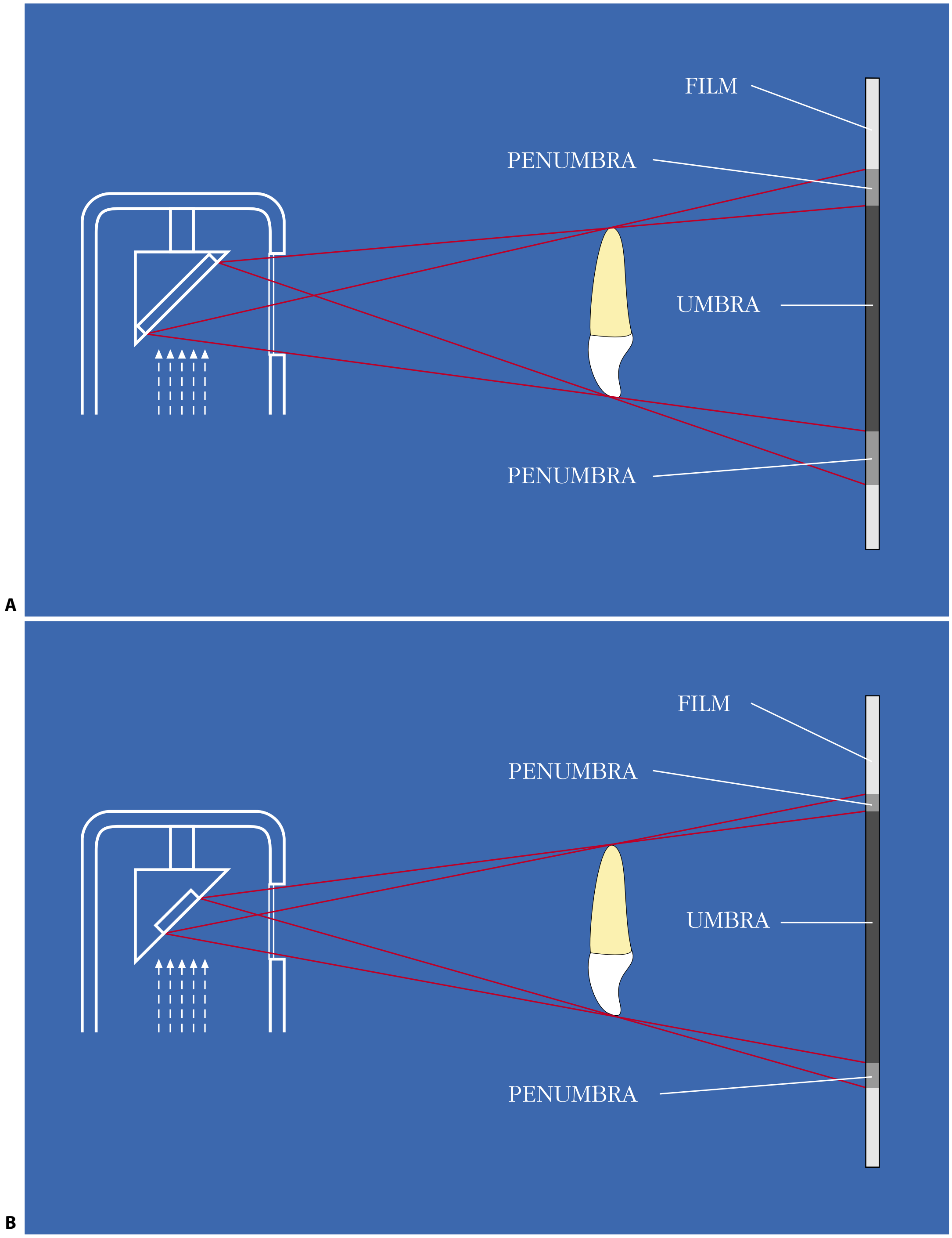


Fig. 5.13. **A, B**. Reducing the size of the radiographic source, the penumbra zone is also reduced, consequently increasing the sharpness and resolution (adapted from P.W. Goaz, S.C. White, Oral Radiology, The C.V. Mosby Company, St Louis, 1982).

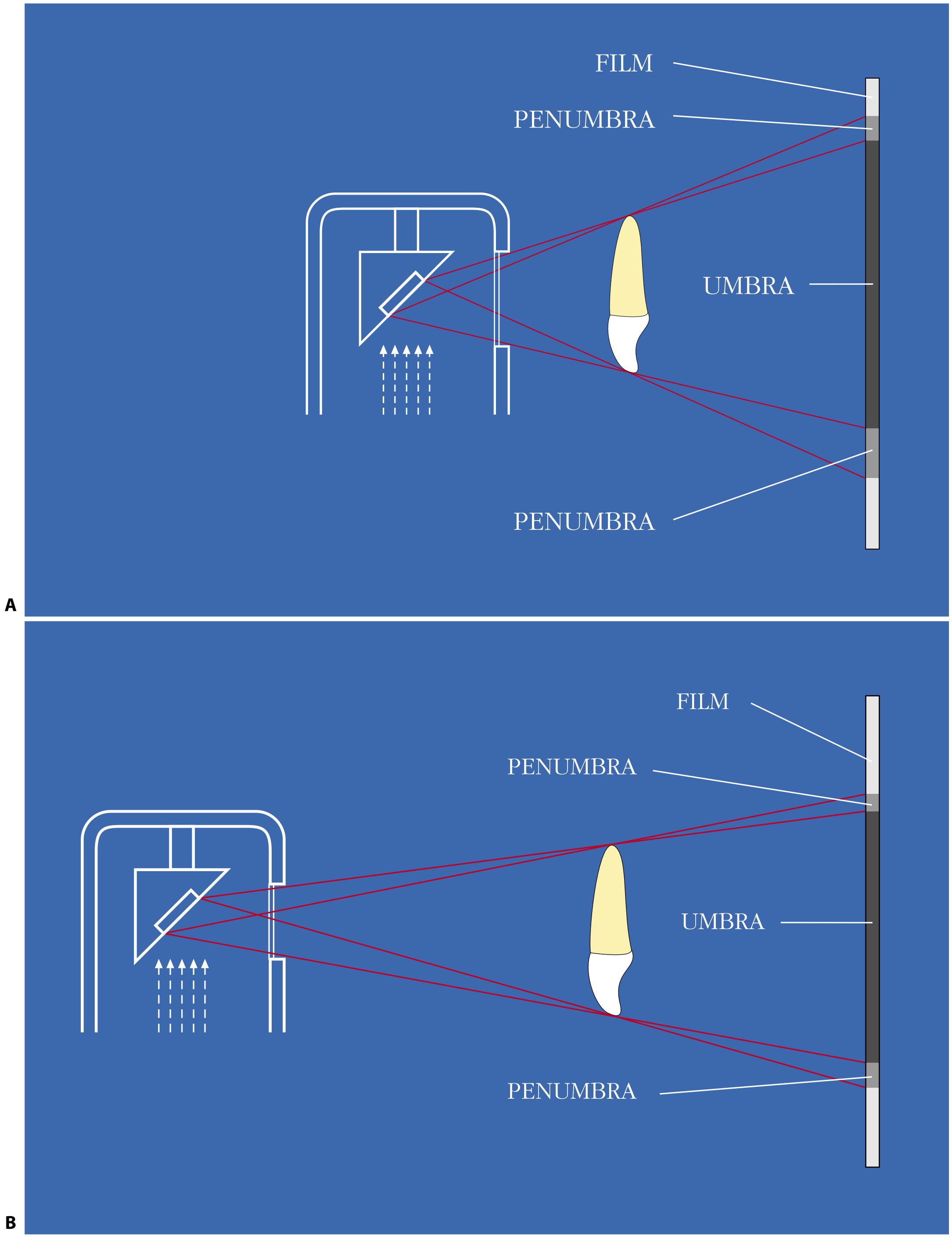


Fig. 5.14. **A, B**. Increasing the distance between the radiographic source and the object, the penumbra zone is reduced, with a consequent increase of sharpness and resolution, and the enlargement of the shadow with respect to the true size of the object is reduced (adapted from P.W. Goaz, S.C. White, Oral Radiology, The C.V. Mosby Company, St Louis, 1982).

ness and resolution by diminution of the "penumbra" zone and lesser enlargement of the shadow with respect to the real size of the object (Fig. 5.15).

Several practical suggestions may be deduced. Obviously, one cannot reduce the size of the target within the tube to allow one to take advantage of a smaller radiographic source; on the other hand, manufacturers are oriented toward the use of small targets, compatible with their capacity to dissipate heat. Furthermore, the use of X-ray machines with high kilovoltage and low milliamperage implies the use of a

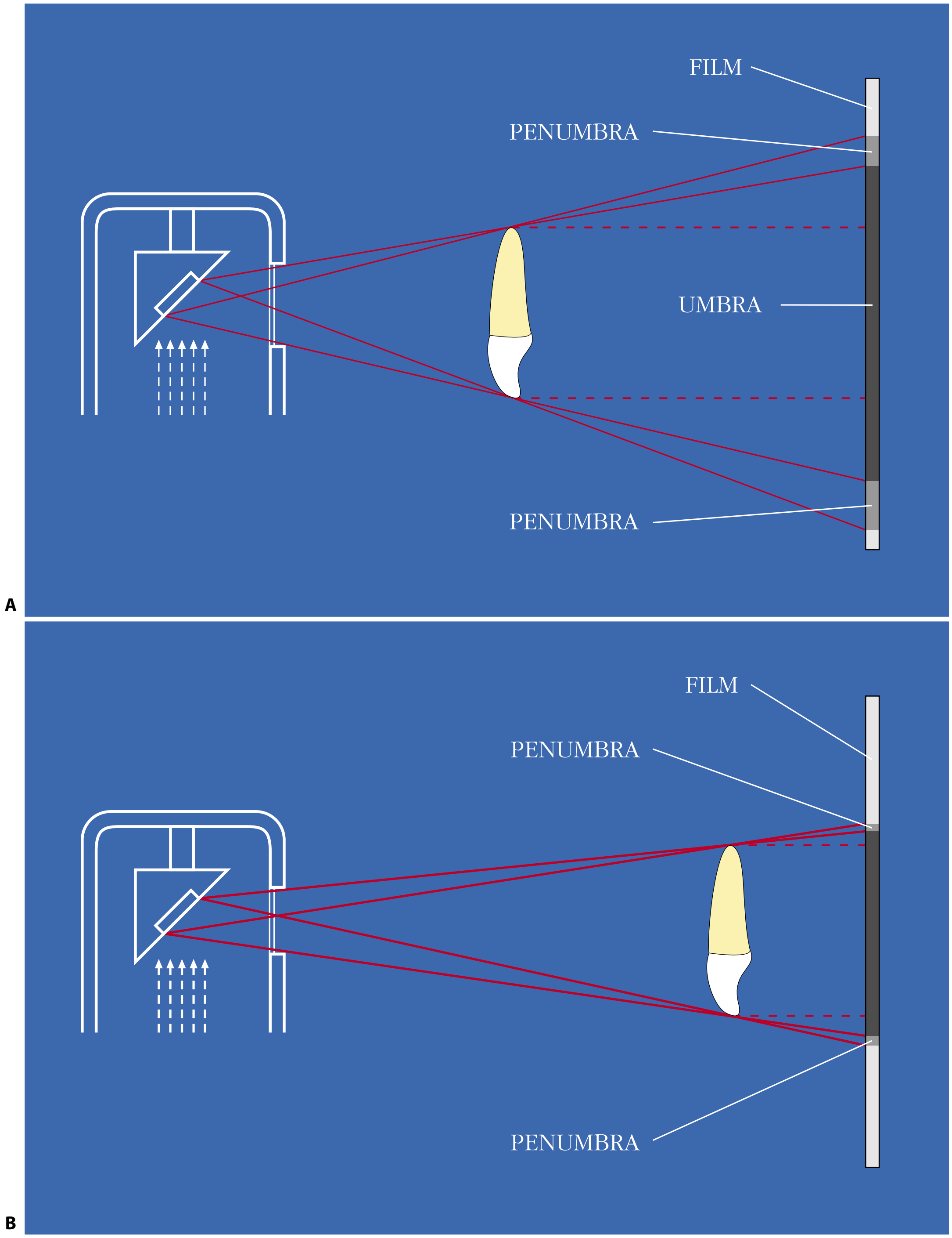


Fig. 5.15. **A, B**. Reducing the distance between the object and the film, the penumbra zone is again reduced, with a consequent increase of sharpness and resolution, and the enlargement of the shadow with respect to the true size of the object is further reduced (adapted from P.W. Goaz, S.C. White, Oral Radiology, The C.V. Mosby Company, St Louis, 1982).

beam of electrons focused on a small focal spot.[26] One aspect, in contrast, in which the radiologist can intervene is the focal spot-to-object and object-to-film distance. The use of a long cone is recommended, as is positioning of the film (anatomic conditions permitting) as close as possible to the zone or teeth being radiographed.

Image magnification

This reflects uniform enlargement of different parts of the same object, in other words an increase of the size of the image on the film as compared to the actual size of the object. This magnification is due to the divergent path of the photons that constitute the X-ray beam and that pass through a cone.
As already mentioned, to reduce this defect, it is necessary to increase the distance between the radiographic source and the object and to reduce the distance between the object and the film.
Once again, therefore, the use of a long cone is recommended (which implies the use of more parallel rays placed at the center of the conical X-rays beam), as is positioning of the film as close as possible to the tooth to be radiographed.

Image distortion

This is the result of unequal magnification of different parts of the same object.
This occurs when:
a) the parts of the object are not all at the same distance from the radiographic source
b) the parts of the object are not all at the same distance from the film.

a) In the first case, the X-rays are perpendicular to the film, but not to the inclined object (Fig. 5.16). A shortening of the radiographic image will result. This situation can be compared to the shadow that the human body projects onto the ground at noon on a clear Summer day: the shadow is almost entirely beneath the body and thus is significantly shortened. In this case, the rays are parallel to each other and perpendicular to the ground, but the body is inclined with respect to them.
b) In the second case, the X-rays are perpendicular to the object, but not to the film, which is inclined. A lengthening of the radiographic image will result. This situation can be compared to the shadow the body projects onto the ground when it is illuminated by the setting sun: the shadow is significantly

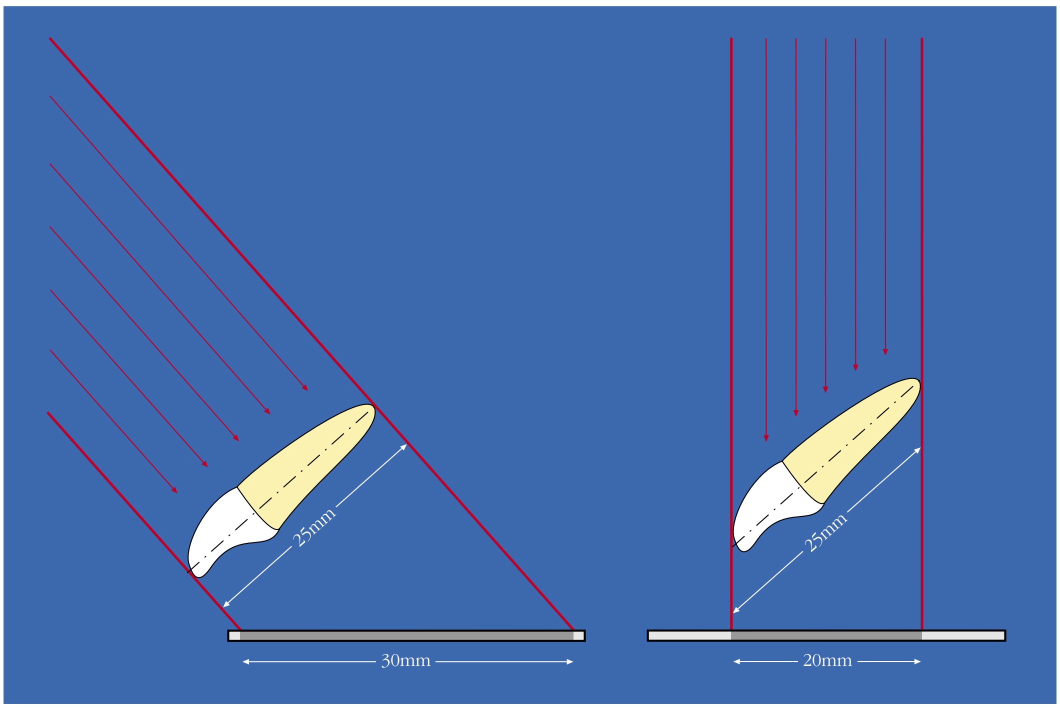


Fig. 5.16. If the X-rays are perpendicular to the object, but not the film, the radiographic image will be elondated. If, instead, the X-rays are perpendicular to the film, but not the object, the radiographic image will be shortened (adapted from P.W. Goaz, S.C. White, Oral Radiology, The C.V. Mosby Company, St Louis, 1982).

lengthened, as the ancient Etruscans had already noted (Fig. 5.17).

To eliminate, or in any case minimize, such distortions, it is necessary to have parallelism as much as possible between the film and the long axis of the tooth to be radiographed, so that the X-rays are perpendicular to both. This, obviously, is always possible in the lower arch, but is quite difficult to achieve in the upper arch because of the presence of the palate.[2]

Fig. 5.17. Etruscan statuette representing the evening shadow.

INTRAORAL RADIOGRAPHIC TECHNIQUES

The most frequently used endoral radiographic techniques are:

– the short cone and bisecting angle technique
– the long cone and paralleling technique.

Bisecting angle technique

This technique, described at the turn of the century by Price[42] and Cieszynski,[10] is based on the principle of positioning the film as close as possible to the lingual surface of the tooth, without causing deformation of the film. In this way, there will be no parallelism between the plane of the film and the long axis of the tooth, and the rays not being able to be directed perpendicularly to both planes, are directed perpendicular to an imaginary plane in the middle (in such a way that they reach an acceptable compromise), which is represented by the bisector of the angle formed by the two named planes (Fig. 5.18).

With this technique, the coronal portion of the tooth is close to the film or actually in contact with it, while the apex is situated at a considerable distance. A distortion therefore results that will be more accentuated at the apical end of the root. This is especially true

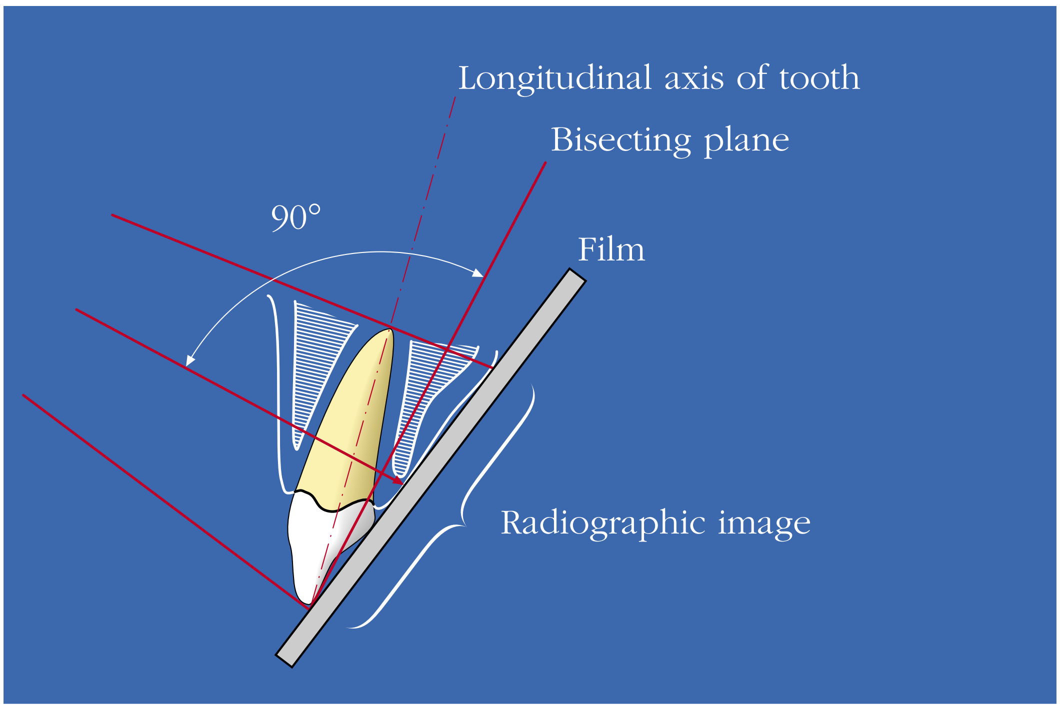


Fig. 5.18. Principle of the bisecting rule.

in the case of teeth of the maxilla and anterior mandible.
Furthermore, if the X-ray beam, rather than being directed perpendicularly to the bisecting angle, is perpendicular to the plane of the film, the image of the tooth will appear shortened (Fig. 5.19). If, on the other hand, it is perpendicular to the long axis of the tooth, the image will appear elongated (Fig. 5.20).

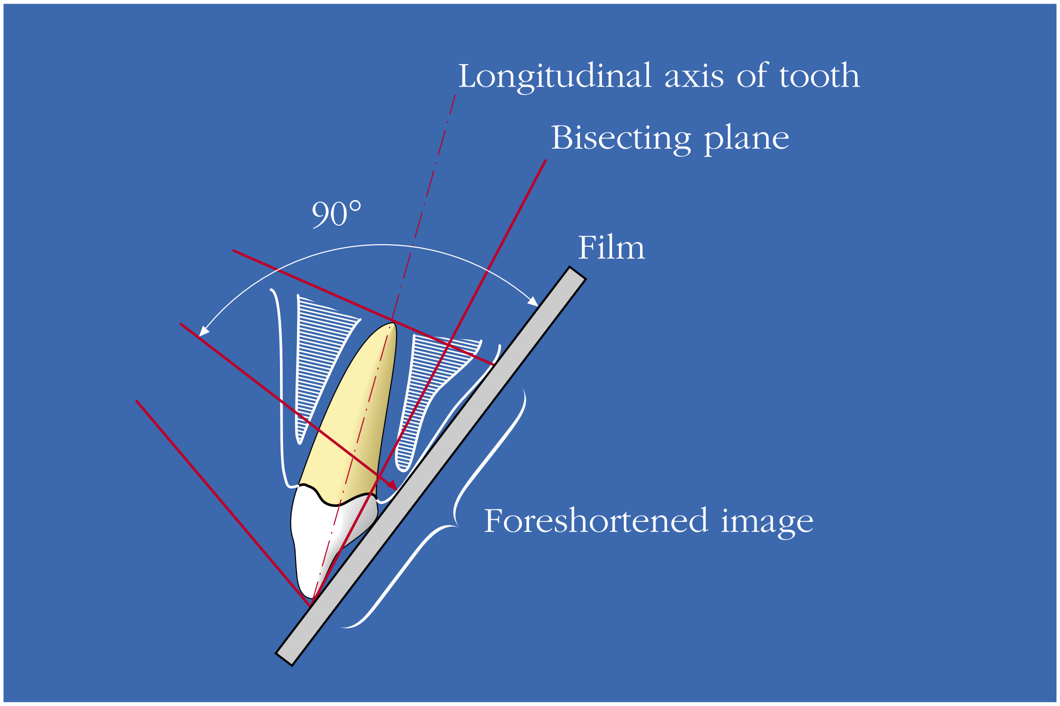


Fig. 5.19. If the X-ray beam is oriented perpendicularly to the plane of the film, the radiographic image will be shortened.

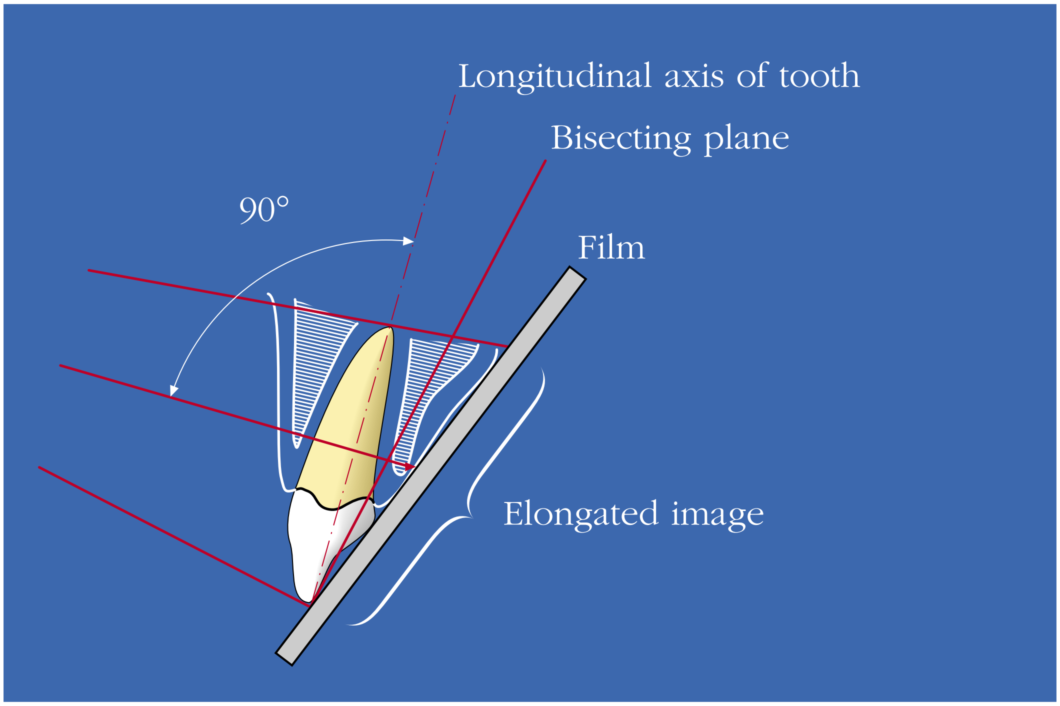
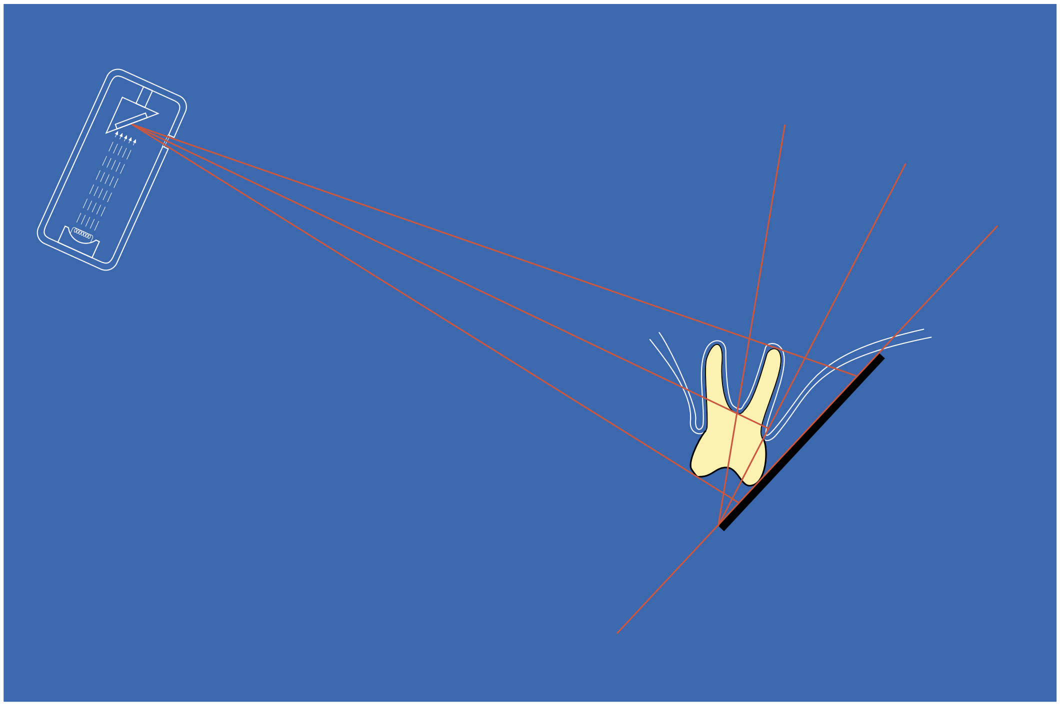


Fig. 520. If the X-ray beam is oriented perpendicularly to the long axis of the tooth, the radiographic image will be elongated.

For this reason, when a radiograph is taken in the zone of the upper second molars using the bisecting angle technique the radiographic images show molars with elongated palatal roots and shortened vestibular roots (Fig. 5.21).
Furthermore, the zygomatic process of the maxillary bone is projected above the apical zone, blocking a clear view of this area (Fig. 5.22).
In recent years, the short cone and bisecting angle technique has been used less commonly in periapical radiology, while the long cone and paralleling technique is increasingly used.

A



B

Fig. 5.21. **A**. The bisecting angle technique applied to the region of the upper molars yields images with elongated palatal roots and shortened buccal roots. **B**. Applying the bisecting angle technique, the X-rays are perpendicular to the long axis of the palatal root, but not to the plane of the film and are furthermore angulated with respect to the long axis of the buccal roots. Furthermore, the zygomatic process of the maxillary bone is very often superimposed on the apices.

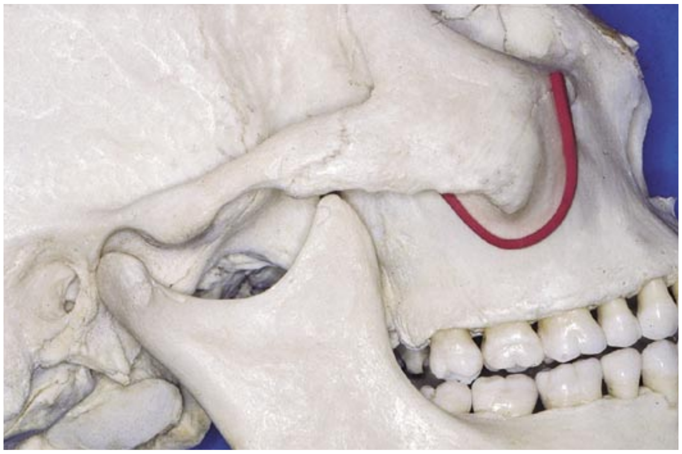


Fig. 5.22. The zygomatic process of the maxillary bone produces the white concave radiopacity directed upward which very frequently is superimposed radiographically on the apices of the roots of the upper molars.

Paralleling technique

Described by Fitzgerald[18,19] toward the end of the 1940s, this technique was realized by the introduction of higher energy X-ray generators and the advent of more "rapid", sensitive films.

This technique is based on the principle of placing the film parallel to the long axis of the tooth. By directing the rays perpendicularly to this axis (more easily verifiable as compared to searching for the perpendicular to the bisector), automatically they will also be perpendicular to the plane of the film (Fig. 5.23).

While it is relatively easy to achieve such parallelism in the lower arch by maintaining good contact between the teeth and the film (so as to avoid image magnification), it cannot be obtained in the upper arch without positioning the film away from the teeth, that is without positioning it toward the middle of the oral cavity, as is frequently necessary. Although this maintains the parallelism between the axis of the tooth and the plane of the film, the result is some image magnification and loss of definition by increasing the penumbra.

To reduce these undesired effects, it is imperative to use the long cone, which permits an increase of the distance between the radiographic source and the object, with the consequent use of more parallel rays (giving the technique its name), which causes less distortion in terms of magnification, as well as increased image sharpness and resolution.

The use of the long cone and therefore moving the radiographic source away would, however, lead to another undesired consequence: the need to increase the exposure time to retain the same degree of density and contrast. Because the intensity of an X-ray beam is inversely proportional to the square of the distance, an increase of the distance must be followed by either an increase of milliampere-seconds and thus an increase of the exposure time or, preferably, an increase of the kilovoltage.

These drawbacks are obviated by the use of high kilovoltage X-ray units and "rapid", that is, more sensitive, films, which need less exposure time to be adequately exposed (comparable in the photographic field to higher sensitivity films and higher ASA, which are suited to environments with little light).

The moderate distortion that occurs with this technique and which derives from positioning the film away from the tooth, differs from the sort of distortion that occurs using the bisector rule: in the latter, there is distortion of *shape*, so that the tooth appears elongated or shortened, especially apically, where the film is far

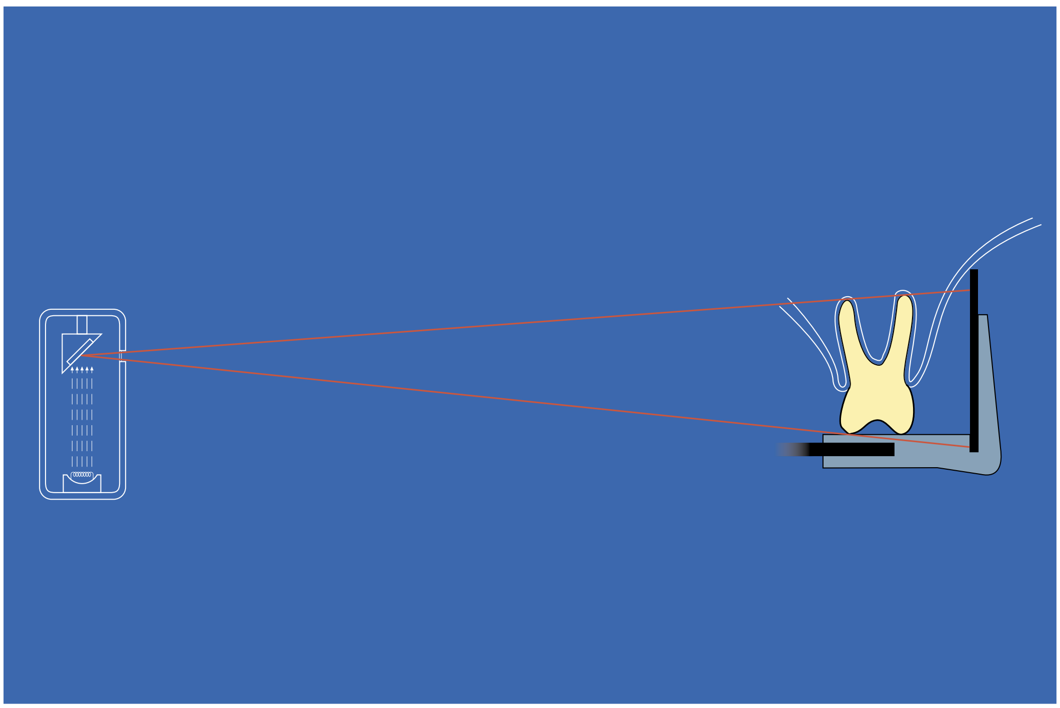


Fig. 5.23. Principle of the long cone and paralleling technique.

from the tooth. If, instead, the long cone and paralleling technique is used, the distortion affects the *size*, causing the entire tooth to appear slightly enlarged. According to Vande Voorde and Bjorndahl,[57] magnification is on the order of 1.054x, that is, 5.4%. The magnification factor is easily calculated by dividing the distance D1 (radiographic source-to-film) by the distance D2 (radiographic source-to-object): E (Enlargement) = D1/D2. It is therefore a uniform deformation that does not alter the relationships between the various anatomical structures (Fig. 5.24).

The proper application of this technique requires the use of appropriate film holders (Fig. 5.25) that allow the film to be properly positioned in the patient's mouth, thereby achieving the desired parallelism. Such film holders make the technique easy to learn and perform; moreover, they allow standardization: it is possible to obtain nearly identical radiographs with constant angulation on different occasions, a fundamental requirement for comparing postoperative radiographs with those performed later.

Despite the fact that the bisecting angle technique has been the most widely used in Endodontics, it is evident from Table I that most authors [3-6,9,15,21-24,32,33,52-55,57] prefer the use of the paralleling technique.

Fig. 5.24. The same quadrant of Fig. 5.21A has been radiographed with the paralleling technique. Note the disappearance of the shadow of the zygomatic process of the maxillary bone and the proper dimensional relationships between the buccal and the palatal roots.

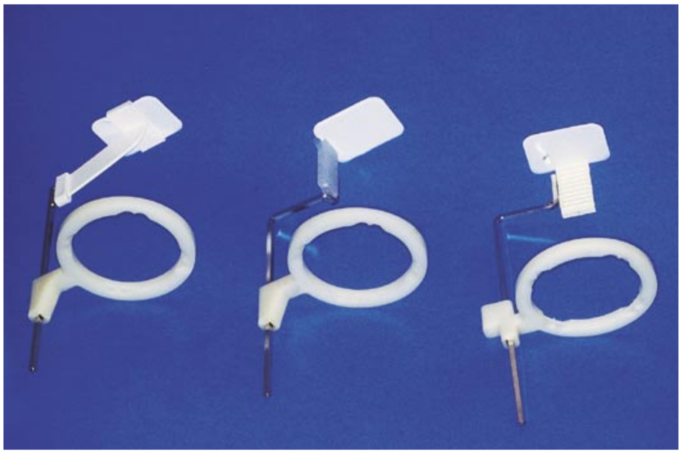


Fig. 5.25. Rinn's film holders, for the proper application of the principle of the long cone and paralleling technique.

Table I

Bisecting Angle Technique	**Parallel Ray Technique**
1) Details obscured by large penumbra	1) Sharp details because of small penumbra
2) Superimposition of zygomatic process	2) Control of the shadow of the zygomatic process
3) Image shape distortion	3) Slight image size distorsion
4) Distortion greater in apical zone	4) Distortion equal throughout the entire image
5) Anatomical relationships altered	5) Correct anatomical relationships
6) Crown-root ratio not preserved	6) Crown-root ratio preserved
7) Poor image standardization and reproducibility	7) High image standardization and reproducibility

SPATIAL LOCALIZATION: BUCCAL OBJECT RULE

As already stated, the radiograph is a two-dimensional representation of three dimensional structures and objects. In practice, it is nevertheless frequently necessary to extract three-dimensional information to allow better spatial localization of certain structures with respect to others.
The most frequently used and most easily performed method for obtaining such information is the "Buccal object rule", which was described by Clark [11] in 1910 and refined and amplified by Richards in 1952 [43] and 1980.[44] According to this rule, when a radiograph is performed at a certain angle, the object closer to the radiographic source – the buccal object – is displaced in the radiograph in the same direction as the X-ray beam. This rule, which is used to determine the relative buccal-lingual location of different structures of the oral cavity,[27] is of fundamental importance in dentistry in general, but in Endodontics in particular, where it finds numerous practical applications (Fig. 5.26).
– The first such application is recognizing the apex of the buccal root during endodontic treatment of a first upper premolar with two roots (Fig. 5.27).
To determine from radiographic examination of a first upper premolar which of the two roots is the buccal and which the palatal, it suffices to know the angle of the X-ray beam and to examine the radiograph closely. If the radiograph has been done at a slight mesiodistal angle, the X-rays have been directed from

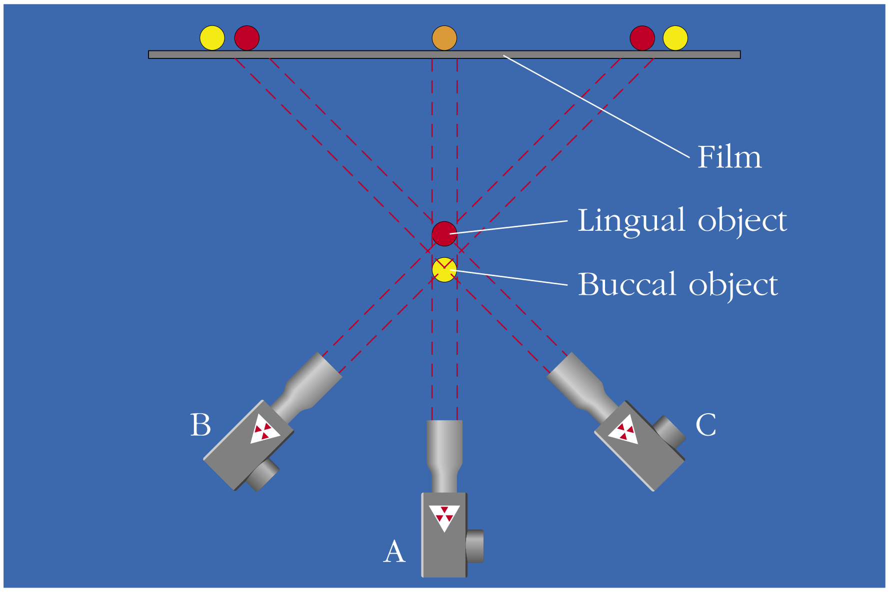


Fig. 5.26. With an orthoradial projection (A), the two objects appear superimposed. With an oblique projection (B, C), the two objects cease to be superimposed and easily become recognizable when the angulation of the X-ray machine is known: the buccal object (the one closest to the radiographic source) is displaced in the same direction as the X-rays.

A B

Fig. 5.27. **A.** With the standard projection, the roots appear superimposed. **B.** Angling the X-ray machine in a mesiodistal direction, the buccal root appears close to the second premolar, while the palatal root appears close to the canine.

mesial to distal; therefore, the buccal root (closer to the radiographic source as compared to the palatal, which is obviously farther) will appear in the radiograph to be displaced in the same direction as the X-ray beam, that is, distally. In other words, the buccal root will appear to be closer to the root of the second premolar, while the palatal root will appear closer to the root of the canine.

If this technique is standardized so that the upper premolars are always radiographed at a slight mesiodistal angle, the buccal roots will always appear to be distal, while the palatal roots will be mesial. Obviously, if the angle of the X-ray beam was reversed in a distomesial direction, the buccal root would appear close to the canine in the radiograph, while the palatal would appear close to the second premolar.

Such displacements may not be so easily obtained in the radiograph if the tooth is unnaturally rotated around its own axis.

– The same rule also applies to the upper molar region, which many endodontists consider one of the most difficult zones to treat because of the difficulty of obtaining properly oriented radiographs that show the apices of the roots that require treatment without the superimposition of nearby anatomical structures. In the case of upper molars, especially if their roots are not wide apart, radiographs frequently demonstrate the apices of the buccal roots to be superimposed on the palatal root (Fig. 5.28).

For good visualization of the distobuccal root, the X-ray tube can be angled mesiodistally. In this way, the distobuccal root (buccal object with respect to the palatal root) is displaced distally and is therefore uncovered from the superimposed shadow of the palatal root, to lie in the space mesial to the mesiobuccal root of the second molar (Fig. 5.29). When, once the preparation of the distobuccal canal has been completed and one continues to the mesiobuccal canals, it is necessary to change the angle, because if the same angle is maintained, the mesiobuccal root appears completely superimposed on the palatal root. Therefore, this time the X-ray angle will be distomesial, so that the root is displaced mesially and in the new radiograph it appears in the space immediately distal to the second premolar (Fig. 5.30).

– Another anatomical structure that can complicate treatment of the molars is the zygomatic process of the maxillary bone.

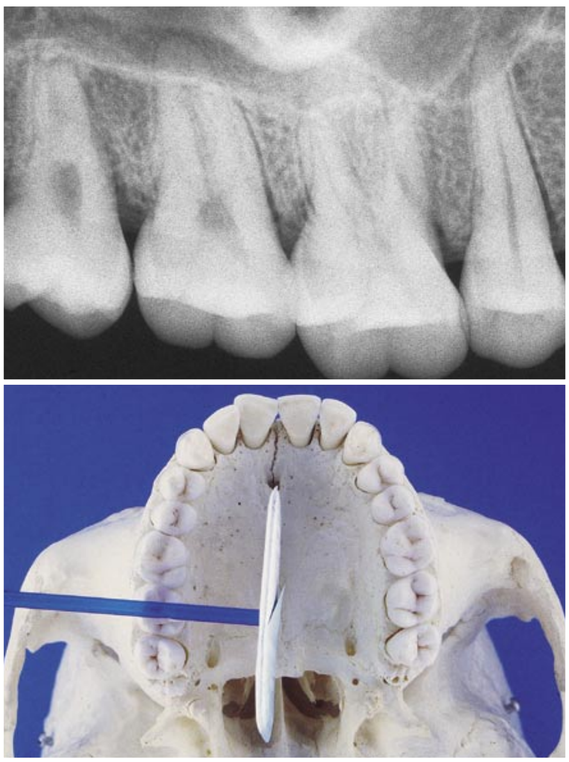


Fig. 5.28. **A.** This radiograph demonstrates the apices of the buccal roots of the second molar superimposed on the palatal root. **B.** Path of the X-rays in a standard projection.

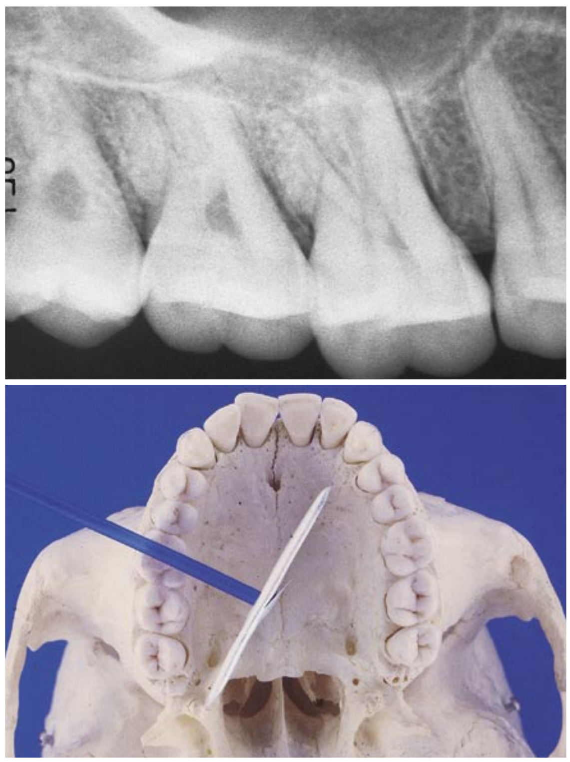
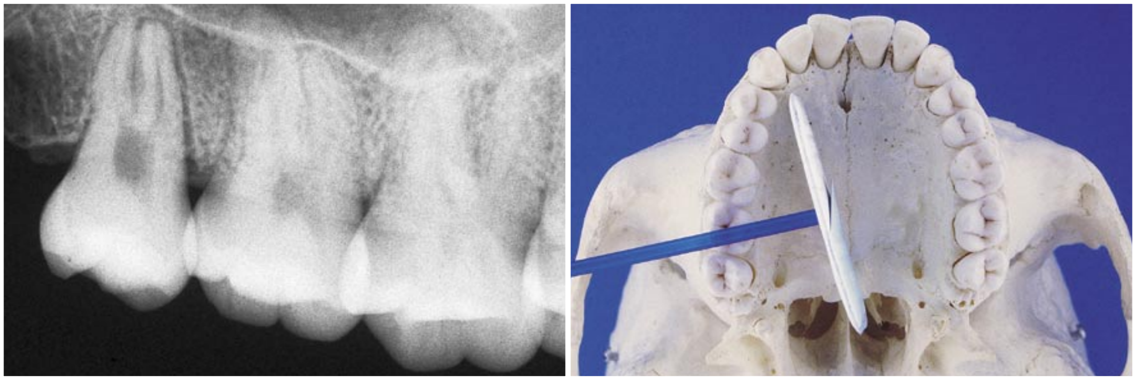


Fig. 5.29. **A.** Angulation of the X-rays mesiodistally takes away the distobuccal root from the superimposition with the palatal root. **B.** Path of the X-rays in the mesiodistal projection.

This structure can be superimposed on the apices of the molar under treatment, making it difficult, if not impossible, to determine the working length of the instruments. In this case also, the application of Clark's rule can be enormously helpful, as this structure is on a different plane (more buccal) with respect to the apices that we are treating.
In the case of the upper first molars, it is advisable that the shadow of this structure is displaced distally, angling the X-rays mesiodistally. This angle permits perfect visualization of the apices of the palatal root and of the distobuccal root (Fig. 5.31).
In the case of the upper second molars, on the other hand, it is frequently necessary to displace the shadow of the zygomatic process mesially, angling the radiographic cone distomesially (Fig. 5.32).



A B

Fig. 5.30. **A.** Distomesial angulation reveals the mesiobuccal root not superimposed on the palatal root. **B.** Path of the X-rays in the distomesial projection.

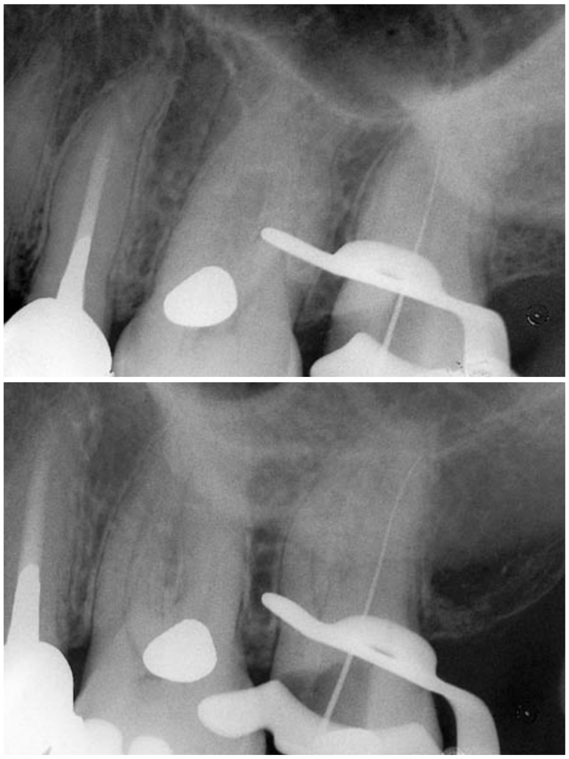
A B C D

Fig. 5.31. Application of the buccal object rule in the upper first molar for visualization of each root. **A.** The shadow of the zygomatic process completely obscures the apex of the palatal root. **B.** The X-ray machine has been angled mesiodistally (to displace the shadow distally) and also slightly corono-apically (to displace the same shadow more apically). Note that the shadows of the wings of the clamp are closer together consequent to the latter angulation. **C.** Keeping the preceding radiographic angulation, the working length of the distobuccal canal is checked. **D.** The X-ray machine has been angled distomesially: the palatal and distobuccal roots appear superimposed, while the mesiobuccal root is visible in its entire length.

As already stated, the dentist must consider the possible natural rotation of the tooth around its own axis, which may require that the X-rays be angled in the exact opposite manner to that just described (Fig. 5.33).

– Sometimes, even when the angle has been varied mesially or distally, it is not possible to eliminate the shadow of the zygomatic process, which continues to be superimposed on the apices of the molar.

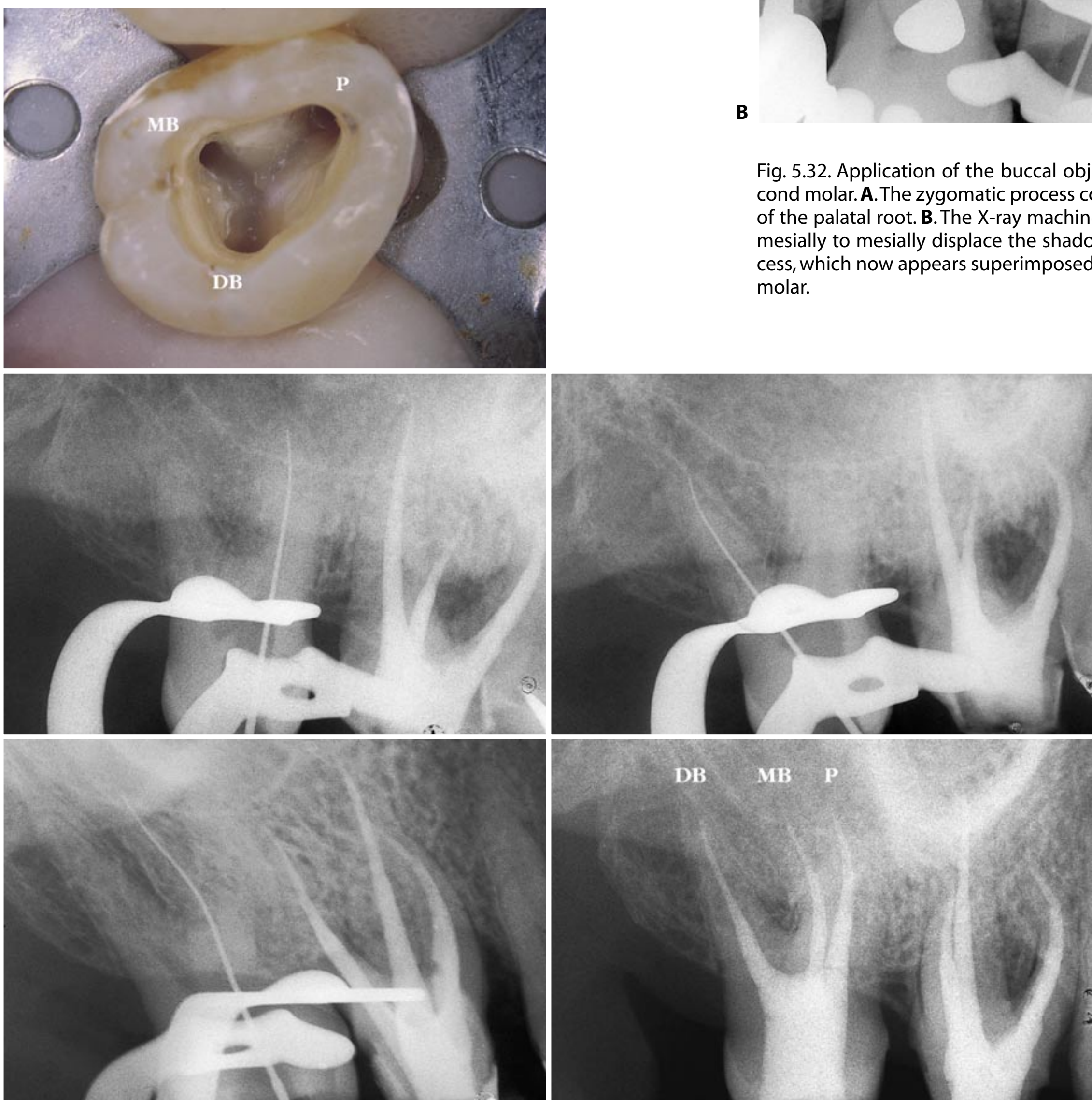
In such cases, rather than vary the horizontal angulation by rotating the X-ray unit on its vertical axis, so as to direct the X-ray beam mesially or distally (Fig. 5.34), the vertical angulation is varied by turning the unit around its horizontal axis, so as to direct the X-ray beam upward or downward (Fig. 5.35). More preci-



A

B

Fig. 5.32. Application of the buccal object rule in the upper second molar. **A.** The zygomatic process completely hides the apex of the palatal root. **B.** The X-ray machine has been angled distomesially to mesially displace the shadow of the zygomatic process, which now appears superimposed on the apices of the first molar.



A

B

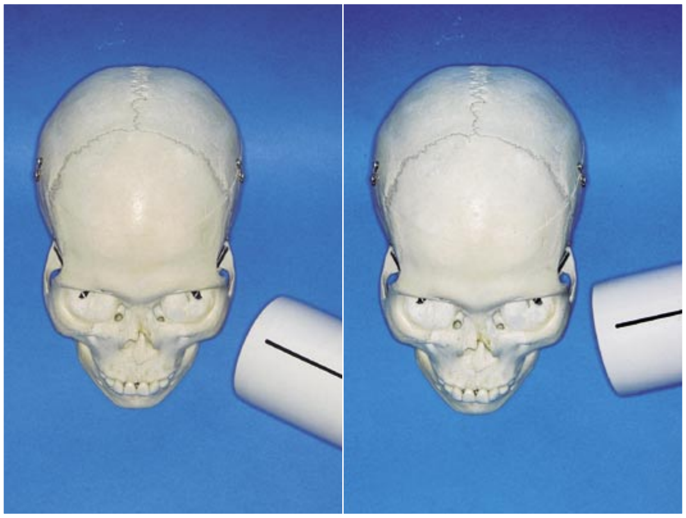
C

D

E

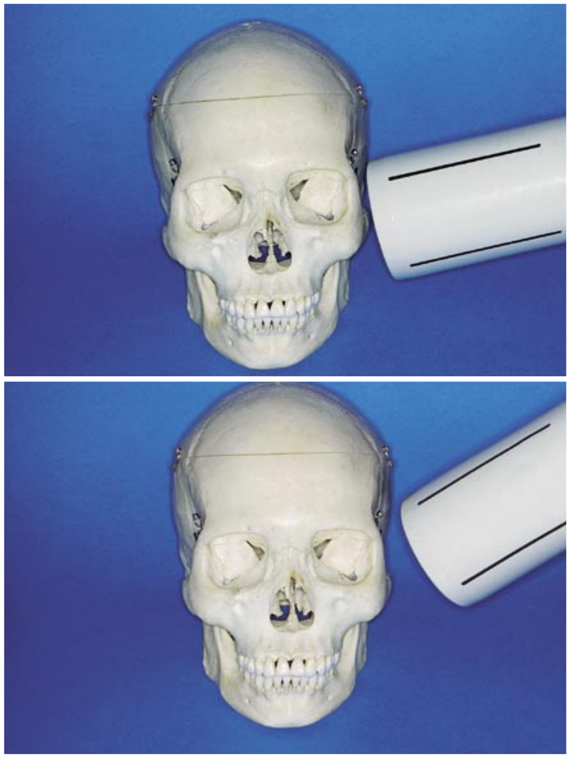
Fig. 5.33. **A.** Access cavity of a right upper second molar. The tooth is slightly rotated counterclockwise: the more mesial orifice is the palatal canal; the root that appears radiographically between the other two is the mesiobuccal one. **B.** With a distomesial angulation (which causes the mesiobuccal root to be superimposed upon the palatal root), the apex of the palatal root is visible. **C.** The same angulation also reveals the distobuccal root. **D.** The displacement of the X-ray machine mesiodistally has distally displaced the mesiobuccal root which no longer appears superimposed on the palatal root, but is easily identifiable. **E.** Post-operative radiograph. Proceeding distomesially, the distobuccal, mesiobuccal, and palatal roots are identified.

sely, angling the X-ray machine apico-coronally with respect to the occlusal plane of the patient (apico-coronal angulation), one achieves displacement of the shadow of the zygomatic process inferiorly and the apex of the palatal root will finally be evident (Fig. 5.36).



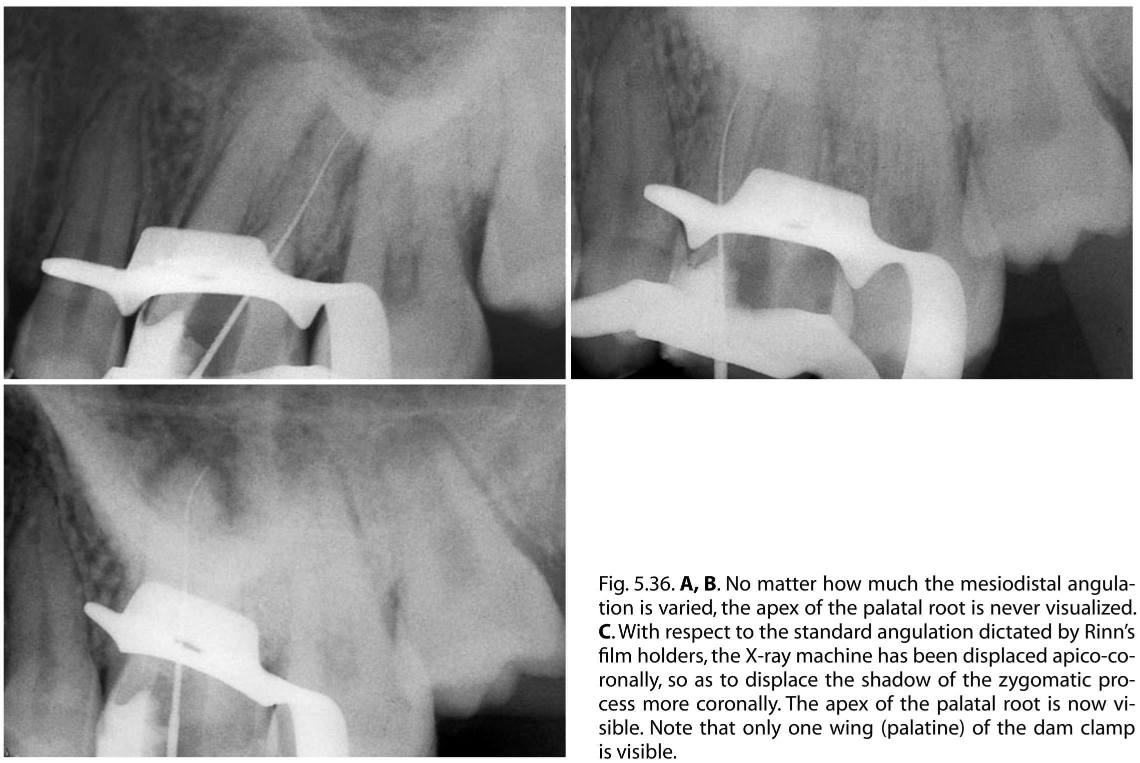
A **B**

Fig. 5.34. Rotation of the X-ray machine around its vertical axis. **A**. Mesiodistal angulation. **B**. Distomesial angulation.



A **B**

Fig. 5.35. Rotation of the X-ray machine around its horizontal axis. **A**. Corono-apical angulation. **B**. Apico-coronal angulation.



A **B** **C**

Fig. 5.36. **A, B**. No matter how much the mesiodistal angulation is varied, the apex of the palatal root is never visualized. **C**. With respect to the standard angulation dictated by Rinn's film holders, the X-ray machine has been displaced apico-coronally, so as to displace the shadow of the zygomatic process more coronally. The apex of the palatal root is now visible. Note that only one wing (palatine) of the dam clamp is visible.

– A radiolucency that appears above the apex of a tooth is not always on the same plane as that apex, and therefore is not always strictly related to it (Fig. 4.14A).
A second radiograph taken with a different angulation (Fig. 4.14B) can reveal, for example, that that radiolucent zone is situated in a palatal position with respect to the apex of the tooth (which therefore responds normally to the vitality tests) and therefore that one is not dealing with a lesion of endodontic origin, but rather, for example, the incisive foramen.
If one were dealing with a lesion and therefore if the two structures were in contact, there would be no displacement of their images in the two radiographs.[17,45]

– Another clinical situation in which the application of the buccal object rule can be of use is the presence of a foreign body.
A comparison of two radiographs taken at different angles can suggest the site (buccal or lingual) of the foreign body and thus the surgical approach for its removal (Fig. 5.37).
– Before beginning an apicectomy in the zone of the lower molars, it is obviously important to know the relationship between the apex of the roots being treated and the course of the mandibular canal. Two radiographs differing in their vertical angulation confirm that the apices of interest are in a more buccal position with respect to the course of the mandibular canal (Fig. 5.38).

A B

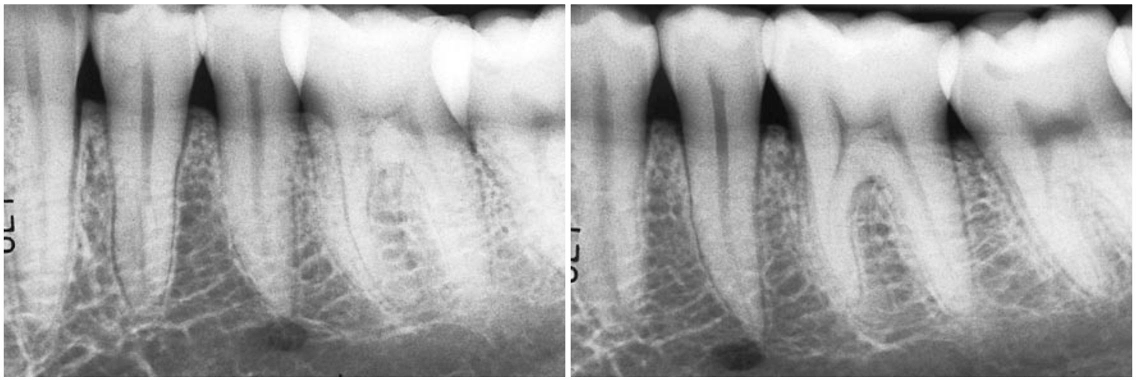
Fig. 5.37. **A**. The patient claims to have been hit with shot. Therefore, the round, radiopaque image seen at the level of the apex of the distal root represents a hunting shot. **B**. A second radiograph with a mesiodistal angulation reveals that the shot is not in contact with the root apex, but is more buccal.

A B

Fig. 5.38. **A**. A metallic wire introduced into the dry mandible in the mandibular spine demonstrates the path of the mandibular canal. **B**. A second radiograph obtained with greater corono-apical angulation (supero-inferiorly) confirms the more lingual position of the mandibular canal with respect to the apices of the second and third molars.

– A radiolucency at the apex of a lower premolar can be due to the radiographic image of the mental foramen (Fig. 5.39). The application of Clark's rule provides information on the spatial relationships between the two anatomical structures. If in the distomesial radiograph the radiolucency loses contact with the apex of the premolar and migrates mesially, it surely represents the mental foramen.

– Furthermore, it is possible to determine whether a dental inclusion is buccal or palatal in location (Fig. 5.40). This obviously allows the appropriate surgical approach.



A B

C

Fig. 5.39. **A**. The radiolucency at the apex of the lower second premolar could be diagnosed as a lesion of endodontic origin. **B**. A second radiograph taken with a different angulation (disto-mesial) confirms that the radiolucency is none other than the mental foramen. **C**. A third radiograph with increased corono-apical angulation confirms once again that the structure is more buccal with respect to the apex of the second premolar.

A B

Fig. 5.40. **A**. Radiograph of the unerupted upper left canine. **B**. A second radiograph taken with greater corono-apical angulation reveals that the canine is in palatal inclusion (note the diminished portion of the apex of the lateral incisor superimposed on the crown of the unerupted canine).

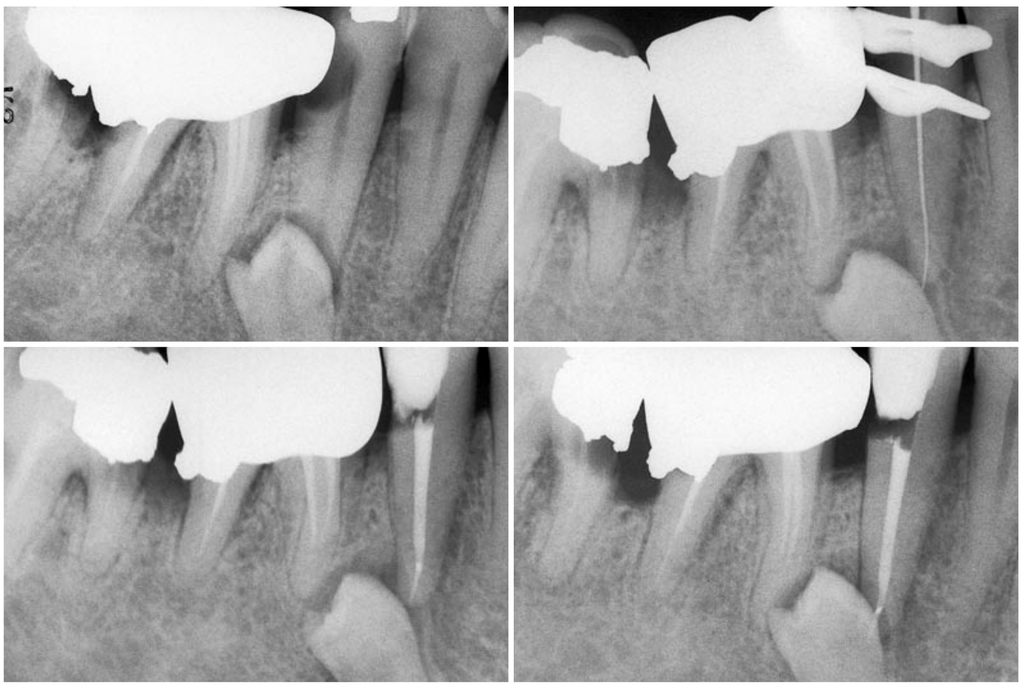
– In the case of Figure 5.41, it was ascertained by application of the buccal object rule that the curve of the apical one third of the root of the upper right central incisor was directed in a buccal direction.

– Finally, in the case of Figure 5.42, the presence of a slight, palpable swelling at the level of the buccal fornix led to the suspicion of a buccal bone inclusion of a supernumerary tooth.

Clark's rule, however, confirmed that the unerupted tooth was lingual, and permitted the proper en-

A B C D

Fig. 5.41. **A**. Preoperative radiograph of the upper right central incisor. The apical foramen rests on the same plane as the path of X-rays: it could be facing buccally or palatally. **B**. A second radiograph with a distomesial angulation reveals that the curve faces buccally. Endodontic therapy has been completed, keeping this angulation, which in this case also allows the visualization of the radiographic terminus of the canal. **C**. Postoperative radiograph. Note that only with this angulation does the small endodontic lesion at the level of the root apex become visible. **D**. Post-operative radiograph performed in standard projection. Note that the filling can seem short by almost 2 mm and the lesion already healed!



A B C D

Fig. 5.42. **A**. A supernumerary premolar hides the apex of the necrotic lower right second premolar, which is the cause of the slight buccal swelling of which the patient complained. **B**. A distomesial angulation confirms the lingual position of the supernumerary tooth and allows the complete visualization of the apex of the second premolar. An apico-coronal angulation has also been provided to inferiorly shift the shadow of the unerupted tooth. **C**. Postoperative radiograph with the same angulation. **D**. Postoperative radiograph with a standard angulation.

dodontic treatment on the necrotic second premolar. These are only some examples of the practical application of the buccal object rule, which can and must be applied each time the spatial location of two anatomical entities or structures, one buccal and the other lingual or palatal, must be determined: to which root does the image of a certain canal filling correspond? Is the broken instrument present in the lingual canal or in the buccal canal? One finally found one canal in the mesial root of a lower molar: is one in the mesiobuccal or mesiolingual canal? To which cusp on the preoperative radiograph must one refer to determine the working length of the instruments? The images are superimposed: what new angle must one give to the X-ray tube? Does the root lie in the maxillary sinus or is it buccal to it? A tooth is partially hidden by one wing of the dam clamp: is it the buccal or the palatal wing? The root has an inclined horizontal fracture: is it angulated buccally or lingually (Fig. 5.43)?

A B

Fig. 5.43. **A**. Preoperative radiograph of a traumatized right upper central incisor. The root has a horizontal fracture. The radiograph simulates the presence of a lentil-shaped radicular fragment interposed in the fracture line. **B**. A second radiograph with greater apico-coronal angulation reveals that there are two and not three radicular fragments and that the fracture line is directed palatally.

RADIOGRAPHIC ORIENTATION

When reading a radiograph, one must first of all orient it properly. It is wrong to discuss a radiograph and interpret it without determining up, down, right, and left.
First of all, one must recall that radiographs must be examined in such a way that the teeth are oriented the same way as in the patient's mouth: the observer must have the teeth of the right-sided quadrants to the left and those of the left-sided quadrants on the right. In this way, the images are in the anatomical position and have the same relationship with respect to the examiner as when he or she is facing the patient. The dentist can thus pass from examining the teeth to the radiographs without eye fatigue and without having to cross the midline with the gaze.[26]
To properly orientate radiographs, however, the dentist and the assistant who will later develop the film must observe a fundamental rule that must be applied from the moment in which the radiograph is positioned in the mouth. Each film, of whatever brand, has a small round impression (or "dot") in one corner on the back of the wrapper (Fig. 5.44).
The radiograph must be placed in the patient's mouth in such a way that the dot is always in the occlusal position.
A small convexity on the film facing the anterior part of the radiograph – and thus the source of X-rays – corresponds to this mark.
The assistant who develops the radiograph in the dark room can identify this corner even in the dark because of this convexity, and the film holder will be placed there. In this way one avoids placement of the film holder on the apex of the tooth of interest, leaving a halo or a stain.
When the radiograph is later dried, it will be easy to orient it based on the position of the convexity: the radiograph must be read with the convexity facing the viewer, just as, within the wrapper, it faced the X-ray source.

Fig. 5.44. On the reverse side of every radiograph there is a symbol (a black dot on Kodak DF 58, a circle on Kodak DF 57), which is useful for proper orientation of the film in the patient's mouth (left). The symbol on the external part of the envelope corresponds to a concavity on one side (center) and therefore a convexity on the other side of the film (right), which is useful for positioning of the film clip in the dark room and for right/left orientation.

This is the only way to know whether one is facing the right-sided or left-sided teeth.
Obviously, as already said before, this rule must be recognized by all the office personnel, first of all the dentist, then the assistants, especially the ones who develop and file the radiographs.

ENDORAL RADIOGRAPHIC EXAMINATIONS

A) PREOPERATIVE OR DIAGNOSTIC RADIOGRAPHS

It is unthinkable to begin an endodontic treatment without having radiographed the tooth in question.
It is always necessary to perform a preoperative radiograph of the patient; from it, one can extract a considerable amount of information (see Chapter 4). Sometimes, it can even be useful to have several radiographs taken from different angles to better evaluate the situation.
The diagnostic quality of every radiograph must be optimal so that the operator may draw from it the greatest amount of information possible.
For this reason, each radiograph must include the entire area of interest. The apices of the teeth must be completely visible, and they must be at least 3 mm away from the border of the radiograph.[56]
If there is a lesion around the apex of a tooth, a radiograph that shows the entire lesion and some surrounding healthy bone must be obtained.[26] If the periapical radiograph is not adequate, it will be necessary to resort to occlusal or extraoral radiographs (Fig. 5.45).
Furthermore, the radiographs must have as little distortion as possible. This requires careful angulation of the X-ray tube and accurate positioning of the film in the patient's mouth.
Finally, the radiographs must be developed, fixed, rinsed, and dried well to be free of stains, scratches, or other artefact that could occur as a result of mishandling (Fig. 5.46).
It is suggested that the preoperative radiograph always be obtained using a special type of radiograph that contains two films per wrapper (e.g., Kodak's Ultrarapid DF 57) (Fig. 5.47), because the patient may ask for a copy of "his/her" radiograph. While it is true that the documentation regarding a patient must not leave the premises for fiscal or medicolegal reasons, the patient has all the reason to claim that the radiograph of "his/her" tooth be given to him/her, since he/she should feel free to ask for the opinions of other dentists without having to repeat the radiographs. Using double films, the problem is solved from the start.
The radiograph must then be positioned in the patient's mouth in an optimal, stable, and reproducible manner. One must keep in mind that this radiograph will have to be compared with the postoperative film and to future radiographs, so that the technique must be as standardized as possible.
Numerous instruments for the intraoral positioning of radiographic films are on the market. The instruments of the Rinn Corporation, also called XCP (X-tension C-one P-aralleling) are particularly useful and easy to use. It goes without saying that positioning the radiograph with the patient's finger (Fig. 5.48), as was once suggested,[37] should be avoided.[5]

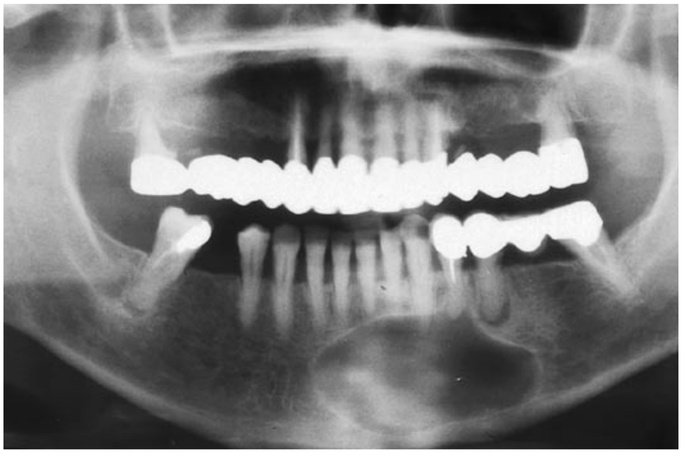


Fig. 5.45. In this case, in view of the lesion's extensiveness, a panoramic radiograph was obtained to visualize the limits of the radiolucency.

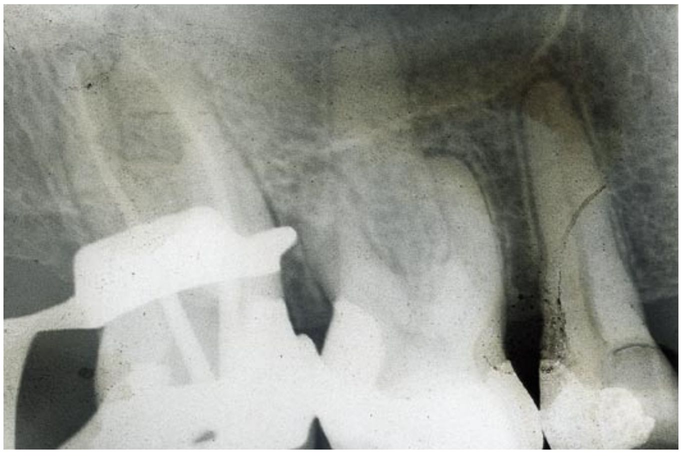


Fig. 5.46. The radiograph was not rinsed properly. At the level of the clip, there are large streaks of the fixer solution, evidently still present in the rinsing water.

Fig. 5.47 Ultraspeed radiographs DF 57 contain two films inside the envelop.

Fig. 5.48. Positioning of the film using the patient's finger doesn't give reproducible results (taken from McCoy, 1923).

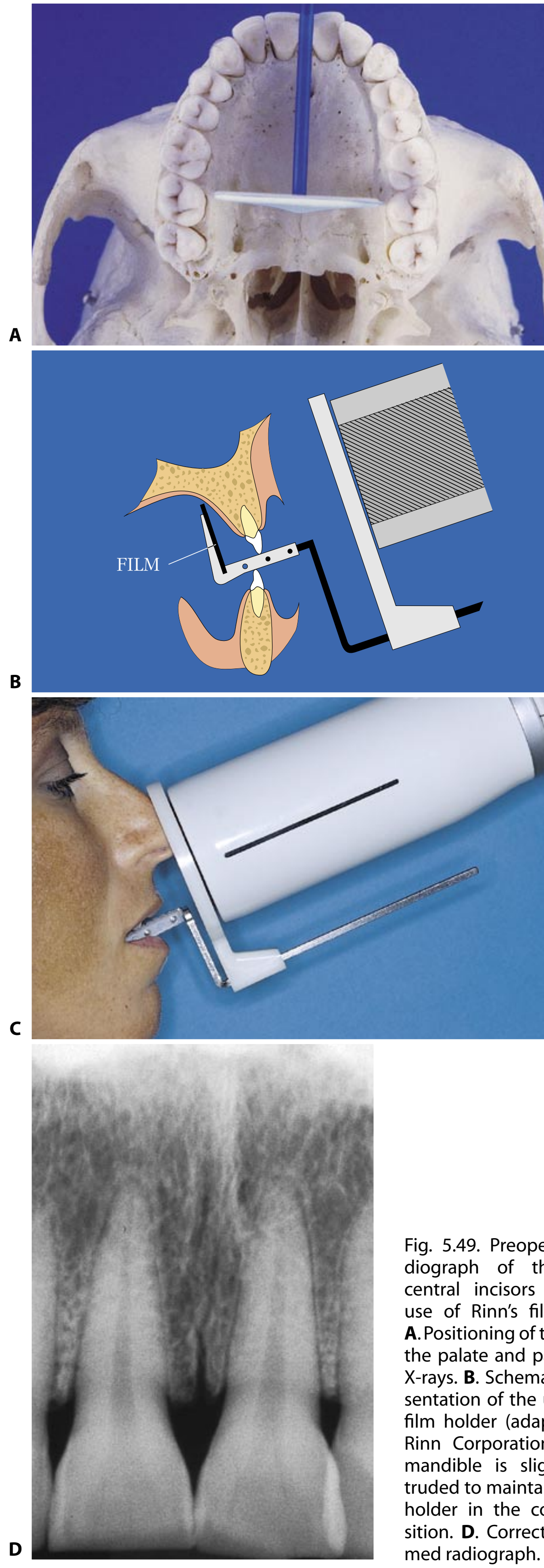
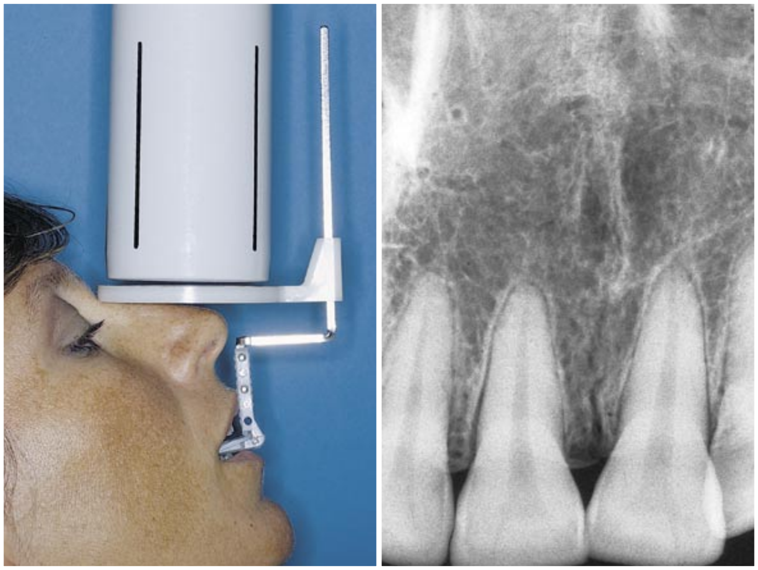


Fig. 5.49. Preoperative radiograph of the upper central incisors with the use of Rinn's film holder. **A.** Positioning of the film on the palate and path of the X-rays. **B.** Schematic representation of the use of the film holder (adapted from Rinn Corporation). **C.** The mandible is slightly protruded to maintain the film holder in the correct position. **D.** Correctly performed radiograph.

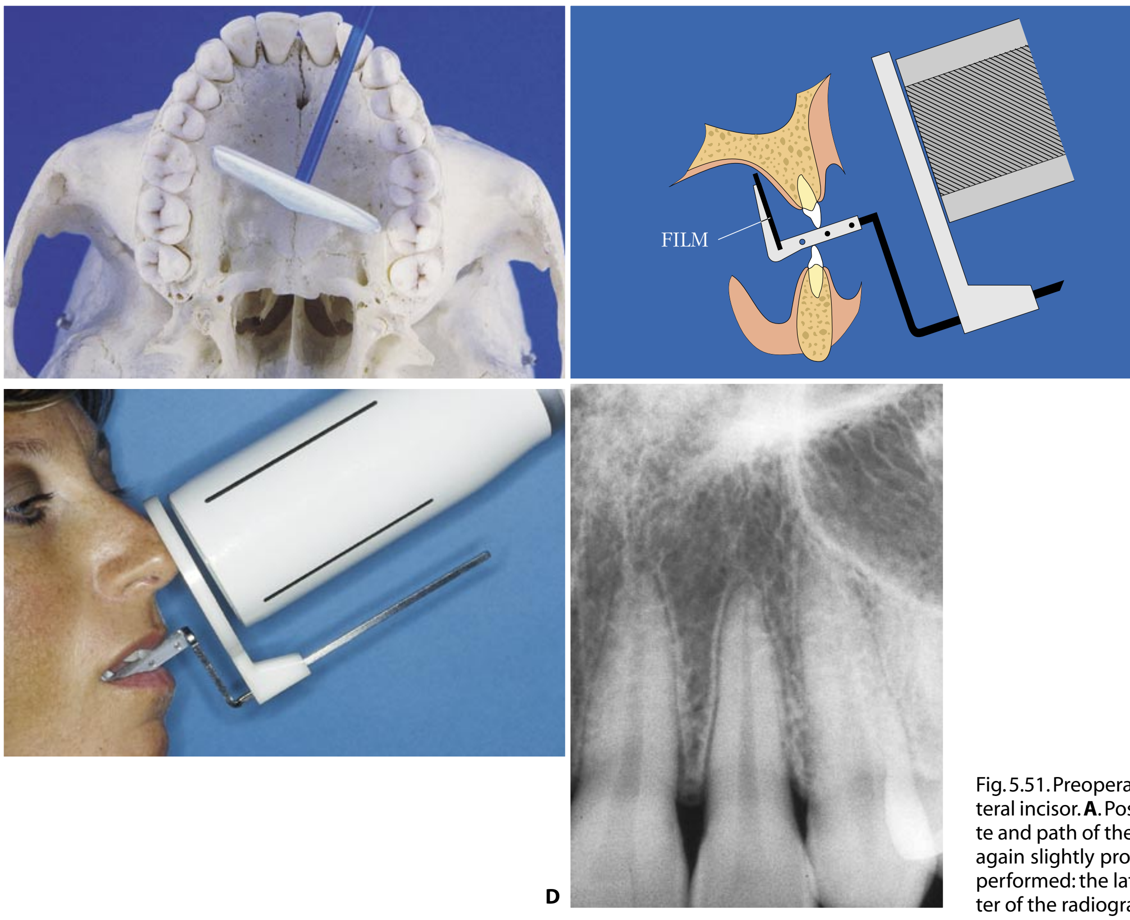
Upper incisors

The film must be positioned deeply enough in the palate, so that the apices are included in the radiograph.
The midline of the radiograph must coincide with the midline of the dental arch. The plane of the film must be parallel to the long axis of the teeth. For this reason, the patient must bite the plastic support, holding the mandible in a slightly protruded position (Fig. 5.49) to avoid improper positioning (Fig. 5.50).
When the palate is particularly low, it is necessary to interpose a cotton roll between the plastic support and the incisal border of the upper incisors to maintain the parallelism between the radiograph and the tooth.
In the case of the lateral incisor, the tooth of interest must be centered in the radiograph, without superimposition of the adjacent teeth (Fig. 5.51).



A B

Fig. 5.50. **A**. The mandible is not protruded, the corner of the plastic support is outside the mouth, and the X-rays are perpendicular to the radiograph but not to the long axis of the tooth. **B**. A shortened image results.



A B C D

Fig. 5.51. Preoperative radiograph of the upper lateral incisor. **A**. Positioning of the film on the palate and path of the X-rays. **B**. The mandible is once again slightly protruded. **C**. Radiograph correctly performed: the lateral incisor must be in the center of the radiograph.

Upper canine

Once again, one must make certain that the tooth is centered in the film in accordance with the parallelism rule (Fig. 5.52). The radiograph must be positioned with its larger side parallel to the long axis of the tooth.

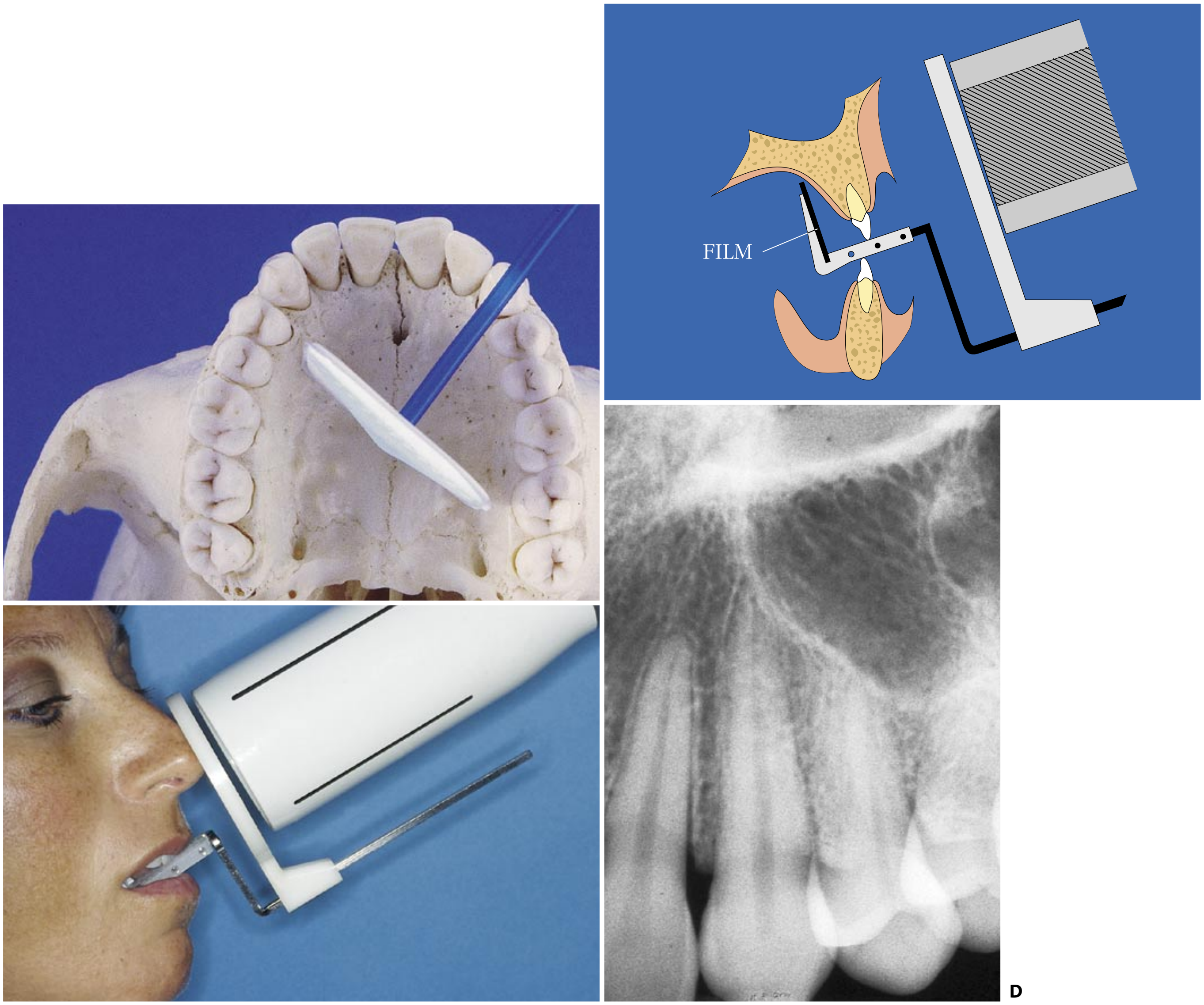


Fig. 5.52. Preoperative radiograph of the upper canine. **A**. Positioning of the film on the palate and path of the X-rays. **B**. The mandible, still slightly protruded, keeps the film holder in position. **C**. Radiograph correctly performed.

Upper premolars

The radiograph must be positioned in the palate far enough from the teeth being examined to allow the parallelism rule to be observed. The long axis of the film must be parallel to the occlusal plane. Because of the presence of the palate and the dental "arch", the two premolars are centered with much difficulty in the radiograph, while it will almost always be mesially displaced.

In addition to the premolars, part of the canine, the first molar, and the mesial portion of the second molar will be visible in the same radiograph (Fig. 5.53).

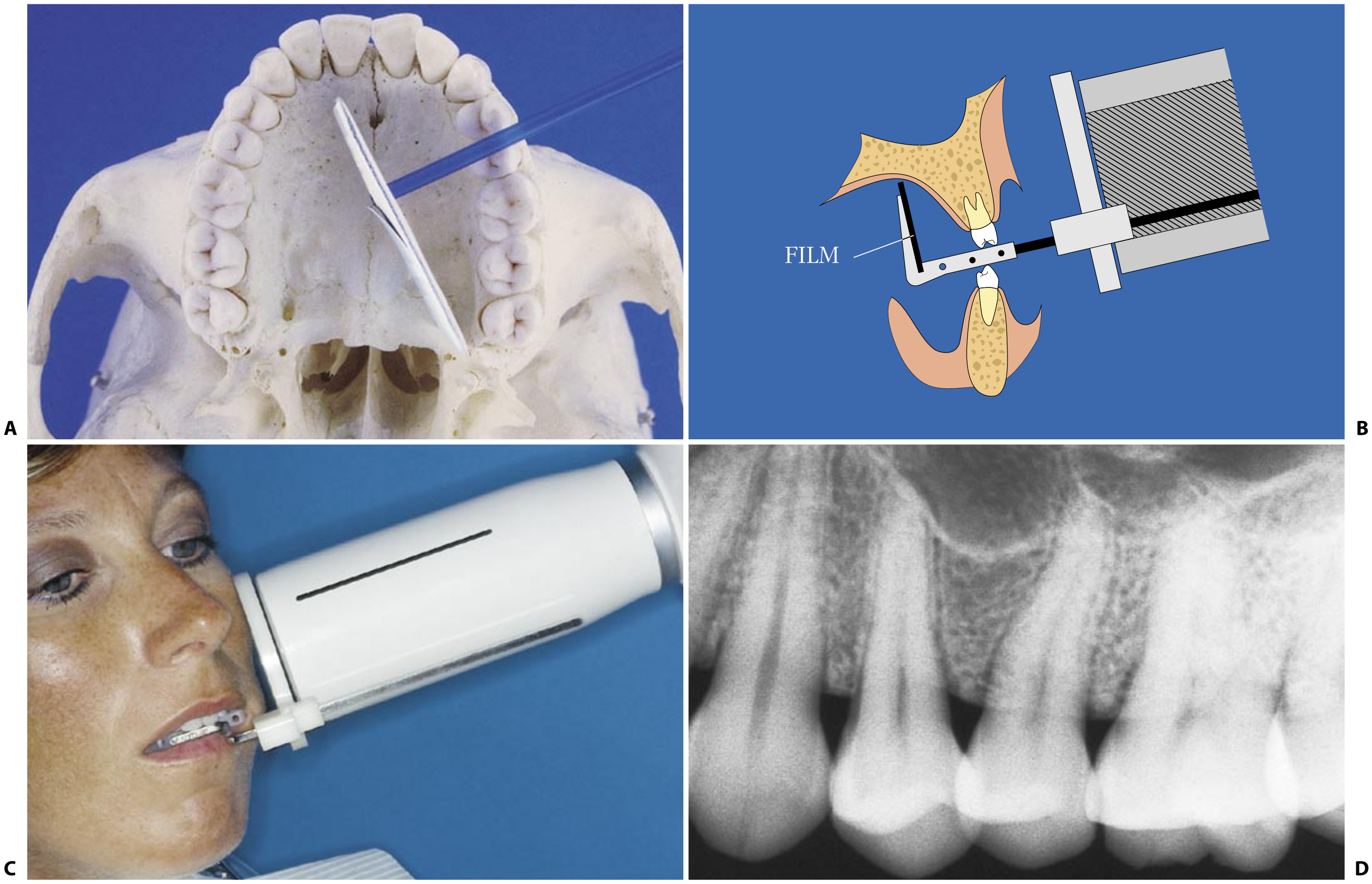
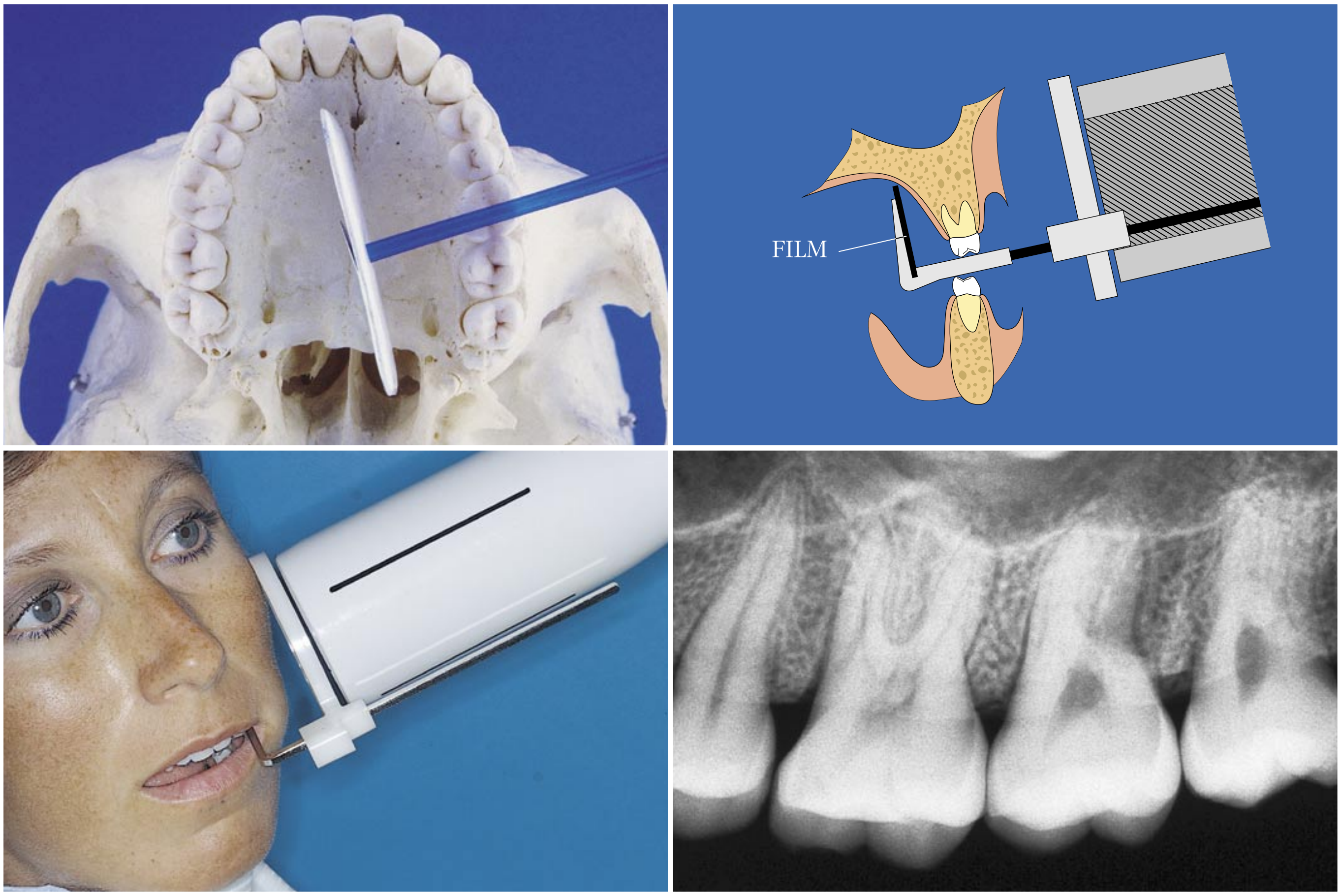


Fig. 5.53. Preoperative radiograph of the upper premolars. **A**. The film must be positioned with its long side parallel to the occlusal plane. **B**. Schematic representation of the use of the film holder (Rinn Corporation, modified). **C**. Correct positioning of the film holder in the mouth. **D**. Correctly performed radiograph.

Upper molars

The superior margin of the film coincides with the midline of the palate and the lower margin is parallel to the occlusal plane.
The film will thus show the distal portion of the second premolar and all three molars, without the superimposition of the zygomatic process of the maxillary bone (Fig. 5.54).
If the patient claims to have an easily stimulated gag reflex, one must take certain precautions.
The patient must be upright and not recumbent in the seat, and must cooperate by breathing deeply through the nose or not breathing for a moment. The patient must also avoid oral respiration. The radiograph holder must be positioned in such a way as not to touch either the base of the tongue or the soft palate. In some cases, it is advisable to rest the plastic support on the opposing teeth and then ask the patient to close together quickly. The X-ray tube should already have been positioned, so as to avoid any delays, and one must quickly leave the room to shoot the radiograph. Right then, every second counts.
Taking these precautions, one can obtain all the required radiographs, even in a patient with the most sensitive reflex.



A B C D

Fig. 5.54. Preoperative radiograph of the upper molars. **A.** The long side of the radiograph is aligned along the median line of the palate. **B.** Schematic representation of the use of the film holder (Rinn Corporation, modified). **C.** Correct positioning of the film holder in the mouth. **D.** Correctly performed radiograph.

Lower incisors

The film must be oriented vertically and rather posteriorly, but not too much, so as not to interfere with the lingual frenulum. The patient must then close the teeth, biting the plastic support.

Obviously, the law of parallelism must always be respected.

The lower incisor of interest must be centered in the film, since this guarantees the least distortion (Fig. 5.55).

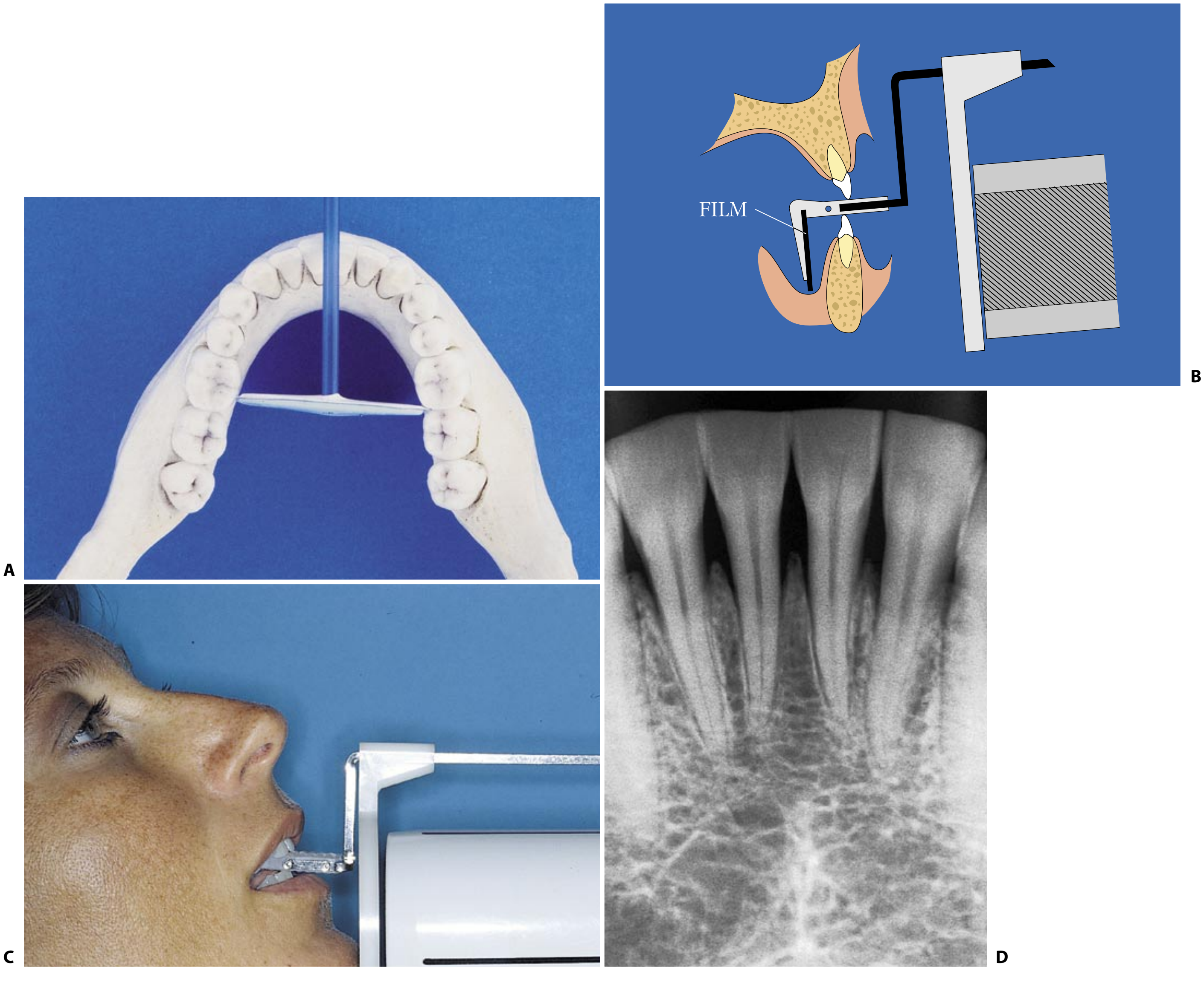
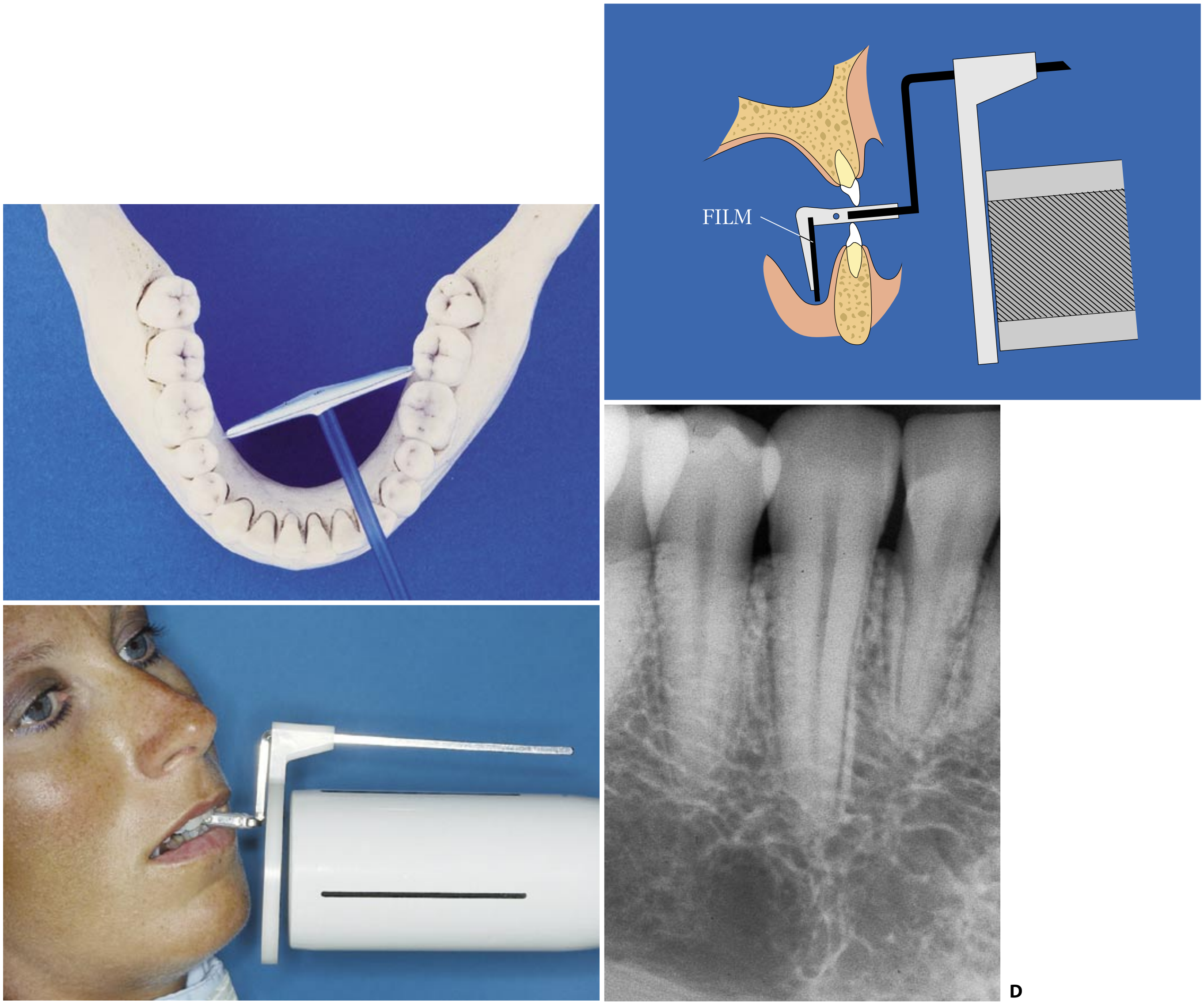


Fig. 5.55. Preoperative radiograph of the lower incisors. **A**. The radiograph is positioned vertically. **B**. Schematic representation of the use of the film holder (Rinn Corporation, modified). **C**. Correct positioning of the film holder in the mouth. **D**. Correctly performed radiograph.

Lower canine

The film must be positioned vertically with its long side parallel to the long axis of the tooth and the canine must be in the center of the radiograph. Respecting the presence of the frenulum and tongue, the film must be positioned in a considerably posterior position so as not to cause the patient pain in the floor of the mouth (Fig. 5.56).



A B C D

Fig. 5.56. Preoperative radiograph of the lower canine. **A.** The radiograph is positioned vertically. **B.** Correct positioning of the film holder in the mouth. **C.** Correctly performed radiograph.

Lower premolars

The radiograph must be positioned with its long side perpendicular to the long axis of the tooth. Its upper margin must be parallel to the occlusal plane.
Since the premolars are midway along the dental arch, they are difficult to center in the radiograph, which will reveal the distal aspect of the canine, the two premolars, the first molar, and the mesial portion of the second molar.
The radiograph must not be placed too close to the teeth, or else the patient will feel pain in the floor of the oral cavity (Fig. 5.57).

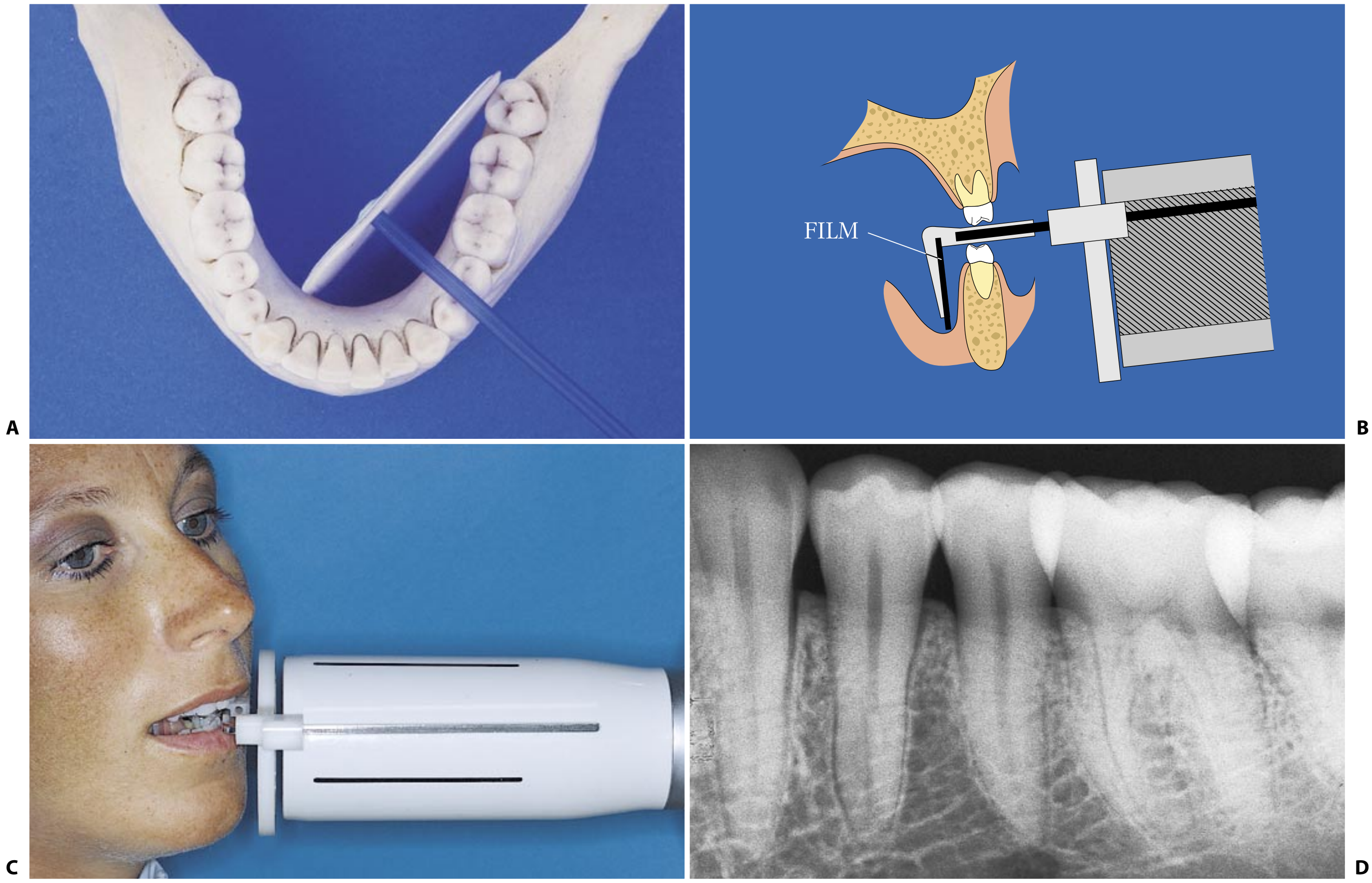


Fig. 5.57. Preoperative radiograph of the lower premolars. **A.** The long side of the radiograph is parallel to the occlusal plane. **B.** Schematic representation of the use of the film holder (Rinn Corporation, modified). **C.** Correct positioning of the film holder in the mouth. **D.** Correctly performed radiograph.

Lower molars

The radiograph must be positioned horizontally with the upper margin parallel to the occlusal plane. The plastic frame that contains the radiograph must find room between the tongue and teeth of the arch, so that it can descend into the lingual fornix without causing the patient any discomfort.

A patient who has an easily provoked gag reflex should be seated and asked to breathe deeply through the nose when the radiograph is introduced. Alternatively, the patient may be asked not to breathe for a moment.

If the patient, anticipating the gag reflex, uses the tongue to resist the introduction of the radiograph in the lingual fornix, the plastic support can be placed against the teeth of the upper arch while the patient bites down as he or she breathes through the nose. In this case, instead of one pushing the film down in the lingual fornix, it is the patient who raises both teeth and tongue alongside the radiograph and therefore the gag reflex will not be stimulated, nor will there be any pain in the floor of the mouth.

The distal portion of the second premolar and the three molars will be visible in the radiograph (Fig. 5.58).

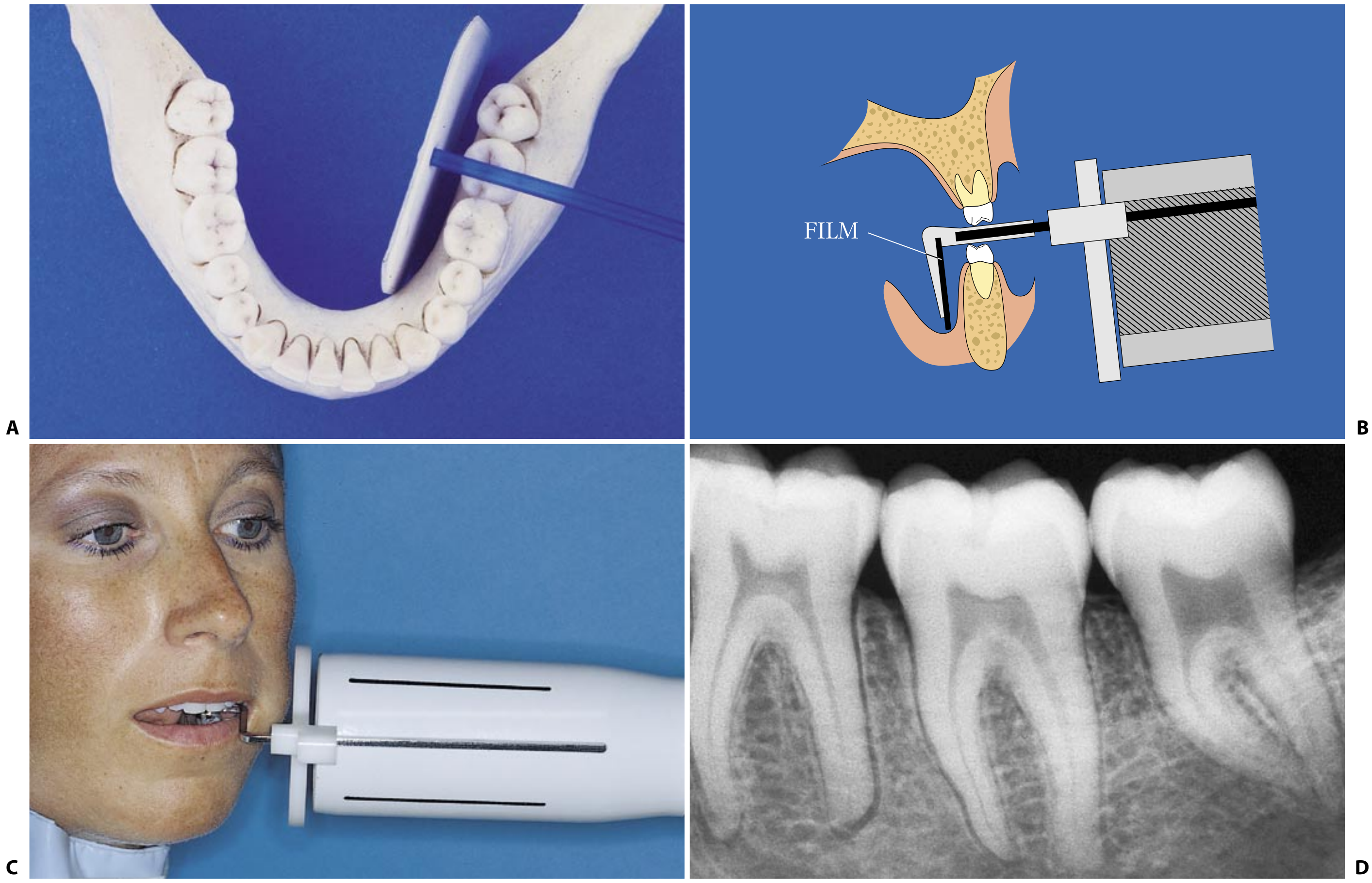


Fig. 5.58. Preoperative radiograph of the lower molars. **A**. The radiograph is positioned horizontally. **B**. Schematic representation of the use of the film holder (Rinn Corporation, modified). **C**. Correct positioning of the film holder in the mouth. **D**. Correctly performed radiograph.

B) INTRAOPERATIVE RADIOGRAPHS

The presence of the rubber dam, the metal clamp surrounding the tooth, and the instrument inside the canal preclude the intraoperative use of the standard film holders. Other film holders are available today (Fig. 5.59) which allow one to center the radiograph while using the rubber dam and having the instrument inside the root canal. The only disadvantage is that it is necessary to remove the frame of the rubber dam, therefore their use is not always easy and comfortable.

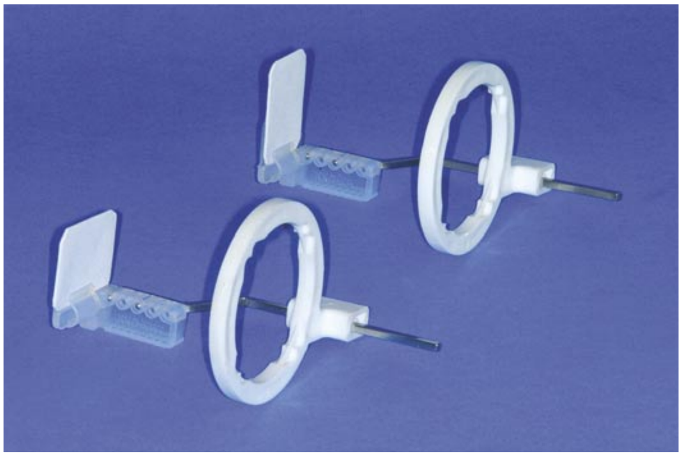


Fig. 5.59. Film holder to be used with the rubber dam to center the film while taking the working length.

In this case, the patient must hold the radiograph in position in such a way that the optimal conditions of the film holder are maintained.
Once again, one must avoid positioning with the patient's finger, as it frequently causes image distortion and complicates the dentist's control of the correct alignment of the film. Rather, the radiograph must be placed within the oral cavity with hemostatic forceps, or better yet Steiglitz's forceps (Fig. 5.60), which are thinner and less cumbersome. The forceps may be held in place by the patient's hand.
To assure the same intraoperative angulation as the preoperative radiograph, several tricks are necessary:
1. Before performing the preoperative radiograph, the patient must be seated in precisely the same position in which the work is to be done.
2. Once the preoperative radiograph has been obtained, the head and arm of the X-ray machine are moved away from the patient's mouth without changing the horizontal or vertical angulation.
3. If the patient arrives with his/her own preoperative radiographs done well or if the radiograph has already been done on a previous visit, the ideal angulation can be found simply by positioning the film holder again in the mouth without taking the radiograph. This only serves to give the radiographic cone the correct spatial orientation.

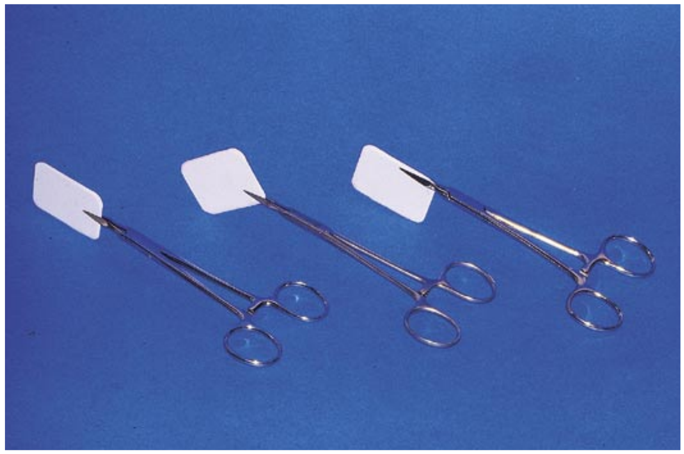


Fig. 5.60. Steiglitz's forceps is an optimal instrument to have the patient support the intraoperative radiographs under the rubber dam.

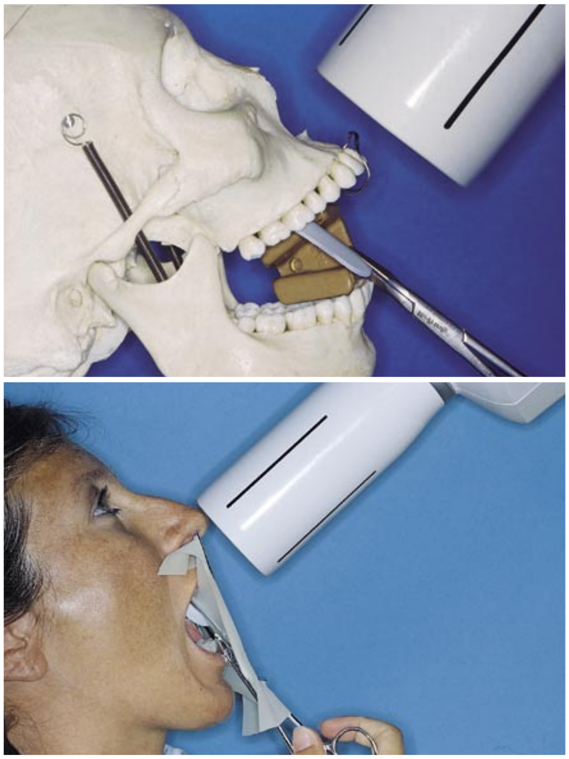
4. The forceps with which the film is introduced below the dam must be placed by the dentist and held by the patient in a position as close as possible to that of the pre-operative radiograph. Particularly in the upper arch, it must be at a certain distance from the tooth of interest (the presence of the wings of the dam clamp are helpful). The dot must be oriented towards the occlusal part; the occlusal border of the film must always be parallel to the occlusal plane.
Thus, one must be careful to observe the parallelism between the radiograph and the long axis of the tooth. The use of a light-colored dam helps with its trasparency in confirming the correct positioning.

Upper incisors and canines

The forceps are placed halfway along the short side of the radiograph and placed posteriorly in the palate. Shifting the dam slightly, it is possible to check the parallelism between the film and long axis of the tooth (Fig. 5.61).

Upper premolars

The forceps are placed at about 45° in the mesial angle. The radiograph is positioned horizontally in a slightly withdrawn position in the palate with respect



A B

Fig. 5.61. Intraoperative radiograph of the upper incisors and canines. **A**. Correct alignment of the film, parallel to the long axis of the tooth. **B**. The patient, using Steiglitz's forceps, keeps the radiograph in the same position as the film holder.

to the teeth to be radiographed (Fig. 5.62). One must keep in mind that if the cone is inclined in a mesio-distal direction, the palatal roots will appear mesial, while the buccal roots will appear distal.

Upper molars

Also in this case, the forceps are placed at 45° in the mesial angle and the film is positioned horizontally.
The upper margin of the film is placed along the median line of the palate, while the dam clamp separates it from the teeth (Fig. 5.63).
If the patient fears that the gag reflex will be stimulated, one must take care not to touch the palate, especially the soft palate, nor the base of the tongue. It helps to place the radiograph on the wing of the clamp. The patient is then requested to close the mouth partially and to breathe deeply through the nose.[26,49] Usually, it is not necessary to bring the patient back to the sitting position (see Table II).

A B

Fig. 5.62. Intraoperative radiograph of the upper premolars. **A**. The radiograph is held in place by the forceps at an angle of 45° in the mesial angle. **B**. The forceps are held by the patient with the contralateral hand.

A B

Fig. 5.63. Intraoperative radiograph of the upper molars. **A**. The long side of the radiograph is aligned along the median line of the palate. **B**. To keep the radiograph more firmly in position, the patient may hold Steiglitz's forceps against the lower incisors.

Table II

Precautions for abolishing or reducing the gag reflex during endoral radiography

1) The dentist must behave in a confident, decisive, and convincing manner.
2) The dentist must explain the procedure in such a way as to earn to patient's trust.
3) The positioning of the film must be done in a gentle but quick and resolute manner. The radiograph must be taken immediately, without any waste of time.
4) The patient is requested to swallow before positioning the film. This contributes to relaxing the tongue and causing it to lay down in the floor of the mouth.
5) The patient is asked to breathe deeply through the nose, since oral respiration favors the reflex.
6) In the most obstinate cases, the patient is asked to hold his breath.
7) The patient is asked to half-close the mouth.

To prevent the metallic frame of the dam from projecting its shadow onto the radiograph (Fig. 5.64), the dam is prophylactically placed in an asymmetric position with respect to the patient's face, so that the vertical arm of the frame is shifted distally and does not interfere with the teeth under treatment. For more security, the metallic frame can also be rotated so as to drape over the patient's nose (Fig. 5.65).

One must further keep in mind the usefulness of the application of the buccal object rule to radiographically isolate the apices of the roots which interest us (Fig. 5.66).

Lower incisors and canines

The forceps are placed on the short side of the film and plunged into the lingual fornix until the metal touches the neighboring teeth. This provides a point of support to the patient, who can thus easily keep the radiograph in the desired position (Fig. 5.67).

Lower premolars

The forceps are placed on the long side of the film and positioned so as to be perpendicular to the long axis of the teeth in question. To be certain of including the apices in the radiograph in addition to having a point of support, it is still necessary that the forceps rest against the opposing premolars (Fig. 5.68).

Lower molars

Also in this case, the forceps are placed on the long side of the radiograph, which must be parallel to the occlusal plane. The radiograph must descend into the lingual fornix until the metal of Steiglitz's forceps touches the incisive border of the lower incisors (Fig. 5.69).

It is necessary to recall that the inclination of the va-

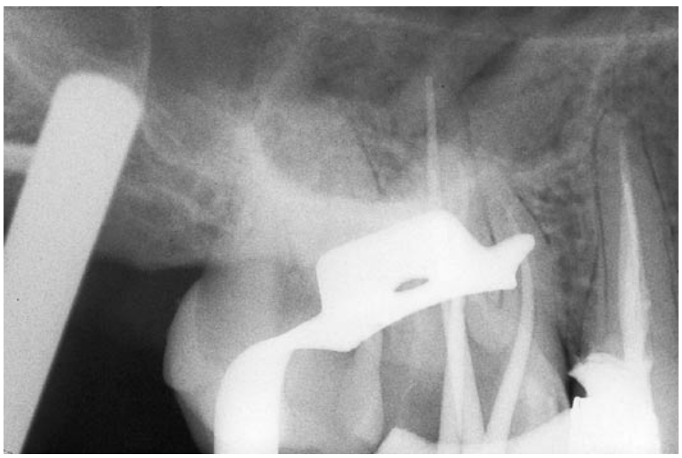


Fig. 5.64. The cylindrical shadow to the left is caused by the metal frame in the path of the X-rays.

Fig. 5.65. To avoid the radiographic superimposition of the metal frame of the rubber dam, one can turn the dam so that it drapes over the nose.

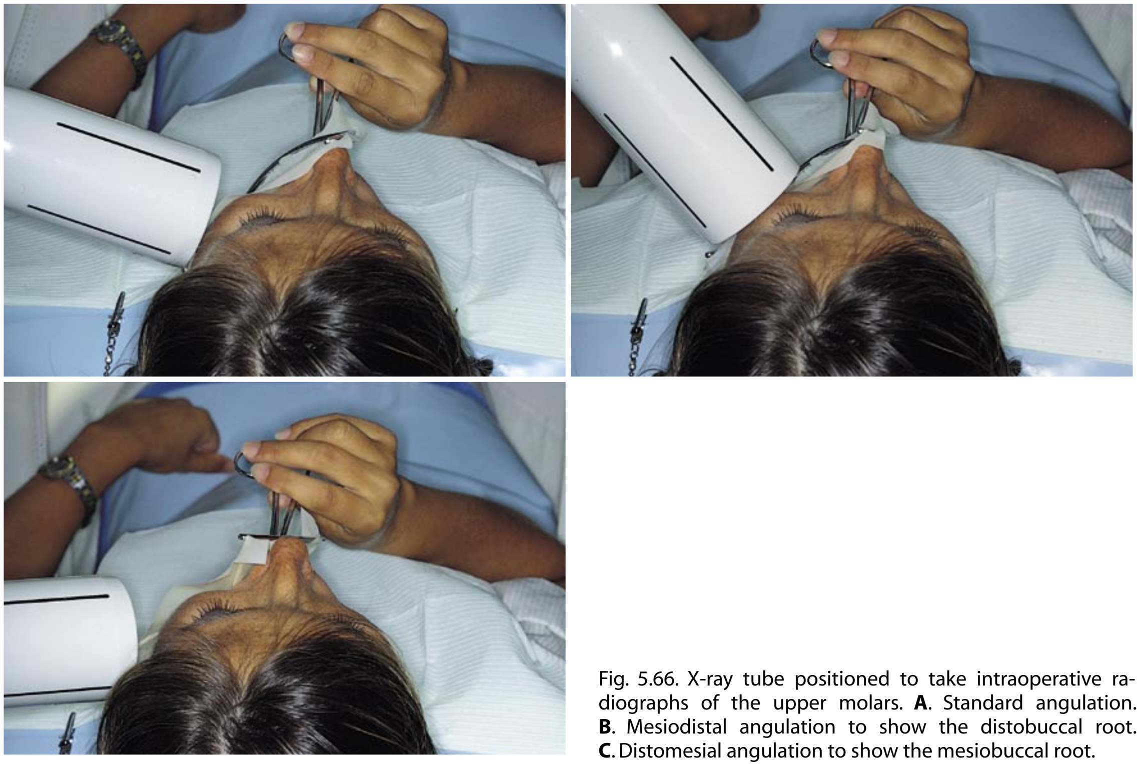


Fig. 5.66. X-ray tube positioned to take intraoperative radiographs of the upper molars. **A**. Standard angulation. **B**. Mesiodistal angulation to show the distobuccal root. **C**. Distomesial angulation to show the mesiobuccal root.

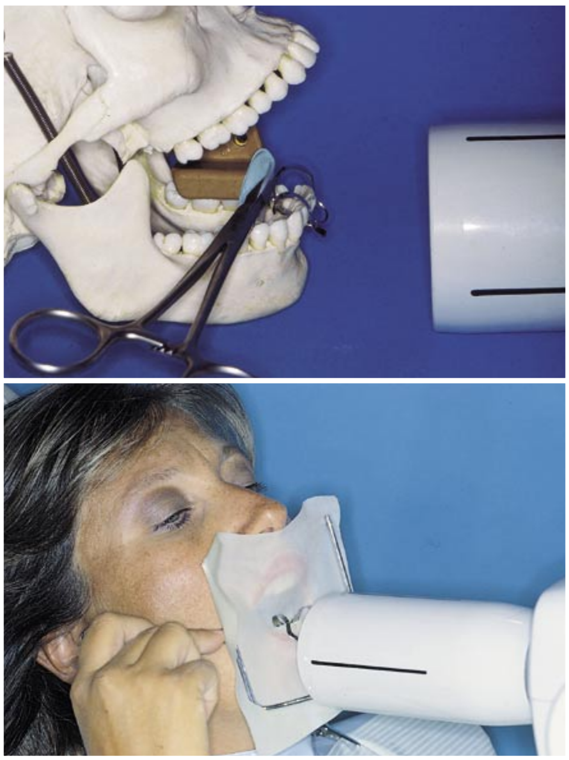


Fig. 5.67. Intraoperative radiograph of the lower incisors and canines. **A**. The film is clamped by its short side and held apart from the teeth so as not to have deformations. **B**. The forcep rests against the neighboring teeth for greater stability.

Fig. 5.68. Intraoperative radiograph of the lower premolars. **A**. The film is positioned horizontally. **B**. The patient rests the forceps on the controlateral teeth.

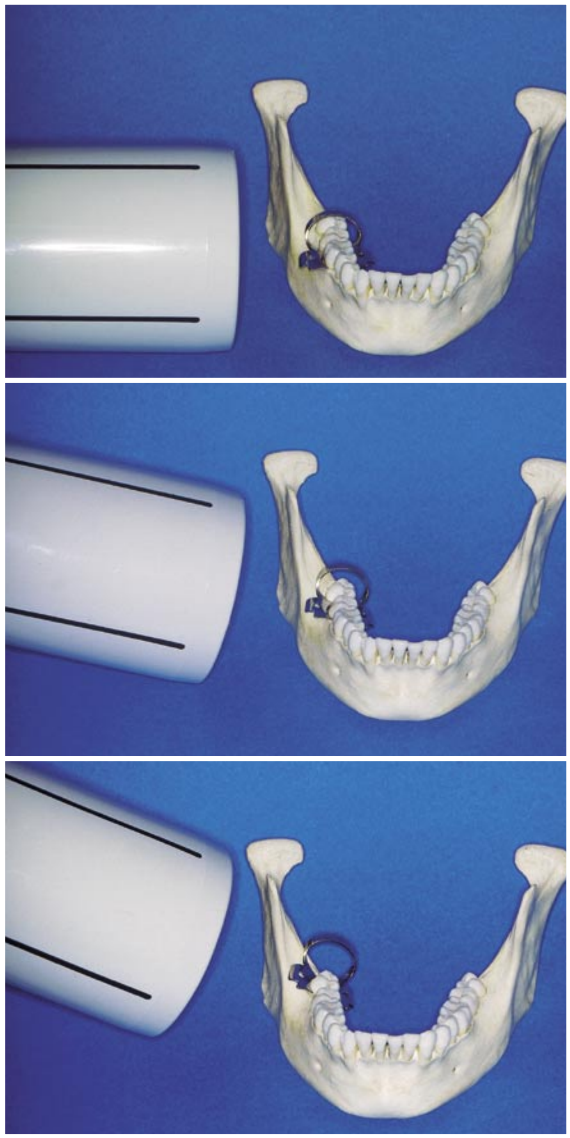
rious molars in the mandible is different and thus the inclination of the radiographic cone must also vary. More precisely, passing from the first to the second and then the third molars, the crowns of the teeth are increasingly lingually displaced with respect to the apices, with a consequent lingual inclination of the long axis of the tooth. This inclination increases anteroposteriorly.

This means that to maintain the x-ray beam perpendicular to the tooth and to the plane of the radiograph, one must gradually incline the radiographic cone in an increasing rostrocaudal manner (corono-apical angulation) as one proceeds to treatment of the second and third molars (Figg. 5.70, 5.71).

A

B

Fig. 5.69. Intraoperative radiograph of the lower molars. **A**. The radiographic film is positioned horizontally, with its long side parallel to the occlusal plane. **B**. The forceps is supported by the lower incisors for greater stability. Note the slight corono-apical angulation of the X-ray tube.



A

B

C

Fig. 5.70. The angulation of the X-ray tube is increased in a corono-apical direction as one passes from the first (**A**) to the second (**B**) and third (**C**) lower molars.

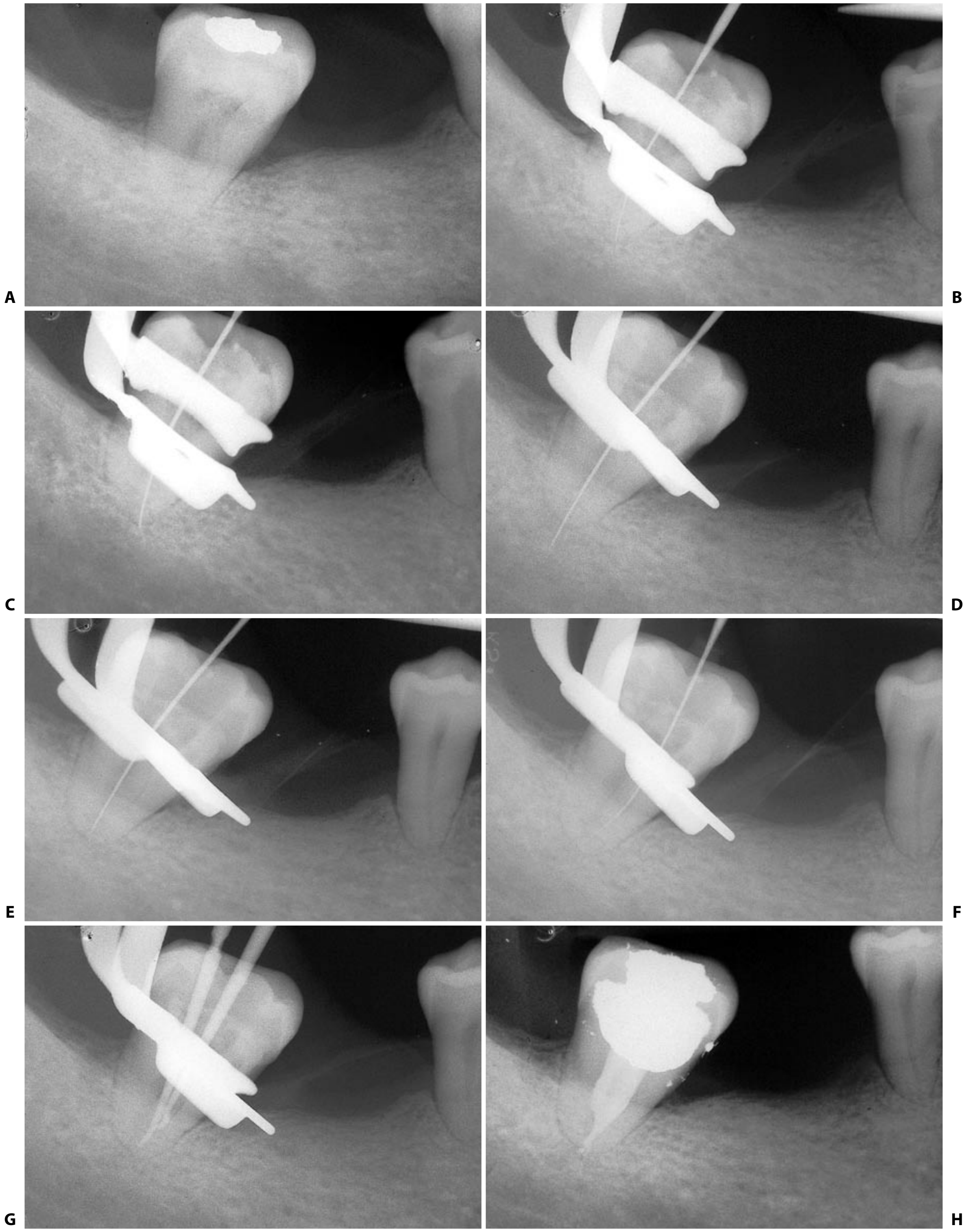


Fig. 5.71. The importance of correct orientation of the X-ray tube in determining the correct working length of the instruments. **A**. Preoperative radiograph of the lower right third molar. **B**. Radiograph to check the working length of the distal canal. The # 08 file appears at the radiographic terminus of the canal. Note the angulation of the wings of the clamp. **C**. Radiograph to check the working length using a # 20 file: the instrument seems to be a fraction of a millimeter beyond the apex, but the heavy bleeding arising from this canal raises the suspicion that it lies well beyond the apex. Note once again the angulation of the wings of the clamp. **D**. Without changing the working length of the file, a new radiograph is performed with a greater corono-apical angulation: note that the wings of the clamp, which are properly positioned at the neck of the tooth, are finally superimposed, confirming correct angulation of the X-rays. The instrument appears now to be beyond the apex by several millimeters and is therefore the clear cause of the abundant bleeding. **E**. The working length has been corrected, and a new radiograph has been obtained without altering the angulation of the X-ray tube. The bleeding stopped instantaneously. **F**. A check of the working length in the mesial canal. **G**. Fitting the cones in the two canals, which become confluent in a common apex. **H**. Postoperative radiograph: the filling ends at the proper "radiographic terminus of the canal".

COMMON CAUSES OF ERRORS

The radiograph certainly plays a very important role in diagnosing certain pathological conditions, and the instruments presently available can assure excellent quality. On the other hand, a poor quality radiograph can give erroneous information, simulating the presence of pathologies that do not in fact exist or hiding their presence from the viewer.

Therefore, to avoid errors of radiographic interpretation, the dentist must be familiar with some basic dark room rules, in addition to the rules of geometric projection that regulate image formation on the radiographic film.

Insufficient knowledge of these rules leads to waste of time and materials, film, and fluids, but especially increases the patient's radiation exposure in the attempt to obtain a flawless film.

Because a colleague or the patient himself may request the radiograph, it must be not only presentable and legible, but absolutely perfect. Radiographs must be considered visiting cards of the dental office!

The following are the most common causes of errors.[26,38,39,50]

1) Light radiographs (Fig. 5.72)

A) Exposure errors (underexposed film)

a) Insufficient milliamperage (when adjustable)
b) Insufficient kilovoltage (when adjustable)
c) Insufficient exposure time
d) Excessive film-to-radiographic source distance
e) Film packet reversed in the mouth (with the lead facing the teeth) (Fig. 5.73)
f) Use of expired film

Fig. 5.72. Light radiograph.

B) Processing errors

a) Underdeveloped film because of
   – bath temperature too low
   – development time too short
   – broken dark room thermometer
b) Dilute or contaminated developing solution
c) Exhausted developing solution
d) Prolonged immersion in the fixing bath

2) Dark radiographs (Fig. 5.74)

A) Exposure errors (overexposed film)

a) Excessive milliamperage (when adjustable)
b) Excessive kilovoltage (when adjustable)
c) Excessive exposure time
d) Film-to-radiographic source distance too short

B) Processing errors

a) Overdeveloped film because of
   – too high bath temperature (dark or large-grained film) (Fig. 5.75)
   – prolonged development time
b) Developing solution too concentrated
c) Too brief immersion in the fixing bath
d) Accidental light exposure
e) Inadequate red light in the dark room
f) Filtration of light through the doors or windows of the dark room

A

B

Fig. 5.73. The radiograph has been placed back to front in mouth.

3) Radiographs with poor contrast (Fig. 5.76)
- a) Underexposure
- b) Underdevelopment
- c) Excessive kilovoltage

4) Dark stains
- a) Fingerprints (Fig. 5.77)
- b) Film in contact with the basin or with another film during fixation (Fig. 5.78)
- c) Film contaminated by developer before treatment (Fig. 5.79)
- d) Excessive folding of the film (Fig. 5.80)

5) Light stains
- a) Film contaminated by the fixer before treatment (Fig. 5.81)

Fig. 5.74. Dark radiograph.

Fig. 5.75. Dark, grainy radiograph.

Fig. 5.76. Radiograph with too little contrast.

Fig. 5.77. Fingerprints on the radiograph.

Fig. 5.78. The radiograph had been partially in contact with another film during fixation.

Fig. 5.79. A finger contaminated with developer has touched the film in the dark room prior to treatment.

Fig. 5.80. The dark line that simulates a vertical fracture of the lower right central incisor, as well as a mandibular fracture, is in fact due to excessive bending of the film prior to its positioning in the mouth.

Fig. 5.81. The clip with which the radiograph was immersed in the developer was contaminated with fixer, because it had not been adequately washed.

Fig. 5.82. The radiograph had been partially in contact with another film during development.

b) Film in contact with the basin or with another film during development (Fig. 5.82)
c) Name of the patient written on the wrapper before treatment in the dark room (Fig. 5.83)
d) Scratches on the film (Fig. 5.84)

6) Yellow or Brown stains

a) Exhausted developing solution
b) Exhausted fixer
c) Contaminated solution
d) Insufficient washing of the film before drying and filing (Fig. 5.46)

7) Blurry radiographs (Fig.5.85)

a) Patient movement
b) Movement of the X-ray machine
c) Double exposure

8) Radiographs with partial images

a) Film not immersed completely in the developing solution (Fig. 5.86)
b) Poor alignment of the long cone (Fig. 5.87)

It is advisable to have an adequate supply of film in the office, without overstocking, so that one is not left with an enormous stock of expired film.
If there are several packages, open and use those that expire soonest.
The films must be kept in the refrigerator, far from hot or humid environments, but particularly from radiation. For the ideal developing and fixing times, see Table III.

Fig. 5.83. The name of the patient was written with a ball-point pen on the film wrapper before processing.

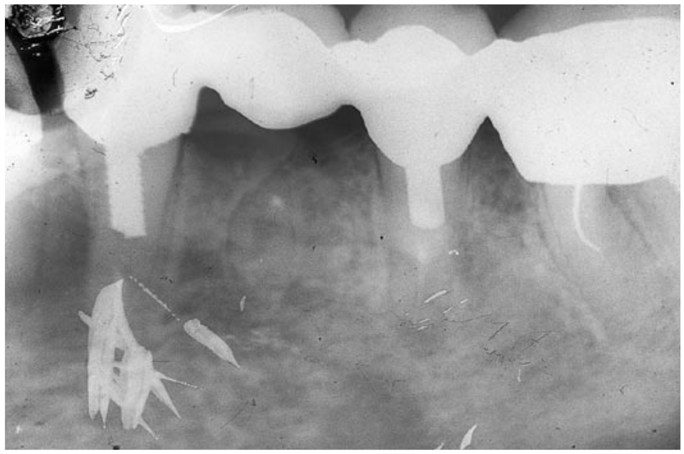


Fig. 5.84. The film has been "rinsed" in a basin containing other films, as well as more clips!

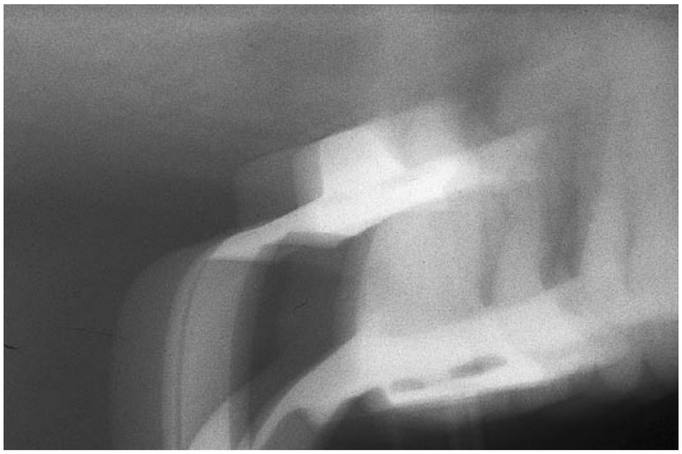


Fig. 5.85. Blurred radiograph caused by movement during exposure.

Fig. 5.86. The film has not been completely immersed in the developer.

Table III

Times recommended for Ultrarapid film, 65 kilovolts, 7.5 mA, developing bath at 25° C, with constant agitation of the immersed film.

Development	20"	dark room
Rinse	2"	dark room
Fixing	3"	dark room
Fixing	15'	Ambient light
Washing	20'	Ambient light

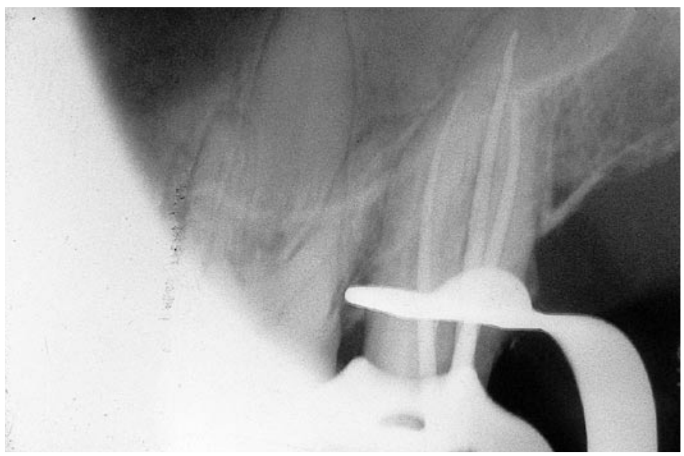


Fig. 5.87. The X-ray tube head was misaligned. This error can confirm that the X-ray beam is well collimated!

Note that the film needs never be completely fixed so as to be read in ambient light. Immersion in the fixer for a few seconds suffices, and the film can then be removed from the dark room and read by incident light (Fig. 5.88). The film must then be reimmersed in the fixer, where it remains for about 15 minutes. It can then be removed after 10 to 20 seconds to be read by light transmission (Fig. 5.89). A good reader of radiographs eliminates the circumambient light, which can be achieved with a simple visor (Fig. 5.90) and the use of an adequate magnifying lens (Fig. 5.91).
If one takes into consideration the time required to close the dark room door, open the radiographic film wrapper, immerse the film in the baths, reopen the dark room door, and exit, it is clear that it should take no more than 40 to 50 seconds before a film can be examined.
If "rapid" developing and fixing solutions are used (Fig. 5.92), this time can be halved. The importance of reducing the developing time is obvious, especially in the case of intraoperative radiographs; in this situation, it is important to eliminate delays, and one need not wait for the radiographs to dry.
If, on the other hand, one can wait longer and needs a dry radiograph to give to a colleague or patient, one can use an automatic developer (Fig. 5.93) which in a few minutes (more or less, depending on the manufacturer) produce dry radiographs.
A very important but unfortunately frequently overlooked phase is that of washing. The quality of film

Fig. 5.88. Although barely immersed in the fixer and removed from the dark room, the radiograph can be read by incident light. It is illuminated from above by the lamp of the unit or a light on the cabinet.

Fig. 5.89. After the radiograph has been properly fixed, it can be read by transmitted light on a light box.

Fig. 5.90. Prof. Langeland uses a visor to eliminate ambient light.

Fig. 5.91. Interpretation of radiographs is facilitated by enlargement (Designs for Vision, 2.5x) and the elimination of surrounding light (shielding of the light box).

Fig. 5.92. Rapid developing and fixing solutions.

Fig. 5.93. The Dürr automatic developer, which is essential whenever dry radiographs are needed immediately.

preservation depends on this step, which can reduce yellowing with time. The films must therefore always be rinsed for 20 minutes in running water.

PROTECTION OF THE PATIENT, DENTIST, AND AUXILIARY PERSONNEL

In dentistry, the basic principle of protection from ionizing radiation is to reduce as much as possible the radiation exposure of the patient and then of the staff, without of course denying the dentist the desired benefits of diagnostic radiography.[26]

The decision whether or not to obtain a radiograph must be based on a risk-benefit assessment. The patient should be exposed to radiation only when the benefits outweigh the risk.[51]

It is important to emphasize to the patients that it is more likely that they will sustain an injury for having refused a clinically important radiograph as compared to the remote possibility that they will develop any diseases as a result of exposure to ionizing radiation.

Studies on the doses of radiation absorbed by the bone marrow from taking dental radiographs have demonstrated that the radiation absorbed in a complete oral examination including 21 endoral radiographs is equivalent to that of a 65-day exposure to natural ionizing radiation (cosmic, from terrestrial or non-terrestrial sources).[26,59]

Nonetheless, even if the biological damage consequent to radiation exposure in a dental practice is minimal,[13] it must not be overlooked.

The principal methods of protection are as follows:

A) Fundamentally, a thorough familiarity on the part of the dentist of the techniques of stomatological radiology, so as to obtain consistently well-oriented and correctly exposed and developed radiographs, so that the maximal diagnostic information can be drawn from them.

B) The dentist must never hold the radiographs in the patient's mouth, placing his/her hands in the path of the primary X-ray beam. In the past, various types of damage to the fingers have been described, ranging from simple dystrophic changes to cancerous lesions. The radiograph must be kept in the mouth by the patient himself. If the patient cannot (e.g., in the case of children, elderly patients with Parkinson's disease, etc.), then an adult companion with no professional radiation exposure must keep it in place.[26]

C) Numerous studies indicate that, at parity of kilovoltage, the patient's exposure with the use of the long cone and the paralleling technique is much less than that which occurs with the use of the short cone and the bisecting angle technique.[35]

D) The use of high kilovoltage is recommended. The X-ray machine must also have good overall shielding, a good centerer of the beam, which must be filtered and collimated, so that its diameter is between 6 and 7 centimeters (Fig. 5.94).

E) The X-ray machine switch must be fitted with an alarm that emits sound and light to indicate the precise moment and length of execution of a radiograph.[35] The switch must also be provided with an extension cord so that the operator can stand at least 2 meters from the tube. This is the minimum distance for protection against the primary X-ray beam as well as the secondary beams that form (by

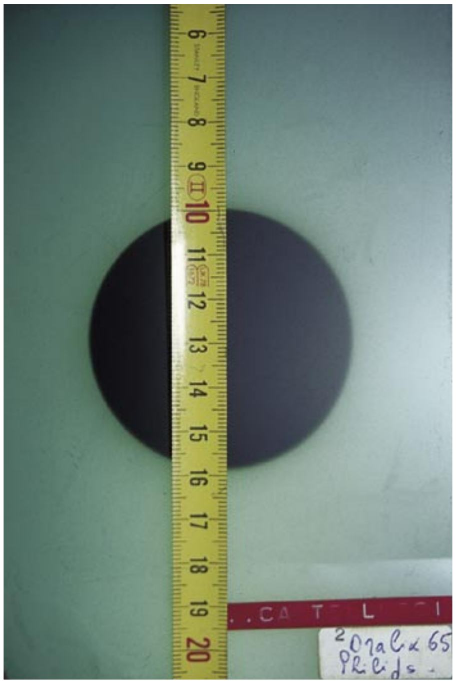


Fig. 5.94. The diameter of the well collimated X-ray beam must not exceed 6-7 cm.

the Compton effect) from radiation scattered from the patient, the floor, the walls, or nearby objects. It is better still if the switch is located outside the area in which the radiographs are taken. If this is not possible, the operator should wear a lead apron.

F) Where possible, it is always advisable to position the switch outside the treatment room. Floors, walls, and ceilings usually do not require additional shielding. If, however, the dividing walls are made of wood or other light materials, it is advisable to provide shielding with lead panels.

G) It is a good idea to use a timer to regulate the maximum and minimum exposure times to standardize the results. Adequately connected to a system of switches, the timer can control several X-ray machines in different rooms. In this case, an expert electrician should perform the wiring, so that it is impossible to mistake the position of the switch and erroneously expose the dentist, patient, and auxiliary personnel to accidental or undesired radiation. The use of a switch fitted with interdependent satellites eliminates the risk of undesired exposure and adheres fully to the safety standards of the dental office[36] (Fig. 5.95).

H) The patient must always be protected with a lead apron, which principally protects the gonads, and a lead collar to protect the thyroid[58] (Fig. 5.96). When radiographs are performed in the upper quadrants, it is advisable to protect the crystalline lens with sunglasses to whose inner aspect at least 3 lead sheets obtained from radiograph wrappers have been attached (Fig. 5.97). Nonetheless, Danforth and Torabinejad[13] have demonstrated that one would have to undergo at least 10,900 endoral radiographs to receive the threshold radiation dose required to produce cataracts.

Fig. 5.95. This Philips timer (right) is used to automatically regulate the exposure time according to the teeth being treated. A switch (left) allows a single timer to control several X-ray machines in different rooms.

Fig. 5.96. The patient's gonads and thyorid must always be protected by a lead apron.

Fig. 5.97. Three lead sheets obtained from endoral radiographic film wrappers are glued to the inner surfaces of sun glasses. They are more efficacious in protecting the patients' crystalline lens.

I) In the case of pregnant patients, one should refrain from obtaining radiographs. As Marci[34] confirms, "somatic damage to the embryo is due to maternal abdominal irradiation during pregnancy, which can cause abnormalities of variable severity and type, depending on the dose administered and the developmental age of the embryo. Limited use of dental radiology is necessary, as for other types of radiological studies, since, although the practice of oral radiography carries a low risk of radiation exposure, it is also true that during the period in which the human species undergoes organogenesis (fifteenth to twenty-fourth days of gestation), even the administration of doses of only 35 Rem can cause malformations incompatible with life. In the subsequent phases of pregnancy, the sensitivity of the product of conception to the teratogenic action of X-rays progressively diminishes, and, at parity of radiation dose absorbed, the percentage of malformations thus decreases". According to Marci, to avoid damage caused by irradiation of the embryo, practitioners in many countries apply the "ten day" rule, which limits diagnostic radiation exposure to the ten days that follow the beginning of the menstrual cycle.
   Although this procedure refers only to exposure of the pelvis to primary rays, it would be prudent to apply such limitations also in the dental practice, or else to take the appropriate precautions to protect the abdomen of a woman undergoing dental radiographs with the appropriate lead apron.
   The concept of *not* performing even simple endoral radiographs in cases of presumed pregnancy is still valid, as there is no concrete information about the dose the embryo can tolerate. One must keep in mind, however, that even a simple radiograph could create troublesome medico-legal problems in cases of damage to the product of conception, which obviously could arise from causes other than from the radiograph."[34,36]
L) When one performs radiographs, the patient's family members or friends must not stay in the room, as they should not be needlessly exposed to the radiation.
M) It is a good idea to use high speed radiographic film such as Kodak Ultraspeed or Ektaspeed (Fig. 5.98) which require exactly half the exposure time than the earlier very sensitive films,[14,16,20,25,30,31,51] so as to reduce the exposure time to a minimum, fractions of a second. The use of high sensitivity or high speed film requires a more precise exposure technique and suitable manipulation in the dark room. It must be kept in mind that although the Ektaspeed is safer for the patient due to the shorter exposure time required, on the other hand the Ultraspeed film is superior in terms of contrast and image quality.[30]

In 1994, Ektaspeed Plus dental X-ray film (Eastman Kodak, Rochester, NY) was introduced. Recent studies[7,12,41] demonstrate that the use of Ektaspeed Plus film for working length determination can reduce patient radiation exposure by 50%, while producing a quality, diagnostic radiograph with good contrast and density. When compared to Ektaspeed, Ektaspeed Plus has a higher contrast, is less grainy and faster. When compared to Ultraspeed film, Ektaspeed Plus demonstrates that it is superior or equivalent and only

Fig. 5.98. Ultra-Speed films and, even more, Ekta-Speed, are very rapid films that allow the use of considerably shorter exposure times.

slightly more grainy. Considering the reduced radiation exposure required for Ektaspeed Plus (only half the time compared to Ultraspeed film), several authors suggest substituting Ultraspeed and Ektaspeed with Ektaspeed Plus film for intraoral imaging.[12,41]

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6

Digital Radiography Systems (DRS)

MARIO LENDINI

ORIGINS AND TECHNOLOGICAL EVOLUTION

In 1984 Dr. Francis Mouyen from Toulouse (France), patenting the concept of an intra-oral radiographic sensor featuring instant image capture, gave birth to Digital Radiography System (DRS).[19]
The first radiographic image capturing device was an image sensor based on a large silicon matrix integrated circuit. This was based on the principle of a charged coupled device (CCD). This sensor was assembled with a scintillator, a device made up of a surface of phosphor atoms, which, triggered by incident X-rays, emit a luminous radiation.
This image is transferred through optical fibers from the scintillator itself to the CCD sensitive elements. The first system was not computer-linked. It allowed to see images only on a video screen, but it could not save them on a computer (Trophy 1988).[20] The first computer-linked system was the Visualix by Gendex (1992) This, in its turn, is linked directly, through a connector, to the computer. Here it goes through an electronic card which transforms the electronic signal coming from the sensor into a digital one, which can be memorized, containing the image. These data, which make up the captured image, can be converted by the software into one of the various standard graphic formats (.TIF, .JPEG, .PCX, .BMP, .PIC, etc.) differing from one another mainly for the features of information compression.[17,18]
During the first development stages, one of the first problems for the researchers was the need to adapt the then commercially available CCD to the operative needs in dentistry. The said CCD, deriving from a B & W 9x13 mm telecamera, was too small in size to cover the area corresponding to the size of a single tooth. To remedy this drawback, it was decided to create a scintillator equipped with a sufficient 16x27 mm area. The scintillator was to be connected to a smaller area CCD by a bundle of optical fibers shaped as an inverted pyramid trunk functioning as a lens. These optical fibers were made of lead glass capable of fully blocking the X radiation, harmful for the chemical-physical CCD structures.
The first devices, derived from these prototypes, made and marketed by Trophy in 1988, featured a sensor with an overall 20x40 mm size and a 14 mm thickness. Their actual sensitive area, however, was only 16x27 mm (Fig. 6.1).[9]
The tapered optical fiber bundle in a short time was no longer necessary, following the development of CCDs featuring a bigger size, about 20x39 mm, sensitive window. This allowed to reduce the thickness of the optical fiber bundle down to 0.8 mm, the absolute minimum to block X-rays (Figs. 6.2 and 6.3).
Users requested sensors as thin as possible, whereas manufacturers needed structures with a lower mechanical fragility and a lower risk of loss of functional integrity due to the X-ray action.[21]
Researchers, then, had to adopt a particular techno-

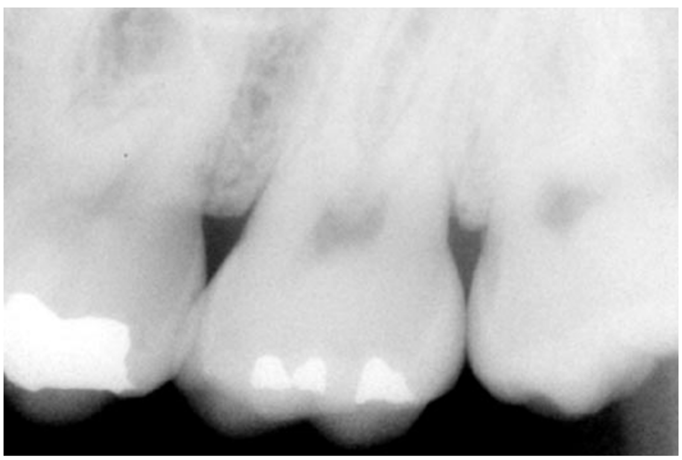


Fig. 6.1. The reduced size of the sensor did not allow an optimum framing and the definition was insufficient.

logy aiming at hardening the CCD structure (hardened device) which allowed to eliminate the fiberglass layer. The present day CCD technological development provides sensors with an actual capture area of over 36x25 mm and thickness up to 5 mm. Moreover, the width of the outline edge has been further reduced (Figs. 6.4 and 6.5).

The first systems envisaged an electrical coupling with the X-ray generator, so as to be able to synchronize the image capture with the emission of rays.[21]

Most present day devices, on the contrary, work in a totally asynchronous way: the sensor is actually capable of synchronizing automatically as soon as it picks up the presence of radiation.[23]

Microscopic silicon cells make up the structure of the CCD sensitive matrix. At present CMOS [Complementary MOS (Metal Oxide Semiconductor chip)] sensor feature 40μ pixel whereas CCD sensor feature 20μ pixels.[33] The Visualix HDI CCD by Gendex features 20μ pixels and it can work both in high and in standard resolution. In the later case pixels are coupled. Each of these cells corresponds, in practice, to a photosensitive element (pixel), the basic component of an electronic image. At first it was thought to use smaller size silicon cells, less than 20μ each, which, combined in groups of four, made up the area corresponding to a pixel. Technical difficulties and no actual compliance in terms of obtainable quality moved the choice towards the present size of cells.[1,2]

This technical solution gives a theoretical output up to a maximum of 25 pairs of lines per millimeter in terms of space resolution when referring to 20μ pixels. At

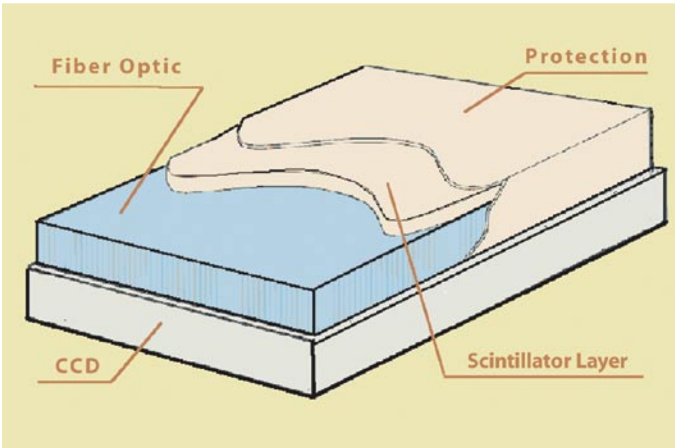


Fig. 6.2. Structure of a CCD sensor.

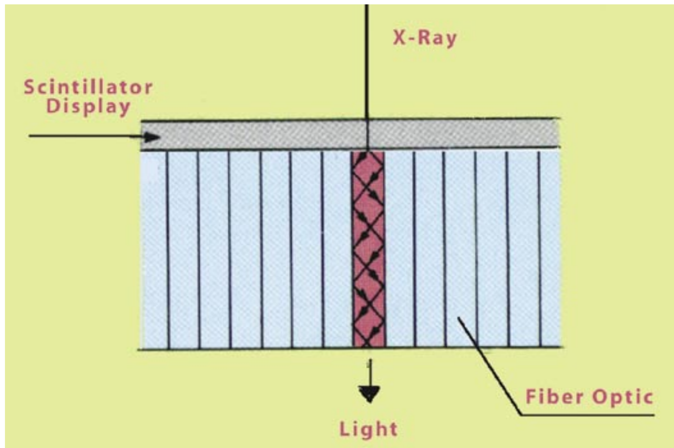


Fig. 6.3. The optical fiber protects the CCD from non-absorbed X-rays, it reduces light dispersion and, therefore, it increases spatial resolution.

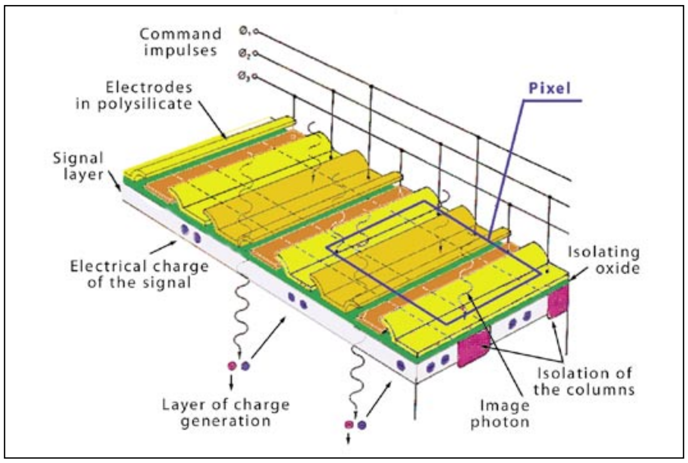


Fig. 6.4. Structure of a CCD.

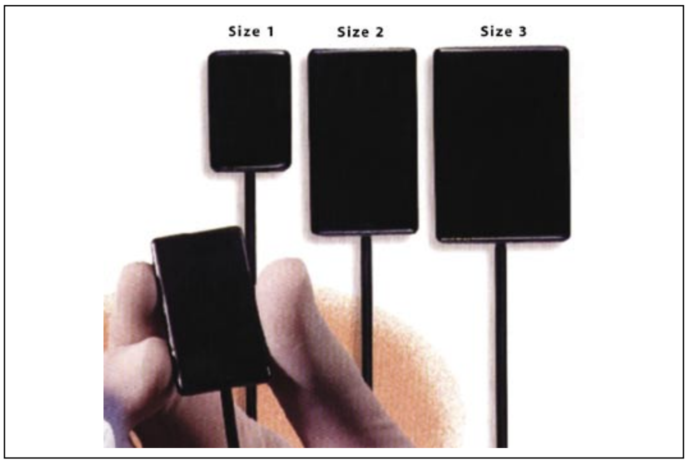


Fig. 6.5. Last generation sensors (in the picture, those produced by Schick Technologies) feature an excellent ratio between overall size and sensitive surface.

present, through high definition sensors, one can get 25 nominal pairs of lines per millimeter, which become 18 or 20 real ones. The most widespread sensors on the market give a definition of 18 nominal pairs of lines per millimeter which become 13 real ones.

All the available sensors have been designed specifically for intra-oral use, envisaging the fitting into a sealed capsule which at the same time gives both protection against mechanical stress and the possibility of disinfection through immersion into a liquid. Throwaway protections are available in order to avoid cross contamination (Fig. 6.6).

This brief outline has simply illustrated the features of the oldest and wide-ranging family of DRS, the one with CCD sensors.

Another family of DRS, with excitable phosphor sensors, the earliest example of which is the Digora system (Soredex) has been available for a few years (since 1994).

The philosophy of these systems is sharply different from the one of the previously illustrated devices. The sensor has no direct link with the computer, but it is read by a device with a laser beam and photocapturing feature (linear scanner) which transfers the image to the computer itself (Fig. 6.7).[28]

The sensor, which actually presents the look, size, thickness and flexibility of a traditional X-ray plate (Fig. 6.8), features a semi-rigid polyester support with a scintillator fitted on it; in practice a thin layer of a material made up of excitable phosphor atoms (activated barium fluorohalide crystals) which, hit by X-rays, go through an excited state creating a latent image. The layer of this material must be as thin as possi-

A

B

Fig. 6.6. Throwaway protections for CCD type sensors (above) and for memory phosphor type sensors (belove).

Fig. 6.7. The Denoptix system laser reader (Gendex) featuring a drum on which the sensor-films are positioned. The same sensor-films can be seen in the foreground in their different sizes.

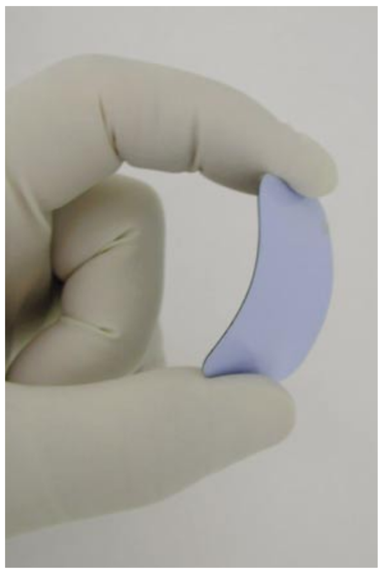


Fig. 6.8. The appearance and consistence of the active phosphorous sensor are similar to those of a traditional radiographic film.

ble to avoid light diffusion phenomena which would reduce the image quality. For the same reason, the compound granulometry too must be extremely fine. The principle is similar to the one of photographic emulsions in which less definition corresponds to a gross grain.
Granulometric fineness of the sensitive compound and thickness of the layer of material (as fine as possible) being the same, the latest technical evolution uses blue phosphor (Denoptix – Gendex) instead of white phosphor. Blue phosphor is more luminous and enables the laser reader to read the latent image better, affecting, then, in the last analysis, the technical features of the image itself. The main advantage, however, is for blue phosphor to be more sensitive to radiation allowing then, a reduction of X-rays.[5]
It has been observed that X-rays incident on these sensors cause the excitation of the phosphor atoms which can be stimulated and which delineate the latent image (Fig. 6.9).
The sensor must then be inserted into the reader, which performs a complete scanning of the whole surface of the sensor. The reading is performed by a very thin laser red beam which releases the latent energy by stimulating the phosphor atoms to emit either a white or a blue luminosity, depending on the quality of the sensitive material (Fig. 6.10).
The amount of released energy is measured at every pixel. At this stage an analog-digital converter comes into play and converts the electrical signal resulting in a digital signal. The converter sends the digital signal to the computer through a connection cable and an interface electronic card. The actual acquisition phase is usually preceded by a pre-reading phase which supplies the information through which the system sets the reading final level.
After the reading, the latent images contained in the sensors can be fully cancelled through the exposure to an intense source of light, for example an examination table. The sensor, unless damaged by scratches or folds, can be re-used hundreds of times. The same sensor is inserted into special throwaway bags whose function is to protect the side sensitive to light from unintentional exposures which could either alter or cancel data before reading.[18,28]
Sensors from this group are available in a number of sizes (22x35, 24x40, 31x41, 27x54, 57x76 mm) (Fig. 6.7). This technical solution at present gives an output of 12 pairs of lines/millimeter in terms of space resolution with a feature for high and low resolution (300 and 600 dpi = dots per inch).

FEATURES OF THE DRS IMAGE

After this short and deliberately simple view of the sensors available at present we can now examine the features of the images obtainable through the DRS analyzing them both in absolute terms and, where possible, in relation to conventional radiographic

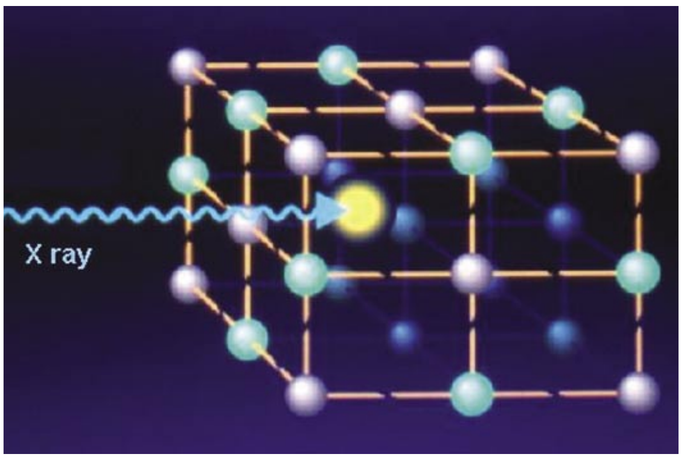


Fig. 6.9. The incident X rays on the surface of the sensor demarcate the latent image.

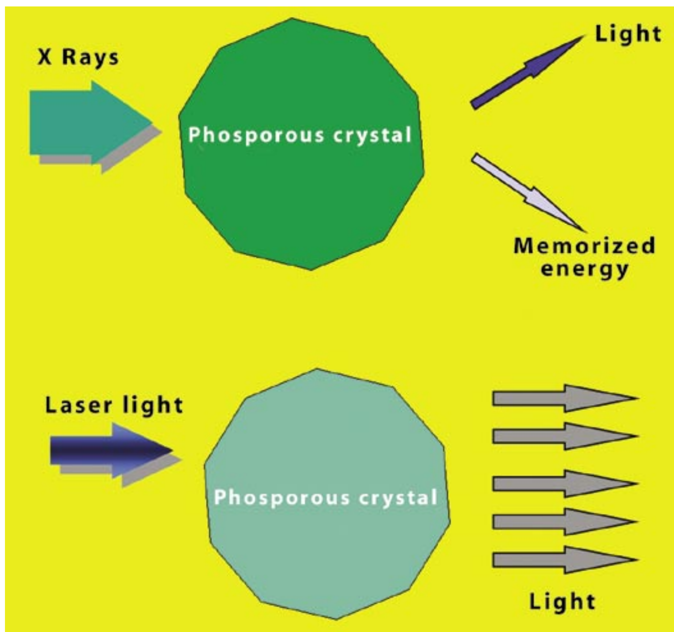


Fig. 6.10. Memorising phosphorous function as normal reinforcing screens, but a part of X-ray energy is stored in the phosporous crystals. Stimulated by the laser light the crystals discharge light in function of the memorised energy.

images.[6] Usually the image acquired by the DRS sensor is digitalized (Tab. I, II, III and IV) under the form of 8-bit data. An 8-bit image has 256 levels of luminosity from 0 (black) to 255 (white). The contrast resolution is measured as differences of level of gray, or pixel values, on a scale of grays of logarithm or semilogarithm default.[8]

Table I

Requirements of a good sensor

– *High sensitivity* to X-rays
– High *resolution* capacity
– Maximum *depth of color* (a high number of levels of gray)
– *Compatibility* with existing radiological systems
– *Acceptable costs*
– *Duration of sensor*

Table II

Digitalization progress

– Consists of *sampling* a signal which varies continuously at constant intervals
– One will obtain a *series of whole numbers* which approximate the starting function and allow its reconstruction
– This process, then, represents the *transformation of an analog function into a more or less long sequence of discrete values.*

Table III

Digitalization of an analog signal

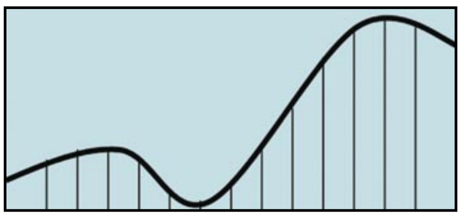
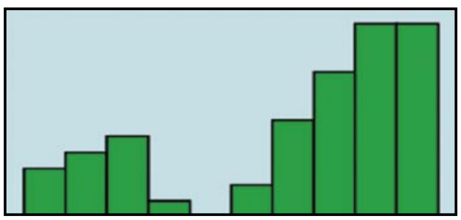


Image luminosity and its sampling



Digital transformation of luminosity
The sampled value is calculated
on the mean point of intervals.

Table IV

Digitalization

– In the digitalization process not only is the sampling frequency important, but also the *amplitude* of the digitalized signal.
– This value represents the *level of gray* which is assigned to the point under examination.
– We can think of digital images as of a set of *elements memorized in a numerical form*, so as to maintain the *biunique correspondence* between the image and the element which represents it.

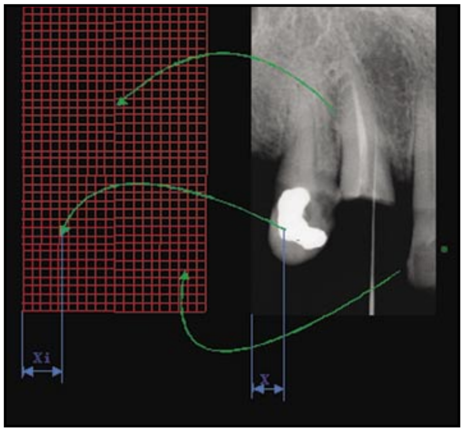
Reading and processing of DRS images

The factors which may affect the ease of reading of both a traditional and a digital radiographic image could be defined as intrinsic and extrinsic to the characteristics of the image itself.
Among extrinsic factors we have to consider the properties of the means we use for viewing the image.
In the case of a traditional image the X-ray examination table must feature a white, homogeneous and sufficiently powerful light.

It is important, however, to equip the viewer with a black screen with windows of the same size as the used radiographic plates. In this way the X-rays will have an adequate back-lighting, enabling us to focus our attention exclusively on the details of interest; while our ability to pick them increases thanks to the absence of luminous "pollution", a lesser eye fatigue and, of course, optical magnification systems (Fig. 6.11).
Whereas in the case of a digital image the technical features of the monitor are very important. Particular attention must, then, be paid to resolution, definition, chromatic output, but also, not a minor detail, to image stability; a flickering screen or continuous and sudden changes of luminosity and contrast will fatigue our visual ability and distract our attention from the particulars of interest.
The intrinsic factors of the image which affect the ease of reading are mostly its size; also the image definition is very important of course. This, however, is a parameter which, having its own absolute specific importance, will be analyzed at a later stage.

Table V

Digitalization process



– In the image digitalization process a *biunique correspondence* between the original image and its *digitalized form* is maintained.
– $X_i = X/p_x$, where p_x stands for the size of the pixel.
– Each element of the matrix contains the "*depth*" of the point as a *level of gray*.

Understandably it may be more difficult and demanding to read the details of a 3x4 cm or 2x3 cm image – widely used sizes in endodontic radiology -, by comparison with an image displayed on a 15- maybe 17-in video-screen, naturally with comparable quality criteria (Fig. 6.12).
Other features are more properly connected with the possibilities of processing the digital image (Tab. V).
Contrast and luminosity of traditional radiographs are strictly linked with carrying out the investigation (emission time of X-rays and their quality and quantity) and the transition of developing and fixing (concentration, effectiveness and temperatures of liquids, absence of luminous pollution, adequate washing and drying procedures).

Fig. 6.11. Screened X-ray examination table and optical magnification systems.

Fig. 6.12. DRS images on a monitor.

Digital radiographic images are, on the contrary, characterized by the possibility of modifying luminosity and contrast in a continuative way, with no limits of range and in a fully reversible way, even though they maintain unaltered their basic properties (resolution and definition).[31]

This option, managed through a graphic processing program (one of the software components of DRS) allows an easy and fast manipulation of the image, optimizing its final output.[7]

There are, in addition, some more functions offered by the graphic processing programs. These functions allow:

– image enlargement, enhancing in this way important details;
– to see the image as a negative through a complete inversion of chromatic components;
– to modify the histogram of the levels of gray to improve the dynamics of the image;
– to apply a three-dimensional filter to the image to obtain a "bas relief" effect (Fig. 6.13).

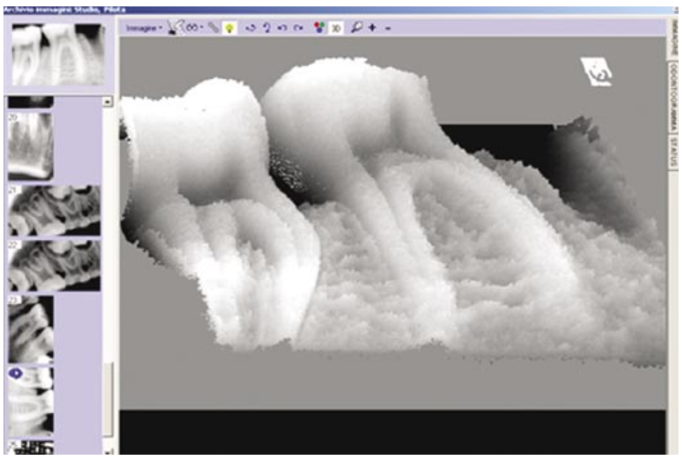


Fig. 6.13. Image processing with 3-D effect application.

These and other functions are meant to offer the professional more reading scales so as to identify each time the most effective one in terms of global comprehension of the image (Fig. 6.14).[24,25]

Other interesting options are the ones which allow the computer - basing itself on pre-set reading scales - to carry out a rough analysis of the bone density of the sectors investigated by the radiovideographic image, interpolating the quality of the tones of gray there present and to take length measurements with a precision up to 1/10 mm.[14]

This is also possible on curved stretches by approximation with a line of measurement subdivided in more segments angled among themselves even with degree fractions. It is obvious that the more detailed and close to reality the computer reading scales are, the more effective the interpretation may be (Fig. 6.15).

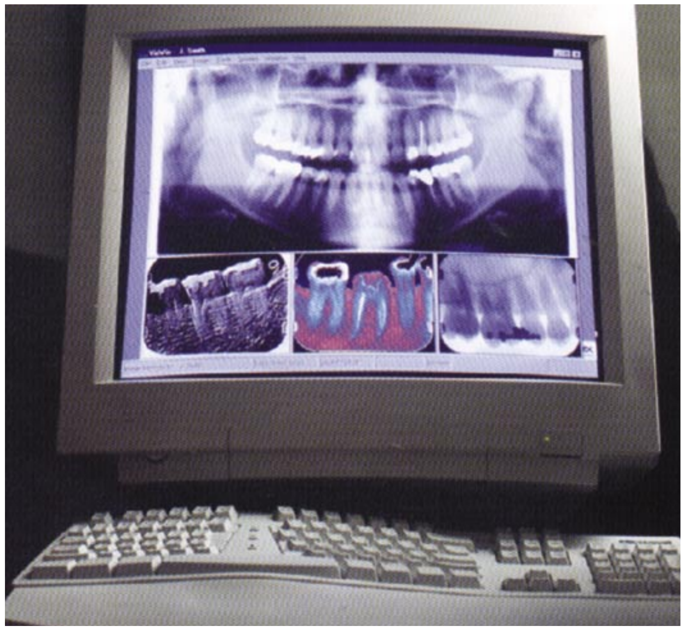


Fig. 6.14. The software of the image graphic management can process it with different "effects".

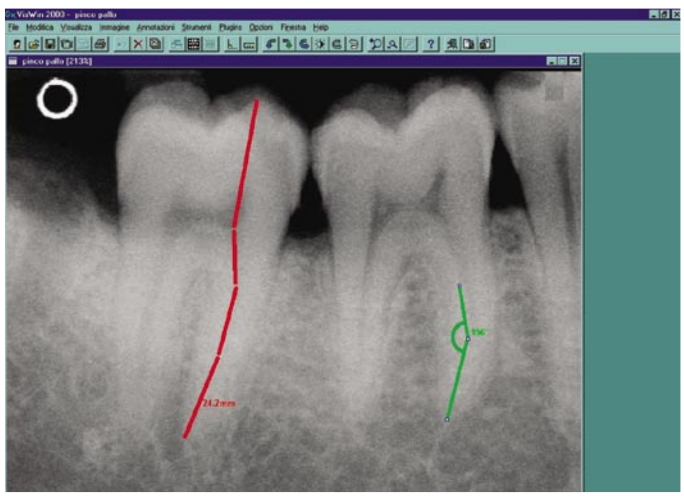


Fig. 6.15. Length and angle measurements may be useful for a preventive appraisal of the level of difficulty of the planned endodontic treatment.

Quality of DRS images

The quality of the digital radiographs images is in step with the features of the different components of the system: hardware, acquisition sensors and software.[13]

Hardware

In this case the following are particularly important: not only the monitor, but also the computer features, then the quality of the graphic card (which physically allows the computer to acquire and process any type of image), the type of processor (the computer "brains"), the size of the memory on the fixed disk ("the store") and the so called RAM memory (which allows the computer to keep programs and images "alive" and active). All these components, affecting not only the image quality, but also the speed and the efficiency of the processing, are so strictly correlated that the inadequacy of a single one of these may determine a remarkable worsening of the quality of the end product.[32]

Acquisition Sensors

The two main groups of DRS acquisition sensors and their respective features have already been described. Needless to say that this component of the system has a decisive influence on the definition quality of the acquired image.[3] It is, however, also necessary to emphasize that sensors, in particular silicon cell ones, have seen a very rapid evolution, both on terms of physical size and on terms of quantity and quality of the acquisition points, total surface being the same. It is likely that this rapid technical progress is far from ending and that there may be important improvements in methodology also in the short term.
I would like, anyway, to quote some important parameters which directly affect the definition of the final image.

1) The resolution of an "imaging" system is defined by its ability to "resolve" different density structures placed one next to the other.
   It is usually measured through a "grid test" which consists of a series of lead bars alternate with spaces subdivided into groups of decreasing amplitude. In each group, the full and the empty ones are equally spaced.
   The whole set of a bar and a space is defined as a "pair of lines" (Fig. 6.16). The quality of a sensor is then linked with the highest number of "pairs of lines" which allow an adequate resolution of the investigated object (Fig. 6.17).
   This feature is linked not so much to the normal vision of an image – (also the human eye has a maximum resolution limit on terms of number of pairs per millimeter, about 16, and then a higher resolution in theory would not be necessary), but, abo-

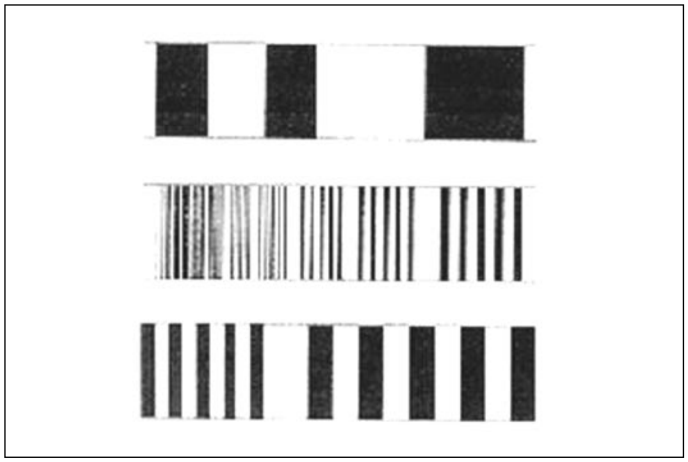


Fig. 6.16. The set of a bar and a space is defined as a "pair of lines".

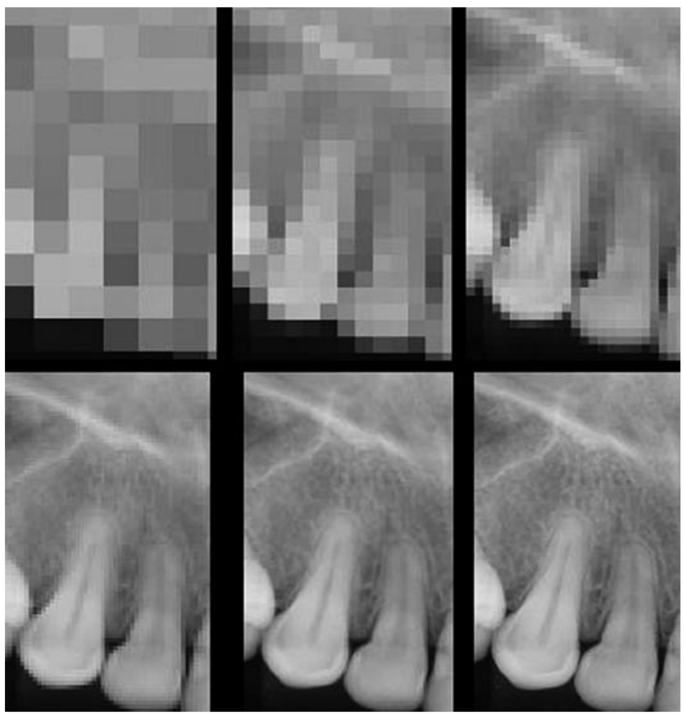


Fig. 6.17. Examples of a subsampling. If the acquisition system does not feature sufficient resolution, the resulting image will not be sufficiently defined.

ve all, to the possibility of magnifying smaller and smaller details keeping high the quality itself of the magnified image.[11]

2) The signal-to-noise ratio (SNR = signal-to-noise ratio) (Fig. 6.18) quantifies the performance of the system relating the technical qualities of the sensors (both DRS and traditional) - in keeping with their characteristic "background noise" - to quality and quantity of X-rays necessary to obtain a good image.
   For simplification's sake, one can say that the greater the disturbance (background noise) of the sensor or devices to it correlated (for instance: laser readers or electronic cards), the greater will have to be the quantity of X-rays necessary to outdo them and obtain a good image (Fig. 6.19).
   A system which may boast a high SNR will then be able to supply images with a better definition, X-ray dosages being the same.
3) The frequency interval of data collection (or dynamic range) is the parameter which quantifies the ability to collect faithfully small details without the "luminous tail" effects, that is the quantity and quality of the images obtainable through the system.
   Also in this case a better technical setting corresponds to a high value. In particular the ability to acquire images both with a low and a high radiant energy level of an equal quality standard, with the reduction of over- and underexposure risks of the images themselves, corresponds to a wide spectrum of dynamic range.

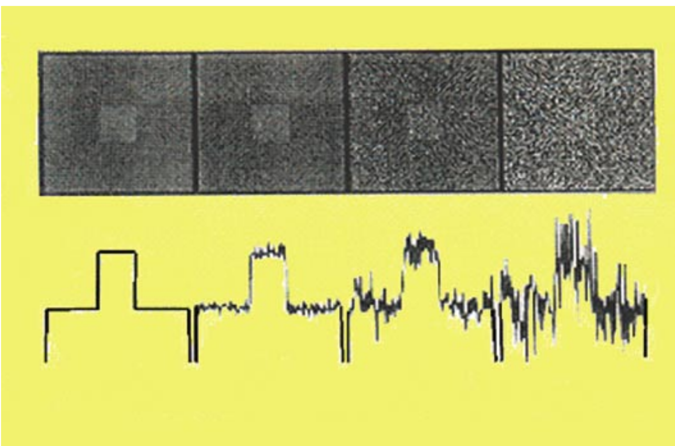


Fig. 6.18. Image quality is measured not so much by noise but by the ratio between the useful signal and the noise itself. SNR = SIGNAL TO NOISE RATIO

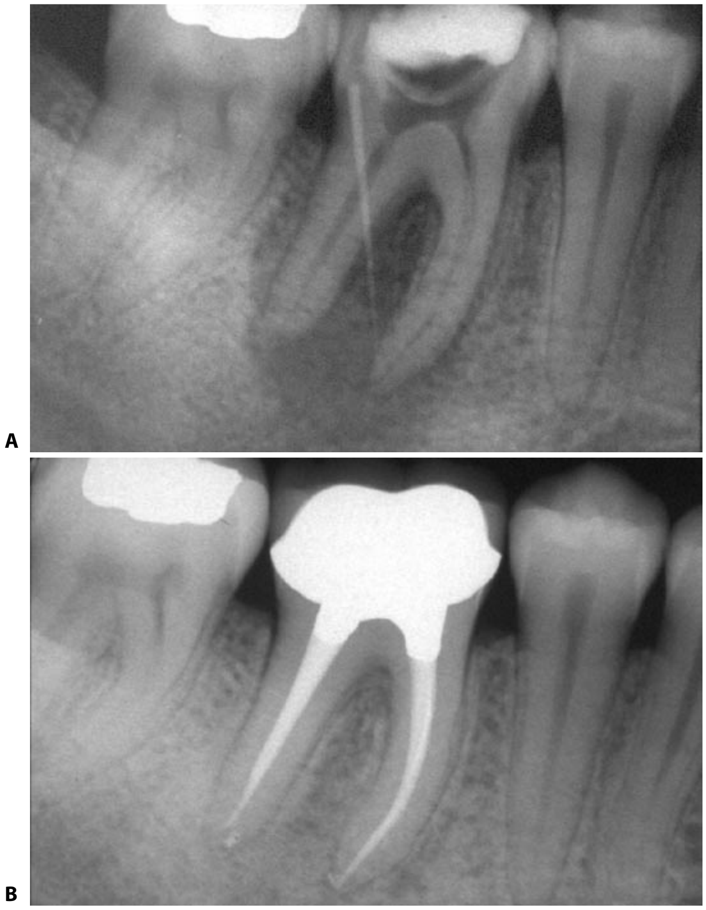


Fig. 6.19. Images with a good contrast can be interpreted with greater confidence.

Software

The programs which run the transition of information from the sensor to the computer memory and which, then, in the last analysis, control first the production and, then, the management, processing and filing of the image, should hardly affect the determination of definition, meant as amount of dots for a given surface.[2,26]

Software should be, then, particularly in the "production" stage of the image, only and exclusively as a means, an intermediary between the sensor perceiving the object, as it is drawn by the X-rays, and hardware which then physically shows it.

Actually software – particularly in DRS with silicon cell sensors – still plays an important role at this stage.

One can imagine the sensitive surface of a silicon cell sensor subdivided by a sort of grid into a number of

about 40x40 micron small squares, each of which is the sensor's basic acquisition unit.
A physical distance, even if a very small one, exists between each of these dots and the one close to it. This ensures that the information making up the investigated object and falling exactly into this space may not be acquired and then may get lost.
In addition a certain number of the sensor's basic units may not function correctly, both due to manufacturing faults (here manufacturers must take action for the accuracy of their quality control) and wear and tear as well as fatigue.
At this stage of the process software comes into play and reads each pair of neighboring dots, gives them a value, corresponding to a scale of "grays", and fills the empty space with a few dots with an intermediate value between the two. In short, what we could see at the end of the process is an image which is artificial in a small part: this fact shows as an insufficient definition of the image itself.
The above-mentioned process was particularly incidental with the first generation DRS.
The technical evolution of the sensors has allowed to reduce the distance between each pair of dots more and more and to have an accurate check on the critical phases of production. The last generation DRS – equipped with silicon cell sensors – supply images with a technical definition close to the one of traditional radiographic images. The DRS images, however, present final reading features which can nearly overlap.[13]
A different consideration must be made for DRS which use excitable phosphor sensors: in this case the basic acquisition units feature a molecular size as in traditional radiographic plates (Fig. 6.9). The latent image, which develops after the exposure to X-rays, has potentially the same definition which can be found in traditional radiography. The discriminant which acts in this system is in step with the reading ability of the photo-acquisition device which, through digitalization, must transfer the information contained in the sensor. Also in this case software could come into play making up for possible failings. The technological evolution of the systems based on this type of sensors allows today to obtain DRS images which are both strictly faithful to reality and with a definition which can practically overlap the one given by traditional X-rays (Fig. 6.20).

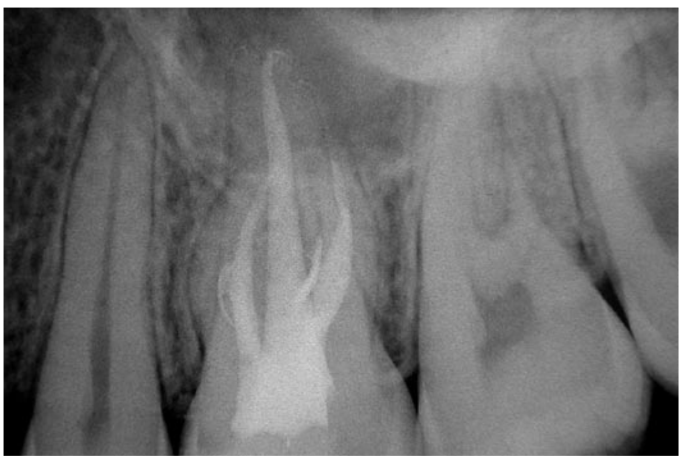


Fig. 6.20. Details are well outlined.

EXECUTION AND PROCESSING TIME

The speed of execution is, together with the necessary low radiant load, the real great advantage of DRS, in particular for the ones which use CCD sensors. These sensors, in actual fact, require really few seconds for the radiographic image to appear on the video-screen between the moment of exposure and the time the radiographic image actually appears on the video-screen.[25,31]
The excitable phosphor sensors, on the contrary, require – in addition to the time necessary to free them from their protective covers and insert them in the reader – a lapse of time from one to two minutes (depending on the reading definition required) before the image appears on the video-screen. One must consider, however, that with one of these systems (Denoptix – Gendex) the reading time will not vary, if from one to eight sensors are inserted at the same time into the magazine. In the same lapse of time (about two minutes), then, up to eight radiographic images can be available.
The processing time of the image already visualized on a monitor is similar for any type of DRS. The variability is functional with the efficiency and the ease of operation of the image management programs which are integrated with the various DRS, with particular regard, however, to the operator's needs. It is clear that more time will be required if one has to modify many parameters (luminosity, contrast, magnification) or obtain more information (measurements, densitometric analyses, chromatic toning or three-dimensional visions). The actual speed of the system, however, and the operator's practice allow, anyway, a remarkable absolute reduction of the waiting time.

SUPPLIED DOSAGE

To compare the radiation dosage necessary to obtain a high quality image from (both a CCD or an excitable phosphor) DRS and from an X-ray film, may be considered a disputable approach as it compares quantities which are physically inconsistent. In actual fact, while a certain X-ray dosage causes a specific blackening of the film, that is (given a correct chemical process) an optical effect, the same dosage causes an electrical signal in an electronic sensor, with a level which can be amplified and altered in the next stages of electronic processing, before obtaining a visible image.
The radiation dosage required by DRS is, anyway, surely lower than the one necessary in traditional radiology, even taking into account that the radiation dosage must not be reduced too much in order to have a good signal-to-noise ratio (that is a good image quality).[30]
In general one can state that the required exposure is at least six times lower compared with a D-type film and three times lower compared with an E-type film. One can expect the same correlation to exist between the absorbed dosages (in gray) (Tab. VI).
Regardless of the type of image acquisition device used, one must remember that a further reduction of the supplied dosage will be obtainable, if one uses – for a radiogenous head – a rectangular collimator equipped with a limiting device in proximity of the focal spot (Fig. 6.21). In this way one obtains an effective suppression of the diffused and extrafocal radiation and, in the last analysis, a better image quality.

Fig. 6.21. Detail of a head with a rectangular collimator

Table VI

Exposure times in seconds recommended for the Oralix DC (Gendex) intra-oral device with a constant 60 and 70 kV potential

	DRS Systems		Agfa Dentus M4 Films		Kodak Ektaspeed E-type Films		Kodak Ultraspeed D-type Films		Very Slow speeds	
	60 kV	70 kV	60 kV	70 kV	60 kV	70 kV	60 kV	70 kV	60 kV	70 kV
Incisors	0.100	0.050	0.160	0.080	0.250	0.125	0.400	0.200	0.630	0.320
Canines	0.100	0.063	0.160	0.100	0.250	0.160	0.400	0.250	0.630	0.400
Premolars	0.125	0.080	0.200	0.125	0.320	0.200	0.500	0.320	0.800	0.500
Lower molar	0.160	0.100	0.250	0.160	0.400	0.250	0.630	0.400	1.000	0.630
Upper molars	0.200	0.125	0.320	0.200	0.500	0.320	0.800	0.500	1.250	0.800
Bite Wing	0.160	0.100	0.250	0.160	0.400	0.250	0.630	0.400	1.000	0.630
Occlusal	0.250	0.160	0.400	0.250	0.630	0.400	1.000	0.630	1.600	1.000

ADAPTATION AND REPETITIVENESS

3x4 cm and 2x3 cm X-ray plates can satisfy most requirements in endodontic radiology. One can usually center perfectly the tooth or the group of teeth and the neighboring tissues of the object to be investigated, so as to obtain intraoperative or diagnostic examinations meeting the operator's requirements (Fig. 6.22). The size of the sensitive plate corresponds with a one-two millimeter gap to the sizes of the external protective cover. The first CCD sensors featured a definitely larger overall size, - even seven, eight millimeters – compared with the one of the sensitive area. This size was, anyway, much reduced by comparison with the sensitive area of traditional X-ray plates. For this reason it was not always possible to obtain sufficient data with a single projection, particularly in the case of polyradicular or larger teeth. It was often necessary, anyway, to define the area of greater interest with care and to sacrifice the vision of neighboring areas. In addition one must consider that sensors were fairly thick and cumbersome and, often, it was not easy to position them in the area of interest so as to obtain a correctly framed projection without distortions. At first centering devices were not even available, whereas the first ones were cumbersome, not much functional and difficult to use. In addition, then, to the problem of a difficult initial centering there was also the one of an impossible correct repetition, after some time, of the same frame, an almost – I would say – mandatory requirement in Endodontics.
These important failings have been given the right consideration by research centers, so that today the most advanced DRS feature CCD sensors of different sizes, suitable to various clinical situations, with a limited overall size, thickness in particular, with a sensitive area which is only slightly smaller compared with the sensor's total area.[4] In addition to this the centering devices for CCD sensors have evolved – also thanks to the co-operation by specific manufacturers – so that today it is much easier to perform correct and repeatable radiological examinations (Fig. 6.23).[10,12]
These problems are not obviously found with DRS featuring excitable phosphor sensors, which, with nearly the same size and thickness as traditional radiographic plates, can use all the standard centering devices (Figs. 6.24 and 6.25).[16,27]

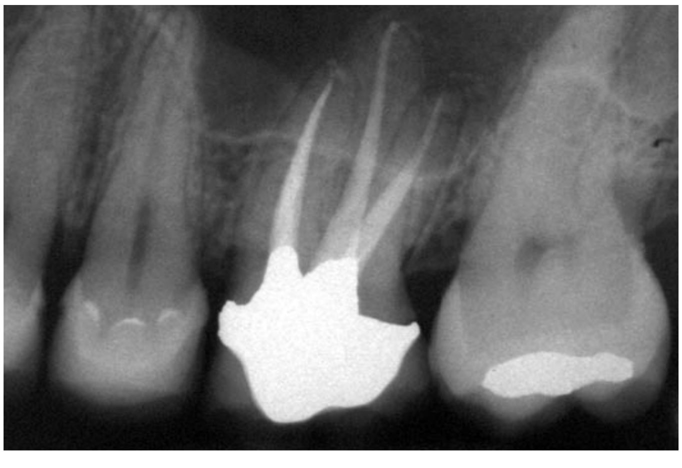
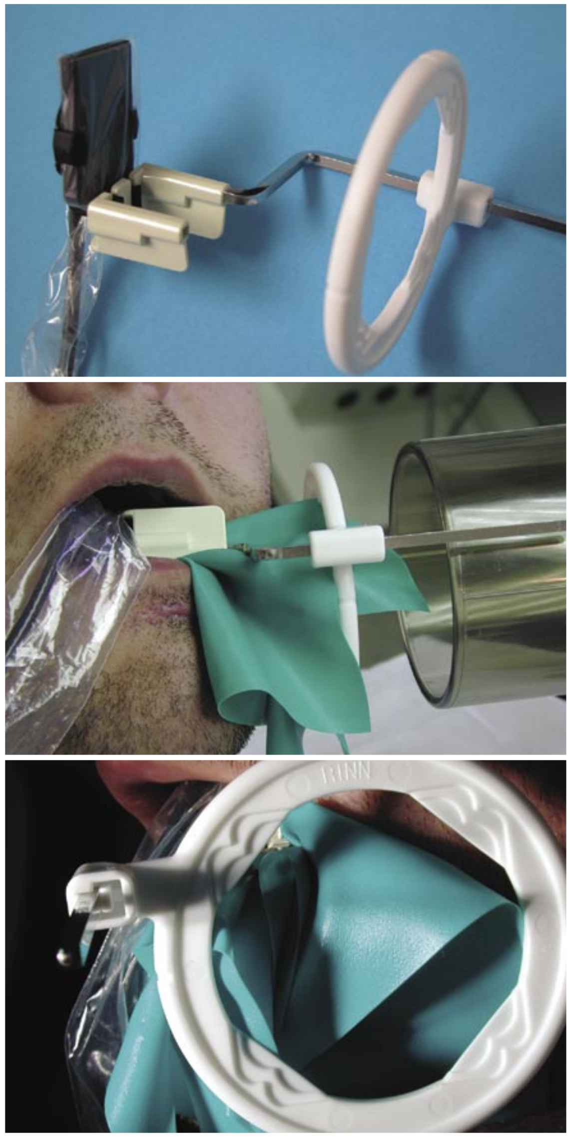


Fig. 6.22. The affected tooth and the neighboring tissues are well framed.

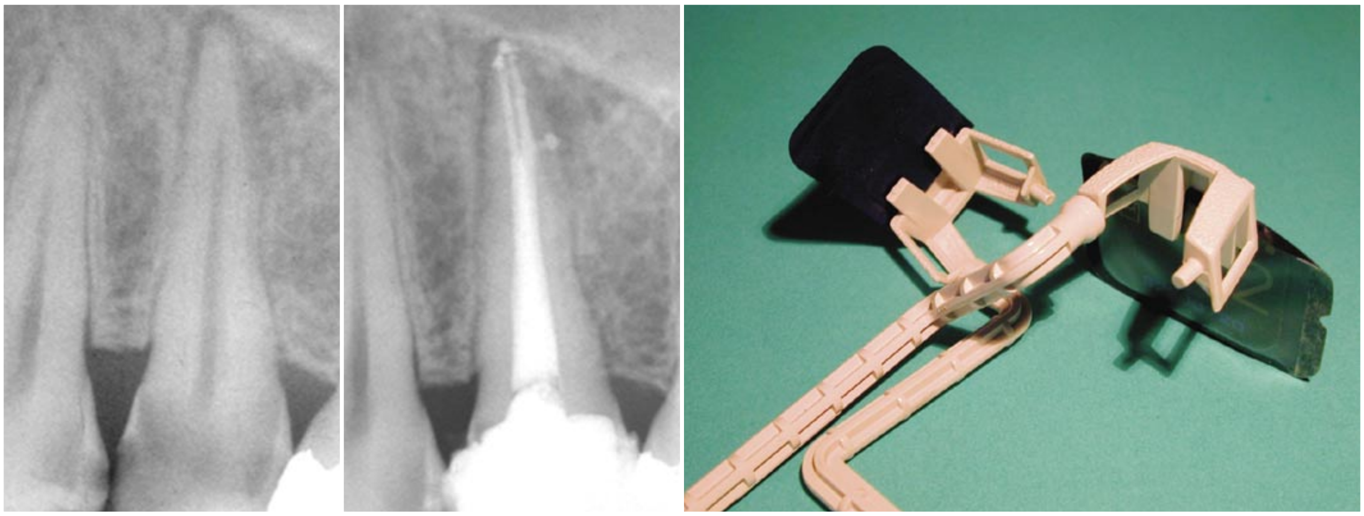


A
B
C

Fig. 3.23. **A.** (Rinn) Endodontic centering device for Gendex CCD sensors. **B.** Front view: (Rinn) Endodontic centering device for Gendex CCD sensors, placed in patient's mouth during endodontic treatment. **C.** Side view.

A B

Fig. 6.24. Postoperative and at 12 months check with an "individualized" centering device on a patient with a resin *bite*



A B C

Fig. 6.25. **A.** Preoperative radiograph. **B.** Postoperative radiograph. **C.** Endodontic centering devices for ordinary X-ray plates can be used with memory phosphor type sensor, thanks to their identical size. Their overall size is smaller than the endodontic centering devices for CCD sensors.

FILING

Patients' X-rays are such an important amount of data – both from the clinical and the forensic medicine point of view – that their filing should be a straightforward, safe and easy-to-check process.[22] In reality this does not always happen. It is not infrequent, in actual fact, for X-rays to deteriorate and get lost due to both an incorrectly performed developing and fixing process and unforeseeable accidents (Tab. VII). It is necessary to bear in mind, however, that current legislation does not offer univocal interpretations for what regards the forensic validity of digital images. It would be a good rule, at a close periodical interval, to make copies of the filed images on no longer modifiable supports after the first recording. The hypothesis would be for the presence of an image, exactly identical on numerous chronologically progressive registration supports, to be valid in practice also on its unaltered originality. All this, however, will not be valid, if the image has been tampered with before the initial filing registration: all the next copies, of course, would not equally correspond to reality. This problem, of course, takes on particular importance and it is, then, a subject of study in an attempt to reach an adequate solution.

One of the suggested solutions (Gendex) consists of filing inside the image file itself a small "file" – no longer modifiable by the user – which registers and

Table VII

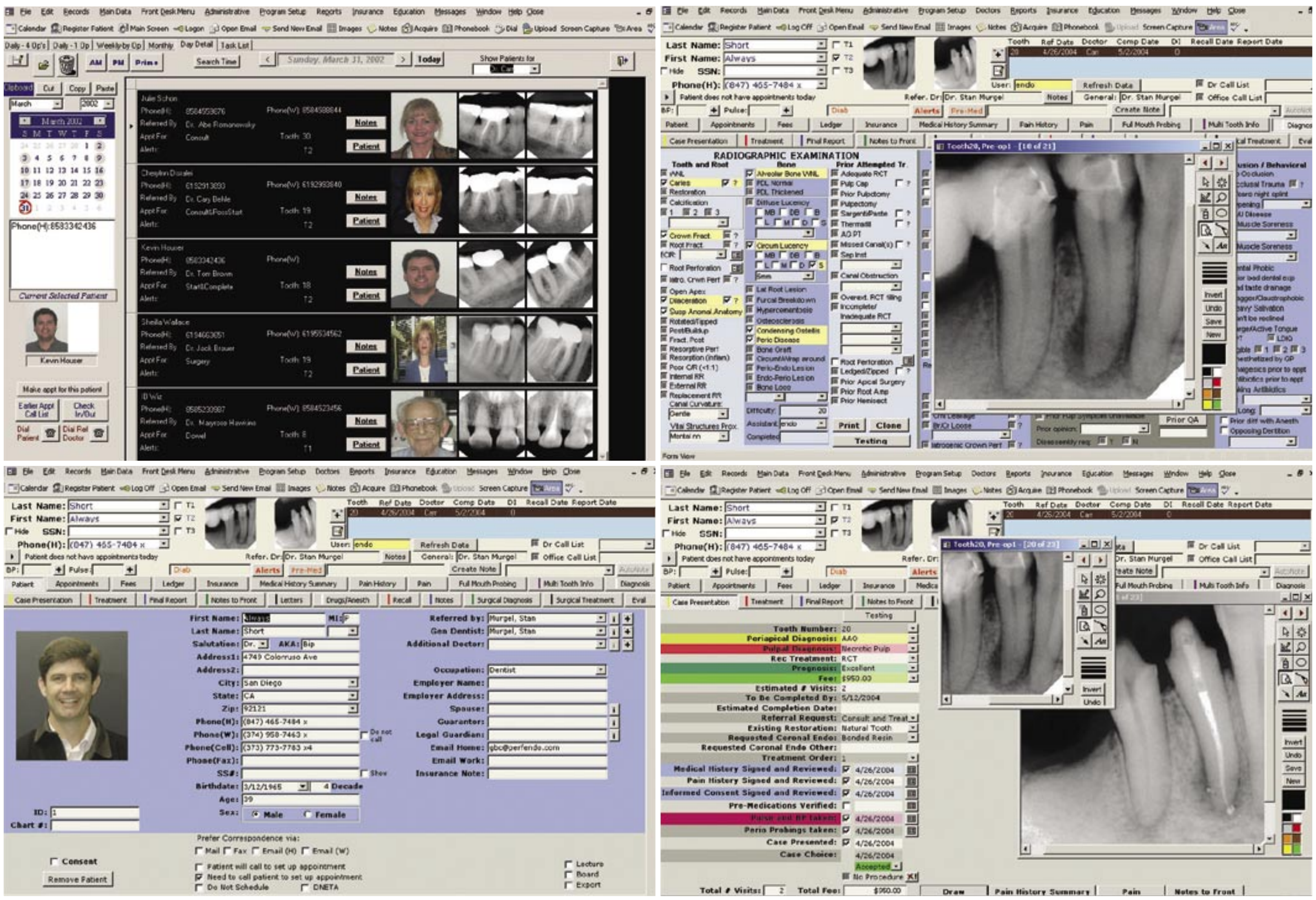
Why digital radiology

- Reduction of the dose absorbed by patients (75-80%)
- Immediate production of an image during endodontic procedures
- Image digital processing
- Efficient filing and re-calling of images from database
- Elimination of dark chamber
- Elimination of plates (purchasing, storage and manipulation problems)

keeps automatically all the changes and modifications performed on the image after its acquisition. This "file" may easily be consulted through a management software utility and it is an actual identity card of the DRS image. DRS filing, that is digital images, is an easy and fast process, as its later consultation, which has ever perfect images available even years later.

In order to obtain a good digital file it is then necessary to get computers and storage saving hardware in line with or oversized in relation to the specific requirements of the adopted DRS. The chosen hardware should also feature facilities for updating, integrating and, if necessary, expanding its memory capacity above-all as the mass of data will grow progressively.

The program which manages the clinical or DRS image filing (Fig. 6.26) must be easy and intuitive to use, featuring easy-to-follow systems for filing and later search. It should be compatible, ready for integration, if required, with the management program of the dental surgery so that clinical, statistical and book-keeping data, traditional X-ray images, clinical or intra-operative images (acquired through a scanner or directly via modem or digital cameras) and



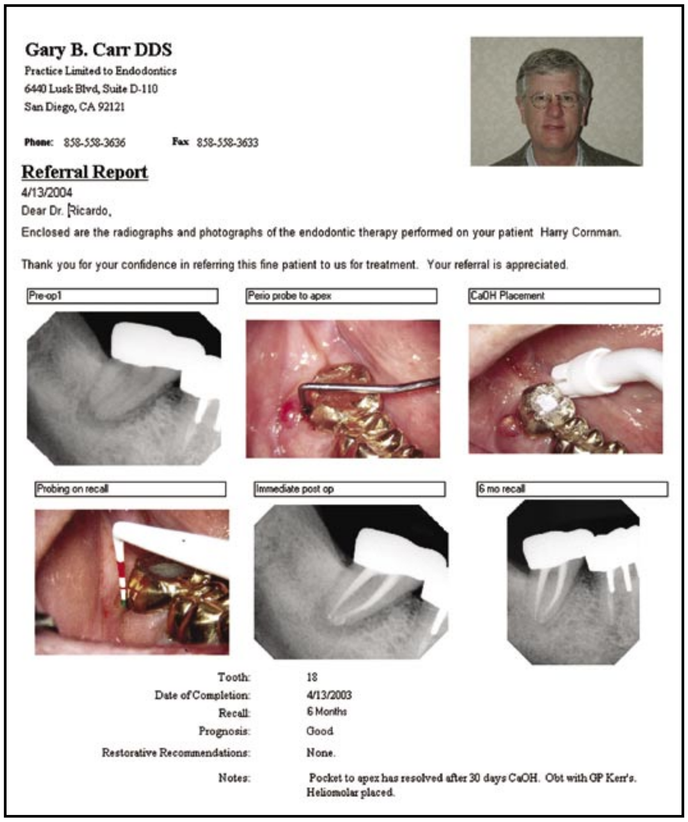
A B C D

Fig. 6.26. **A-D**. Radiographic and clinical images may be filed in each patient's clinical card. An example of the software "The Digital Office" (TDO). Courtesy of Dr. Gary Carr.

radiovisiographs may be linked and grouped in a single clinical card to facilitate the patient's overall management.

A particular of no secondary importance which may and should affect the choice not only of the DRS, but also of a computer management program for the dental surgery, is the guarantee of reversibility of data. They must be filed in standard formats so as to offer access to any other programs. It is necessary to beware of anyone who suggests filing formats or systems outside common standards, even if highly efficient. Should one change to other systems, one would risk losing data or having to cope with complex, costly and often uncertain operations for the extraction and the translation of the data themselves in order to make them compatible.[26]

The possibility to make all the security copies from the file, believed to be necessary, protects from any chance of loss or deterioration of data. Moreover a copy or a print can easily be made and handed to either the patient or the colleague who has requested the specialist's consultation (Fig. 6.27).


Gary B. Carr DDS
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Phone: 858-558-3636 Fax 858-558-3633

Referral Report

4/13/2004

Dear Dr. Ricardo,

Enclosed are the radiographs and photographs of the endodontic therapy performed on your patient Harry Cornman.

Thank you for your confidence in referring this fine patient to us for treatment. Your referral is appreciated.

Pre-op1 | Perio probe to apex | CaOH Placement

Probing on recall | Immediate post op | 6 mo recall

Tooth: 18
Date of Completion: 4/13/2003
Recall: 6 Months
Prognosis: Good
Restorative Recommendations: None.
Notes: Pocket to apex has resolved after 30 days CaOH. Obt with GP Kerr's. Heliomolar placed.

Fig. 6.27. Referral report made with "The Digital Office" software (TDO). Courtesy of Dr. Gary Carr.

LARGE FORMATS

Both DRS featuring excitable phosphor sensors of adequate size (Gendex, Durr, Soredex) and the CCD group systems (Planmeca, Trophy, Gendex, Sirona, Instrumentarium) can already perform orthopantomographic examinations (Fig. 6.28). The chance to have digital orthopantomographs as well presents the advantage, - in addition to the ones mentioned before for endo-oral radiovisiographs - to enable the dentist to view immediately an exam, if obtainable as a file, e.g. via the Internet, which is usually performed in radiographic centers far away from dental surgeries. In this way one may decide on the necessity of further examinations while a patient is still ready for the radiologist.

A development of the management of radiological exams heading this way would enable a patient to be entrusted with a copy of all his radiographic documentation on an adequate data support. This would entail undeniable advantages both for the patients and the health professionals not usually in charge, who could have the patient's full clinical history ready on hand at any time.[29,34]

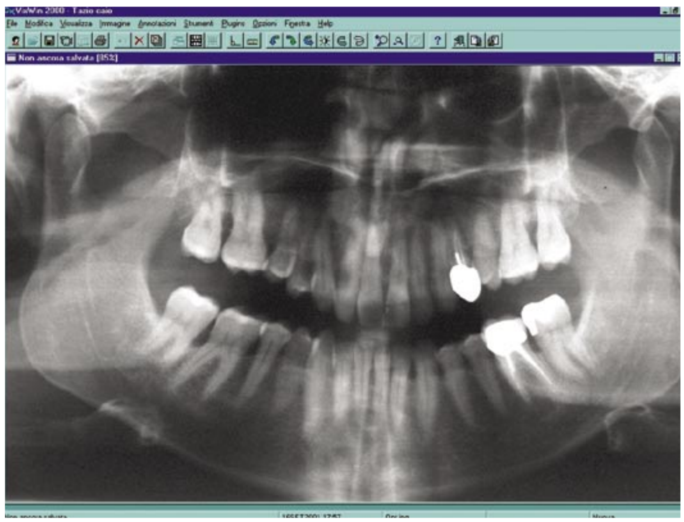

Fig. 6.28. Also orthopantomographic examinations may be performed through radiovideographic systems.

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7

Pulpal Pathology

Arnaldo Castellucci

THE REPARATIVE CAPACITY OF PULP TISSUE

Opinions regarding the reparative capacity of pulp tissue are contrasting. Several maintain that the pulp cannot sustain any insult,[50] while others are convinced that because it is very resistant any attempt to preserve it is justified.[24]

These are two extreme positions. Neither is correct; rather, the truth lies somewhere in between.

Histologically, the pulp, apart from the odontoblasts, is a fibrous connective tissue of mesenchymal origin,[22] has most of the characteristic cells of this tissue, and responds in an analogous manner to various irritant stimuli. Its responses are thus typical of connective tissue of any other part of the organism: an irritation produces damage, and this stimulates an inflammatory process whose final end is the "*restitutio ad integrum*".

Nonetheless, the responses of the pulp are different from those of the other tissues. This is due to topographical and anatomical conditions that cannot be modified.

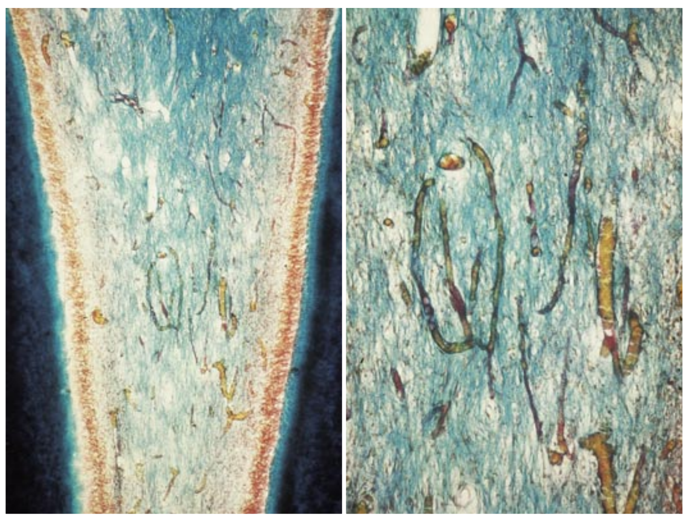
In 1939, Gottardi[18] noted that the pulp was enclosed in a mineralized, rigid, and inextensible theca. Other authors have even said that the pulp is already enclosed within its own coffin!

The source of its blood supply is at a considerable distance from the large mass of coronal pulp tissue, and the volume of the pulp is relatively large if compared with the transverse diameter of its foramen or foramina,[54] except in the case of teeth with an immature apex. This means that the blood supply of the pulp is abundant (Fig. 7.1). Unfortunately, however, all the arteries enter the tooth through a relatively restricted apical opening, and the veins exit through the same foramen.

For this reason, the pulp, having to react to external stimuli and pathological processes, both inflammatory and infectious, is unfavorably situated. Indeed, when the pulp is in some way injured at the coronal level, it responds with inflammation and a consequent increase of vascular permeability and exudation of fluid into the surrounding tissues, as in other connective tissues. In contrast to the latter, however, the pulp has no room to expand and swell as it manifests the five pathological signs of inflammation: "rubor, calor, *tumor*, dolor, and functio lesa".

Thus, the pulp draws no advantages from the inflammatory process. On the contrary, the increased volume of its inflamed tissues and the simultaneous inability to swell, the compromised efferent circulation and rapid reabsorption of the exudate induce necrosis of a large number of cells.

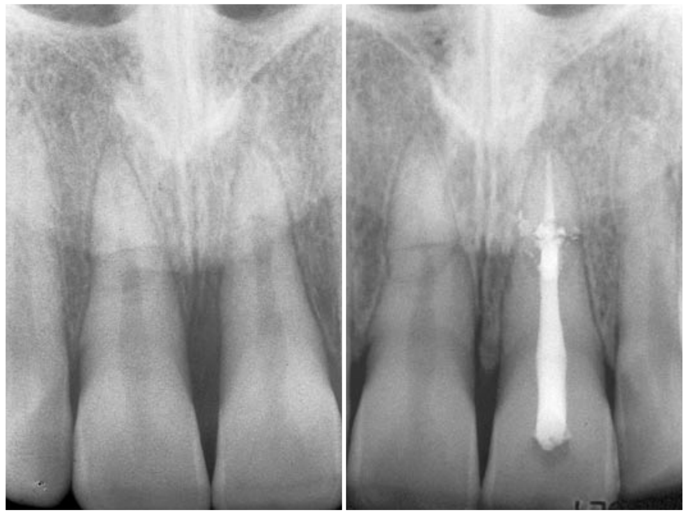
Further aggravating the situation, the pulp lacks collateral circulation, since its circulation is of the terminal type, especially at the coronal level, where there is a greater amount of tissue.



A B

Fig. 7.1. **A**. Blood vessels in a healthy, adult pulp. **B**. Detail (courtesy of Dr. N. Perrini).

Moreover, the coronal pulp is the first to sustain insults of any sort and the furthest from the entrance of the blood supply in the apical foramen.
When the pulp sustains an insult sufficient to create true inflammation, its anatomy makes it highly susceptible to necrosis and gangrene. Indeed, the pressure caused by edema is frequently sufficient to interrupt the circulation at the level of the apical foramen. The stasis of blood flow provokes destruction of this peduncle of soft tissue.[54]
In conclusion, when the pulp is exposed to external pathogenic agents, in particular bacteria, following an accidental insult or pathological process, it is incapable of reacting to them. Rather, in spite of opposing them with its reactive and defensive processes, it is fatally destined to succumb to necrosis.
On the other hand, this does not mean that the pulp dies no matter what! Many studies have demonstrated the reparative capacity of the pulp tissue.[2,6,40,51]
Nonetheless, one must be very prudent when undertaking so-called "vital pulp therapies" and must determine very carefully whether the compromise has caused reversible or irreversible damage in the pulp that one is about to treat.
Many have confirmed that, in the absence of bacterial infection, the most important parameter to be taken into consideration is the blood supply. If the pulp has an ample blood supply, its reparative capacity may be considerable.
A pulp exposed by trauma to a tooth with an immature apex can retain its vitality. (Proper maintenance will maintain the vitality of the pulp tissue until it has carried out its primary, formative function, and thus has led to maturation of the root and of the apex. From this point of view, the pulp could be considered a supporting tissue of the odontoblasts[54]). The pulp of a tooth that has sustained a radicular fracture to its middle one third, where there is a certain mass of pulp tissue and a discrete blood circulation, and the fracture is close enough to the entrance of the blood vessels in the root, can maintain its vitality (Fig. 7.2). The apical portion of the pulp of an horizontally fractured tooth can remain vital (Fig. 7.3). The pulp of an immature tooth that is extracted with its follicle and reimplanted in the bleeding alveolus of another just-extracted tooth can remain vital (Fig. 7.4). Even the pulp of a tooth that is accidentally injured by a dental burr in the course of apicectomy can retain its vitality (Fig. 7.5)!
Revascularization is a function of the diameter of the apical foramen, of the mass of the exposed tissue,



A B

Fig. 7.2. **A**. The upper right central incisor has sustained trauma and presents a horizontal fracture at the middle one third of the root. The vitality of the pulp has been preserved. **B**. One year later. The vitality of the pulp of the upper right central incisor is still maintained, while the upper left has required the endodontic therapy.

A B

Fig. 7.3. **A**. The upper right central incisor has an horizontal fracture between the coronal and the middle one third. **B**. Seven years later the pulp of the apical fragment of the root is still vital.

and therefore it is a function of its blood supply.[1,25,31,76]
The case of pulp exposure in a tooth with a mature apex, however, is very different, especially if it is complicated by bacterial infection. In the long term, the possibility of recovery is quite low in this case.
For these reasons and for the reasons that will be analyzed in detail in the paragraph on vital pulp therapy, Schilder and his entire school is definitely opposed to the various types of pulp capping and considers pulp exposure to be an indication for endodontic therapy.

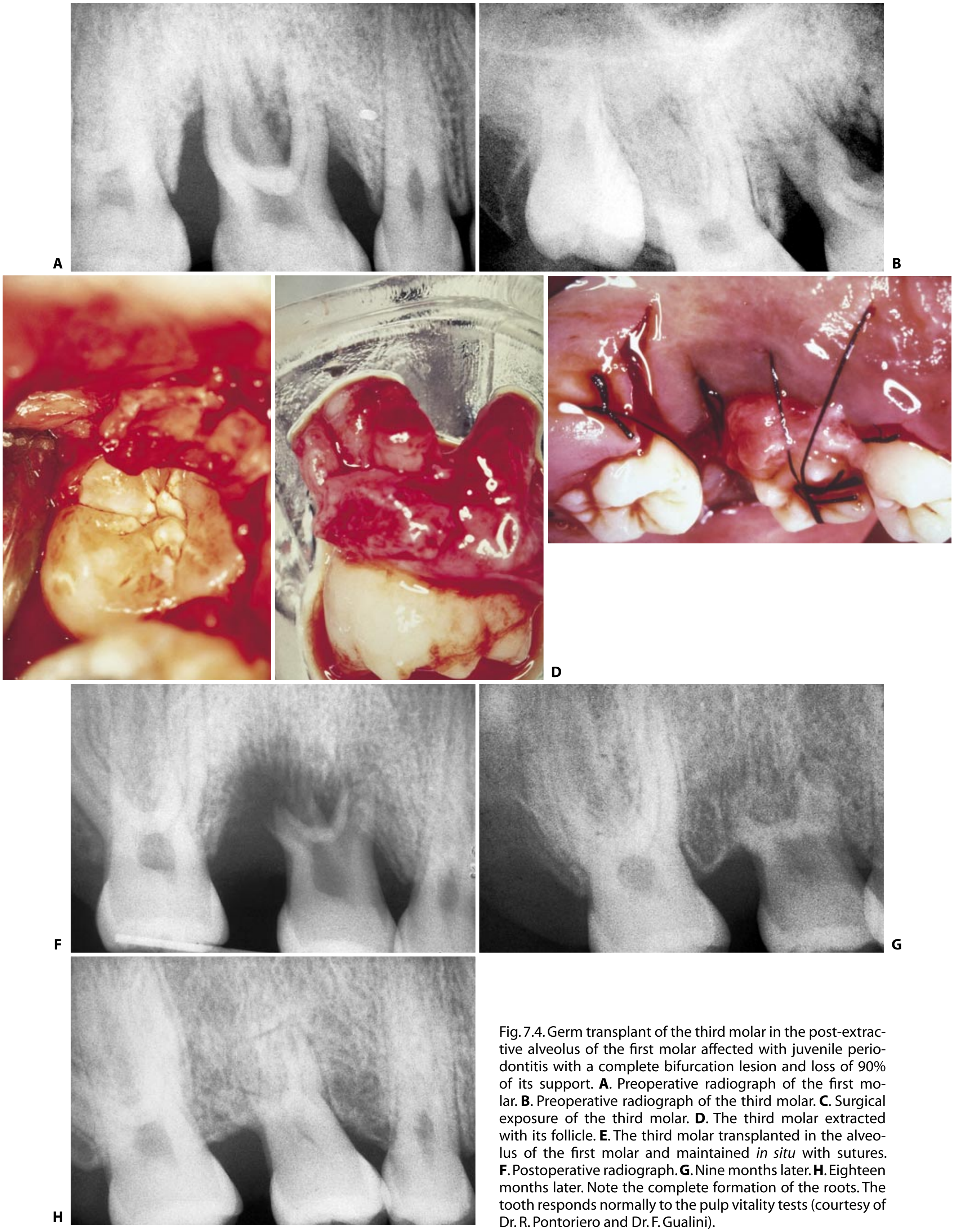


Fig. 7.4. Germ transplant of the third molar in the post-extractive alveolus of the first molar affected with juvenile periodontitis with a complete bifurcation lesion and loss of 90% of its support. **A**. Preoperative radiograph of the first molar. **B**. Preoperative radiograph of the third molar. **C**. Surgical exposure of the third molar. **D**. The third molar extracted with its follicle. **E**. The third molar transplanted in the alveolus of the first molar and maintained *in situ* with sutures. **F**. Postoperative radiograph. **G**. Nine months later. **H**. Eighteen months later. Note the complete formation of the roots. The tooth responds normally to the pulp vitality tests (courtesy of Dr. R. Pontoriero and Dr. F. Gualini).

Fig. 7.5. The patient reports having undergone an apicoectomy of the upper right lateral incisor. The adjacent canine reveals the signs of radicular sectioning at the level of the apical one third. The apex is still in place. The tooth responds positively to the various tests of pulp vitality.

PULPAL DISEASES

Clinical classification

Many authors[16,34,59-61,63] agree that because of poor correlation between the histological appearance of the pulp tissue and the clinical situation, it is impossible in practice for the dentist to classify the various clinical situations with which the patient may present in accordance with any histological system and from there draw the treatment of choice.
The absolute lack of correlation between the intensity of pain and the extent of pulp compromise is a reality of which one can only take note.[42] On the other hand, what truly interests the dentist is not so much arriving at the subtle distinction between serous and seropurulent pulpitis, as making the sometimes difficult decision to treat the tooth endodontically or to attempt preventive measures. Once the need for endodontic intervention has been established, knowledge of the precise histopathological nature of the pulp tissue has only academic value, since it will not change the therapy, which in any case is total extirpation or pulpectomy.
The real problem is rather the difficulties that one sometimes encounters in deciding when to intervene and when not to, in recognizing reversible and irreversible situations whose distinction is not always clear.
The importance of correct diagnosis is obvious: it is pointless to perform an endodontic treatment when it is not necessary. On the other hand, it is futile to continue to try to maintain the vitality of a pulp that is already condemned.
For these reasons, we will adopt a clinical classification based on the symptoms with which the patient may present and on the signs which the dentist must look for.

Healthy pulp

The healthy pulp of an asymptomatic tooth responds normally to the various vitality tests and to percussion and palpation.
Such a tooth shows no radiographic signs of canal obliteration by "asynchronous" calcification as compared to the pulp of the adjacent teeth (Fig. 7.6), nor signs of root resorption, but rather an intact lamina dura and a normal periodontal ligament space along its entire radicular lenght.

Fig. 7.6. The canine has sustained trauma years previously. Now its pulp appears "precociously aged" with respect to the pulp tissues of the adjacent teeth. Note the total radiographic disappearance of the pulp chamber and radicular canal.

The pulp of a tooth with an immature apex, contained within dentin walls that are still thin (Fig. 7.7) is healthy, as is the pulp of an elderly patient whose root canal, because of the continuous deposition of secondary dentin by the odontoblasts, seems to be nearly obliterated (Fig. 7.8).

Because of their high frequency and because of the absolute lack of symptoms that accompany them, the calcifications that are frequently observed radiographically within the pulp tissue, especially in the crown, can be considered normal findings.

They may vary in size, from microscopic pulpoliths to concretions that occupy almost the entire pulp chamber or canal lumen (Fig. 7.9).

The etiology of these pulp calcifications is unknown. They can occur around nests of cellular degeneration, in the form of dystrophic degeneration, but in the absence of such tissue degeneration, their cause remains obscure. They have even been described in still-unerupted teeth, which have not been influenced by the same functional stresses.[36]

There is undoubtedly a cause-and-effect relationship

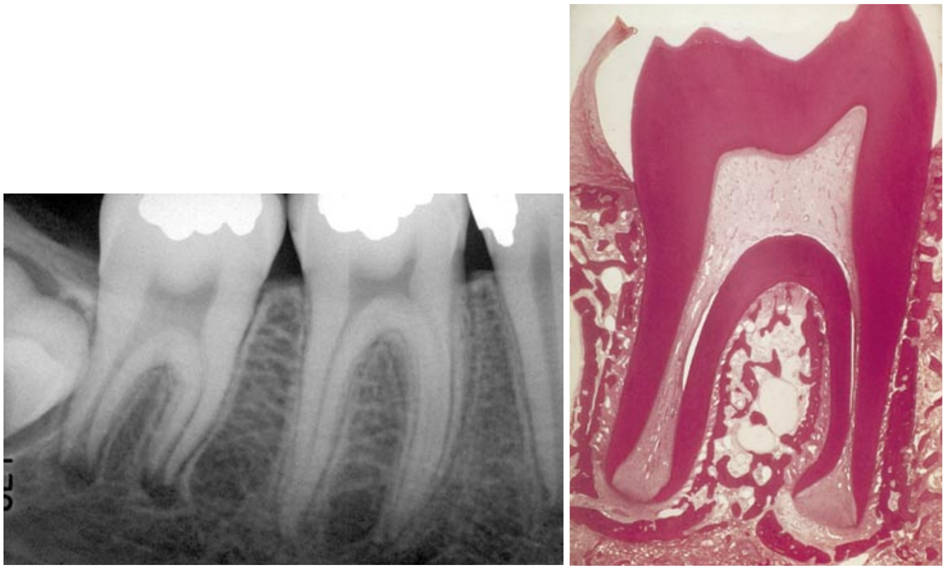
A  B

Fig. 7.7. **A** Radiographic appearance of a normal pulp in a second molar with an immature apex. **B**. Histologic appearance of a normal pulp in a molar with immature apices (courtesy of Prof. A. Bloom, Boston University).

Fig. 7.8. Radiographic appearance of a normal pulp in an elderly patient. Note the sizes of the pulp chamber and of the canals of the upper right second molar.

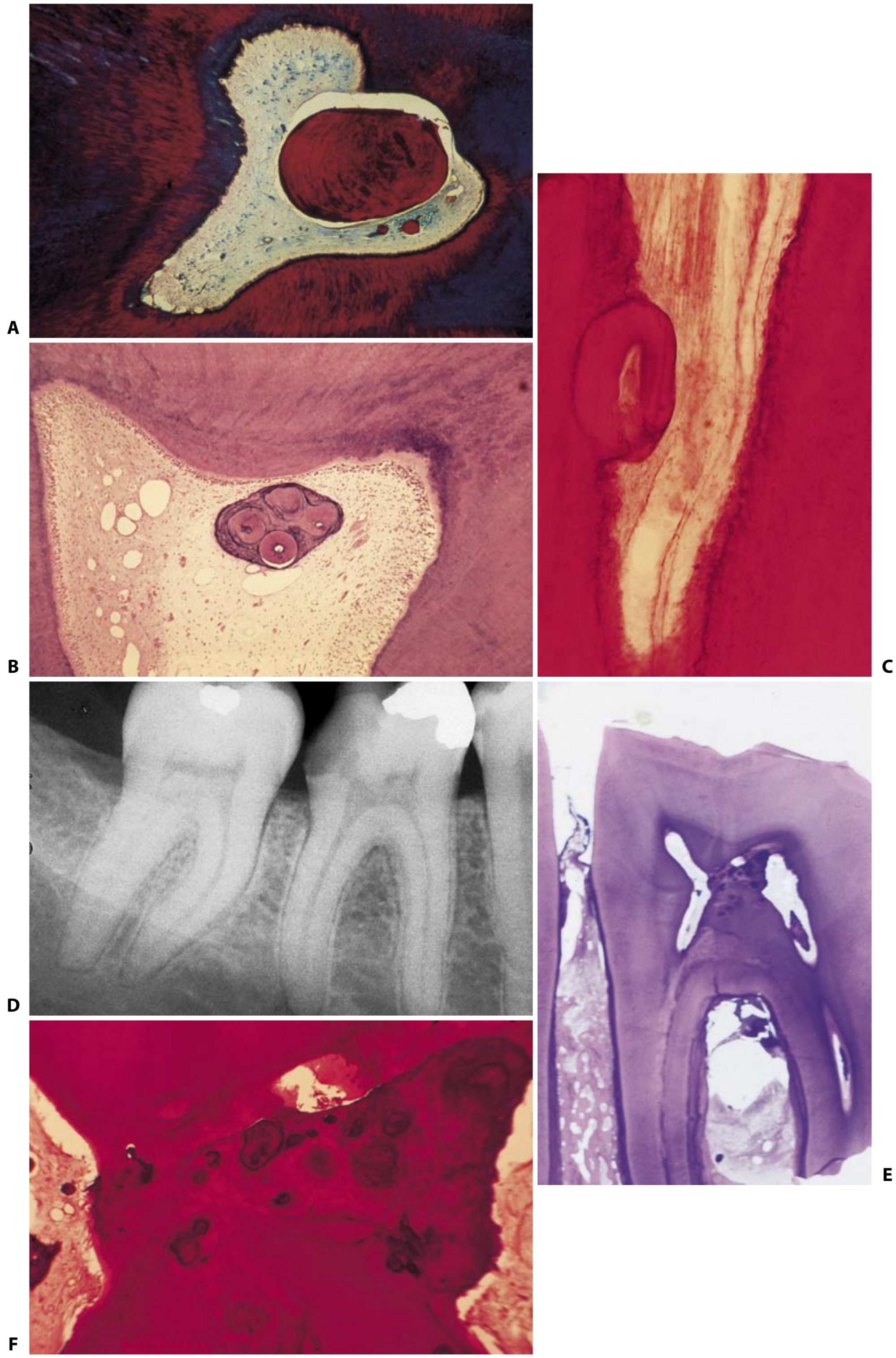


Fig. 7.9. **A**. Large free-false pulpal calculus (concentric layers, without tubular elements) (courtesy of Dr. N. Perrini). **B**. Small free-false pulpal calculus with four concentric calcification nuclei in the pulp chamber of a lower molar (courtesy of Prof. A. Bloom, Boston University). **C**. False pulp calculus, adherent to the wall of the apical one third of the canal (courtesy of Prof. A. Bloom, Boston University). **D**. The pulp chamber of the lower right first molar with penetrating caries and pulpitic symptomatology is invaded by calcifications. The pulp chamber and a good part of the distal canal of the second molar are also occupied by calcifications. The tooth responds normally to the vitality tests. **E**. Histologic appearance of a lower first molar with an enormous calcification that has caused the roof and chamber floor to fuse. **F**. Detail of the preceding figure at higher magnification (courtesy of Prof. A. Bloom, Boston University).

between calcifications and pulp pathology, especially when the tooth has a long history of chronic irritation, such as that caused by dental caries.[53]
These calcifications "steal space" from the cellular component of the pulp and in some way can also interfere with the vascularization of the surrounding tissue. This must be considered when one is deciding whether to undertake a direct pulp capping.
Even with the passage of years, the odontoblasts do not cease their activity. Thus, it is normal to find a gradual diminution of the endodontic space, both coronal and radicular, in the elderly patient, owing to the continued apposition of secondary dentin.
Furthermore, within the pulp itself the number of cellular components diminishes, while the content of collagen fibers increases. These are therefore normal findings in the elderly, whose pulps "age" synchronously in both the dental arches.
The situation of so-called "precocious", "out of step", or "asynchronous" aging of the pulp of a single tooth is quite different; it is an index of pulp tissue compromise. It may occur, for example, as the consequence of trauma. Such "aging" is frequently asymptomatic and most often comes to the attention of the dentist because of the unaesthetic discoloration of the dental crown, as an incidental radiographic finding, or because of symptoms of periodontitis that can arise after the compromised pulp has become necrotic (Fig. 7.10).

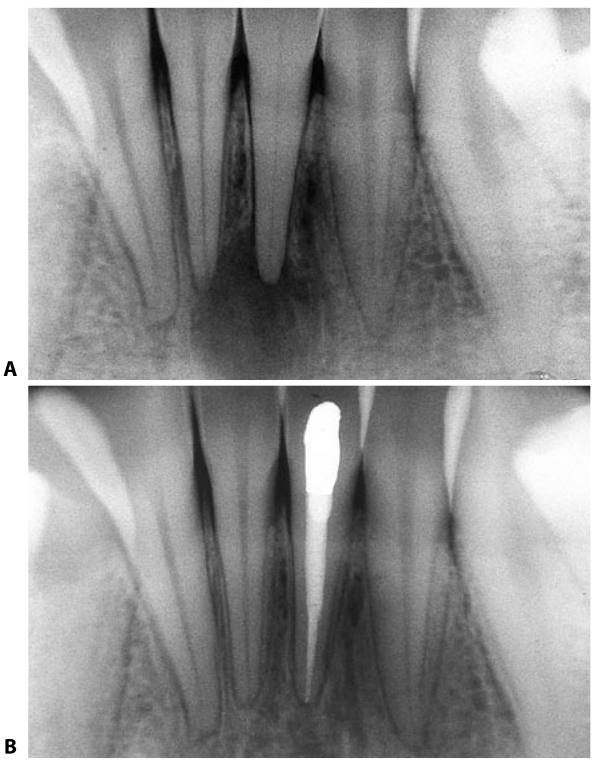


Fig. 7.10. **A.** Years following trauma, the pulp of the lower left central incisor, after protracted compromise which has led to "asynchronous" restriction of the canal lumen, has finally become necrotic, causing the lesion and symptoms. Note that, although it extends into the lesion, the apex of the right central incisor responds to the vitality tests. **B.** Two years later. Note the complete healing of the lesion and the maintenance of pulp vitality in the right central incisor.

Hyperemia

The term "hyperemia" is used in reference to a reversible clinical situation characterized by the onset of a sudden, sharp pain in response to a cold stimulus which resolves almost immediately once the stimulus has been removed.
In medicine and physiology, hyperemia indicates an increase of the amount of blood in a certain tissue. However, numerous histological studies have demonstrated that pulps that are clinically classified as hyperemic are only infrequently found to be histologically hyperemic.[29]
In these latter cases, therefore, rather than speak of hyperemia or reversible pulpitis, like other authors,[13,21,75] it would be more correct to speak of dentinal hypersensitivity.[74]
Clinically, dentinal hypersensitivity can be associated with a histologic appearance of hyperemia; on the other hand, hyperemia can also exist without clinical hypersensitivity. Furthermore, the clinical and histological situations may coexist, as in the case of dentinal hypersensitivity with hyperemia.
In conclusion, hyperemia and reversible pulpitis are not diseases, but symptoms.

Clinical symptoms

Clinically, the patient presents with the sudden onset of sharp pain provoked by a cold stimulus. It lasts only a few moments and resolves immediately after the stimulus is removed. The pain never occurs spontaneously, but is always provoked; in fact, there is a strict cause-and-effect relationship. The cause of the pain could be cold beverages or cold air. The patient may complain of it after a metallic restoration has been performed or as the first sign of incipient caries. In the latter case, the pain may also be provoked by sugar containing substances. It may also occur in response to the curettage or root scaling or after a periodontal procedure that exposes the root surface. The exposed dentin of the root surface can also be stimulated by acidic substances, by the bristles of a toothbrush, by flossing, or by a probe. In these cases, the cementum covering the dentin is missing or has been removed by curettage or excessively vigorous brushing with the consequent exposure of the dentinal tubules.

The pain associated with dentinal hypersensitivity is explained by the “hydrodynamic theory” of Brännström,[8] according to which the back-and-forth movements of fluids within the dentinal tubules stretch and stimulate the nerve fibers.

According to Brännström, “if the movement occurs quite rapidly, the dislocation of the contents of the dentinal tubules can produce deformation of the nerve fibers of the pulp or predentin or even damage the cells; both these effects can produce pain. This mechanical transmission of the stimulus can explain the high pain sensitivity of the dentin in spite of the absence of nerve fibers in this tissue”.

When dentin is exposed to a brief air blast, the fluid within the dentinal tubules evaporates to a depth of 0.1 to 0.3 mm. This leads to the aspiration of odontoblasts and nerve fibers within the tubule. The nerve fibers are stretched or even disrupted, with the consequent production of pain (Fig. 7.11).

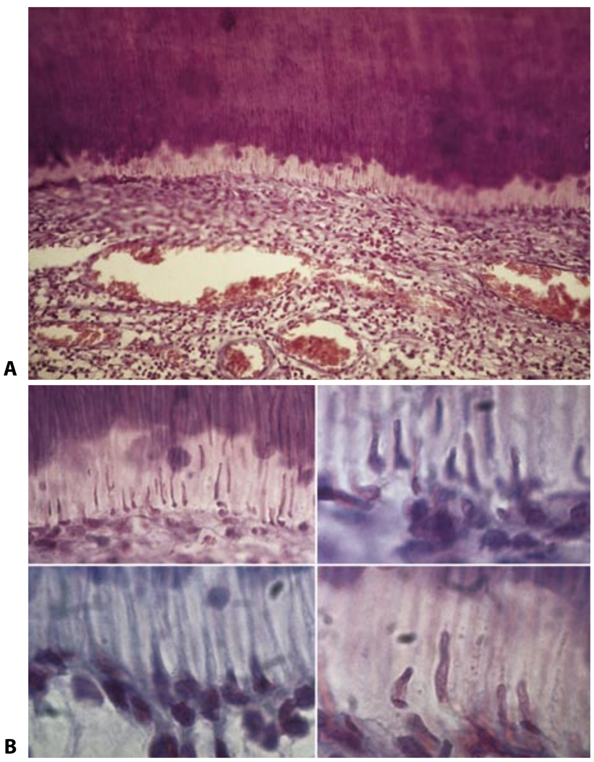


Fig. 7.11. **A.** The movement of the fluids contained within the dental tubules has caused the aspiration of the odontoblasts within these tubules. **B.** Details of the preceding figure (courtesy of Dr. N. Perrini).

The physiopathology is similar in the case of cold stimulation. The cold causes the fluids within the tubules to contract, causing the fluids to flow in a centrifugal direction, owing to the pressure within the pulp. This flow causes the nerve fibers to stretch within the tubules, together with the odontoblasts.[9]

Brännström states that the fluids have a coefficient of dilatation considerably larger than that of solids and that this explains the excursions that occur in very restricted spaces such as the dentinal tubules in response to variations in temperature.

The same phenomenon is caused by burs, heat produced by friction, and surface pressure, which causes displacement of the intratubular fluids and thus pain. A probe or excavator passed over the dentin also produce similar pressure and pain.

Diagnosis

The diagnosis is made on the basis of the patient’s symptomatology and the results of testing.

Since the pain is of pulpal origin and the pulp lacks proprioceptive nerve endings, the patient cannot localize the diseased tooth and sometimes not even the arch, upper or lower, but can only say whether it is right or left, as the pain does not cross the midline.[17,75]

The case of a patient with pain arising from the lower left central incisor but referred to the right hemimandibular canine has been described,[15] but such cases are quite rare.

Because the patient’s attempts to localize the pain may in fact be misleading, it is necessary to perform some basic tests to find the diseased tooth by reproducing the symptoms.

If the patient has said the magical word “cold”, the application of a cold stimulus is an excellent method for identifying the involved tooth.

Beginning with the least suspected tooth to avoid frightening the patient, one touches the cervical areas of the teeth with an ice stick until the diseased tooth is touched (Fig. 4.21). The ice must be applied at the cervical area. Here the enamel, a poor conductor of heat, is thinnest, so that the dentinal response is quicker.

Sometimes, the patient may complain of dentinal hypersensitivity to cold beverages, while stimulation with an ice stick of the cervical area of the suspected tooth does not provoke an unusual response. In this case, the entire dental surface must be surrounded by cold, so that the pulp may react. The tooth must therefore be isolated with a thick dam and then completely immersed in icy water (Fig. 4.22). Hypersensitivity of the cervical area can also be tested simply by touching the neck with a probe.

The electric test is not very helpful in these cases, since the response sometimes occurs early, but this is not the rule. The tooth responds normally to percussion, palpation, and mobility, and the radiographic examination is completely negative.

Therapy

The best treatment for this sort of symptomatology, as Grossman[20] correctly states, is prevention. Good oral hygiene to prevent the development of caries, early filling once the carious cavity has formed, desensitization of the cervical area of the tooth when there is marked gingival recession, the use of a varnish or cement as a cavity liner prior to filling, and care in the preparation of the cavity and in finishing the filling are all preventive measures.

When dentinal hypersensitivity is present, the removal of the noxious stimulus is usually sufficient. After the resolution of symptoms, it is necessary to recheck the vitality of the tooth to ascertain that pulp necrosis has not developed in the interval.

The persistence of pain despite treatment indicates that the cause was not a simple dentinal hypersensitivity or hyperemia; rather, one must suspect the presence of irreversible inflammation.

The prognosis of so-called "hyperemia" is therefore favorable if the irritant is removed early on, before the clinical situation, sometimes after a long time, is transformed into pulpitis.

Pulpitis

Symptomatology

Pulpitis, an irreversible inflammation of the pulp tissue, is clinically manifested by spontaneous pain that is exacerbated in particular by hot stimuli, never cold. In fact, cold very often brings relief to the patient.

Pain produced by heat peaks with some latency, remains at this level even after the stimulus has been removed, and takes several minutes to hours before it resolves completely.

The inflammation present within the pulp tissue initially causes an exudation with a consequent increase of the intrapulpal pressure beyond the pain threshold and thus causes spontaneous pain.[7,75] In its early phases, such pain can be described as bothersome or annoying, but quickly becomes more intense, sharp, diffuse, and referred to another area.

The pain may arise spontaneously if the patient simply assumes the supine position. This explains the frequent nocturnal occurrence of the spontaneous pain, which can nevertheless be caused by any manoeuvre that leads to an increase of intracranial pressure.

The typical history of a patient with pulpitis includes the complaint of insomnia since at least the preceding night. The patient with pulpitis frequently presents urgently to the office in the early hours of the morning. Sometimes, a typical statement is: "Doctor, the pain went away as soon as I entered your office!" This suggests that the pulp has become necrotic.

Diagnosis

As in all other pain of pulpal origin, because there are no proprioceptive nerve endings in pulp tissue, the patient with pulpitis cannot identify the origin of the pain, which can radiate to the eye, ear, or other areas, depending on the tooth affected. This must be made clear to the patients, who may regard the dentist with suspicion when they see that the dentist's attention is directed to a tooth different from the one they continues to identify as the culprit.

In the case presented in Fig. 7.12, the patient presented with pulpitis in the upper left central incisor and pain referred to the lower first premolar of the same side.

It is up to the dentist to correctly diagnose the origin of the pain. While diagnosing the pulpitis may be easy, identifying the tooth responsible may sometimes be very difficult and may require some time. The patient may indicate the side, but may not be able to distinguish between the maxillary and mandibular arches.

In this case, as in the case of dentinal hypersensitivity, the diagnosis is based on the reproduction of symptoms. Since the patient's history never lacks the information that the pain is provoked or exacerbated by hot foods or beverages, the application of heat in a controlled, sequential manner to the individual teeth is undoubtedly helpful in localizing the diseased tooth.

Fig. 7.12. Preoperative radiograph of the upper left central incisor affected by pulpitis. The patient presented with pain referred to the lower left first premolar.

By causing dilatation of the blood vessels, tissues, and gaseous products of proteolysis, heat increases the pain. In contrast, cold has a contractile effect on the remaining functional vascular bed, reducing the intrapulp pressure below the pain threshold of the pain receptors still present.[75] This is also known to the patients who may come to the dentist with a bottle of cold water in their hands![11]
The best method for applying heat to the individual teeth is to heat a ball of gutta-percha attached to the end of a small spatula or other old instrument over a flame and touch the cervical area of the tooth (Fig. 4.18), always remembering to begin with the least suspect tooth. In this way, the patient first learns the response of a normal pulp and will better tolerate the typical response of the inflammed pulp. One must not forget that these patients are often anxious, fearful of the dentist, and come to the office with little sleep the preceding night. One must therefore try not to make them feel that they are being attacked in the dentist's anxiety to find the diseased tooth. A good rule to further reassure such patients is to have an anesthetic at hand.
Warm gutta-percha must be applied to the cervical area of the tooth, where the enamel, a poor conductor of heat, is thinner and where the response is therefore more rapid. Metallic fillings that absorb and retain heat must be avoided, as they may cause exaggerated responses to thermal tests, even in the case of a normal pulp. Synthetic fillings must likewise be avoided, since they do not transmit heat and may therefore give false negative responses.[55]
Another valid method for the application of heat is the "Touch'n heat" or the "System B" (Fig. 4.22).

Pulp tests

When the heat test is performed on a tooth with normal pulp, the patient experiences a brief sensation of heat or slight discomfort, after which the heat source must be moved away from the tooth. This sensation will disappear within a few seconds.
When the heat test is performed on a tooth with necrotic pulp or a tooth that has been treated endodontically, there is no response at all.
The tooth with pulpitis responds in a characteristic manner. After a slight latency period, the pain increases with paroxysm, and even when the stimulus has been removed, it persists for a variable length of time unless it is interrupted with the administration of cold water or local anesthesia.
The sharp, lancing pain of pulpitis is described as one of the most intense that one can experience. It is comparable to renal colic or the pain of childbirth.
The clinical examination of the patient's mouth can also be helpful in making the diagnosis, since a tooth affected with caries may be highly suspect. The tooth must however have a closed pulp chamber; otherwise, the tremendous intrapulp pressure cannot develop.
The electric test is not very helpful. A positive test indicates that the pulp is vital, but provides no information about its health. The tooth responds normally to palpation and percussion. Only in the most advanced cases, in which inflammation or infection also extends to the periodontal ligament, then the tooth also becomes sensitive to percussion. This is the sign of apical periodontitis, and one must keep this in mind when performing an emergency treatment.

Radiographic examination

The radiographic examination may provide information about the presence of interproximal caries that are not visible on intraoral clinical examination and of caries underneath an old restoration, close to a pulp horn (Fig. 7.13). The periapical zone usually appears intact. At most, it may present a slight widening of the space of the periodontal ligament (Fig. 7.14). The presence of early resorption of the bony trabeculae close to the apex is the exception and certainly not the rule; furthermore, it is not necessarily accompanied by symptoms of pulpitis (Fig. 7.15).

In the earliest phases of pulpitis, the patient's responses to the clinical examination and the various tests may not be very helpful in reaching the correct diagnosis. In such cases, especially if the patient is using

Fig. 7.13. The upper left second premolar of this young patient with pulpitis presents clinically with an old occlusal amalgam restoration and an intact dental crown.

Fig. 7.14. Preoperative radiograph of the lower left first molar with pulpitis. Note the proximity of the old composite restoration to the pulp horn and the slight widening of the periodontal ligament on the distal aspect of the distal root.

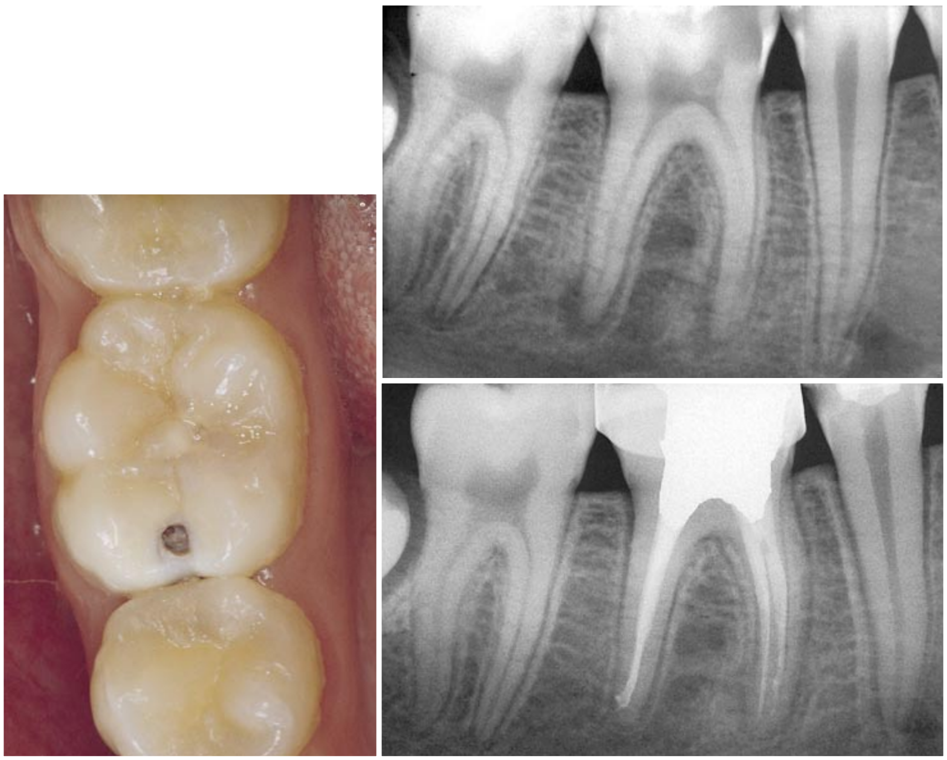


Fig. 7.15. **A**. Occlusal surface of the asymptomatic lower right first molar with "small" interproximal caries in a 16-year-old patient. **B**. Radiographic appearance of the same molar. Note the extent of the penetrating caries, the widening of the periodontal ligament space on the distal aspect of the mesial root, and the radiolucency at the apex of the distal root. The root responds normally to all the pulp vitality tests, including the cavity test. **C**. Eight months later. Note the normal appearance of the lamina dura around the radicular apices.

strong analgesics and gives an unclear response, it is better to postpone further examination until another appointment. The patient should return when the tooth begins to hurt, without taking any analgesics, so that it is easier to make the correct diagnosis. It is better that the patient pass another sleepless night than that the dentist devitalize the wrong tooth.

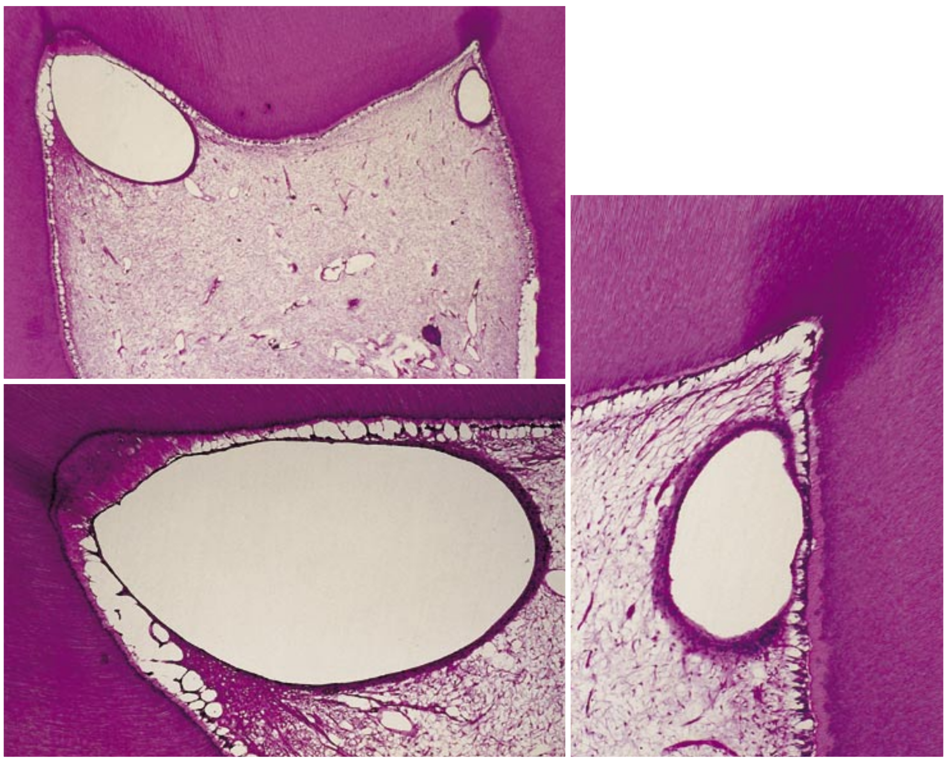
Therapy

Before performing the various diagnostic tests in search of the tooth affected by pulpitis, and especially before performing the heat test, which will definitely provoke unbearable pain, the dentist must have an emergency treatment plan clearly in mind. This must be done before discharging the patient, since pulpitis will not pass with an antibiotic prescription! The patient must be informed of this, and although the words "reproduce the symptoms" might be alarming, one can calm the patient with the assurance that with anesthetic and emergency treatment the pain will disappear.

As already stated, there is no correlation between the clinical and histologic appearances of the pulp (Fig. 7.16). Indeed, different histopathologic situations coexist within the pulp itself, and the transition from one to another is very gradual.

The first area affected by the pathogenic injury is usually the pulp horn or, in any case, a part of the pulp chamber.

All the etiologic agents act at the coronal level. Thus, with a few exceptions that will be described in the chapter on endodontic-periodontal relationships, the diseases of the pulp always proceed in a corono-apical direction. If one imagines the histopathology of clinical pulpitis, one can find a small abscess collection in the horn (Fig. 7.17) (not infrequently, one notes a noxious odor at the chamber opening and the exudation of pus, then blood); around the microabscess, there can be an area of necrosis, then an area with an infiltrate of polymorphonuclear leukocytes and a hyperemic area with many dilated and bulging vessels filled with blood. Proceeding corono-apically, one can find a proliferation of fibroblasts trying to isolate the



A B C

Fig. 7.16, Histologic appearance of the pulp of an extracted upper third molar. A deep decay was present, but the tooth was completely asymptomatic! **A**. The pulp chamber has two microabscesses in each pulp horn (2,5 x). **B, C**. Same areas at higher magnification (10 x).

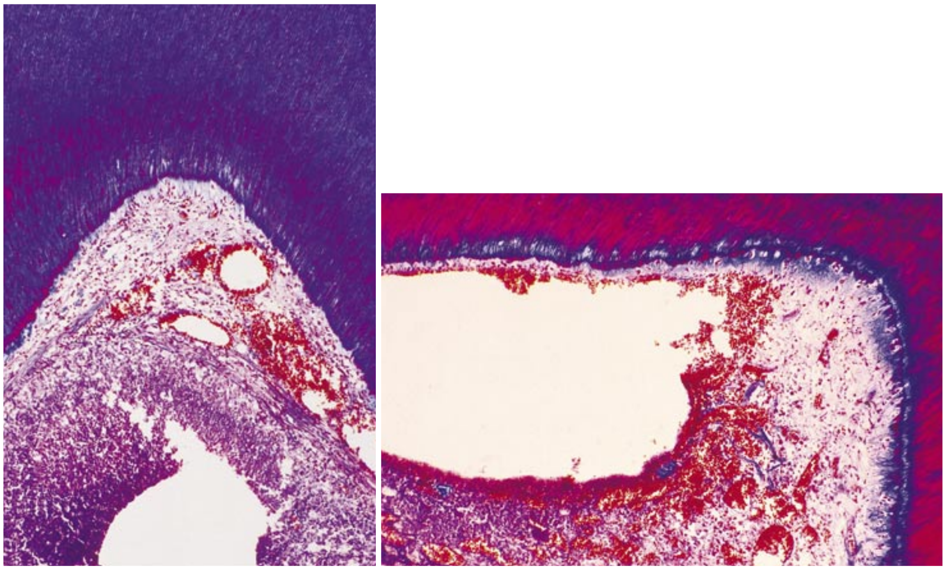


Fig. 7.17. **A**. Histologic appearance of the pulp tissue of an upper third molar extracted for pulpitis. Note the presence of an abscess collection and of leaking blood vessels below the mesial pulp horn (20x). **B**. The abscess is even bigger below the distal pulp horn (20 x).

lesion, and beyond this, within the canals, normal, intact pulp tissue (Fig. 7.18).

From this histopathologic situation two conclusions may be drawn: 1) it is pointless and impossible to try to label this clinical situation with a histologic classification; 2) since the disease proceeds in a corono-apical direction and the pulp tissue that responds to the vitality tests is that in the pulp chamber, then if the tooth responds according to the criteria of clinical pulpitis, the pulp of the root canal is evidently still intact, and this justifies our emergency treatment.

The therapy for pulpitis is pulpectomy and endodontic therapy. However, since the patient with pulpitis presents on an emergency basis, it is unlikely that one will have all the time that is necessary to perform the entire therapy. It is sufficient to undertake the proper emergency treatment to discharge the patient without any symptoms.

The treatment varies slightly, depending on whether one is dealing with a single- or multi-rooted tooth.

In the single-rooted teeth, emergency treatment consists of total extirpation of the pulp or pulpectomy, following anesthesia. Once the anesthetic has taken effect, the rubber dam is put in place, an access cavity is made, and then the pulp is extirpated with the appropriate barbed broach. Sodium hypochlorite is used for irrigation. The bleeding, which rapidly ceases, is controlled, the canal is dried with sterile paper points, and a cotton pellet soaked with vapors of Cresatin is placed in the pulp chamber. The access cavity is sealed with Cavit, and the patient is discharged. The pain will resolve, and the dentist will have won the patient's confidence.

If the radiograph of the diseased tooth shows any contraindication to the use of the barbed broach, it is a good idea to allow more time for the emergency treatment, since the pulp must be removed using files and therefore the canal must be completely measured and prepared.

In the multi-rooted teeth, the recommended emergency treatment is pulpotomy with Cresatin.

As already suggested, a tooth that responds to a heat stimulus in the way described definitely contains vital pulp within the chamber and thus in the various canals, even if in the pulp chamber there is a small abscess or a small zone of necrosis at the level of a pulp horn.

On the other hand, since the diseases of the pulp always proceed in a corono-apical direction, the presence of necrotic pulp within a canal in a multi-rooted tooth is necessarily accompanied by necrosis of all the pulp chamber tissue. Such a tooth would not have manifested signs of clinical pulpitis to testing.

Because of the presence of vital pulp within the canals, pulpotomy is a rapid and safe emergency treatment, assuming of course that one has the greatest respect for the pulp canal stumps.

Once anesthesia has been achieved and the pain has resolved, the rubber dam is placed, an access cavity is created (in this visit, in haste because of the emergency of the situation, it would be a great mistake to only make a limited access cavity, planning to enlarge it when the complete therapy is performed), and then with a large, sharp, sterile spoon excavator the entire pulp is removed from the pulp chamber. One should try to section the pulp cleanly at the level of the canal orifices. A smaller excavator or a small round bur with a long shank mounted on a slow speed contra-angle may be helpful. Better still is a # 1 or # 2 Gates-Glidden bur, used only at the entrance of the canal. The purpose of the clean cut is to insure better control of bleeding. Hypochlorite is used for irrigation, and once the bleeding has ceased the pulp chamber is dried and medicated with Cresatin and Cavit. Cresatin (metacresyl acetate), which has been used for medical purposes since 1911 and in dentistry since 1929, is an antiseptic with antibacterial and antifungal actions. It does not irritate tissues and has a slight fixing action on the cells with which it comes into immediate contact. This is comparable to the "necrotizing" action of calcium hydroxide and the fixing action of formocresol.[56]

Histological, clinical, and radiographic studies[52] have demonstrated the presence of vital tissue in the apical one third of root canals treated with pulpotomy and Cresatin in 84% of cases, the absence of post-operati-

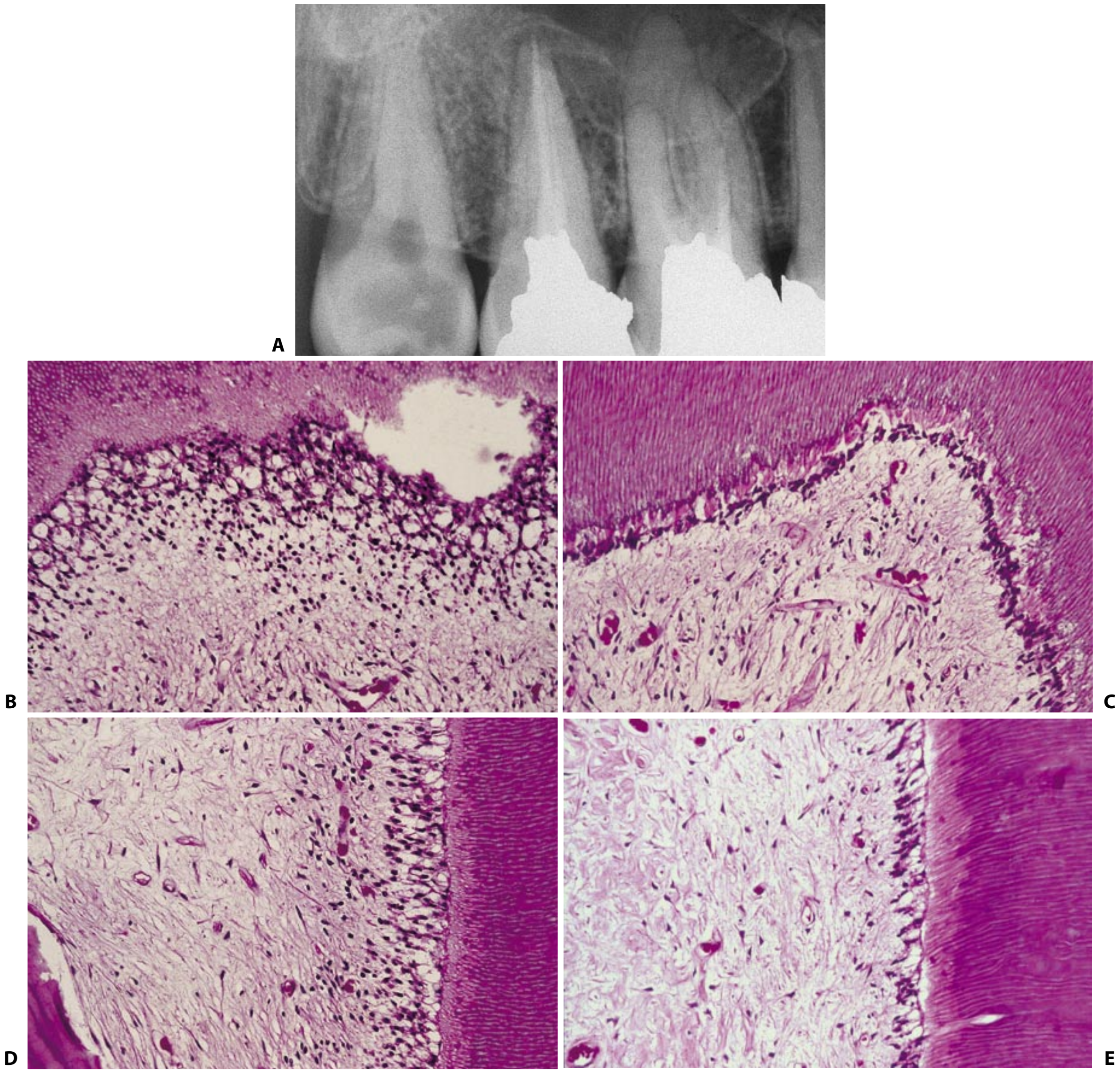


Fig. 7.18. **A**. Radiograph of an upper left third molar with pulpitis. **B-E**. Histologic appearance of the pulp tissue of the same tooth (40x). The pulp presents an increasingly normal appearance as one proceeds apically. **B**. Mesial pulp horn. **C**. Distal pulp horn. **D**. Entrance of the canal. **E**. Middle one third of the canal.

ve symptoms in 96%, and the absence of radiolucencies in 100%.

The success of pulpotomy with Cresatin depends on two factors:

1. The correct diagnosis of "pure" pulpitis, that is, without a component of periodontitis (lack of pain on palpation and percussion).
2. The presence of vital tissue within the root canal (positive response to vitality tests).

If the two circumstances are confirmed, the patient can live with the medicated tooth for as long as a month without any bother. There is thus plenty of time to plan the necessary appointments to complete the therapy. It is absolutely mistaken to give in to the temptation to also remove the pulp of the canals, if there is insufficient time to complete the cleaning and shaping of these canals. As will be seen later, the instruments must and can be placed inside the root canals only if they can be cleaned and shaped completely.

If the situation is not consistent with pure pulpitis – that is, if the tooth, in addition to responding to heat stimulation, is also sensitive to percussion – this indicates that a component of periodontitis is already present. Therefore, the treatment with Cresatin can be performed only after the canals have been cleansed and shaped. The removal of their contents prevents the development of an acute alveolar abscess.

However, since the tooth with pulpitis presents urgently, it is unlikely that one will have the necessary time to prepare the canals. In these cases, once the pulpotomy has been performed, it is advisable to leave the pulp chamber completely open, without any medication, so that it may drain. The tooth will remain open until the date scheduled for the completion of the therapy.

The diagnosis of pulpitis with concomitant periodontal involvement (pulpitis with acute apical periodontitis) is easy to make, since the patient can localize the tooth, which is sensitive to pressure and thus to percussion. This is due to involvement of the proprioceptive nerves in the periodontal ligament.

Whether a "closed" treatment is performed or the tooth is left "open," in the therapy of pulpitis, one must not forget to remove the tooth from the occlusion.

Necrosis

The irreversible inflammation of the pulp that occurs in pulpitis may persist for a certain period of time, but eventually it causes total necrosis of the pulp tissue. Necrosis, or death of the pulp tissue, is thus the direct consequence of pulpitis, but it may also arise immediately after trauma that damages the vascular peduncle.

As a result of an inflammatory process, the pulp tissue continues to disintegrate, forming a slowly enlarging zone of liquefactive necrosis. The lack of collateral circulation and the presence of the inextensible walls of dentin aggravate and accelerate the process that leads to total necrosis of the tissue. Indeed, there is no drainage whatsoever of the inflammatory exudate, with a consequent increase of the tissue pressure that causes the destruction to proceed, until the entire pulp has become necrotic.[74]

The rapidity of the progression of the liquefactive necrosis varies, depending on whether the inflammatory fluids can drain, and thus on the rate of increase of intrapulpal pressure.

Pulpitis in a tooth with a completely closed pulp chamber leads more rapidly to total necrosis of the entire pulp, with the almost miraculous resolution of all symptoms. In contrast, pulpitis in a tooth with penetrating caries or, especially, an open pulp chamber leads to slower destruction, with degeneration of the coronal pulp and the presence of vital tissue at the radicular level.[10]

The zone of necrosis contains irritants that arise from both tissue destruction and aerobic and anaerobic bacteria. These irritants come into contact with the adjacent vital tissue and continue to cause damage in an apical direction.

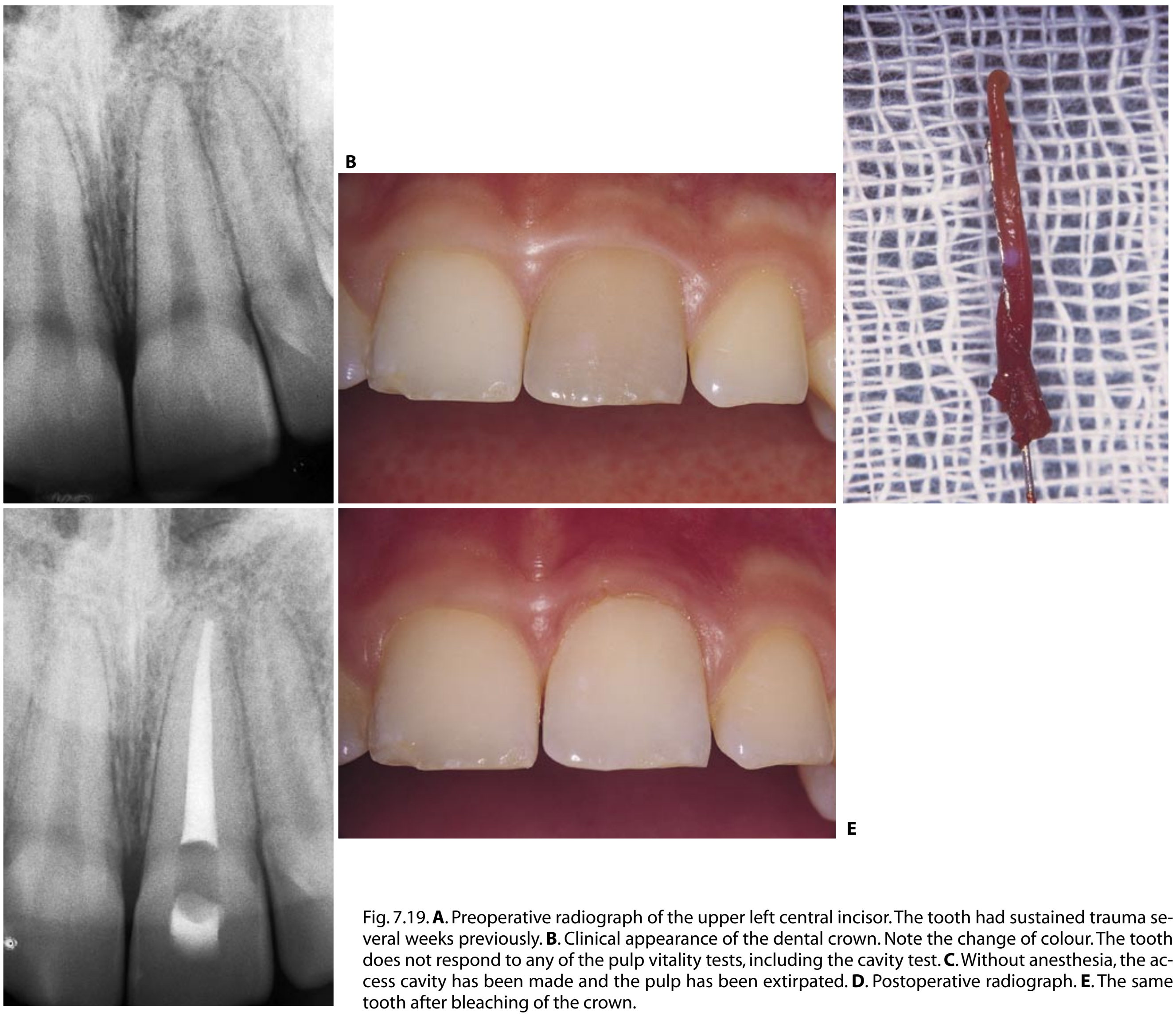
When the pulp has become completely necrotic, the irritant substances may begin their destructive action on the periapical tissues. This occurs in most cases, but is not the rule.

On occasion, there are already symptoms and radiographic signs of periapical inflammation in the presence of vital, albeit inflamed, pulp in the pulp chamber and histologically normal pulp in the root canals.[19] It is believed that this is due to the passage of irritants arising from the coronal tissue through the radicular pulp, with a consequent periapical inflammatory response and resorption of the bony trabeculae. This clinical situation is more often found in young patients (Fig. 7.15).

On the other hand, it should not be surprising to find vital – and therefore sensitive – pulp within a root canal in a tooth whose pulp chamber was completely necrotic, whose pulp tests were all negative, and whose access cavity was created without the need for anesthesia. The more the necrosis nears the blood supply and the tissue is far from the exposure site, the more the tissue is resistant to degeneration.[74] This situation is often encountered in multirooted teeth, in which an apparent diagnostic problem may present itself. The fact that the diseases of the pulp proceed in a corono-apical direction, together with the observation that, because of the necrosis of the pulp chamber, such a multirooted tooth responds to vitality tests like a necrotic tooth, helps in reaching a diagnosis. The finding of vital pulp in one or more canals requires the intra-operative use of anesthesia, but this changes nothing in terms of the aims of therapy.

More rarely, true diagnostic problems may present themselves, such as when the pulp chamber is completely divided into two sectors by the presence of a calcification and, depending on where the tests are performed, contrasting responses are elicited. One part of the chamber still has vital tissue, as does the underlying canals; in the other portion, the pulp chamber and the pulp of the underlying canal are completely necrotic, and there are already clinical and radiographic signs of a periapical lesion, possibly draining through a fistula (Fig. 4.26).

In the case of necrosis secondary to trauma, there is compromise of the blood supply of the pulp, which initially degenerates without progressing to liquefactive necrosis, but transforms into a homogeneous mass varying from pink to deep red in color (Fig. 7.19). This can easily be extirpated with the help of a barbed broach, obviously without the need for any anesthesia.



A B C D E

Fig. 7.19. **A**. Preoperative radiograph of the upper left central incisor. The tooth had sustained trauma several weeks previously. **B**. Clinical appearance of the dental crown. Note the change of colour. The tooth does not respond to any of the pulp vitality tests, including the cavity test. **C**. Without anesthesia, the access cavity has been made and the pulp has been extirpated. **D**. Postoperative radiograph. **E**. The same tooth after bleaching of the crown.

Symptomatology

The tooth with a necrotic pulp is completely asymptomatic. The patients may give a history of pulpitis, from which they may believe they just recovered, or a history of trauma. Sometimes, the patients may be suspicious only because of the discoloration of the crown of the tooth (Fig. 7.20). On occasion, the patient's history is completely unremarkable, and there is no apparent explanation of the pulp necrosis, which is identified on routine check-ups or possibly by the development of a mucosal fistula (Fig. 7.21).

Pain associated with pulp necrosis arises from the pe-

A B C

Fig. 7.20. **A, B**. The chief complaint was the discoloration of the tooth. The radiograph shows a lesion involving the periapical and mesial areas of the cuspid and the distal aspect of the lateral incisor. **C**. Postoperative radiograph. The lateral incisor tests vital.

A B C D

Fig. 7.21. **A**. Preoperative radiograph of the upper left canine with a necrotic pulp and intact crown, free of caries, with no apparent reason to explain the pulp necrosis. The patient was referred because of the presence of a mucosal fistula. **B**. Postoperative radiograph. Some sealer has been pushed into the fistulous tract. **C**. Seven months later. **D**. Two years later.

riapical tissues. The associated inflammation is the cause of the swelling, mobility, and pain on percussion and palpation of the tooth.

Radiographic examination

The radiographic findings are normal. A slight widening of the space of the periodontal ligament may be present (Fig. 7.22).

Pulp tests

The tooth with a necrotic pulp does not respond to the heat or cold test, to the cavity test, or to the electric test. Nonetheless, in some cases, a very slight response may occur at the highest levels of the electric pulp tester. This happens when the current is transmitted to the surrounding vital periodontal tissues by the products of liquefactive necrosis in the canal. This is therefore not a false positive response, but rather the minimal sensation that the patient feels only when the instrument achieve its maximal output of electrical current.

Therapy

Treatment consists of endodontic therapy, which, in the absence of symptoms, can be planned normally.

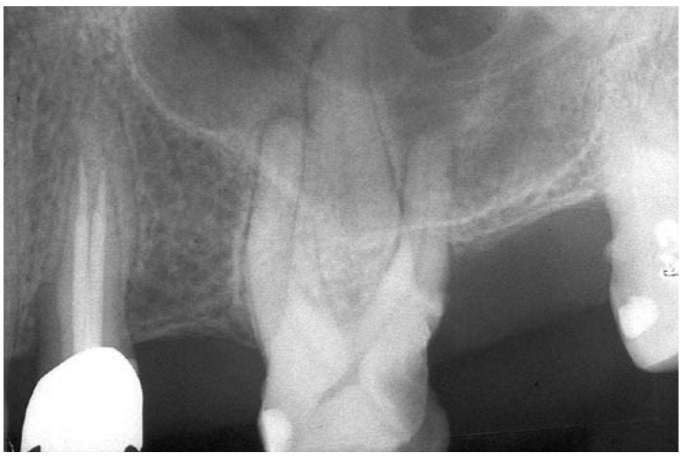


Fig. 7.22. Upper left first molar with a necrotic pulp. Note the widening of the periodontal ligament space around the radicular apices.

VITAL PULP THERAPY

On no other subject in dentistry has there been as much written and discussed as the maintenance of the vitality of an exposed pulp. Everything, including the droppings of the English sparrow,[28] has been tried.

At the beginning of the last century, to avoid extirpation at all costs, any attempt at maintaining the vitality of the pulp was justified, since there was no way to perform proper endotontic therapy and the success rate was higher after pulp capping as compared to pulpectomy and canal treatment.

Today, however, given the abundant research that has been performed, such an attitude is no longer acceptable. The exposed pulp horn must no longer produce the same fear that it did almost one hundred years ago.

Herman[23] first introduced the use of calcium hydroxide in such cases, and Teuscher and Zander[64] first described the formation of the dentin bridge below the treatment. Using labeled radioactive calcium, Pisanti and Sciaky[46] demonstrated that calcium hydroxide does not participate actively in the formation of the dentin bridge, and concluded that the calcium of the dentin bridge came from the bloodstream only.

Via[73] noted that after 24 months 68.9% of the cases that he had treated with calcium hydroxide had failed, primarily as a result of internal resorption.

Ostrom and Lyon[44] and Quigley[49] also reported high failure rates, in addition to the observation of zones of pulp degeneration below the dentinal bridges.

Mitchell and Shankwalker[38] have described the intense calcification that occurs in the pulp tissue following such treatment. This phenomenon has also been described by Baume.[5] The quality and quantity of newly-formed dentin is unpredictable.[48] Other authors[3,45] have shown that the radiopaque zone observed beneath the site of exposure cannot always be related to the calcific barrier. Tziafas and Beltes[72] have also demonstrated that many radiopaque zones are in fact zones of necrosis present beneath the capping material. The radiopaque quality of these zones can be attributed to impregnation with calcium salts, which derive at least in part from the capping agents.[27,62]

From these and other similar research, it is clear that, independent of the size of the exposure, pulp capping, when performed in a desperate attempt to maintain the vitality of a condemned pulp, is not only an unpredictable procedure with an uncertain prognosis, but it is also dangerous, since it may cause internal resorption, calcific pulp degeneration, or both. This may make possible the routine endodontic therapy which sooner or later will become necessary.[37]

Weine[75] states that calcium hydroxide is the material of choice in direct pulp capping, but if such therapy fails and the tooth becomes symptomatic, it may be difficult, if not impossible, to treat it by traditional endodontics because of severe calcifications in the root canal, which are frequently associated with internal resorption, as described also by other authors.

Seltzer and Bender[59] concur with Weine in stating that sometimes, notwithstanding the formation of the dentinal bridge, the remaining pulp is chronically inflamed and can become necrotic. Internal resorption has been found in at least 33% of the teeth treated with pulpotomy and calcium hydroxide. In others, complete mineralization with the disappearance of the remaining pulp tissue has been reported. Such mineralization may obstruct the canal at such a point as to complicate its instrumentation if endodontic therapy becomes necessary in the future.

What makes pulpotomy or pulp capping with calcium hydroxide dangerous is that the pulp tissue is in some way stimulated to become isolated from communication with the outside and thus form the dentinal bridge without knowing when to stop making these calcific depositions. The process of apposition, which is known to be associated with resorption, therefore continues.

Schultz et al.[57] claim that "exposure of the pulp tissue that occurs during the preparation of the cavity requires a decision as to whether it is better to *attempt* capping of the pulp or to *treat* the tooth endodontically".

In a histological assessment of the success of vital pulp therapies, Mullaney[41] emphasizes the importance of examining serial sections, since the dentin bridge is often incomplete and areas of necrosis are frequently present. He also notes the shortcoming of radiographic examination when used as the sole method of assessing success, since sufficient information regarding the completeness of the dentinal bridge cannot be obtained.

Tronstad and Mjor[71] also state that, although the formation of the dentinal bridge has been used as one of the criteria of the success of direct pulp capping, it can also occur in teeth with irreversible inflammation.

Nevertheless, when the decision is made to undertake such therapy[75]

– because of the poor endodontic skill of the dentist
– because of the anatomical challenges presented by the tooth and the dentist's inability to overcome them
– because the patient is unable to afford the fee

the following criteria must be carefully confirmed:

a) the tooth must not be sensitive to heat or cold, nor must there be spontaneous pain
b) there should be no pain on palpation or percussion
c) there should be no periapical radiographic change
d) marked narrowing of the pulp chamber or root canal should not be present
e) there should be no calcifications in the pulp chamber
f) there should not be the slightest suspicion of bacterial infection, since asepsis is the most important factor in pulp healing following exposure.[30]

The indications for direct capping are therefore drastically reduced to the following:

a) the patients should be young and well motivated, so that they will easily return for check-ups and necessary radiographs
b) the exposure must be in healthy dentin and not below caries, and therefore not in infected dentin
c) the maintenance of strict intra-operative asepsis is mandatory
d) the pulp chamber must be free of calcifications, which occupy space and reduce the blood supply to the pulp tissue which must heal.

Finally, Langeland[35] is also clearly opposed to indirect pulp capping, which he calls an unacceptable procedure. The reasons for its apparent success, as for direct capping or pulpotomy, are due to the removal of most of the disintegrated tissue, but the technique is destined to fail because of the presence of bacteria and sometimes a small zone of pulp necrosis that is left in contact with the capping agent. The success of any therapy depends on the total removal of all the disintegrated tissue.

In conclusion, the dentist's efforts to maintain the vitality of a pulp that has been exposed are not only justified but obligatory in *teeth with an immature apex* especially if the exposure is a result of recent trauma. The treatment of choice in such cases is undoubtedly pulpotomy, which is preferable to direct pulp capping. This therapy should be considered a *provisional therapy*, pending maturation of the apex and root. The pulp must be kept vital, because it must still complete its primary, formative function. Seltzer and Bender[59] state that, once the development of the root has been completed, the pulp has no reason to remain there. Since it represents only a threat because of the calcifications and internal resorption that may develop, it must be removed, and the tooth must be treated endodontically. After all, who can inform the pulp to stay vital and inert inside the root canal after the dentin bridge has been completed and the apical closure has occurred?

On the other hand, pulp exposure in a *tooth with a mature apex* must be considered an indication for endodontic treatment, since, as Rebel[50] stated as long ago as 1922, "an exposed pulp is a lost organ".

Pulp capping with MTA

Recently, Dr. Mahmoud Torabinejad[67] of Loma Linda University, California, has developed a new cement named Mineral Trioxide Aggregate (MTA; ProRoot MTA, Dentsply Tulsa Dental) (Figs. 7.23, 7.24), which appears to have all of the characteristics requested of the ideal cement to seal pathways of communications between the pulp and the oral cavity (mechanical and carious pulp exposures), and between the root canal system and the periodontium (iatrogenic perforations, open apices, resorbed apices, root-end preparations).

MTA is an endodontic cement that is extremely biocompatible, capable of stimulating healing and osteogenesis, and is hydrophilic. MTA is a powder that consists of fine trioxides (Tricalcium oxide, Silicate oxide, Bismute oxide) and other hydrophilic particles (Tricalcium silicate, Tricalcium aluminate, responsible for the chemical and physical properties of this aggregate), which set in the presence of moisture. Hydration of the powder results in formation of a colloidal gel with a pH of 12.5, that solidifies to a hard solid structure in approximately three-four hours.[67] This cement is different from other materials currently in use because of its biocompatibility, antibacterial properties, marginal adaptation and sealing properties, and its hydrophilic nature.[67]

In terms of biocompatibility, Koh et al.[32,33] and Pitt Ford et al.[47] demonstrated the absence of cytotoxicity when MTA came in contact with fibroblasts and osteoblasts, and the formation of dentin bridges when the material was used for direct pulp capping.

Several in vitro and in vivo experiments [4,43,66,68-70] have shown that sealing ability and biocompatibility of MTA are superior to those of amalgam, Super-EBA and IRM; dye and bacterial leakage studies have confirmed the sealing ability of MTA; the citotoxicity of MTA was found to be less than that of Super-EBA or IRM.

The characteristic that distinguishes MTA from other materials used to date in endodontics is its hydrophilic properties. Materials used to repair perforations, to seal the retro-preparation in surgical endodontics, to close open apices, or to protect the pulp in direct pulp capping, are inevitably in contact with blood and other tissue fluids. Moisture may be an important factor due to its potential effects on the physical properties and sealing ability of the restorative materials.[66] As shown by Torabinejad et al,[66] MTA is the only material that is not affected by moisture or blood contamination: the presence or absence or blood seems not to affect the sealing ability of the mineral trioxide aggregate. In fact, MTA sets only in the presence of water.[67]

Fig. 7.23. White ProRoot MTA (Dentsply Tulsa Dental).

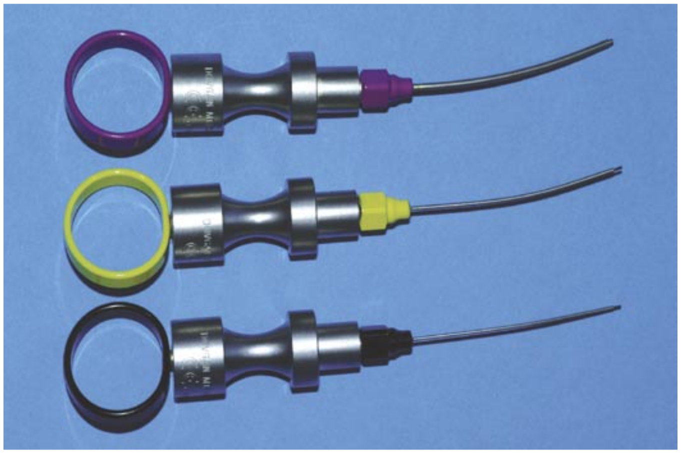


Fig. 7.24. The Dovgan carriers, specifically designed for MTA (Quality Aspirators, Duncanville, Texas).

MTA has been used also as a pulp capping material in exposed pulps[47] (Fig. 7.25) and seems to be today the material of choice.

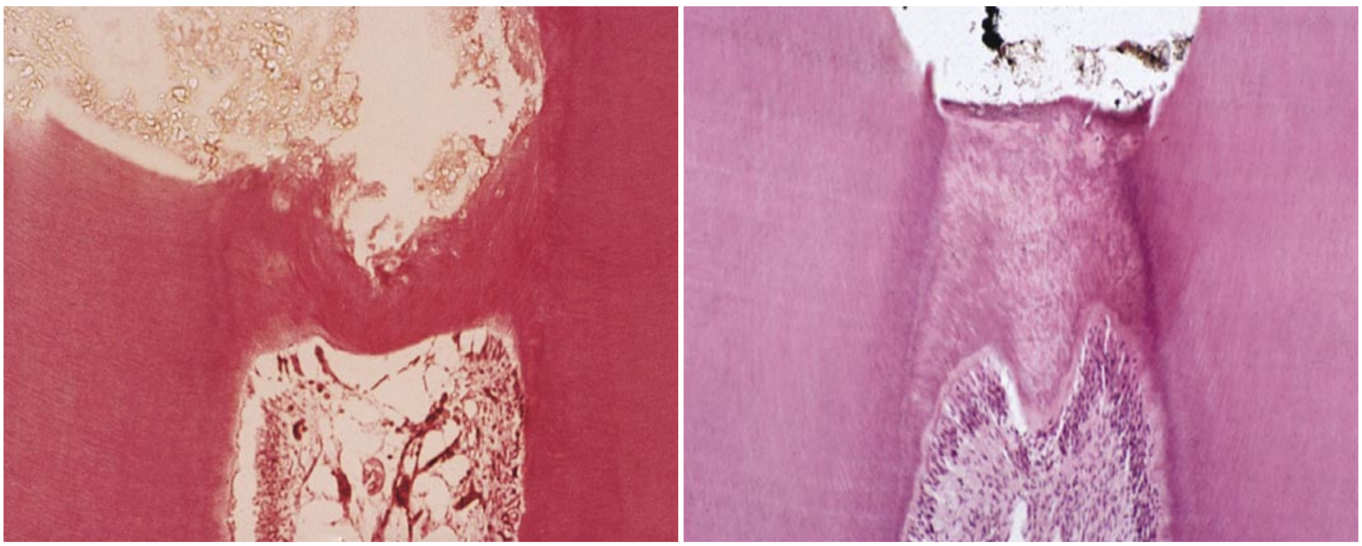
Pulp capping is indicated for teeth with immature apices when the dental pulp is exposed, and there are no signs of irreversible pulpitis:[65] in such cases the exposures must be sealed to preserve vitality of the pulp tissue (Fig. 7.26). Recent studies have shown that MTA stimulates dentin bridge formation adjacent to the dental pulp. Dentinogenesis of MTA can be due to its sealing ability, biocompatibility, and alkalinity.[47]

Faraco and Holland,[14] demonstrated that in teeth treated with MTA all bridges were tubular morphologically, and in some specimens the presence of a slight layer of necrotic pulp tissue was observed in the superficial portion of these bridges. This suggested that the material, similarly to calcium hydroxide, initially causes necrosis by coagulation in contact with pulp connective tissue. This reaction may occur because of the product's high alkalinity, whose pH is 10.2 during manipulation and 12.5 after 3 hours.[67] In a previous article, Holland et al.[26] demonstrated the presence of calcite cristals in contact with MTA implanted in rat subcutaneous tissue. Those calcite cristals attract fibronectin, which is responsible for cellular adhesion and differentiation. Therefore we believe that the MTA mechanism of action is similar to that of calcium hydroxide, but in addition, MTA provides a superior bacteria-tight seal.[14]

For all these reasons MTA is to be preferred to the use of calcium hydroxide. Nevertheless, MTA has only recently been introduced, and no long-term studies on its efficacy have been published yet. Therefore, it is necessary to recall treated patients on a regular basis to determine if treatment has been successful, or if root canal therapy is needed.

Operative sequence for pulp capping

After achieving anesthesia and isolation with a rubber dam, the exposed pulp is irrigated with NaClO to control bleeding. The MTA powder is mixed with sterile water and the mixture is placed in contact with the exposure using a Dovgan carrier. Compress the mixture against the exposure site with a moist cotton pellet. Place a moist cotton pellet over the MTA and fill the rest of the cavity with a temporary filling material. After four hours, the patient is seen again, the rubber dam is positioned, the temporary filling material and cotton are removed, and the set of the material is assessed. Then, the tooth can be restored and the patient is scheduled for regular recalls.



A B

Fig. 7.25. **A, B.** Histologic appearance of a pulp capping procedure. The MTA is at the top of the pictures. Vital pulp tissue is surrounded by normal dentin. Between the two is the dentin bridge, which has formed following the placement of the ProRoot MTA (Courtesy of Dr. M. Torabinejad).

Fig. 7.26. **A**. The lower first molar of the six year old patient is only partally erupted (with the mesial cusps) and has a deep decay involving the pulp. The tooth is completely asymtomatic and responds to vitality tests. Note the immature apices. **B**. Postoperative radiograph: the decay has been removed and MTA has been gently positioned over the pulp exposure. **C–F**. 7, 22, 40, 53 month recall: the roots have completed their development and no sign of pulp calcification is present. The tooth is still responding normally to vitality tests. **G**. The MTA just before the restoration. **H**. The tooth has been restored with a composite onlay (G, H: courtesy of Dr. R. Becciani). **I**. Six year recall.

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8

Periapical Disease

Arnaldo Castellucci, Uziel Blumenkranz

THE REPARATIVE CAPACITY OF PERIAPICAL TISSUES

The diseases of the periapical or periradicular tissues must be considered in the context of the larger category of diseases of the attachment apparatus of the tooth. These structures include the radicular cementum, the bone, and the periodontal ligament.

Pulp disease is one cause of disease in this apparatus, which may also be injured by periodontal disease, occlusal trauma, or various combinations of a number of factors.

The diseases of the attachment apparatus of the tooth can therefore be of endodontic or periodontal origin, secondary to occlusal trauma, or a result of a combination of several etiologic factors.

Endodontic diseases of the attachment apparatus of the tooth will now be considered.

Because of the close relationship between the pulp and periradicular tissue, it is easy to see that inflammation of the pulp may cause inflammation in the periodontal ligament, even before the entire pulp has become necrotic. When the necrosis is complete, bacteria with their toxins, immunological agents, and the products of pulp degeneration and tissue necrosis reach the periradicular zone through pathways (portals of exit) by which the endodontium and periodontium communicate. This gives rise to inflammatory and immunologic reactions which are simply called *lesions of endodontic origin*, using a etiopathogenic criteria.[71]

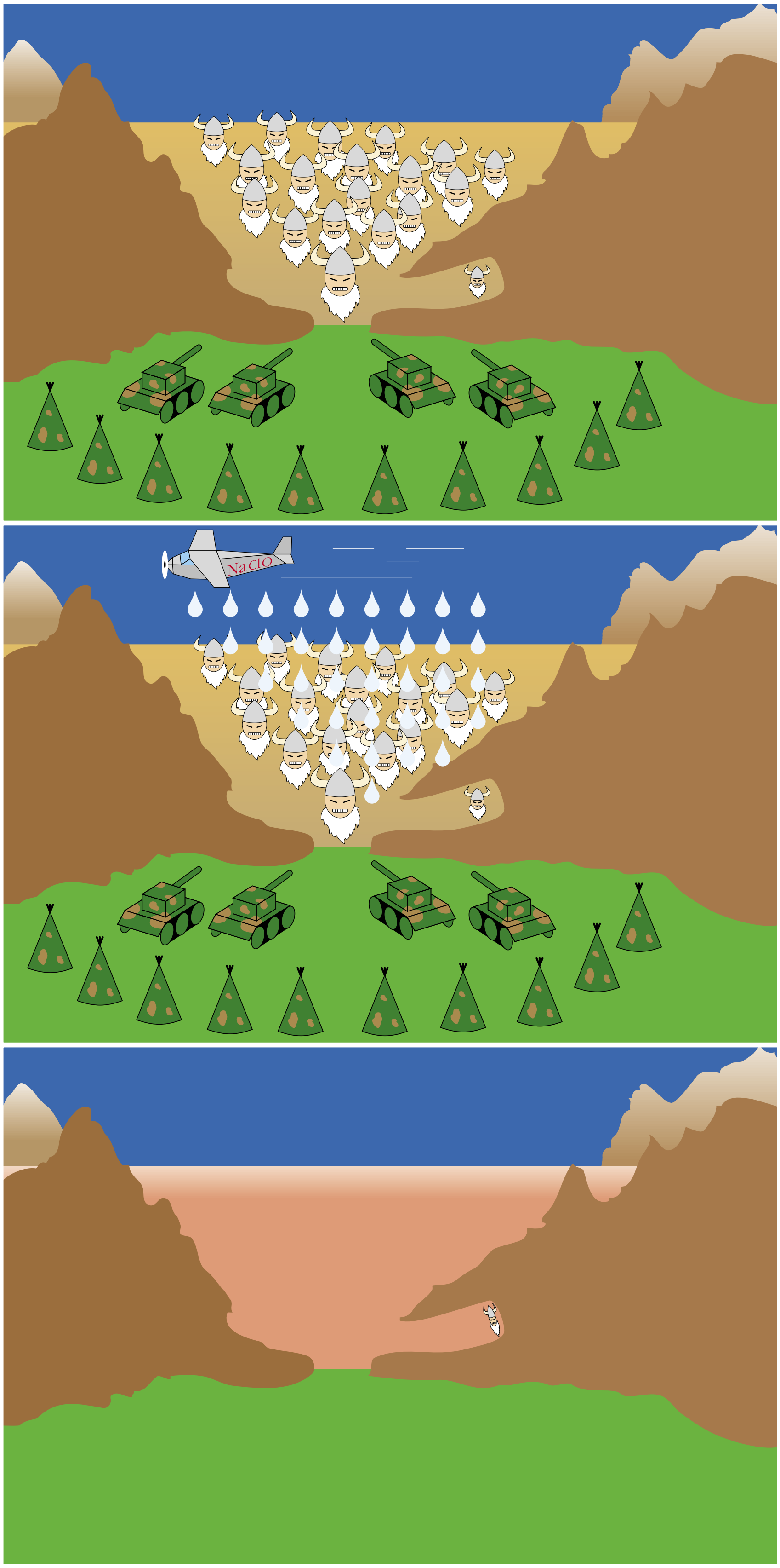
To better understand their significance, it is useful to recall the analogy provided in 1939 by Kronfeld,[16] who likened the bacteria in an infected root canal to an army of enemies entrenched behind high, inaccessible mountains.

This army tries to descend through a mountain pass (the apical foramen) to invade the plains beyond the pass (the periodontal soft tissue and surrounding tissues). Another army in the plains controls the pass. Having constructed trenches and fortifications (granulation tissue), it tries to block the advance of the mountain army. The defending army represents the white blood cells and other cells of the granulation tissue. Naturally, the soldiers of the defending army are grouped around the opening of the pass which the enemy is trying to conquer. This is analogous to the accumulation of white cells near the opening of the apical foramen (Fig. 8.1).

Nothing may happen for a long time. Occasionally, some soldiers of the mountain army (bacteria) descend through the pass (apical foramen), but they are usually captured and destroyed by the defenders (blood cells). At a certain point, however, the army of mountain soldiers mounts a massive attack and the battle begins. Such a battle between invasive bacteria and the tissues of the organism is clinically manifested as acute inflammation.

The outcome of this battle may vary. The bacteria may win and invade the plains. This is clinically manifested as an acute alveolar abscess or even septicemia. On the other hand, the defenders – the white blood cells – may win. They may overwhelm the invading bacteria and then the rest of the mountain army is confined anew beyond the pass, in the root canal, through which the white cells have no access.

This analogy may be carried further. If the attacking mountain army (the bacteria) are eliminated either by extraction of the tooth or sterilization of the root canal, the defending army is no longer necessary and is thus withdrawn. The granulation tissue withdraws, and the soldiers (white cells) leave and return to the general circulation to be used somewhere else to repulse a similar attack. This explains why the apical granulation tissue disappears after extraction of an infected tooth or following appropriate root canal therapy.



A

B

C

Fig. 8.1. Analogy between the defence mechanism of granulation tissue and the defence of a mountain pass. **A**. Acute and chronic inflammatory cells guard the "pass". **B**. The invading enemies may be neutralized only by a surprise attack from behind, for example by irrigating solutions and endodontic instruments. **C**. Once the invading enemies have been eliminated, the defending soldiers abandon the pass, which no longer needs to be defended. Everything returns to normal, and the situation remains unaltered in the time after the space that had been previously occupied by the enemies is completely filled in three dimensions. In this manner, any escaped "enemies" that may be "hidden" in a ravine after the cleaning procedure, are also neutralized.

Its defects notwithstanding, this analogy allows one to understand other considerations. For example, it explains why bacteria are sometimes present in granulomas, but not always. It illustrates the unreachable position of bacteria in an untreated root canal, as well as the defense mechanism against a sudden reactivation of chronic periapical inflammation. Finally, it emphasizes the function of the granuloma, which is not a dangerous entity, but a defense against the spread of infection.

The analogy also prompts other observations.

First, the granuloma should not be seen as the site in which germs survive or reproduce, but as the site in which they die.

Under normal conditions, when an asymptomatic, "closed" tooth is not contaminated by the oral environment, the granuloma contains no bacteria, which reside within the infected root canal system.[15] Even the slightest discharge is perfectly controlled by the body's defense mechanisms, namely the neutrophilic granulocytes that immediately neutralize the bacteria. In an asymptomatic lesion, the neutrophils are the only acute inflammatory cells present in the lesion. They are present only in the immediate vicinity of a "portal of exit".

The only clinical situation in which the bacteria are present in the lesion is the acute apical periodontitis or, if the bacterial invasion is more intense, the acute alveolar abscess – that is, when the lesion becomes symptomatic. However, once the drainage of pus occurs, the lesion becomes sterile again within a few hours.

There is a relationship between clinical signs and symptoms on the one hand and the presence of bacteria in the periapical tissues on the other. However, there is no correlation between the size of the radiographic lesion and the presence or absence of bacteria.[15]

These observations have great clinical importance, since an awareness of them both conditions and guides our therapy.

The "granuloma" should not be seen as a strictly *surgical* problem, inasmuch as its surgical elimination is not required to achieve healing. As already suggested, it represents the body's defense against the spread of infection, not the seat of infection itself. Thus, to raise a flap to curette the lesion surrounding the apex without doing anything to the root canal system serves absolutely no purpose.

On the other hand, the granuloma should not be seen as a strictly *medical* problem, either, since it need not be "medicated" to disappear. There is no sense in applying medicated pastes, such iodoformic paste, beyond the apex to medicate and sterilize a lesion that is already sterile and has no need of medications.

The real problem is therefore another. Arguably, it is more surgical than medical, but one must deflect one's attention from the granuloma, where the bacteria die, to the root canal, where they survive. The mechanical, surgical removal of the entire infected contents of the root canal system will inevitably lead to healing of the granuloma and to resolution of the lesion of endodontic origin.

In contrast to pulp tissue, which does not have a very high healing potential, periapical or periradicular granulation tissue has a healing potential of 100%. Indeed, once the cause has been eliminated, nothing can impede healing and *restitutio ad integrum*. All the factors required for healing of 100% of lesions are present: the lesion is highly vascular, its most numerous cells are the fibroblasts, and the fibers of the periodontal ligament are disordered, but still present.

One's success rate may be less than 100%. This must not be attributed to the lesion's biology, but rather the anatomical difficulties of individual cases and the dentist's ability to overcome these challenges.

The patient comes to the office with a 100% healing potential; it is the dentist who lowers this percentage. Success in Endodontics cannot be related to the patient's age, the size (big or small), geography (apical or lateral) or histological nature of the lesion of endodontic origin, or the type of microorganism present within the root canal system.

Success or failure in Endodontics depends on the degree to which the dentist observes three basic principles: 1) complete cleansing and shaping, 2) complete sterilization, and 3) complete tridimensional filling of the root canal system.

The final outcome depends on the dentist's ability to overcome the anatomical problems of each root canal. Without exception, every periodontally sound or curable tooth will respond positively to endodontic therapy if its root canals can be completely cleaned, shaped, *sterilized*, and filled.[69]

On the other hand, 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.[14,18,19,55,84,87] For this simple reason, it is more correct to use the term *disinfection*, since after our treatment the root canals are almost never completely sterile, but rather they are disinfected.

The microorganisms may remain isolated inside the root canal system, possibly in a small resorptive defect or within dentinal tubules that have remained infected deeper than the level of the shaped dentinal wall.[71] 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.
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 [2,3,46,47,60] (Fig. 8.1 C).
Confirming Morse's findings,[48] Moawad[45] and more recently Peters et al.[60] have demonstrated that such bacteria entrapped within a completely filled root canal are nonviable within five days after root canal filling. It is obvious therefore that the obturation must be extended to the real terminus of the root canal (the foramen), without leaving any portion unfilled and unsealed: that portion would give "space" and therefore "food" to the forgotten bacteria, causing the failure of the root canal treatment. This subject will be deeply discussed in the obturation charter.

CLASSIFICATION OF THE LESIONS OF ENDODONTIC ORIGIN

Clinically, lesions of endodontic origin may be distinguished and classified as follows:
1) Acute apical periodontitis
2) Acute alveolar abscess
3) Chronic apical periodontitis
4) Reactivation of chronic apical periodontitis.

Taking into consideration the frequency of their occurrence, the chronic lesions will be discussed first, then the acute ones.
One must keep in mind that all the lesions are of endodontic origin with somewhat variable radiographic or clinical presentations, but they share a similar pathogenesis, which determines the dynamic of their development.
In discussing lesions of endodontic origin, one must first address two mistaken concepts:
– "geography" is of no importance, since the lesion may be periapical, but can also present at the radicular side (Fig. 8.2) or in a bi- or trifurcation;
– "histology" is of no significance, as modest widening of the periodontal ligament, granulomas, and cysts are different aspects of the same process. They share the same etiology and pathogenesis and therefore require the same therapy: they all are *lesions of endodontic origin*.

Chronic apical periodontitis

Once the pulp tissue has become necrotic, the products of cellular degeneration, bacterial toxins, and occasionally the bacteria themselves within the canal

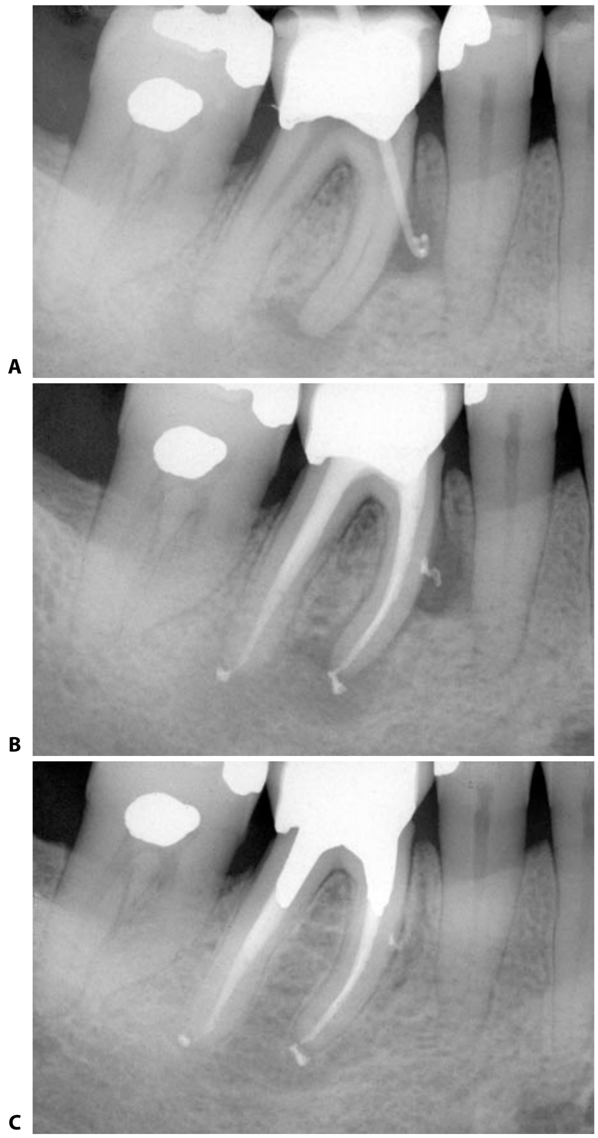


Fig. 8.2. Fig. **A**. Preoperative radiograph of a lower right first molar: the tooth has a fistula arising from a lateral canal. **B**. Postoperative radiograph: note the filling of the lateral canal. **C**. The recall radiograph 24 months later shows the complete healing of both the apical and the lateral lesions.

spread through the apical foramen or the various lateral foramina into the surrounding periradicular tissue. A slow inflammatory process thus begins in the tissue contained within the periodontal ligament. Left to itself, it may manifest in a variety of ways ranging from simple widening or thickening of the ligament to granuloma or cyst.
The increased space of the periodontal ligament in this area is due to resorption of the surrounding bony trabeculae with secondary fusion of the connective tissue of the periodontal ligament with the intertrabecular connective tissue of the medullary spaces. The fibers of the periodontal ligament, which become disordered and dysfunctional, lose their insertions in the surrounding bone. However, their insertions in the cementum, particularly in the periphery of the lesion, are preserved. The pathological entity commonly known as a *granuloma* develops in this way. Sometimes, the inflammatory process also involves other cellular elements within the periodontal ligament, namely epithelial rests of Malassez, which, when stimulated to proliferate, give rise to a cavity and a radicular *cyst*.[69]
In its various clinical manifestations, chronic apical periodontitis is generally asymptomatic. It is usually discovered on routine radiographic check-ups, which on occasion is prompted by suspicious discoloration of the dental crown. The patients may relate a history of acute (pulpitic) pain which spontaneously resolved or a history of trauma, but they may also present with a completely unrevealing history. Sometimes, a fistula may be present, through which the patients reports having noticed an intermittent discharge of pus (Fig. 8.3).
The fistula provides a means of continuous drainage of the lesion. This usually prevents reactivations, either spontaneous or consequent to intervention.
Some authors[6,20,29,32,58] are still convinced that the presence of a fistula indicates a more serious lesion that requires special intervention, such as surgical incision and excision of the entire fistulous tract, in addition to extraction of the diseased tooth (Fig. 8.4).
In fact, the presence of a fistula should be seen as a favorable sign, since it is associated with a number of advantages, so much so that some authors[7,25,37,59,67,73,88,91] suggest that if there is none, one should be created.
It may be extremely helpful in diagnosis. Opacification of the fistulous tract by the insertion of a gutta-percha cone clearly demonstrates the diseased tooth[38] (Fig. 8.5). The opening of the fistula may be found on the mucosa overlying the tooth that sustains it, but it may also often be found at a considerable distance from the diseased tooth (Fig. 8.6). Indeed, it may cross the midline, as in cases described by Feiglin[26] and Kaufmann.[38]
In other situations, the fistula may run in the space of the periodontal ligament of the same tooth (Fig. 8.7). It may even traverse the periodontal ligament of the adjacent healthy tooth,[39] thus simulating a lesion of periodontal origin (Fig. 8.8). In such cases, negative pulp tests performed on the crown of the tooth indicated by the gutta-percha cone inserted into the fistula assist in making the correct diagnosis.
Furthermore, healing of the lesion about one week after cleaning and shaping of the infected root canals without the use of any medications within the canal (Fig. 8.9) confirms that the diagnosis was correct and testifies to the efficacy of the treatment. This also suggests a favourable prognosis for the lesion.
Finally, as already suggested, the fistula provides a means of continuous drainage of the suppurative contents of the periapical lesion. This discourages sudden reactivations, either spontaneous or as a result of our intervention.
If the drainage is not continuous, but rather intermittent, it is preceded by slight swelling of the area as a result of the increased pressure of pus behind the closed orifice. When this pressure is great enough to rupture the thin wall of soft tissue, the suppurative material issues externally through the small opening of the fistulous orifice.[31] This orifice may heal and re-close, only to re-open later. The discharge of pus is never accompanied by intense pain. At most, the patient will complain of slight soreness in that area prior to re-opening of the external orifice.
The pus creates a tract in the surrounding tissues, following the *loci minoris resistentiae*. It may exit at any point of the oral mucosa or even the skin.[44] It is not uncommon, particularly in young patients, to find cutaneous fistulae at the level of the mental symphysis, if lower incisors are involved (Fig. 8.10), or in the submandibular region, if a lower first molar is involved (Fig. 8.11), or in the floor of the nasal fossa, if a central incisor is involved.[33,79]
Cutaneous fistulae, which unfortunately are sometimes treated as though they were independent dermatologic lesions, have the same pathogenic and prognostic significance as mucosal fistulae and require the same therapy.[57,93] A review of the literature[17,22,41,76] reveals that patients with cutaneous fistulae are sometimes subjected to repeated surgical excisions and biopsies (Fig. 8.4 C) before it is clear that the fistula is none other than an extension of pulp disease in the periradicular tissues.

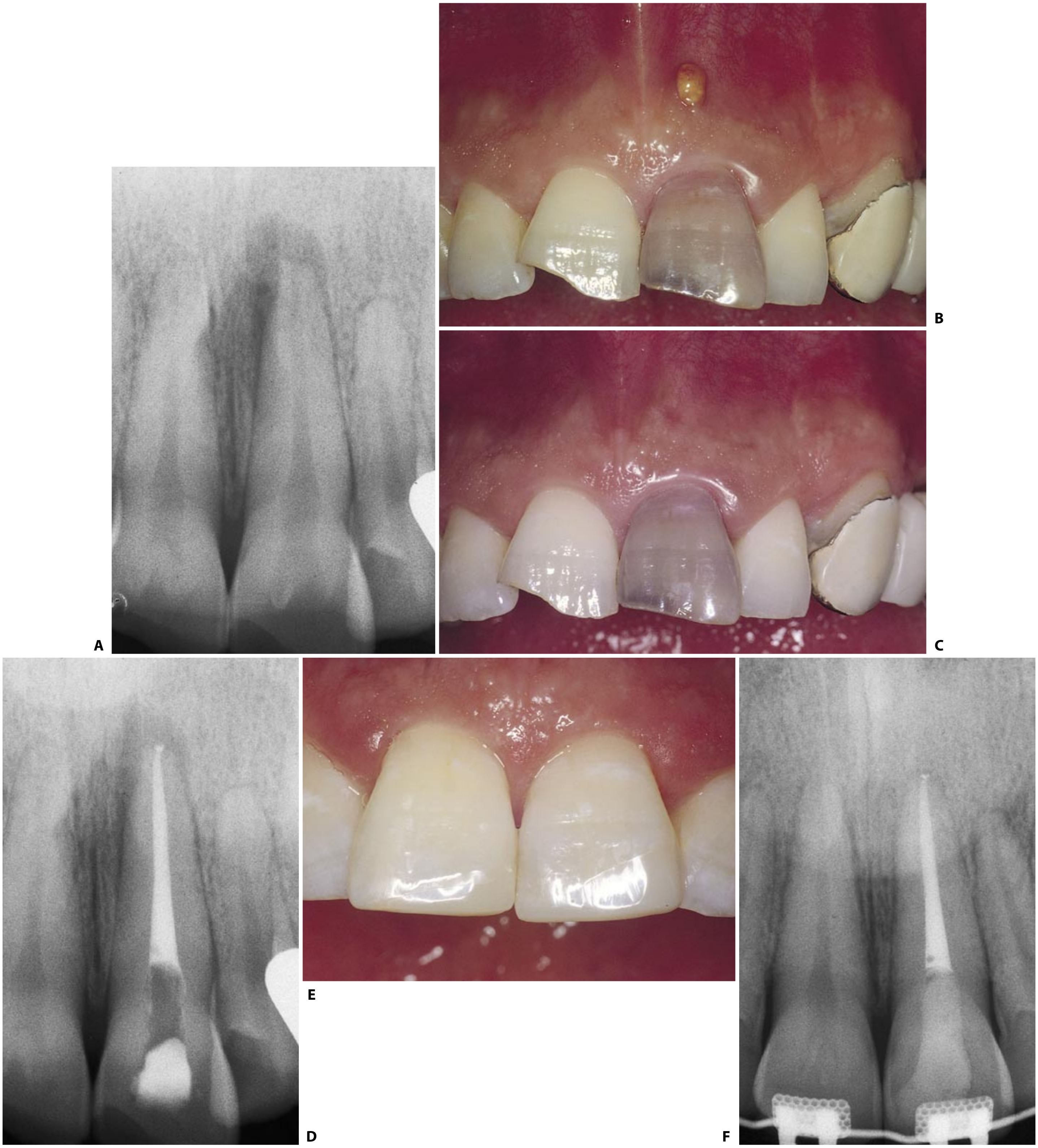


Fig. 8.3. **A**. Preoperative radiograph of the upper left central incisor with a necrotic pulp caused by preceding trauma. **B**. The dental crown is strongly discolored by hemorrhage secondary to the trauma. Note the mucosal fistula. **C**. One week following the cleaning and shaping procedure only, the fistula has completely disappeared. **D**. Postoperative radiograph: the filling has been performed after determining clinically that the fistula had healed. **E**. Appearance of the dental crown after bleaching. **F**. One year recall.

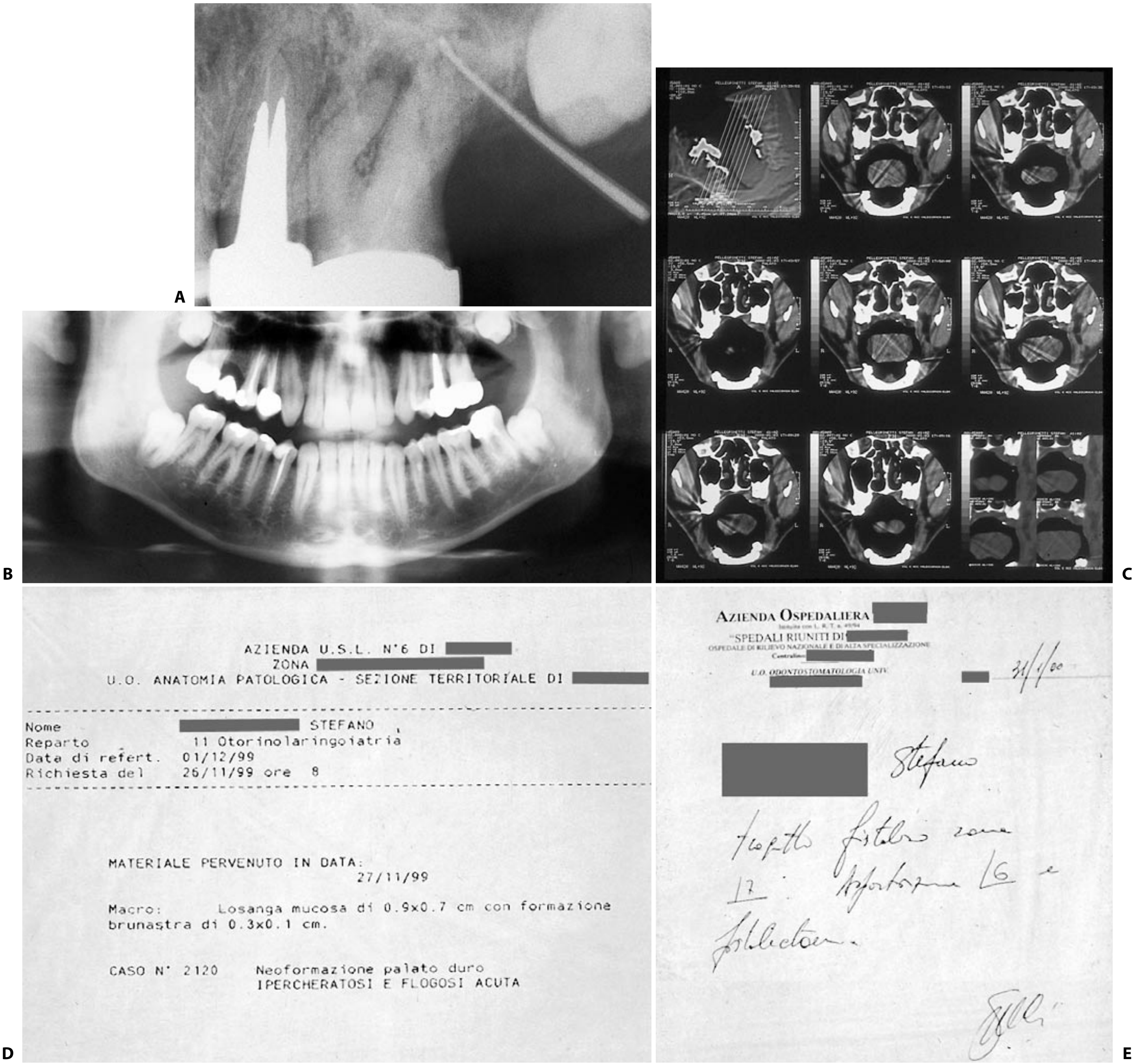
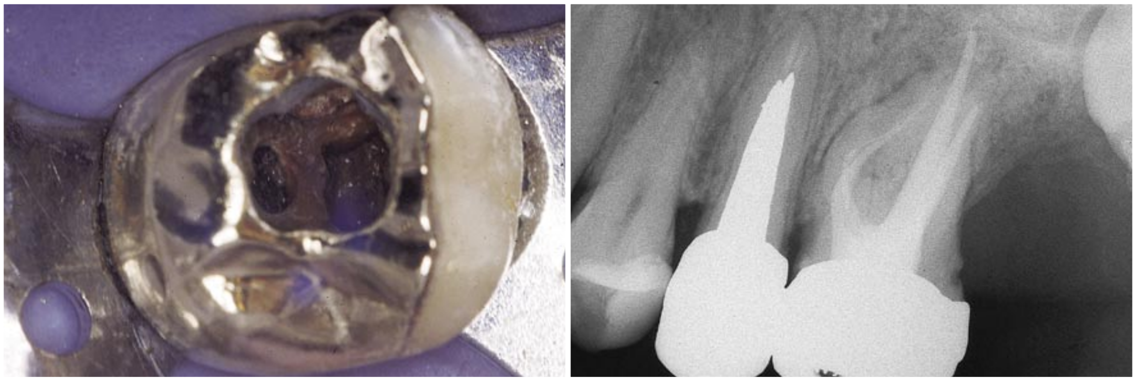


Fig. 8.4. **A**. The endodontic treatment of the upper left first molar is completely inadequate. A gutta-percha cone is tracing a sinous tract, originating on the palate, in the area of the missing second molar. The patient already received a pantomograph (**B**), a computerized tomography (**C**), a biopsy (Iperkeratosis and acute inflammation!) (**D**), and the prescription for tooth extraction and the *fistulectomy* (!) (**E**) (continued).



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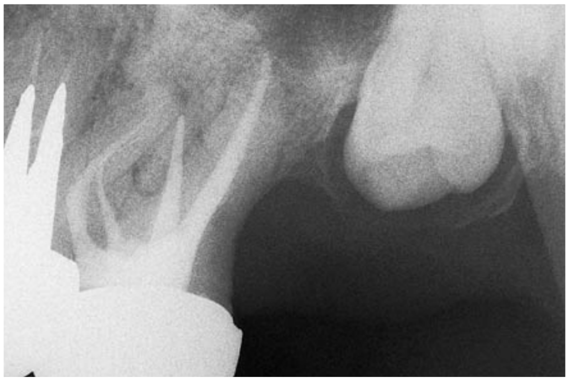


H I

Fig. 8.4. (continued) **F**. After the removal of the old restoration, it is evident the way the access cavity was previously made: the pulp horns have been misdiagnosed for canal orifices and the clinician forgot to remove a big portion of the roof of the pulp chamber. **G**. Postoperative radiograph. **H**. The fistula is healed. **I**. Six month recall.

Trying to treat such lesions with a circular incision of the orifice of the cutaneous fistula and excision of its entire tract, with all the ramifications – particularly esthetic – of such an intervention, is not consistent with the present standard of care and can be considered pure folly.

These fistulae simply require identification of the diseased tooth, whose root canal system must be cleaned and shaped.

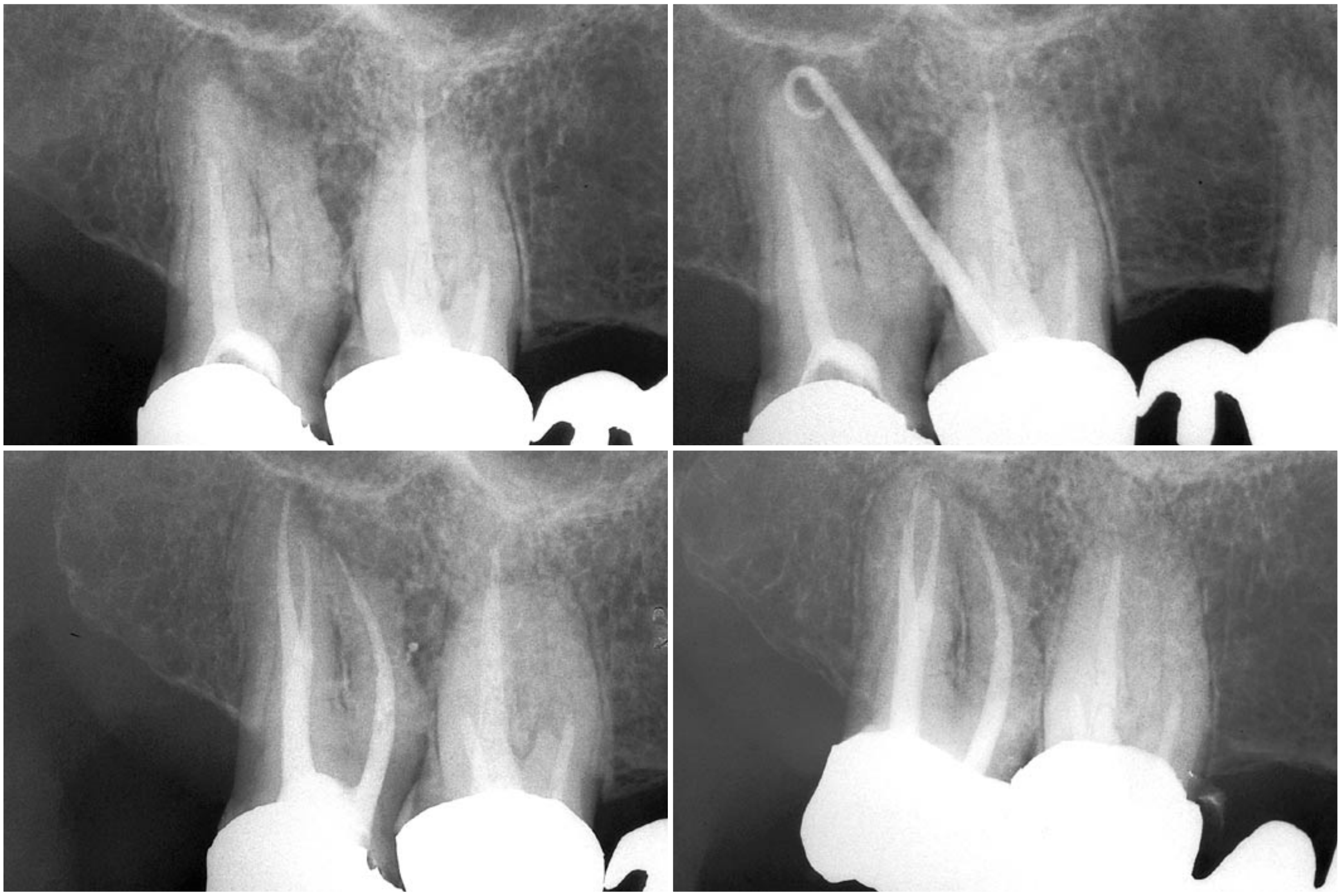
If the tooth presents any obstacles to nonsurgical treatment or retreatment, or if the patient specifically requests surgery, one may proceed surgically, but one's attention must be directed solely to achieving a retrograde apical seal, and not eliminating the fistulous tract or its cutaneous orifice (Fig. 8.10). The reason why some authors believe in the need for surgical removal of the fistulous tract lies in the mistaken conviction that it is lined by an epithelium.[75] Grossman[31] states, however, that such tracts are lined by granulation tissue: in his study, he was unable to identify any epithelium at all.

Bender and Seltzer[9] have also made histologic studies of numerous fistulous tracts without finding an epithelial lining.

Other authors[4,36,88] agree that the fistulous tract may be lined by flat, multilayered epithelial cells, but that more often it is lined by granulation tissue, with acute and chronic inflammatory cells.

Given the current state of knowledge, there is no reason to recommend surgical removal of such tracts. There is no reason that even epithelium-lined fistulous tracts should not heal after appropriate endodontic therapy.

When it is present, the epithelium may arise from the oral mucosa or proliferating epithelial cells from the periapical lesion. However, there is no correlation between the presence or absence of an epithelium and the clinical appearance of the fistula or its chronicity.



A B C D

Fig. 8.5. **A**. Preoperative radiograph of the upper right first and second molars. Note the round radiolucency between the mesiobuccal root of the second molar and the distobuccal root of the first. The patient had presented with a vestibular fistula at the level of the first molar, and for financial reasons only wanted to retreat the diseased tooth. **B**. A gutta-percha cone placed in the fistula indicates that the fistulous tract arises from the second molar. **C**. Postoperative radiograph of the second molar. Note that a small lateral canal in the mesiobuccal root, which was apparently responsible for the lesion seen in the preoperative film, has filled up. **D**. Five year recall.

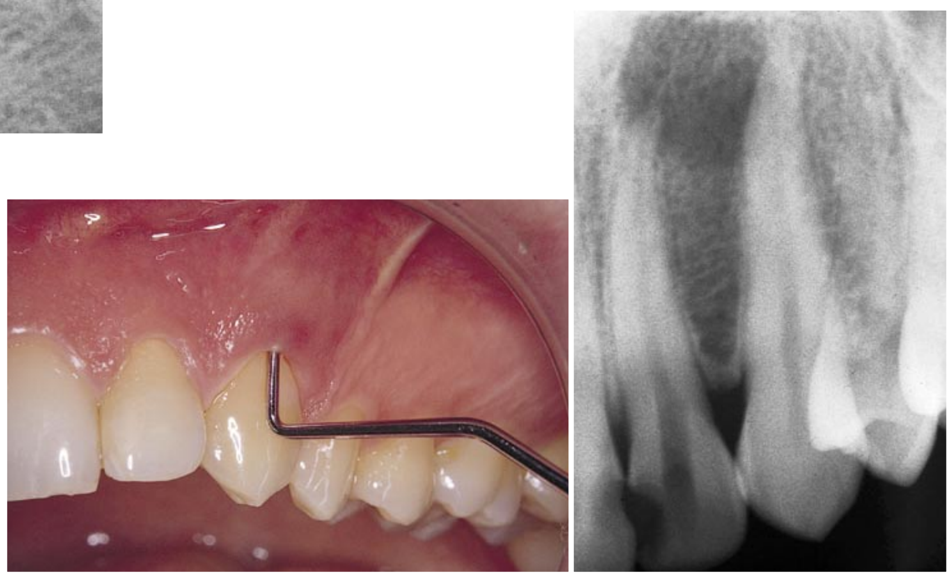
A B

Fig. 8.6. **A**. This young patient presented with a fistula between the canine and lower right first premolar. A gutta-percha cone has been inserted into the fistulous tract. **B**. Radiographically, the gutta-percha cone seems to implicate the lateral incisor as the diseased tooth. All the teeth heretofore identified have responded positively to the vitality tests (continued).

C D E F

Fig. 8.6. (continued) **C**. Deeper insertion of the gutta-percha cone finally identifies the two lower central incisors as the diseased teeth. Both respond negatively to the various vitality tests. **D**. One week after cleaning and shaping, the fistula has closed. **E**. Postoperative radiograph. **F**. Two year later.

Fig. 8.7. Preoperative radiograph of a necrotic lower left second premolar with a fistula opening into the space of the periodontal ligament. A gutta-percha cone has been inserted into the fistula.



A B

Fig. 8.8. **A**. The periodontal probe disappears in the sulcus of the canine in a patient with good oral hygiene and healthy periodontium in the different quadrants. The canine responds positively to the tests of vitality, while the lateral incisor is necrotic. **B**. Preoperative radiograph of the lateral incisor. Note that the lesion "rests" on the mesial side of the root of the adjacent canine (continued).

C
D

Fig. 8.8. (continued) **C.** Clinical appearance of the canine gingiva one week after cleaning and shaping of the lateral incisor. **D.** Postoperative radiograph.

A
B
C

Fig. 8.9. **A**. Fistula corresponding to the upper left central incisor. **B**. Healing of the fistula one week later. The canal has been cleaned, shaped, and irrigated with sodium hypochlorite, while the pulp chamber has been medicated with Cresatin and Cavit. In other words, it has been treated as though the fistula did not exist. Its resolution confirms that the diagnosis and therapy were correct and justifies proceeding with three-dimensional filling of this root canal system. **C.** Another view one year later.

In animal experiments, Ordman and Gillman[56] have demonstrated that cutaneous sutures may become completely epithelialized if the sutures are left in place for several weeks. Once they are removed, however, the epithelium-lined tract always heals completely.

There is no reason that the same should not happen to the possibly present epithelium of the fistula of a necrotic tooth once the inflammatory stimulus is removed.

Obviously, these fistulae must be distinguished from congenital fistulae of the neck, both lateral (arising from the second branchial cleft) and medial (arising from rests of the thyroglossal duct), which are lined by an epithelium.

Such fistulae, however, have a different pathogenesis and obviously do not resolve spontaneously, but only after careful surgical excision of the entire tract.[74] The differential diagnosis includes the following:[33,57]

– localized infections of the skin, such as pyoderma, pimples, ingrown hairs, and obstructed sweat glands
– traumatic or iatrogenic lesions
– osteomyelitis
– neoplasia
– tuberculosis
– actinomycosis.

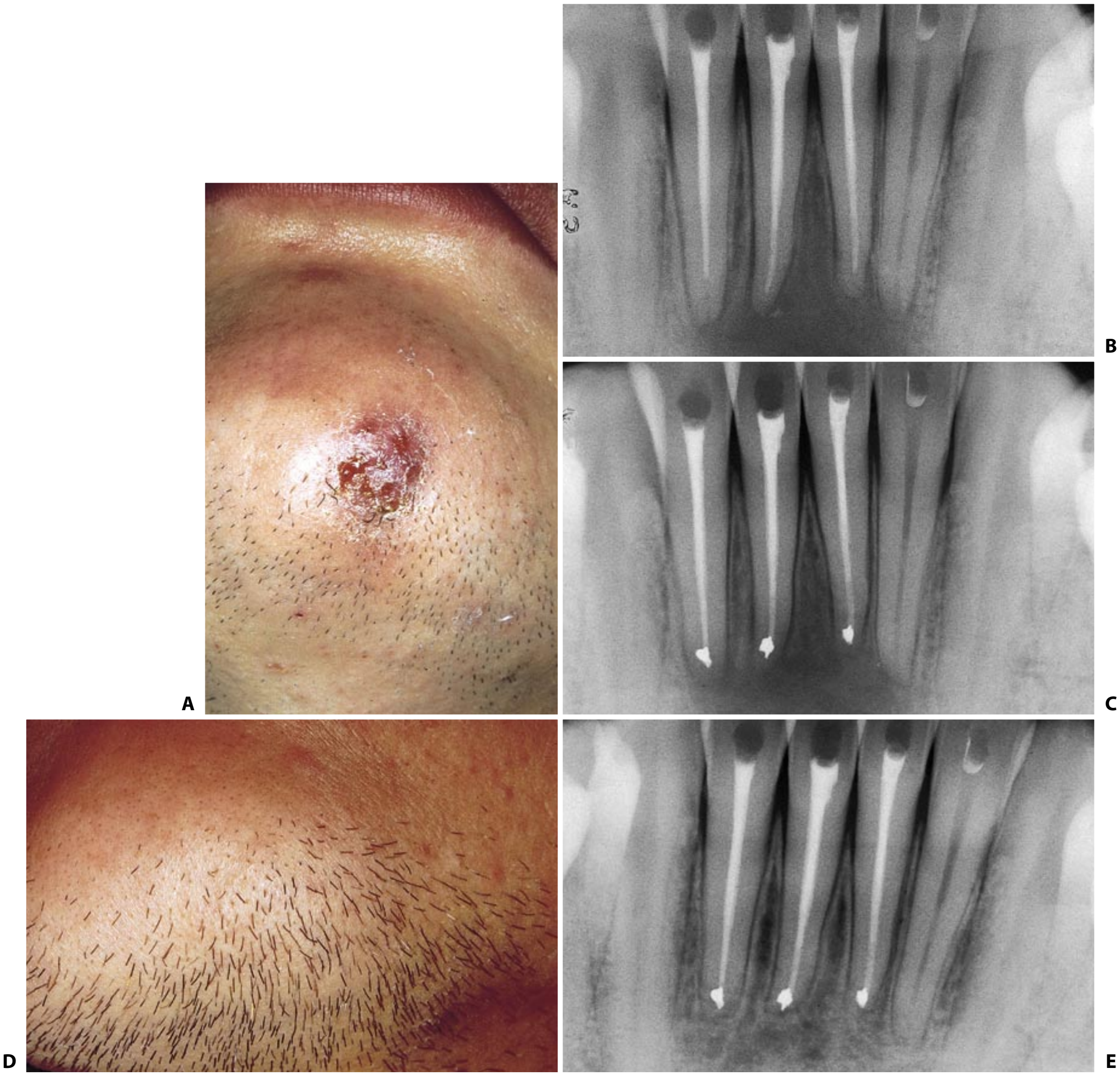


Fig. 8.10. **A**. Cutaneous fistula in the mental region. **B**. Preoperative radiograph of the lower incisors. The patient elected surgical therapy for economical reasons. The left lateral incisor had already been subjected to a cavity test. **C**. Postoperative radiograph. Three apicoectomies with amalgam retrofilling have been performed. *Not* the least attention has been paid to removal of all the granulation tissue *or* to curettage of the surrounding bone or apices, *or* to removal of the fistulous tract, *or* even to circular incision of the cutaneous orifice of the fistula. **D**. Complete healing of the cutaneous fistula without any residual scarring after two years. **E**. Radiograph two years later confirms total resolution of the previous radiolucency.

Granuloma and Cyst

Histopathologically, chronic apical periodontitis is classically distinguished as “granuloma” or “cyst”.
Apart from being impossible to make on clinical and radiographic grounds,[90] this distinction is also pointless, since therapy is unaffected.
Grossman[31] states that the periradicular diseases are all treated in the same way, namely endodontically, and do not need to be differentiated so long as they are recognized.
The distinction cannot be made radiographically, but only histologically.
Clinically and practically, the dentist must know that the clinical spectrum, from enlargement of the space of the periodontal ligament to granuloma, from cyst to fistula, and from chronic abscess to acute alveolar abscess, represent different aspects of the same process. All these lesions are *lesions of endodontic origin*.

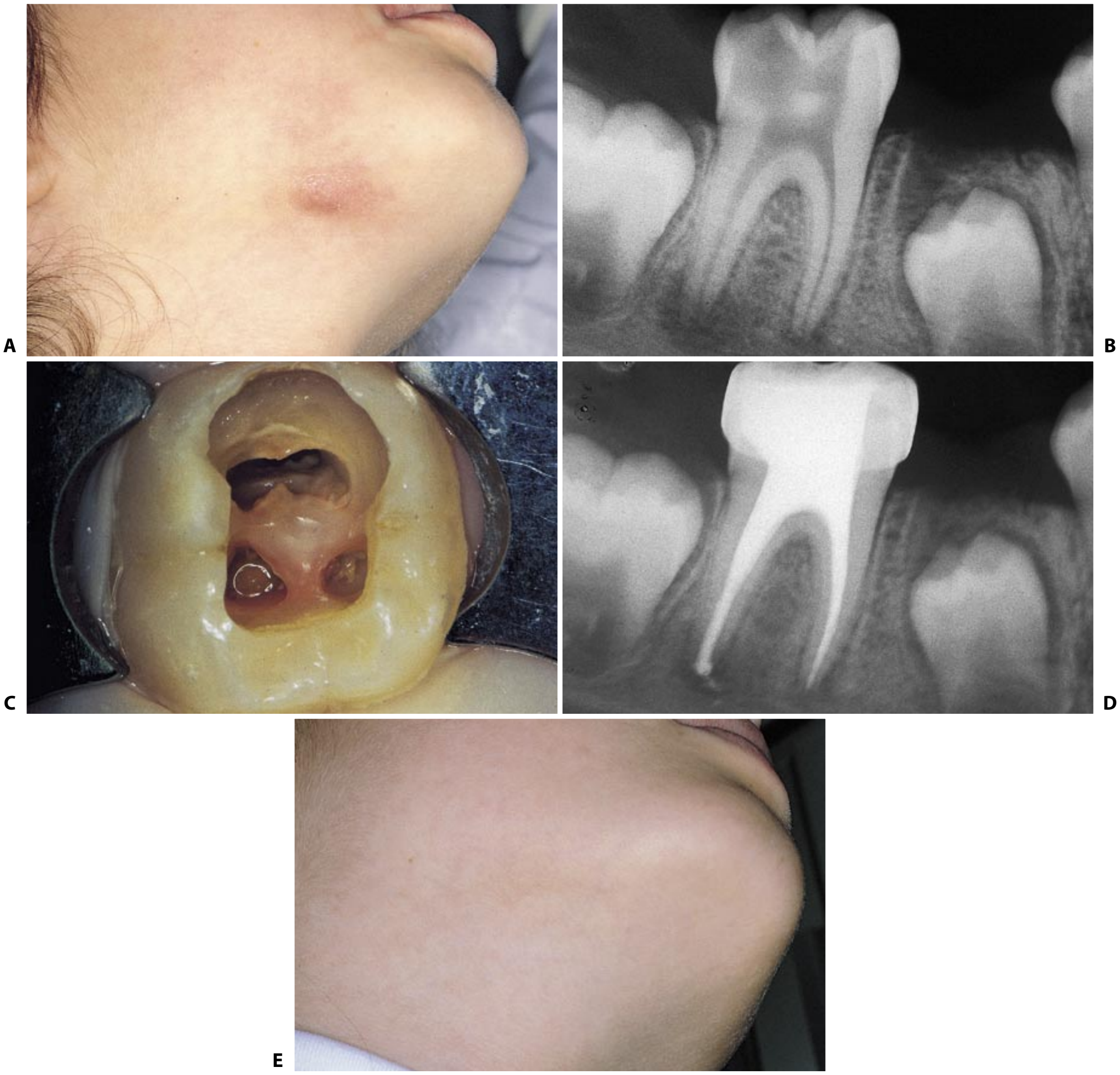


Fig. 8.11. **A.** Cutaneous fistula in the right submandibular region. **B.** Preoperative radiograph of the ipsilateral lower first molar. The tooth had been "opened" one month before and left open "to drain". Note the small radiopacity at the center of the access cavity, due to a residuum of the chamber roof left in place. **C.** Clinical appearance of the access cavity: three openings have been made in the roof of the pulp chamber! One, corresponding to the distal canal, is shaped like an "8"; the two round ones correspond to the mesial canals: the pulp horns have been misdiagnosed for canal orifices. **D.** Postoperative radiograph. The tooth has been pretreated with a cooper band. **E.** Healing of the fistulous tract two years later. Note the complete absence of any scarring.

Granuloma

Histologically, this lesion is characterized by the presence of inflammatory granulation tissue, with capillaries, fibroblasts, connective fibers, an inflammatory infiltrate, and, usually, a peripheral capsule of connective fibers.[83]
Grossman[31] and Weine[88] correctly point out that the term "granuloma" is erroneous, insofar as it is not a tumor, but a chronic inflammatory tissue. A granuloma contains "granulomatous" tissue, in other words granulation tissue and chronic inflammatory cells that infiltrate the connective tissue fiber of its stroma.[88] It arises in response to infection or inflammation of the periapical tissue caused by pulp necrosis.
Granulomas may vary in size from a few millimeters to one centimeter or more, and they are separated from the surrounding bone by a cleavage plane (Fig. 8.12). When a tooth with a granuloma is extracted, the granuloma is often easily removed together with the root to which it remains attached (Fig. 8.13). This is because the granuloma is covered by a capsule which forms

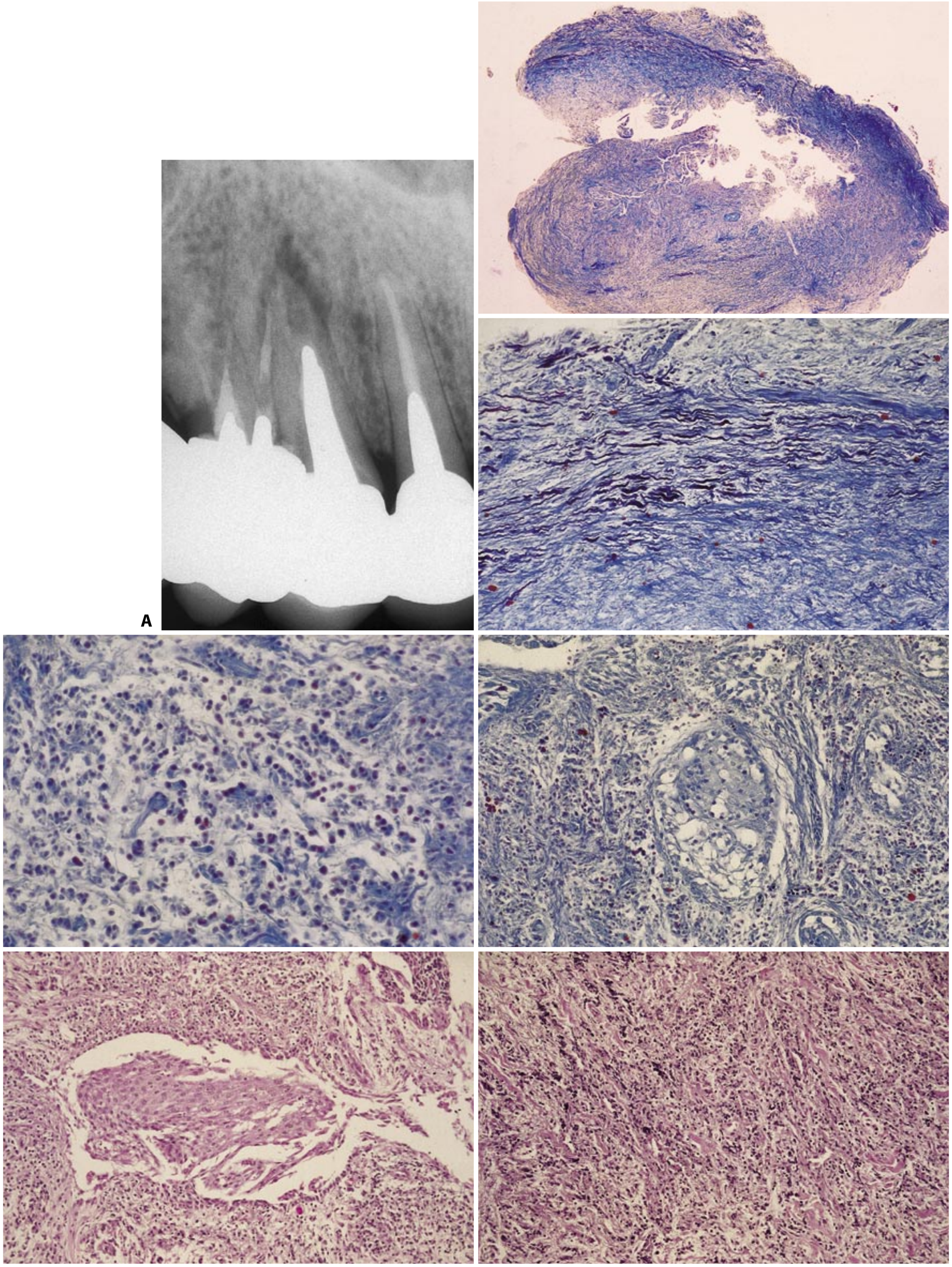


Fig. 8.12. **A**. Preoperative radiograph of an upper right canine about to undergo apicoectomy with retrofilling. **B**. Histologic appearance of the surgically-excised lesion (x2,5). **C**. Connective fibers at the periphery of the lesion (x100). **D**. Chronic inflammatory cells at the center of the lesion (x100). **E, F**. Nests of epithelial cells in the lesion (x250). **G**. Typical appearance of a granuloma (x250).

Fig. 8.13. During extraction, the granuloma very often remains adherent to the root apex.

at the level of the periodontal ligament as a result of the cohesion of the soft tissue contained within it with the intertrabecular soft tissue of the adjacent bone, while the bony trabeculae are being resorbed.[70] At its bony insertion, the fibers of the periodontal ligament become disorganized and dysfunctional, but they preserve their insertion in the radicular cementum.

Another common observation is the ease with which the lesion is surgically separated from the bone, while to remove it from the root surface before performing an apicoectomy it is necessary to perform careful apical curettage.

Weine[88] distinguishes four histological zones (Fig. 8.14), which were already described in 1939 by Fish.[27] Starting from the center of the lesion, they are:

a. *Zone of necrosis and infection*, which contains products arising from the necrotic or infected root canal, polymorphonuclear leukocytes (neutrophils), and possibly bacteria. It corresponds to the zone immediately adjacent to Kronfeld's mountain pass, and it is the only one in which bacteria may be found.

b. *Zone of contamination* or zone of exudative inflammation, which represents the immediate response to toxic elements arising from the root canal, with vasodilatation, exudation of fluid, and cellular infiltration, first with polymorphonuclear leukocytes, then macrophages and lymphocytes.

c. *Zone of irritation,* or granulomatous zone, a proliferative zone characterized by true granulation tissue with defensive and reparative functions. It is notable for the presence of lymphocytes, plasma cells, histiocytes which differentiate into macrophages, osteoclasts, and epithelial nests.

d. *Zone of stimulation* or encapsulation by productive fibrosis, which contains osteoblasts and many fibroblasts seeking to surround the entire inflammatory complex.

The predominant inflammatory cells are therefore chronic inflammatory cells, including macrophages, lymphocytes, and plasma cells, all of which participate in various immunological responses.[83] Immune complexes also have a role in the resorption of the bony trabeculae,[52,78] as do prostaglandins,[34] lysosomal hydrolytic enzymes,[51] and endotoxins.[64,68]

The lysosomal hydrolytic enzymes include acid phosphatase, beta-glucuronidase, hyaluronidase, and elastase. These enzymes have three sources:

1. The inflammatory cells, which seem to be the principal source. The presence of hydrolytic enzymes in polymorphonuclear leukocytes, lymphocytes, monocytes, histiocytes, and macrophages has been amply demonstrated in the literature.
2. Degenerating pulp or periradicular tissue. It has been shown that the cells of these tissues contain lysosomes which, upon rupturing, release their enzymes into the extracellular environment, causing destruction of the surrounding tissues.
3. Microorganisms, which cause the release of enzymes from phagocytic lysosomes, which overflow into the surrounding tissues.

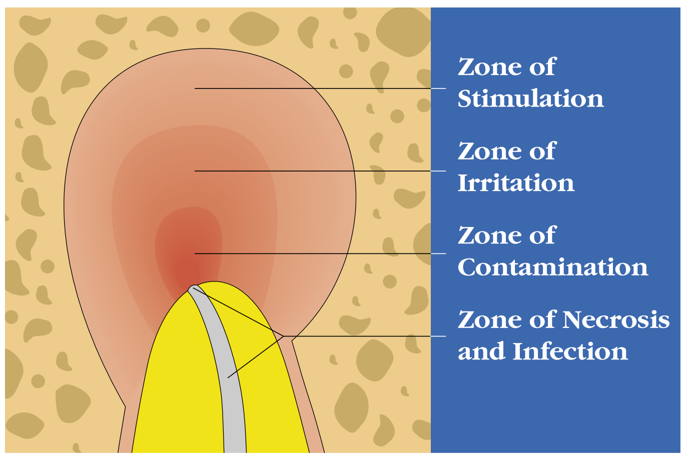


Fig. 8.14. Schematic representation of a granuloma as described by Fish. a) Zone of necrosis and infection, b) zone of contamination, c) zone of irritation, d) zone of stimulation.

Recent studies have shown that bacteria also contain hydrolytic enzymes. Thus, in addition to participating indirectly, they may act as a direct source.[51]

The endotoxins are derived from bacterial lysis. A study by Schein[68] has demonstrated that endotoxins may be shown within an infected root canal and that there is a relationship between the amount of endotoxin and both clinical symptomatology and the radiographic size of the lesion. Their role in bone resorption, possibly due to osteoclast stimulation,[64] is therefore apparent. Endotoxins are lipomucopolysaccharide complexes derived from the cell wall of Gram-negative bacteria, mostly anaerobic. They are released upon lysis of the dying bacterium in the process of disintegration. They are distinct from exotoxins formed by the microorganism and spread throughout the surrounding tissues, while the cell that formed them remains alive and intact.

As long as the irritating substances are not removed from the root canals, these destructive phenomena, in association with reparative processes, continue indefinitely, and the lesion persists chronically.

In addition to resorption of the bony trabeculae, resorption of the radicular cementum and apical dentin may occur.

This is the so-called “external inflammatory resorption” that ceases with the removal of the irritants from the infected endodontium. This radicular resorption may also occur in the adjacent healthy tooth, which obviously preserves its vitality (Fig. 8.15). Indeed, the granuloma grows without involving other structures. This subject will be deeply discussed in the chapter on resoption.

The development of a granuloma depends on the equilibrium between the pathogenicity of the irritants of the root canal system and the organism’s defenses. Virulent transformation of the infecting bacteria or failure of the organism’s defense mechanisms may transform a chronic inflammatory process into an acute one.

In terms of symptomatology, as already suggested, a granuloma is generally asymptomatic and may be an incidental finding in routine radiographic check-ups. Radiographically, the lesion appears radiolucent; it is variable in size and definition, corresponding to various portals of exit of the root canal system at the apex (Fig. 8.16), on the side of the root (Fig. 8.17), or at the level of a bi- or trifurcation (Fig. 8.18).

Therapy requires removal of the infected canal contents, disinfection of the endodontic space, and sealing of every portal of exit.

In a study performed on human samples, Schilder[72] has shown that healing of lesions of endodontic origin is histologically demonstrable only four days after cleaning and shaping have been completed – therefore even prior to canal filling – and may be documented by the newly-formed bony trabeculae at the periphery of the lesion.

A B

Fig. 8.15. External resorption of the apex of an upper left lateral incisor, caused by pulp necrosis of the adjacent canine, treated inadequately. The lateral incisor responds positively to the pulp tests. **A**. Preoperative radiograph. **B**. Recall radiograph 12 months later: the resorption has been arrested, the lesion has healed, and one can identify the lamina dura around the apex of the lateral incisor whose pulp has obviously preserved its vitality.

A B

Fig. 8.16. **A**. Preoperative radiograph of the upper left central incisor: the lesion may be called “periapical”, even though it has shifted distally because of a slight distal curvature of the radicular apex and a lateral canal. **B**. Two-year recall. Note the little apical bifurcation and the little lateral canal.

A

B

Fig. 8.17. **A**. Preoperative radiograph of the upper right second premolar. Note that the lesion is particularly pronounced distally. **B**. Two years following nonsurgical retreatment. The lesion was sustained by a very thin lateral canal which is barely visible radiographically.

A

B

Fig. 8.18. **A**. Preoperative radiograph of the lower left first molar. Note the radiolucency which completely surrounds the distal root and also involves the bifurcation. **B**. One year later. Note that an apical delta has been filled on the distal root. The radiopaque image in the apical third of the mesial root is due to filling of the confluence of the two canals.

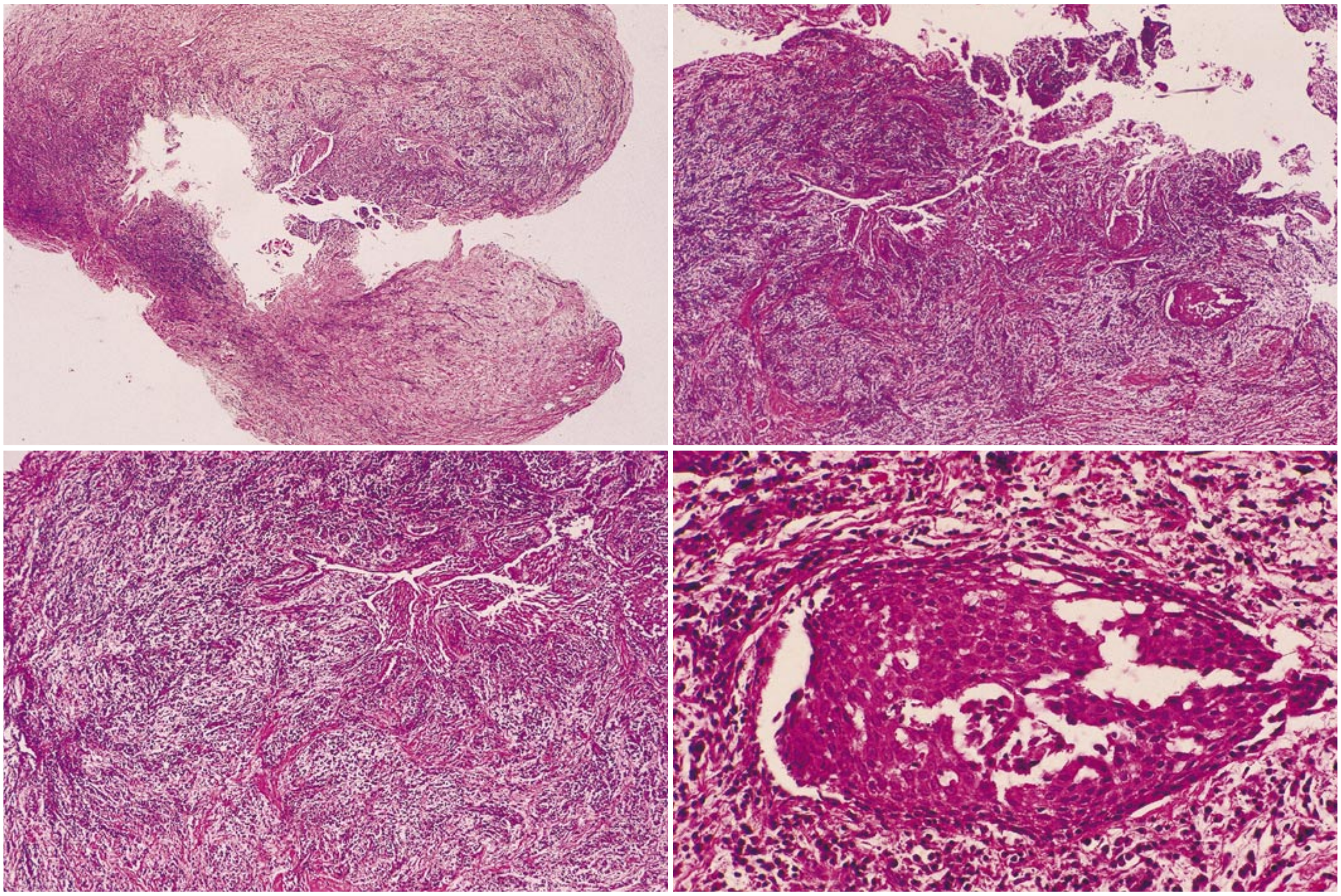
Because it proceeds centripetally, healing is initially observed at the periphery of the lesion, where there is an increase of the number of reparative cells.[10] The inflammatory cells disappear, and the inflammatory tissue of the granuloma is transformed into non-inflammatory granulation tissue. This leads to the gradual neoformation of bony trabeculae until a new lamina dura has been formed; in other words, to the *restitutio ad integrum*. The osteoblasts, which are numerous at the periphery of the lesion, elaborate a bony matrix which gradually mineralizes and matures. If inflammation has caused the resorption of portions of the cementum or dentin, remodelling and repair of the apex by apposition of the cementum occurs. The periodontal ligament is the last tissue to be restored to its normal architecture.[83]

Cysts

The epithelial rests of Malassez are natural components of the attachment apparatus of the tooth. Normally, they are of no clinical significance.
However, when a lesion of endodontic origin develops at the level of the periodontal ligament, the inflammatory process inevitably also involves these cellular nests. Under the irritative stimulus, they may proliferate and constitute the nucleus of a cystic formation. The presence of epithelial nests is therefore quite frequent, if not the rule, in lesions of endodontic origin in general (Fig. 8.19). Sometimes, though, the stimulus to epithelial proliferation is so intense that a fluid-filled cavity lined by epithelium, i.e., a cyst, may form.

There are several pathogenic theories of cyst formation. One of the most credited suggests that, by the continued growth of epithelium and an increase in size of the lesion, the distance between the central cells and their nutritive source increases; consequently, the most internal cells of this cellular nest actively proliferating die, and their degenerative products attract fluid by simple osmosis, with a consequent increase of lesion size.

It is important to realize that this is an inflammatory process. Therefore, once the stimulus is removed, there is no reason it should not heal, like any other lesion of endodontic origin.[63]



A B C D

Fig. 8.19. Epithelial nests in a "granuloma-type" lesion. **A**. Overview (x2,5). **B, C**. Details of the preceding figure (x40, x80). **D**. Cellular nest visible in Fig. B, photographed at higher magnification (x280).

Histologically, cysts resemble apical granulomas, the only difference being the presence of a central cavity filled with fluids or semi-solid materials and lined with a flat, multilayered epithelium. The connective tissue surrounding the epithelium contains all the cellular elements that are present in the granuloma. This is not surprising, if one considers that both lesions are of endodontic origin (Fig. 8.20).

Cysts are usually asymptomatic. If they reach a significant size, they may present as swellings, and their pressure may cause loosening of the diseased tooth or those adjacent. The tooth may become very loose. If not treated, the cyst can expand at the expense of the mandibular or maxillary bone. The cyst may appear to involve the apices of the nearby teeth whose roots may also be subjected to external resorption. Their vitality is preserved, however, and one must keep this in mind if a surgical procedure such as apicoectomy with retrofilling of the diseased tooth becomes necessary.

The diagnosis is based on radiographic findings. Negative responses to all pulp tests confirm the odontogenic nature of the cyst.

Several authors maintain that the radiographic image of a round, sharply-demarcated radiolucency 1 cm or greater in diameter suggests a cyst, while a smaller, less well-defined radiolucency indicates a granuloma.[43]

As already stated, there is no practical need to distinguish the two entities; in fact, it is not possible to do so by radiographic criteria alone.[5,11,40,42,49,62,86,90] Numerous studies[24,28,35,49,62,86] have confirmed the lack of correlation between the size and shape of the radiolucencies and their histology. Furthermore, even histologically, there is no clear division between granulomas and cysts: small lesions may contain cystic vacuoles, and large lesions may consist entirely of granulation tissue (Fig. 8.21). The only way to make a correct diagnosis is by histopathologic examination, but there are numerous histological transitional forms.[90]

However, the differential diagnosis must be made with other radiolucencies that cannot be attributed to pulp necrosis and that radiographically may resemble odontogenic cysts. These are lateral periodontal cysts, cysts of the incisor canal, cysts of the naso-palatine duct (Fig. 4.16), traumatic cysts,[1] also called hemorrhagic[61] or solitary[65] cysts (Fig. 8.22) which are bony cavities lacking an epithelial lining,[54] and keratocysts[30,66] (Fig. 8.23).

For many years, globulo-maxillary cysts were also counted among the non-odontogenic cysts. In 1937,

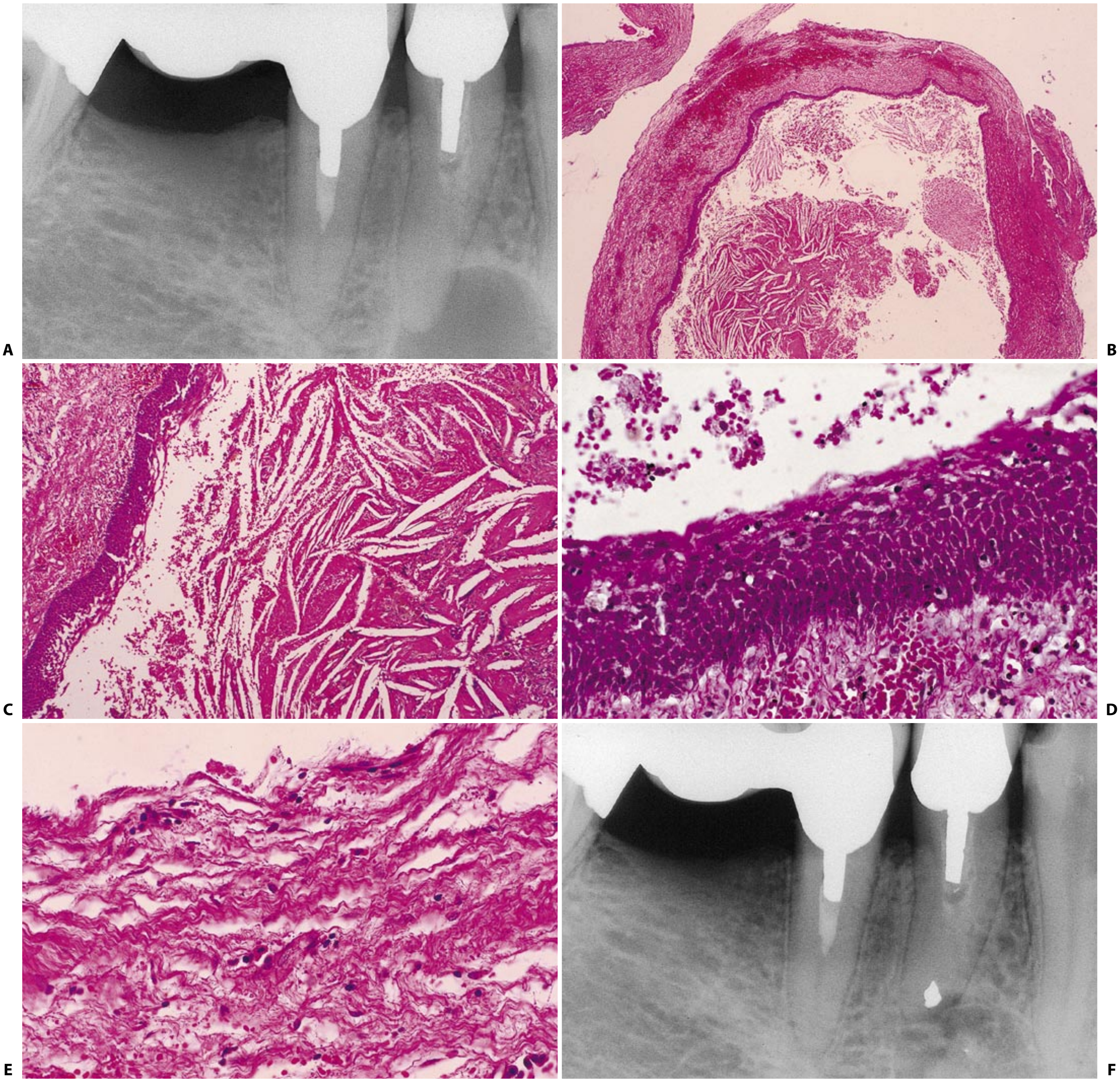


Fig. 8.20. **A**. Preoperative radiograph of the lower right first premolar. **B**. Histologic appearance of the cystic lesion, which has been removed during apicoectomy with retrofilling (x2,5). **C**. The cystic contents at higher magnification (x100). **D**. The multilayered epithelium which lines the cystic cavity (x400). **E**. Connective fibers at the periphery of the lesion (x400). **F**. Four years later.

Thoma[80] first described this radiolucency in the anterolateral region of the maxillary bone between the canine and the lateral incisor. It could provoke a certain divergence in the roots of these teeth. Thoma believed that they were "fissural cysts" arising from epithelial rests entrapped at the junction of the globular and maxillary processes. Sicher[74] subsequently clarified that the globulo-maxillary cyst could not develop in this way. Since the globular portion of the medial nasal process is an integral part of the maxillary pro-

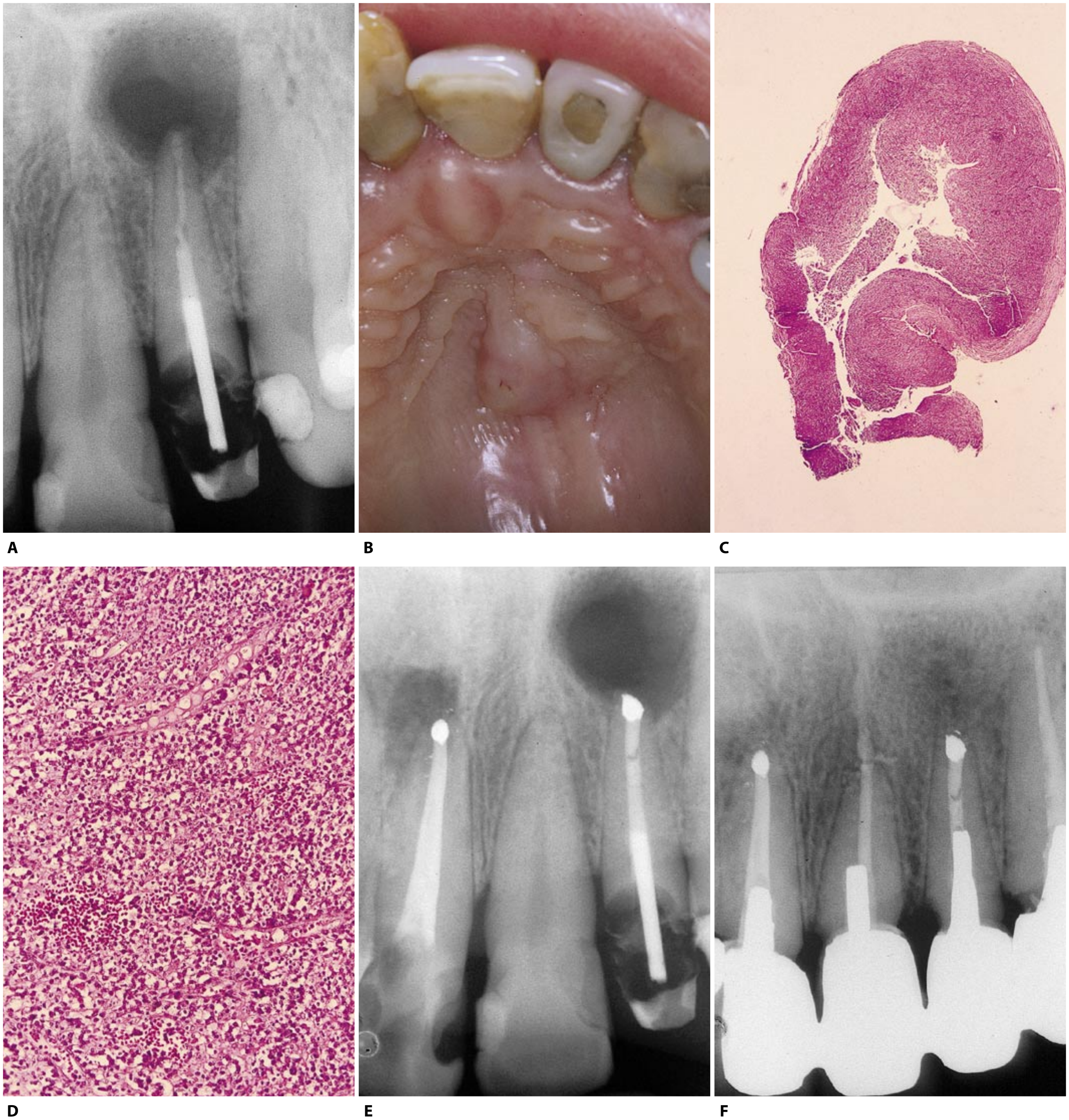


Fig. 8.21. **A**. Preoperative radiograph of the upper left lateral incisor. The shape, degree of radiolucency, sharp borders, and size suggest a cystic lesion. **B**. A palatal swelling is present. **C**. Histologic appearance of the lesion (x2,5). **D**. At high magnification, the lesion has all the characteristics of a granuloma (x250). **E**. Postoperative radiograph. Retrofilling has also been performed in the right central incisor. **F**. One year later. Note the "apical scar" several millimeters above the root of the lateral incisor.

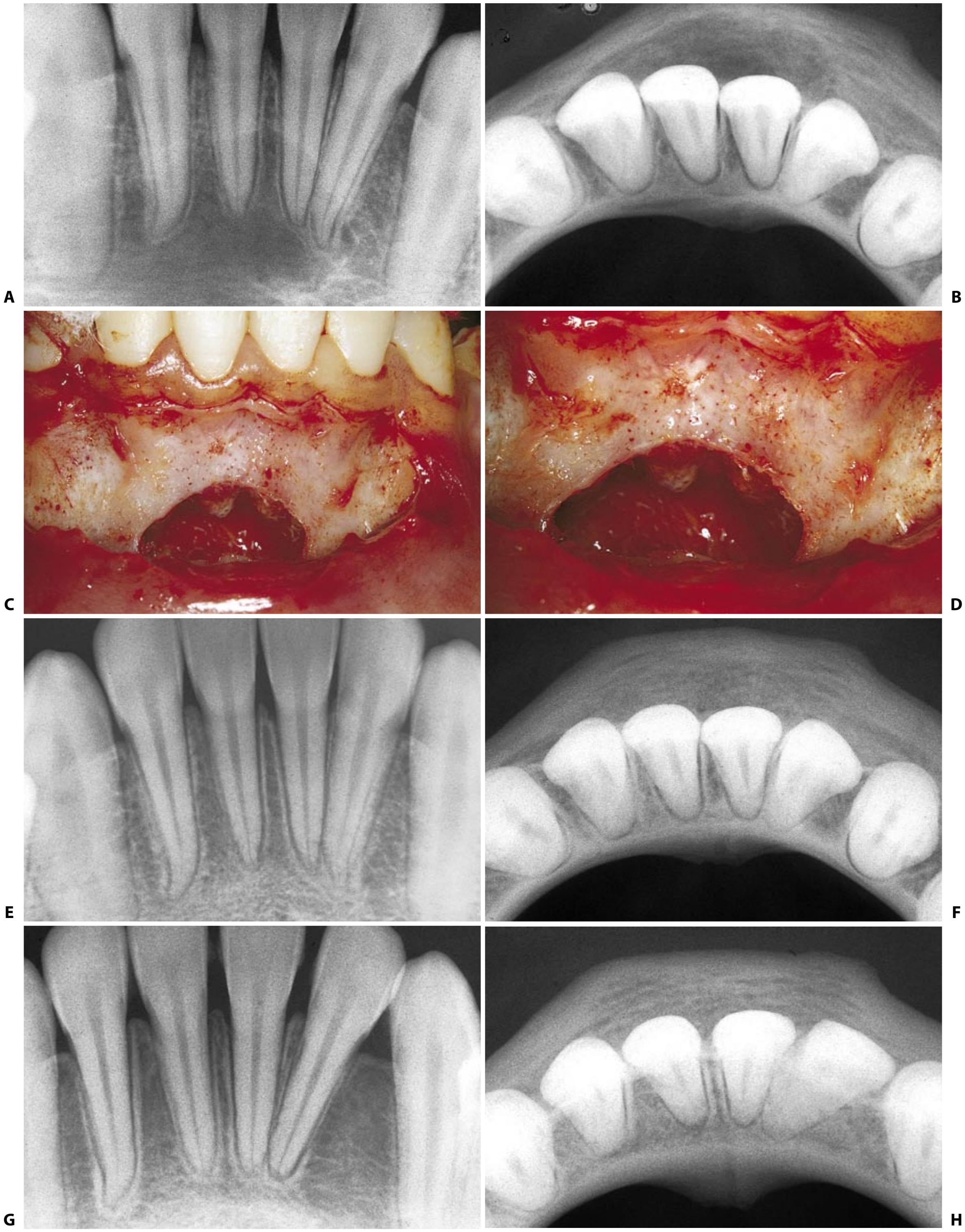


Fig. 8.22. **A**. Preoperative radiograph of the zone of the lower incisors. A large radiolucency with sharp borders is present. It seems to involve the apices of the four incisors and that of the right canine. All the teeth respond positively to the vitality tests. The young patient recounted a history of trauma in this area about two years before. The diagnosis of traumatic cyst was made. **B**. The same lesion seen in an occlusal radiograph. **C**. The flap has been raised and the thin layer of vestibular bone has been removed. The cavity appears empty, lacking any hemorrhagic or cystic content, and it is not lined by epithelium. Note that the apices of the two incisors seem to dip into the cyst. **D**. The bony cavity at higher magnification. The two apical foramina of the right central incisor are visible. **E**. Eight months later. **F**. The same area seen in an occlusal radiograph. **G**. Four years later. The teeth have preserved their pulp vitality. **H**. The same area radiographed in an occlusal projection.

Fig. 8.23. Keratocysts in a patient with Gorlin-Golz Syndrome, or basocellular nevomatosis. Case published by Gazzotti et al.[27]

cess, no epithelium could become entrapped between these two processes. Other authors[21,92] have argued that globulo-maxillary cysts must be removed from the classification of fissural cysts, because in most if not all cases, cysts in this anatomical site are odontogenic and therefore should be included among the lesions of endodontic origin[77] (Fig. 8.24).

Cysts are treated by endodontic therapy, by which even unsuspected or undiagnosed cysts are treated to resolution. Bhaskar[11] claims that cysts represent about 42% of bony rarefactions at the apices of teeth with necrotic pulp. The high success rate of endodontic therapy, which according to Ingle[37] ranges from

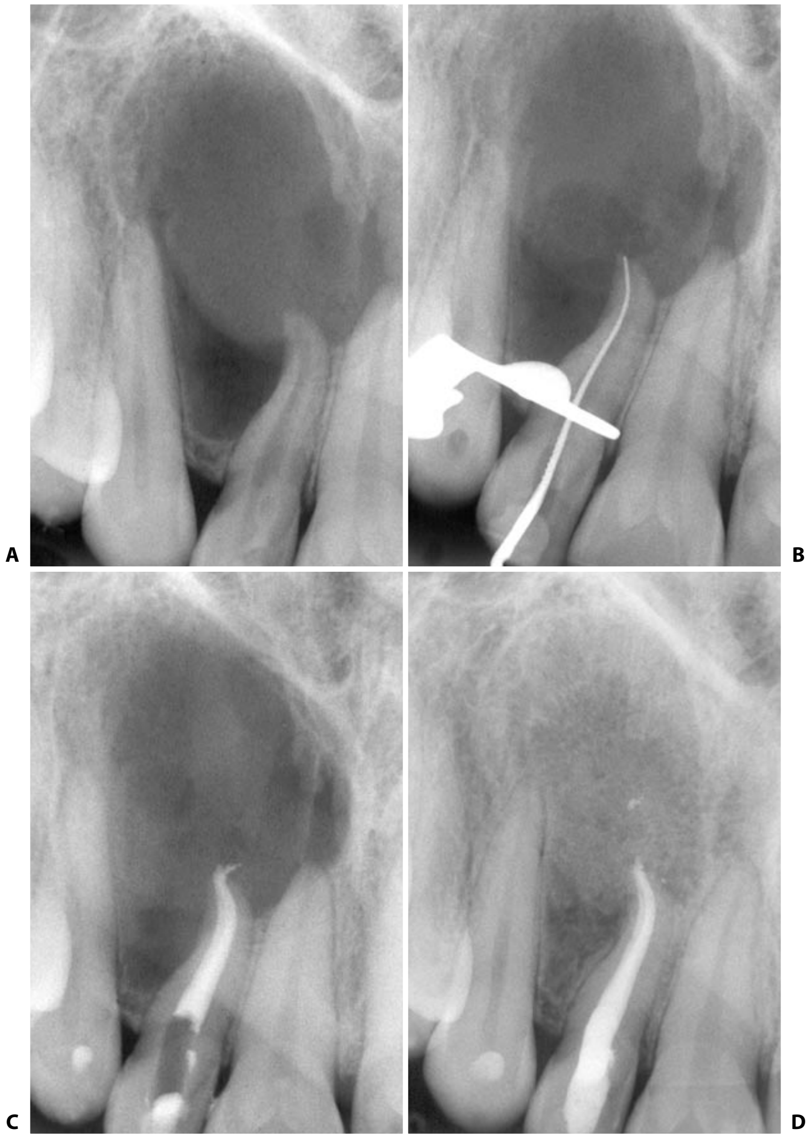


Fig. 8.24. Tipical aspect of a lesion of endodontic origin, simulating a globulo-maxillary cyst. **A**. Preoperative radiograph. **B**. Working lenght. **C**. Postoperative radiograph. **D**. Two year recall (Courtesy of Dr. Costantinos Laghios).

80% to 90%, is indirect confirmation that odontogenic cysts resolve with proper endodontic therapy (admittedly, though, many oral surgeons would not concur) (Fig. 8.25).
The treatment of choice of cysts is therefore not surgical enucleation, but endodontic therapy of the diseased necrotic tooth, followed as always by periodic check-ups and radiographs [13] (Fig. 8.26).
Surgical treatment is indicated only *after* traditional nonsurgical therapy has failed or if new symptoms develop [31] (Figg. 3.19, 8.27).
A reason for the failure of nonsurgical therapy of odontogenic cysts may be failure to achieve complete drying of the canal, an essential prerequisite for a good apical seal. In these cases, calcium hydroxide as intracanal medicament may be indicated (Fig. 8.28) with the aim of stimulating the healing mechanism and easily obtaining a dry canal.
Furthermore, when intervening surgically, enucleation of the cyst may be indicated only if it is absolutely certain that it will not compromise the vascular peduncles of nearby apices or important adjacent anatomical structures, such as the floor of the maxillary sinus, nasal fossae, mental nerve, or inferior alveolar nerve. If there is even the slightest doubt, it is preferable to excise a small flap of the cystic wall, which will suffice to assure adequate surgical access to the apex of the involved tooth. The remains of the lesion may be left in place (Fig. 3.19) without concern.[53]
Healing of the cyst following nonsurgical treatment is

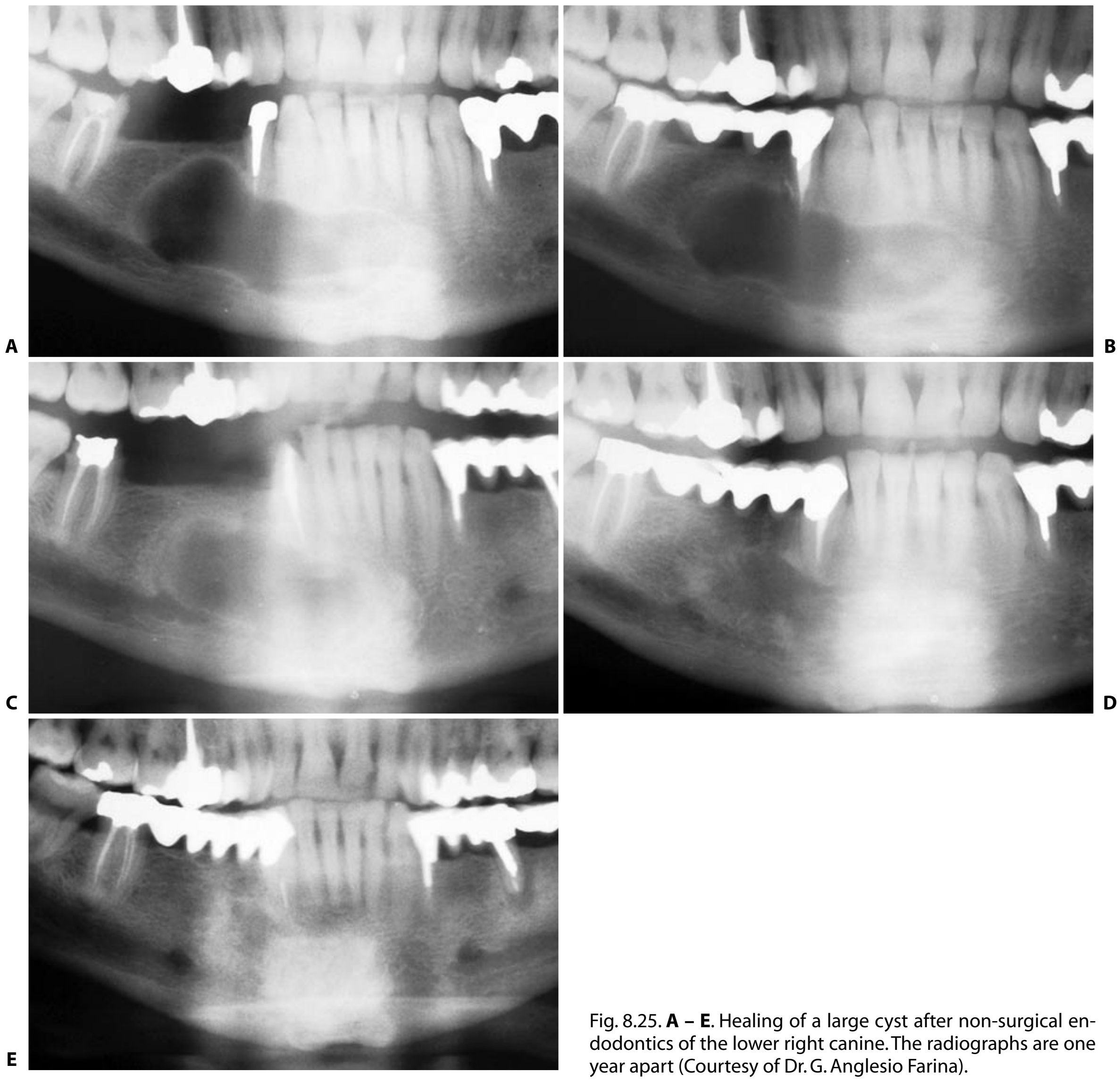


Fig. 8.25. **A – E**. Healing of a large cyst after non-surgical endodontics of the lower right canine. The radiographs are one year apart (Courtesy of Dr. G. Anglesio Farina).

due to spontaneous disintegration of its walls, which occurs after elimination of the irritating substances within the root canal that originally stimulated it.[13] Further, healing is definitely favored by the reduction of internal pressure, which is achieved by drainage of the liquid contained within the cyst [8] and also, according to Bhaskar,[12] by the acute inflammation or hemorrhage that can arise from instrumentation beyond the apex, even involuntarily.

The most modern and plausible theory of cyst healing is that of Torabinejad,[83] who suggested that once the irritative stimulus is eliminated, the immune system gradually destroys and removes the epithelial cells that in the meantime have proliferated to become a foreign tissue.

A B C D

Fig. 8.26. **A**. Preoperative radiograph of the upper left central and lateral incisors. The two teeth do not respond to the tests of pulp vitality. The radiographic appearance of the large lesion which surrounds the two apices suggests a cyst. **B**. Postoperative radiograph. **C**. Six months later. **D**. Two years later.

A B C D

Fig. 8.27. **A**. Preoperative radiograph of the upper right lateral incisor. A large, abscess-like cystic lesion is present. The canine and the first premolar respond positively to the tests of vitality, while the central incisor gives negative responses. **B**. An acute alveolar abscess has developed from a chronic lesion and is visible on the palate. **C**. Postoperative radiograph. **D**. Eight years following apicoectomy. Following the recrudescence of acute symptoms (presumably related to inadequacy of the apical seal consequent to the difficulty of achieving a dry canal), apicoectomy with amalgam retrofilling was performed on both the lateral and central incisors.

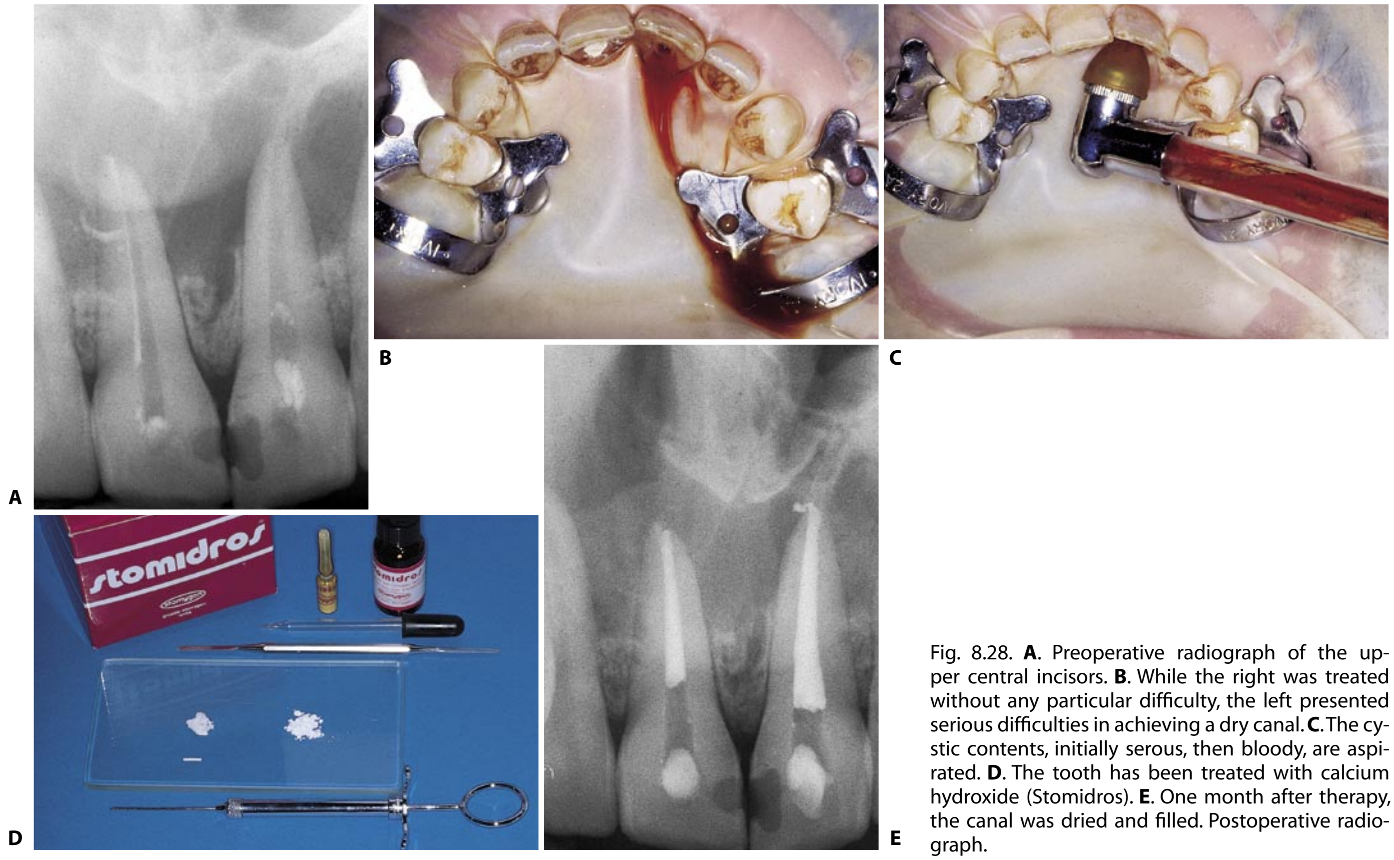


Fig. 8.28. **A**. Preoperative radiograph of the upper central incisors. **B**. While the right was treated without any particular difficulty, the left presented serious difficulties in achieving a dry canal. **C**. The cystic contents, initially serous, then bloody, are aspirated. **D**. The tooth has been treated with calcium hydroxide (Stomidros). **E**. One month after therapy, the canal was dried and filled. Postoperative radiograph.

Reactivation of Chronic Apical Periodontitis

Also called a "Phoenix" abscess,* this is an acute inflammatory reaction that establishes itself in a pre-existing chronic lesion, granuloma, or cyst. The symptoms are those of an acute alveolar abscess, from which it differs only by the clear radiolucency that accompanies the symptomatology (Fig. 8.28).

An asymptomatic chronic lesion may suddenly exacerbate, either spontaneously or following an endodontic procedure. In the former case, a failure of the organism's defenses against bacteria coming from the root canal system, upsets an equilibrium that had prevailed for years and provokes an acute exacerbation.[31]

In the latter case, the abscess spontaneously develops immediately after the initiation of a root canal therapy in a tooth with an apical lesion of endodontic origin dating back years, possibly after the patient has been persuaded of the need to undergo treatment to heal a lesion whose existence he had not even suspected. Indeed, it is not uncommon that such patients remark, "Look what happened to my tooth, which didn't give me any trouble for years! I was right not to want to treat it".

In these cases, the mechanical irritation caused by overinstrumentation, the infected material unintentionally beeing forced beyond the apex, or, more often, the incomplete cleaning and shaping with only partial removal of necrotic debris can be the cause of the recrudescence.

Schein[68] states that bacterial endotoxins may play a role in causing these sudden flare-ups. It is well known that phenol may be used to extract endotoxins from bacteria.[89] In endodontics, paramonochlorophenol, a phenolic compound, is used as intracanal medicament. If cleaning of the canal has not been completed and some necrotic material remains within it, the medication may provoke bacteriolysis. The sudden liberation of endotoxins from the bacterial cell wall may cause a flare of acute symptoms.

It should be noted that this process *never* occurs in a tooth with a fistula, which provides a means of spon-

(*) The Phoenix, according to classical and medieval legends, was a fantastical Arabian bird that every 500 years constructed a pyre with aromatic plants for the purposes of self-immolation and rebirth.

taneous drainage for the pus that would otherwise provoke an acute flare-up. The patient with a fistula therefore experiences no pain. It is clear that fistulous lesions must be considered "welcome", since they never embarrass the dentist in front of the patient!
Treatment of such exacerbations requires the same emergency treatment as that of an acute alveolar abscess.

Acute Apical Periodontitis

Acute apical periodontitis is an acute inflammation at the level of the periodontal ligament. It can be provoked by a variety of factors.
In the vital tooth, it may be caused by occlusal trauma from a recent restoration that extends beyond the occlusal plane[31] or by chronic bruxism.[23]
It may also be caused by the extension of pulp disease into the periapical tissues. Not infrequently the earliest signs of acute apical periodontitis may be present even in advanced cases of pulpitis, when the tooth still responds to the thermal tests. This is manifested by pain on percussion and radiographically by a slight widening of the space of the periodontal ligament (Fig. 7.14).
In the necrotic tooth, it may arise spontaneously from the diffusion throughout the periodontium of bacteria and toxins present in the root canal. Alternatively, it may be iatrogenic, arising after instrumentation beyond the apex (overinstrumentation), from the spread of infected material or bacteria beyond the apical foramen, or by the use of medications that are excessively irritating or used in excessive quantities (overmedication).
Slight soreness of the tooth following root canal filling that lasts no more than one week is not uncommon. Indeed, it may be considered normal, especially if the treatment is performed in a single visit, independent of the presence or absence of a small overfilling.
The symptoms of acute apical periodontitis are pain on percussion and, sometimes, palpation. The patient is able to identify the affected tooth, since the periodontal ligament, the site of the inflammatory process, is well innervated by proprioceptive nerve endings.
The patient may report that the tooth feels longer. This is due to slight extrusion of the tooth from the alveolus, which is caused by the accumulation of exudate between the fibers of the ligament. Stretching of these fibers causes this sensation. Radiographically, widening of the space of the periodontal ligament may be seen; if the tooth is necrotic, it may appear as a small radiolucency. If the tooth is vital, its periradicular structure may be radiographically normal.[31]
Since such symptoms may occur in both vital and necrotic teeth, it is imperative to perform the tests of vitality and reach an accurate diagnosis.
If the cause is occlusal trauma, simple adjustment of the occlusion leads to rapid healing.
If acute apical periodontitis occurs in association with pulpitis, pulpotomy is not advisable. The tooth should be left completely open to allow drainage of the exudate that has accumulated between the fibers of the periodontal ligament.[81]
If it arises spontaneously in a necrotic tooth, it is also advisable to leave the tooth completely open to prevent the development of an acute alveolar abscess. In such cases, the canal may be medicated with a "closed" medication such as Cresatin and Cavit, as long as the canals have been previously and adequately cleaned and shaped.
Finally, if periodontitis occurs iatrogenically, it is important to determine the cause and, if possible, eliminate it. In general, it is sufficient to re-check the working length, to re-check the apical patency, possibly to perform a new recapitulation, and to eliminate the previously-used irritating intracanal medicament. However, it is particularly important to perform prolonged irrigations with sodium hypochlorite. By its hypertonicity, this solution will osmotically extract fluid from the surrounding tissues, particularly the periodontal ligament, the site of inflammation. If the cause has definitely been eliminated, the tooth need not be left open, which should be avoided whenever possible.
In treating acute apical periodontitis, one must never forget to relieve the tooth from the occlusion.

Acute Alveolar Abscess

An acute alveolar abscess indicates the collection of pus at the level of the alveolar bone surrounding the apex of a tooth whose pulp has become necrotic. It represents an advanced stage of acute apical periodontitis arising from pulp necrosis, in which the infection has extended to the periradicular tissues through the apical foramina.
The patient may relate a history of trauma, or the pulp may have become necrotic from chemical or mechanical irritation. More often, acute alveolar abscess represents the continuation of a pulp infection into the

periradicular tissue. Its proximate cause is the invasion of bacteria from necrotic pulp tissue. In these cases, the patient will relate a recent history consistent with pulpitis.

At this point, however, the *symptomatology* is different. There is no radiating pain or intense response to thermal stimuli. On account of the gradual accumulation of exudate in the space of the periodontal ligament, which is known to be rich in proprioceptive nerve endings, the pain becomes localized.

The first symptoms may be slight soreness of the tooth, which is sensitive to percussion or mastication. Soon enough, however, the pain becomes increasingly intense and throbbing. The patient may complain that the intensity of the toothache corresponds to his heartbeat. He may also feel that the tooth has become elongated, because of the strong pressure on the fibers of the periodontal ligament, which are literally upside-down and distended. For the same reason, an increased degree of mobility may also become apparent. The increasing pain is due to increasing pressure from the accumulation of exudate in the surrounding tissues. This exudate creates a pathway among the bony trabeculae in search of an exit. Once it causes erosion of the bony cortical plate, the purulent exudate causes detachment of the periostium, the moment of greatest pain. Once the periostium is eroded, the pus collects in the surrounding soft tissues, which are easily distended. This is simultaneously associated with the almost immediate resolution of the intense pain and the development of swelling. Left to itself, the purulent collection may spontaneously tract outwards, perforating the oral mucosa and sometimes the skin, thus creating the fistulous opening. This is the start of fistulous chronic apical periodontitis.

Pus forms from the infiltration of polymorphonuclear leukocytes and inflammatory exudate in response to an infectious process. The periapical bony tissue is resorbed, and the number of granulocytes dying after having phagocytized bacteria progressively increases, leading to an increase of the amount of pus formed.

In its path outward, pus follows the “loci minoris resistentiae”; at a certain point, therefore, the center of the purulent collection may no longer communicate with the apex of the diseased tooth, and the spontaneous aperture may even occur at a distance from it. Nonetheless, a purulent collection in the maxillary bone is usually expressed in the vestibular mucosa, since the vestibular cortical bone is thinner than that of the palate. Still, the lateral incisor (Fig. 8.27) and the palatal root of the upper premolars and molars may give rise to palatine abscesses, given the proximity of their apices to the palatal cortical bone.

Likewise, in the lower arch, the purulent collection is usually vestibular, but may also be lingual in the case of lower molars with root apices close to the lingual bony cortex (e.g., in molars with the distolingual root).

In addition to local symptoms, constitutional symptoms such as fever and malaise may also occur.

As far as *diagnosis* is concern, identifying the site of infection is generally easy, since the patient presents by indicating the diseased tooth. The tooth is painful on percussion and palpation; further, it may demonstrate an increased mobility. When it has crossed the cortical bone and periostium, the purulent collection appears circumscribed and fluctuant. The tests of pulp vitality – all negative – confirm that the abscess is of endodontic origin.

Radiographs are of little help in arriving at the diagnosis, since the apical zone is usually normal. At most, it may show a slight widening of the periodontal ligament. This is because the lesion is recent and confined only to the cancellous bone; thus, it is not visible radiographically. If the radiograph reveals a sharp apical radiolucency, the acute alveolar abscess represents a re-exacerbation of pre-existing chronic apical periodontitis (granuloma or cyst), also called a “Phoenix” abscess.

The symptoms of an acute alveolar abscess are identical to those of an acute periodontal abscess. The distinction between the two entities is based on the fact that in the lesion of periodontal origin the tooth has a vital pulp and thus responds positively to all the pulp tests. Furthermore, it has a pocket from which a purulent exudate may issue after probing. This may also occur in the case of an acute alveolar abscess when the collection drains spontaneously through the fibers of the periodontal ligament. In this instance, the tract into which the periodontal probe can be introduced is not a pocket, but simply a fistula (Fig. 8.7).

The swelling associated with an acute periodontal abscess is more circumscribed and more coronal with respect to that which occurs with an acute alveolar abscess. In the latter, the infection arises in the apex of the tooth and extends primarily into the soft tissues; thus, the swelling is more apical and diffuse.

Teeth in hyperocclusion may also produce symptoms similar to those of the early phases of acute alveolar abscess, but in this case also the responses to the various tests of pulp vitality are positive.

Therapy of an acute alveolar abscess consists of draining the purulent collection (“*Ubi pus, ibi evaqua”*). This helps relieve the patient’s pain or, at any rate, the sense of tension in the affected area; further, it contributes to improving his/her general status.

The most natural way of obtaining drainage is through the root canals. Hence, therapy consists of preparing an adequate access cavity.

This must be done *without* the use of anesthesia for the following reasons:

1. On account of the acidic environment generated by the inflammatory process, anesthesia would not be significantly effective.
2. If one employs anesthesia, one cannot check whether, once the tooth has been opened and drainage achieved, the patient has experienced the expected relief of pain. The patient who presents urgently in pain should leave the office only after he has had relief of his pain as a result of our therapy.
3. If one uses anesthesia, one is deprived of the useful information that might be provided by the cavity test, the most important and “truthful” test of pulp vitality.
4. Since the abscess is of endodontic origin, the pulp is necrotic; thus, anesthesia is useless.

Obviously, one must use a high-speed handpiece and a new bur to minimize vibration in the tooth. In these cases, still to minimize vibration in the diseased tooth, the dentist must hold the tooth all the more firmly, *simultaneously* applying pressure on the vestibular and lingual sides of the tooth itself.

If the abscess collection still communicates with the apex, a spontaneous discharge of purulent first and then hemorrhagic exudate occurs once the access cavity has been created. Slight manual pressure on the submucosal swelling may facilitate expression of the pus (fig. 8.29).

The pus may not always drain spontaneously. In such cases, the drainage may be facilitated by an endodontic instrument *voluntarily* pushed beyond the apex. This is the only time when one can and should go beyond the apex with instruments. If one is working without the use of rubber dam because the tooth is painful and the patient is unable to tolerate the clamp, the instrument must be anchored to the wrist with dental floss (Fig. 8.30).

If drainage still does not occur, the purulent collection is too far from the apex and one must provide another means of drainage.

In this case, after having ascertained the limits of the collection and its fluctuance by bimanual palpation, an incision is made with a Bard-Parker # 11 scalpel blade at the lowest point of the collection, into which it is slowly pushed until it encounters bone (Fig. 8.31).

As this procedure may be very painful, it is necessary to use local anesthesia.

A

B

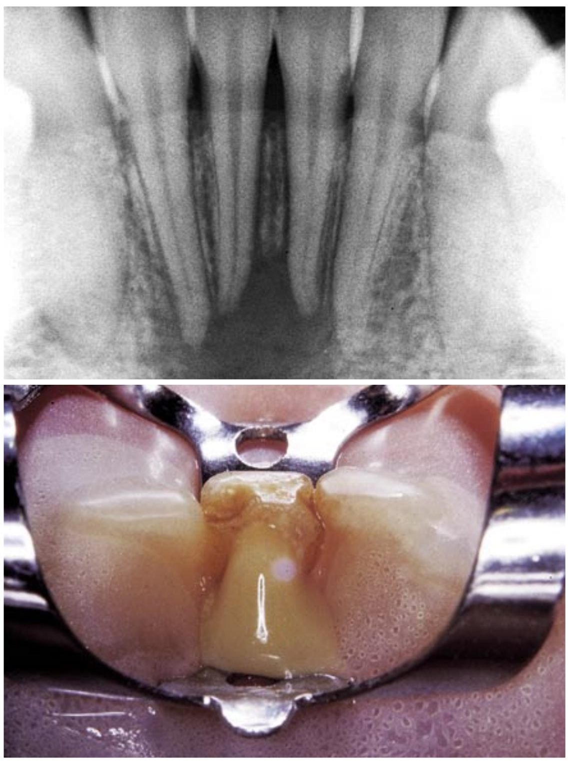


Fig. 8.29. **A**. Preoperative radiograph of the lower central incisor with an acute alveolar abscess **B**. At the opening of the access cavity the pus has spontaneously drained, and the pain resolved instantaneously.

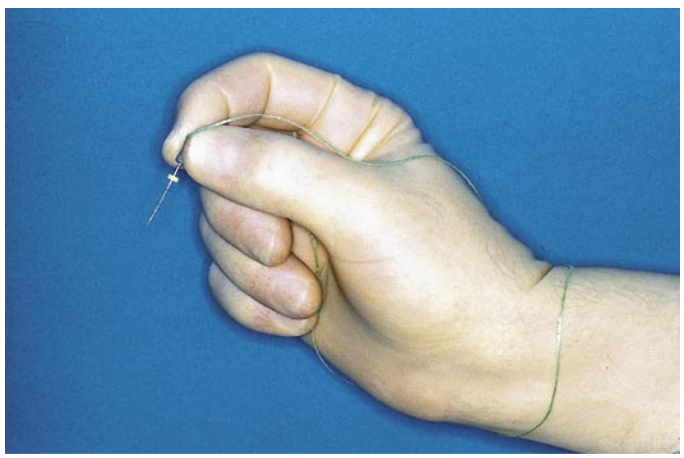


Fig. 8.30. The # 08 file is anchored to the wrist by dental floss.

The mucosa overlying the abscess may be anesthetized with a squirt of ethyl chloride, but the anesthesia will not last more than a few seconds. If the scalpel blade has been introduced too "timidly", only blood rather than pus will issue, and the patient will not consent to another attempt while the operator will feel frustrated. Therefore, longer-lasting anesthesia is required. This may be achieved by the injection of an anesthetic with a vasoconstrictor in the thickness of the mucosa itself, preferably after the mucosa overlying the purulent collection has been anesthetized with a topical anesthetic (Fig. 8.31 E). The needle should not penetrate the purulent collection, as this would only increase the pressure within the collection and cause the pus to extend into the nearby tissues. In doing so, the patient would experience pain rather than anesthesia, while the infection would spread. The needle should be introduced tangentially to the mucosa and should be visible through the transparency of the tissues. The anesthetic must be injected sparingly and slowly: one should just see the ischemic effect of the injected anesthetic (Fig. 8.31 F). Administered in this way, the anesthesia is sufficient for an incision of the purulent collection with a scalpel and to establish drainage of the pus, with immediate relief for the patient.

If the tooth with an acute alveolar abscess cannot be opened (for example, because of a post in the root), the only means of drainage is incision. In this case, however, the drainage must be maintained for at least one or two days. This may be achieved by attaching a small piece of rubber dam to one flap of the incision with a suture (Fig. 8.32).

This is not necessary if, in addition to incision of the purulent collection, the tooth has been opened with an adequate access cavity, since the drainage may continue through this natural pathway.

Once the symptoms have receded, the patients may be discharged with the tooth open and the following instructions:

– Rinses should be done with hot salt water for five minutes every hour until the pain has completely resolved.

Fig. 8.31. **A.** Preoperative radiograph of the upper right first molar. **B.** The tooth presents a large, painful, and elongated vestibular swelling, and it does not respond to the tests of pulp vitality. **C.** A deep pocket is present around the palatal root: the advanced periodontal disease has caused retrograde pulp infection and necrosis and thus the development of the acute alveolar abscess. **D.** The opening of the access cavity is not accompanied by any drainage (continued).

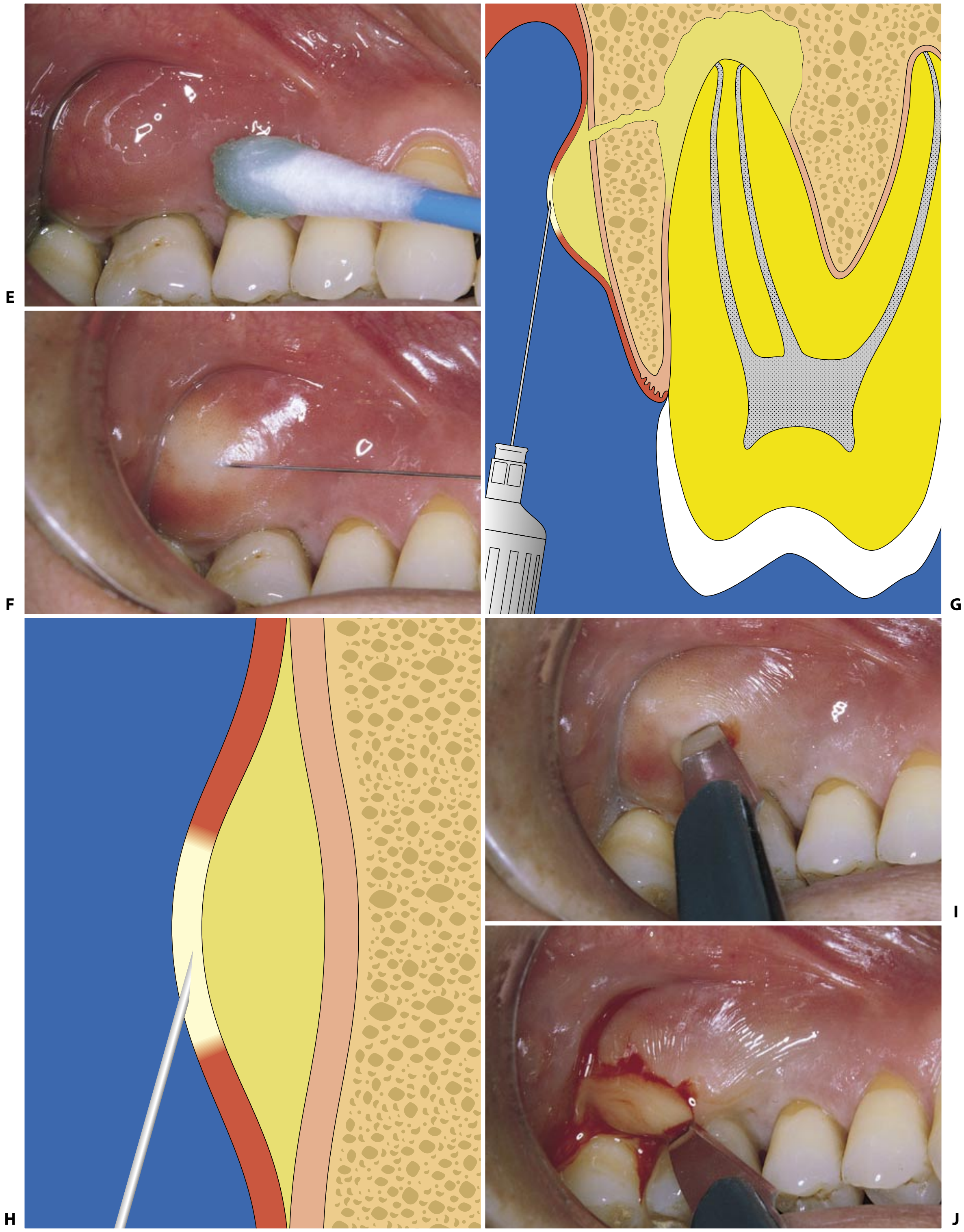
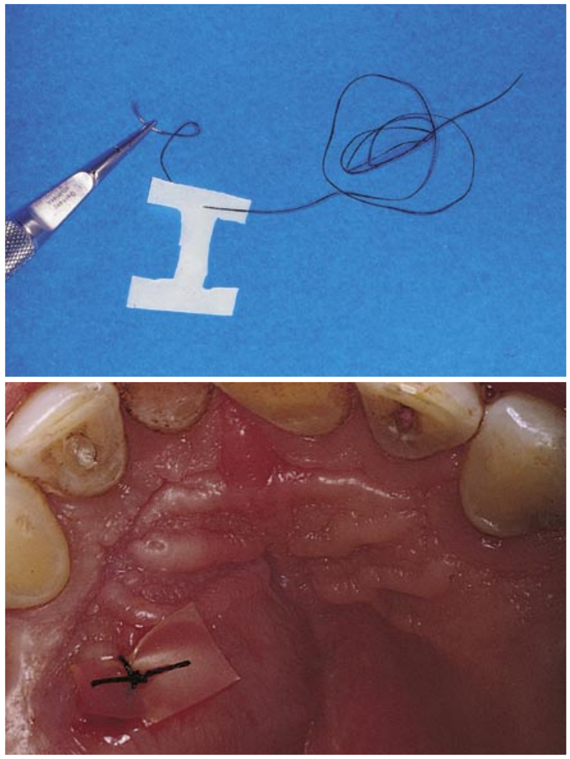


Fig. 8.31. (continued) **E.** The rubber dam has been disassembled, and topical anesthesia is applied to the mucosa overlying the fluctuant collection. **F.** Intramucosal anesthesia is effected. **G.** Schematic representation of the technique of anesthesia for incision of an abscess. **H.** The anesthesic must be injected intramucosally. **I.** An incision has been made with a # 11 scalpel blade, which is introduced at the lowest point. **J.** The purulent collection issues from the incisional opening (continued).

K

L

Fig. 8.31. (continued). **K.** Postoperative radiograph: the palatal root is ready to be amputated. **L.** Five years later.



A

B

Fig. 8.32. **A.** A small "I-shaped" piece of rubber dam is ready to be sutured to one flap of the incision. **B.** The drainage in place.

– Water should be hot, not warm, and rinses should be done with vertical movements of the jaw, as though patients were chewing the water. In this way, the hypertonic solution will penetrate the root canals better and, by extracting fluids by osmosis, facilitate further drainage.
– Once the spontaneous pain has completely passed, it is sufficient that the rinses are done only after meals to avoid occlusion of the canal openings with food particles, which could provoke a recurrence of symptoms.
– After a minimum of 24 hours without symptoms, the patients may be seen again for a normal visit of cleaning and shaping: if the lesion became asymptomatic, it is also sterile.
– A prescription for antibiotics should be given to the patients. However, they should take them only if the pain does not resolve with the salt water rinses alone.

It is important that no medication be placed in the tooth and that it remains completely open, to allow maximal efficacy of rinses with the hypertonic solution.

The canals may also be closed temporarily, but this may be done only after they have been completely cleaned and shaped. However, since acute alveolar abscess presents as an emergency, it is difficult to have the necessary time for proper preparation of the canals. Furthermore, the tooth is painful, and the patient does not always tolerate the rubber dam clamp or the use of endodontic instruments.

The *prognosis* of teeth that have had an acute alveolar abscess is excellent; in general, there is complete "restitutio ad integrum" with appropriate endodontic treatment. Even cases that seem very tenuous on account of very pronounced mobility may heal perfectly.

In fact, the bony destruction that occurs for endodontic reasons heals completely, in contrast to bony destruction of periodontal origin. Even if the abscess begins to develop at the level of the fibers of the periodontal ligament, they become distended and disordered, but are not destroyed. For this reason, once the acute symptomatology has passed, the tooth again becomes firm and stable in its alveolus.

If the endodontic lesion had drained spontaneously through the fibers of the periodontal ligament and the gingival sulcus, and if it remains untreated for a long time, there may be an accumulation of bacterial plaque directed apically along the fistulous tract and an apical migration of the epithelial attachment. At this point, the fistula has yielded to the advent of a true pocket, and the originally endodontic lesion is now complicated by a secondary periodontal lesion. The prognosis of such a case no longer depends solely on the efficacy of the endodontic therapy, but also the periodontal therapy.

THE CRACKED-TOOTH SYNDROME

Uziel Blumenkranz S., D.D.S.

If one considers the various complaints of patients with different forms of pulp pathology - e.g., sensitivity to cold in hyperemia or sensitivity to heat in pulpitis-or periapical disease - e.g., pain upon pressure in periodontitis or abscess - one might conclude that they cannot coexist in the same tooth.
While the patient may claim that the tooth is sensitive to cold, heat and pressure, this is usually due to the condensing of symptoms from previous toothaches.
However, there is one such case in which the three symptoms may originate and coexist in the same tooth. This is known as the “cracked tooth syndrome”.[6]

Introduction

Leading up to 1964,[6] many different terms had been suggested to name this condition.[18,35,50] But it was Cameron[6] who introduced the term the “Cracked Tooth Syndrome”, adding that “The most important factor in diagnosis of a cracked tooth is awareness that these cracks occur”.
Although many articles have been written on this topic since then, many patients with this syndrome go by undiagnosed. In addition, there is a confusion in dental literature regarding teeth diagnosed with “cracked tooth syndrome” and those fractured as a consequence of procedural accidents. Fractures in the latter category have been termed Apically Induced Fractures by Williams[61] and vertical root fractures by others.[2,35] While in both cases the impact on the tooth may be identical, the etiology is different.[33,53] It is also a fact that so long as the dental profession relies mostly on radiographic evaluations this syndrome cannot be readily detected. The cracks occur from distal to medial, where the X-ray film is unable to capture them. Therefore, more and more teeth will become casualties of the “Cracked Tooth Syndrome.” Yet, if they are detected they may be salvaged. Cracked teeth are very difficult to diagnose, especially if the dentist is not looking for them.
In many instances, due to ignorance on the part of the dentist, the patient is dubbed as being “paranoid,” and is sent home with a prescription of tranquilizers. It is noteworthy that in his study Cameron[7] reported that one patient afflicted with cracked tooth syndrome was being medicated with Tegretol for a possible trigeminal neuralgia, and for another brain surgery was being considered.
Cracked teeth are an intermediate stage in a series of events which, if unrecognized and untreated, will culminate in the extraction of the tooth. Diagnosis and early treatment can often prevent unnecessary discomfort and more invasive treatment.[64]

Definition

The “Cracked Tooth Syndrome” is characterized by an incomplete fracture of a posterior tooth with vital pulp, which includes dentin and possibly the dental pulp.[16,18,21]
In an attempt to expand the domain of the syndrome, cracked teeth with necrotic pulp and/or alveolar abscesses should also be included in its definition.
A tooth is considered “cracked” when the potential segments of the fracture are held intact by a portion of the tooth through which the fracture has not yet extended.[64] “Crack” refers to a disruption or interruption of the continuity of the tooth surface which involves the enamel and dentin without a perceptible separation. It is not possible to wedge this line, separate the fragments, or demonstrate the crack radiographically, although it may precede a true fracture[17] which may condemn the tooth to extraction (Fig. 8.33).

CRACKED TOOTH SYNDROME

The fractures resulting from traumatic lesions are usually horizontal, and those resulting from tension and/or iatrogenic episodes are vertical in nature, whether in mesiodistal or buccolingual directions.
Once the fracture line advances in an occluso-apical direction and crosses the epithelial union, a linear defect is created in the epithelial attachment, periodontal ligament, and adjacent alveolar bone resulting in an infrabony defect. It will remain as such until the tooth is extracted. These pockets may persist without treat-

ment, but can never be reversed.[13] In the same token, once a vertical radicular fracture crosses the limits of the attachment apparatus and the root canal system, and comes into contact with the oral environment the affected root or tooth must be extracted.[24,34,62]

Many convoluted and, frankly, strange solutions have been proposed to treat this syndrome:[13,33,43,48,53,56] circumferential ligatures, removal of the smaller fractured portion, extraction and luting of the fractured portions with cyanoacrilate cement and reimplantation, use of calcium hydroxide, etc. Yet, none of the aforementioned procedures have been effective or methodologically sound.

Etiology

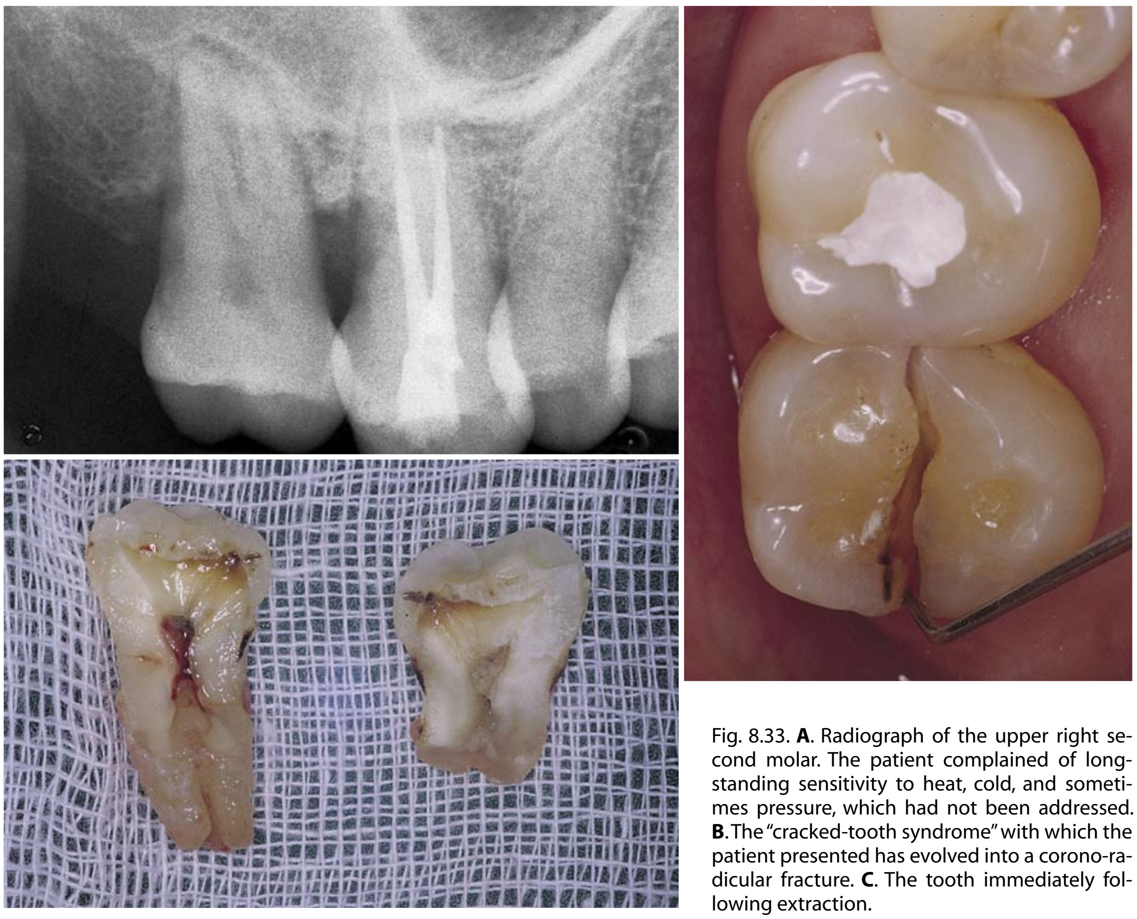
The exact etiology of the phenomena that induce these types of microfractures is unknown, although numerous explanations have been proffered regarding their origin.

Most authors concur that teeth crack and fracture mainly because of occlusal forces.[2,18,24,30,31,64] It is common knowledge that teeth with amalgam restorations experience higher thermal stress than teeth lacking restorations, as a result of which they are more susceptible to fracture[52] (Fig. 8.34).

Hiatt [24] claims that the parafunctional motions of the mandible play an important role in inducing cracked teeth. The teeth he examined had an excellent cusp-to-fossa ratio. One may presume that the force exerted on the fossa, (which is structurally weaker because it is the area of coalescence of different degrees of calcification) by the cusp caused these cracks. It has further been observed that these cracks are more frequent in mandibular molars as compared to maxillary ones, suggesting that the transverse ridge (in addition to the marginal ridges) have a protective function.

In the same paper Hiatt[24] proposes two reasons for this phenomenon:

1) Structural fatigue-present in teeth that function in cusp-fossa relationships-usually appears in lower teeth first because they lack the transverse apophisis that protects upper molars.



A

B

C

Fig. 8.33. **A**. Radiograph of the upper right second molar. The patient complained of longstanding sensitivity to heat, cold, and sometimes pressure, which had not been addressed. **B**. The "cracked-tooth syndrome" with which the patient presented has evolved into a corono-radicular fracture. **C**. The tooth immediately following extraction.

2) The lever principle-which states that an exerted force is greatest close to the fulcrum-explains the higher incidence of cracks in the second molars as compared to the first. If the third molars were not so frequently extracted, and if they functioned in normal occlusal relationships, they would be affected the most.

Similar conclusions were reported by Llamas Cadaval.[29]

Silvestri[40] mentions two other factors that significantly weaken tooth structure and thus contribute to the higher incidence of fractures. First he cites the excessive drilling in preparation of MOD cavities. This factor is directly affected by the speed at which the bur turns, making it difficult to control in some instances. The second factor is the tremendous anesthetic capabilities of current drugs. The final result is a weakened cuspal structure, increasing the likelihood of incomplete or complete fractures. The lateral mastication forces, which create internal shearing components, will also induce incomplete or complete fractures. If dentin is involved the fracture will extend into the pulp chamber and may very well extend along the full length of the root. Over time, the pulp will become infected with septic material seeping from the gingival sulcus or saliva. If adequate measures are not taken, a retrograde periodontal dissolution will occur with formation of periodontal pockets.[24,34]

The possibility of the development of microfractures into complete fractures has also been studied.[15] The authors reported the emergence of superficial hairline fractures when preparing drill holes for stainless steel peripulpar pins. In the same study they also noted an increased number of microfractures when screwed pins were used instead of cemented pins.[31,32,46,47]

Despite the fact that use of peripulpar pins is no longer common, previous experience necessitates that we question current methods. For example, do new

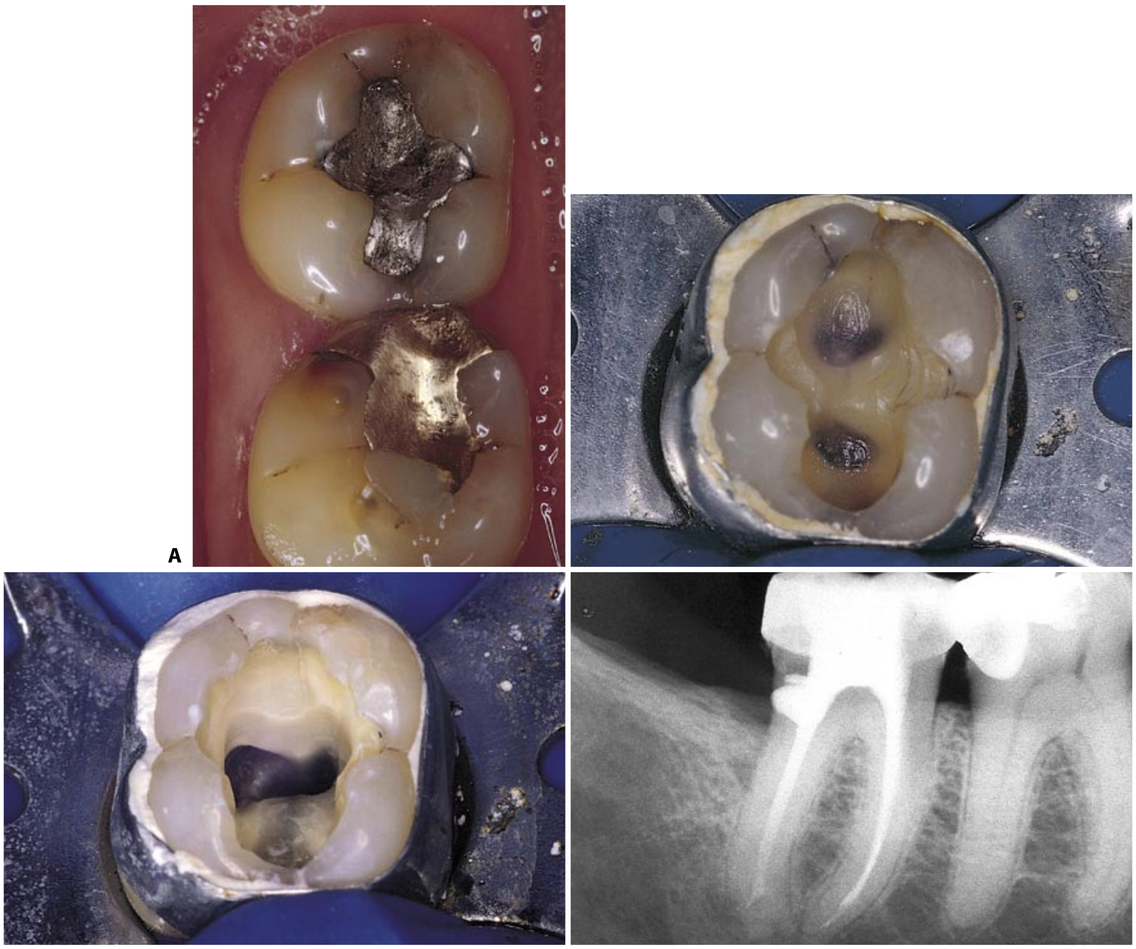


Fig. 8.34. **A.** The lower right second molar presents all the symptoms of a dentinal crack. **B.** The tooth has been pretreated with an orthodontic band, and the old occlusal amalgam was removed. Note the presence of a mesiodistal crack. **C.** Once the access cavity has been created, the crack is visible along the entire distal wall of the pulp chamber. **D.** Postoperative radiograph.

dentinal adhesive systems produce shearing forces in the dentinal complex which cause the discomfort reported by many patients?
Other etiological factors associated with incomplete crown root fractures include repetitive masticatory forces due to: abnormal chewing habits,[8,25] accidental trauma - e.g., shotgun pellets in pheasant meat, stone in rice, chewing hard food such as betel nuts[9] or Brazilian nuts,[3] and of late tongue piercings[11,14] (Fig. 8.35).

Symptoms

If the crack affects only the enamel, there are no outward symptoms. On the other hand, a crack that reaches the dentin is a veritable highway for bacteria headed for the pulp, as well as stimuli that awaken dentinal sensitivity. The patient will therefore complain of sensitivity to heat and cold that is difficult to pin down, as well as pain when chewing certain food on the affected side (Fig. 8.36). These episodes of heightened discomfort may last for long periods of time,[6,38,64] or may occur once during mastication. Many patients describing the aforementioned symptoms for extended periods of time are dismissed by their dentists.[7,12,16] The condition is finally diagnosed when the symptoms resemble those of an endodontic problem; that is, until the pulp becomes pulpitic and subsequently necrotic (Fig. 8.37). Or, when the crack reaches the outer surface of the root and resembles periodontal symptoms marked by the development of a pocket and/or a periodontal abscess (Fig. 11.137). In other instances the tooth may fracture, after which the symptoms either recede or are of a different nature[63] (Fig. 8.33).
In some instances patients are able to determine the side of origin of the pain, in others they will be able to point out whether the pain originates in the upper or lower arch, and but very rarely the actual tooth. Assuming other pathological conditions are not present, other subjective or objective symptoms should not be present either.
The symptoms associated with Cracked Tooth Syndrome arise from incomplete fractures caused by bruxism or clenching. Unfortunately, these fractures occur along cleavage lines that are perpendicular to the incidence plane of X-ray beams, rendering them impossible to view through X-ray imaging.[37]
The growing number of microfractures is directly related to operative procedures which allow patients to retain natural dentition, such as the restoration of teeth that were previously extracted, higher life expectancy, and advances in the fields of Periodontology, Orthodontics and others.
Sensitivity to changes in temperature, masticatory forces are noted during the initial stages of the microfractures. The combination of sensitivity to pressure and thermal changes are practically pathognomonic to this condition. Wright[63] mentions: "A sharp, lacerating pain of short duration during mastication of firm or fibrous foods is pathognomonic of an incomplete crown fracture". Williams[62] mentions that some patients report a strong discomfort during mastication, after which episode the tooth never feels normal again.
According to Dewberry,[13] the acute pain probably has its origin in the exposure, stretching and tearing of the odontoblastic processes along the fracture plane. A hairline fracture, which slightly intersects the pulp space or is tangentially close to it, may explain sudden pain along any area innervated by the fifth cranial nerve (trigeminal nerve).

A B

Fig. 8.35. **A.** and **B.** Tongue piercing. This cosmetic devices have been incriminated as etiologyc factor in complete fractures.

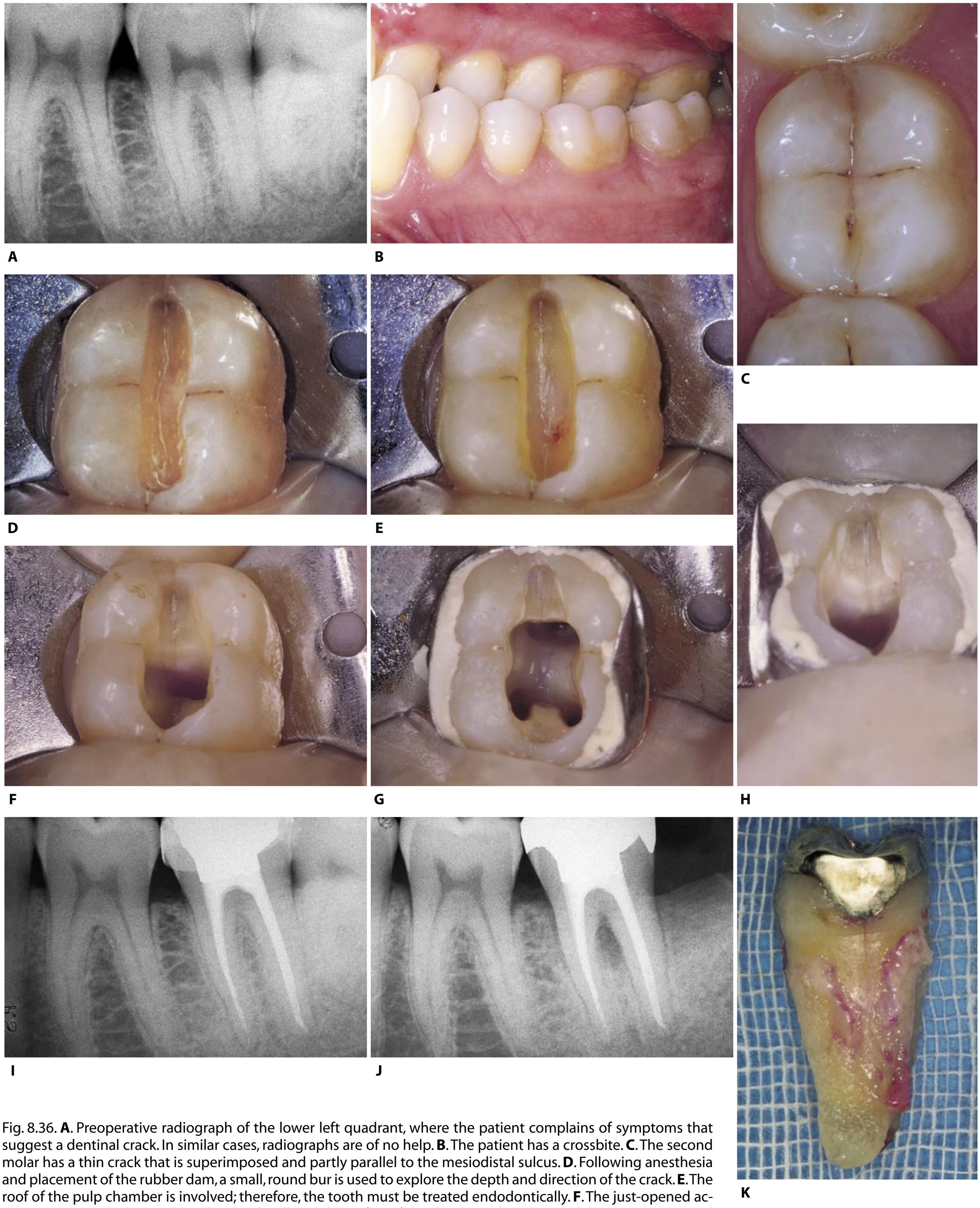


Fig. 8.36. **A**. Preoperative radiograph of the lower left quadrant, where the patient complains of symptoms that suggest a dentinal crack. In similar cases, radiographs are of no help. **B**. The patient has a crossbite. **C**. The second molar has a thin crack that is superimposed and partly parallel to the mesiodistal sulcus. **D**. Following anesthesia and placement of the rubber dam, a small, round bur is used to explore the depth and direction of the crack. **E**. The roof of the pulp chamber is involved; therefore, the tooth must be treated endodontically. **F**. The just-opened access cavity reveals the crack on the distal wall and the orifice of the distal canal. **G**. The tooth has been protected with an orthodontic band. **H**. The crack also descends along the distal wall of the distal canal. **I**. Postoperative radiograph. **J**. Three years later: the crack has transformed into a vertical fracture. **K**. The vertical fracture is visible on the distal aspect of the distal root.

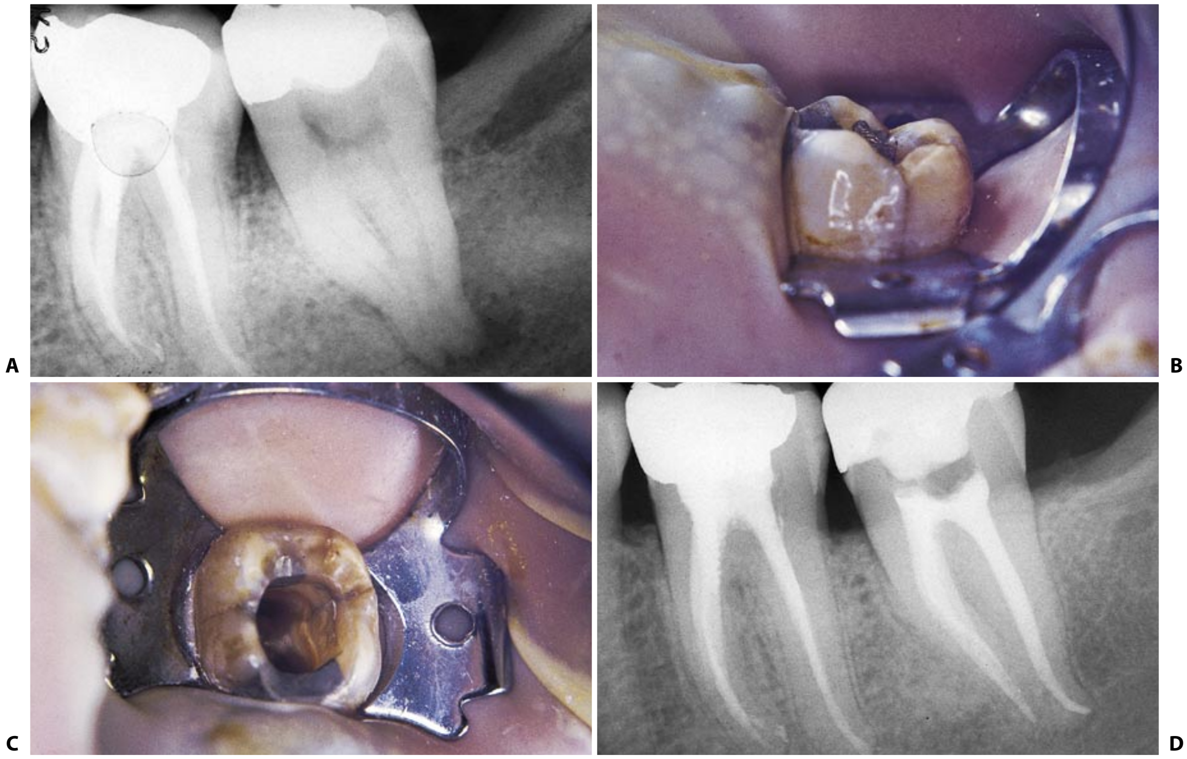


Fig. 8.37. **A.** The patient presented with symptoms typical of a dentinal crack, which went undiagnosed until the pulp of the lower left second molar became necrotic. Preoperative radiograph. **B.** Examination of the tooth reveals a crack on the buccal surface. **C.** The crack is also visible on the buccal wall of the access cavity. **D.** Two years later. The tooth has been restored with an onlay.

Clinical findings

Clinically, the following are the most prevalent findings:[16,24,35,58]

1) heavily developed masticatory musculature
2) wear facets in molars and premolars
3) big cusps accompanied by deep grooves and fossae
4) stained grooves and fossae.

The second lower molar was the tooth demonstrating the highest number of incomplete crown root fractures with 40% of the total number. The first lower molar came in second place with 29%.[24]

However, in a study of 476 teeth Dewberry[13] reported that the first lower molar had the highest incidence of incomplete fractures at 30.7%, followed by the second lower molar at 27.5%, and the upper first molar at 20.8%.

The first lower bicuspid was the tooth showing the least number of incomplete fractures with 0.2%. Yet, in another study of 120 teeth, Abou Rass[1] reported that the most fractures occurred in the second lower molars, then the first lower molars, upper bicuspids and upper second molars.

While it has been suggested that the Cracked Tooth Syndrome usually affect older patients, this assertion is not corroborated. Although Cameron[7] mentioned that patients are usually in their sixties or older, Hiatt[24] reported that most of his findings were among patients between the ages of 30 and 40, and Dewberry[13] mentioned the average age of patients to be 50 years. The youngest patient reported in Dewberry's study was 23 years old. He theorized that the elasticity of the periodontal ligament together with dentin that is less mineralized and more resilient prevent microfractures in younger patients.

With age the dentin becomes more mineralized and fragile increasing the chances of microfractures. Snyder[45] found that most of the patients were between the ages of 30 and 59, while Testori's[51] were between the ages of 45 and 60.

In the author's practice, patients in their early twenties to those in their eighties have been treated for Cracked Tooth Syndrome.

Another interesting parameter reported by Cameron[7] was that most of the studied patients were women; on the other hand, Dewberry[13] reported different percentages: 52.3% masculine and 43.7% feminine.

Diagnosis

Diagnosis of the Cracked Tooth Syndrome is "at times difficult and insidious".[4,6,19,35,44,45,64]
The Cracked Tooth Syndrome may be confused with sinusitis or ATM derangement. Even if the patient has symptoms of the syndrome this may be misleading.[23]
While many cases can be diagnosed with relative ease, the fact that many patients go from dental office to dental office searching for a cure for their pain cannot be overlooked. The fact that in some instances the manifestations are dismissed[45] clearly indicates that the phenomenon has not come to the full attention of many dentists. Schilder[38] asserted: "If you are not diagnosing enough incomplete fractures you are probably not looking for them either".
Different methods have been proposed for the diagnosis of the partially fractured tooth. Clearly as the crack progresses it becomes easier to diagnose the condition.
Schilder[38] emphasizes that if any possibility of an incomplete crown root fracture is present all existing restorations should be removed. The dentist should conduct a thorough examination of the proximal walls and floor of the cavity, checking for craze lines present. If found, appropriate measures must be taken to avoid further damages. The presence of craze lines, even in the absence of symptoms, ought to alert any clinician of future problems, especially when teeth have not been properly restored. This concept was discussed by Abou Rass[1] and Walton.[57] Lin[27] reported a case in which a fractured tooth was undetected at an early stage. In fact, the offending tooth was restored with a full crown-making the condition more elusive since cracks are nearly invisible through crowns or large restorations. The origin of the pain is difficult to diagnose due to the absence of propioceptors in the dental pulp.
Unfortunately, this is a common mistake. Even today with new operating microscopes it is still difficult to observe these cracks.
In the attempt to diagnose a cracked tooth, it is necessary to duplicate the patient's symptoms in the dental office.[16,38,64] The sensitivity to pressure can be difficult to manifest, although many times, having the patient bite and release a wet cotton roll, burlew wheel or wood does the trick. The perceived pain corroborates the diagnosis of a cracked tooth.[24] Other authors recommend the use of orange woodsticks.[33,57,68]
Recently a device called Tooth Slooth has been introduced into the market (Fig. 8.38). It consists of a plastic handle tied to a pyramidal shaped block with a small concavity. Patients are asked to bite on the concavity placed on the cusps. This action is repeated until a response is obtained. The manufacturer claims the device is more effective than other methods in the diagnosing the Cracked Tooth Syndrome. Ehrmann[16] warns that it is dangerous to strike the various teeth with the handle of the mirror or have the patient bite on a wooden stick because the forces on the occlusal surfaces are not evenly distributed during these maneuvers. They may not elicit any symptoms or, worse, they may cause further fragmentation. It is best to have the patient bite on a moist cotton roll, one tooth at a time (Fig. 8.39).
As already indicated, the teeth most frequently affected by the Cracked Teeth Syndrome are the second molars of the upper or lower arch. Yet, it is re-

Fig. 8.38. Tooth Slooth. Extremely useful device in diagnosing incomplete fractures.

Fig. 8.39. Bite test using a wet cotton roll for the early diagnosis of dentinal crack.

commended to begin the check-up from the unlikeliest tooth-the first premolar. (As mentioned earlier, incisors and canines will not be affected by incomplete crown root vertical fractures.)

As soon as the patient bites down on a cracked tooth, the pressure will provoke a small separation of the fragments stimulating the pulp and causing sharp pain. In this manner the dentist will discern which tooth or teeth are affected[24] (rebound tenderness).

To properly diagnose crown root fractures the following diagnostic tools should be employed:

1) Transillumination (Fig. 8.40). If the tooth being examined has a fracture, then the fiber optic light placed on the buccal or lingual surface of the tooth will stop at the site of the fracture.[1,6,30,36,39,58]
2) Use of different coloring agents such as fucsin, methylene blue (Fig. 8.41), gencian violet.[1,39,60]

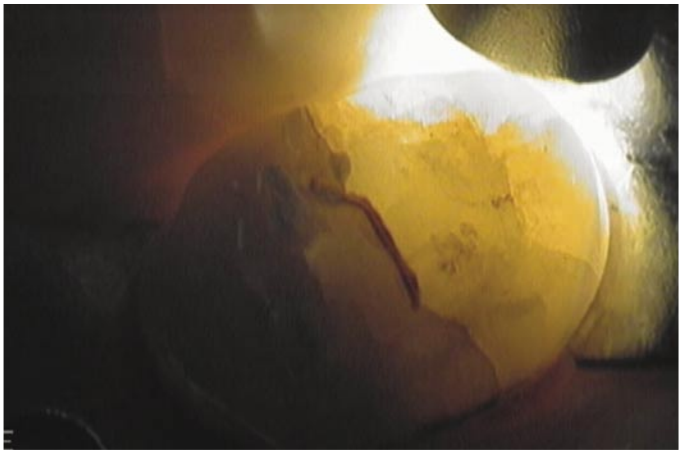
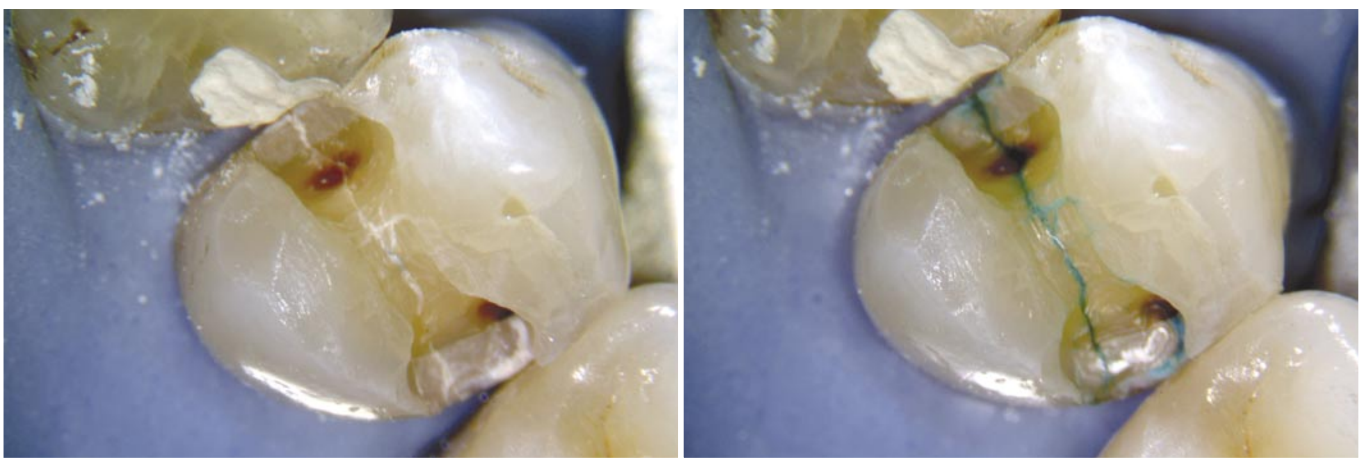


Fig. 8.40. The use of transillumination will disclose the presence of a crack. The light will be stopped at the site of the incomplete fracture.

Caries detecting solutions can be used to uncover fractures. The coloring agent can be left in the tooth and covered by sedative cement for a couple of days for best results.
3) A wet cotton roll, burlew wheel, wood stick, etc.[45,61] Others have proposed the use of a saliva ejector[44] or the latest device on market, the Tooth Slooth and equivalents.
4) Periodontal probing. In most cases where the pulp is still vital, probing will only be effective in locating defects of periodontal origin. If the syndrome is undiagnosed and the crack traverses the periodontal ligament, a periodontal defect will form, and a lesion will develop. This very narrow lesion can be probed only along the fracture line.[22,39] This type of lesion, while associated with endodontically treated teeth, is pathognomonic of a fractured tooth.
5) In the event that a strong suspicion exists that a tooth is fractured but the fracture is not uncovered by any means, then exploratory surgery should be considered. However, it is crucial that the patient understands that the surgical procedure is not a corrective one, but rather a diagnostic one.

If you suspect that a possible fracture exists, the patient's symptoms have to be validated in the dental office.[38,62] Once diagnosed, anesthesia should be applied, a rubber dam placed, any existing restoration removed, and then the tooth can be examined. The use of round burs has been suggested[62] in order to avoid possibilities of confusion when using fissure burs. In the case of a hairline fracture, no further probing should be attempted so as not exacerbate the si-

A



B

Fig. 8.41. **A**. Upper first premolar with a mesio-distal crack. **B**. After using methylene blue, the crack is more evident.

tuation. As mentioned earlier, in the early stages neither electric or thermal stimuli, nor X-ray imaging can provide significant information for diagnosis. In more advanced stages of the syndrome, the tooth may respond in a pulpitic way and some periodontal derangement may be seen. Snyder[45] and Zuckermann[64] maintain that the presence of large proximo-occlusal restorations and unrestored teeth with steep cusps and deeply fissured developmental grooves, particularly if the fissures extend over the marginal ridges, are indicative of cracked teeth. This is especially true if the patient's symptoms aren't attributable to other maladies.

Patients treated once for cracked tooth syndrome will be able to diagnose themselves in the future. Cameron[7] mentions that 25% of the patients studied were subsequently able to diagnose a cracked tooth by themselves. It is also possible to have multiple cracked teeth at any given time. Chong,[9] for example, cites a case where a patient had two undiagnosed cracked upper second molars that were not decayed or restored. Lack of proper preemptive measures caused the deepening of the cracks into complete vertical fractures, resulting in loss of these teeth.

Classification

Depending on the depth of the crack and the types of tissues involved, different classifications have been proposed.

Williams[61] proposes four different categories:

1) Class I: Incomplete vertical fracture of the enamel and the dentin that do not affect the pulp
2) Class II: Incomplete vertical fracture that affects the pulp
3) Class III: Incomplete vertical fracture that crosses the attachment apparatus
4) Class IV: Complete fracture that divides the tooth.

Czarnecki[12] proposes the following classification:

1) Cuspal fractures without pulpal exposure
2) Vertical fractures with vital pulp:
   a) no pulp exposure, accompanied by hyperemic symptoms
   b) with pulp exposure or pulpitic symptoms
   c) extending apically across the attachment apparatus but not probeable periodontally (vital pulp)
3) Vertical Fractures with necrotic pulps:
   a) without radiographic evidence of bone loss, no probeable periodontal defects
   b) without radiographic evidence of bone loss (except apically) but probeable periodontal pockets adjacent to the fracture line or acute pain
   c) bizarre bone loss, probeable periodontal defects and/or acute symptoms.

Abou Rass[1] classifies cracks in the following way:

1) Craze lines
2) Structural cracks
3) Cuspal fractures
4) Vertical fractures

While other classifications have also been proposed,[10,30] the classification proposed by Walton[58] and Rivera[36] seem to be gaining popularity in dental literature. Their proposed classification, also accepted by the AAE, is the following:

1) Craze lines
2) Fractured cusp
3) Cracked tooth
4) Split tooth
5) Vertical root fracture

Evidently there are different criteria in regards to the classification of incomplete and complete coronal, radicular fractures whether of tensional or iatrogenic origin. Taking into consideration the difficulty of obtaining a correct diagnosis, it is easily seen that the different classifications only complicate the situation.

Rivera[36] questions the term "Cracked Tooth Syndrome" and proposes the previously mentioned classification, which, according to his opinion, lends itself to a better understanding, etiology and treatment of the different lesions.

Treatment

The literature on cracked teeth describes a number of techniques by which it is possible to remedy the problems with cracks that have traversed the attachment apparatus. Many of the proposed treatments, sometimes bizarre and many times strange, are appropriate for teeth fractured due to iatrogenesis and not necessarily for cracked tooth syndrome.

Once the fracture has been diagnosed, visualized and typified, the discussion will follow Williams's[61] protocol of treatment.

Class I

These fractures are characterized by incomplete vertical fractures of enamel and dentin without the involvement of pulp. Teeth in this category manifest symptoms related to stimulation of nociceptors in the dental pulp. Patients usually change their mastication patterns, converting into unilateral chewers to avoid discomfort on the affected side.

Once the affected tooth is diagnosed, it is anesthetized, isolated with a rubber dam, and any existing restoration is eliminated. In unrestored teeth in which a fracture is suspected, a round bur is inserted along the central groove until the defect is exposed. Care must be taken not to penetrate any further than necessary so as not to weaken the dental structure or to expose the pulp horn. If the symptoms displayed by the patient correspond to what Schilder[38] calls "Hyperemia", (i.e., a fleeting sensitivity to thermal and pH changes) a zinc oxide eugenol cement is used as to temporarily restore the teeth. Removing the tooth from occlusion and placing a well fitting copper band or orthodontic band prevents possible interference that may worsen the situation. With the new composites and glass ionomer cements now available, a temporary restoration using these products may be a better option, especially when an underlying base of calcium hydroxide is used. The author shares the opinion of others[16,20.21,28,38,61,64] that the tooth should be protected with a tight-fitting copper or orthodontic band, or temporary crown to prevent propagation of the crack.

If no further symptoms are manifested, a final restoration can be undertaken. A range of option is opened to the practitioner, varying from adhesive amalgams[4,54] to gold inlays with cusp protection[10,41,61] and full crowns. Prior to the final restoration, the tooth is rebuilt with glass ionomer cement, ceromers, or adhered resins. The use of acid etching to eliminate the smear layer and residues from the crack is also advised.[10]

Liebenberg[26] recommends using partial ceramic restorations cemented with resin cement. Behle[5] and Cobb[11] concur. They consider the use of metallic restorations with cusp protection and crowns to be invasive procedures. Such procedures are not justified considering the excellent results obtained with adhesive dentistry so long as the manufacturer's instructions are followed closely in the use of the materials.

Fig. 8.42. **A.** Preoperative radiograph. Patient chief complaint was "loose tooth". **B.** As seen by the arrow, the mesiopalatal cusp fractured in this caries and restoration free upper right first molar. **C, D.** In a 8 year postoperative radiographic and clinical image the tooth is symptom free.

Presently it would be interesting to find out the behavior of the ceramic restorations as substitutes of metallic restorations.
If the crack underlies a cusp, removing the cusp will be enough to deliver the patient from previous symptoms. The cracked tooth can then be restored as if the crack had never existed (Figs. 8.42, 8.43).

Class II

This category is characterized by incomplete fractures that affect the pulp. If the crack has reached the pulp chamber and the pulp is vital, endodontic treatment must be done immediately. It is advisable to probe the affected tooth to determine it's periodontal condition. The tooth is taken out of occlusion, and a tight fitting band or temporary crown is placed. Although the prognosis is good, patients ought to be informed that the outcome is not always the one expected. Sometimes the symptoms do not subside.[10,55] The patient should be recalled in approximately 15 days. If the symptoms have subsided, it is appropriate to proceed with final restoration. Intraradicular posts should not be used to avoid their wedging effect.
Where the symptoms of the affected teeth (Class II) do not subside, final treatment is postponed until the patient is symptom free. In cases where long-term prognosis is guarded or poor, an alternative procedure consisting of hemisection or extraction may be performed.[55] The prognosis for the vast majority of class II fractures is excellent (Fig. 8.44).

Class III

This category is characterized by incomplete vertical fractures that cross the attachment apparatus. In many cases the pulp is necrotic and bone loss may be observed in X-rays. It is very important not to confuse these cases with simple cases of pulp necrosis associated with a periodontal lesion (primary endodontic lesion with secondary periodontal involvement, according to the Simon, Glick and Frank[42] classification). The cases in category III can be very different from one another. Only cases showing discrete bone loss should be treated in view of their very guarded prognosis and then only under express request from the

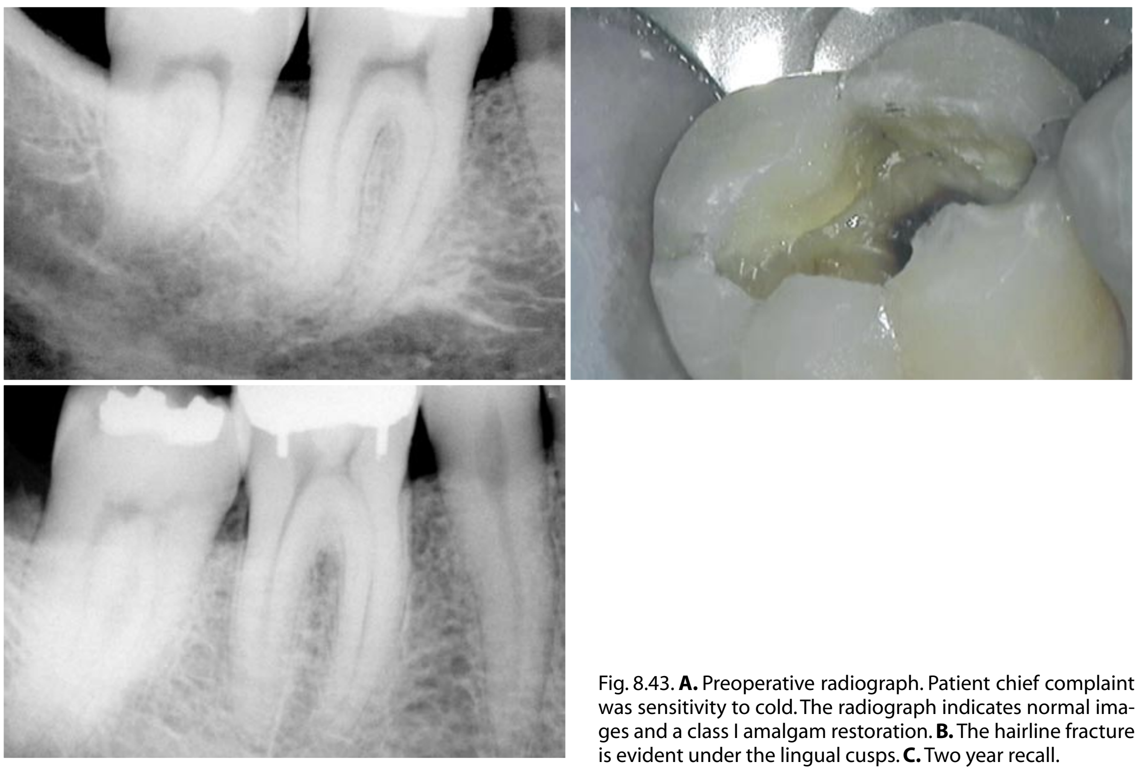
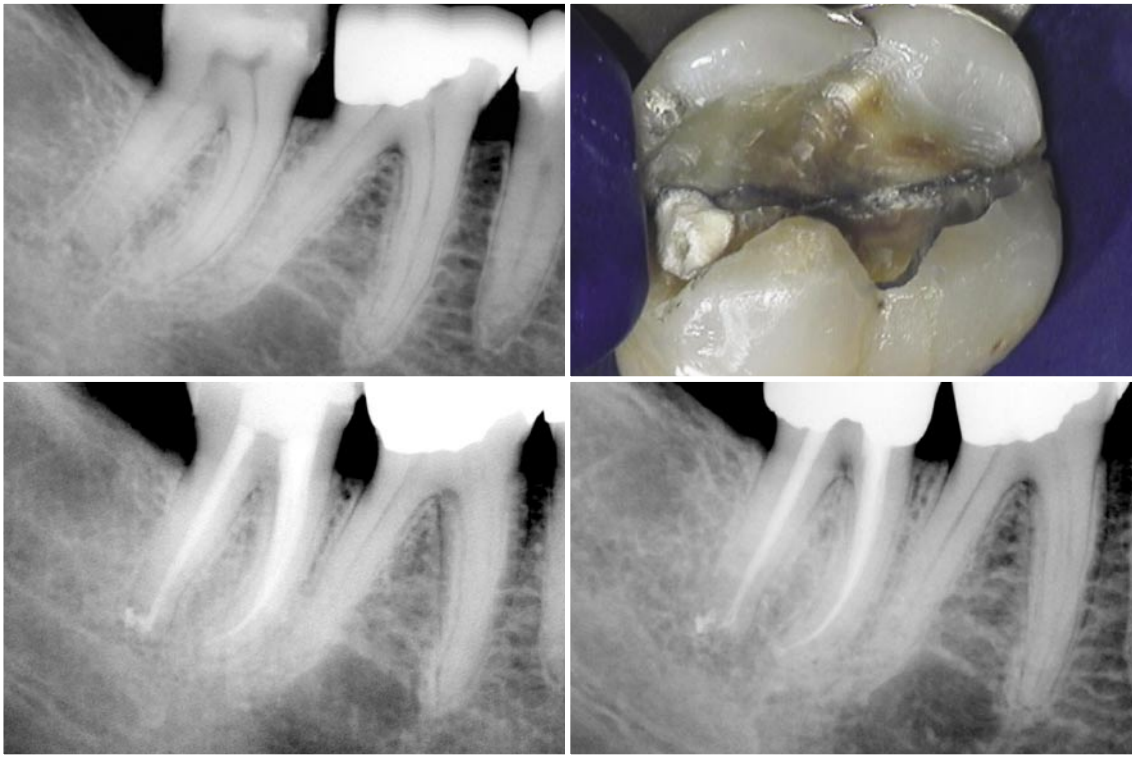

A B C

Fig. 8.43. **A.** Preoperative radiograph. Patient chief complaint was sensitivity to cold. The radiograph indicates normal images and a class I amalgam restoration. **B.** The hairline fracture is evident under the lingual cusps. **C.** Two year recall.

patient. Luebke[30] and Stewart[48] propose using calcium hydroxide for these cases. This procedure is similar to apexogenesis (i.e., the apposition of cement by the periodontal tissues on the fracture line in a way allowing the completion of the case at a later stage) once the fracture has consolidated. Luebke[30] proposes different treatment options depending on the severity of the case. The prognosis in these cases is, at best, very guarded. Treatment should be undertaken only at the express request of the patient (Figs. 8.45, 8.46).



A B C D

Fig. 8.44. **A**. Preoperative radiograph. The patient was sent as an emergency from the general practitioner's office. The chief complaint w2as "tenderness to mastication and discomfort to cold". **B**. A dark hairline is running from mesial to distal, indicating a possible crack of long standing. Symptoms did not subside and endodontic treatment was performed. **C**. Postoperative radiograph. **D**. Two year recall.

A B

Fig. 8.45. **A**. Clinical view of hairline fracture in upper first molar. Patient chief complaint was discomfort to chewing and sensitivity to palpation in buccal area. **B**. The extent of the fracture to the entrance of the MB2 canal. Patient decided to have the tooth extracted due to guarded prognosis (pulp necrosis).

Class IV

This category is characterized by a fracture dividing the tooth in half.
With the exception of some upper bicuspids with two roots and some upper molars where it is feasible to maintain one root after completion of endodontic treatment, the divided tooth has to be extracted. Considering the excellent results obtained with osseointegrated implants, this alternative offers a much better prognosis (Figs. 8.47).

Conclusion

The prognosis for Class I and Class II is excellent. The patient should, nevertheless, undergo periodic check-ups, for the crack may progress with time culminating in fracture of the tooth.

If endodontic treatment is performed on a cracked tooth without a proper diagnosis of the case, a future routine radiograph will undoubtedly demonstrate the failure of an ostensibly well done root canal therapy.[59]

A
B
C

Fig. 8.46. 80 years old lady. Discomfort on chewing did not disappear after removal of the old amalgam restoration. **A**. Upon removal of amalgam and cement, a hairline fracture is clearly seen running in the mid aspect of the cavity floor. **B**. Access cavity of the same tooth. **C**. One year recall.

A
B

Fig. 8.47. **A**. Preoperative radiograph of the first upper premolar. **B**. Clinical view showing the deep fracture: the tooth has been extracted.

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9

The Use of Anesthesia in Endodontics

Arnaldo Castellucci, Kirk A. Coury

In achieving the elimination of pain during dental procedures, and in particular endodontic therapies of vital teeth, it is necessary to use anesthetic solutions. By blocking the transmission of nerve impulses, they make it possible to carry out such therapies by putting the patient at ease and thus permitting the dentist to operate optimally.

Very frequently, the patient anticipates endodontic treatment with great anxiety. What is most frightening is the fear of experiencing pain. It is the dentist's responsibility to calm the patient and elicit the maximal cooperation by successful anesthesia. Nonetheless, one must not abuse anesthetics as tranquillizers. If the planned treatment is definitely painless, such as the cleaning and shaping of a necrotic root canal or the filling procedure of a canal, it is perfectly useless, if not in fact contraindicated, to administer anesthetics. There are several reasons for this. In the case of the necrotic tooth, the preparation of the access cavity corresponds to the very important "cavity test", and if one is working under anesthesia, one may realize too late that a lesion that originally seemed to be of endodontic origin was rather of periodontal origin, and thus that the pulp was vital. Furthermore, if one uses anesthetics when not indicated, one excludes the admittedly minimal and not always reliable collaboration of the patient.

The dentist has many techniques available for controlling pain: topical anesthesia, local anesthesia, regional anesthesia or nerve blocks, and other so-called supplemental forms of anesthesia.

TOPICAL ANESTHESIA

Topical anesthesia refers to the topical application of anesthetics for various reasons, such as rendering localized areas of mucosa insensible. The principal means by which topical anesthesia is administered are liquids, troches, gels (Fig. 9.1), sprays,[41] and cooling[20] (Fig. 9.2). This type of anesthesia is indicated for desensitizing the mucosa to needle pricks, which would be necessary for local infiltration.

Fig. 9.1. An anesthetic gel is applied topically to the mucosa, where it takes effect after 20-30 seconds.

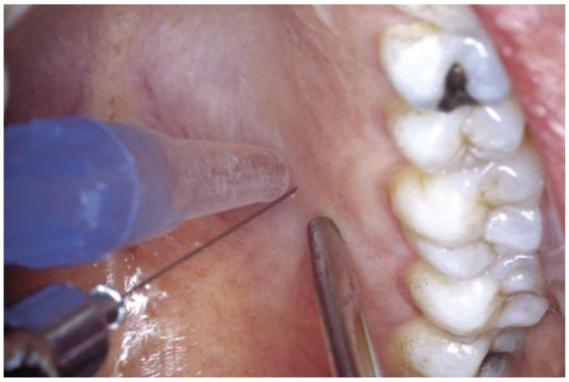


Fig. 9.2. An ice stick achieves anesthesia by cooling the palatal mucosa. This allows painless introduction of the needle.

LOCAL INFILTRATION

Local infiltration may be defined as a technique by which an anesthetic solution is deposited within the treatment area.[30] This technique permits rapid, efficacious anesthesia for all the maxillary teeth and mandibular incisors. The needle is introduced vestibularly at the mucogingival junction at the level of the affected tooth. A short needle is used to inject at least 2 cc of anesthetic solution into the region of the apices.[33]

Malamed[31] recommends that local anesthesia be performed with a single injection. He suggests depositing the solution above the periostium and then taking advantage of its capacity to diffuse through the periostium itself and the cancellous bone. This blocks the small nerve endings of the affected area. His is therefore a submucosal and supraperiosteal anesthesia (Fig. 9.3). In contrast, Bence[2] recommends that local infiltration be performed in two steps. First, about one-fifth of the anesthetic vial is injected above the periostium, thus anesthetizing this structure. In the second step, the syringe needle is introduced more deeply until it encounters bone, after which it is directed apically, below the periostium, as close as possible to the apex of the tooth being treated. The remainder of the vial is then injected (Fig. 9.4). The anesthetic should be injected slowly and only after the periostium has been anesthetized, because it is painful. The periostium limits the diffusion of the anesthetic; in addition, the resulting compression facilitates the absorption of the anesthetic by the bone.

Complete pulp anesthesia is thus attained in just a few minutes. In the time it requires to place the rubber dam, the degree of anesthesia reaches the desired level.

To anesthetize the nerve fibers that innervate the palatal root of the upper molars or premolars, or any other tooth that has a palatal root, it is advisable to perform a palatal infiltration after the vestibular infiltration (Fig. 9.5). The palatal root is usually closer to the palatal than vestibular cortical bone; thus, a buccal infiltration alone may not suffice.

To perform a palatal infiltration, it is not necessary to reach the periostium. The palatal mucosa is so adherent and thick that it is able to limit the diffusion of the anesthetic and force the solution into the underlying bone, like the periostium of the vestibular side.

Palatal infiltration is quite painful. Therefore, it should be performed slowly by steadily depositing a small amount of anesthetic (0.5 ml) under adequate pressure. Before performing the palatal infiltration, it is advisable to achieve anesthesia of the mucosa, for example by cooling.[20]

As already described in Chapter 8, special precaution is required for infiltration of the mucosa overlying the

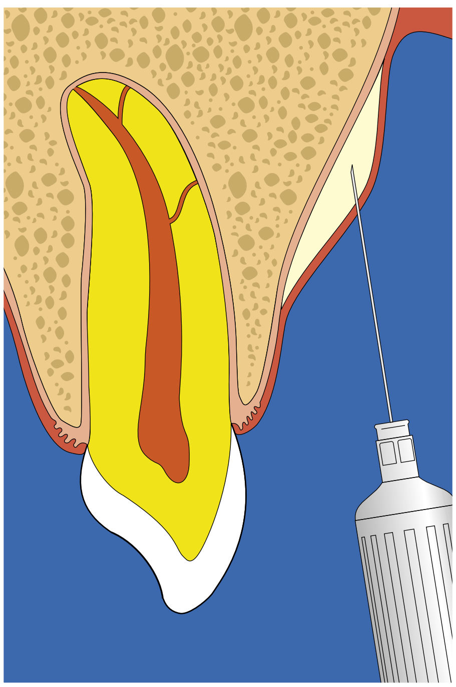


Fig. 9.3. Submucosal and supraperiosteal anesthesia.

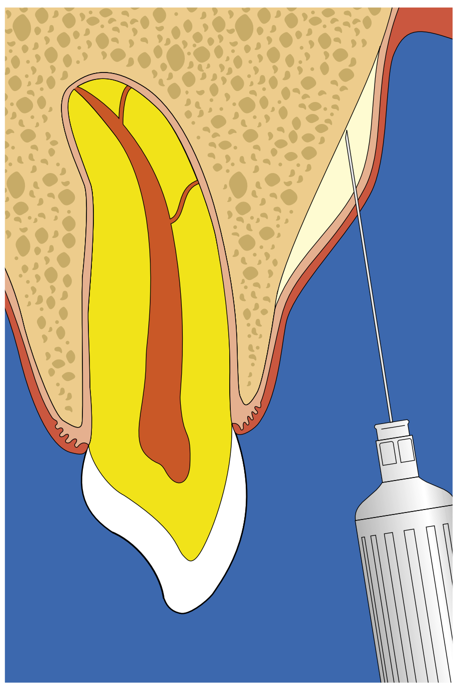


Fig. 9.4. Subperiosteal anesthesia.

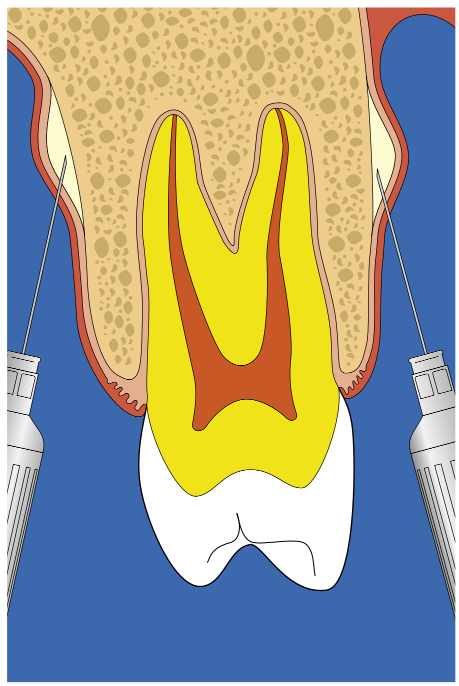


Fig. 9.5. Teeth with palatal roots require a palatal infiltration too.

purulent collection of an acute alveolar abscess, before making an incision for drainage. The needle should not penetrate the purulent collection, but should be introduced tangentially to the mucosa and should be visible through the transparency of the tissues, creating a rapid ischemic effect. The use of anesthetic solution with vasoconstrictor is advisable (Fig. 9.6).

Fig. 9.6. Anesthesia of the mucosa overlying the purulent collection, before the incision for drainage.

REGIONAL ANESTHESIA OR NERVE BLOCKS

Regional anesthesia or nerve block involves a larger area than the forms of anesthesia discussed above; however, it more precisely anesthetizes the entire distribution of a specific nerve. It is achieved by depositing the local anesthetic near the trunk of a major nerve, thus blocking the afferent impulses from travelling proximal to that point.
The success of this method depends on the dentist's precision in depositing the anesthetic solution at a pre-selected anatomical point. The anesthetic diffuses from this point in sufficient amounts and concentrations to produce the desired effect.[41]
Block of the inferior alveolar nerve will be discussed in detail, while the other nerve blocks of dental interest will receive briefer attention.

Inferior alveolar nerve block

This is usually called "mandibular nerve block". It serves to anesthetize all the mandibular nerves of the same quadrant. However, because the lower central incisors may be innervated by the controlateral hemiarch, it is preferable to anesthetize them by a vestibular infiltration to obtain more certain results.
Adequate anesthesia is indicated by tingling and numbness of the lower lip and, when the lingual nerve is affected, the tip of the tongue. This technique does not achieve anesthesia of the vestibular mucosa or periostium associated with the molars, which are innervated by the buccinator nerve. One must keep this in mind if one must intervene surgically in this area. Anesthesia of the buccinator nerve is performed by inserting the needle into the mucosa distal and buccal to the last molar.
To anesthetize the inferior alveolar nerve with this technique, the anesthetic solution must be deposited in the vicinity of the nerve before it enters the mandibular ramus at the level of the mandibular spine.
Either the indirect or direct technique may be used.

Indirect technique

The indirect technique is performed with a long needle. The needle is directed toward the ramus, starting from the controlateral molars, until it encounters bone. The needle is then withdrawn slightly, redirected parallel to the hemiarch to be anesthetized, and inserted more deeply. Once it contacts the bone, the needle is inserted slowly along the medial surface of the mandibular ramus, for about 2 cm (Fig. 9.7).
With this technique, the onset of anesthesia is often slow, and the inexact insertion of the needle may produce anesthesia in other, unintended, areas. If the needle is introduced too superficially, the anesthesia will affect only the lingual nerve; if introduced too deeply, it may anesthetize the facial nerve.

Direct technique

The aforementioned drawbacks are usually avoided by the use of the direct technique, which is associated with a much quicker onset of action. A short needle is used to penetrate as close as possible to the mandibular spine (Fig. 9.8). With the patient's mouth wide open, the dentist places the thumb into the patient's

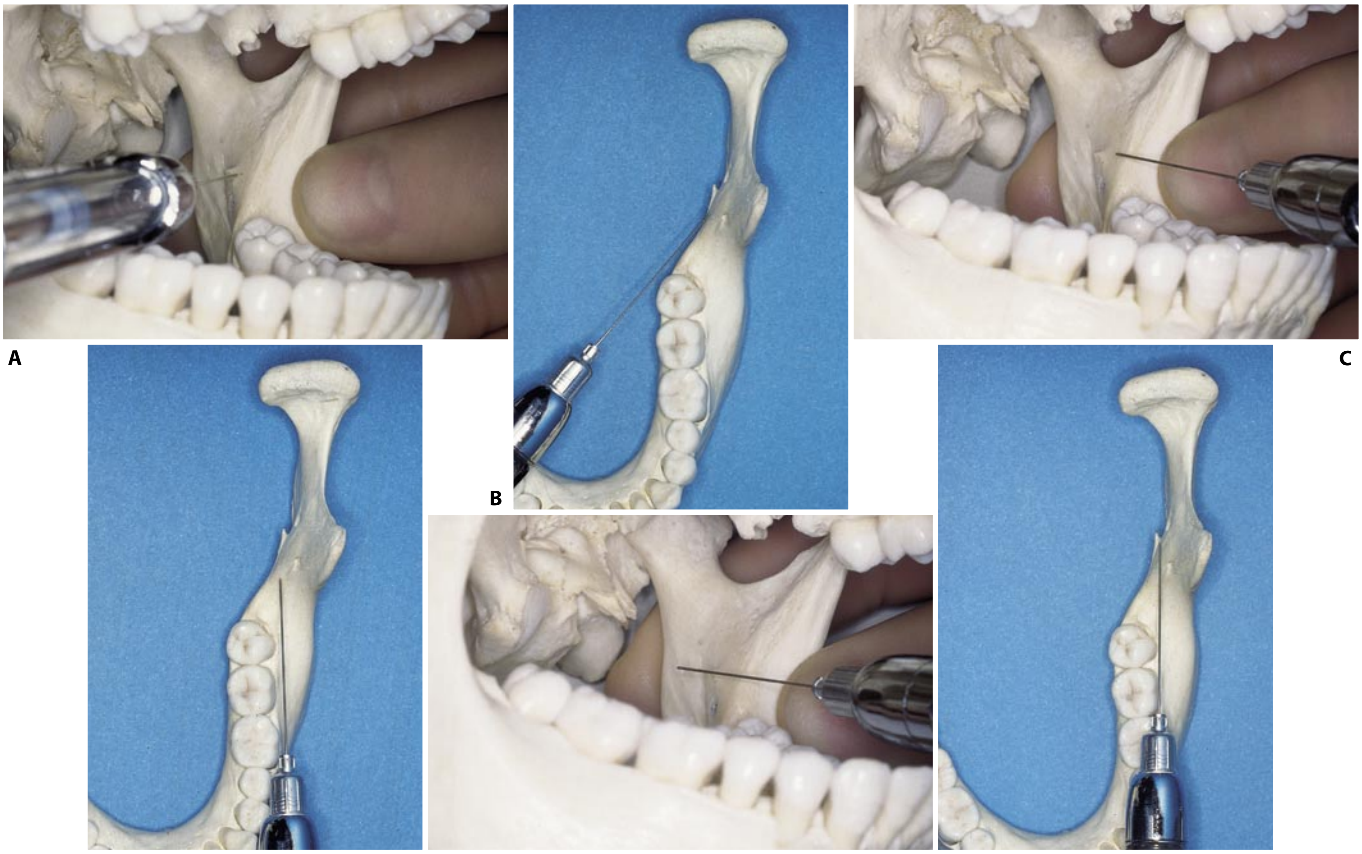


Fig. 9.7. **A-F**. Block of the inferior alveolar nerve, using a long needle and the indirect technique.

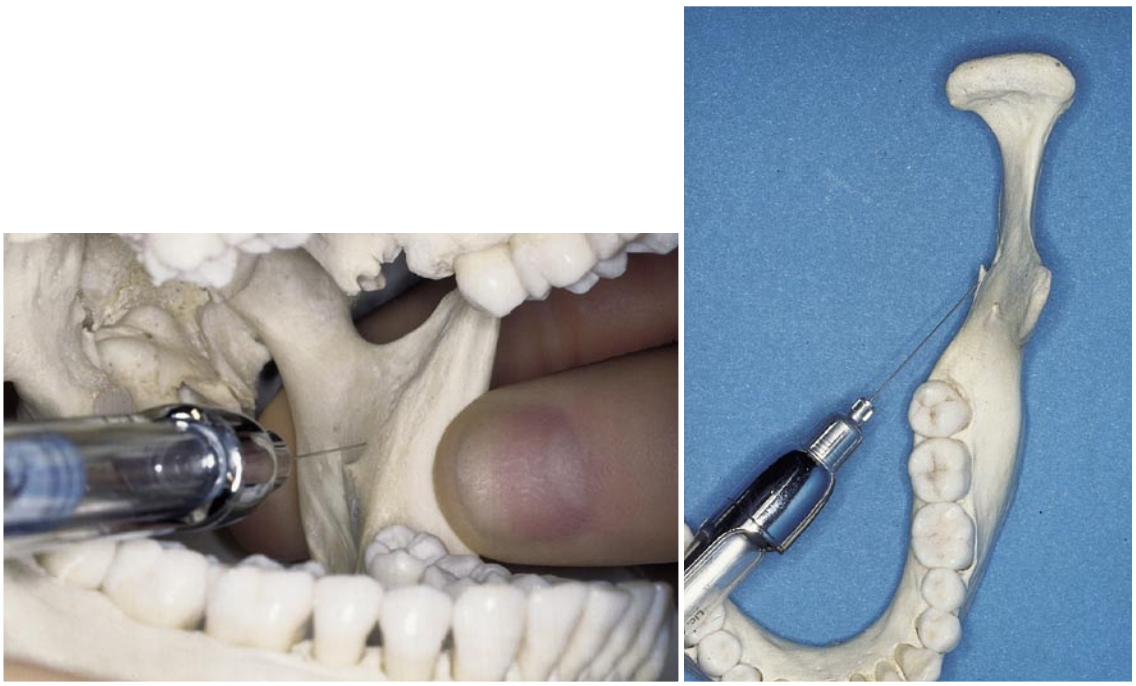


Fig. 9.8. **A, B**. Block of the inferior alveolar nerve, using a short needle and the direct technique.

mouth to identify the anterior border of the mandibular ramus (Fig. 9.9). The middle finger supports the posterior border, outside the mouth (Fig. 9.10).
With the syringe directed along an imaginary line passing above the controlateral premolars, one penetrates the mid-point between the thumb and middle finger, and after aspirating to avoid injecting the anesthetic directly into the circulation, the solution is injected. The point of insertion of the needle is just lateral to the pterygomandibular raphe, which is midway between the two hemiarches, to a depth of about 1 cm. During this procedure, it is important to ask the patient to remain wide open.[33]
This type of anesthesia is the principal means of anesthetizing the teeth of the lower arch, since local anesthesia would not be efficacious, given the bony density of the mandible.

Mental nerve block

Anesthesia of the canine and lower first premolar can be achieved at the level of the mental foramen (Fig. 9.11), rather than mandibular spine. This has the advantage of taking effect sooner and avoiding anesthesia of the tongue, thus sparing the patient pointless paresthesiae.
It is performed by depositing the anesthetic solution near the mandibular canal, at the level of the mental foramen. The needle is inserted in the alveolar mucosa between the two premolars, about 1 cm external to the vestibular surface of the mandible (Fig. 9.12).
Particular attention must be paid to not injuring the mental nerve with the point of the needle. It must not be introduced in the mental foramen.

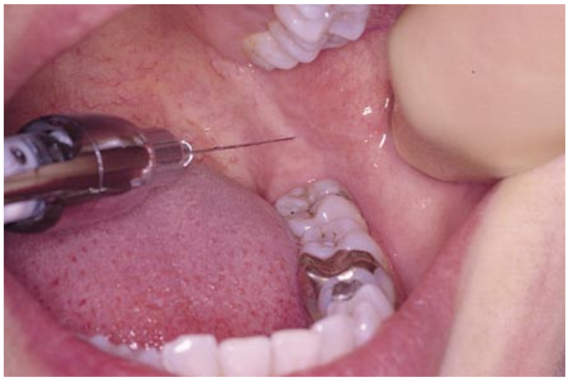


Fig. 9.9. The thumb is used to identify the anterior margin of the mandibular ramus.

Fig. 9.10. The middle finger is used to support the posterior margin of the mandibular ramus.

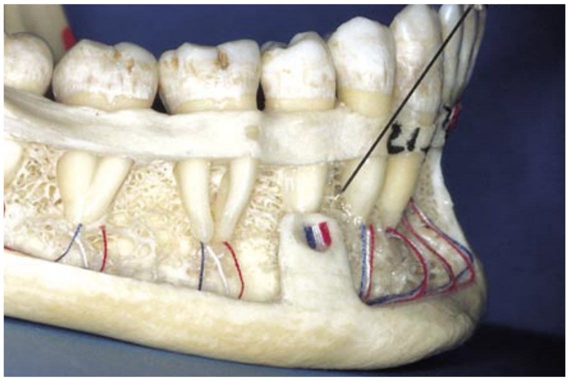


Fig. 9.11. Mental nerve block.

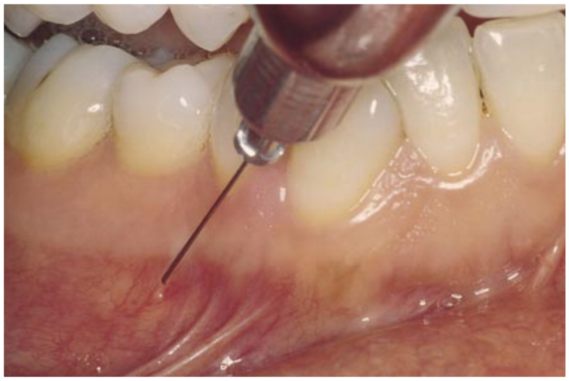


Fig. 9.12. To achieve anesthesia at the level of the mental foramen, the needle must be introduced into the alveolar mucosa between the first and second premolars, about 1 cm external to the vestibular surface of the mandible.

Nasopalatine nerve block

The innervation of the soft tissues of the anterior one third of the palate arises from the nasopalatine nerve, which emerges from the incisive foramen (Fig. 9.13). In the region of the canine, terminal branches of this nerve are superimposed on terminal branches of the anterior palatine nerve.

Anesthesia is achieved by introducing the needle into the palatine surface, next to the incisive papilla, and injecting the anesthetic under pressure (Fig. 9.14). This procedure may be quite painful. However, it is usually necessary in the case of extractions or other surgical procedures in this area.

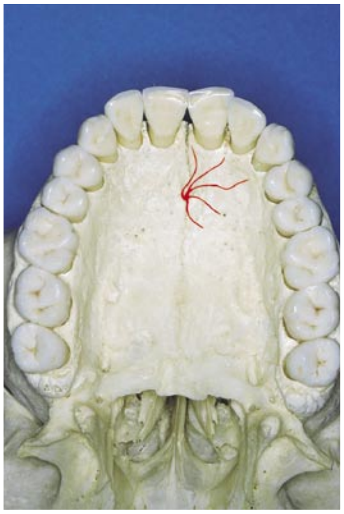


Fig. 9.13. Course of the nasopalatine nerve after its emergence from the incisive foramen.

A B

Fig. 9.14. **A,B**. Site of introduction of the needle in performing a nasopalatine nerve block.

Anterior palatine nerve block

The innervation of the soft tissues of the posterior two-thirds of the hard palate arises from the anterior palatine nerve. This nerve emerges from the greater palatine foramen, which lies between the second and third molars, half-way between the alveolar crest and midline of the palate (Fig. 9.15). Anesthesia is achieved by introducing the needle near the point of emergence of the nerve from the foramen (Fig. 9.16). This procedure is also quite painful and is used for extractions or surgical procedures, when anesthesia of the soft tissues of the hard palate from the tuberosity to the region of the canine or from the midline of the hard palate to the gingival margin is required.

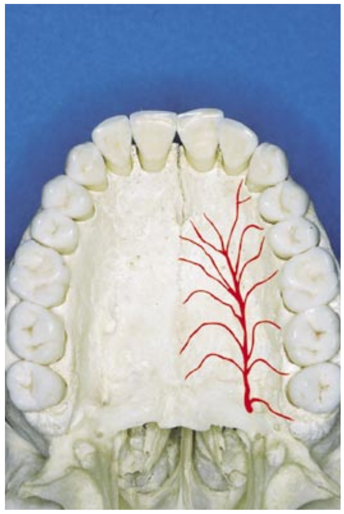
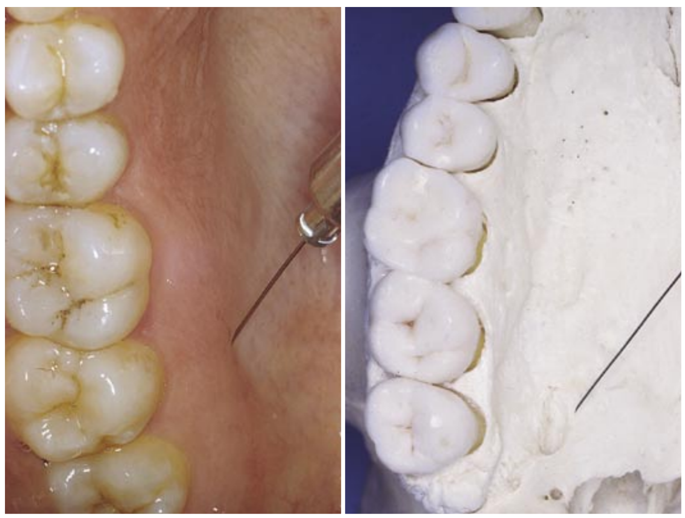


Fig. 9.15. Course of the anterior palatine nerve after its emergence from the greater palatine foramen.



A B

Fig. 9.16. **A,B**. Site of introduction of the needle in performing an anterior palatine nerve block.

SUPPLEMENTAL ANESTHETIC TECHNIQUES

Applying the commonly-used techniques of local infiltration or nerve block to endodontic therapy, one may sometimes encounter problems related to inadequate anesthesia of a tooth. This tipically happens with lower molars affected by irreversible pulpitis.
The endodontically involved tooth that exhibits symptoms consistent with an irreversibile pulpitis is perhaps one of the most challenging and frustrating conditions to manage in terms of achieving profound anesthesia. If mismanaged, the patient will often relate the experience as physically and mentally agonizing.
We are many times at a disadvantage. As if apprehension is not enough to deal with, when combined with inflammation[40,53] they both act to significantly decrease the level of pain threshold.[10] The consequences of this hypersensitivity to stimuli that ordinarily would not be perceived or interpreted as pain may result in a marked difficulty in attaining profound anesthesia. While apprehension is usually common in most dental patients and can be managed by a variety of techniques, inflammation and infection can present their own kinds of unique challenges for the dentist when trying to achieve profound anesthesia to perform comfortable treatment for the patient. Other known factors which may contribute to anesthetic complications include patient fatigue and previous episodes of unsuccessful anesthesia.[64,68]

Anesthetic solutions and inflammation

It is well known that the pH of the local anesthetic solution and the pH of the tissue into which it is deposited can affect its nerve-blocking action.[34] Environmental changes in the pulp and periradicular tissues during inflammation and/or infection significantly alters the pH in the tissues surrounding the involved tooth, lowering it from a normal pH of around 7,4 to as low as 5 to 6 in purulent conditions.[34] This has a marked influence on the efficacy of local anesthetic solutions.[34]
When an anesthetic solution is deposited into areas of inflammation, the acidic environment decreases its effectiveness by liberating a much higher anesthetic concentration of the charged cation (RNH+) relative to uncharged (free) base form (RN).[34] It is the uncharged, free-base form that is responsible for penetrating the nerve sheath, thereby creating the desired anesthetic effect. For example, injecting an anesthetic solution with a pKa* of 7,9 (See Table I) into normal tissues would result in approximately 75% of the local anesthetic molecules in the cationic form and 25% in the free-base form.[34] With inflammation, a drop in pH results in approximately 99% of the same local anesthetic agent (pKa of 7,9) to be in the cationic (charged) form, leaving only one per cent of the free-base form to penetrate into the nerve, adversely affecting the anesthetic response.
One possible way to overcome the effects of tissue pH on anesthetic solutions is to deposit a greater volume of aneshetic into the area. Eventually, enough of the uncharged free-base molecules will become available for nerve penetration and will frequently be adequate in achieving the desired anesthetic effect.[34] Another method might be to regionally block the area by injecting into tissues distant from the site of inflammation or infection. By doing so, one can presume that the tissues in this area have a more normal pH and, therefore, should enhance the anesthetic effect. For this reason, regional blocks can be very beneficial in the treatment of some endodontically involved teeth.

Table I

Dissociation constants (pKa) of frequently used local anesthetics

Anesthetic solution	*pKa*	*a % base at pH 7,4*	*Approximate onset of action (min)*
Mepivacain	7,6	40	2 to 4
Etidocaina	7,7	33	2 to 4
Lidocaina	7,9	25	2 to 4
Prilocaina	7,9	25	2 to 4
Bupivacaina	8,1	18	5 to 8

If conventional anesthetic techniques fail to provide effective anesthesia, (i.e. regional blocks and infiltrations) and proper injection technique was performed, (which is the most common reason for anesthetic failure[34]) then it may be useful to repeat an injection only if the patient does not exibit the classic signs

(*) pKa affects the onset; the lower equals more rapid onset of action, more RN molecules present to diffuse through the nerve sheath, thus onset time is decreased.[34]

of soft tissue anesthesia. However, if the anesthetic effects have been confirmed, but the patient cannot tolerate dentin or pulp manipulation, reinjection is generally ineffective. This is the appropriate time to consider a supplemental anesthetic technique.[68]

These types of anesthesia, intraligamental in particular, may also be necessary in patients in whom the use of routine anesthesia, such as an inferior alveolar nerve block, is contraindicated. This may apply to patients with hemophilia[22] or other disorders of coagulation, in whom post-injection bleeding may be dangerous. It may also apply to mentally or physically handicapped patients, in whom there is a great risk of traumatizing soft tissues still under the anesthetic effect of the block, such as the tongue or lower lip[30] (Fig. 4.1C).

In a 1981 study by Walton and Abbott,[66] 47% of teeth that required supplementary anesthesia were lower molars. This may have been related to the accessory innervation that these teeth can receive from different branches of the inferior alveolar nerve.[14,60]

Supplementary anesthesia includes the lingual infiltration, the intraseptal injection, the periodontal ligament injection, the intrapulpal injection and the intraosseous injection.

Lingual infiltration

It is useful in lower first molars with pulpitis. Holding the syringe parallel to the occlusal plane, the needle is introduced into the lingual gingiva about halfway between the gingival margin and the base of the fornix (Fig. 9.17). The development of a whitish area of ischemia assures that the technique is correct. If, instead, a bubble-like collection of anesthetic forms in the lingual fornix, the technique is incorrect. The approach must be repeated by inserting the needle more occlusally.

Schilder[51] recommends the routine use of lingual infiltration each time an endodontic treatment is performed on a lower molar. Once the nerve block has been accomplished with 3/4 of the vial, the remaining 1/4 may be used to perform the lingual infiltration, which in practice is nothing more than a subperiosteal lingual infiltration.

Intraseptal injection

Described by Bandford[1] in 1970 and by Marthaler[37] in 1973, is accomplished at the level of the bony septum by introducing the needle into the dental papilla and injecting a minimum amount (0,2-0,4 ml), distally to the tooth to be anesthetized.[5] Because this type of anesthesia must be performed directly within the cancellous bone, the dentist must overcome high pressures with the injection. For this reason, the use of an appropriate pressure syringe, such as Peripress (Fig. 9.18), is recommended, together with a 27-gauge short needle.

As for all the intraosseous injections, it is advisable to use an anesthetic solution without vasoconstrictor, in order to avoid systemic effects.

This anesthesia is indicated when the periodontal in-

A B

Fig. 9.17. **A,B.** Subperiosteal lingual anesthesia.

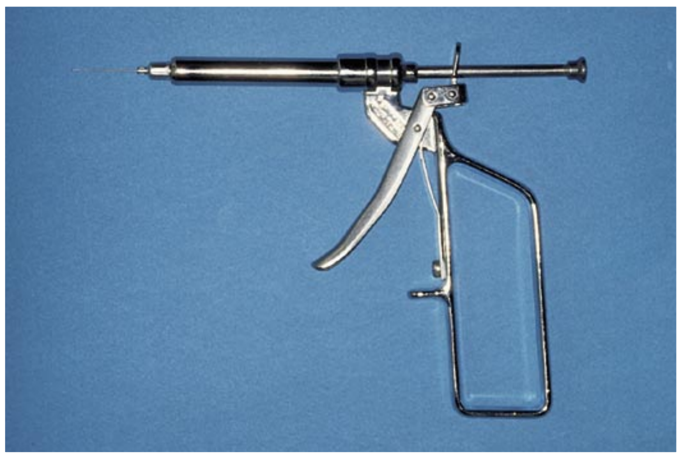


Fig. 9.18. Peripress pressure syringe.

volvement precludes the use of the intraligamental injection. The advantages of the intraseptal anesthesia are several: only a minimum volume of solution is required, there is no lip and tongue anesthesia, immediate onset of action (less than 30 seconds) and presents very few postoperative complications.[47] The pulpal anesthesia has a short duration, and this has to be into consideration during endodontic treatment.

Intraligamental infiltration

Castagnola et al.[8] in 1976, Walton and Abbott[66] in 1981, and Malamed[32] in 1982 have demonstrated that injection into the space of the periodontal ligament is most effective in situations in which the local anesthesia achieved with traditional techniques is incomplete.

This type of anesthesia is performed with the appropriate syringe, such as Peripress, Citoject (Fig. 9.19), or Ligmaject, by introducing the small needle (27-gauge) into the space of the periodontal ligament, making sure that the needle's bevel faces the bone of the alveolar crest (Fig. 9.20), according to some authors,[23,55,57,65,66] or, according to others,[30,35] the root of the tooth so as not to damage the radicular cementum. According to the author opinion, since the solution usually enters into the bone marrow spaces rather than penetrating into the periodontal ligament[61] the needle's bevel should face the bone.

The needle must be forced to the point of maximal penetration, and the anesthetic must be injected under high pressure.

If the anesthetic solution flows out of the vial without much effort on the part of the dentist, the needle is malpositioned. It must be re-positioned and introduced more deeply. In multirooted teeth, the anesthesia must be repeated for each root (Fig. 9.21), The indroduction of the needle should always be in the interproximal areas, never on the buccal. The anesthetic effect is immediate and prolonged. The size of the needle has little relation to the anesthetic effect. The manufacturers of pressure syringes recommend very thin needles (0.30 mm in diameter), but these tend to bend easily. Better results are obtained with short, 25/27-gauge needles.[36,58]

Numerous studies have investigated the periodontal damage caused by this type of anesthesia, which was first described by Fischer[13] in 1923 but fell into disuse because it was thought to be detrimental to the periodontal ligament.

Castagnola et al.[8] assert that they have never found the

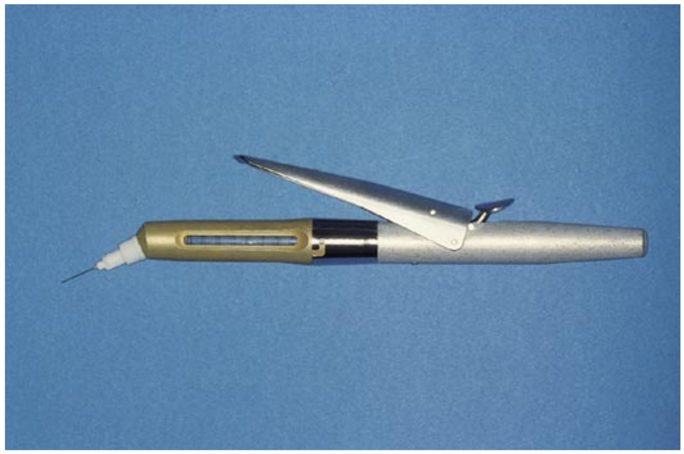


Fig. 9.19. Citoject syringe for intraligamental anesthesia.

Fig. 9.20. Some authors contend that the bevel of the needle must face the bone of the alveolar crest.

Fig. 9.21. In multirooted teeth, intraligamental anesthesia must be performed on all the roots.

sort of damage that other authors have feared, namely necrosis of the periodontal ligament as a result of the action of the anesthetic, periodontitis from the inoculation of microbes, and traumatic arthritis from the insertion of the needle. Nor has such damage ever been demonstrated experimentally; indeed, the clinical impression arising from the use of this technique is that there is no irreversible damage to the periodontal ligament.[70] This clinical impression is confirmed by histologic studies in monkeys[67] and dogs.[15] These studies have shown that the periodontal ligament experiences only limited, reversible injury. The damage is confined to the region of the injection and to the zones immediately adjacent to it, and it is followed by rapid "restitutio ad integrum". Thus, this method of anesthesia may be considered innocuous for the periodontium.[45,46,52]

Contraindications to the intraligamental injection include infection or severe inflammation at the injection site and primary teeth. Brannstrom et al.[7] reported the development of enamel hypoplasia in permanent teeth, following the administration of the periodontal ligament injection.

In contrast to intrapulpal anesthesia, which is always painful for the patient, intraligamental anesthesia is painless if done after standard anesthesia. Other advantages of intraligamental anesthesia are that it does not require special equipment. It may be done with a pressure syringe, but may also be done with the same syringe and needle used for the standard injection.

Nevertheless, the use of appropriate syringes is recommended, since they may attain pressures more than twice as high as regular syringes.[15] Furthermore, since the vial is sheathed in a metallic or Teflon container, they better protect the patient against accidental rupture of the glass vial, which can occur as a result of the high pressure generated. Finally, it is easier to dose the injected anesthetic at a consistent volume with each activation of the syringe.

If it becomes necessary to use this type of anesthesia when the rubber dam is already in position, it is not necessary to remove or lift it. The opening of the rubber dam may be stretched slightly to identify the space into which to insert the needle (Fig. 9.22).

Regarding the anesthetic solution's distribution in the tissues, intraligamental anesthesia must be considered to all effects an intraosseous anestesia.[36,43,65] The injected solutions are rapidly absorbed by the systemic circulation[55,57] (Figs. 9.23, 9.24). For this reason, the use of anesthetics containing catecholamines for intraligamental anesthesia is inadvisable in patients with ischemic heart disease or hypertension.[55] In this respect, intraligamental anesthesia is identical to intraosseous anesthesia; compared to the latter, however, it is easier to perform. In animal experiments, the effects of intraligamentally-administered vasoconstrictor-containing anesthetics on heart rate and blood

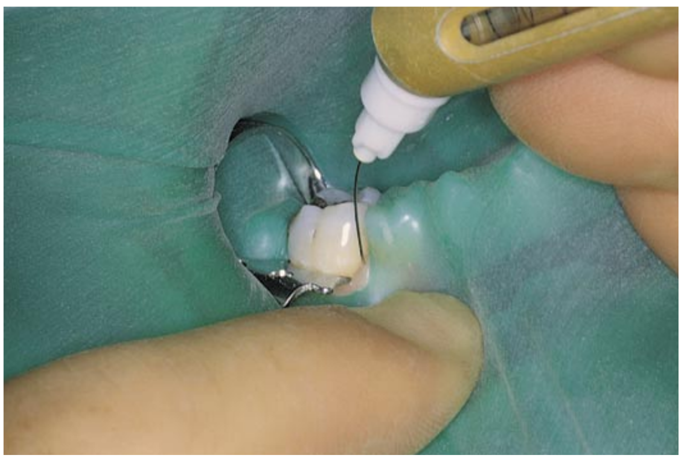


Fig. 9.22. If the need arises, intraligamental anesthesia may also be performed with the rubber dam in place. There is no need to remove the rubber sheet; it needs only be stretched aside.

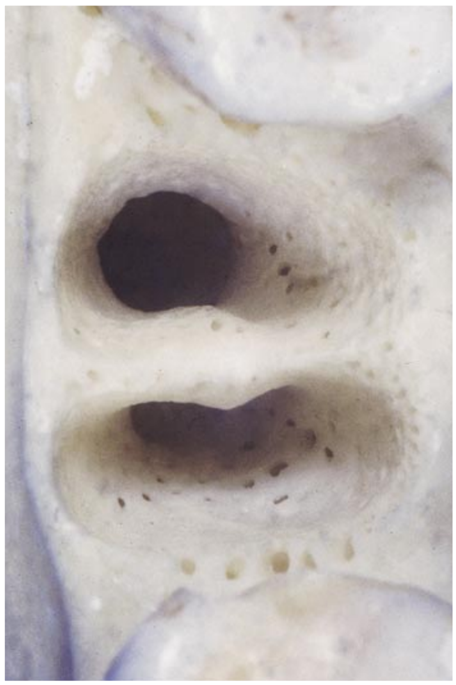


Fig. 9.23. Alveolus of the lower first molar in a human skull after removal of the tooth. The cortical bone has a cribriform appearance, especially in the cervical region, where the anesthetic passes into the medullary spaces. That which is radiographically defined as the lamina dura is in fact a porous structure.

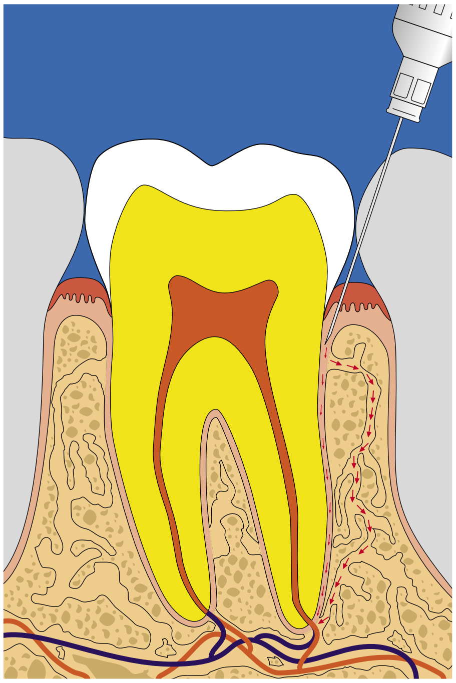


Fig. 9.24. Schematic representation of the probable path of distribution of a local anesthetic solution injected into the space of the periodontal ligament.

pressure are the same as those which occur after intraosseous or intravenous administration of the same substances. However, these effects are completely absent if the route of administration is submucosal, intrapulpal, subcutaneous, or intramuscular.[43]

Therefore, if we need to use the intraligamental injection or any other intraosseous anesthesia in a patient with high blood pressure, cardiovascular disease or any contraindication to epinephrine use, it is prudent to choose 3% mepivacaine, which has minimal cardiovascuar effects.[16,47,49]

As previously reported by Castagnola et al.[8] and Langeland,[25] Lin et al.[28] have demonstrated that intraligamental anesthesia does not cause any histological damage to healthy pulp tissues and is thus also indicated for procedures other than endodontic ones. It may therefore be confidently used as a diagnostic aid in localizing pulpalgia by selectively administering the anesthetic to the individual teeth,[51] though some authors have expressed scepticism.[11,23,65]

In conclusion, the preferred supplemental technique to obtain profound pulpal anesthesia if the standard block or infiltration injection is not effective, at this time is the periodontal ligament injection. If even the periodontal ligament injection does not effect profound pulpal anesthesia, the intrapulpal injection is the next option.[63]

Intrapulpal infiltration

Described by numerous authors,[4,18,21,31,39,69] the intrapulpal injection assures certain results in 100% of cases. It requires the injection of anesthetic through as small an opening as possible in the roof of the pulp chamber (Fig. 9.25).

The pressure with which the anesthetic solution must be injected is actually responsible for the anesthesic effect of this technique.[4] In fact, the same degree of anesthesia may be obtained by injecting saline solution.[63]

It is important that the chamber opening be small and that the needle be well engaged. This assures good pressure within the chamber itself. The pressure thus transmitted to the pulp tissue causes instantaneous, profound anesthesia, even for very prolonged endodontic procedures. If the opening into the pulp chamber is too large to wedge the needle, a larger size needle can be used. Other times it is necessary to place pieces of rubber, wax or cotton pellets over or around the needle to for a stopper.[63]

In multirooted teeth, however, it may be necessary to repeat this type of anesthesia in the individual canals.[56] The anesthesia may be painful, but the sensitivity will last for only a few seconds. It suffices to inject a few drops of anesthetic under pressure to obtain the desired effect.[31] If the pulp is not completely removed during the visit, the remaining tissue will remain vi-

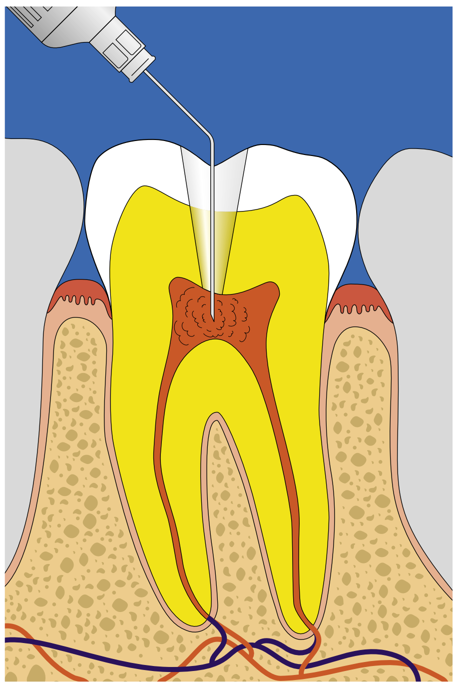
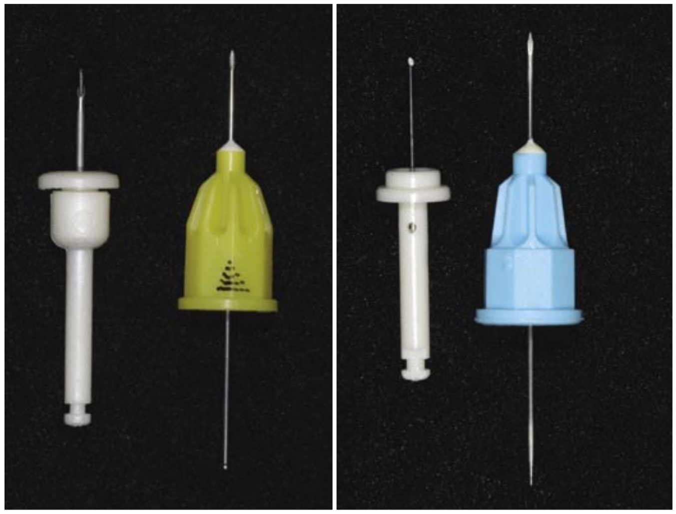


Fig. 9.25. Intrapulpal anesthesia.

tal until subsequent appointments. Therefore, the anesthesia must be repeated.[4]
Some authors[38] state that intrapulpal anesthesia can also be used in the course of pulpotomy in teeth with an immature apex and vital pulp compromised by caries or trauma. The chances of preserving the vitality of the remaining portion of the pulp tissue increases when one limits the depth of penetration of the needle into the pulp to less than 2 mm and when one regulates the pressure during the injection.
Other authors[24] claim that intrapulpal anesthesia should be avoided in pulpotomy on teeth with an immature apex, since it would force contaminants present in the coronal pulp into the radicular pulp and would cause a laceration in the tissue.
The intrapulpal anesthesia has no contraindication and at the same time offers several advantages: lack of lip and tongue anesthesia, minimum volume of solution required, immediate onset of action, no cardiovascular effect and very few postoperative complications. On the other hand, it requests a "small" opening in the roof of the pulp chamber. Sometimes, to get the little pulp exposure to insert the needle is very painful for the patient who is asked to "cooperate", even though the previous anesthesia failed!
As a precaution, it is not advisable to inject into infected tissue, to avoid the risk of spreading the infection in the periapical tissues.[36]

INTRAOSSEOUS ANESTHESIA

Intraosseous anesthesia is a technique whereby teeth are anaesthetized by injecting local anesthetic solution directly into the cancellous or medullary bone around the affected tooth.[59] Historically, the intraosseous injection was inconvenient and burdensome, requiring the clinician to make a small (1.0-3.0 mm) incision, and with a small, round bur, drill or reamer, penetrate through the dense cortical plate of bone into cancellous bone.[6,26,29,44] Then, with a short needle, approximaytely 1.0 ml of solution was deposited. The results were very favourable, but the technique proved tedious for the dentist and somewhat intimidating for the patient. Currently, two intraosseous systems are available commarcially (Stabident Local Anesthesia System, Fairfax Dental Inc. and X-Tip Intraosseous Anaesthesia Delivery System, Dentsply Maillefer) that supply the dentist with a "perforator" and ultrashort needles (Fig. 9.26), precluding the need for an incision and the use of a round bur. Consequently, this technique, with a little practice, is more user-friendly and is well tolerated by the patient. The technique has shown favourable results in that its pulpal anesthetic effect is extremely rapid, almost immediate.[9] For this reason, it is very successful as a supplemental technique,[9,12,44] and it is particularly effective in cases of irreversibly inflamed pulps in mandibular molars.[42] More importantly, if performed with care, it can be administered to the patient with little or no discomfort. Although its use as a primary technique has been suggested, its short duration (15-30 minutes) precludes its use as such for lengthy endodontic procedures.[9,12,42,48]



A B

Fig. 9.26. Perforators and ultrashort needles. **A.** X-Tip. **B.** Stabident.

The intraosseous technique

As previously mentioned, the intraosseous anesthetic technique is based on the premise that anesthetic solution is deposited directly into cancellous bone adjacent to the affected tooth. The technique involves three simple steps:
1. anesthesia of the attached gingiva
2. cortical bone perforation
3. deposition of anesthetic solution into cancellous bone.

Step 1: anesthetize the attached gingiva

Using the ultrashort needles provided in the kit, inject a few drops of solution into the attached gingiva until slight blanching occurs (Fig. 9.27). This can be painless for the patient if the injection is slow and deliberate. The use of topical anesthetic is optional. Despite

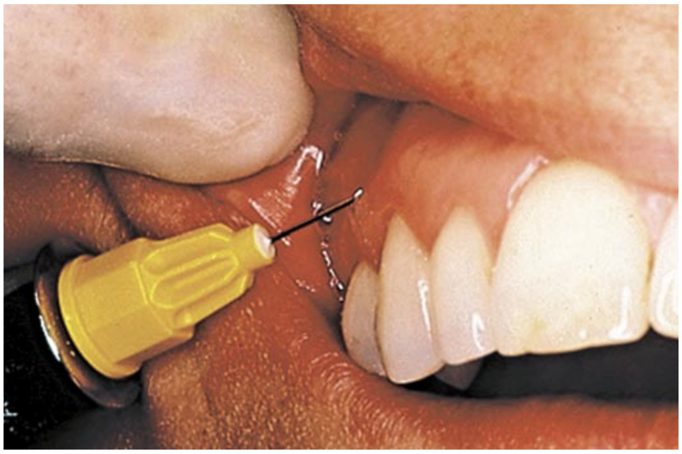


Fig. 9.27. Anesthetize the attached gingival (Spetp 1).

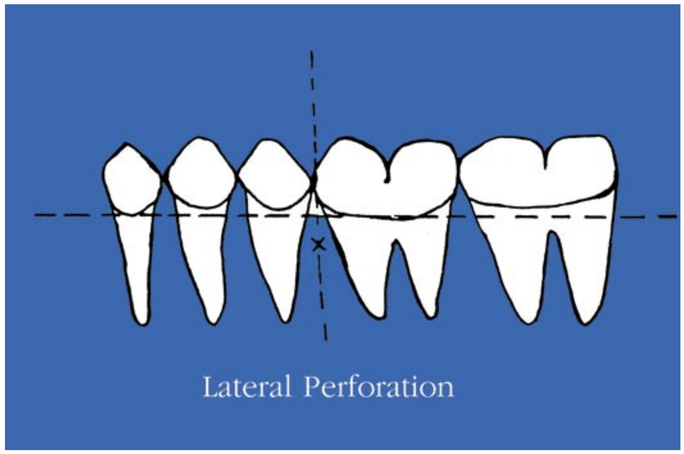


Fig. 9.28. General guideline for perforation site selection.

its questionable effectiveness, its use, if for no other reason, demonstrates to the patient that every effort is being made to ensure their comfort and well being.[17,50,68]

Step 2: Cortical plate perforation

The "perforator" comprises a 27-gauge, solid needle shank with a bevelled end designed to fit into a standard slow-speed, contra-angle handpiece. It is 9.0 mm in length and correspond to the diameter and length of the needles. It has a narrow-diameter collar which provides a safety stop against excessive penetration, with a wider diameter collar that is designed to aid in preventing debris and lubricant from contaminating the perforator needle. The perforators are supplied gamma-ray sterilized and are to be disposed of after patient treatment.[59]

Selection of injection site

To determine the correct placement for the cortical penetration, imagine a horizontal line along the gingival margins of the teeth, and a vertical line through the papilla. At a point approximately 2.0 mm apical to where these lines intersect is usually a suitable site for the perforation[59] (Fig. 9.28). Prior to perforating the plate, it is helpful to refer to the preoperative radiograph to assess the space between the roots of the adjacent teeth and to note the relative interproximal bone heigh in the area. Injecting into soft tissue will result in inadequate anesthesia. Care must be taken to avoid injecting too far coronally into the papilla. The bone in this area tends to be thin and fragile and tissue necrosis could occur. Conversely, if the perforation is made too far apically, the bone becomes thicker and a shallow depth of perforation would result in an inadequate anaesthetic effect.

The manufacturer suggests injecting distally rather than mesially whenever possible, because a smaller dose suffices.[59] From personal experience, there has been no significant difference noted when injections were performed mesially to the affected tooth. In fact, in the mandibular molar region, where the technique has been most useful, the mesial approach tends to be more accessible. It is also recommended that the thin bone between the maxillary and mandibular central incisors be avoided. Should these teeth require intraosseous anesthesia, approach the perforation site distally, or perhaps even better, avoid to use the technique altogether and rely on infiltration.

Perforating the cortical bone

Once the site has been selected, and the tissue has been anaesthetized, place the perforator in a latch-type contra-angle of a slow-speed handpiece and remove the safety cap. Orient the perforator perpendicular to the cortical plate at the predetermined site, and gently advance it through the gingiva until it rests firmly against the bone (Fig. 9.29). Next, engage the motor for approximately two seconds and apply light, intermittent pressure until perforation occurs. This will be evident as the sensation closely resembles the "give" experienced when accessing the pulp chamber. The patient should be forewarned of the sensation of slight vibration and pressure.

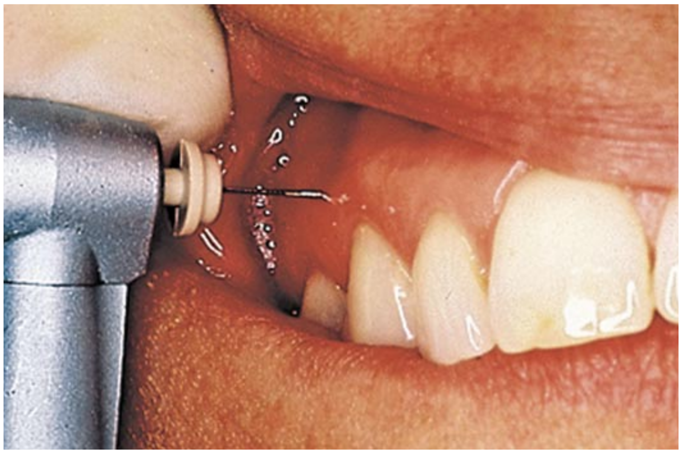


Fig. 9.29. Perforate the cortical plate (Step 2).

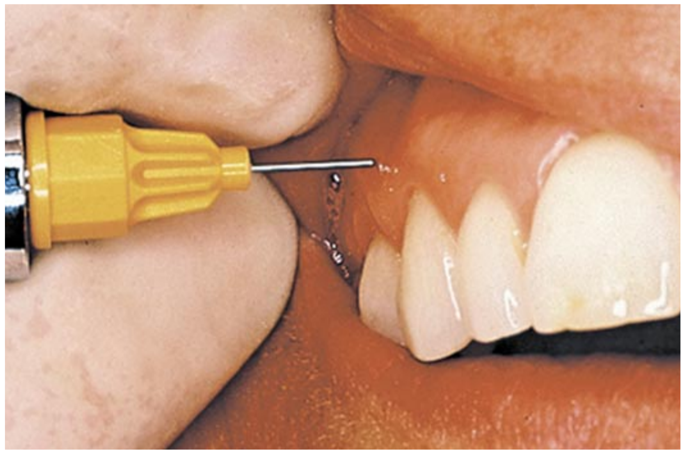


Fig. 9.30. Insert the needle into perforation site and slowly inject (Step 3).

Step 3: Injecting into the cancellous bone

After perforation is completed, it is important to note the exact site of penetration. One suggestion for its identification is to compress a cotton roll against the mucosa for a few seconds to absorb any blood in the area. Once the puncture wound has been isolated, the chairside assistant should pass the anesthetic syringe in a pengrip fashion, align and gently insert the needle into the perforating site (Figs. 9.30, 9.31). This may take a few attempts initially, but with experience, this phase of the technique become easier. On the other hand, when starting to use intraosseous anesthesia initially sometimes can be found some difficulty inserting the needle in the drilled hole. In such cases can be very helpful to use of the X-Tip or the Alternative Stabident. In the X-Tip (Fig. 9.32), drilling with the perforator automatically places the guide-sleeve in position in the cortical bone, to provide a precise injection of anesthetic into cancellous bone.

The Alternative Stabident guide-sleeve is manually inserted in the drilled hole (Fig. 9.33). When the guide-sleeve has been inserted in the bone one way or the other, the injection needle is loaded into the funnel-shaped entrance at the other end of the guide-sleeve, to slowly and gently inject the solution.

A good rule of thumb is to allow 60 seconds per carpule as a guide to the speed of injection. Usually,

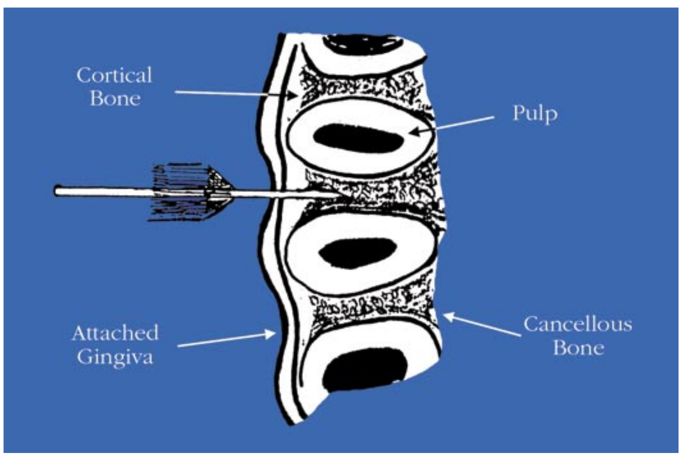


Fig. 9.31. Diagram representing location for preparation site and injection.

A

B

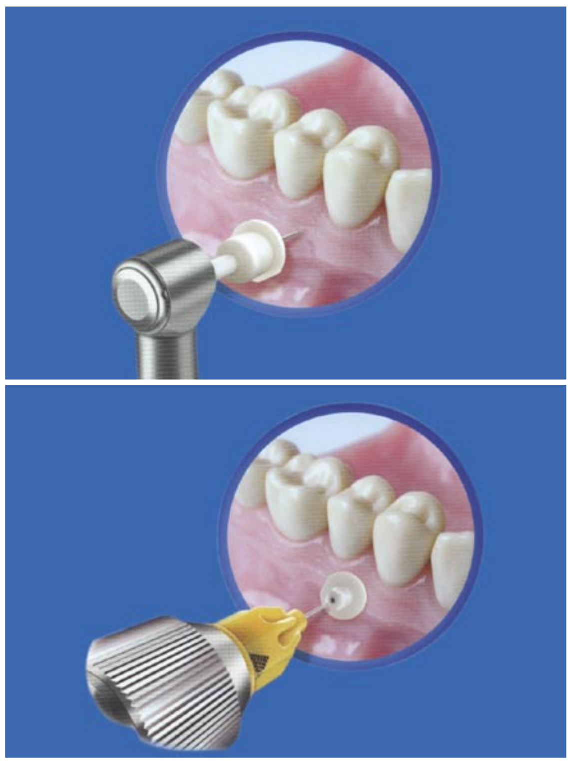


Fig. 9.32. **A, B.** The X-Tip leaves the guide-sleeve in position in the cortical bone (Courtesy of Dentsply Maillefer).

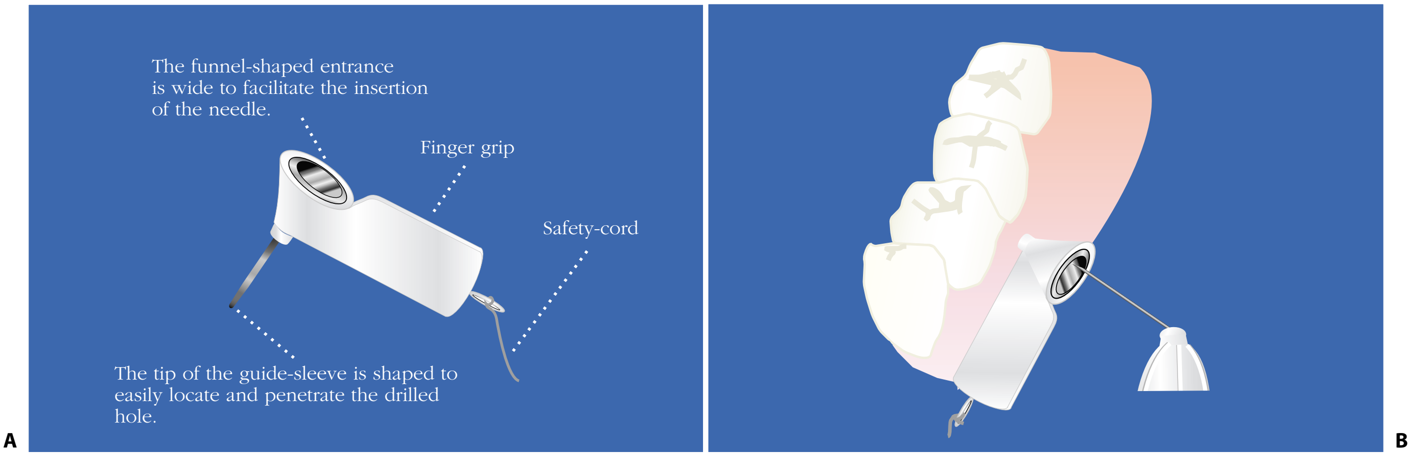


Fig. 9.33. **A, B.** Using the Alternative Stabident, the guide-sleeve is manually inserted in the drilled hole (Courtesy of Fairfax Dental Inc.).

only about 0.45 to 0.90 ml or 1/4 to 1/2 of a cartrige is all that is required to render profound anesthesia. However, up to 1.8 ml or one cartrige must be used. As with any injection method, a rapid influx of the solution can cause transient discomfort and an increase in heart rate.[12,26,48] It is best to always prepare the patient for this potential consequence before injection begins. As the anesthetic is delivered, the plunger should advance with ease. Should considerable force be required to inject, assume that either the needle is not in cancellous bone, or is butted against root surface. If considerable back pressure is met, attempt to rotate the needle one-quarter turn. If repeated attempts to redirect the needle prove unsuccessful, then choose another penetration site and repeat Step 2. In the posterior regions of the mouth, due to compromised access, extreme caution must be taken to avoid root perforation. For better access into posterior perforation sites, it is sometimes beneficial to bend the needle at the hub 45 degrees.

Beginners are encouraged to restrict themselves to the anterior regions until the system has been mastered. This precaution is suggested because the angle of perforation required in the posterior regions of the mouth is more critical, with a greater chance for the occurrence of procedural mishaps, such as root perforations or perforator and needle breakage.

Dosage reccomendations

Absorption of the anesthetic into the blood supply following intraosseous administration is more rapid than with primary injection techniques, thus requiring much less to produce the desired anesthetic effects as compared to traditional methods.[59] Therefore, only one cartridge of anesthetic per patient is recommended and concentrations of vasoconstrictor should not exceed 1:100,000.[26,34]

The recommended anesthetic agent for this technique is 2% lidocaine with 1:100,000 epinephrine.[68] Research has shown that 3% mepivacaine without epinephrine does not produce the desired anesthetic effect when compared to 2% lidocaine with 1:100,000 epinephrine.[48]

Duration of anesthesia

As with all supplemental injections, the duration of anesthesia using the intraosseous technique is shorter than with standard infiltration or blocks. One can expect approximately 15 to 30 minutes of profound pulpal anaesthesia.[59] This should provide the practitioner with ample time to access the pulp chamber and extirpate the pulp in a comfortable, expedient manner.

Considerations for intraosseous anesthesia

Anatomical considerations

Caution should be exercised when injecting between the mandibular premolars due to the proximity of the mental foramen, even though a perforation at a distance of 2.0 mm from the gingival margin should be well away from the neurovascular bundle. Additionally, care should be taken to avoid perforation into the maxillary sinus. Although this would not result in a serious complication, it could be uncomfortable to the patient

Table II

Contraindications for using the intraosseous technique

– Physical structures prevent perforation
– Inadequate space between roots for perforation
– Areas of advanced periodontal disease or acute infection
– Avoid mandibular premolar region due to close proximity of the mental foramen
– Avoid injecting between maxillary and mandibular central incisors

and result in inadequate anesthesia.
Other considerations that may discourage or prevent the use of the intraosseous technique are listed in Table II.

Patient considerations

Various researchers have shown that solutions containing epinephrine injected by the intraosseous route are rapidly absorbed into the systemic circulation and can cause a decrease in blood pressure and increase in heart rate in the majority of the patients. This effect usually subsides within two to three minutes.[12,26,27,48]
In a normal, healthy patient, this can be frequently circumvented by injecting slowly and reassuring the patient that the effect, should it occur, will be transient.
For the medically compromised patient, specifically those with cardiac deseases, there are genuine concerns regarding the use or avoidance of vasoconstrictors. Frequently, however, we allow those concerns to overshadow the actual benefits that the vasoconstrictor offers. The practitioner should always keep in mind that if the medically compromised patient's condition is stabilized through medical treatment, there are no absolute contraindications to the use of vasoconstrictors, except for those patients with uncontrolled hyperthyroidism with clinical evidence of thyrotoxicosis and patients with sulfite allergies.[19]
Patients with uncontrolled hypertension, and/or a present or past history of cardiovascular disease are conditions that may require medical consultation prior to treatment.
Assuming proper injection technique is performed, vasoconstrictors are important additions to local anesthetic solutions.[34]
Epinephrine and other vasoconstrictors provide a wide safety margin for normal, healthy adult patients and most medically compromised patients who are stabilized. Paradoxical as it may seem, the greater the medical risk of a patient, the more important effective pain and anxiety control becomes.[19] The avoidance of their use will result in a shorter duration of the anesthetic effect, thereby diminishing the potential for painless treatment.[19,34]

Other considerations

A small number of patients who receive anesthetic via intraosseous route may develop exudate or swelling at the injection site.[9] Although the areas should heal uneventfully, the possibility of this untoward effect must be considered when using the intraosseous technique.
The manufacturer claims that the wound site created by the perforator has a surface area approximately 1/700th the size of an extraction socket and generally has a healthy gingival covering.[59] Secondly, the perforator is supplied sterile. As long as the clinician is prudent not to inject into areas of active periodontal disease and infection, the potential for infection is extremely rare.
Should swelling or drainage occur, judicious use of antibiotics, such as penicillin or clindamycin, would be indicated.

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10

Tooth Isolation: the Rubber Dam

ARNALDO CASTELLUCCI

The need to work under dry conditions, free of saliva, has been recognized for centuries, and the idea of using a sheet of rubber to isolate the tooth dates almost 150 years! The introduction of this notion is attributed to a young American dentist from New York, Sanford Christie Barnum, who in 1864 demonstrated for the first time the advantages of isolating the tooth with a rubber sheet. At that time, keeping the rubber in place around the tooth was problematic, but things soon improved a few years later, when in 1882 S. S. White introduced a rubber dam punch similar to that used still now. In the same year, Dr. Delous Palmer introduced a set of metal clamps which could be used for different teeth.

This said, it seems incredible that even today, two centuries later and living now in the third millennium, there are still dentists who are not convinced of the usefulness of this very simple rubber sheet. On the other hand, it is also incredible that the Scientific Associations who are in charge of laying down the "Guidelines" do not say that the use of rubber dam is ***mandatory*** to perform any kind of nonsurgical endodontic treatment. The Quality Assurance Guidelines of the American Associations of Endodontists [2] says that "cleaning, shaping, disinfection and obturation of all canals are accomplished using an aseptic technique with dental dam isolation *whenever possible*". According to the author's opinion, when it is not possible, the clinician has two options: one is to make it possible and the other is to extract the tooth! There is no other choice.

The operative procedures that are performed in the patient's mouth must be seen as larger or smaller surgical procedures. In dentistry, as in general surgery, isolation of the operative field is imperative, even for a simple filling.

Even more so than in restorative dentistry, the rubber dam is ***obligatory*** in Endodontics,[15] so much so that Endodontics should not be performed without a dam. Furthermore, an endodontic treatment should not be undertaken unless the tooth – particularly if damaged – has not been reconstructed to allow easy positioning of the rubber dam. There should be no excuse for not using the rubber dam in Endodontics; the law should severely punish the dentist who causes serious injury, including death, to a patient because he did not use one.[8,16,18,21,26] Patick Wahl in a recent article says that in the United States any law suit is lost if the rubber dam has not been used.[27]

The only tooth that may be treated without the rubber dam is the tooth that is so severely damaged that the only instruments to be used are the extracting forceps. As Aiello[1] states, one must recall that the rubber dam clamp occupies the future position of the marginal closure of the prosthetic crown. It is therefore unthinkable to endodontically treat a tooth on which the rubber dam cannot be assembled, since it is not known whether and how the tooth will be restored.

A contraindication to the use of the rubber dam is a patient's allergy to the chemical constituents of rubber.[5,11] In this circumstance, albeit rare, the teeth may be isolated with polythene sheets,[22] which impose limitations related to the lack of elasticity of this material as compared to rubber. Today "no-latex" dam is available,[17] to be used on allergic patients (Fig. 10.1).

There are odd rumors about the use of the rubber dam; for example, it is claimed that it takes too much time to assemble. Cragg[10] correctly states that "that which takes more time, with respect to the rubber dam, is trying to convince the dentist to use it".

It is worth spending a few seconds to assemble the rubber dam for use in endodontic procedures and thus improve the entire treatment.

In Endodontics, use of the rubber dam confers the following advantages:

1. The patient are protected from the ingestion[26] (Figs. 10.2, 10.3) or, worse, the aspiration[16] of small

Fig. 10.1. No-latex rubber dam, for allergic patients.

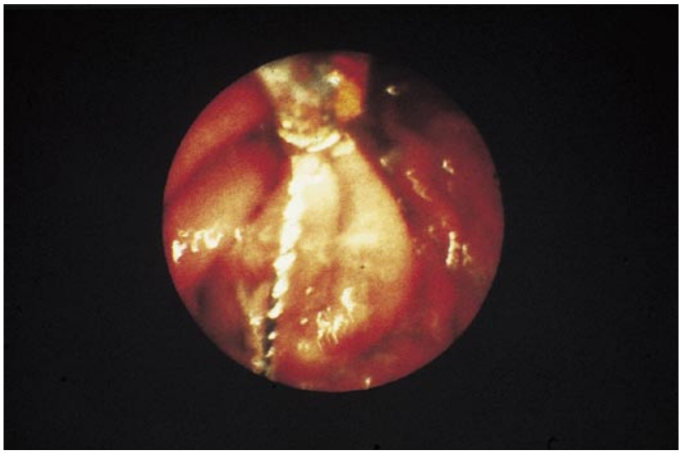


Fig. 10.2. This photograph, taken during gastroscopy, shows a large root canal reamer among the folds of the gastric mucosa.

instruments, dental fragments, irrigating solutions, or irritant substances.

2. The opportunity to operate in a clean surgical field.
3. Retraction (very important for working in the posterior areas) and protection of the soft tissues (gums, tongue, lips, and cheeks), which are sheltered from the cutting action of the bur.
4. Better visibility in the working area. The advertisement of a famous manufacturer of instruments for the assembly of the rubber dam correctly reads: "Do better what you see and see better what you do".
5. Reduction of delays: the patients, with fortunately rare exceptions, cannot converse except with great difficulty; besides, they will not have to rinse their mouth every five minutes.

Fig. 10.3. This radiograph shows the presence of an endodontic instrument among the intestinal loops. Few weeks later, the patient died![12]

6. The dentists and dental assistants are protected against infections which can be transmitted by the patient's saliva.[9]
7. The dentists are more comfortable, as they may work at a more leisurely pace and may be permitted to answer an important telephone call, leaving the patients well protected with the rubber dam and the dental assistant close to them.
8. Better tactile sensitivity during the cleaning and shaping procedure. Without the rubber dam, the dentists, aware of the risk of causing the patients to ingest or aspirate an instrument, holds the files in such as way that they will not slip from their fingers. The pressure they applie to the handle of these instruments reduces the sensitivity of their fingers and precludes the use of the instruments to perform delicate procedures. With the rubber dam in place, on the other hand, they may hold the instruments delicately, without fearing that they may slip from their hand.[19]
9. The patients are more comfortable, as they do not feel that their mouth is invaded by hands, instruments, and liquids.

Patients increasingly appreciate the use of the rubber dam. On occasion, they may ask whether it is a new invention,[24] and once they have tried it, they do not want to do without it in the future.

INSTRUMENTS

To facilitate the assembly of the rubber dam, it is advisable to have the appropriate instruments within arm's reach. This is simpler than it might appear (Fig. 10.4).

1) Rubber dam

The dam comes in different sizes (5" x 5" inches and 6" x 6" inches, as well as rolls), colors (light, blue, gray, and green), and thicknesses (special heavy, extra heavy, heavy, medium, and thin).
The 6" x 6" format is useful in restorative dentistry, where it is necessary to isolate several teeth at the same time. In Endodontics, where one tooth is isolated at a time, the 5" x 5" format is more than sufficient, even for working in the posterior sectors of the mouth.
Some prefer the dark colors, since the tooth stands out better, but it is really a question of habit. The light-colored dam is slightly transparent, unlike the other colors, which may be helpful in positioning the intraoperative radiograph.
The quality of the dam sheets deteriorates with time; in particular, they lose elasticity. One should therefore stock them in moderate quantities, keep them refrigerated, observe the expiration date on the back of the box, and obtain one's supplies from a distributor that sells them at high volume, so as to avoid buying supplies that have already been in the warehouse for a long period of time and have thus already expired.
To test them, one can perform the same test as that to check the adequacy of the dam punch: just after punching a hole in the dam, it is stretched in different directions to confirm that it does not tear.

2) Rubber dam punches

It is used to make round holes of different diameters (0,7 – 2 mm), depending on the tooth to be isolated. Several brands are available. Nonetheless, it is necessary to check whether the dam opening is exactly round, without irregularities. To determine this, it suffices to punch a hole in a dam sheet and then enlarge this opening by stretching the sheet in different directions. The dam should not tear.

3) Rubber dam clamps

The fit of the rubber dam essentially depends on the choice of the appropriate clamp and its correct positioning.
The clamps are classified as winged or wingless. The dentist may choose those with which he feels more comfortable (Figs. 10.5-10.7). The positioning techniques vary slightly, but the final result is the same. Sometimes wingless clamps are preferable, inasmuch as they are less bulky and may be used easily in the posterior sectors in patients with particularly thick cheeks.
The most commonly used are:

FRONT TEETH:
IVORY .... # 6
IVORY .... # 9
IVORY .... # 90N
IVORY .... # 212S
IVORY .... # 15

PREMOLARS:
IVORY .... # 1
IVORY .... # 2
IVORY .... # 2A

MOLARS THAT ARE COMPLETELY ERUPTED, WHOLE, OR COVERED BY FULL CROWNS:
IVORY .... # 7

MOLARS THAT ARE INCOMPLETELY ERUPTED OR ALREADY PREPARED FOR A FULL CROWN:
IVORY .... # 14
IVORY .... # 14A
IVORY .... # 7A

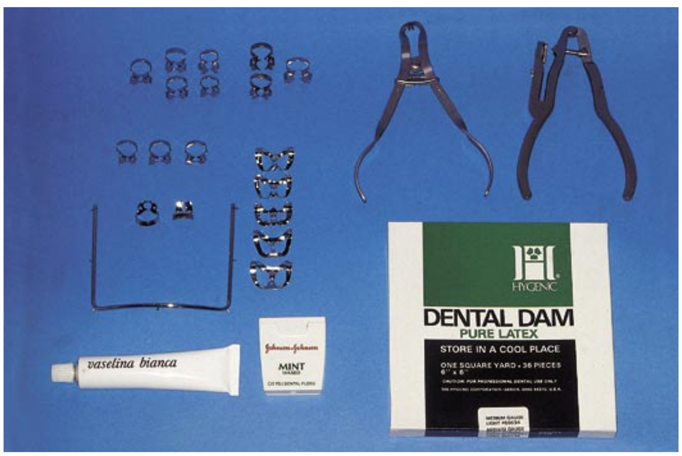


Fig. 10.4. Minimum set of instruments necessary for the assembly of the rubber dam in the different sectors of the mouth.

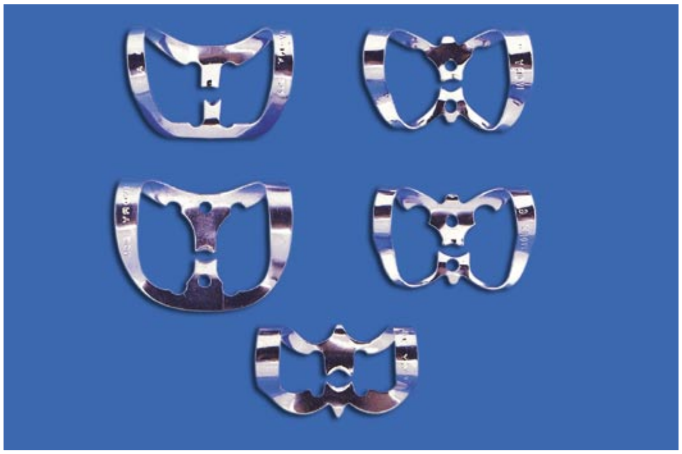


Fig. 10.5. Clamps for the front teeth.

Fig. 10.6. Clamps for the premolars.

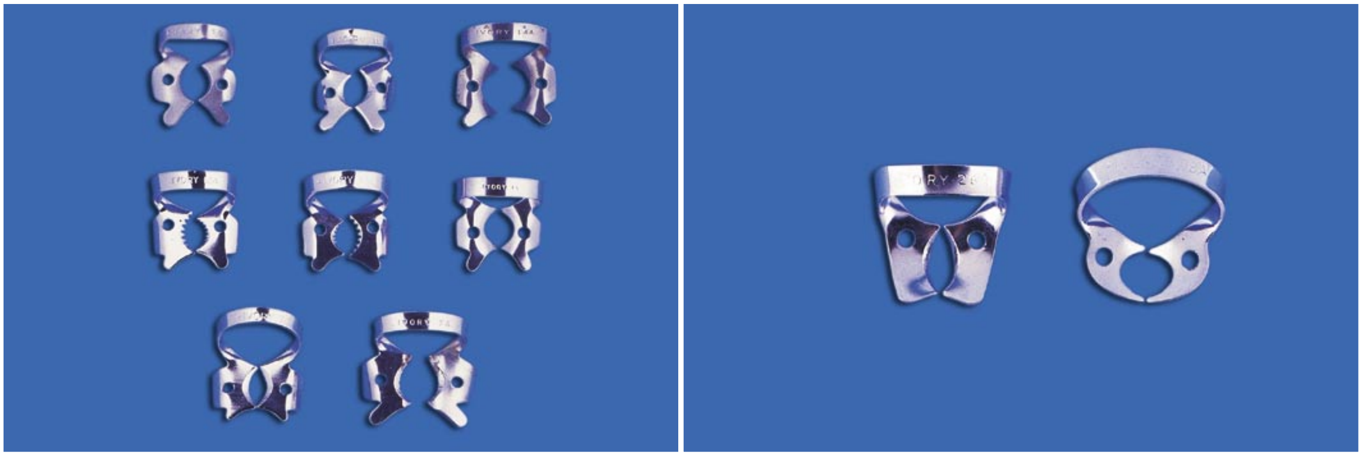
A  B

Fig. 10.7. Clamps for the molars. **A**. Winged. **B** Wingless.

ASYMMETRICAL MOLARS, IN PARTICULAR THE SECOND AND THIRD:

IVORY .... # 10
IVORY .... # 11
IVORY .... # 12A
IVORY .... # 13A

WINGLESS, TO BE USED WHEN THE WINGS OBSTRUCT THE WORKING FIELD:

IVORY .... # W8A
IVORY .... # 26N

The clamps may also be modified to improve their grip and allow a more precise fit.[13] Moreover, there is no reason not to use a premolar clamp on a small molar or frontal tooth, or a # 9 clamp on a hemisected root of a lower molar; any such adaptation is permitted, as long as the final result – correct placement of the rubber dam – is achieved.

The only danger is fracture of the rubber dam clamp once it has been positioned in the mouth. If this occurs, the elasticity of the dam will cause the fragments to be ejected from the patient's mouth. It is therefore prudent to secure the clamp with dental floss and anchor it to the dam frame.

4) Rubber dam clamp forceps

This instrument is necessary to open the clamp and position it around the tooth. The Ivory forceps are preferable, because they allow the dentist to apply direct pressure toward the gum, which is frequently necessary to position the clamp securely below the bulge of the tooth crown.

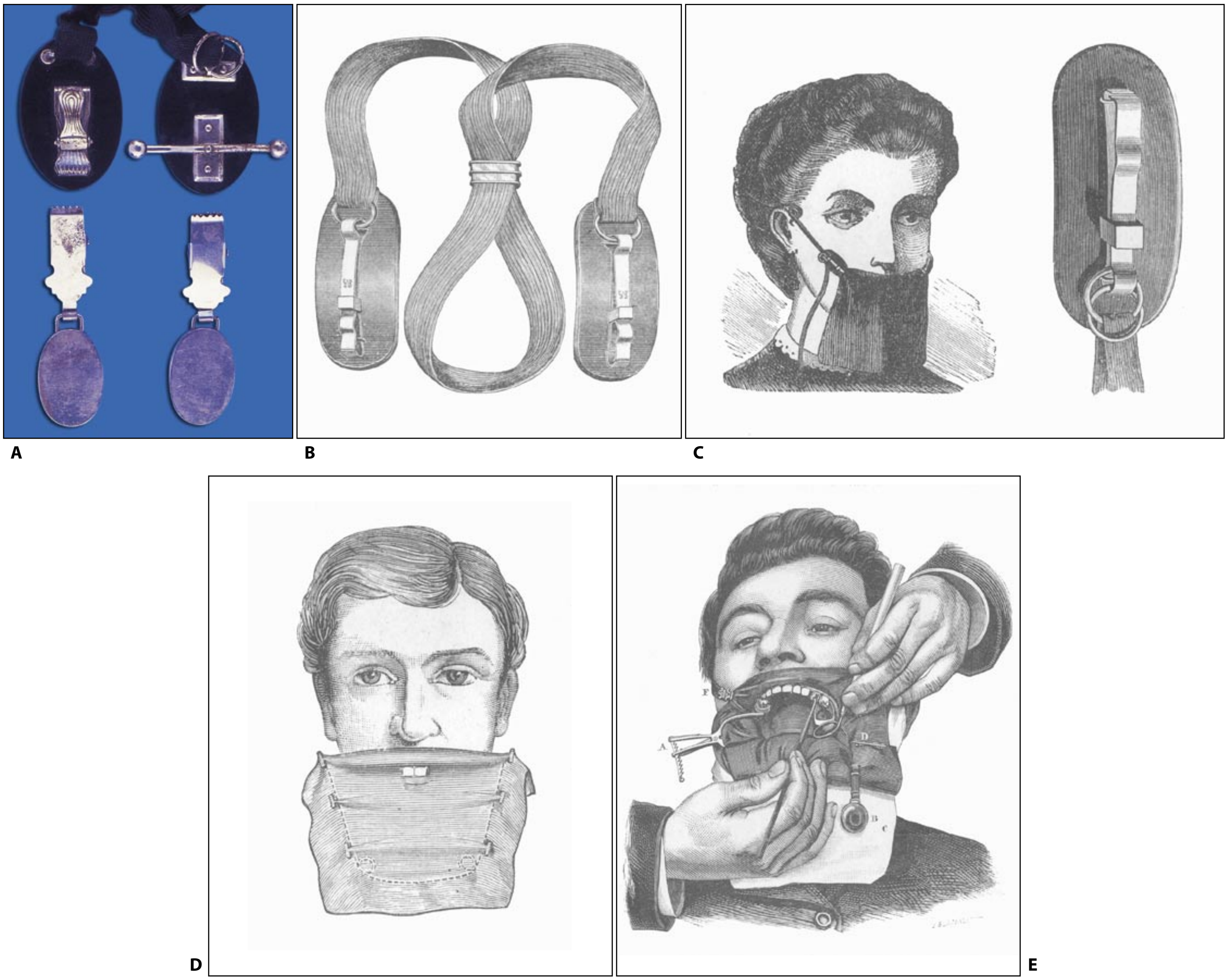
5) Rubber dam frame

This is necessary to maintain tension in the dam so that the lips and cheeks may be retracted well. Some frames, including the Young frame, are made of very thin metal; others, including the Nygaard-Ostby or Starlite frame, are plastic. In comparison to the Young frame, the latter have the advantage of being transparent; on the other hand, they are bulkier.

Dam tensors such as those of Woodburg,[23] Cogswell, Mitchell, and Fernald,[3] (Fig. 10.8) which are based on the principle of maintaining tension in the dam by the use of clips and elastic bands passing directly over the nape of the neck, are out-dated and have no use in modern Endodontics.

Furthermore, they have numerous disadvantages: they require more time for positioning; they completely cover the patient's nose and mouth, giving him the unpleasant sensation of suffocation; and they do not cause the least bit of retraction of the lips or cheeks, like the others.

New rubber dams recently introduced in the market are the Handidam (Aseptico, Woodinville, WA) and the Insti-Dam (Zirc Company, Buffalo, MN), two rubber dam systems with built-in foldable radiolucent plastic frame (Fig. 10.9).



A B C D E

Fig. 10.8. **A**. Woodburg's rubber-dam tensors, which are no longer used (courtesy of Dental Trey, Forlì). **B**. Dr. Cogswell's dam holder. **C**. Dr. Cogswell's dam in place. **D**. Dr. Fernald's dam holders. **E**. Dr. Brasseur's dam holder (from E. Andreu: Traité de dentisterie operatoire, Paris, 1889).

Fig. 10.9. The Insti-Dam (left) and the Handidam (right).

6) Lubricant

Before positioning the dam, it is an advisable to lubricate the inner surfaces well with Vaseline or, more simply, soap, so that the sheet will slide better over the contours of the teeth, more easily overcome the contact areas, and close tightly around the cervix of the tooth.

7) Rubber dam napkins

These prevent direct contact between the rubber sheet and the patient's cheek. By absorbing the saliva that accumulates beneath the dam by capillary action, they facilitate treatment. Their use is not mandatory; however, they are particularly indicated in cases of allergy to the rubber of the dam.

8) Dental floss

Apart from preventing the ingestion or aspiration of the clamp, dental floss is particularly useful for assessing the condition of the mesial and distal contact areas, and thus for facilitating the passage of the rubber sheet beneath them.

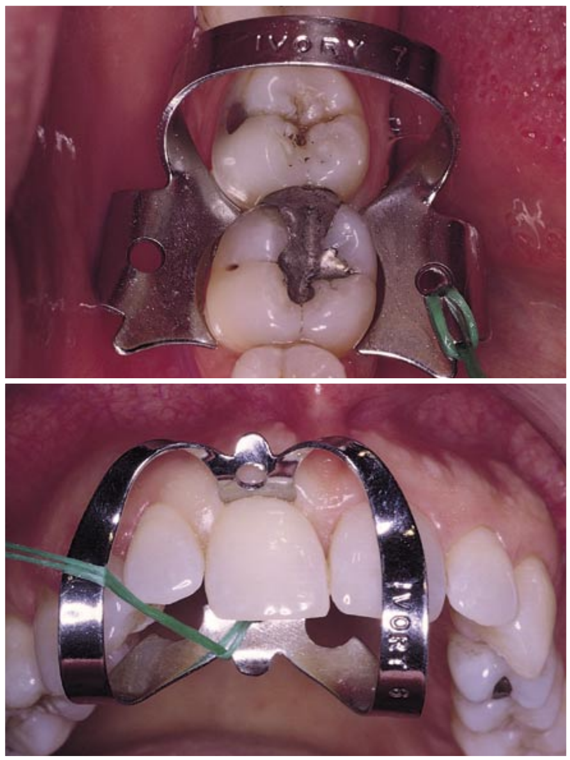
9) Assistant

The dentist may position the rubber dam on any tooth using only his hands, but it is obvious that this procedure is facilitated by the help of an assistant.

POSITIONING OF THE DAM

After using dental floss to check the nature of the contacts (Fig. 10.10) and determine whether there is welding between prosthetic crowns or whether there are irregularities of old restorations that need to be eliminated, one selects the clamp that one thinks might be appropriate for the case and tries it in the mouth (Fig. 10.11). It is advisable to secure the clamp with den-

Fig. 10.10. The use of dental floss provides information about the contact areas.



A

B

Fig. 10.11. **A**. The clamp is positioned around the tooth in such a way that it is stable and does not damage the periodontal tissues. Dental floss has been tied to this clamp for security reasons. If it slipped off during the trial placement, it could be swallowed or aspirated. If it broke while being opened with the rubber dam clamp forceps, the lingual part could easily disappear into the patient's throat. **B**. Same precaution for a front tooth.

tal floss, to protect the patient from the ingestion or the aspiration of the clamp. If it comes off easily, it should be changed. If it appears stable, one inserts it in the opening of the rubber sheet (Fig. 10.12), which should already have been prepared.

Initially, it may be difficult to position the opening

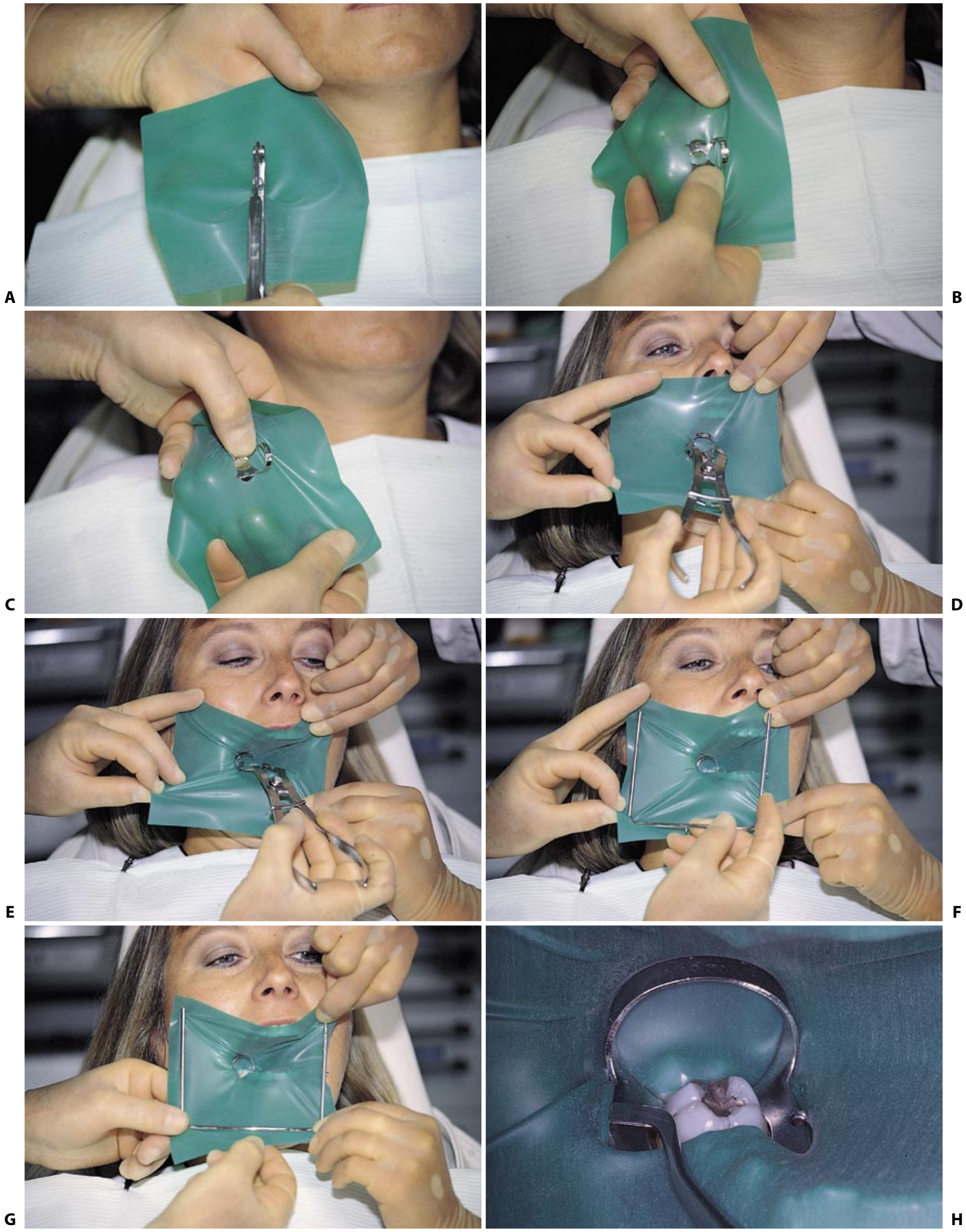
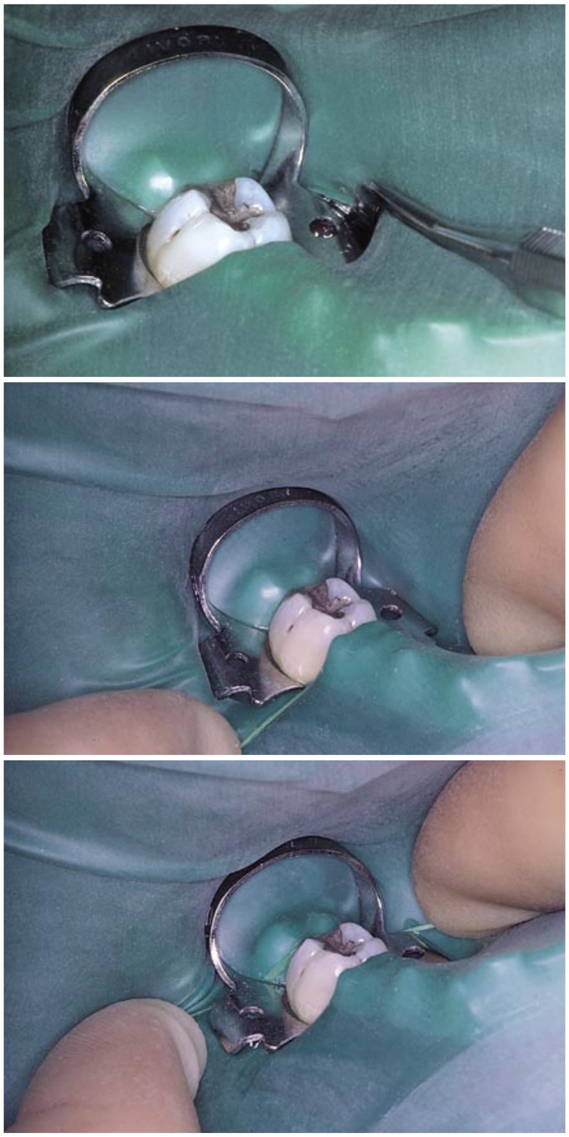


Fig. 10.12. **A**. The rubber sheet is punched with the rubber dam punch. **B, C**. The rubber dam is stretched over the wings of the selected clamp. **D**. With the help of an assistant, the dam and clamp are placed in position in the patient's mouth. **E**. The rubber dam clamp forceps positions the clamp around the tooth to be treated. **F, G**. Young's frame is positioned to produce tension in the dam. **H**. Using an instrument, the dam is slipped beneath the clamp wings on the buccal side (continued).



I J K

Fig. 10.12. (continued) **I.** The same is done on the lingual side. **J, K.** Dental floss is used to force the dam through the interproximal contacts.

correctly so that the dam disturbs neither the dentist nor the patient. The posterior teeth may present greater problems. In these cases, it is advisable to punch the opening more centrally than suggested by the commercially available stamps or at the point corresponding to the imaginary ellipse that represents the distribution of the teeth in the patient's two arches (Fig. 10.13). In treating a posterior tooth, it is preferable to place the tooth in the center of the dam, placing the dam asymmetrically with respect to the patient's face (Fig. 10.14), rather than the opposite (Fig. 10.15). The more distal the position of the tooth, the closer the opening must be to the center of the rubber sheet.[25] It is better that the tooth under treatment be in

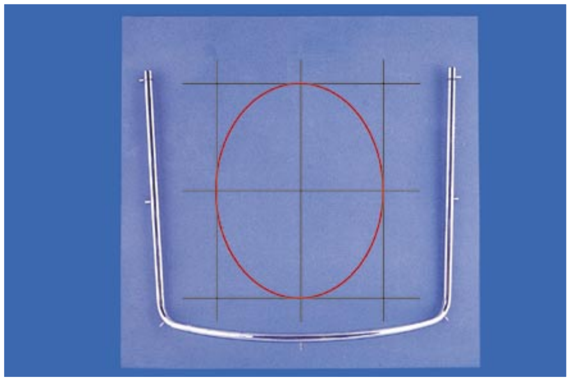
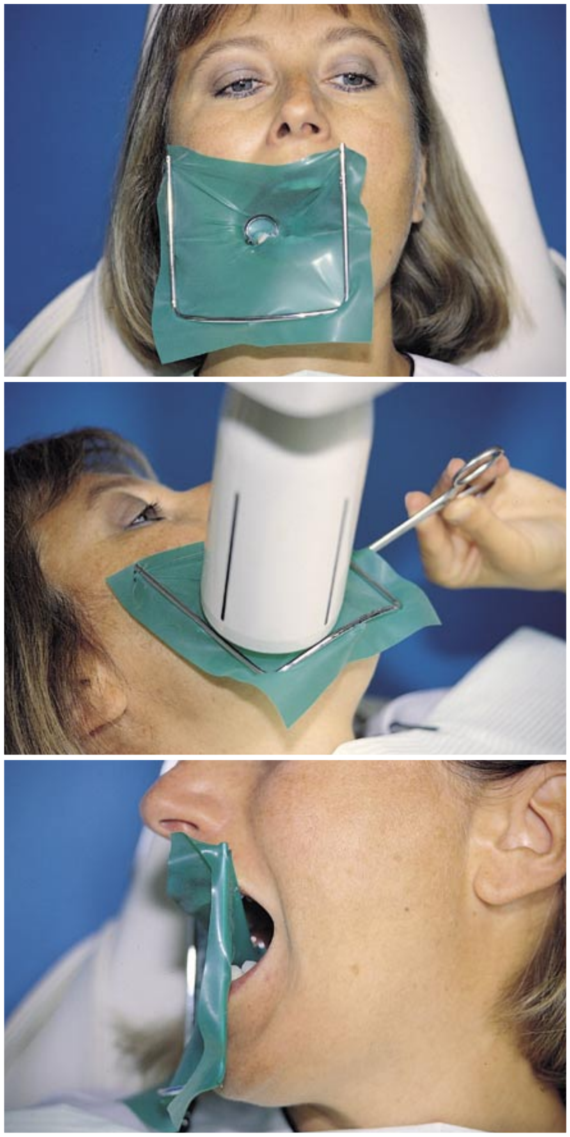


Fig. 10.13. In deciding where to punch the opening in the rubber sheet, one can mentally trace three vertical and three horizontal lines. The ellipse inscribed within the central rectangle corresponds to the two dental arches.



A B C

Fig. 10.14. **A.** The opening has been made more or less within the center of the dam, which is asymmetrical with respect to the patient's face. **B.** In this way, the metallic frame does not interfere with the X-ray machine. **C.** The patient can also breathe through the mouth.

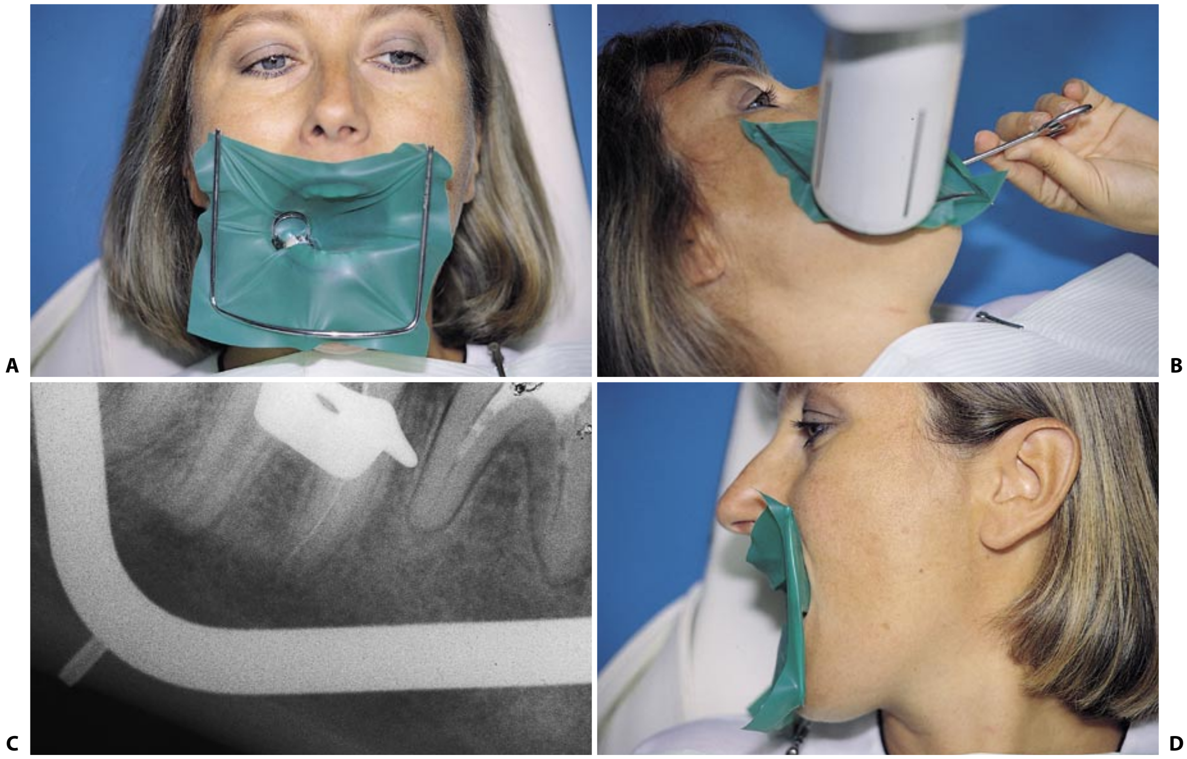


Fig. 10.15. **A.** The opening has been made at the point indicated by the ellipse rule. The dam is therefore asymmetric with respect to the patient's face, while the tooth emerges at a point close to the metallic frame. **B, C.** The metallic frame interferes with the X-ray machine, causing it to project the frame's shadow onto the radiograph. **D.** The dam adheres to the entire circumference of the mouth, precluding oral respiration.

the center of the operative field than that the rubber be in the center of the mouth.[6]

Central positioning of the opening has several advantages in treating the molars:

- Once positioned, the dam will be quite asymmetrical with respect to the patient's mouth, and therefore further displaced from the side being worked on. This insures greater retraction of the lips and ipsilateral cheek.
- Since the dam is asymmetrical, there is enough space from the controlateral part to permit oral respiration on the part of the patient, which is essential in patients who have difficulty with nasal respiration. The dentist can also easily introduce any radiographs into the patient's mouth that need to be taken intraoperatively without having to dismount the frame of the dam.
- The same space can be useful in the patient with abundant salivation to keep an aspirator in the mouth.
- Because the dam is displaced from the side in which one is working, the risk of obtaining intraoperative radiographs obstructed by the metal frame is reduced.

Before positioning the rubber dam, it is a good idea to illustrate to the patients the utility and function of the dam, especially in very young patients; for example, we can place a fingertip in the dam opening (Fig. 10.16). The patients must also be told that, with the dam in place, they may safely swallow, cough, or yawn and that they may do so without placing their hand in front of their mouth! The only things they must not do are talk and rinse.

Patients with an easily-provoked gag reflex should relax since the rubber dam will not touch the areas that may provoke their reflex; still, the dam is definitely better tolerated and safer than cotton rolls.

There are many methods of placing the dam. They are more or less simple, and the dentist can choose the preferred one. The assistant can place the dam around the tooth (Fig. 10.17) as the dentist positions the clamp (Fig. 10.18) and then the frame (Fig. 10.19). This procedure is often difficult, if not impossible, especially in the posterior areas or particularly small mouths.

Another method requires placing the clamp within the opening of the dam. Both the clamp and dam are positioned around the tooth, even without an assistant. The positioning of the frame follows. Obviously, in this case the technique varies slightly, depending on whether one uses winged (Fig. 10.20) or wingless

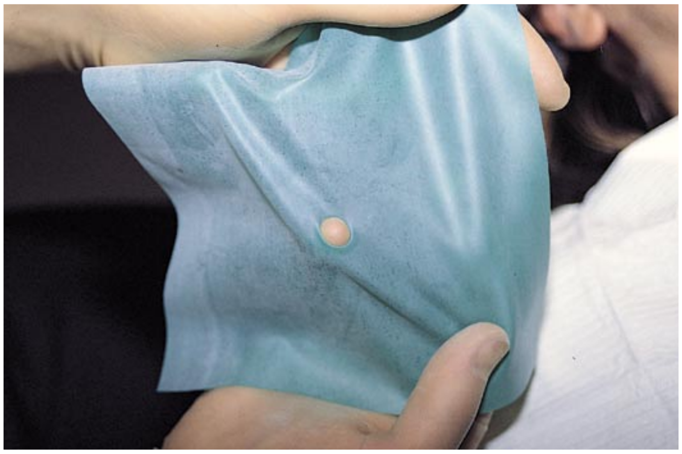


Fig. 10.16. The fingertip is introduced in the dam opening to better illustrate to the patient the functions of this rubber sheet.

Fig. 10.17. The assistant's hands position the dam directly around the tooth to be treated.

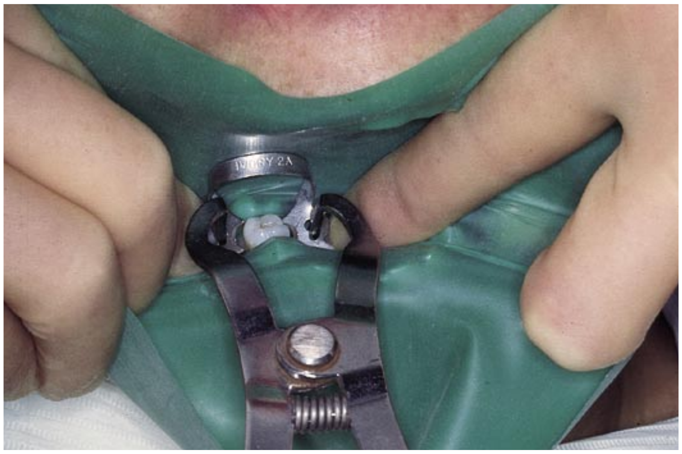


Fig. 10.18. The dentist positions the clamp.

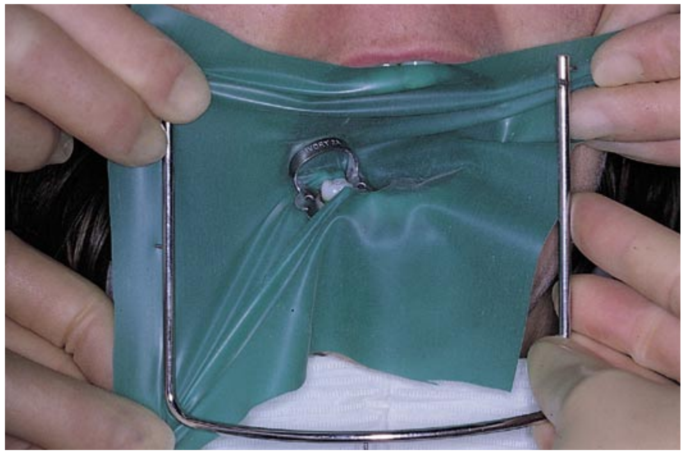
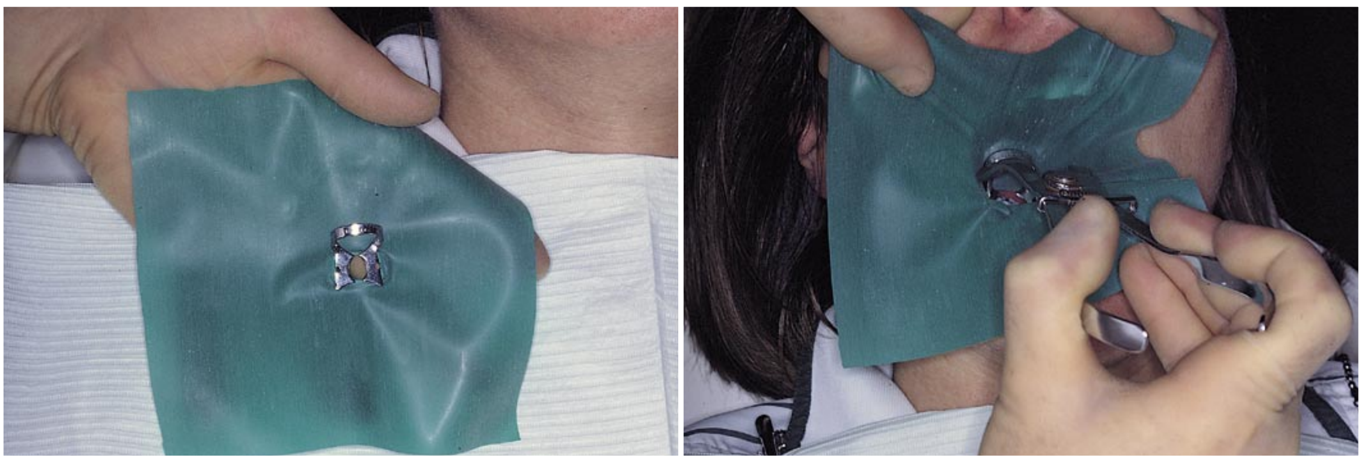


Fig. 10.19. With assistance, the dentist positions Young's frame.



A B

Fig. 10.20. Positioning of the dam can be performed without the help of an assistant. **A**. The perforated dam has been stretched over the wings of the clamp. **B**. While the dentist's left hand supports the upper margin of the dam, his right hand positions the clamp around the tooth.

clamps (Fig. 10.21). One can also put the clamp on a dam that has already been placed onto a frame and position the entire assembly in the patient's mouth (Fig. 10.22). Finally, one can place the clamp on the tooth and then slip the framed dam around it (Fig. 10.23).

Fig. 10.21. Positioning of the rubber dam with a wingless clamp. **A**. The clamp's arch is passed through the dam's opening. **B**. The rubber dam clamp forceps are introduced into the clamp's openings. **C**. The dam is folded with the clamp at the tip, while the clamp is moved toward the tooth. **D**. The clamp has been positioned. **E**. The dam is stretched with Young's frame. **F, G**. The dentist is sliding the dam completely below the clamp with the fingers.

Fig. 10.22. A dam with a winged clamp has been stretched over Young's frame. The clamp, dam, and frame are positioned in the mouth as a single unit.

A

B

C

Fig. 10.23. **A**. A wingless clamp has been positioned around the tooth. **B, C**. The rubber sheet has been slid below the clamp, which is already in place.

The technique most commonly used is that described in Fig. 10.12.
Removal of the dam is easy, as all one needs to do is to take away the clamp. If several teeth lie beneath the dam and one of them has a temporary or recent restoration, it is preferable to cut it and extract it from below rather than passing the rubber sheet through this delicate contact area (Fig. 10.24). Once it has been removed, the dam must always be checked so that no small fragments are left below the contact areas.
In the case of incompletely erupted teeth that are very conical or where the bulge is apical to the gingival crest, there are no undercuts to prevent the clamp from sliding coronally.
In such cases, one can resort to an expedient that takes a few minutes but allows one to work as one should. One can acid etch the enamel buccally and palatally or lingually to allow the adhesion of two small ribbons of composite resin, which serve as areas which the clamp may grip.[14,28]
These composite ribbons must not interfere with the periodontium, but must be positioned 1 or 2 mm from the gingival margin to allow positioning of the clamp. The lingual or palatine spots should not interfere with the future access cavity or the occlusion. They will require smoothing, so as not to damage the lips, especially if, as in the case of Fig. 10.25, they must be left in place for several months and multiple appointment procedures.
In the case of very damaged teeth which require immediate attention, such as for esthetic reasons, it may be useful to anchor the dam to the adjacent teeth (Fig. 10.26).

Fig. 10.24. To facilitate its removal, the dam is cut rather than passed through the interproximal contact.

The dam's stability can also be maintained with the help of small rubber fragments of the rubber dam itself, which are passed below the contact areas of the adjacent teeth (Fig. 10.27). In particularly crowded teeth, such fragments may even substitute for the dam clamps (Fig. 10.28). Special elastic wires are also available in different thickness (Fig. 10.29), to stabilize the dam in the same way.

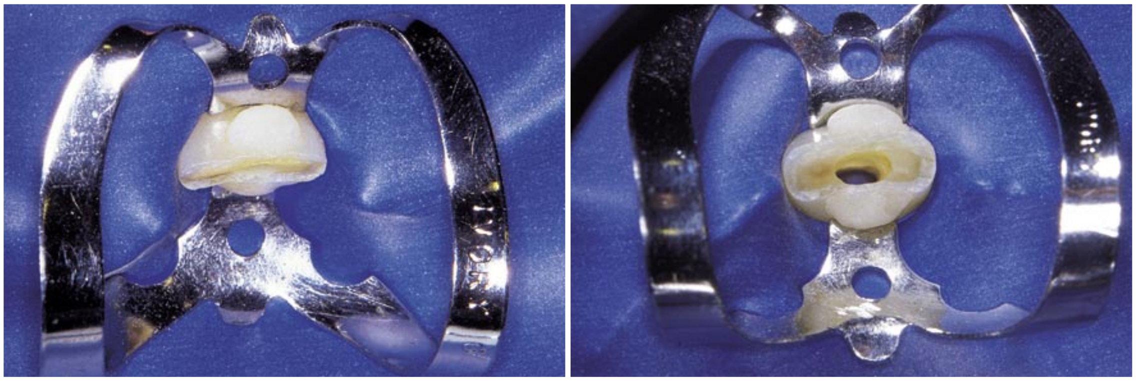

A B

Fig. 10.25. **A**. The fractured tooth requiring endodontic treatment still has not completely erupted, and its height of contour is still apical to the gingival margin. To position the rubber dam clamp, it was necessary to polymerize two spots of composite resin on the buccal and palatal enamel. **B**. Access cavity created on the fracture rim. Note the two composite spots that hold the clamp in position.

Fig. 10.26. The dam has been placed on the canine and central incisor to allow endodontic therapy of the root of the lateral incisor.

Fig. 10.27. The dam is kept in place by a clamp positioned on the mesial tooth and by a fragment of the dam which has been passed beneath the distal contact area of the distal tooth.

Fig. 10.28. Since the front teeth of this patient were so crowded, there was no space for the clamps. The dam is kept in place by two fragments of the dam which have been passed under the distal contact areas of the lateral incisors.

A

B

C

Fig. 10.29. **A**. Elastic wires of different thickness to keep the rubber dam in place. **B, C**. The clamp was interfering with the mirror used in this particular case for documentation purposes, therefore the elastic wires were used.

When treating endodontically a bridge abutment or a tooth with an intracoronal splinting or orthodontic wire, one can use various techniques to ensure that the dam isolates the field from saliva well:

– Suturing of the dam below the connections of the prosthesis or splinting.[4,20]
– Use of cavity varnishes (for small defects), cavit, Orabase,[25] oral adhesives, periodontal dressing,[29] Rubber base adhesive,[7] mixture of denture adhesive and zinc oxide powder (PGZ),[30] or Oraseal (Fig. 10.30-10.32). The last mentioned is the material of choice, because it is very easy to use.

In the case in which the tooth under treatment is connected to the adjacent teeth by orthodontic wire, one can try to position the clamp above the orthodontic attachment and wire (Fig. 10.33).

Fig. 10.30. Oralseal is the material of choice to improve the sealing of leaking rubber dams.

If the tooth requiring endodontic treatment is particularly damaged, so that the clamp cannot be positioned stably, it must be pre-treated (see Chapter 12) so as to allow adequate positioning of the rubber dam. An easy and fast way to pre-treat the damaged tooth is curing a “collar” of dentin bonding, after acid etching the dentin (Fig. 10.34). Another suggestion could be positioning the clamp on a distal tooth, so that the elasticity of the dam doesn’t interfere with the tooth to be treated, where a second clamp can be gently positioned (Fig. 10.35).

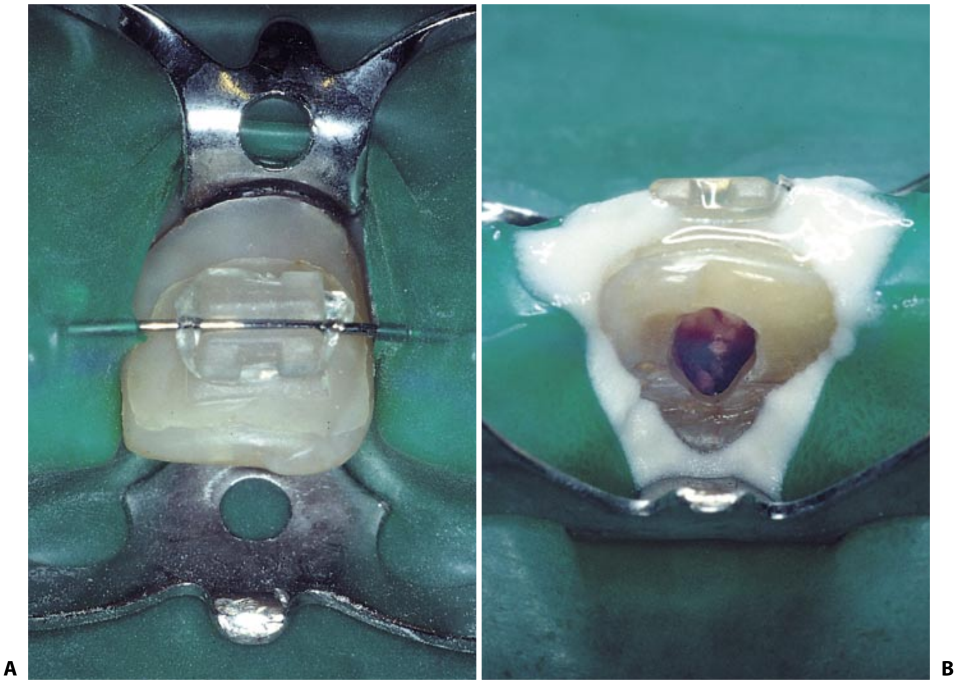


Fig. 10.31. **A**. The orthodontic wire precludes tight sealing of the rubber sheet. **B**. A tight seal has been achieved with Oraseal.

Fig. 10.32. **A**. The presence of the welding hampers the dam from passing below the contact area. **B**. Oraseal helps to obtain an equally good seal.

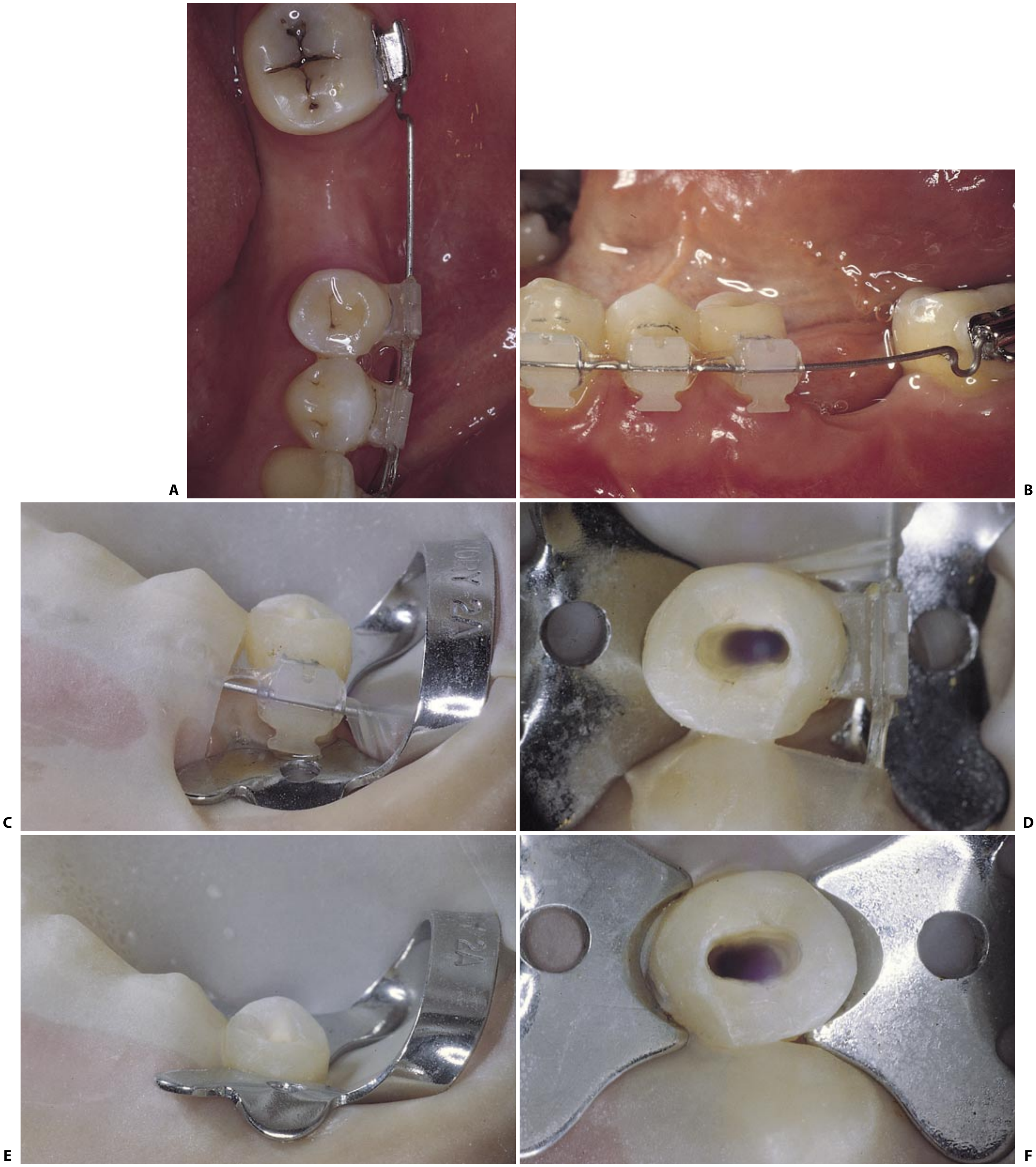


Fig. 10.33. The lower left second premolar requires endodontic therapy. **A**. Occlusal view. **B**. Buccal view. **C, D**. Positioning the clamp below the orthodontic attachment, the dam straddles the wire and therefore does not seal. **E, F**. The clamp has been positioned above the orthodontic attachment and wire; thus, the dam seals perfectly.

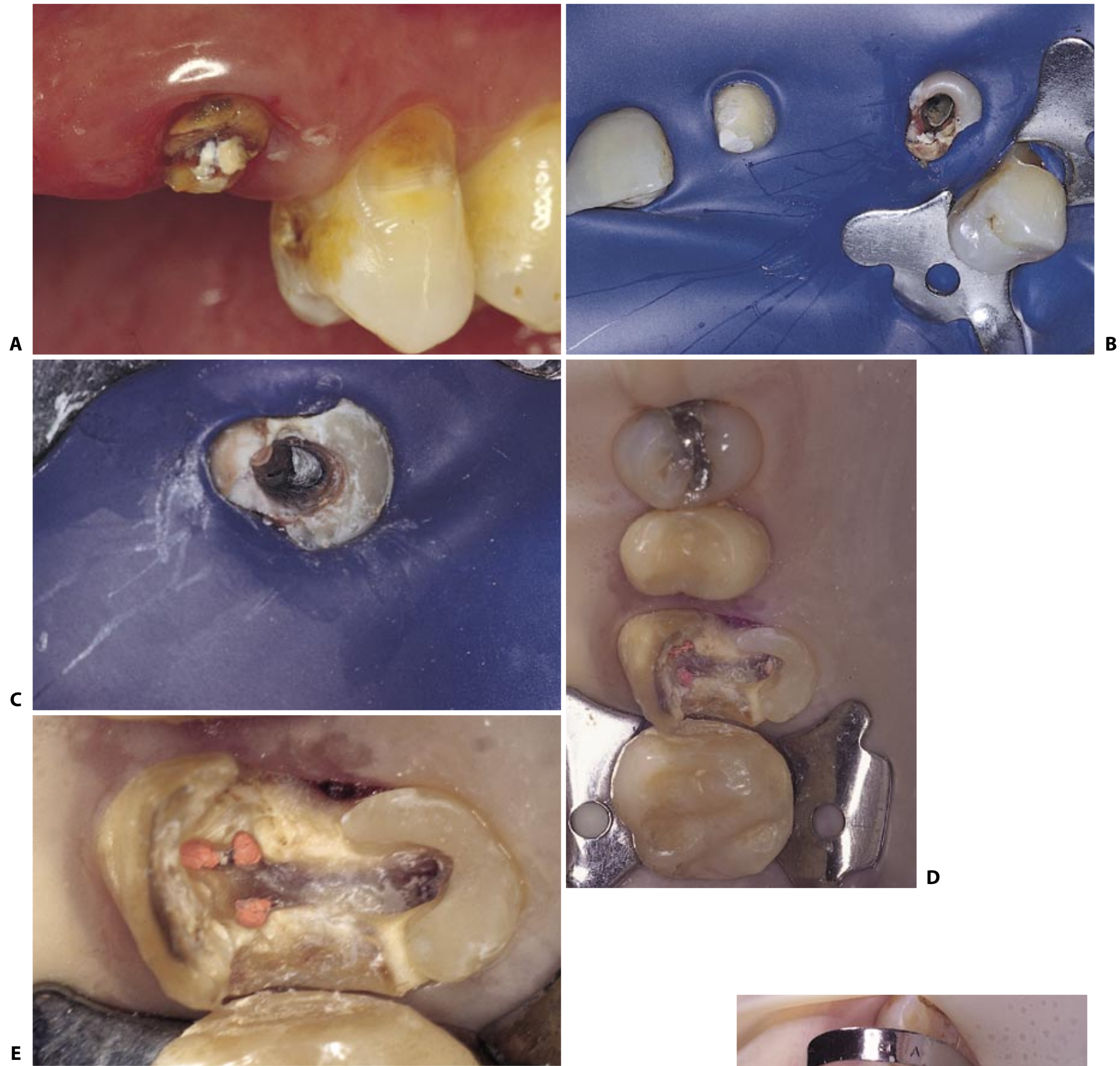


Fig. 10.34. **A**. The upper left cuspid has no crown. The patient had esthetic problems, which precluded a crown lenghtening procedure to be done before the endodontic retreatment. **B, C**. The clamp has been positioned on the adjacent premolar and also the two central incisors have been isolated. A small "collar" of composite has been cured on the buccal aspect of the root of the cuspid. **D, E**. The same kind of pretreatment was done to the first molar, to have a more stable rubber dam clamp.

Fig. 10.35. The upper right second premolar has a 45° crown fracture and the 90N clamp keeps sliding under the tension of the rubber sheet. One clamp has been positioned on the second molar and another one (90N) on the second premolar to be treated. Now the elasticity of the dam is pulling on the molar and not at all on the premolar.

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11

Access Cavity and Endodontic Anatomy

ARNALDO CASTELLUCCI

It is well-recognized and universally accepted that a successful outcome in endodontic treatment essentially depends on three factors:

1) cleaning and shaping
2) disinfection
3) three-dimensional obturation of the root canal system.

Although it is impossible to determine which of the three factors is the most important, it is obvious that greater importance should be given to the first; an old axiom in endodontics states that what you remove from the root canal is more important that what you place inside.[77] Proper cleaning and shaping establish the necessary conditions for the success of the next two factors. It would be mistaken to try to disinfect and three-dimensionally obturate a root canal that had not been previously cleaned and shaped.

However, there is one other step that precedes these three. It affects all three and therefore should absolutely not be undervalued or neglected. An error in this preliminary step would compromise all subsequent work.

This preliminary step is the preparation of the access cavity, the opening in the dental crown that permits localization, cleaning, shaping, disinfection, and three-dimensional obturation of the root canal system.

The success of the endodontic treatment depends entirely on precise, proper execution of this step. An access cavity that has been prepared improperly in terms of position, depth, or extent will hamper the achievement of optimal results.[92]

REQUIREMENTS OF THE ACCESS CAVITY

The access cavity must make the succeeding steps easier and safer. It must therefore meet the following requirements:[60,76]

1) Permit the removal of all the chamber contents

As stated above, one of the first steps for a favorable outcome in Endodontics is proper cleaning of the endodontic space, which comprises not only the root canal, but also the pulp chamber and its pulp horns. Cleaning should be as thorough as possible.

Good endodontic cleaning, therefore, begins with the removal of the endodontic contents from the pulp chamber and its horns.

To accomplish this, it is necessary to completely remove the chamber roof. This allows the removal of all the pulp tissue, any calcifications, and all residue or traces of old filling material.

If the chamber roof is not completely removed, it will not be possible to perform proper cleaning of the pulp horns. There are two consequences:

– contamination or infection of the endodontic space that the dentist is trying to clean.
– discoloration of the endodontically-treated tooth (especially the front teeth).

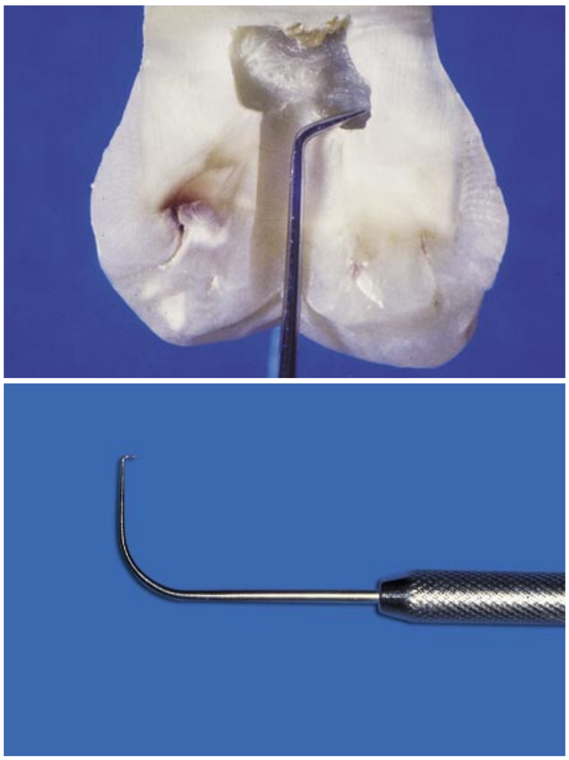
To ensure adequate removal of the roof above the pulp horns, one can use a small, curve probe, such as a # 17 (Fig. 11.1A), as Lasfargues et al.[58] suggest. It is used to probe the walls of the access cavity for the presence of overhangings. Ardines' probes[3] (Fig. 11.1B) are also useful for this purpose.

2) Permit complete, direct vision of the floor of the pulp chamber and canal openings

The entire extent of the floor must be visualized, as its landmarks help in identifying the canal openings. This applies particularly to the posterior teeth: the floor frequently has natural grooves, at the end of which the canal orifices are located (Fig. 11.2).

To meet this second requirement, the access cavi-

ty must sometimes be slightly modified to give it the so-called "convenient shape". Following complete removal of the roof, it is necessary to orient the cavity slightly toward the dentist, particularly when dealing with the molars and patients with limited mouth opening. This gives the walls a slight anterior inclination that facilitates inspection of the floor and thus localization of the canal openings[60] (Fig. 11.3).
Inspection and localization are facilitated by the use of the endodontic probe (Fig. 11.4), which is to the endodontist what the periodontal probe is to the periodontist.[17] By reaching, feeling, and frequently moving the hard tissue, this probe functions as an extension of the dentist's fingers.
The natural anatomy of the floor frequently indicates the site of the orifices. Sometimes, however, restorations, dentinal neoformations, or dystrophic calcifications may alter the original configuration and hide the root canal orifices. Using the endodontic probe to explore the chamber floor, one can enter the canal openings and sometimes displace calcific deposits that obstruct them.



A

B

Fig. 11.1. **A.** With a small, angled probe, such as a # 17, it is easy to confirm complete removal of the pulp chamber roof. **B.** Detail of Ardines' probe, which may be used for the same purpose.

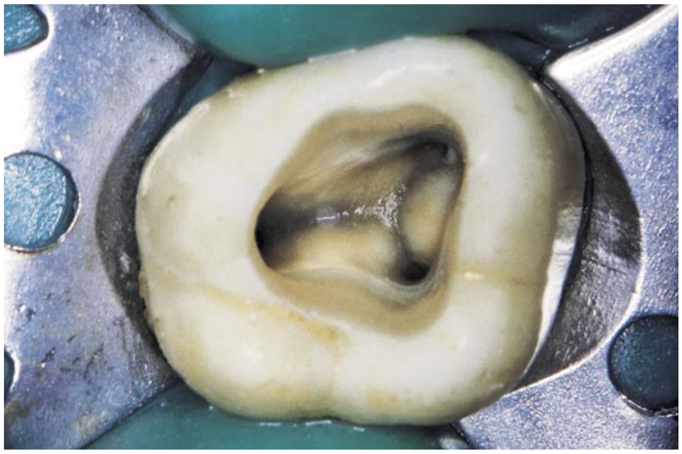


Fig. 11.2. Access cavity of an upper right second molar. Note the grooves in the floor of the pulp chamber, which are excellent natural guides to the canal openings.

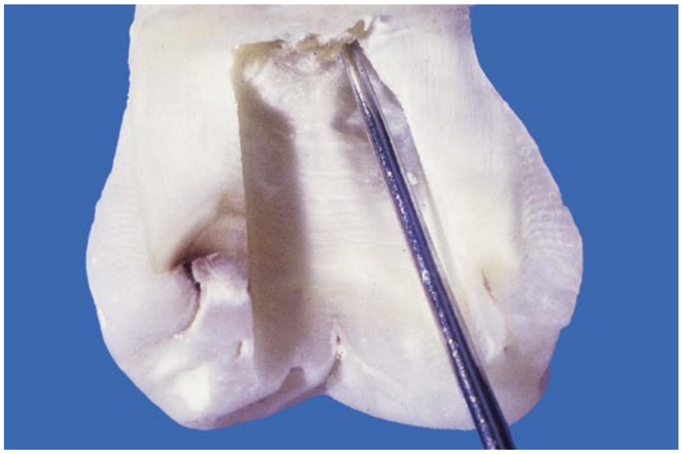
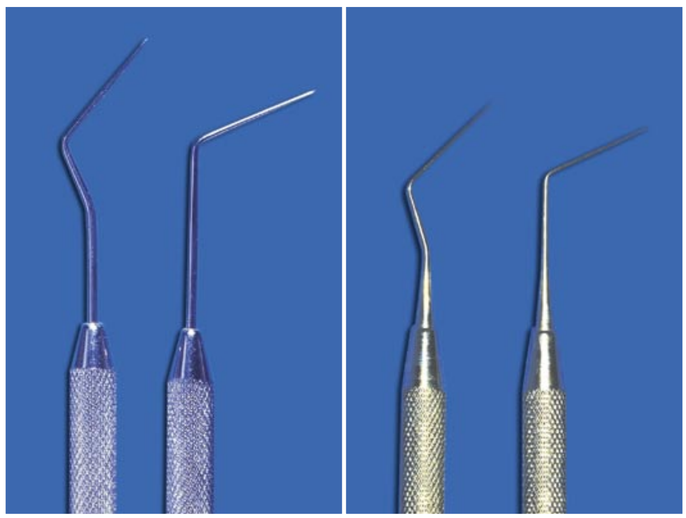


Fig. 11.3. Convenient access cavity shape. The aperture has been enlarged at the expense of the mesial wall.



A B

Fig. 11.4. **A**. Hu-Friedy DG-16 endodontic probes. **B.** The new endodontic probes JW-17 (C K Dental Specialties) designed by John West are very sharp.

Lastly, the endodontic probe can be used to determine the angle between the root canals and the floor of the pulp chamber.

3) Facilitate the introduction of canal instruments into the root canal openings

As stated above, the pulp chamber floor of the posterior teeth frequently has grooves that serve as guides, not only to find the orifices of the root canals, but also to the introduction of endodontic instruments within them.
The floor is also frequently convex and forms an acute angle with the chamber walls. It seems as though Nature had considered the work that the endodontist would have to do. Thus, if the access cavity has been well made and, especially, if the chamber floor has not been affected by the cutting action of the bur, the instruments will enter the canals easily without encountering any obstacles. It suffices to slide the canal instrument along the wall at the point where the canal opening is located. The walls prepared by the endodontist and the floor created by Nature will guide the instrument toward the apex (Fig. 11.5).
If the anatomy of the floor has been modified, resulting in flattening or irregularities, each introduction of an instrument must be checked with a mirror with the pulp chamber free of any irrigating solution, to allow visualization of the canal orifice.

4) Provide access as direct as possible to the apical one third of the canal for both preparation instruments and canal filling instruments

Endodontic instruments should not be deflected by any obstruction in the crown. When working in the canal, they should move freely, particularly in the apical one third (Fig. 11.6).
For a variety of reasons, the endodontic instruments should never touch the walls of the pulp chamber:
– They must be able to work on the entire circumference of the canal. An access cavity that is too narrow will force the dentist to work on only one wall of the canal, while the other remains completely untouched (Fig. 11.7). Deformations of the apical foramen may result.[39,50,60]
– The friction of the instrument's shaft against the coronal obstructions will have to be overcome. The force required to do so impairs the endodontist's ability to sense how much the working portion of

Fig. 11.5. Access cavity in a lower first molar. The convexity of the pulp chamber floor guides the endodontic instruments into the canal openings.

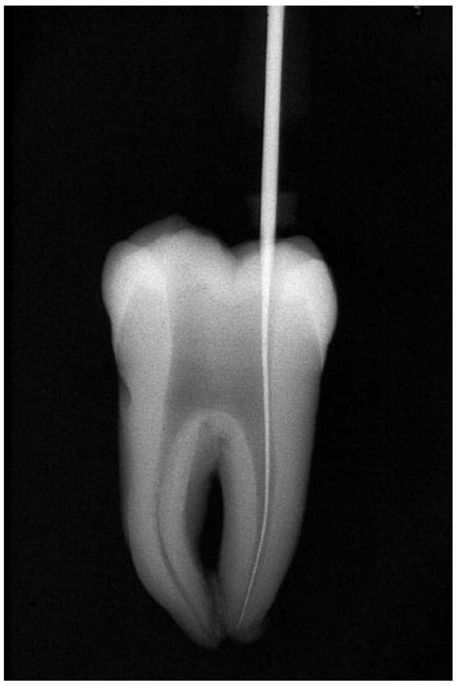


Fig. 11.6. The instrument descends freely into the root canal without encountering any coronal interference.

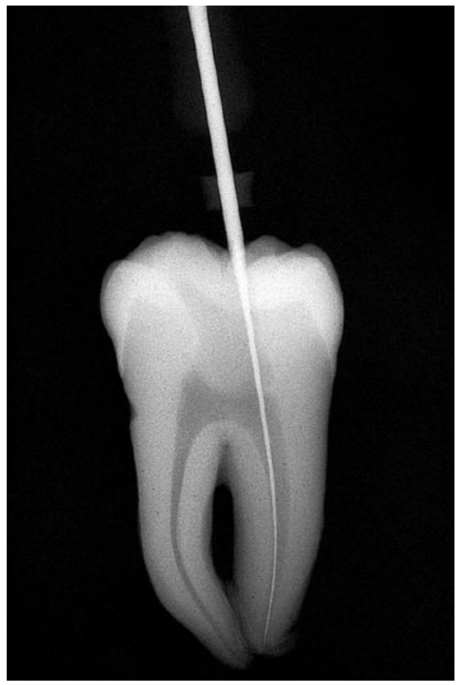


Fig. 11.7. The limited access cavity and incomplete removal of the chamber roof limits the instrument to working on the mesial wall of the distal canal. The opposite wall cannot be cleansed.

the instrument is engaged against the canal walls.[60] This could easily lead to fracturing of the instrument.

To avoid both of these complications, the access cavity must be wide enough to permit the endodontic instruments unhindered entry; there must not even be minimal contact with the walls of the access cavity. This is particularly important with the use of rotary Nickel Titanium instruments.

The cavity need not necessarily remain unaltered throughout treatment; rather, it should be considered subject to modification at any time, if the need arises. If any hindrance arises in mid-preparation because larger and more rigid instruments are called for, one should put down the canal instruments, pick up the high-speed handpiece, and enlarge the cavity as needed until the hindrance has been removed, even if this requires removing a cusp.

To prevent any fragments of dentin or, worse, amalgam or other filling material, from falling into the canal being prepared or into the neighboring canals that have already been cleaned and shaped, it suffices to place small cotton pellets into the canal openings (Fig. 11.8). One principle should never be forgotten: it is always advisable to prepare wide access cavities and generously remove old metallic restorations to avoid having to enlarge the cavity intraoperatively. Such enlargement carries the risk that the handpiece spray will obstruct the canals that have already been prepared or are in the preparation phase by forcing fragments into them.

In markedly curved canals, but particularly in the curves of the coronal one third, obstructions that can reduce the tactile sensitivity of the instruments in the apical one third are encountered not only in the walls of the pulp chamber, but also in the coronal one third of the canal itself. Such curves must be prophylactically eliminated following the "anticurvature" filing method as suggested by Abou-Rass, Frank, and Glick.[1] Obviously, if the access to the apical one third is straight for instruments used in canal preparation, it is also so for materials and instruments used for obturation of the root canal system (Fig. 11.9).

Fig. 11.8. An access cavity made through a prosthetic restoration has been enlarged mesially after the distal canal had already been prepared. The spray of the high speed handpiece has caused metallic filings to fall into the distal root canal.

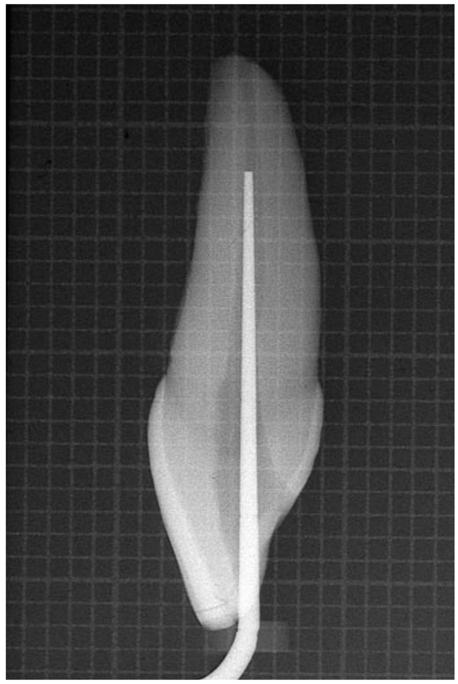


Fig. 11.9. A correctly-made access cavity permits straight-line access to the apical one third of the root canal, even to instruments necessary for canal filling.

5) Provide a positive support for temporary fillings

When the access cavity is temporarily obturated to seal a medication within, the temporary cement must form an hermetic seal to avoid contamination of the cavity. The cement must be unaltered for the entire period of time required (Fig. 11.10), and it must not collapse into the chamber (Fig. 11.11). To prevent this, the walls of the access cavity must be flared slightly in the shape of a funnel, so that the occlusal surface is slightly wider than the floor.

Clearly, this requirement only applies for the duration that the medication has to act; it is therefore useless to enlarge the access cavity too much, as this would pointlessly weaken the residual dental structure. To avoid needless mutilation, the enlarging should not begin at the floor of the chamber, but should affect only the most coronal part of the access cavity, where the temporary cement will be positioned (Fig. 11.12).

If the walls of the cavity are parallel or, worse, if they diverge apically (Fig. 11.13), the temporary cement would be displaced by the force of mastication.
The shape of the access cavity is determined by these considerations. In practice, it should correspond to a slightly enlarged projection of the contour of the pulp chamber floor onto the occlusal surface of the tooth.

Fig. 11.10. Slight flaring of the walls of the access cavity is advantageous for the temporary filling that can thus stably seal the medication placed into the chamber.

Fig. 11.11. Insufficient flaring of the walls of the access cavity has caused the temporary filling to sink into the chamber.

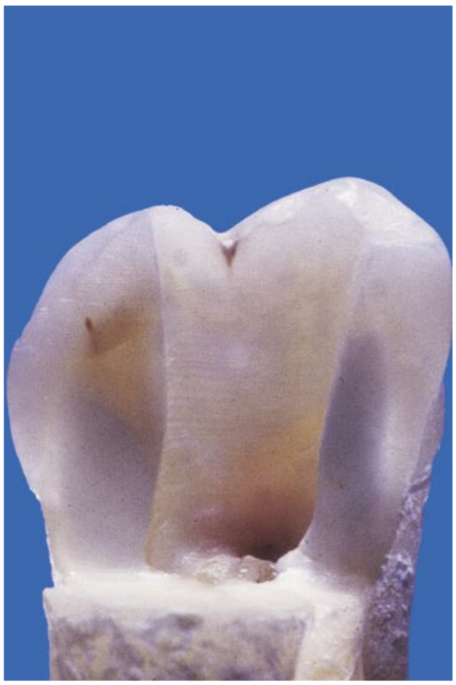


Fig. 11.12. The flaring of the walls should involve only the more coronal part of the access cavity.

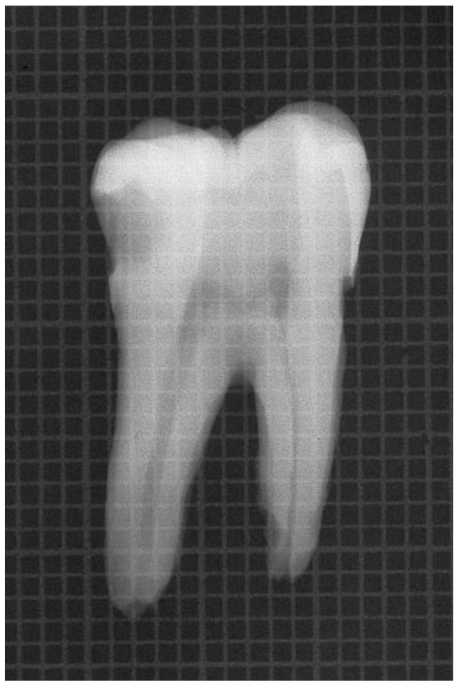


Fig. 11.13. The walls of this access cavity diverge apically rather than coronally. Dislocation of the temporary cement is inevitable.

6) Always have four walls

The four walls of the access cavity serve several purposes:

– correct positioning of the rubber dam so that the clamp is stable and the rubber dam isolates the field well,
– keeping the pulp chamber constantly flooded with as much irrigating solution as possible,
– defining easily recognizable, stable reference points for the rubber stops on the endodontic instruments,
– introducing the temporary medication without affecting the interproximal papillae, as would occur if one tried to use the temporary cement to fill a class II cavity.

When one or more walls of the access cavity are lacking because of previous carious destruction, it or they must be reconstructed with the help of copper bands,[59] orthodontic bands, or other methods (see Chapter 12).

RULES FOR THE PREPARATION OF AN ADEQUATE ACCESS CAVITY

The creation of an adequate access cavity presupposes that the following rules are applied:[92]

1. In creating the access cavity, one must keep in mind not only the position of the canal orifices, but also the position and, more important, orientation of the apical foramen.
   In markedly curved canals, the portion of the access cavity opposite to the curve of the root must be greatly extended (Fig. 11.14). This ensures that the instrument will encounter a lesser curvature than that of the original curve. This is analogous to entering the on-coming lane when approaching a hairpin curve in an automobile so as to increase the radius of the curve and avoid going off the road.
2. The shape of the access cavity differs from that used in restorative dentistry.
   In preparing a cavity for amalgam, the lay out of

A B C D

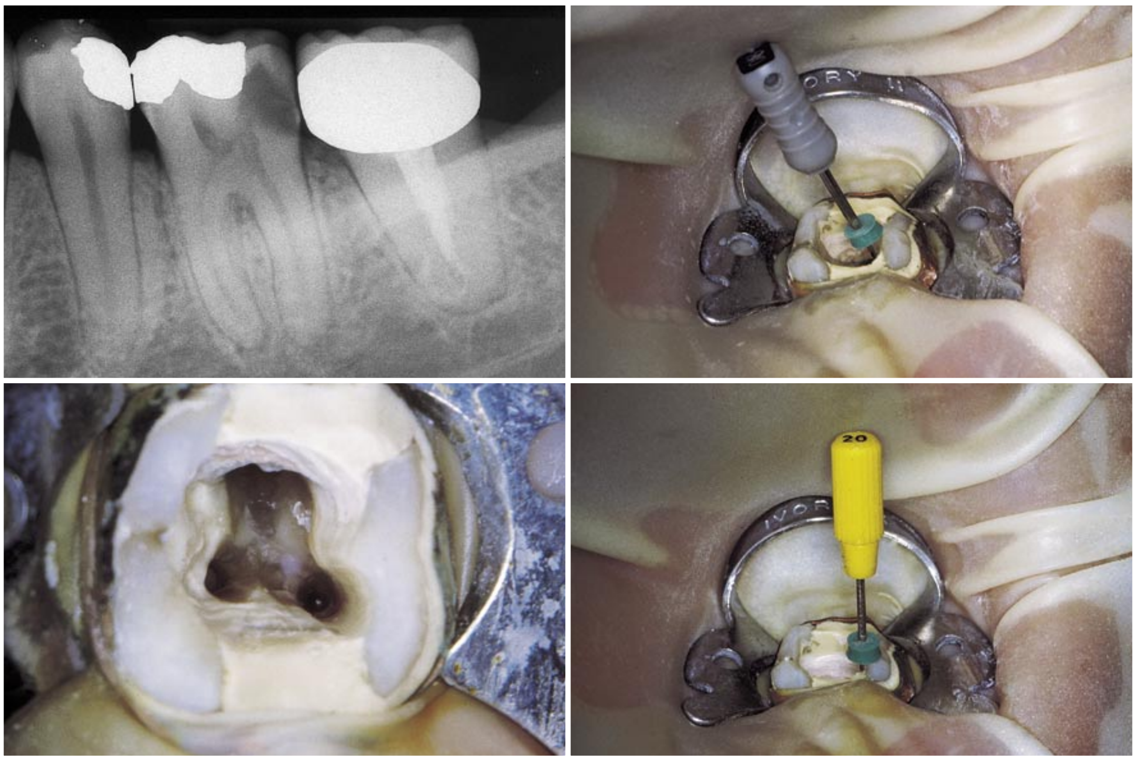


Fig. 11.14. **A**. Preoperative radiograph of the lower left first molar. Note the curvature of the coronal one third of the mesial root. **B**. The # 08 file, introduced in the mesiobuccal canal, indicates that the curvature is directed not only distally, as appreciated radio≠graphically, but also lingually. **C**. The access cavity has been extended mesially and buccally, at the expense of the mesiobuccal cusp. **D**. This instrument, a # 20 file, has straight-line access to the apical one third of the root canal.

the occlusal sulci, fossae, and fissures are pertinent, and one must avoid the underlying pulp.
The access cavity must uncover the pulp; by eliminating the entire chamber roof, rectilinear access to the apical foramina can be obtained through the canals.[92]
3. The access cavity must not assume a pre-determined, geometric shape.
It is not the endodontist, but rather the anatomy of the pulp chamber floor, which determines the shape of the access cavity in each tooth; it can be triangular, elliptical, or trapezoidal. Furthermore, the access cavity need not necessarily remain unaltered during treatment, but can be modified as needed by contingent circumstances.
4. One's familiarity with the anatomy of the tooth to be treated should be as complete as possible. Apart from clinical observation, such familiarity may be acquired from close examination of preoperative radiographs taken with at least two different views.
The endodontist must also be aware of the possible anatomical variants of each tooth, since his eye will recognize what his brain knows, and he will see what he wants to see, but he will not see what he does not know.
5. When the canals are very difficult to find, it is advisable to create the access cavity without using a rubber dam until one reaches the canal openings.[40]
This can be especially useful when treating a tooth that has previously been malpositioned or prosthetically covered, or whose pulp has markedly calcified. The shape and inclination of the adjacent teeth, the gingival tissues, and the hard structures that cover the roots can be helpful in locating the root canals.
Once the access cavity has been made and the canals located, the rubber dam may be placed in position, and the entire treatment may be conducted beneath the rubber dam [92] (Fig. 3.15). If, on the other hand, one cannot do without the rubber dam yet wishes for an overview, Weine [92] suggests isolating an entire quadrant. Frank et al.[40] recommend removing the dam as necessary to get an idea of how the roots enter the alveolus and to obtain a radiograph without the superimposed shadow of a clamp.
6. The access cavity should always be created through the occlusal or lingual surface, never through the approximal or gingival surface, with the exception of very unusual and very particular cases. An approach other than the occlusal or lingual would cause significant bending of the instruments; as a consequence, cleaning and shaping of the canal would be inadequate and the apical foramen would be deformed.

GENERAL PRINCIPLES FOR THE PREPARATION OF THE ACCESS CAVITY

Regardless of the tooth, there are three phases in the preparation of the access cavity: penetration, enlarging, and finishing.

Penetration phase

This phase is performed using a round diamond bur mounted on a high-speed handpiece (Fig. 11.15). The objective of this phase is to "penetrate" the pulp chamber by breaking through the roof with the bur.
If the pulp chamber is wide enough, there is a sensation of "falling into a vacuum" when the roof is penetrated. If, however, the chamber is very narrow or completely absent because of the development of abundant calcifications, one should not expect this

Fig. 11.15. Round, diamond bur mounted on a high-speed handpiece. It is used in the penetration phase. The diameter of the bur required depends on the tooth being treated.

sensation. Rather, one has to scoop out the access cavity to free the canal openings of obstructions, just as Michelangelo unfettered the David of the marble covering it!
If, in drilling a tooth with a completely calcified chamber, one waits for the sensation of falling into a vacuum, it will be too late when it does occur: this would signify perforation.
During this phase, it may help to tilt the bur toward the pulp horn where the pulp chamber is wider.
To facilitate the removal of calcifications, ultrasonics with specific tips, like CPR and ProUltra, are very useful (Fig. 11.16).
Diamond burs are preferred to tungsten burs, because they cut more smoothly and therefore vibrate less and are better tolerated by patients. The diameter of the bur depends on the tooth and pulp chamber being treated.
The opening must not be straight and long; rather, for better visibility and orientation, it should be funnel-shaped, open toward the exterior. Thus, while the bur penetrates until it breaks through the roof, it should also be moved circularly to give the cavity a shape similar to its final one. While the bur penetrates both the enamel and dentin, simultaneously works circumferentially; thus, the movement imparted to it is helical. As stated above, this phase concludes when the bur penetrates into the pulp chamber (Fig. 11.17).

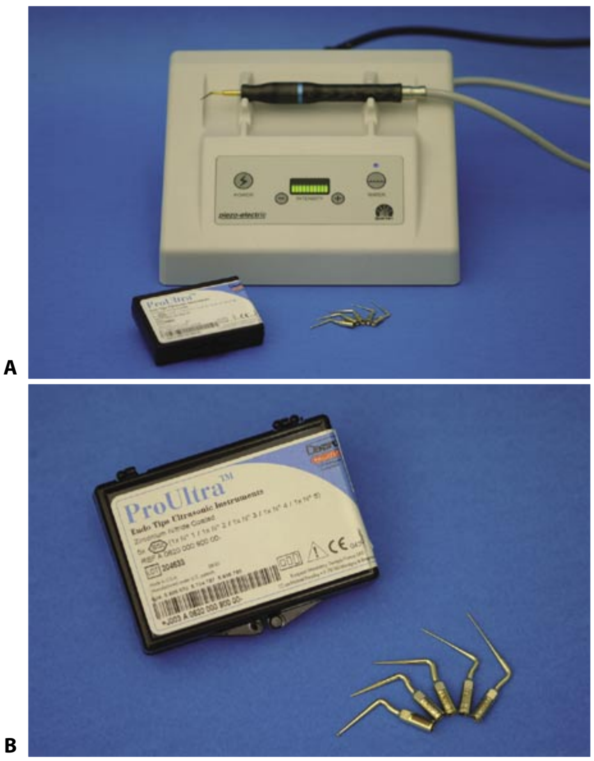


Fig. 11.16. **A**. The ultrasonic source Spartan. **B**. The ultrasonic tips CPR (Spartan Corporation, Fenton, MO) and the ProUltra (Dentsply, Maillefer, Ballaigues, Switzerland).

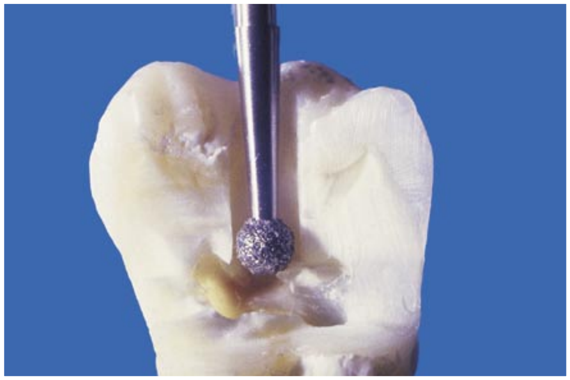


Fig. 11.17. The penetration phase is completed. The diamond bur has broken through the pulp chamber roof.

Enlargement phase

This phase is performed with a round bur mounted on a low-speed handpiece (Fig. 11.18). Its diameter should be slightly smaller than that of the preceding bur, and it should have a long shaft for improved penetration and visibility.

Fig. 11.18. Long-shafted round bur mounted on a low-speed handpiece. It is used for the enlargement phase. The diameter of the bur is always smaller than that of the round, diamond bur used in the preceding phase.

The opening created in the preceding phase is entered, and the action of the bur is applied "on the way out".* It is turned on while exiting the pulp chamber, working on the dentinal walls with a brushing motion. In this way, all the overhangings of dentin left behind in the preceding phase are removed (Fig. 11.19).
During this phase, the definitive form of the access cavity begins to emerge. It will be completed in the following phase.

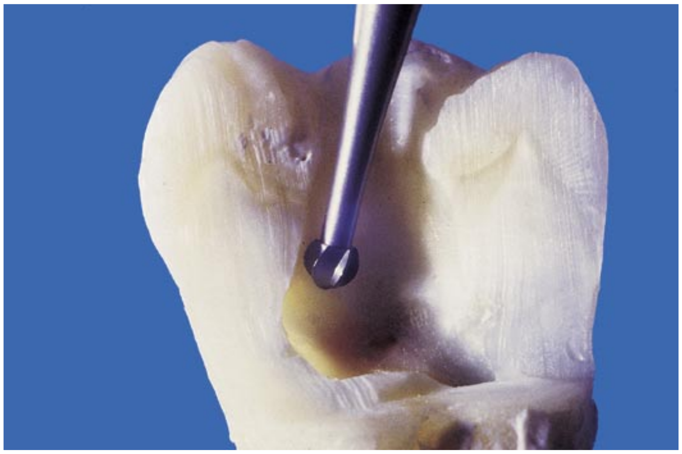


Fig. 11.19. The round bur enters the just-created opening in the chamber roof, is applied to the undercuts of dentin, and removes them on the way out.

Finishing and flaring phase

This phase requires a non-end-cutting diamond bur, also called self-guiding bur, or Batt's bur mounted on a high-speed handpiece (Fig. 11.20). It is used to finish off the work performed during the preceding two phases and to smooth the walls of the access cavity, so that the transition between the access cavity and the pulp chamber walls will be imperceptible to probing. With the appropriate angulation, the same bur is also useful for slightly flaring the most occlusal portion of the access cavity externally, so that it meets the fifth requirement listed above (Fig. 11.21).
The non-cutting head allows one to touch the chamber floor with the bur and at the same time precludes modification of its very important anatomy. The use of a diamond bur on a high-speed handpiece is recommended, as fissure burs at low speed (Fig. 11.22) cause intolerable vibrations when they contact enamel. In this phase, one works simultaneously on dentin and enamel. For this reason, it necessitates the use of a diamond bur at high speed.
Some authors prefer to skip the second phase and after penetrating the pulp chamber, they go directly to the use of a self-guiding bur, which simultaneously eliminates the dentin overhangings and smoothes and flares the walls, avoiding the need to change handpiece and bur.

Fig. 11.20. Non-end cutting diamond bur mounted on a high-speed handpiece, which is used for the finishing and flaring phase.

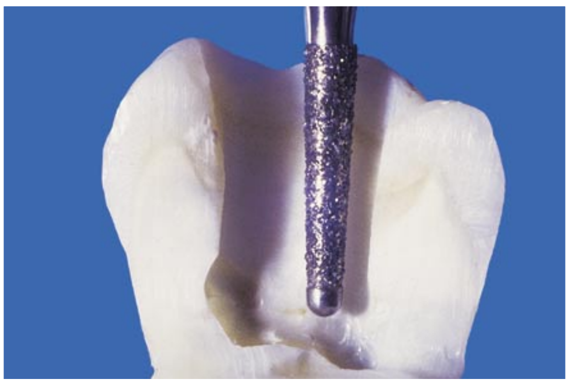


Fig. 11.21. The bur has finished the walls of the access cavity, giving them a slight coronal flare.

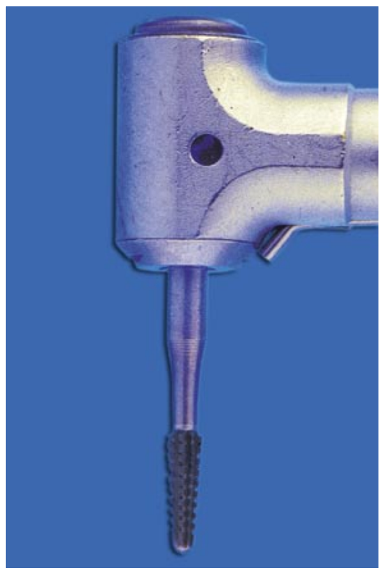


Fig. 11.22. A fissure bur with a non-cutting tip, for low-speed. Its use is not recommended, since it causes too much vibration.

(*) In Endodontics, all instruments *always* work "on the way out", *never* "on the way in".

This can be done if the pulp chamber is free of calcifications. However, if, as frequently happens, the pulp chamber roof has collapsed as far as the floor through the deposition of reparative dentin or if the chamber is full of calcifications, there is no space to work with this bur. In fact, a self-guiding bur would cause the dentin to scorch as a result of overheating created by the friction of its smooth portion against the pulp calcifications. The opening of the access cavity is still limited, and the spray of the handpiece therefore cannot reach the tip of the bur to cool it.

UPPER CENTRAL INCISOR

The access cavity is initiated by applying the bur occlusal to the cingulum (Fig. 11.23), almost perpendicular to the palatal surface (Fig. 11.24).
The cingulum is chosen as a starting point, because, in contrast to the gingival margin which can retract and the incisal margin which can abrade, this ridge remains constant throughout the patient's life.
Once the penetration phase is over (Fig. 11.25), the access cavity is still not complete, as it is still necessary

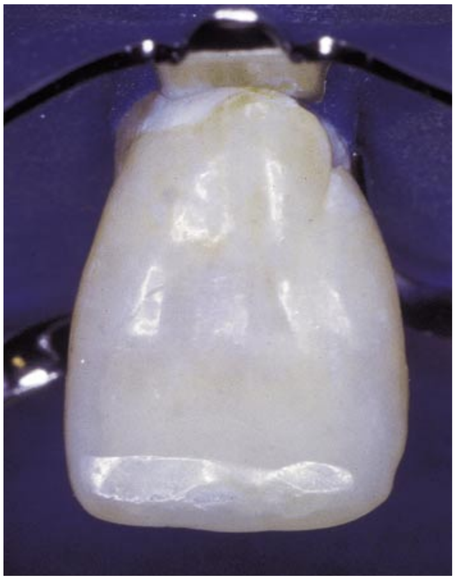
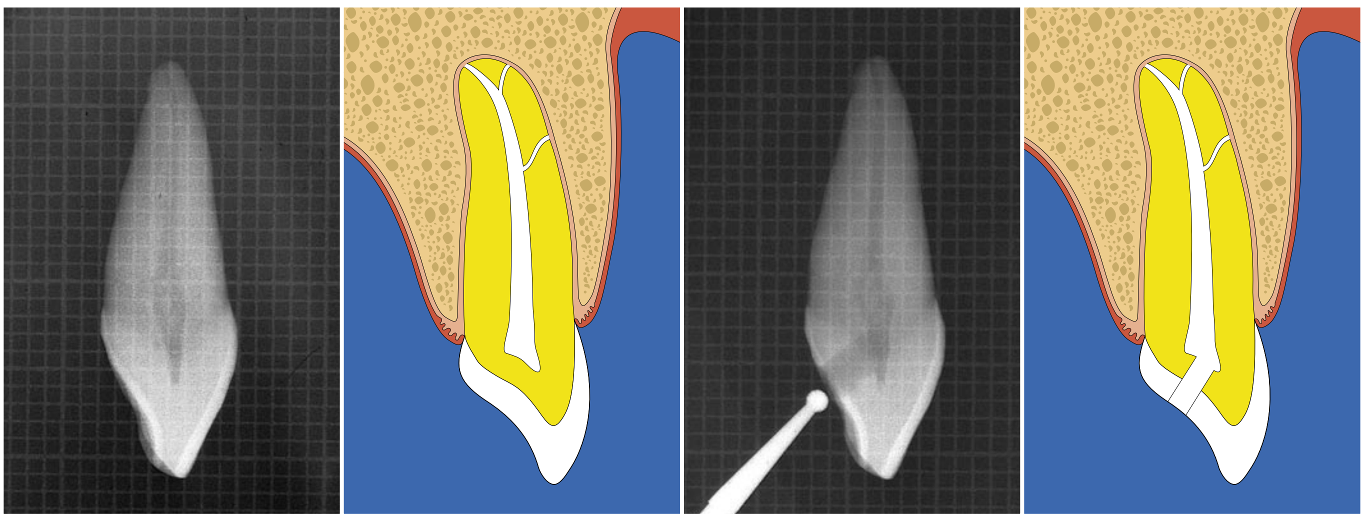


Fig. 11.23. Palatal aspect of the upper central incisor.

Fig. 11.24. The round, diamond bur begins the penetration phase occlusal to the cingulum at a roughly 90° angle to the palatal surface.



A B C D

Fig. 11.25. **A**. Mesiodistal radiographic projection of an upper central incisor. **B**. Schematic representation of the preceding figure. **C**. The round, diamond bur has just completed the penetration phase. **D**. Schematic representation of the preceding figure.

to remove two ledges conventionally called “triangle # 1” and “triangle # 2” during the enlargement phase. The two triangles interfere with the introduction of endodontic instruments so much, that sometimes they may almost completely block the instruments (Fig. 11.26).

“Triangle # 1”, which is essentially constituted of enamel, is removed by the same bur used for penetration, though its angulation and mode of use are different.

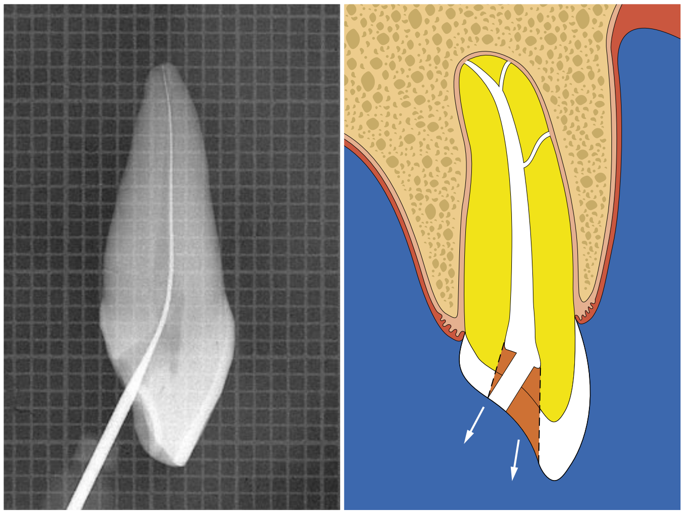
The bur must be held more parallel to the long axis of the tooth (Fig. 11.27). Furthermore, when exiting, the bur must be applied to the enamel edge, which it wears away gradually (Fig. 11.28).

A slight mesiodistal movement must be imparted simultaneously to the bur, so as to remove all of the roof associated with the pulp horns (Fig. 11.29).

“Triangle # 2”, which is predominantly constituted of dentin, is smoothed with a small, long-shafted round bur mounted on a low-speed handpiece (Fig. 11.30). The bur must be introduced into the just-opened aperture, applied to the palatal wall of the canal apically to the point of the triangle of dentin, and is activated on the way out so as to “peel” the small ledge little by little (Fig. 11.31). To finish off the cavity, one can use the self-guiding diamond bur. It must be quite long and thin, and one must ensure that the spray reaches its tip to cool it.

The access cavity achieves a roughly triangular shape with this preparation. This mirrors the anatomy of the pulp chamber, which has one mesial and one distal pulp horn (Fig. 11.32).

Generally, one can obtain straight-line access to the apical one third without having to involve the incisal margin (Fig. 11.33). Where possible, but specifically in teeth that require prosthetic treatment, it is also advisable to extend the access cavity to the incisal margin.



A **B**

Fig. 11.26. **A**. Introduction of a small file after the penetration phase demonstrates the presence of two large coronal obstacles, which impede, if not completely obstruct, the introduction of instruments into the root canal. **B**. Schematic representation of the obstacles encountered by the instruments: the most coronal triangle is conventionally called “triangle # 1”, while the more apical one is called “triangle # 2”.

Fig. 11.27. Removal of triangle # 1 with the round, diamond bur, which is more inclined towards the parallel of the long axis of the tooth.

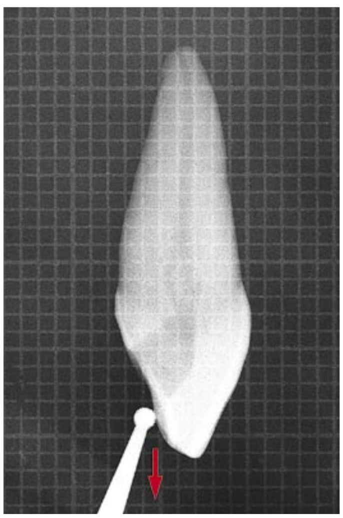


Fig. 11.28. The bur is applied to the enamel ledge, which it wears away on the way out.

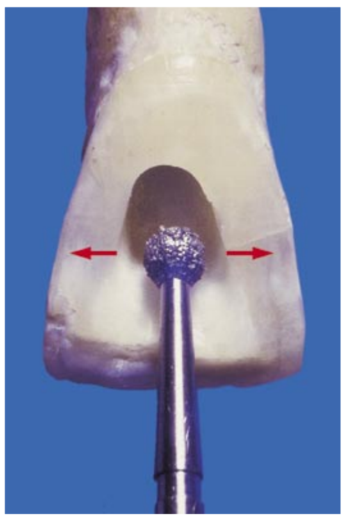


Fig. 11.29. The bur is also used to carry out a mesiodistal movement so as to involve the pulp horns.

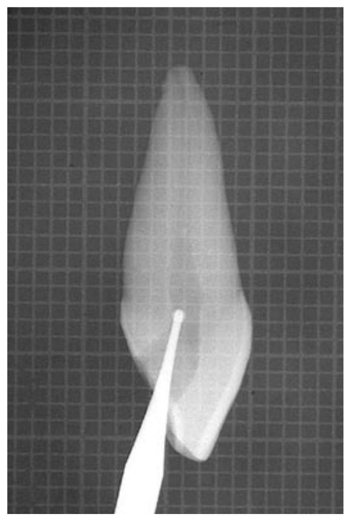


Fig. 11.30. The low-speed, long-shafted round bur is applied to the dentin ledge of “triangle # 2”. The bur is used on the way out, until the triangle is completely removed.

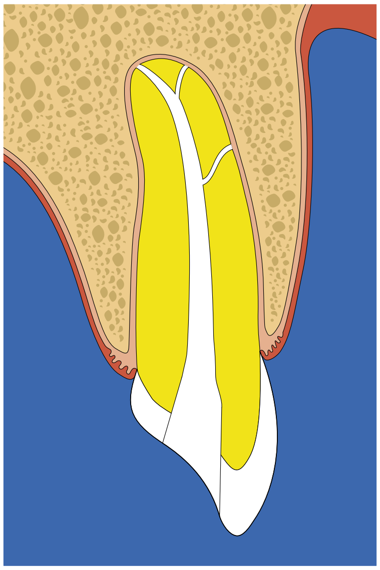


Fig. 11.31. Schematic representation of the access cavity after removal of the two triangles, seen in a mesiodistal projection.

Fig. 11.32. Definitive shape of the access cavity. The involvement of the two horns automatically gives the cavity a more or less triangular shape.

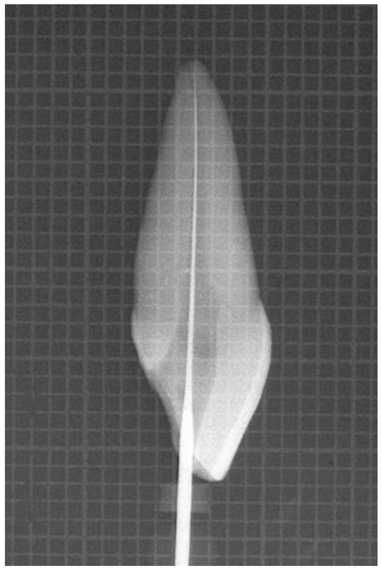


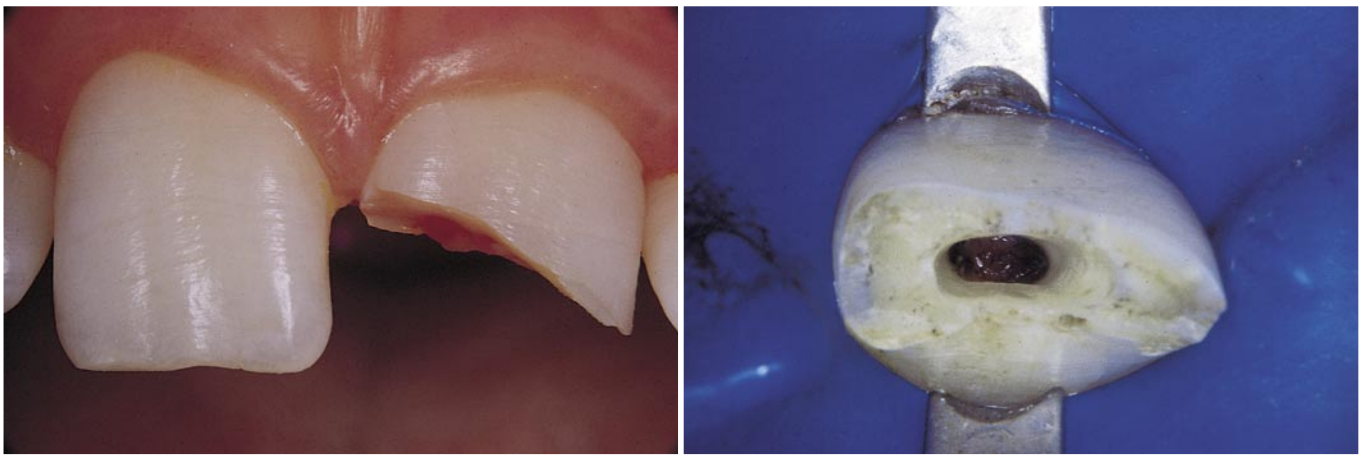
Fig. 11.33. Once the access cavity has been completed, the instrument can be introduced into the apical one third of the root canal without encountering any coronal obstacles. Note that the access cavity has not involved the incisal margin.

This will not only facilitate the endodontist's task, but that of the prosthodontist too, if a post must be used. In a study of 198 extracted anterior teeth, La Turno et al.[57] have found that only 6% of the central incisors had a canal whose coronal projection was entirely palatal and could therefore be approached successfully with an entirely palatal access. In 22%, the projection also involved the incisal edge; in 30%, it straddled the incisal edge, so that it was partly palatal and partly buccal; in 32%, it involved the incisal edge but was completely displaced buccally, and in 10% it was exclusively buccal.

In other words, one can avoid involvement of the incisal edge in only 6% of cases!

There are two situations in which one must necessarily involve the incisal margin: abraded or fractured teeth.

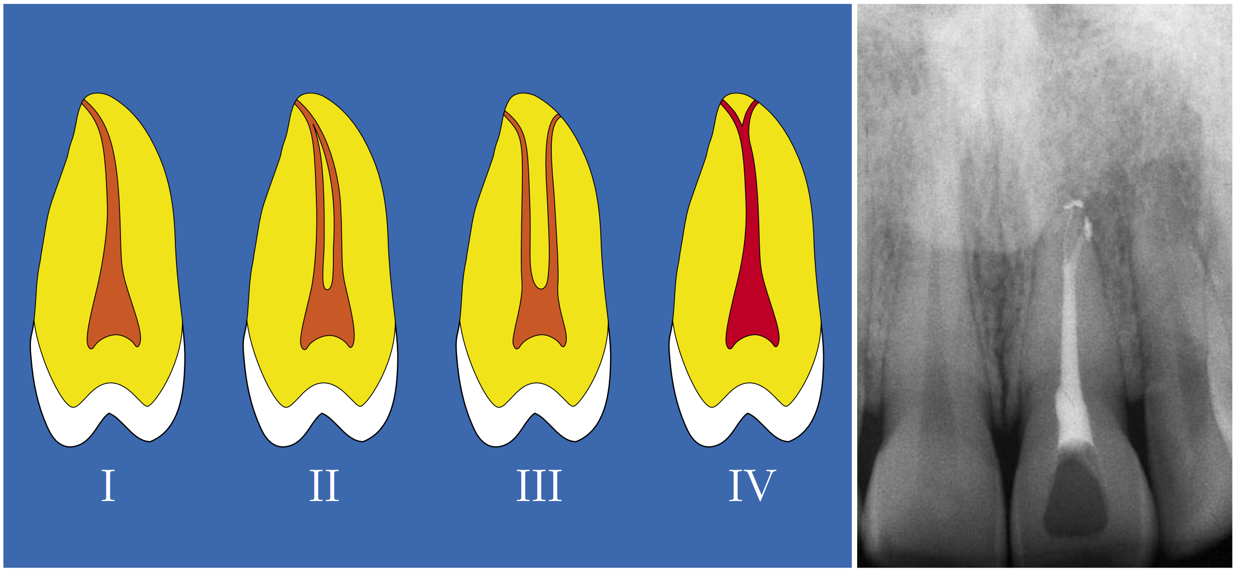
The more abraded a tooth, the more the incisal surface – at this point, one can no longer speak of a margin – will be affected by the preparation of the access cavity. In very abraded teeth or teeth with fractures of the middle one third of the crown, the cavity is prepared entirely on the incisal surface (Figs. 11.34 and 10.25).



A B

Fig. 11.34. **A.** The upper left central incisor has been subjected to trauma, which has caused a fracture of the middle one third of the dental crown, with significant pulp involvement. **B.** In this case, the access cavity has been created entirely at the level of the fracture surface.

The finding of two canals within its root is very rare.[17] However, the canal sometimes divides close to the apex into two very thin canals (Weine's type IV) (Fig. 11.35). The prevalence of lateral canals, which may be found at various root levels, is very high (Fig. 11.36 A, B). Frequently, there is a large lateral canal that branches mesially off the principal canal at a 90° angle about halfway along its course (Figs. 11.36 C, D). Radiographically, the root may present with slight mesiodistal or buccolingual curvatures, though the latter may not be appreciated unless several views are obtained (Fig. 5.41).



A B

Fig. 11.35. **A**. Schematic representation of the four possible canal configurations which may be encountered in a root, as described by Weine. **B**. Upper left central incisor with a canal that divides into three thinner canals near the apex (Weine's type IV).

A B C D

Fig. 11.36. **A**. Intraoperative radiograph of the upper left central incisor. Note the discrete radiolucency situated mesially to the root. This lesion suggests the presence of at least one lateral canal. **B**. Twelve months later. Note the healing of the lesion and three lateral canals filled, one near the apex and two at the level of the middle one third, both facing mesially. **C**. Upper left central incisor with a large lateral canal at the level of the middle one third. The lateral canal faces mesially and branches off from the main canal at a 90° angle. **D**. Upper right central incisor with a small lateral canal near the foramen and another bigger one in the middle one third, facing mesially at a 90° angle.

UPPER LATERAL INCISOR

In this tooth, the access cavity is created in the same way as in the central incisor. The only difference is the final shape of the cavity opening: that of the lateral incisor is ovoid, because the tooth has two closely-situated pulp horns or a single central horn (Fig. 11.37).

Rarely, one may find a canal that bifurcates in the most apical one third into two distinct canals with independent apices (Weine's type IV) (Fig. 11.38).

Very frequently, there is a distal or palatal curvature of the apical one third of the root. Obviously, the latter is not easily recognized radiographically (Fig. 11.39). The presence of a palatal curvature explains why the lesions of endodontic origin of the lateral incisor quite often present in the palatal area (Figs. 8.21, 8.27).

Regarding the involvement of the incisal margin, Zillich and Jerome[100] have conducted a study similar to that of La Turno on the central incisors. Their conclusions are more extreme. In their study of 131 extracted lateral incisors, only 0.8% had a canal whose coronal projection was entirely palatal and thus successfully approachable through an entirely palatal access without having to involve the incisal margin. In 6.9%, the projection was palatal but also involved the incisal margin; in 43.5%, it straddled the incisal margin, indicating that the access cavity would have to be started at the level of the incisal margin and extended equally palatally and buccally; in 32.9%, the projection involved the incisal margin, but was completely displaced buccally; and in 16%, it was exclusively buccal.

This explains why, with inadequate straight-line access to the apical one third of the canal, there is such a high failure rate in treating this tooth and, according to La Turno, it always requires an access cavity that involves the incisal margin, with prosthetic reconstruction of the tooth.[20]

Fig. 11.37. The shape of the access cavity in this upper lateral incisor is ovoid.

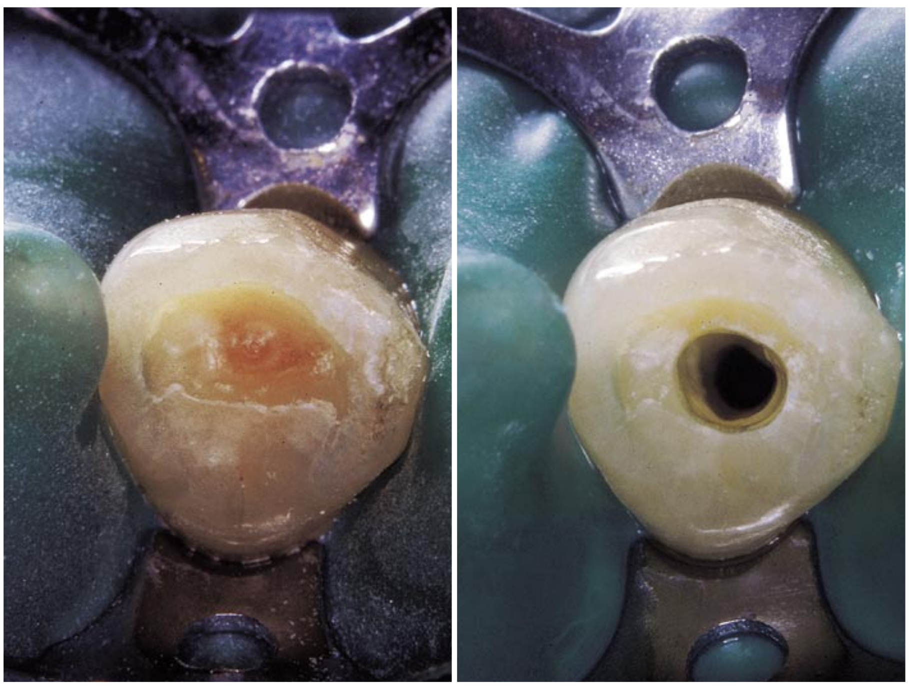
Fig. 11.38. This intraoperative radiograph of this central incisor demonstrates the true endodontic anatomy of the adjacent lateral incisor, which has already been treated endodontically. The angulated radiograph reveals a main canal bifurcating close to the terminus into two thinner canals, each with its own foramen, consistent with Weine type IV. Filling of the bifurcation has occurred automatically during filling of the main canal.

Fig. 11.39. Postoperative radiograph of an upper lateral incisor, with a distal curvature of the apical one third of the root.

UPPER CANINE

The longest tooth of the dental arch, the upper canine is extremely important from the occlusal point of view.
The access cavity begins about halfway up the crown on the palatal side. The same rules that apply to the central incisors are also valid here.
With an ovoid pulp chamber and a single horn, the access cavity is an oval whose larger diameter is apical-coronal (Fig. 11.40). In this case also, if the tooth is abraded or fractured, the incisal surface will be involved in the access cavity (Fig. 11.41).
The root canal is quite straight and long enough to often require the use of 30 mm instruments. In the most apical portion, the root – hence the canal – may present a curvature in any direction.
Less frequently than in the upper incisors, the canines may also have lateral canals. The finding of two canals is very rare (Fig. 11.42).

Fig. 11.40. Ovoid shape of the access cavity in an upper canine.



A B

Fig. 11.41. **A**. The cusp of this upper canine appears very abraded. **B**. The access cavity has been created entirely at the level of the incisal surface.

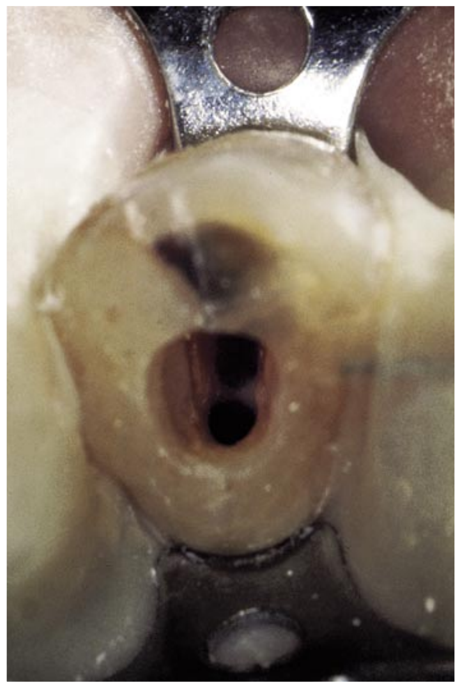


Fig. 11.42. Upper canine with two canals. Two openings can be seen within the access cavity, which has a typical gun-barrel appearance.

UPPER FIRST PREMOLAR

The pulp chamber of the upper first premolar is oriented bucco-lingually. In the great majority of cases, it has two horns – and thus two canals – beneath their respective cusps (Fig. 11.43). The orientation of the access cavity must therefore also be buccolingual, not mesiodistal, as with the cavity created in restorative dentistry.

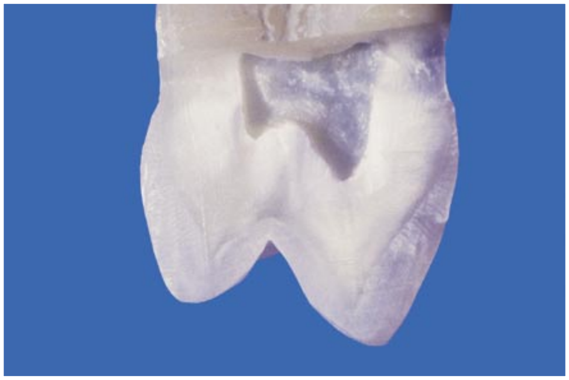
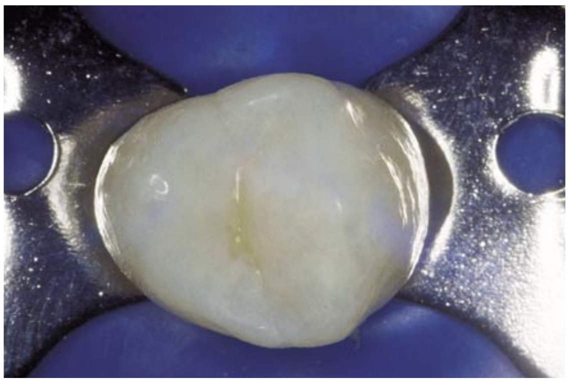


Fig. 11.43. Upper first premolar sectioned longitudinally. Beneath and within the respective cusps, one finds the pulp horns and canal openings.

The two horns are situated just within the peaks of their cusps. The orifices of the two canals are also slightly more within the horns. Thus, one can generally prepare a good access cavity without involving the cusps.
The point of entry of the bur is the middle of the central sulcus (Fig. 11.44 A), and penetration is achieved by drilling parallel to the long axis of the tooth (Figs. 10.44 B, C).
As one penetrates with the round, high-speed diamond bur, one simultaneously applies a bucco-palatal movement to the bur, so as to begin to outline the future occlusal contour of the access cavity. One must keep in mind that the bur used in the penetration phase should not create a parallel-walled tunnel; rather, drilling toward the dentin, it should create a funnel-shaped cavity using a slight helical motion.
Once the chamber is penetrated, a low-speed round bur is used on the way out, to "peel" the undercuts of dentin that remains after penetration (Figs. 10.44 D, E).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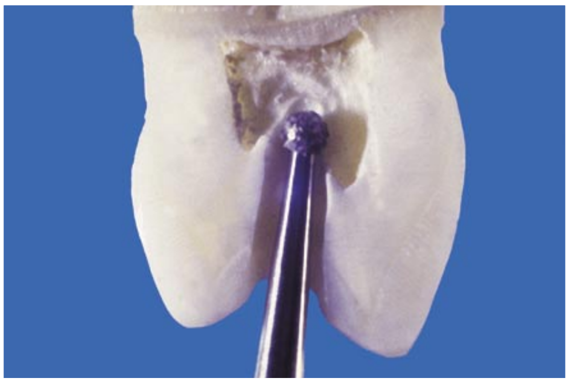
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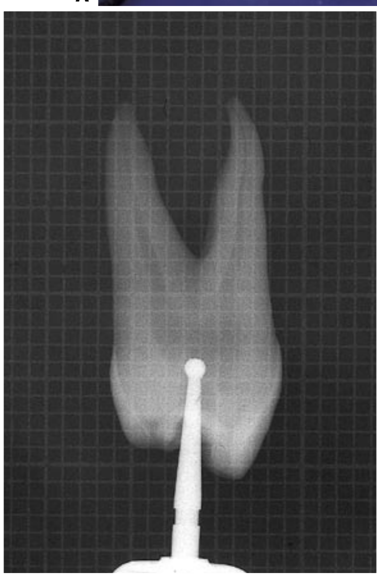
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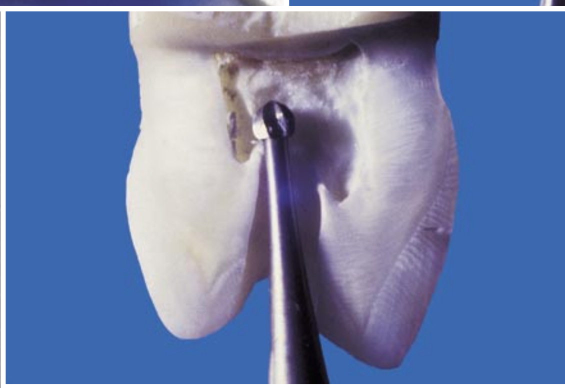
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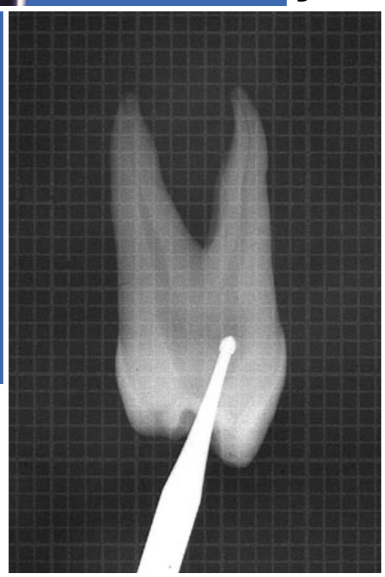
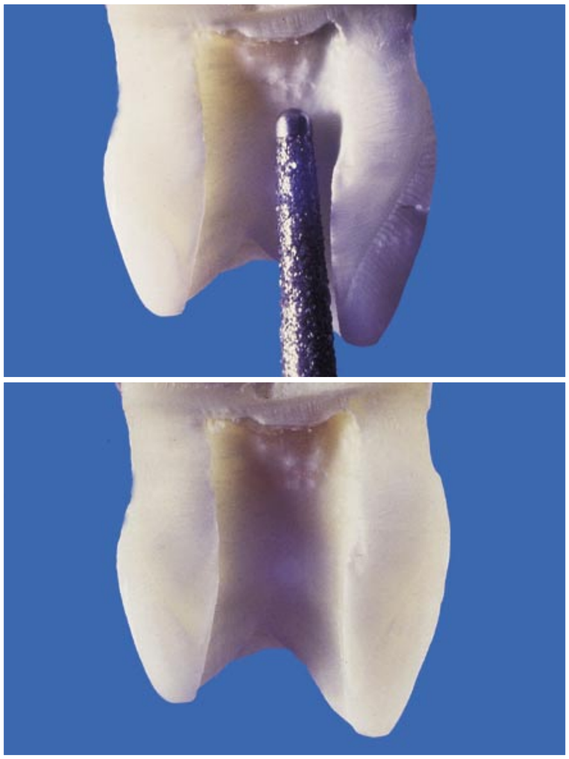
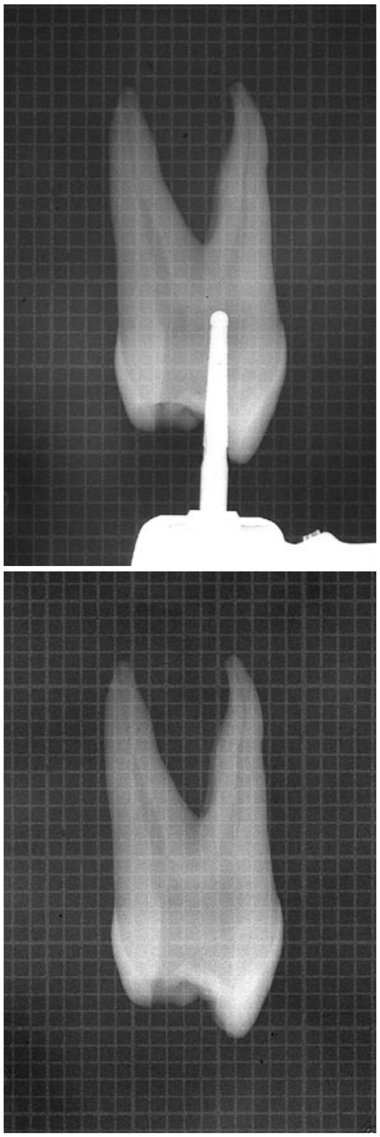

E

Fig. 11.44. **A.** Occlusal surface of the upper first premolar. **B.** The round, diamond bur, penetrating the middle of the central sulcus, has just broken through the roof of the pulp chamber. **C.** The same phase seen radiographically. **D.** Penetrating the opening made by the preceding bur and applied on the way out, the round bur removes the residue of the chamber roof. **E.** The same phase represented radiographically (continued).





F G H I

Fig. 11.44. (continued) **F**. The blunt diamond bur finishes and flares the cavity. **G**. The same phase seen radiographically. **H**. The completed access cavity. **I**. The access cavity as it appears radiographically. The cusp tips are not involved.

Then, with a non-end cutting, high-speed diamond bur, the cavity is finished and flared (Figs. 10.44 F, G). The final shape of the access cavity is ovoid. The larger diameter is oriented bucco-lingually, and it usually does not involve the cusp peaks (Figg. 10.44 H, I). Whether they are involved depends on the degree of divergence of the two roots, and therefore of the two canals. The more divergent they are, the more limited the cavity may be; on the other hand, the more parallel they are, the more likely are the cusps to be involved.

The two canals, which are often joined by a shallow groove, may be located by careful examination of the pulp chamber floor (Fig. 11.45).

Anatomically, the upper first premolars may be quite variable. Bayonet curves of the apical one third of the root are typical of these teeth. Rarely, one may find

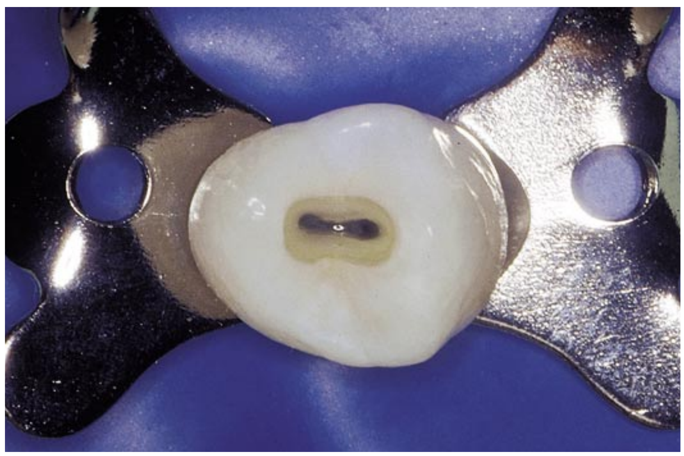


Fig. 11.45. The orifices of the two canals of the upper first premolar are often joined by a groove on the floor of the pulp chamber.

a single, elliptical canal in a single root; more often, one finds two canals with separate apical foramina in a single root, which may communicate in the middle one third (38%), or two canals, usually the same length, in two separate roots (60%).[92] More rarely – in 6% according to Carns and Skidmore[19] and in 5% according to other authors[89] – one may find three roots containing three canals with independent apices. In these cases, the premolar has the appearance of a molar. One wider canal is situated palatally, and two thinner canals are in a buccal position, one mesial and one distal (Fig. 11.46).

Fig. 11.46. **A.** Postoperative radiograph of an upper right first premolar with three canals in three independent roots. **B.** The same patient has a similar endodontic anatomy in the upper left first premolar. **C.** Preoperative radiograph of the upper left first premolar with apparently fused roots. **D.** The off-angled postoperative radiograph shows three canals in three separate roots. **E.** Two year recall. **F.** Preoperative radiograph of the upper right first premolar. This tooth has three roots: the palatal is straight, the two buccal ones are distally inclined. **G.** Three and half year recall.

As always, good endodontic treatment depends on the proper creation of an access cavity: upper premolars with three canals require a modified, "T"-shaped access cavity with a mesiodistal extension in the buccal portion of the traditional cavity. This modification permits good access to both buccal canals.[79] If the three roots are divergent, this can be picked up by careful examination of the preoperative radiograph.[10] If they are very close together or fused (Fig. 11.47A), this may only be discovered intra-operatively. The dentist may suspect the presence of two buccal canals not just by the presence of two openings – which are often not recognizable as distinct – but by the orientation of the endodontic probe when it enters one of them or, better, by the course of the first canal which is negotiated and visualized by an intraoperative radiograph. If the instrument enters a root canal that radiographically appears eccentric with respect to the profile of the root [e.g., completely displaced mesially (Fig. 11.47B)], one may harbor suspicions about the presence of a second buccal canal, whose course is more distal to the first one (Figg. 10.47C, D).

If the buccal bifurcation and therefore the presence of two roots remains undiagnosed, a perforation may occur during the preparation of a post space and the cementation of the post itself in what one might think to be the only buccal canal (Fig. 11.48).

For obvious reasons, it is always preferable to determine in advance the number of canals requiring treatment, even if only to plan better the treatment time required.

In the treatment of prosthetically-treated premolars, it can sometimes be difficult to determine whether the canal that one has found is the buccal or the palatal

A B C D

Fig. 11.47. **A.** Preoperative radiograph of an upper right first premolar. In the presence of fused roots, it may not be easy to detect the presence of three canals. **B.** The first instrument introduced in what seems to be the only buccal opening appears eccentric with respect to the shadow of the root. More precisely, it appears mesially displaced: the instrument has entered the mesiobuccal canal. **C.** Introduced into the same orifice with a distally-facing precurvature, the instrument automatically enters the distobuccal canal. **D.** Thirty-four months later, this radiograph shows the presence of three canals, as well as healing.

one. Looking for the other canal in the wrong direction is very dangerous and can lead to perforation. In these cases, the diagnosis is made very easily by examining a radiograph taken in another view and applying the buccal object rule (see Chapter 5).

Following endodontic treatment of these teeth, most endodontists are in agreement that prosthetic cusp protection should be provided to prevent vertical or crown-root fracture.[17]

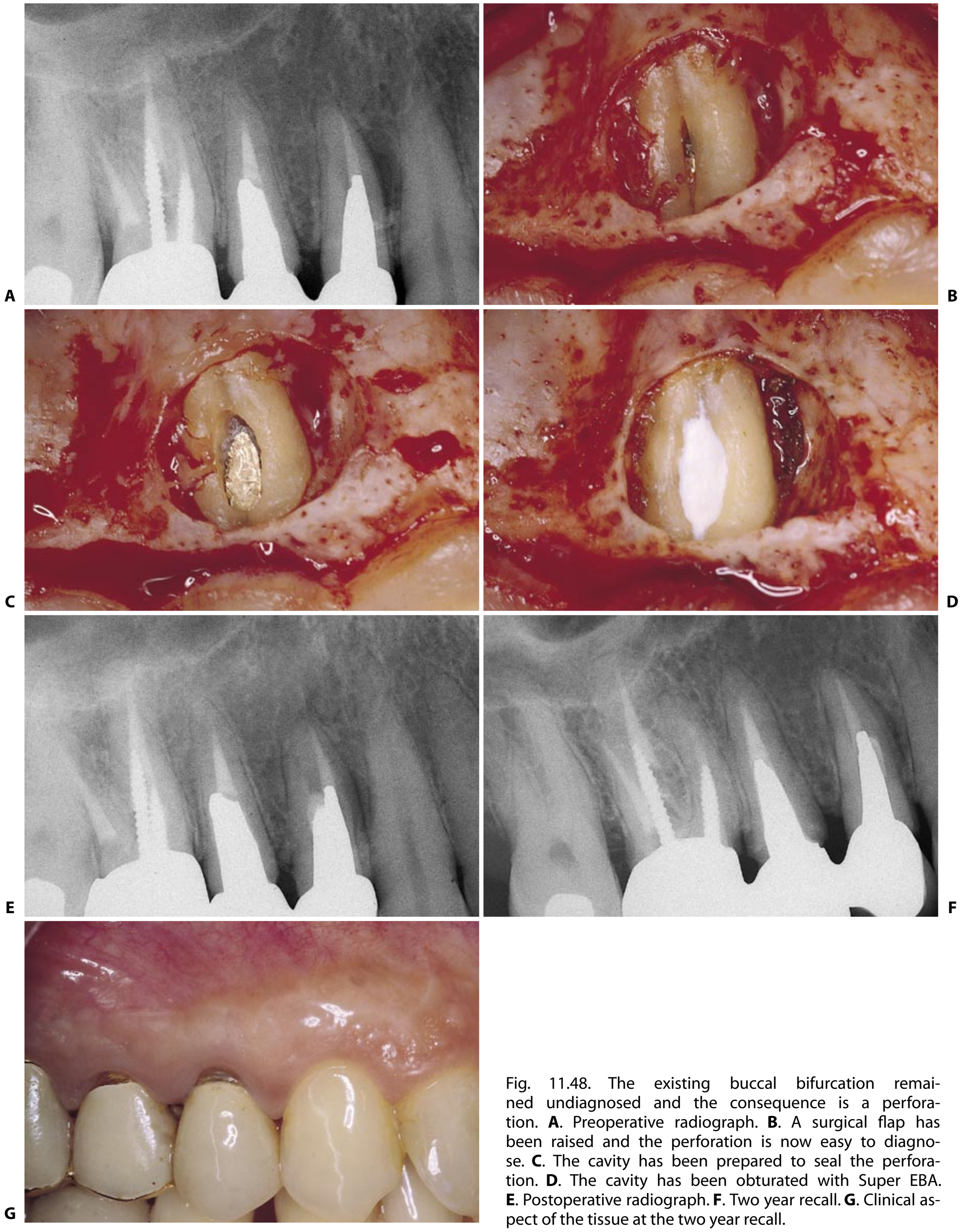


Fig. 11.48. The existing buccal bifurcation remained undiagnosed and the consequence is a perforation. **A**. Preoperative radiograph. **B**. A surgical flap has been raised and the perforation is now easy to diagnose. **C**. The cavity has been prepared to seal the perforation. **D**. The cavity has been obturated with Super EBA. **E**. Postoperative radiograph. **F**. Two year recall. **G**. Clinical aspect of the tissue at the two year recall.

UPPER SECOND PREMOLAR

The procedure for the creation of the access cavity in this tooth is the same as that for the first premolar. Weine[92] states that the second premolar has a single root with a central, ovoid canal in 60% of cases. The canal is sometimes central, but is fissure-like; in which case, the canal is approached and prepared as though there were two, unless there is definitely only one.

The finding of a single, eccentric canal orifice (palatal, for instance) after the access cavity has been opened, indicates that there is another canal opposite to it (buccal, for instance).

In addition to presenting a single, ovoid canal, which is almost the rule, the second premolar can have two completely separate canals that run together into a single foramen or two separate but interconnected canals.

Another possible configuration is a single canal that divides into two branches in the apical one third, one directed buccally, the other palatally (Weine classification type IV) (Fig. 11.49). If one of these two branches goes undetected (usually, the buccal one, which takes a more angulated course), this could lead to treatment failure.

If different radiographic views raise the suspicion of such a configuration, after preparing one canal one must scout the opposite wall with a small, pre-curved file. For example, after preparing the palatal aspect of the canal, one must scout with the precurvature facing buccally. If this small file binds, one has entered the buccal branch of the canal.

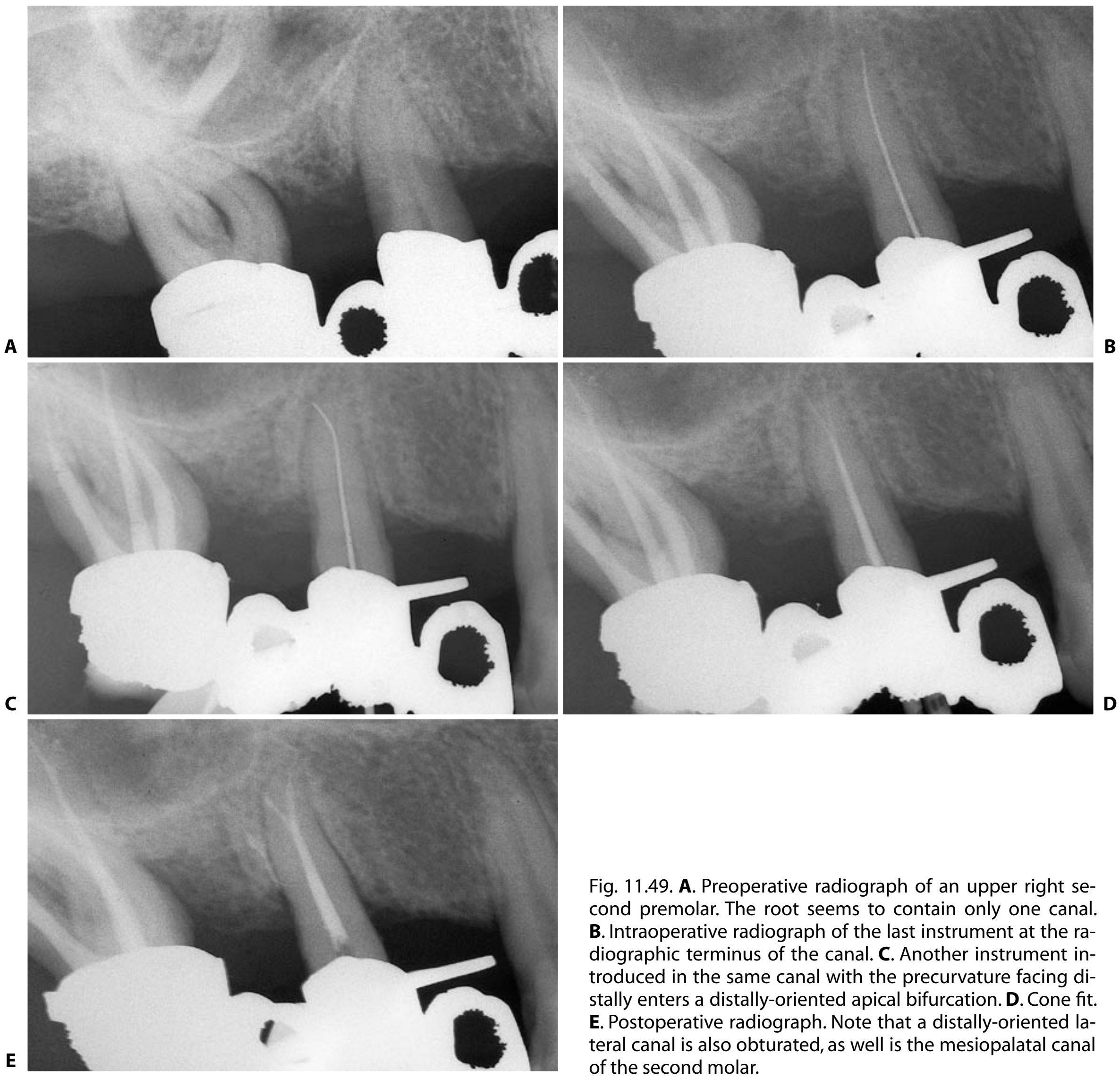
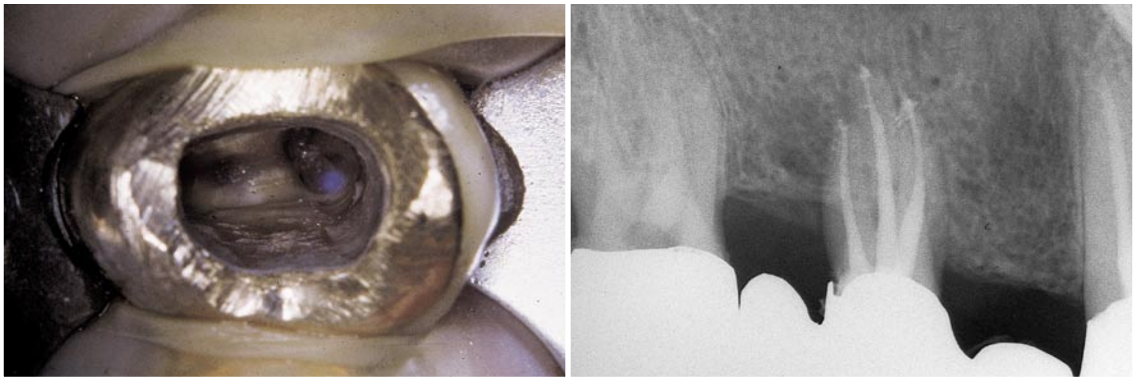


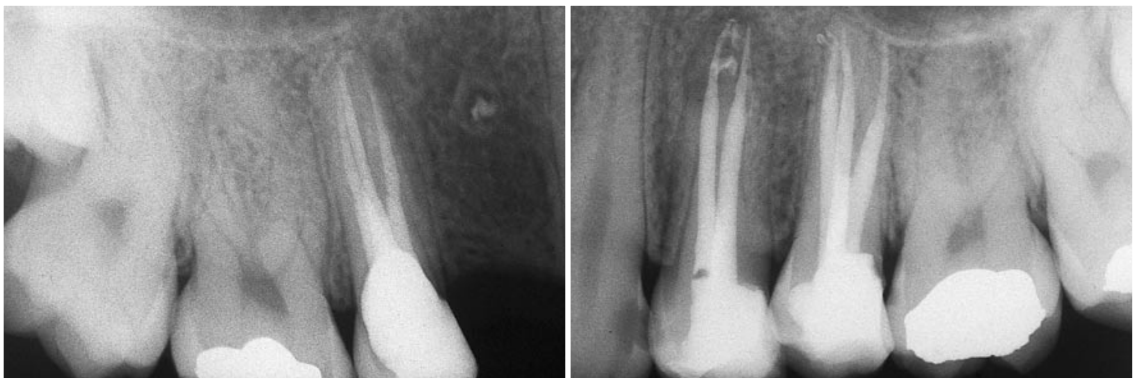
Fig. 11.49. **A**. Preoperative radiograph of an upper right second premolar. The root seems to contain only one canal. **B**. Intraoperative radiograph of the last instrument at the radiographic terminus of the canal. **C**. Another instrument introduced in the same canal with the precurvature facing distally enters a distally-oriented apical bifurcation. **D**. Cone fit. **E**. Postoperative radiograph. Note that a distally-oriented lateral canal is also obturated, as well is the mesiopalatal canal of the second molar.

The prevalence of lateral canals is quite high.
The presence of three canals in three separate roots, as in a molar (Fig. 11.50), is quite rare. Weine[92] states that it is rarer than in the first premolars. Vertucci et al.[90] claim that in only one per cent of cases do the upper second premolars have three canals. In the author's experience, the finding of three roots is more frequent in the second than the first premolars. A certain symmetry has also been noted, in that patients with such canal morphology in one premolar also have it in the controlateral premolar (Fig. 11.51).
The second premolar can also have a bayonet curvature (Fig. 11.52).
Following endodontic treatment, protection of the cusps is recommended.



A B

Fig. 11.50. **A.** Careful examination of the pulp chamber floor of this upper right second premolar reveals the presence of one palatal and two buccal orifices. **B.** This postoperative radiograph confirms the presence of three canals in three independent roots.



A B C

Fig. 11.51. **A**. Postoperative radiograph of an upper right second premolar. The tooth has fused roots but three canals. **B**. The same patient has the same endodontic anatomy in the upper left second premolar. The roots are slightly divergent here, and the three canals are more easily recognized. **C**. Another example of upper second premolar with three canals.

Fig. 11.52. Postoperative radiograph of an upper second premolar, with a bayonet curvature.

UPPER FIRST MOLAR

Together with the lower first molar, this is the tooth that most frequently requires endodontic therapy. It also most often conceals pitfalls or leads to failure.

In the great majority of cases, the tooth has three roots with independent canals. Rarely, there may be two roots with only two canals (Fig. 11.53). The palatal root is the longest and round in cross-section. The distobuccal root is a little shorter, but also roundish in cross-section. The mesiobuccal root is more or less as long as the preceding one, but flatter mesiodistally.

The palatal root is very often curved buccally and this curvature is therefore not easily appreciated radiographically (Fig. 11.54 A). More apically, it is sometimes accompanied by a second, opposite curvature. In

A B

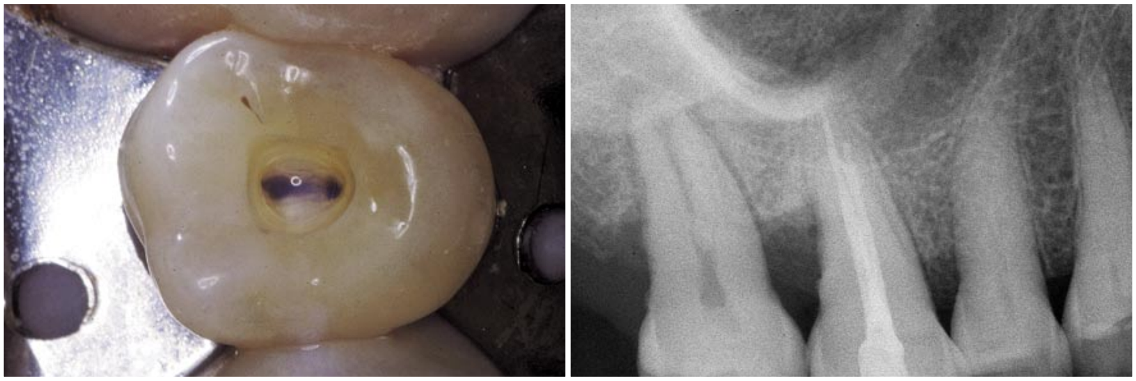


Fig. 11.53. **A**. The pulp chamber floor of this upper right first molar has two orifices, one palatal and one buccal. **B**. Postoperative radiograph of the same tooth. The longer palatal canal and a single buccal canal are visible. The latter has a small bifurcation in its apical one third.

A B C

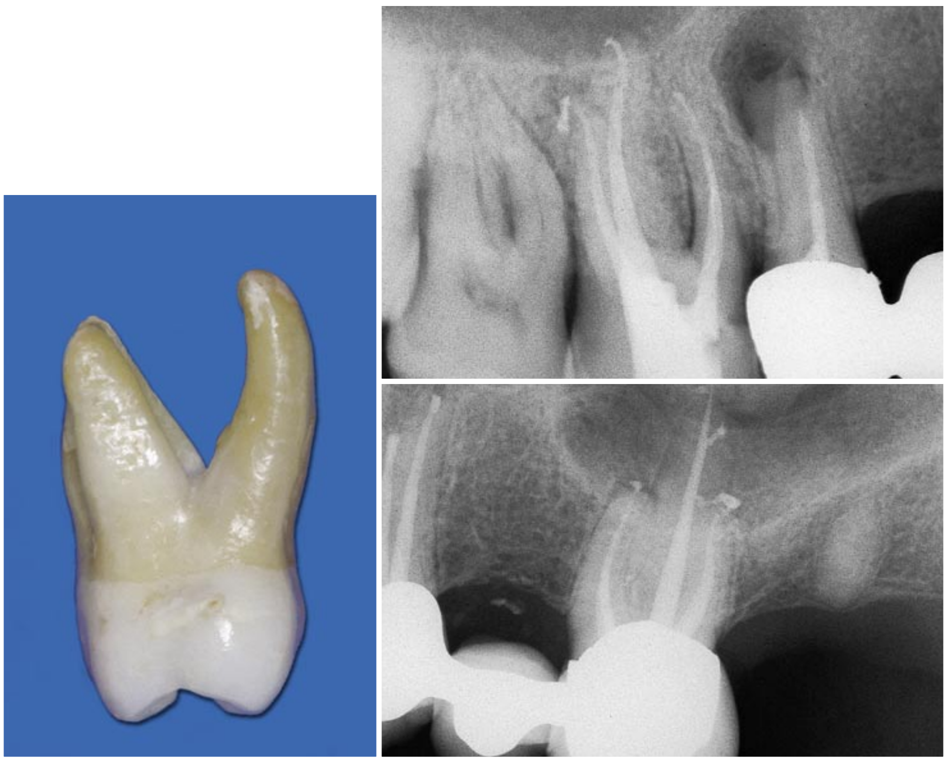


Fig. 11.54. **A**. Photograph of an upper right first molar, seen mesially. Note the curvature of the palatal root, which faces buccally. **B**. Postoperative radiograph of the upper right first molar. Note the sinuosity of the palatal canal. **C**. The palatal canal of this upper molar has a large lateral canal directed distally.

agreement with Pineda and Kuttler,[70] who have found curves in the palatal root of the upper first molars in 81% of cases, clinical experience confirms that this root should always be considered curved, until proven otherwise (Fig. 11.54 B). The orifice of the palatal canal is located beneath the mesiopalatal cusp. The root canal frequently has lateral canals, especially in its apical one third (Figs. 11.54 C, 11.55). More rarely, the palatal root contains two independent canals (Fig. 11.56). This occurs in less than two per cent of cases,[83] but it is equally important to be aware of this possibility. Careful examination of the pulp chamber floor may indicate that this unusual anatomy is present.

Cases of upper first molars with two canals in two di-

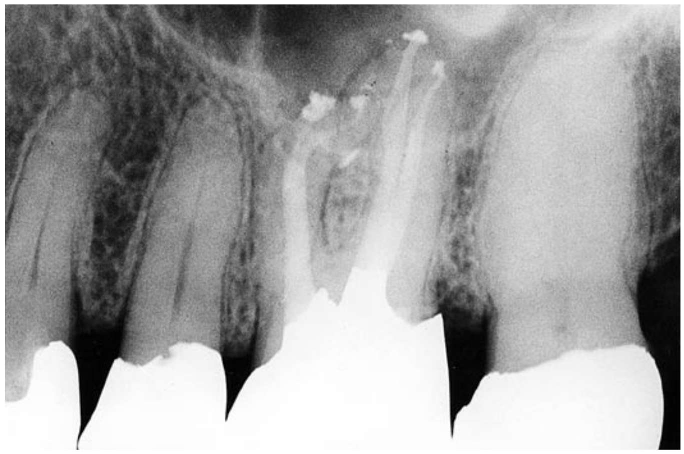
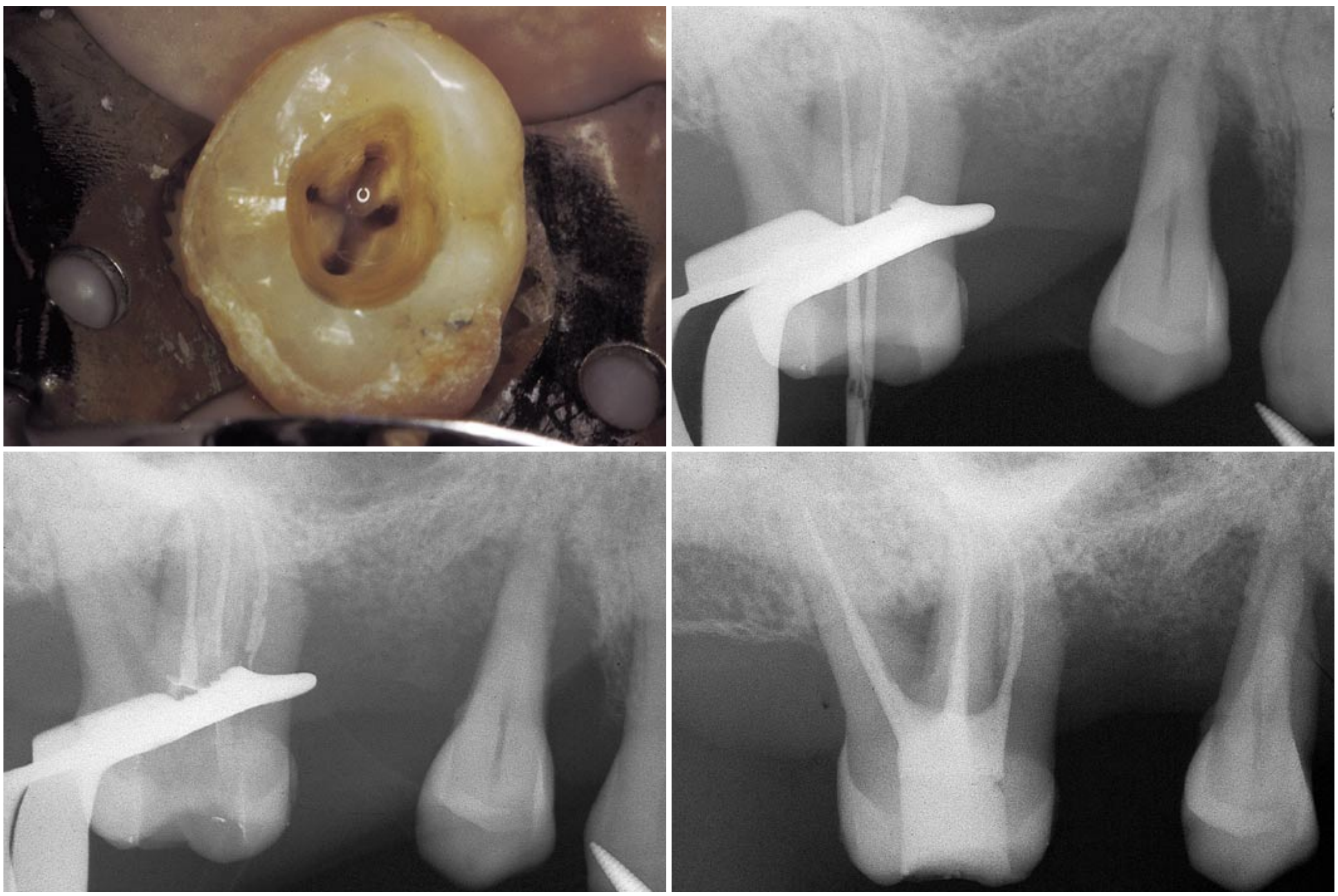


Fig. 11.55. Note the presence of numerous lateral canals in the palatal, as well as mesiobuccal, roots (Courtesy of Dr. C. J. Ruddle).



A B C D

Fig. 11.56. **A**. Access cavity of the upper right first molar with two palatal canals. **B**. Intraoperative radiograph reveals two instruments within the two canals of the palatal root. **C**. Intraoperative radiograph: the two palatal canals and the mesiobuccal canal have been obturated. **D**. Postoperative radiograph.

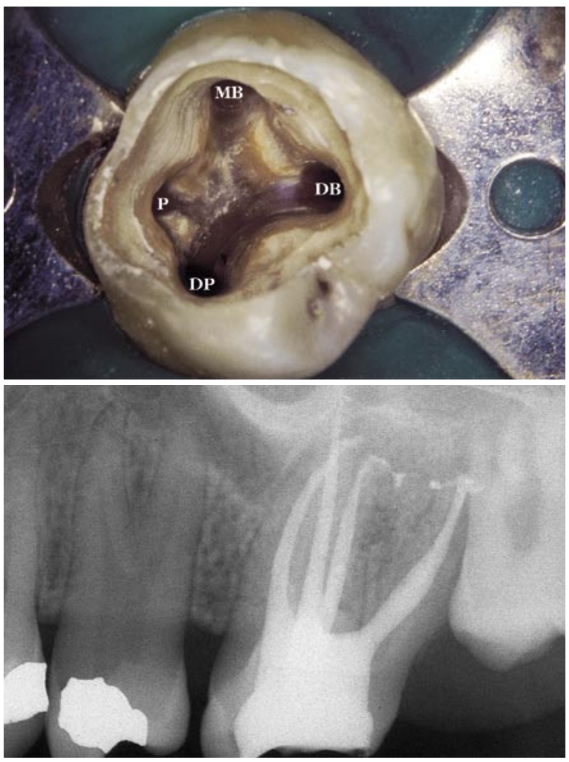
stinct palatal roots[30,31] (Fig. 11.57), two canals in the same root joining at a single foramen,[86] and two canals in the same root with independent foramina[15,46] have been described.

The distobuccal root is usually quite straight, but it may be slightly curved either mesially or distally. The great majority contain one canal whose orifice is not directly related to its cusp but more palatally displaced. However, there are cases of upper molars whose distobuccal root contains two canals, the "extra" or distopalatal canal in a palatal position with respect to the main root canal (Fig. 11.58).

Of the three, the mesiobuccal root is associated with the highest degree of anatomical variability. It is quite flat mesiodistally. This is easily explained if one considers that it may contain a ribbonshape root canal or, much more often, two distinct root canals.

The percentages in which two root canals exist within this root vary according to the various authors, but they all agree on one fact: they may be present in more than half of cases [53% according to Hess,[48] 60.7%, according to Pineda and Kuttler,[70] 64% according to Smith[82] and Nosonowitz and Brenner,[68] 69.4% according to Acosta Vigouroux and Trugeda Bosaans,[2] 84%,

A



B

Fig. 11.57. **A**. Access cavity of an upper left first molar with two palatal canals in two distinct roots: P, palatal canal; MB, mesiobuccal canal; DB, distobuccal canal; DP, distopalatal canal. **B**. Postoperative radiograph of the same tooth.

according to Aydos and Milano,[4] 93% according to Stropko[85] and 96,1% according to Kulid[56] (Tab. I).

Table I

"In vitro" and "in vivo" (*) frequency of mesio≠palatal (MB2) canal in upper first molars (adapted from Marini et al.[63])

Author	*year*	*number of teeth*	*% of MB"*	*1 apical foramen*	*2 apical foramina*
Hess	1925	513	53,0%	-	-
Okamura	1927	-	53,0%	-	-
Weine	1969	208	51,5%	37,5%	14,0%
Pineda e coll.	1972	262	60,7%	12,2%	48,5%
Pineda	1973	245	54,3%	31,5%	22,8%
Aydos e coll.	1973	171	84%	59,0%	25,0%
Nosonowitz e coll.	1973	336	64,6%	54,8%	9,8%
Green	1973	100	36,0%	22,0%	14,0%
Seidberg e coll.	1973	100	62,0%	31,0%	31,0%
		*201	33,3%	-	-
Lane	1974	273	56,4%	19,4%	37,0%
Pomeranz e coll.	1974	100	69,0%	21,0%	48,0%
		*100	31%	-	-
Slowey	1974	103	50,4%	-	-
Vertucci	1974	100	55,0%	37,0%	18,0%
Vande Voorde	1975	97	50,0%	-	-
Smith	1977	50	64,0%	20,0%	44,0%
Acosta Vigouroux	1978	134	69,4%	-	-
Vertucci	1984	100	55,0%	37,0%	18,0%
Mondani	1984	100	21,0%	7,0%	14,0%
Neaverth e coll.	1987	*228	77,2%	15,4%	61,8%
Malagnino	1988	100	50,0%	23,0%	27,0%
Weller e coll.	1989	*835	39,0%	-	-
Lavagnoli e coll.	1989	50	39,6%	-	-
Kulid e coll.	1990	51	96,1%	54,2	45,8
Gilles e coll.	1990	21	90%	-	33,0
Fogel e coll.	1994	208	71,2	68,3	31,7
Stropko	1999	*80	93%	37,5%	62,5%

From this table we can note, particularly in old studies, that discrepancies in the number of canals identified exist between in vitro and in vivo studies. This may be because clinicians encounter difficulty in negotiating some of these canals and, therefore, they don't count them just because they are not treatable. With the use of new technology, several authors have more recently reported a higher success rate in the identification and treatment of these canals. The operating microscope, with its magnification and coaxial illumination, ultrasonic tips and methylene blue are

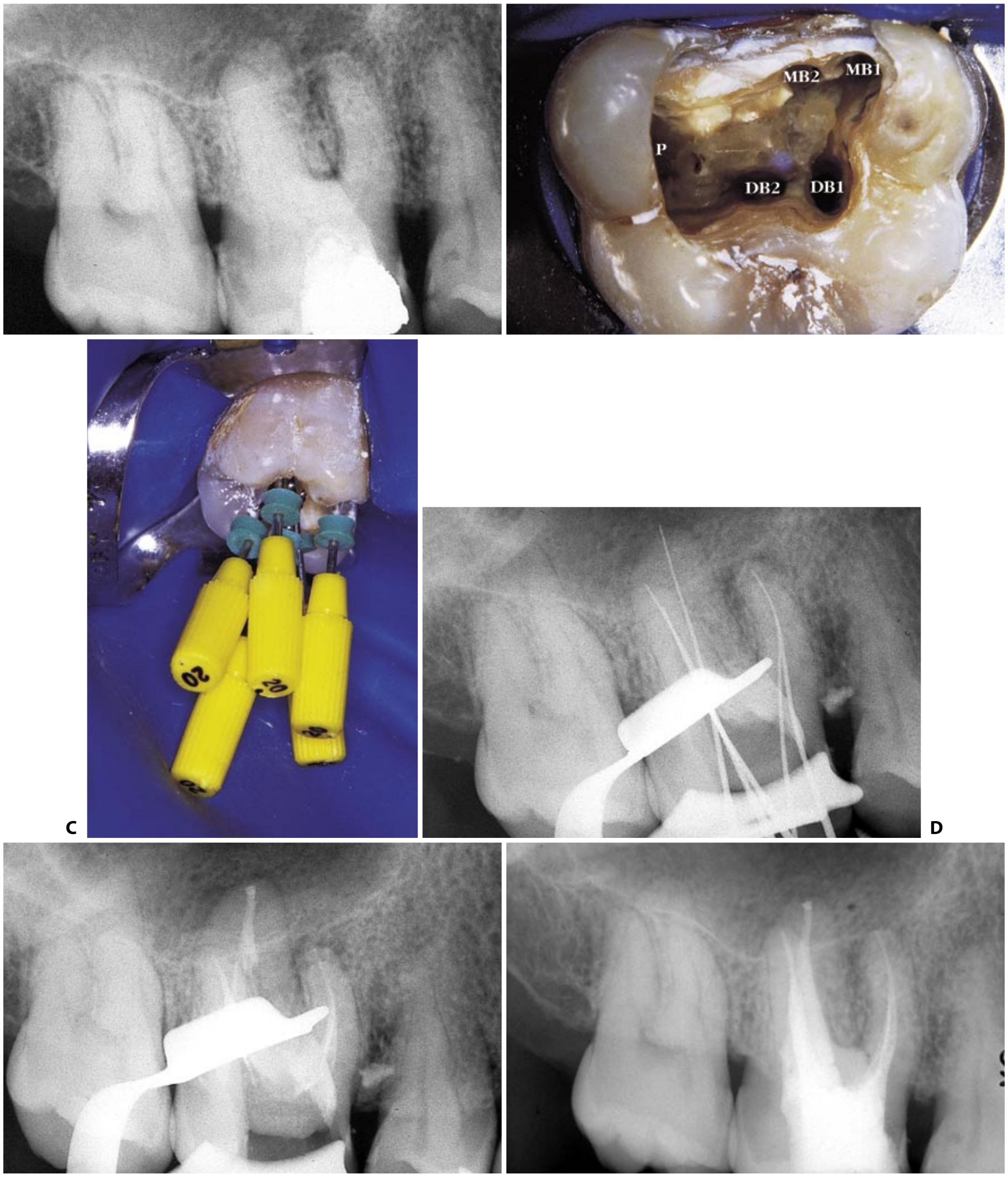


Fig. 11.58. **A**. Preoperative radiograph of an upper right first molar with five canals, two of which are in the distobuccal root. **B**. The access cavity reveals the five openings after the canals have been cleaned and shaped. **C**. Five instruments introduced into their respective five canals (the 5 instruments have been introduced in each canal only for documentation, and not to check 5 working lengths at the same time!). **D**. Intraoperative radiograph. **E**. Radiograph of the apical compaction. The five canals don't seem to have independent foramina. **F**. Postoperative radiograph.

only some of the factors, which contributed to increase those percentages.[52]

This data also indicates that clinicians should *always* consider the presence of two canals in the mesiobuccal root of upper first molars, at least unless a careful examination has demonstrated the opposite. Clinicians must be convinced that MB2 does exist in the mesiobuccal root of upper molars in *100%* of cases and therefore these teeth must be considered having *4 root canals*.

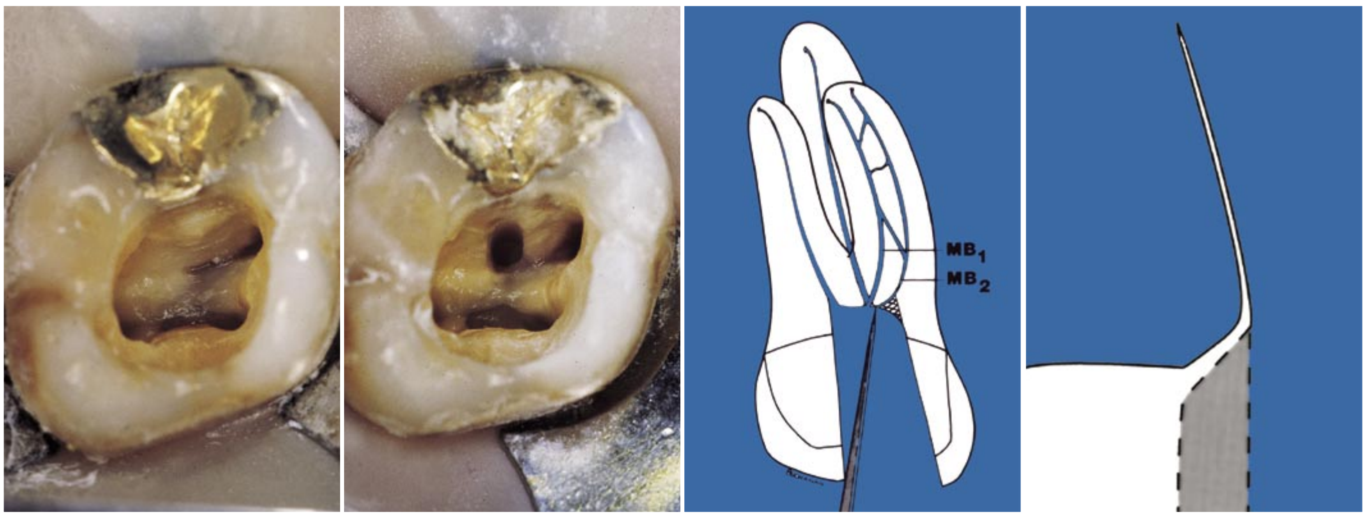
Particularly interesting is the recent study of John Stropko,[85] who demonstrated that the second canal of the mesiobuccal root is present "in vivo" in 93% of cases and it is negotiable to the apical foramen in 90% of cases. Stropko in his article says that the high percentage he found was due to the utilization of the operating microscope and that in some instances, it would have been very difficult, if not impossible, to observe the MB2 orifice if the microscope was not being utilized. It was also of interest to note that studies utilizing microscopes have reported a significantly higher percentage of MB2 canal system occurrence [42,56,75] than studies using other means of determination.[38,48,78]

The orifice of the "MB2" – more appropriately named "mesiopalatal canal" – is located on the groove that joins the palatal and mesiobuccal canals at a variable distance from the latter (Figs. 11.59 A, B). In looking for it, it may be helpful to search for a small depression at the level of the above-mentioned groove, where the point of the endodontic probe is engaged. Sometimes, however, the probe cannot enter, because it encounters the mesial wall of the pulp chamber where it forms a very acute angle with the floor that hampers the visual and tactile detection of the canal opening (Fig. 11.59 C). The mesial wall of the pulp chamber has a dentinal shelf, which frequently hides the underlying MB2 orifice (Fig. 11.60 A).

Because of this angle, MB2 can be very difficult to negotiate. In the first 1-3 mm the root canal is sharply angled in a mesial direction, and this is the reason why sometimes the tip of the file doesn't progress apically more than a few millimeters and stops against the mesial wall. Therefore, before negotiating the canal, it is always necessary to open that angle, to remove from the mesial wall of the access cavity the shelf of dentin which is hiding the orifice of the canal, in order to get a straight-line access to the root canal itself. This can be done easily, safely and efficiently with ultrasonics and the specific tips, like CPR and ProUltra (Fig. 11.60 B). If the clinician removes the shelf of dentin with hand files instead of using ultrasonics, the orifice of MB2 appears like the one of figure 11.59 D.

There are a number of strategies that, when used in combination, greatly increase the identification of the MB2 orifice and system.[75] The most useful concepts and techniques include:

a) First of all, strongly believe that MB2 is always present!
b) Use of magnification, starting from loops and magnification glasses (2,5x – 4x) up to the operating microscope.



A B C D

E

Fig. 11.59. **A**. Access cavity of an upper first molar. Note the presence of a groove originating at the opening of the mesiobuccal canal directed toward the palatal canal. **B**. The same groove following cleaning and shaping of the mesiopalatal canal. The distal groove has also been opened with a small round bur because of the suspicion of a distopalatal canal. **C, D**. The drawings show the angle between the pulpal floor and the shelf of dentin of the mesial wall of the access cavity (Courtesy of Dr. S. Buchanan). **E**. This is the shape of the orifice of the mesiopalatal canal if the shelf of dentin is not removed with ultrasonics.

c) Start looking for MB2 only after MB1 is completely cleaned and shaped and, in theory, is ready for obturation.
d) Use a piezo-electric ultrasonic unit along with specially designed tips (CPR, ProUltra) to remove the dentinal shelf hiding the underlying orifice.
e) Use of 1% solution of Methylene Blue dye, to road map the anatomy by penetrating into orifices.
f) Flood the pulp chamber with a warm 5% solution of sodium hyplochlorite to conduct the "champagne" or "bubble" test. The clinician can frequently visualize bubbles emanating from organic tissue, which is being digested in the extra canal, and rising towards the occlusal table.
g) Irrigate with 17% EDTA to remove the smear layer, then with pure alcohol and then air-dry with a Stropko irrigator fitted with a 27-gauge notched endodontic irrigating needle.
h) Use multiple obliquely angled radiographs (disto-mesial inclination in particular) both preoperatively and intraoperatively: the broader the root, the greater the likelihood of a second canal system.

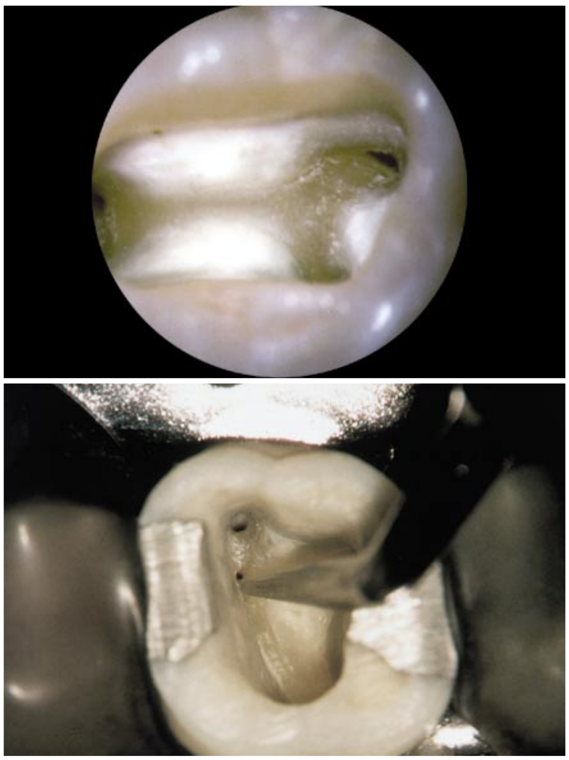

A
B

Fig. 11.60. **A**. A photograph taken at 12x reveals the orifice of the mesiobuccal canal and related groove. A dentinal shelf frequently hides the underlying orifice of the mesiopalatal canal. **B**. After estabilishing a straight-line access, an appropriately selected ultrasonic tip easily, rapidly and safely eliminated the dentine shelf and exposes the more palatal mesiopalatal orifice (Courtesy of Dr. C.J. Ruddle).

i) Know the endodontic anatomy.

The two canals do not always have separate foramina (Fig. 11.61); more often, they join together in a single foramen (Fig. 11.62).

Awareness of the existence of such a communication is important in determining the degree of preparation of the mesiopalatal canal.[22] If the two canals join in

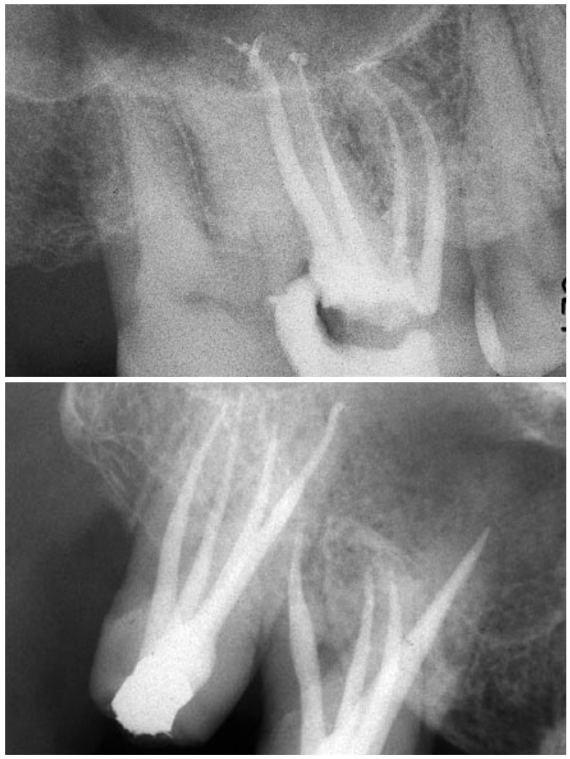

A
B

Fig. 11.61. **A**. Postoperative radiograph of the upper right first molar with a mesiopalatal canal with an independent foramen. **B**. In this patient, both the upper right first and second molars reveal a mesiopalatal canal with an independent foramen.

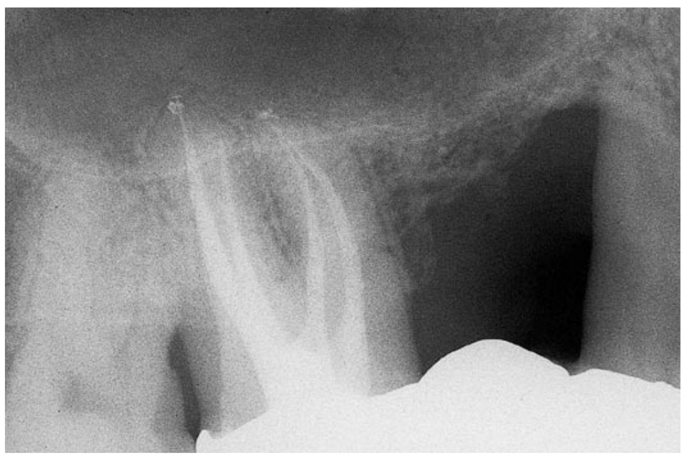


Fig. 11.62. Postoperative radiograph of an upper right first molar with mesiobuccal and mesiopalatal canals joining together at a common foramen.

a common foramen (Fig. 11.63), lesser instrumental preparation of this canal can be justified. A gutta-percha cone will later be condensed in the merging mesiopalatal canal so as to terminate against the cone inserted into the mesiobuccal canal, to which sealing of the common foramen is entrusted. With the aim of preventing excessive weakening of the root, which is quite thin and curved mesiodistally, and concave and thinner buccolingually (Fig. 11.64), this is done so as not to risk stripping of the root or subsequent fracture. As will be discussed in more detail in the next chapters, the introduction of files in the common portion of the root canal coming from MB2 could tear the foramen, brake the files, especially if the two canals join with a 90° angle, like in figure 11.63.
Cases with three canals in the mesiobuccal root have been described[8,65] (Figs. 11.65-11.67).
The mesiobuccal root is often curved distally. The degree of curvature varies from case to case. One must keep this in mind during cleaning and shaping, since it will be necessary to modify the working length of the instruments and always use the "anticurvature" filing method described by Abou-Rass et al.[1] (Fig. 11.68).

Fig. 11.63. The mesiopalatal canal is joining the mesiobuccal with a 90° angle. In such a case, to go to the same working length coming from the mesiopalatal canal is very dangerous and useless!

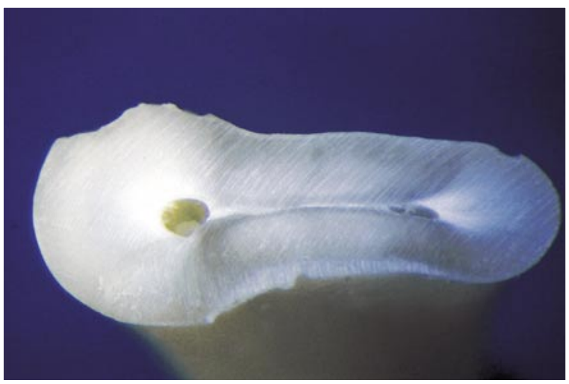


Fig. 11.64. Cross section of the mesiobuccal root of an upper first molar: the root is concave on the distal aspect, both canals are pretty close to the bifurcation, and the root is thinner in a palatal direction.

A

B

C

D

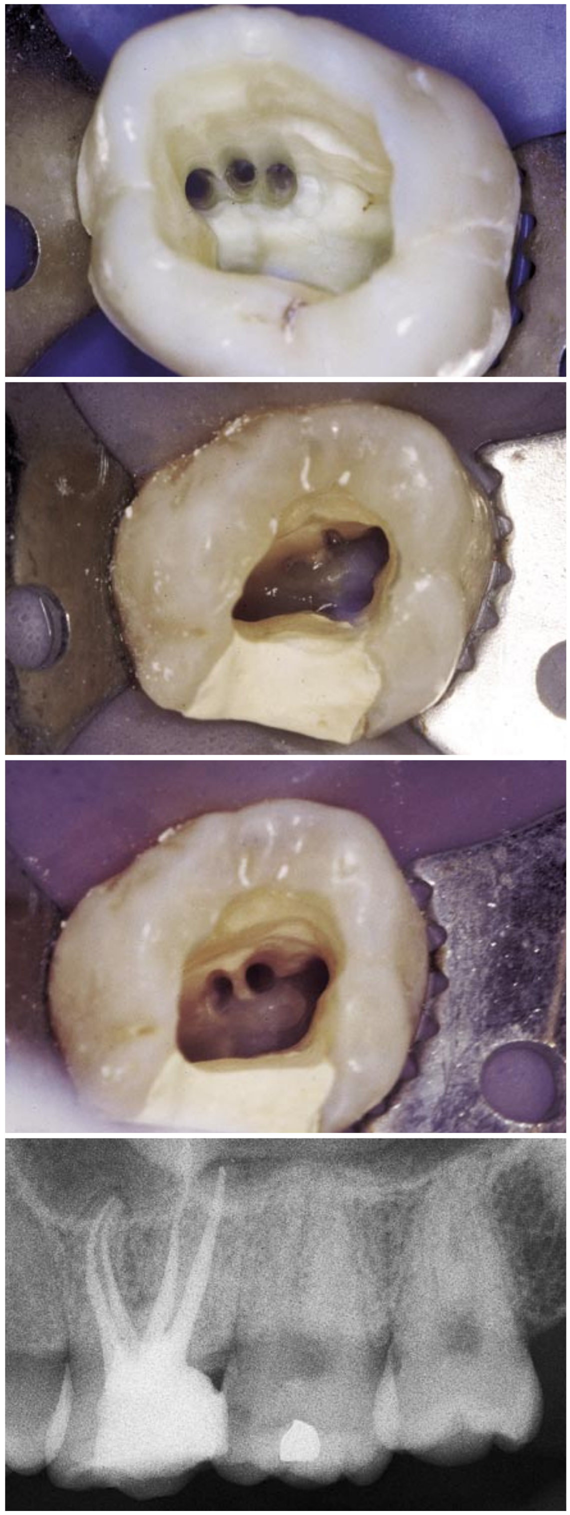


Fig. 11.65. **A**. The access cavity of this extracted molar shows three canals in the mesiobuccal root. **B**. Careful examination of the access cavity of this upper molar shows the presence of a third opening near the orifice of the mesiopalatal canal. **C**. The three canals have been cleaned and shaped. **D**. Postoperative radiograph: MB2 and MB3 were joining together.

Fig. 11.66. **A**. Access cavity of an upper first molar. The mesiobuccal root has three canals. **B**. The postoperative radiograph shows three canals with independent foramina.

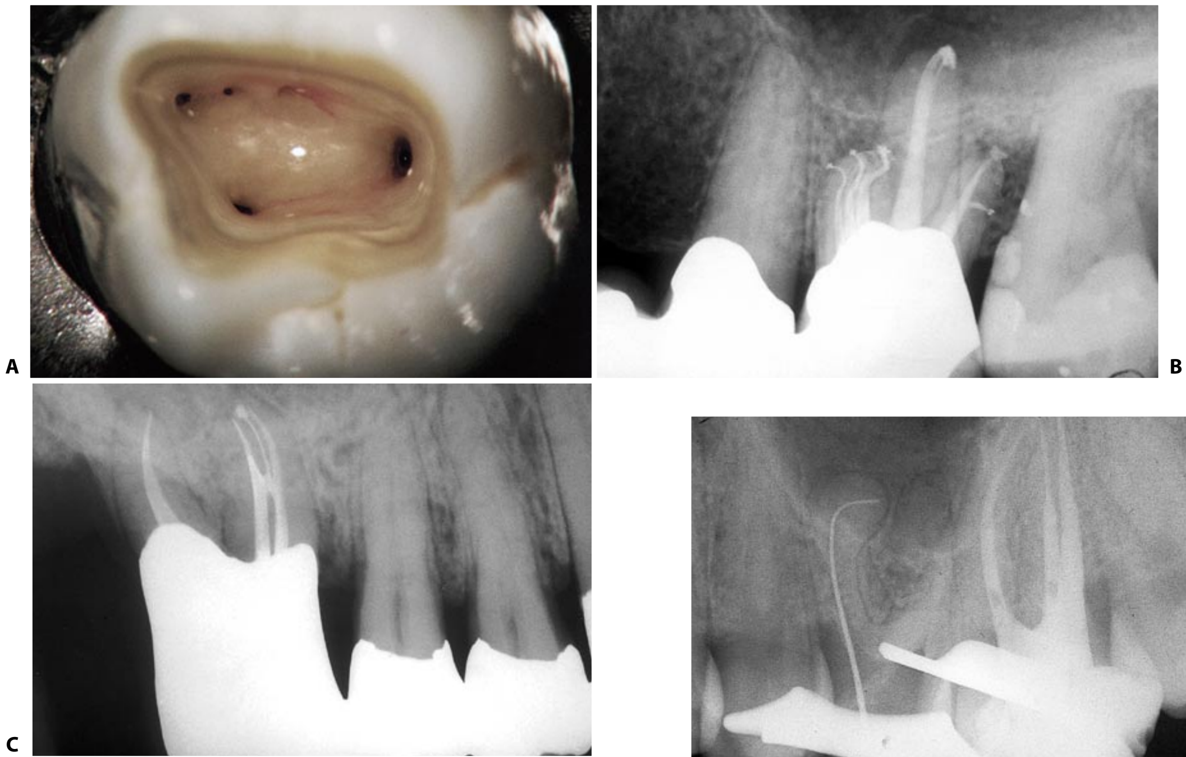


Fig. 11.67. **A**. The operating microscope offers excellent documentation and vision at 15x. Note the three orifices in the mesiobuccal root of this upper molar. **B**. The pack reveals three mesiobuccal systems with significant apical one-third recurvature, palatal bifidity, and a significant lateral canal off the distobuccal system. **C**. The most posterior abutment has had a palatal root amputation and the buccal roots were treated endodontically. Note the mesiobuccal root has three canals, one originating from the isthmus present between the other two (Courtesy of Dr. C. J. Ruddle).

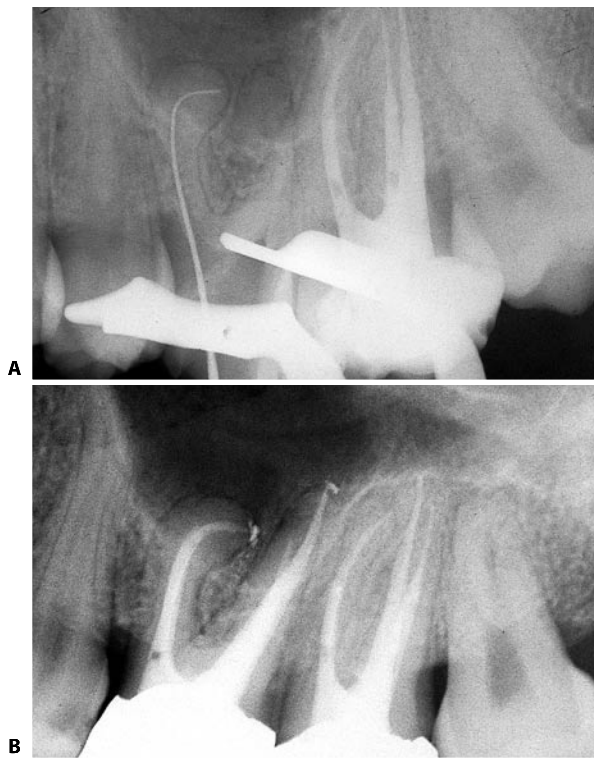


Fig. 11.68. **A**. Radiograph checking the working length of the mesiobuccal canal. Note the considerable degree of curvature of the canal. **B**. Two year recall.

The presence of two canals in the mesiobuccal root is also of great importance from the Surgical Endodontics point of view.
When the root is beveled, one must always look for a second orifice more palatal to the first. One must maintain the same level of suspicion as when one suspects the presence of a mesiopalatal canal in clinical Endodontics, which means *always*. Although the two canals often join in a single foramen, when surgery is undertaken two separate orifices are found, because beveling the apex eliminates the part of the canal that is common to both. Therefore, the surgical apical seal will require two retrofillings always joined together to form a figure "eight" (Fig. 11.69), because, as it will be described in the surgery chapter, between the two canals there is always an isthmus,[97] which must be included in the retroprep and sealed. Furthermore, the root is thinner palatally than buccally; as a consequence, the surgical bevel of the root must be lowered considerably to find sufficient dentin around the mesiopalatal canal to prepare within it the cavity for the retrofilling.
A transverse section at the level of the cervical zone of the upper first molar (Fig. 11.70) reveals that the pulp chamber floor takes the form of a quadrilateral with four unequal sides.[92]
Most authors describe the access cavity of the upper and lower molars as a triangle whose opening is displaced into the most mesial portion of the crown[53] (Fig. 11.71 A-D). However, since the floor of these molars takes the shape of a quadrilateral, it is clear that the access cavity should also have a similar shape.
As already stated, the access cavity may be considered to be the projection of the pulp chamber floor onto the occlusal surface. It therefore must have a quadrilateral shape with rounded corners[21,92,96] (Figs. 11.71 E-G). The shortest side of the quadrilateral is usually the palatal side; the next longest is the buccal side, which is slightly inclined palatally because the distobuccal canal is displaced in that direction; the next longest is the distal side; and the longest is the mesial side.
Regarding the position of the pulp chamber floor with respect to the lateral walls, Acosta Vigouroux and Trugeda Bosaans[2] have found in 134 extracted teeth that the floor was exactly in the center of the dental crown. One must keep this in mind during preparation of a correct access cavity.
Preparation of the access cavity begins with a round, diamond bur mounted on a high speed handpiece and applied at the level of the central fossa. It is inclined toward the pulp horn that radiographically seems widest, generally the palatal one (Figs. 11.72 A-C). With the low-speed, long-shafted round bur, the dentin undercuts are removed, proceeding internally to externally (Figs. 11.72 D-E). Finally, the self-guiding diamond bur on high speed is used for the finishing and flaring (Figs. 11.72 F-I).
If one encounters difficulty in locating the canals, one should always begin by preparing the palatal canal, which is generally the widest, straightest, and thus easiest. Irrigation with sodium hypochlorite will help to orient one better in the search for the orifices of the other root canals.
Following endodontic therapy, protection of the cusps is advisable to avoid cusp or crown-root fractures.

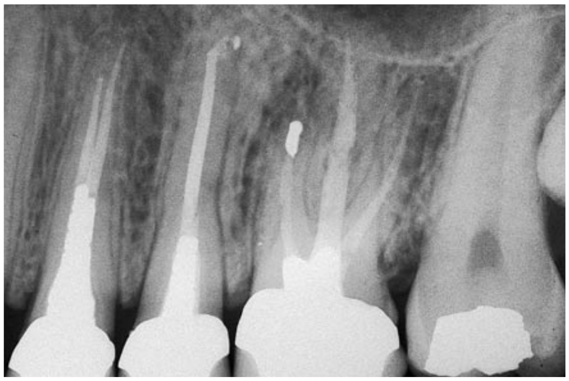


Fig. 11.69. Recall radiograph two years after apicectomy with retrofilling of the two canals of the mesiobuccal root. The two fillings are joined, since the two canals communicate with one another through a thin isthmus, which has been included in the cavity for the retrofilling.

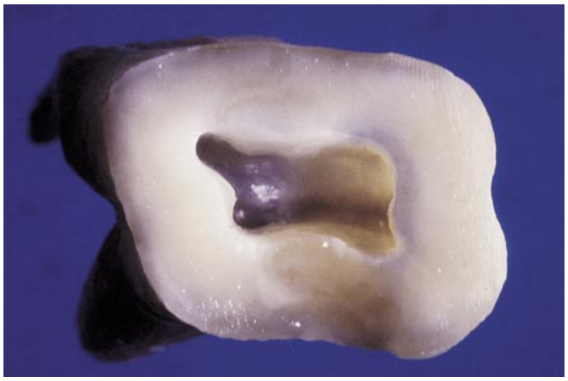


Fig. 11.70. Cross-section of an upper first molar, at the level of the cervical area. The shape of the pulp chamber floor is that of a scalene quadrilateral.

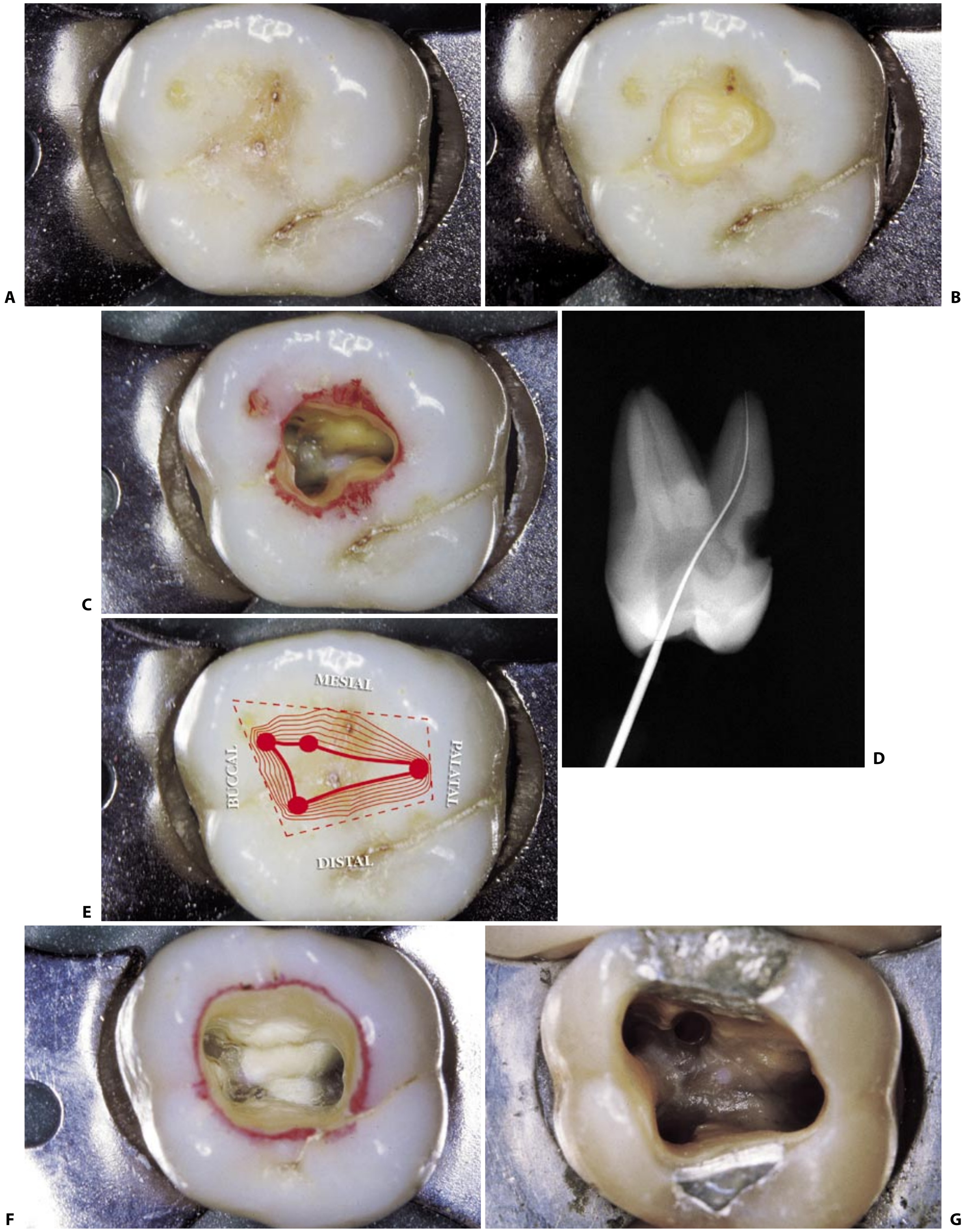


Fig. 11.71. **A**. Occlusal surface of an upper first molar. **B**. A triangular access cavity with a mesially displaced opening is made. **C**. Completed triangular access cavity. **D**. The instrument introduced in the palatal canal through the triangular cavity doesn't have a straight-line access to the apical one third, but meets several interferences of dentin. **E**. The access cavity should be the projection of the pulp chamber floor onto the occlusal surface. **F**. Properly completed access cavity. The definitive form is quadrangular with rounded corners. **G**. Properly created access cavity of a first molar. Note the scalene quadrilateral shape. The canals have already been cleaned and shaped.

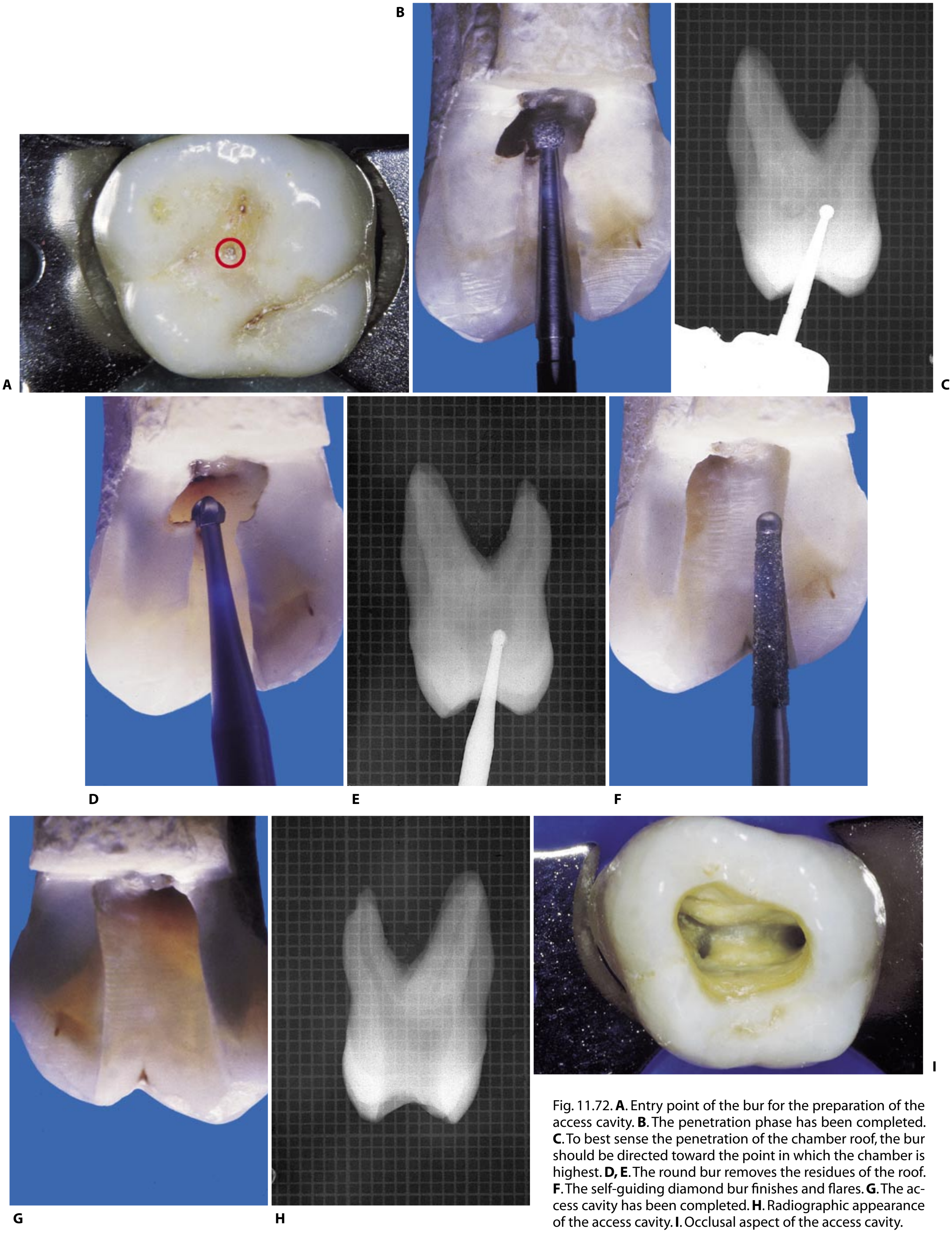
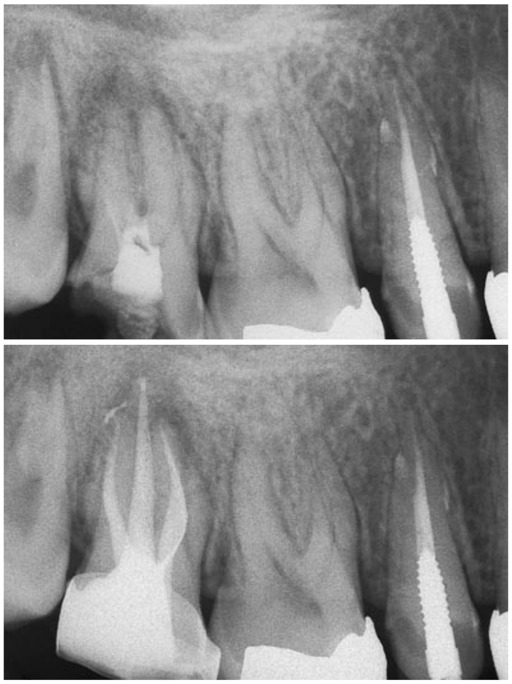


Fig. 11.72. **A.** Entry point of the bur for the preparation of the access cavity. **B.** The penetration phase has been completed. **C.** To best sense the penetration of the chamber roof, the bur should be directed toward the point in which the chamber is highest. **D, E.** The round bur removes the residues of the roof. **F.** The self-guiding diamond bur finishes and flares. **G.** The access cavity has been completed. **H.** Radiographic appearance of the access cavity. **I.** Occlusal aspect of the access cavity.

UPPER SECOND MOLAR

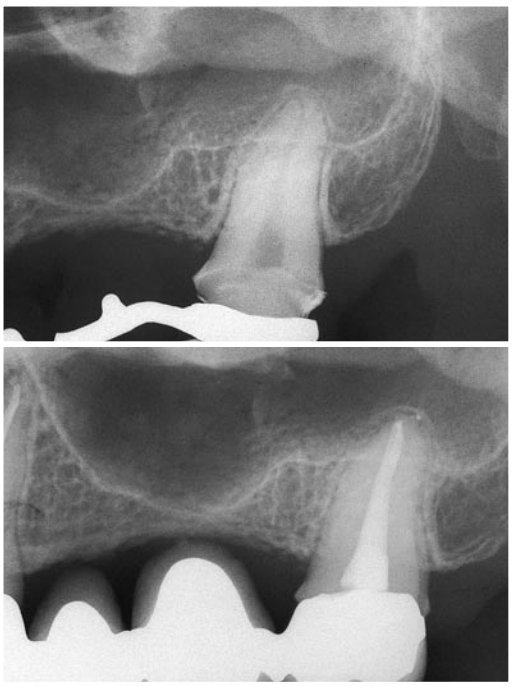
The anatomy of the upper second molar very much resembles that of the upper first molar.



A

B

Fig. 11.73. **A**. Preoperative radiograph of an upper right second molar. **B**. Postoperative radiograph. The mesiopalatal canal has the appearance of a radiopaque loop superimposed on the image of the mesiobuccal canal into which it merged.

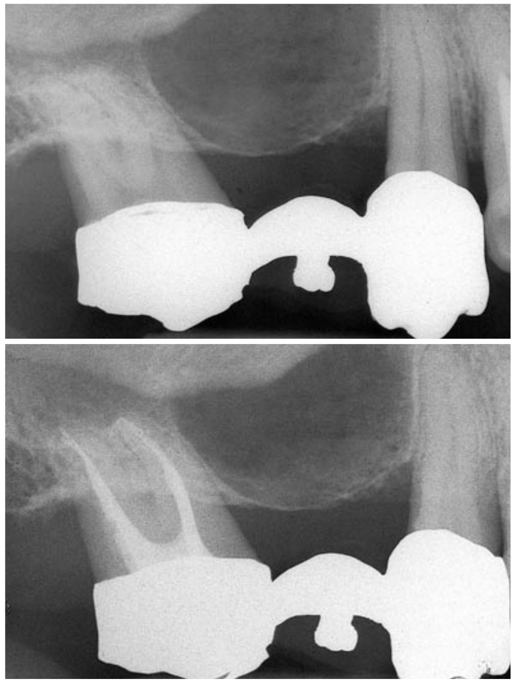


A

B

Fig. 11.75. **A**. Preoperative radiograph of an upper left second molar with a single canal in a single root. **B**. One year after endodontic therapy.

In comparison to the latter, it is slightly smaller, flatter mesiodistally, and slightly less frequently has a mesiopalatal canal (Fig. 11.73). Kulid and Peters[56] found the MB2 in 96,1% in upper first molars and in 93,7% in upper second molars. It sometimes has three fused roots. It may have only two canals, one buccal and one palatal in a single root, or two canals in separate roots (Fig. 11.74); it may have a single, wide canal that extends almost directly from the floor to the apex[37] (Fig. 11.75). Rarely, the upper second molar may have a more complicated anatomy, with two palatal canals in a single root (Fig. 11.76) or in two separate roots[26,30,54] (Fig. 11.77).



A

B

Fig. 11.74. **A**. Preoperative radiograph of an upper right second molar with two roots. **B**. Postoperative radiograph. Two canals in two separate roots are visible.

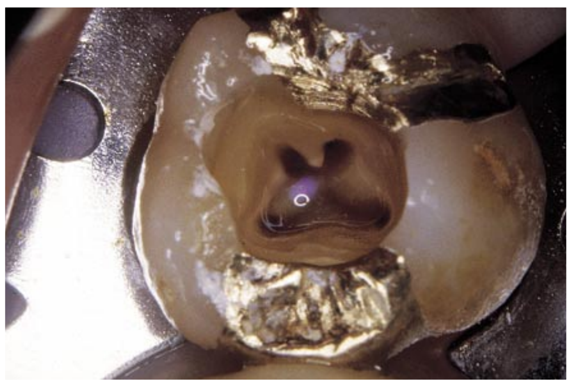


Fig. 11.76. Access cavity of an upper right second molar, with two confluent canals within the palatal root.

The access cavity is created following the same procedure and phases as in the upper first molar.
In comparison with the upper first molar, the pulp chamber floor of the upper second molar is flatter mesiodistally, and the distobuccal canal is found quite palatally displaced. It may even be found halfway between the palatal and the mesiobuccal canals (Fig. 11.78). If one mentally joins the canal openings with linear segments, one obtains a scalene triangle with an obtuse apex corresponding to the distobuccal canal. This triangle may become so flattened as to signify that the three canals practically lie on the same line, oriented buccopalatally.

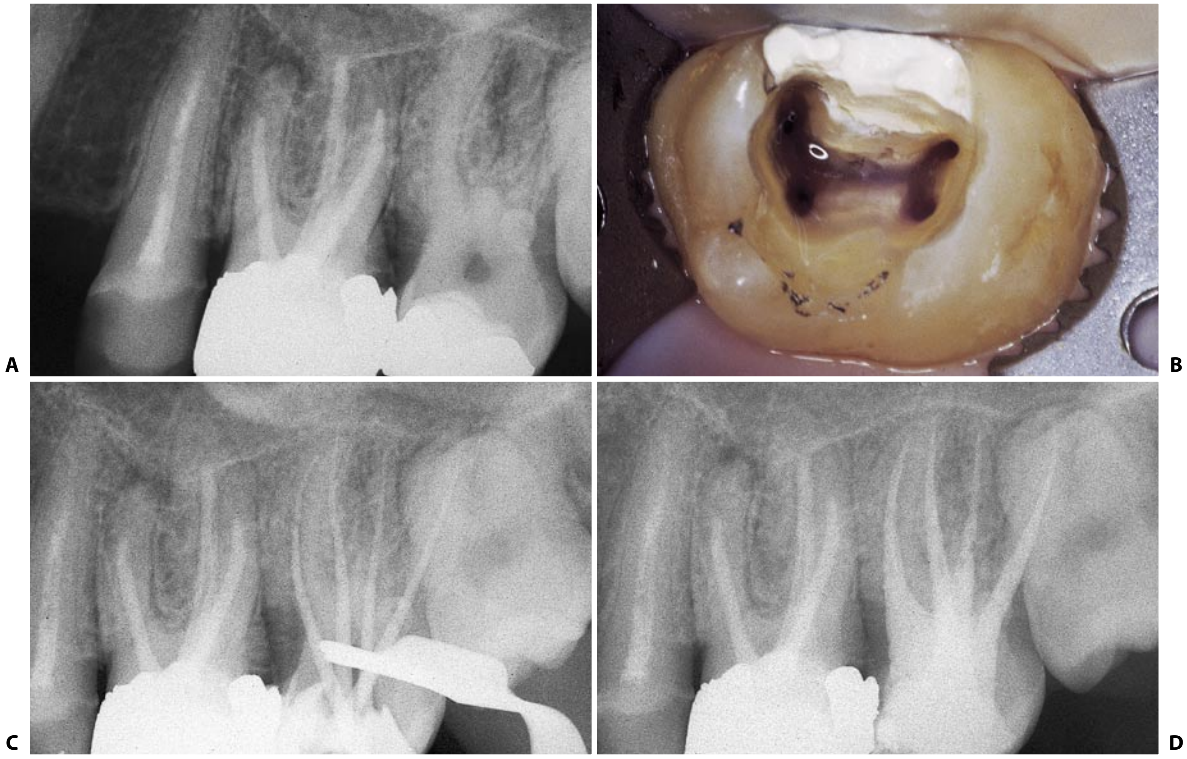


Fig. 11.77. An upper left second molar with two palatal canals in two separate roots. **A**. Preoperative radiograph. **B**. Access cavity. **C**. Intraoperative radiograph. **D**. Postoperative radiograph.

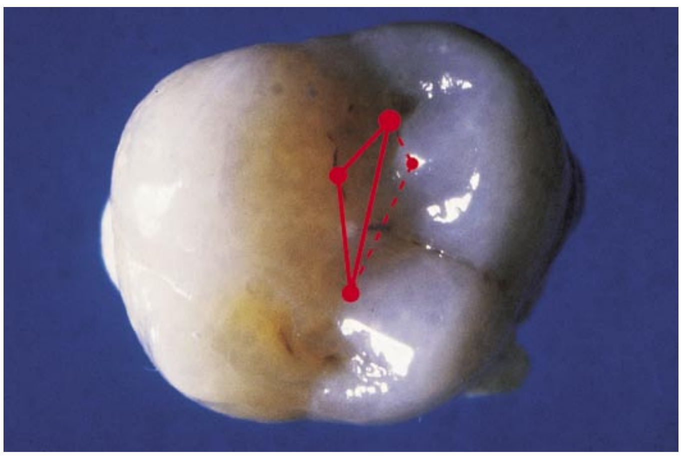


Fig. 11.78. Location of the canal orifices, with respect to the occlusal surface.

UPPER THIRD MOLAR

Loss of the first and second molars is often the reason for considering the third molar a strategic abutment. Because many third molars have well-developed roots, there is no reason they should not remain functional for a long time after endodontic treatment.[18]
Before initiating treatment and before promising the patient a successful outcome, a thorough examination of the root morphology is indicated, however, given that it may be among the most bizarre and unpredictable.
In some cases, the third molar has only one canal. In other cases, it has two, but in most there are three and, sometimes, four (Fig. 11.79).
The access cavity should be made according to the same rules prescribed for the other molars.

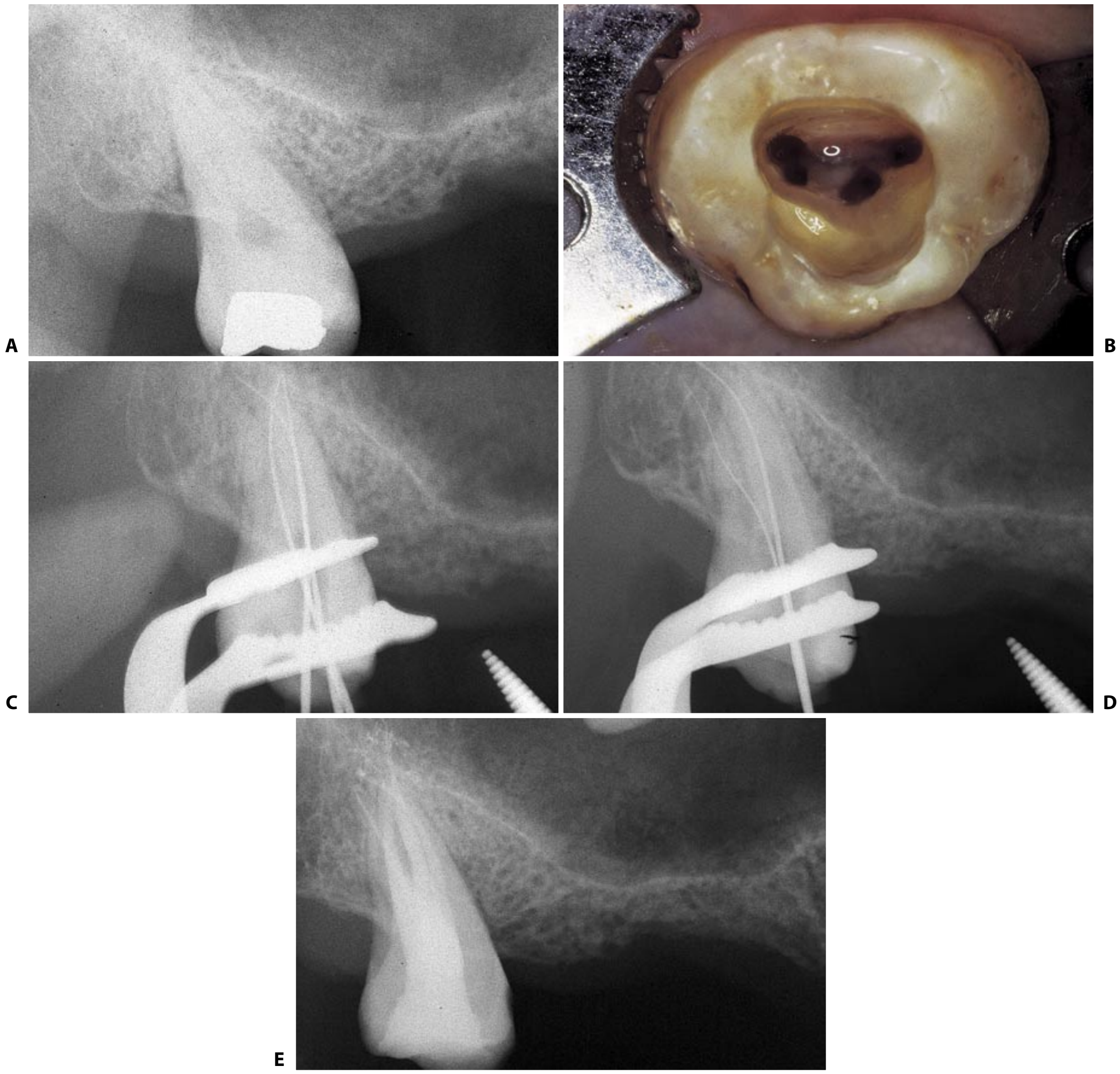


Fig. 11.79. **A**. Preoperative radiograph of the upper right third molar. **B**. The access cavity of the same tooth shows the presence of four canals. **C**. The two palatal canals have independent foramina. **D**. Two instruments have been introduced in the buccal canals. **E**. Postoperative radiograph.

LOWER CENTRAL INCISOR

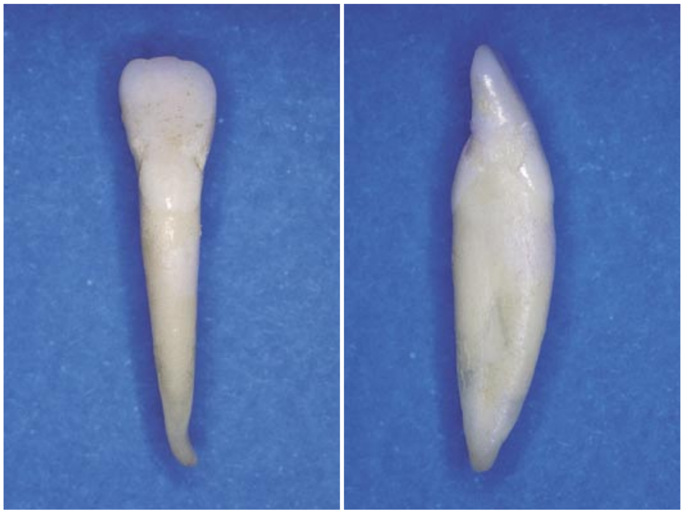
The lower central, as well as the lower lateral incisor, is anything but easy to treat.[69] In a graduated scale of difficulty, Weine[92] places it immediately after the molars and lower premolars with more than one canal.

The difficulties posed by this tooth are related to its mesiodistal thinness (Fig. 11.80 A), when compared to its buccolingual width (Fig. 11.80 B), which makes it very difficult, if not impossible, to widen the canal(s) completely in any direction.

The root, which is sometimes distally or lingually curved, often contains two canals (Fig. 11.81). Benjamin and Dawson[11] report that the lower central incisor has two canals in 41.4% of cases, with independent foramina in only 1.3% of cases. Weine[92] states that a single, ribbon shape canal is found in 60%, two canals running into a single foramen in 35%, and two completely independent canals in 5%. One may conclude that the lower central incisor should always be considered to have two canals, since even when there is only a single canal it has such an elongated buccolingual shape that for the purposes of the access cavity and preparation it must be treated as though it were two canals.

Because of the mesiodistal thinness of the root, one must pay particular attention to preparing the access cavity to avoid lateral perforations. Halfway along the root, there is a concavity on both sides; thus, excessive widening may cause stripping of the root.

The access cavity is initiated with a rather small, round diamond bur, and its final shape will be either ovoid or elliptical (Fig. 11.82).



A B

Fig. 11.80. **A**. A lower central incisor. Note the mesiodistal thinness of the root. **B**. The root of the same tooth is significantly wider buccolingually. Note also the concavity at the level of the middle one third.

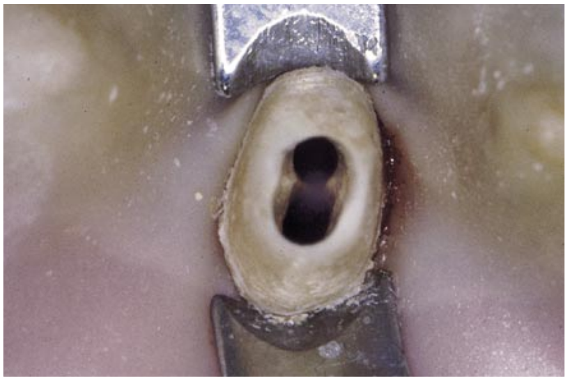
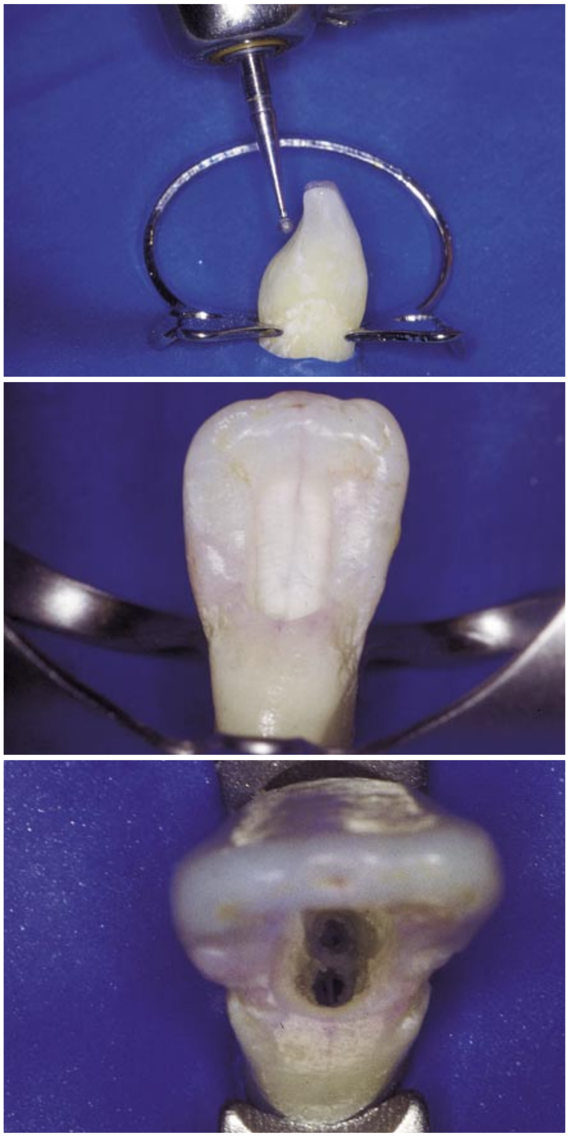


Fig. 11.81. Lower central incisor, with two canals.



A B C

Fig. 11.82. **A**. The access cavity is initiated with a small, round diamond bur. **B**. The final shape of the access cavity is ovoid or elliptical. **C**. Only an adequate access cavity can demonstrate the presence of two canals.

One must be careful to completely remove the triangle # 2 to ensure a straight-line access to the lingual canal.[6] An access cavity that is too limited may allow access to the buccal canal, but would preclude adequate probing and shaping of the lingual canal (Fig. 11.83). A proper access cavity must therefore extend almost from the incisal margin to the cingulum.[60] In abraded or fractured teeth, the cavity also or even solely involves the incisal margin[66] (Fig. 11.84).
Fortunately, the two canals have separate foramina only in a small percentage of cases (Fig. 11.85). This explains why overlooking one canal does not lead to failure, as it might seem.

Careful radiographic examination with a mesial or distal view can demonstrate the presence of the two canals (Fig. 11.86). Some authors suggest identifying the two orifices immediately, but in this author's opinion it is easier to identify the second canal after the first has been prepared, which enhances the tactile sensation from the entrance of the thin instrument into a second thin canal, which has yet to be prepared.
Precise manual instrumentation followed by numerous irrigations will prevent inadvertent blocking of the other canal, which has not yet been prepared.
It has been shown[11] that the confluence of the two canals toward a single foramen frequently occurs in the

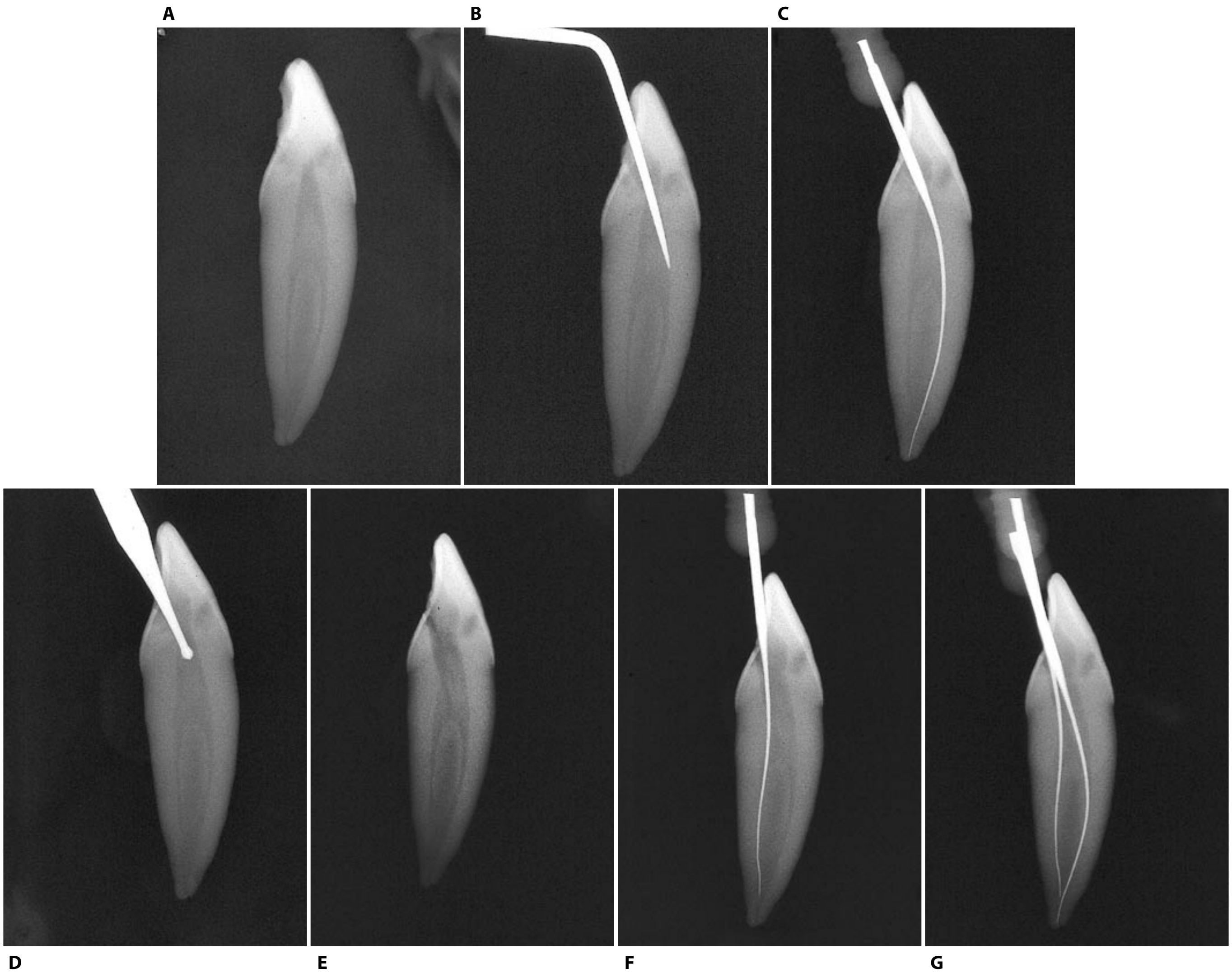
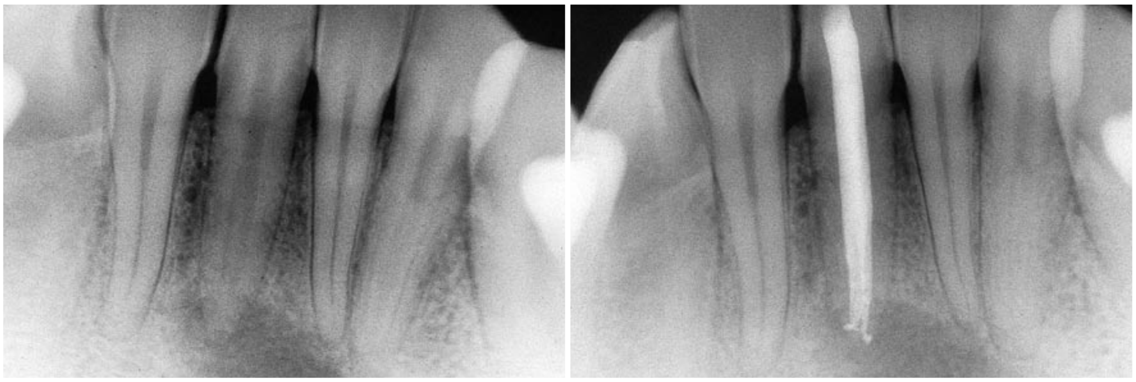


Fig. 11.83. **A**. Radiographic appearance of the lower central incisor in a mesiodistal projection. **B**. A limited access cavity has been created. **C**. A # 08 file enters the buccal canal, though with considerable coronal interference. The presence of "triangle # 2" impedes the entrance of any instrument into the lingual canal. **D**. The low-speed round bur completely excises the dentinal triangle. **E**. Radiographic appearance of the completed access cavity. **F**. The # 08 file can now enter the lingual canal easily. **G**. The two instruments confirm the presence of two canals with a common apex.

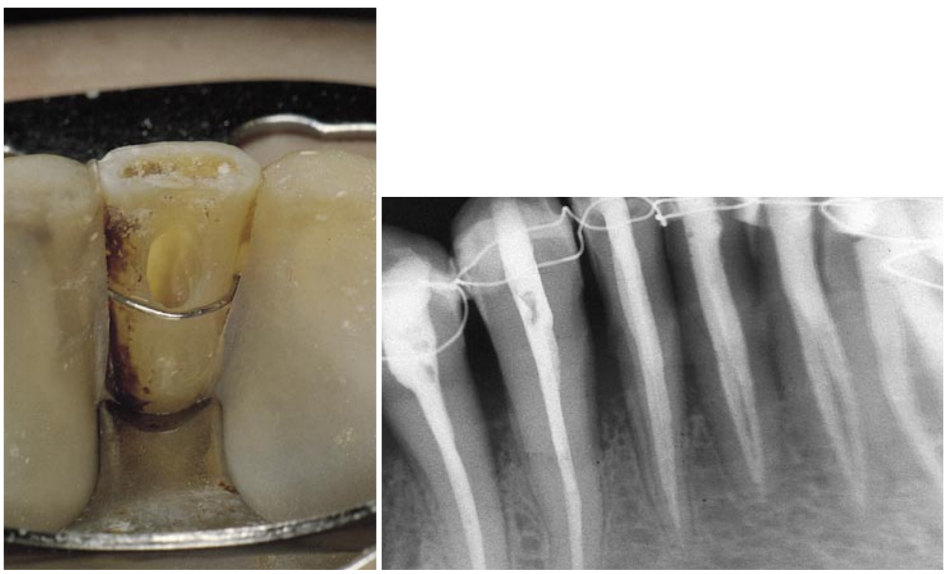
A B

Fig. 11.84. **A, B**. Examples of access cavities in fractured and abraded lower central incisors. The access cavities also involve the incisal margin. In both cases, two canals were present.



A B

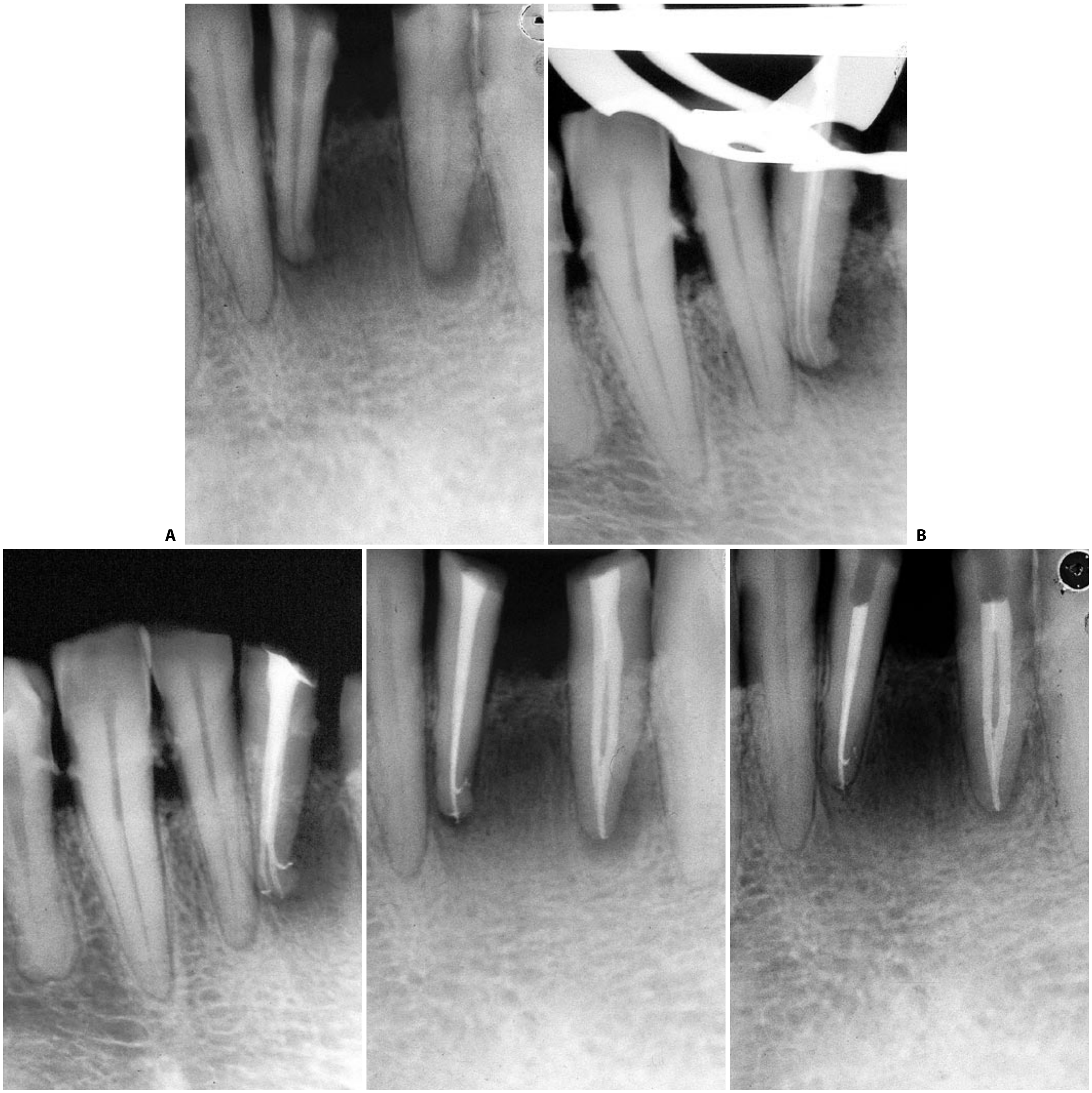
Fig. 11.85. A lower right central incisor, with two canals with independent apices. **A**. Preoperative radiograph. **B**. Postoperative radiograph.



A B

Fig. 11.86. The four lower incisors of this patient all have two canals. **A**. Elliptical access cavity. **B**. Postoperative radiograph. The presence of two canals is easily documented in the left incisors, which have been radiographed in a mesiodistal view.

last millimeter of the root canal. In such cases, obturating the root canal one millimeter short from the radiographic apex means that the common foramen is not obturated. In such a case, neglecting the lingual canal thus necessarily leads to failure.[24] The finding of lateral canals is quite frequent (Fig. 11.87).



A B C D E

Fig. 11.87. The two anatomical variants of the lower incisor with two canals are present in the same patient. The right central incisor has two canals with independent foramina, while the left lateral incisor has two canals with a common apical foramen. **A**. Preoperative radiograph. **B**. Intraoperative radiograph confirms the presence of two independent canals. **C**. Postoperative radiograph. A lateral canal is also visible. **D**. Postoperative radiograph of the left lateral incisor: the two canals become confluent. **E**. Two year recall (Courtesy of Dr. R. Becciani).

LOWER LATERAL INCISOR

This tooth is identical to the central incisor, the only difference being that it is often slightly longer (Fig. 11.88 A, B).

It also can have two canals within the root with a certain symmetry. If the patient has two canals in the right lateral incisor, one can also expect two canals in the left; if a single canal is present in the right lateral incisor, one may also expect a single canal in the left (Fig. 11.88 C, D).

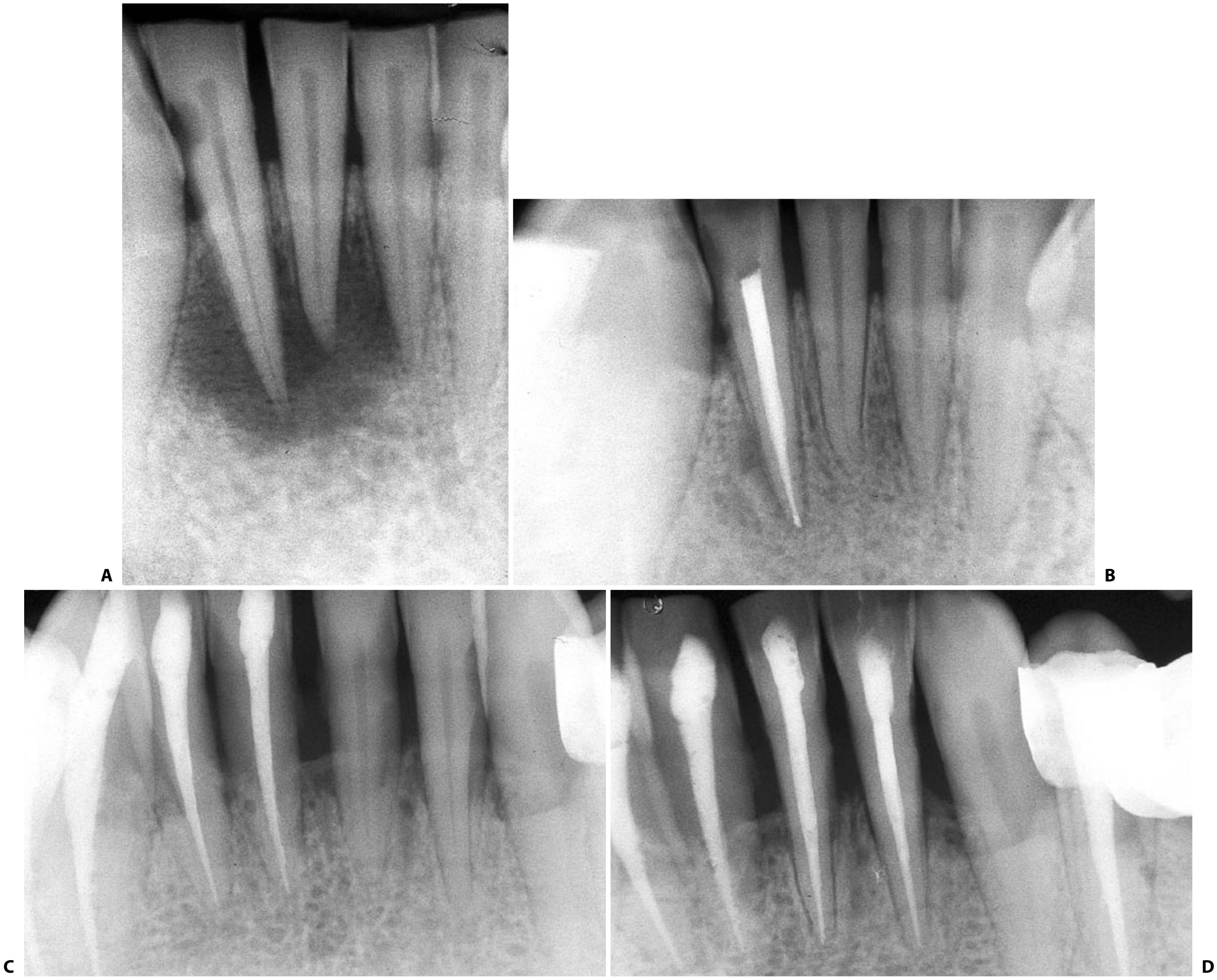


Fig. 11.88. **A**. Preoperative radiograph. The lateral incisor is several millimeters longer than the central incisor. **B**. Recall radiograph 3 years later. **C**. The right lateral incisor reveals a single canal. **D**. The left lateral incisor of the same patient also reveals a single canal.

LOWER CANINE

This tooth usually has one root containing a single canal (87%) (Fig. 11.89 A). In 10%, there are two canals that join at the apex (Fig. 11.89 B), and less commonly (3%) there are two completely independent canals.[44] Rarely, the tooth may have two roots (Fig. 11.90).
Its length may vary, but very often the use of 30 mm instruments is necessary.
The access cavity is ovoid and must be extended buccolingually enough to also allow straight-line access to the lingual canal or, in any case, the lingual wall of the root canal, which is quite elongated buccolingually.[28]
In abraded teeth, the access cavity also (Fig. 11.91) or exclusively (Fig. 11.92) involves the occlusal surface.
If there is a very extensive cervical abrasion, the access cavity can be made entirely from the buccal side (Fig. 11.93).

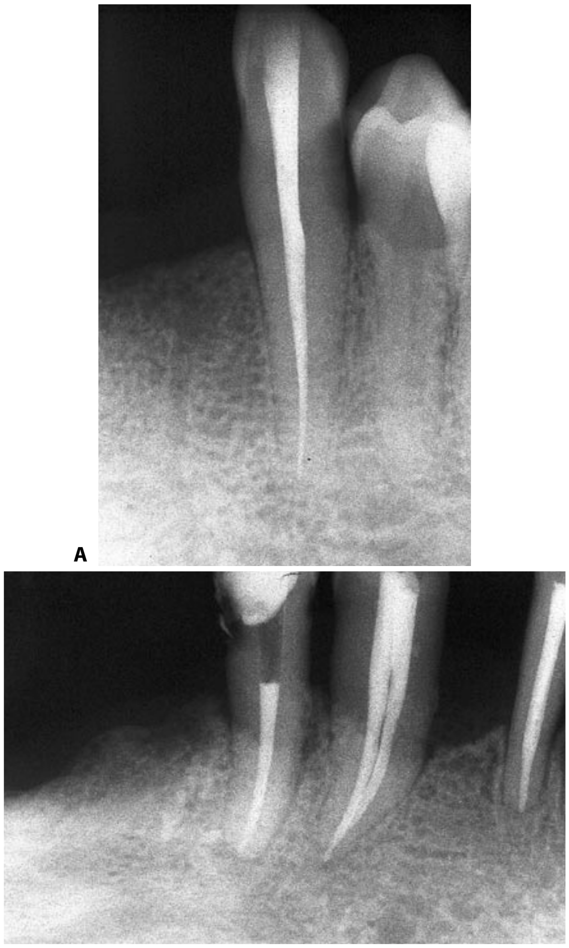


Fig. 11.89. **A**. Postoperative radiograph of a lower canine with a single canal. **B**. Postoperative radiograph of a lower canine with two canals joining at a common apex.

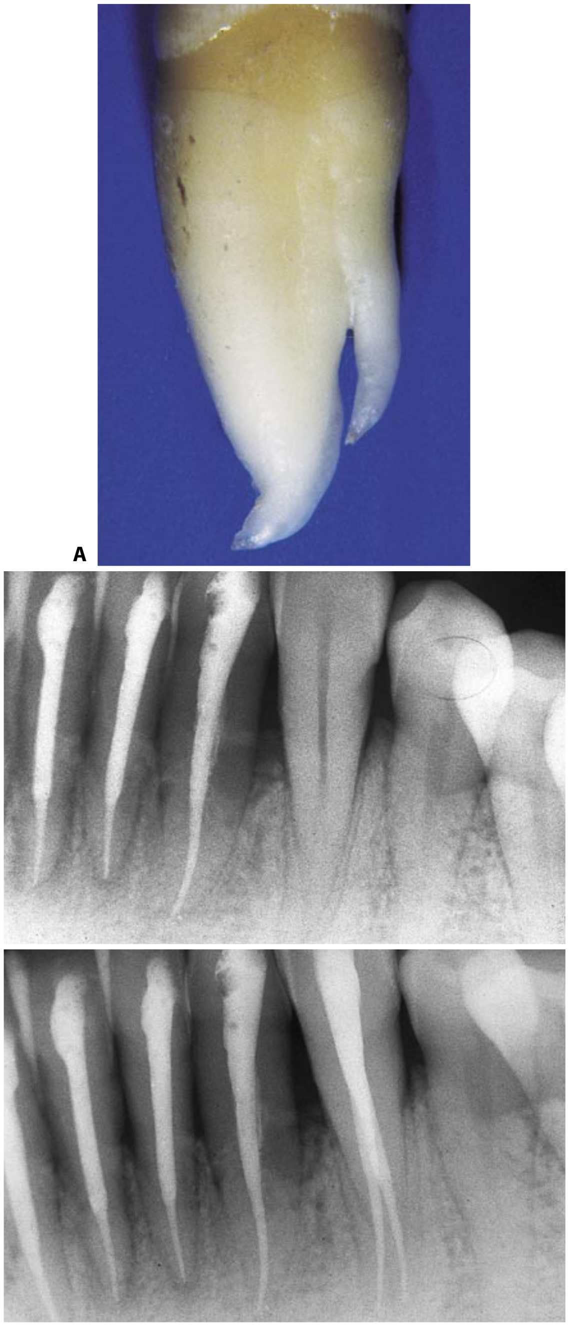


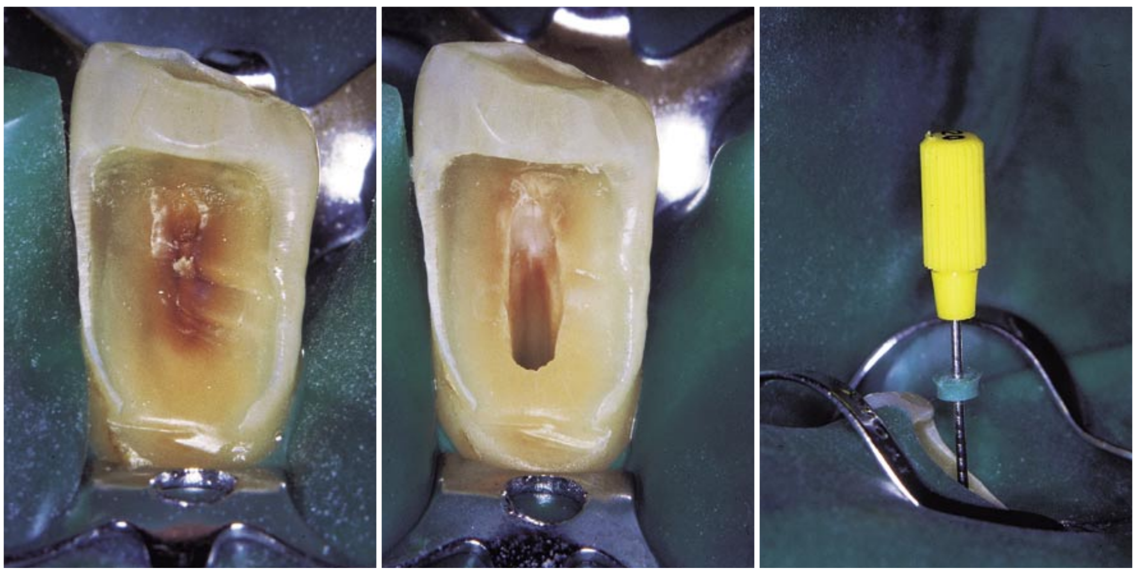
Fig. 11.90. A lower canine with two canals in two separate roots. **A, B**. Pre- and postoperative radiographs of a lower canine with two separate roots.

A B

Fig. 11.91. Example of access cavity in a slightly abraded lower canine. **A**. The cavity necessarily also involves part of the incisal surface. **B**. The cavity must be extended occlusally, until the instrument has unhindered access.

A B

Fig. 11.92. Example of access cavity in a very abraded lower canine. **A**. The pulp chamber is exactly at the center of the abraded surface; therefore, it is there that one must open the tooth. **B**. The access cavity has been entirely created on the incisal surface.



A B C

Fig. 11.93. Example of access cavity in a lower canine with a large cervical abrasion. **A**. The pulp chamber is completely below the thin layer of dentin at the center of the abrasion. **B**. The access cavity has been made entirely on the buccal side of the dental crown. **C**. Note the straight-line access of the instrument, which enters without any coronal interference.

LOWER FIRST PREMOLAR

Given its great anatomical variability, this tooth may be very challenging.

According to a study by Vertucci,[87] a single canal is found in 70% of cases, two canals joining at a common foramen in 4% (Fig. 11.94), two independent canals in 1.5% (Fig. 11.95), one canal that bifurcates at the apex into two branches in 24% (Fig. 11.96), and two separate canals in two independent roots in 0.5% (Fig. 11.97). The mandibular first premolar can be found with three root canals[50] and with a "C shaped" canal.[5] The difficulty of performing proper treatment obviously depends on the anatomical situation, the most complex being that of the single canal that bifurcates in the apical one third of the root.

The dental crown of the lower first premolar is quite unusual, so much so that it is considered a transitional form between the canine and the second premolar (Fig. 11.98 A).

The two cusps of the tooth are quite asymmetric, the buccal one being more pronounced while the lingual cusp is just evident. It could almost be considered a canine with a large cingulum.

The pulp chamber, which is ovoid and directed buccolingually, lies almost entirely below the buccal cusp (Fig. 11.98 B); thus, 90% of the access ca-

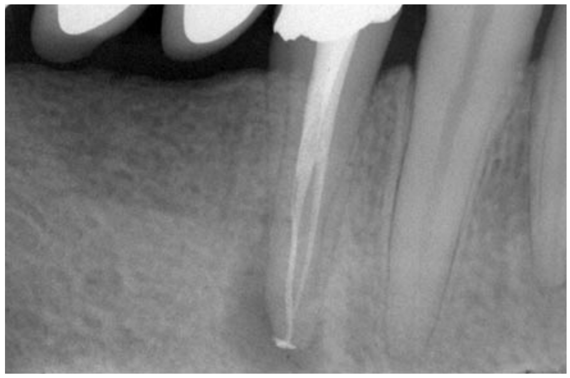
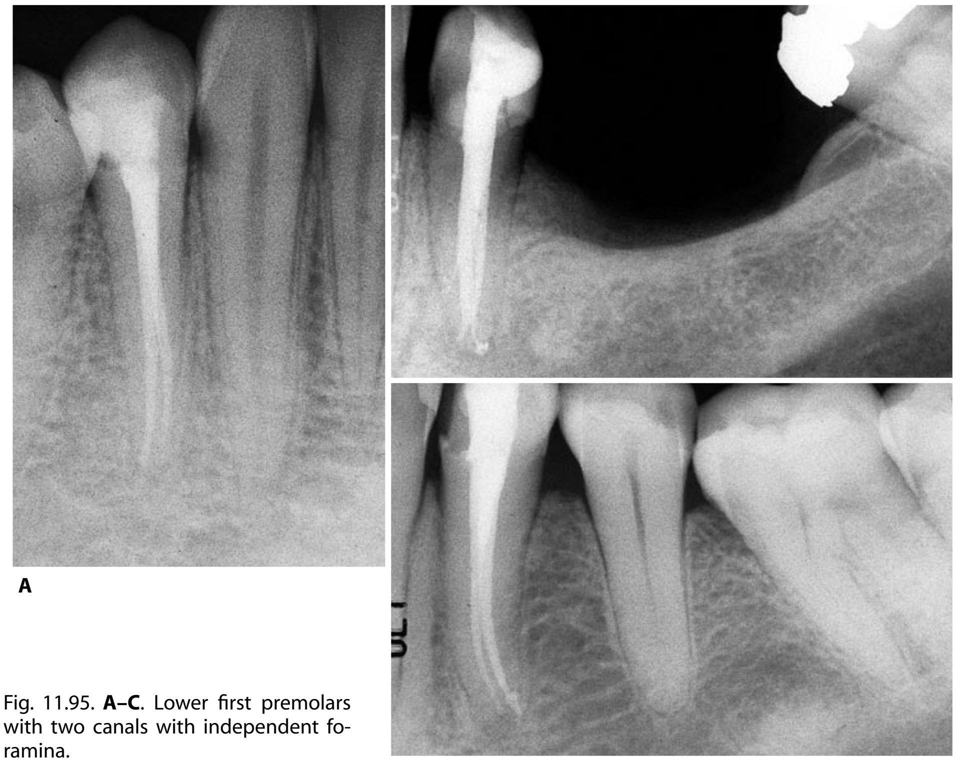


Fig. 11.94. Postoperative radiograph of a lower first premolar with two canals joining at a common foramen.



A

B

C

Fig. 11.95. **A–C**. Lower first premolars with two canals with independent foramina.

Fig. 11.96. A lower first premolar with a bifurcation in the apical one third.

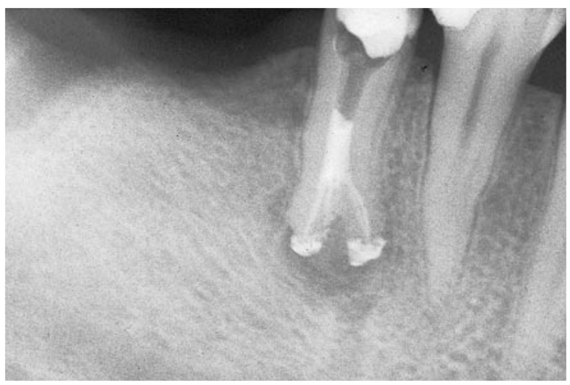


Fig. 11.97. A lower first premolar whose root bifurcates into two independent roots at the level of the apical one third.

vity, which is elliptical, must be created at the expense of the buccal cusp.
The entry point of the bur is in the middle of the central groove, the inclination directed toward the side of the buccal cusp (Fig. 11.98 C), which is eliminated almost at the peak (Figs. 11.98 D-L).
In contrast, the side of the lingual cusp is almost completely preserved. It would be incorrect to orient the bur parallel to the long axis of the tooth, because this could easily lead to a lingual perforation.

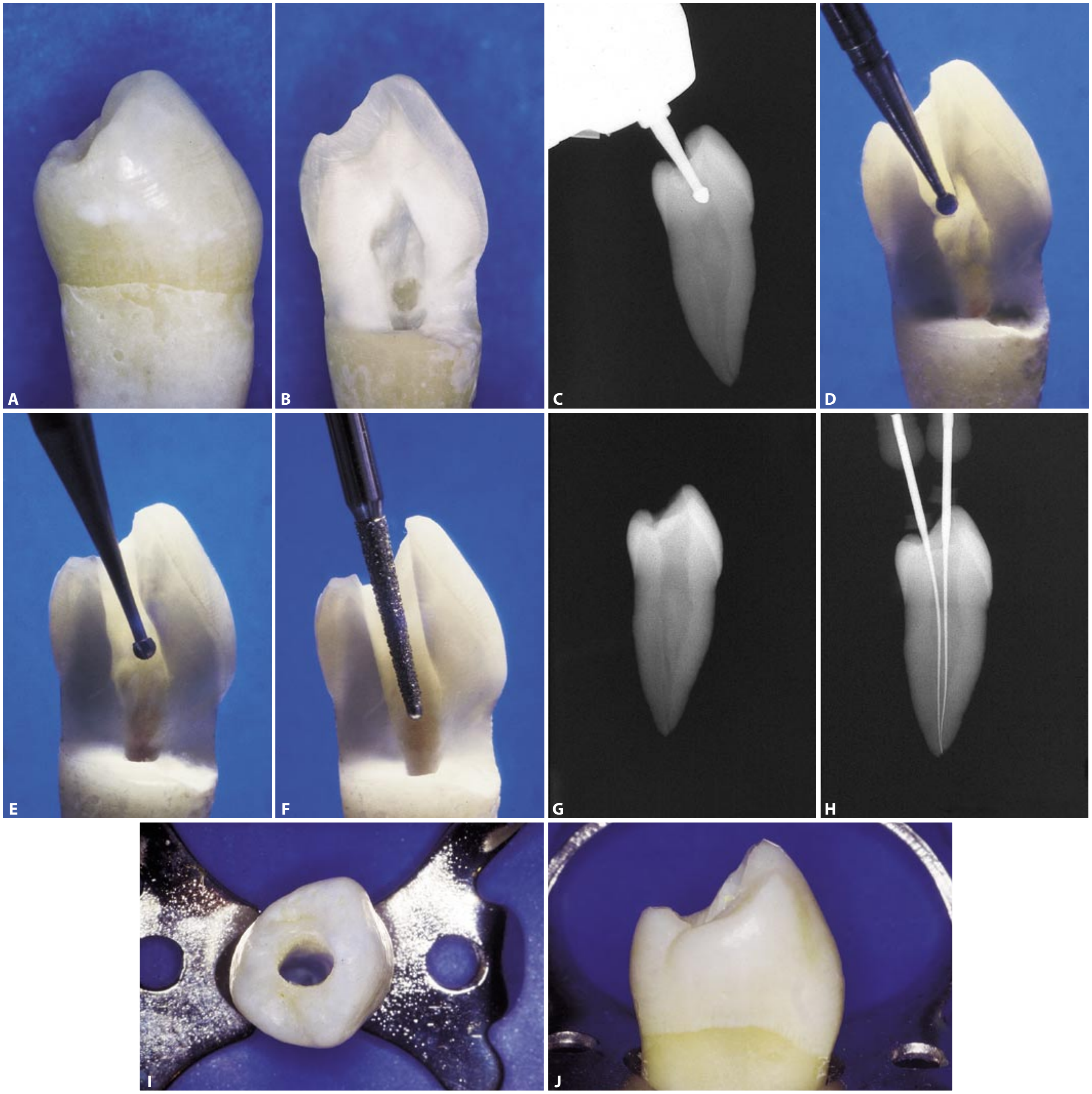


Fig. 11.98. **A**. The crown of a lower first premolar can be compared to that of a canine, given its highly developed cingulum. **B**. The pulp chamber lies almost entirely below the buccal cusp. **C**. In preparing the access cavity, the bur must be oriented buccally. **D**. The round diamond bur has accomplished the penetration phase. **E**. The round bur removes the residue of the chamber roof. **F**. The non-cutting diamond bur finishes and flares the cavity. **G**. Radiographic appearance of the completed access cavity. **H**. A correctly performed cavity allows the introduction of instruments in all the canals that may be present. **I**. Occlusal view of the access cavity. **J**. The cavity has been created almost entirely at the expense of the buccal cusp.

LOWER SECOND PREMOLAR

This tooth has fewer variants as compared to the first premolar. The lingual cusp is better developed, and the tooth is more symmetrical (Fig. 11.99).
Vertucci[87] has found that the lower second premolar has a single root with a single ovoid or round canal in 97.5% (Fig. 11.100 A) and a canal that bifurcates at the apex in 2.5% (Fig. 11.100 B). Other times the canal can trifurcate (Fig. 11.101).

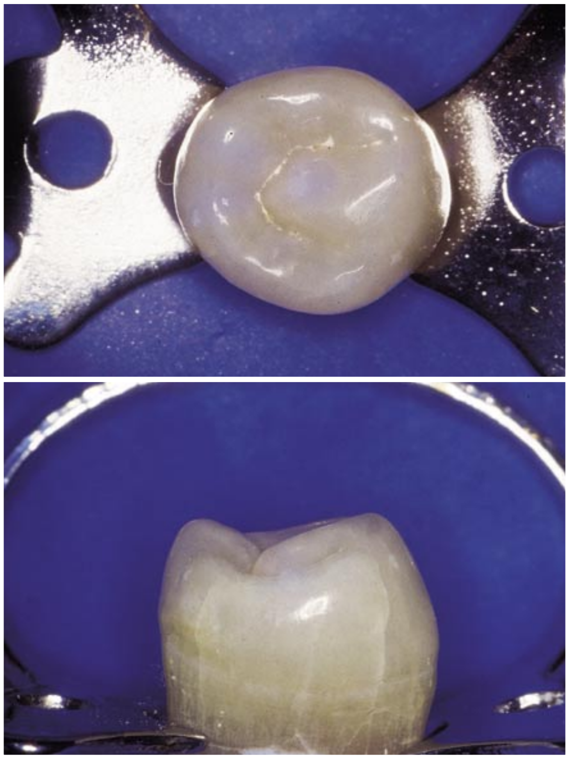

A
B

Fig. 11.99. **A**. Occlusal surface of the lower left second premolar. **B**. Note the greater symmetry as compared to the first premolar.

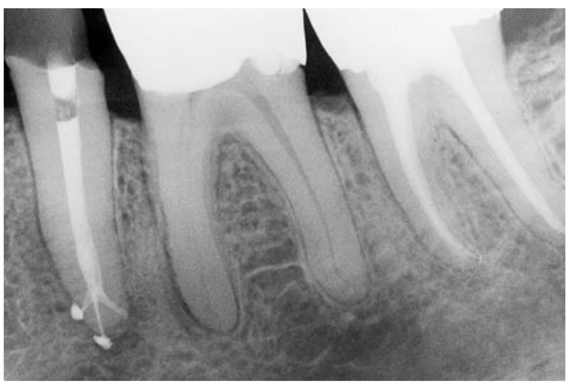


Fig. 11.101. Postoperative radiograph of a lower second premolar, with a trifurcated canal in the apical one third (Courtesy of Dr. C. J. Ruddle).

Other authors, including Green,[44] have found that one may encounter other situations, although rarely. One may find two canals joining at a single foramen (4%) or two completely separate canals (4%) (Fig. 11.102),


A
B

Fig. 11.100. **A**. Postoperative radiograph of a lower second premolar with a single canal. **B**. Postoperative radiograph of a lower second premolar with a canal that bifurcates near the apex.

Fig. 11.102. Postoperative radiograph of the second lower premolar, with two independent canals.

or two canals in separate roots.[43] Even cases with three canals have been described (Fig. 11.103).[32,101]
The access cavity is ovoid and oriented buccolingually (Fig. 11.104).
Lateral canals are very frequent in this tooth (Fig. 11.105). In a study by Fabio,[33] they were found to be histologically demonstrable in 66% of the teeth studied. This is the highest percentage reported in the literature.

Fig. 11.103. The radiograph shows a lower right second premolar with three canals.

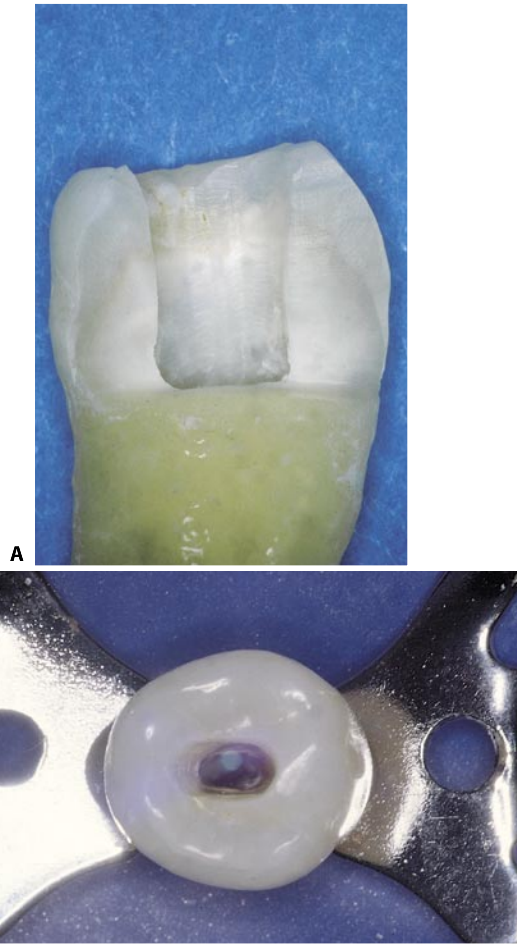


Fig. 11.104. **A**. Completed access cavity. Note that the cusps are not necessarily involved. **B**. Occlusal view of the access cavity.

Fig. 11.105. **A**. Preoperative radiograph of a lower left second premolar with a lesion of endodontic origin on the distal aspect of the middle one third of the root. **B**. Recall radiograph two years later. The lesion, which was adjacent to a lateral canal that is noted to be filled, has healed completely.

LOWER FIRST MOLAR

Together with the upper first molar, this tooth most frequently requires endodontic treatment.

The tooth generally has two separate roots with a round, or more frequently elliptical, canal in the distal root (Fig. 11.106) and two canals in the mesial root. In 90%, they remain separate as far as the foramen [61] (Fig. 11.107); in the remaining 10%, they join together at a common foramen [92] (Fig. 11.108).

Numerous variants have been described:[23]

– In 35% of cases, four canals are present.[47,81] The distal root contains two canals, one in the buccal and the other in the lingual position (Fig. 11.109).

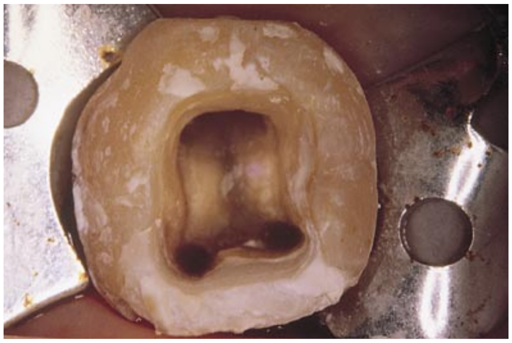


Fig. 11.106. Access cavity of a lower left first molar. The mesial canals have a roundish orifice, while the distal canal is usually elliptical.

Fig. 11.107. The mesial canals of this lower molar have independent foramina. Note the numerous lateral canals in the apical one third (Courtsey of Dr. M. Scianamblo).

Fig. 11.108. The mesial canals of this lower molar are joining in a common foramen. Note the numerous lateral canals in the distal root.

A

B

C

D

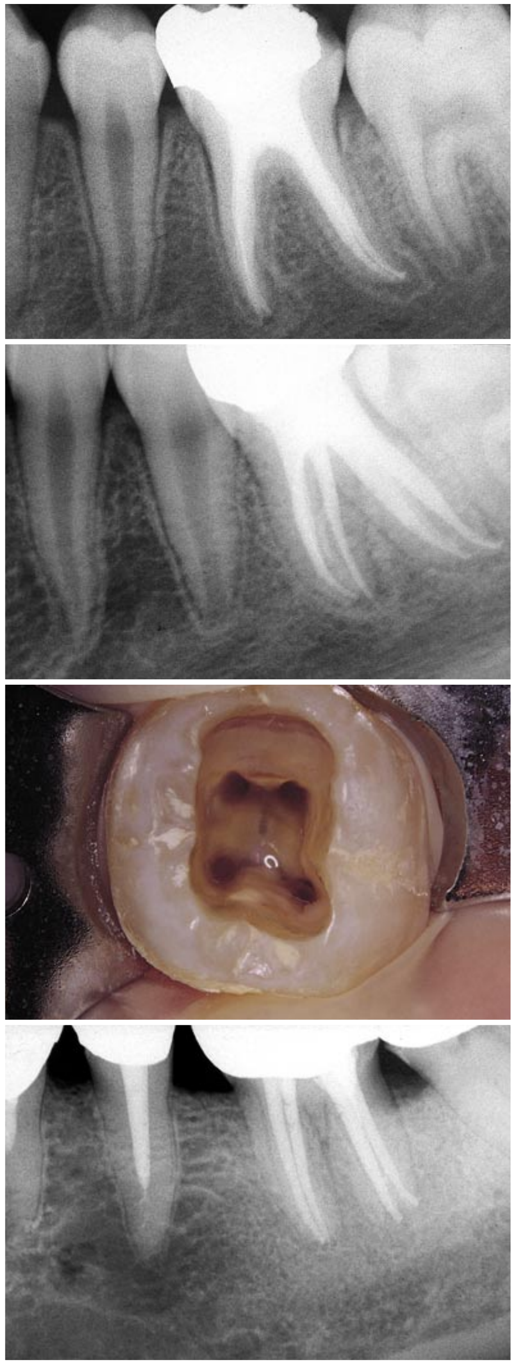


Fig. 11.109. **A**. Postoperative radiograph of the lower first molar. **B**. This mesiodistal view of the same tooth demonstrates, in addition to the two canals of the distal root, the mesial canals which, although they communicate with each other at the level of the middle one third, have independent apical foramina. **C**. Access cavity of a lower left first molar with two canals in the distal root and two canals in the mesial root. **D**. In this other lower molar the four canals in the two roots are visible, each with an independent apical foramen.

– The second distal canal is sometimes found in a separate root in the distolingual position. It is slightly smaller and mesial to the distobuccal root[88] (Fig. 11.110).
– Sometimes, the "extra" canal is found in the mesial root, which therefore contains three canals (Figs. 11.111-11.113). This is the middle mesial canal.[9,14,35,36,50,55,71,93]

In addition, cases with three canals in the distal root and two in the mesial root have been described.[29,34,64,72,84] Cases with two canals in the mesial root and three canals in three distal roots have also been described.[41]

The most salient fact that emerges from an examination of these anatomical variants is that the lower first molar frequently has two canals in the distal root. If


A
B
C

Fig. 11.110. **A**. The slight radiopacity within the bifurcation of this lower right first molar is due to the distolingual root. The lamina dura surrounding this root and the canal contained within are easily recognizable. **B**. First lower molar extracted: the tooth has the distolingual root. **C**. Postoperative radiograph of a lower right first molar with two distal roots and two distal canals.

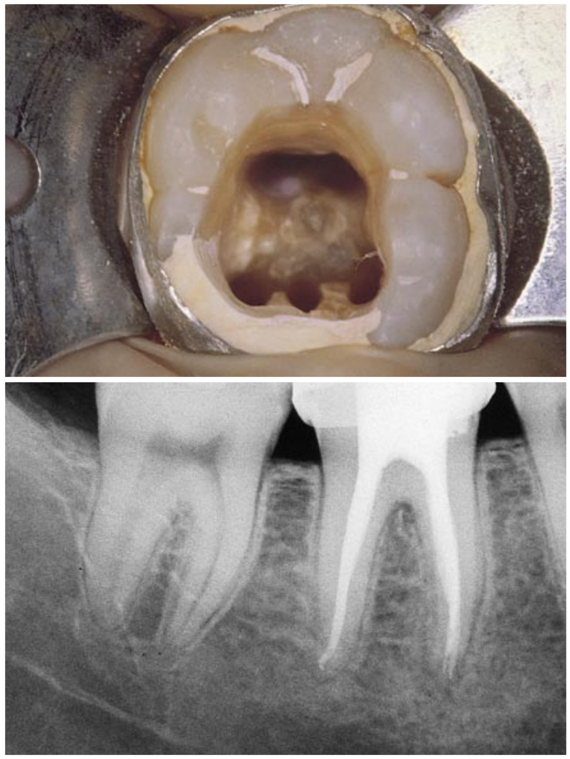

A
B

Fig. 11.111. **A**. A lower right first molar with a distal canal and three mesial canals. Access cavity. **B**. Postoperative radiograph. Radiographically, the three mesial canals appear superimposed.

Fig. 11.112. In this other case, the middle mesial root canal is visible in the apical third of the mesial root (Courtesy of Dr. C.J. Ruddle).

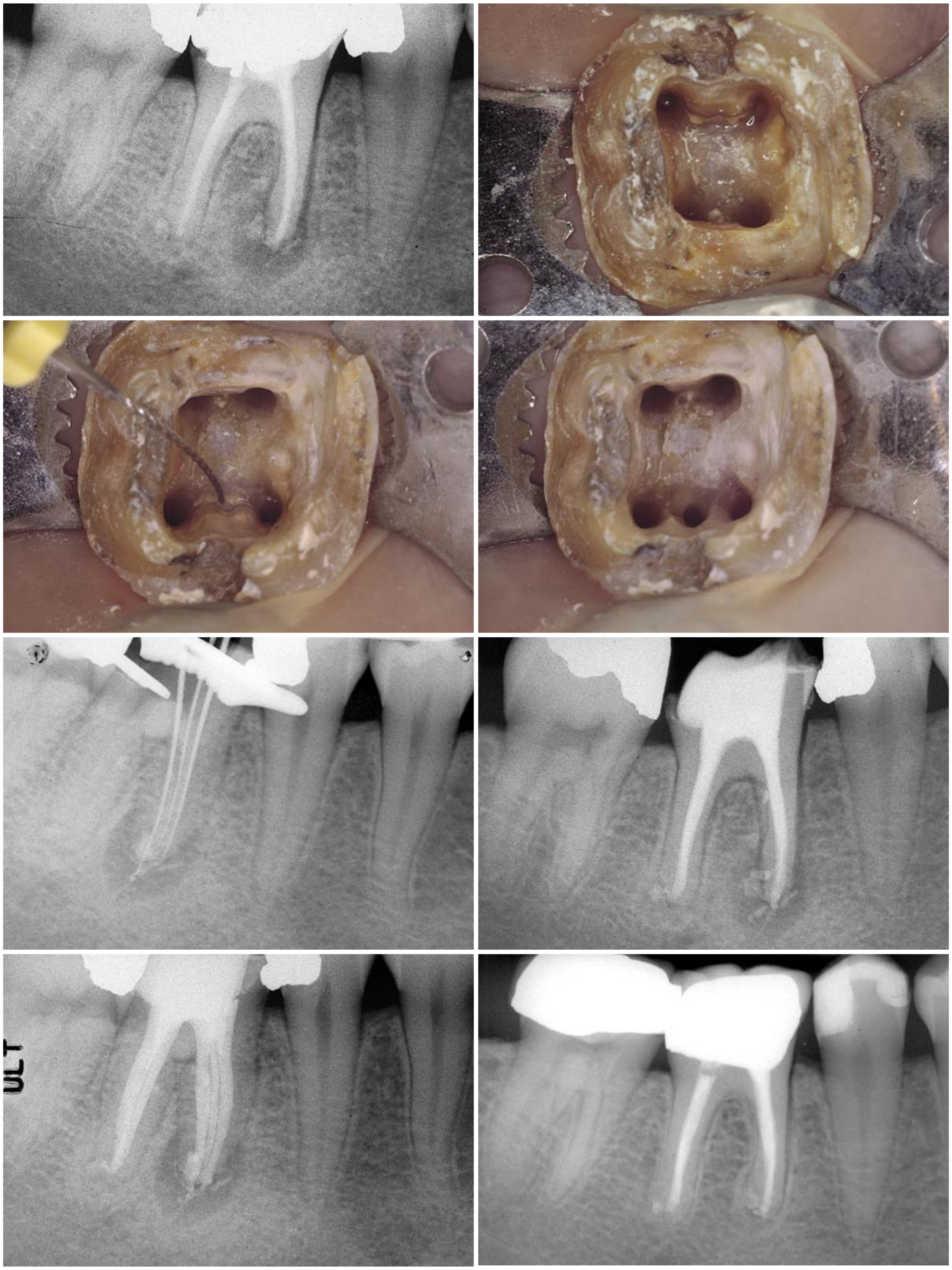


Fig. 11.113. Retreatment of a lower right first molar, where two canals had been missed: the distobuccal and the middle mesial canals. **A**. Preoperative radiograph. **B**. Access cavity after four canals had been prepared. Note the presence of a little depression in the isthmus between the two mesial canals. **C**. A # 10 file introduced into the depression very easily enters the middle mesial root canal, which has an independent foramen. **D**. The access cavity after preparing the five existing root canals. **E**. Three files show the three independent mesial root canals. **F**. Postoperative radiograph. **G**. The off-angle radiograph shows the five canals. **H**. The seven year recall radiograph shows the complete healing of the lesion, which was not caused by the foreign material, but by bacteria left in the missed root canals!

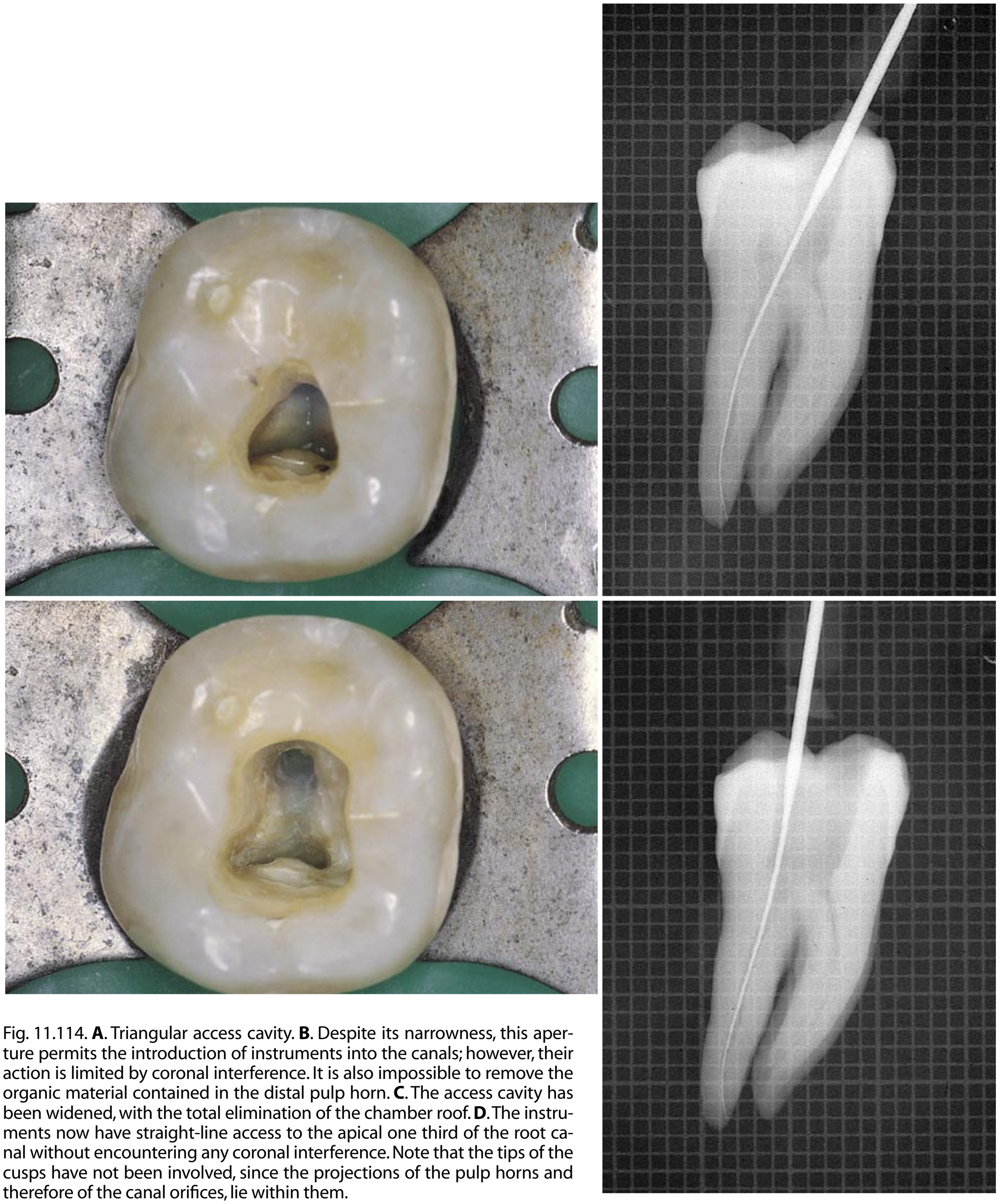
it has only one, it is usually ribbonshape, elliptical, or kidney shaped, that is, buccolingually elongated.

One must keep this in mind when creating the access cavity, which should not be triangular, as described by some authors, but rather trapezoidal or quadrangular with rounded corners.

The classical triangular shape would hamper the identification of the second distal canal (i.e., the distolingual one) and would also hamper adequate cleaning and shaping of a single canal that might be present [21,92] (Fig. 11.114).

Once more, therefore, the rule that it should not be the dentist to decide the shape of the access cavity but rather the anatomy of the pulp chamber floor, holds. The access cavity should therefore not have a pre-determined shape.

The access cavity is initiated with a round, diamond bur mounted on a high-speed handpiece. The bur is



A B C D

Fig. 11.114. **A**. Triangular access cavity. **B**. Despite its narrowness, this aperture permits the introduction of instruments into the canals; however, their action is limited by coronal interference. It is also impossible to remove the organic material contained in the distal pulp horn. **C**. The access cavity has been widened, with the total elimination of the chamber roof. **D**. The instruments now have straight-line access to the apical one third of the root canal without encountering any coronal interference. Note that the tips of the cusps have not been involved, since the projections of the pulp horns and therefore of the canal orifices, lie within them.

applied at the level of the central fossa (Fig. 11.115). A circular, helical movement is imparted to the bur, so as to scoop out an initial, funnel-shaped cavity as one tries to penetrate the roof of the pulp chamber. A careful radiographic examination allows one to orient the bur toward the widest pulp horn (Figs. 11.116 A-C).
With a long-shafted round bur used at low speed, one removes the undercuts of dentin (Figs. 11.116 D, E); then, with the self-guiding diamond bur at high speed, one performs the finishing and slight flaring (Figs. 11.116 F-I).
Only when there is a single, roundish distal canal should the access cavity be given a triangular shape (Fig. 11.114 C). In all other cases, the shape is trapezoidal, with the lesser base corresponding to the distal wall.

Fig. 11.115. The access cavity must have the shape of the projection of the pulp chamber floor onto the occlusal surface. The point of entry of the bur is identified by the central fossa.

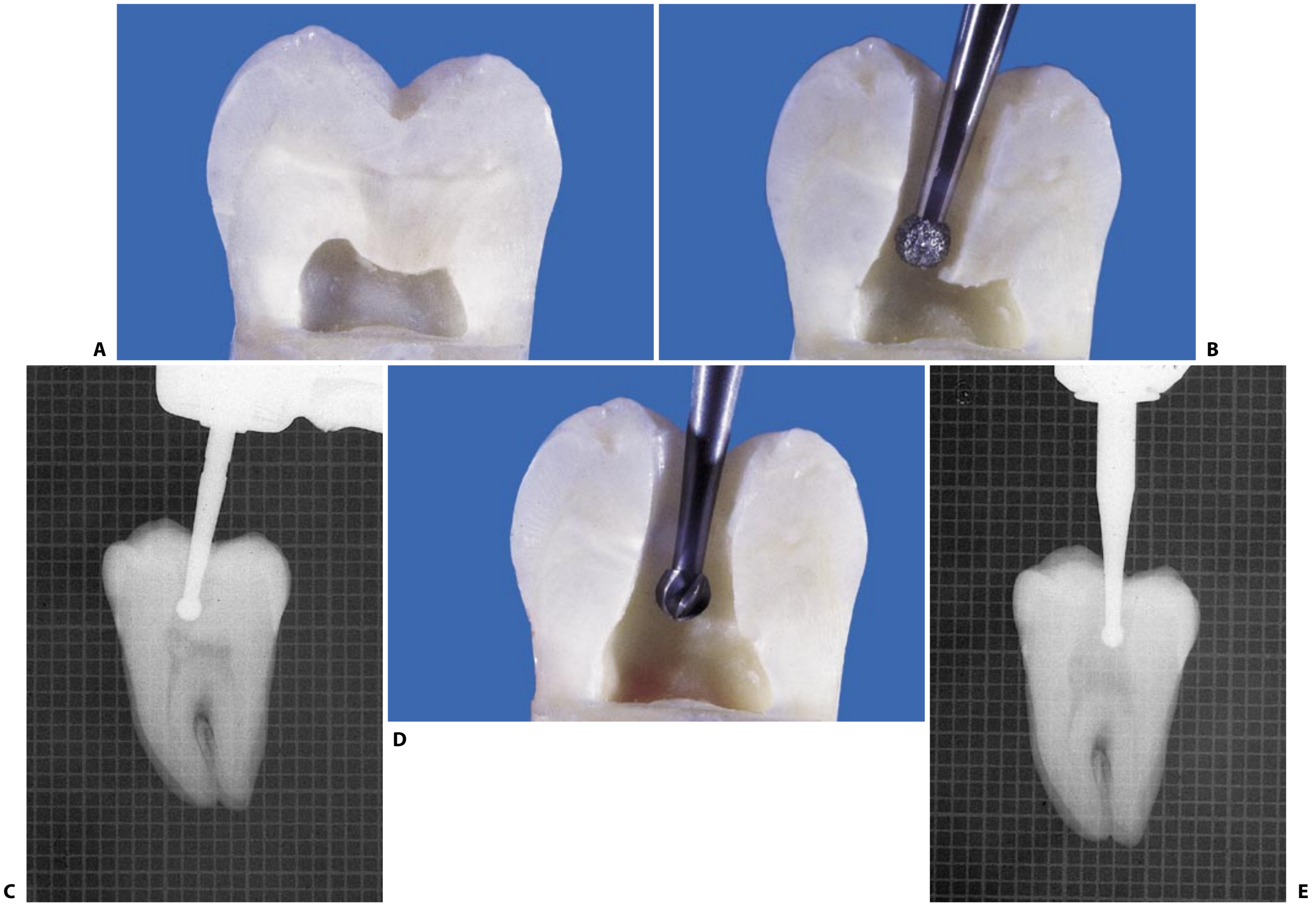


Fig. 11.116. **A**. Pulp chamber in a mesiodistal section. **B**. The round diamond bur penetrates toward the widest pulp horn. **C**. Radiographic appearance of the penetration phase. **D**. The low-speed round bur removes the residue of the chamber roof. **E**. Radiographic appearance of the widening phase (continued).

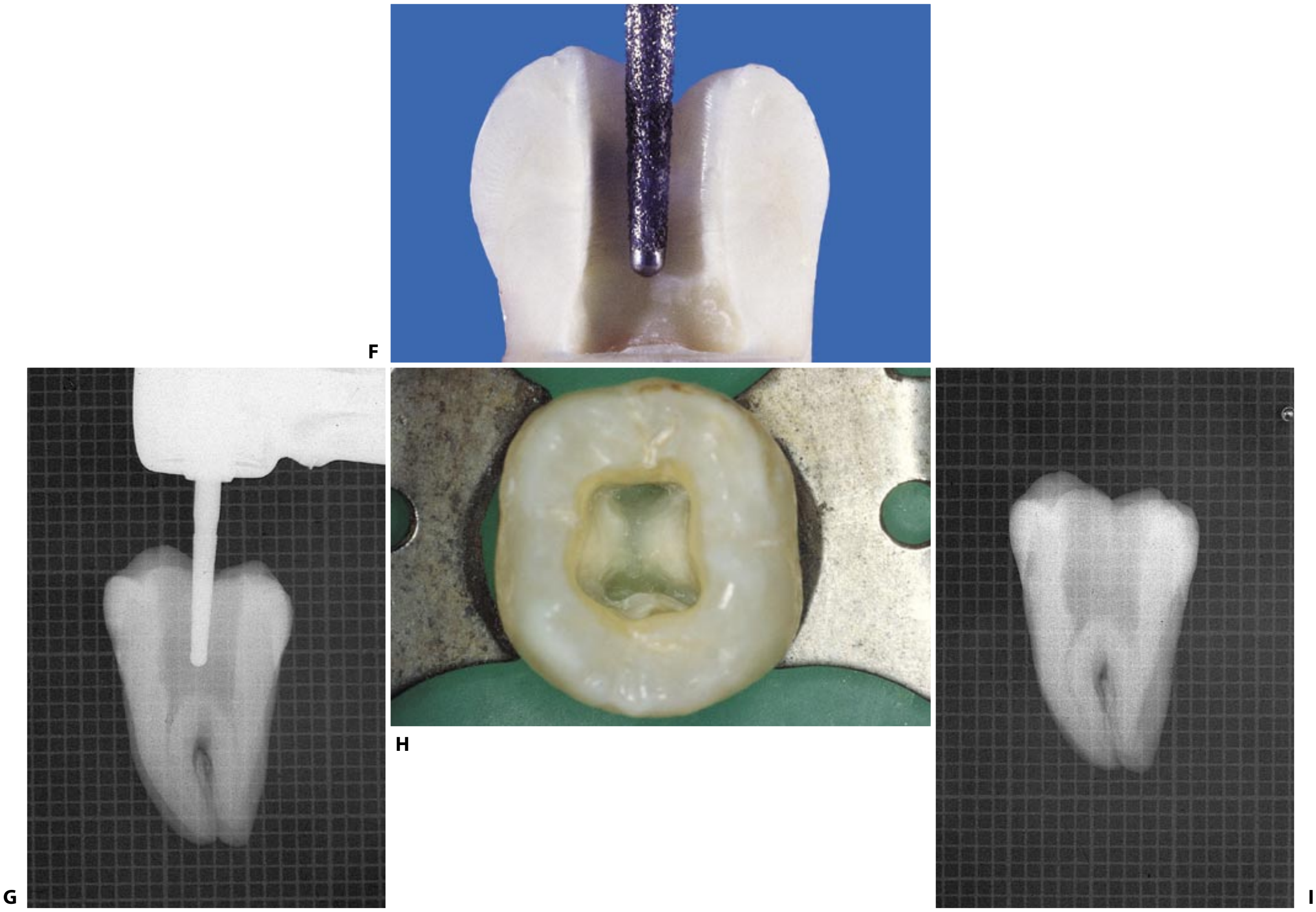


Fig. 11.116. (continued) **F**. The non-cutting diamond bur performs the finishing and flaring phase. **G**. Radiographic appearance of this phase. **H**. Completed access cavity. **I**. Radiographic appearance of the access cavity.

Once the access cavity has been prepared, the distal canal is the easiest to locate. Therefore, if there is any difficulty finding the other canals, it is advisable to start treating the distal. The irrigating solutions will help in identifying the other orifices.
Given that the mesiobuccal canal lies well below its respective cusp, it will very often be necessary to remove the cusp to find the orifice and to complete the treatment. It is certainly preferable to prosthetically reconstruct a cusp in an endodontically well-treated tooth rather than have an intact cusp above an endodontic failure. Furthermore, as in all the posterior teeth, protection of the cusps is always strongly advisable, if not mandatory.
The distal canal usually follows a rather straight course, except in the most apical portion, frequently oriented distally (Fig. 11.117). The reason this curve faces distally is easy to understand, if one keeps in mind that the mandible has grown mesially while the tooth was completing its apical development. Consequently, the apex forms around a vascular peduncle, which, in the meantime, has assumed a mesiodistal inclination.
It is important to keep in mind the existence of this canal curvature and to use small, precurved instruments. A straight instrument of inadequate size would be hampered by the external wall of the curve, giving the impression that it is in contact with the apical constriction or the cementodentinal junction. A small, precurved instrument, on the other hand, can easily negotiate such an apical curvature.
The canals of the mesial root take a more curved course with a mesial orientation immediately below the orifice and then distal in the rest of the root canal. Sometimes, the mesiobuccal canal at its opening faces buccally – in confirmation of which the handle of the instrument introduced faces lingually – and this fur-

ther obliges one to remove the cusp to obtain a straight-line access to the apical one third (Fig. 11.14).

Since the presence of a curvature in the mesial canals – and therefore the root that contains them – is almost the rule, the use of the "anticurvature" filing method [1] is obligatory in the preparation of these root canals, which, together with the mesiobuccal canal of the upper first molars, are the most frequent site of strip perforations (Fig. 11.118).

In 10% of cases, the two canals join at the apex in a single foramen (Fig. 11.119). This joining, in this author's opinion, is more easily recognized after the complete cleaning and shaping of at least one canal rather than at the beginning of treatment. Indeed, two small files can be simultaneously introduced into the two different root canals down to the apex, even if they join together in a single foramen, since it can be sufficiently wide as to let both pass. The introduction of a larger instrument into one and a smaller one into the other can lead to fracture of the smaller instrument which, on the other hand, can also be passed between the spirals of the other and arrive equally at the canal terminus.

A B C D

Fig. 11.117. The distal root canal of the lower molars often faces distally, sometimes with an angle of about 90°. If the instruments are not precurved, the obturation will be short, possibly leaving one with the impression that one has reached the cementodentinal junction or the apical constriction. **A**. Preoperative radiograph. The canals were treated with iodoformic paste. **B**. An adequately precurved # 08 file follows the pronounced curvature of the canal. **C**. Postoperative radiograph. **D**. Recall radiograph two years later. Note that the obturation has been made at the radiographic terminus of the canal and, at the same time, is at least three millimeters short from the radiographic apex!

A B

Fig. 11.118. Neglecting to apply the anticurvature filing method leads as a consequence to excessive thinning of the root and perforation or stripping. **A**. Preoperative radiograph. Note the thinness of the mesial root and its slight curvature. **B**. Postoperative radiograph. The result of the stripping is evident.

In this author's opinion,[22] the use of a gutta-percha cone in a canal which has just been prepared and a small instrument in the other yet to be prepared, is safer. If the two canals join together, the imprint left by the instrument on the gutta-percha cone will be visible (Fig. 11.120).

Because it is easier to cause stripping in the mesiobuccal than the mesiolingual canal of the lower first molar,[12] it is advisable always to begin by cleaning and shaping the two canals of the mesial root, beginning with the mesiolingual canal and then seek, with the help of a gutta-percha cone and a small instrument, the confluence of the mesiobuccal canal in a common foramen.

Such an occurrence allows one to save dentin in the mesiobuccal canal by enlarging the canal less, and one therefore runs less risk of causing stripping.

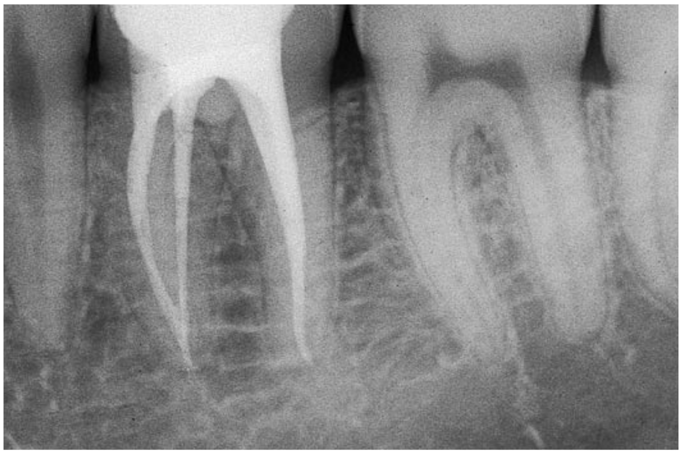
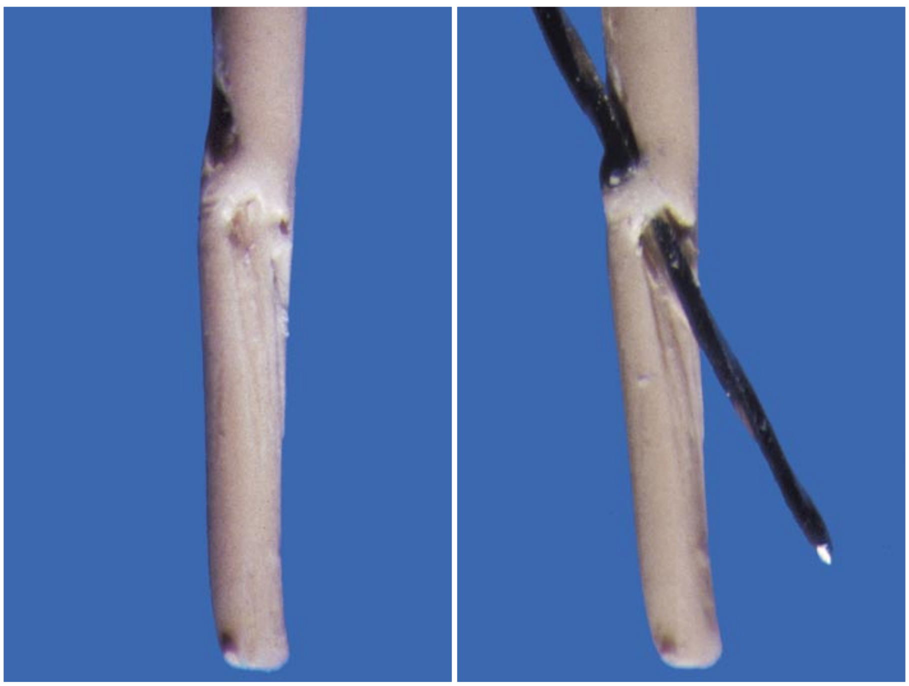


Fig. 11.119. The postoperative radiograph shows the mesial canals joining at a common foramen.

A



B

Fig. 11.120. **A, B**. The gutta-percha cone had been inserted in the cleaned and shaped mesiolingual canal, and the # 08 file has been inserted into the mesiobuccal canal, which has yet to be prepared. Given the confluence, the file has tunneled through the gutta-percha cone.

LOWER SECOND MOLAR

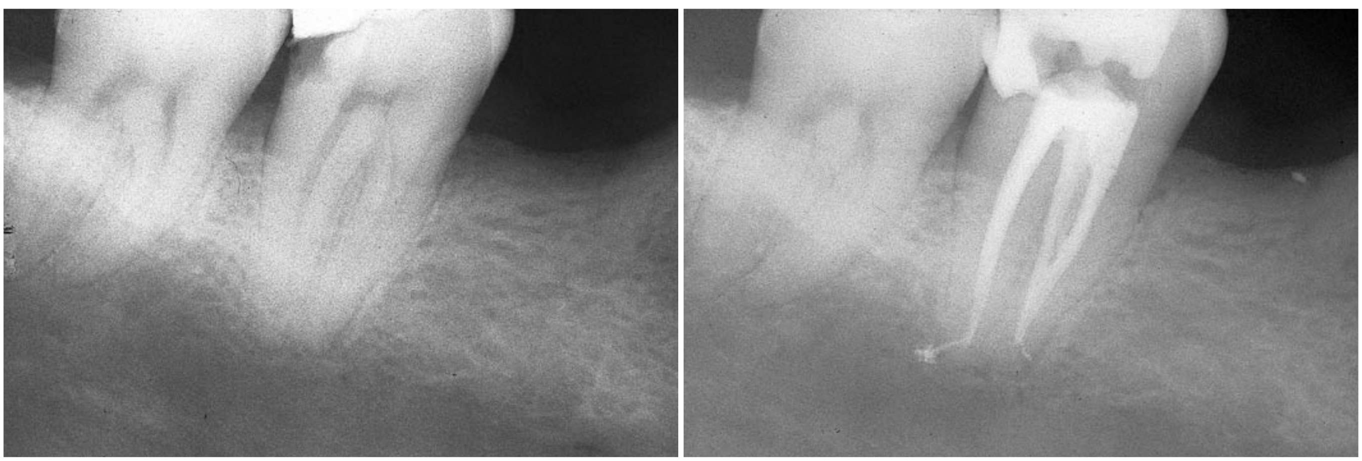
The anatomical variability of the lower second molar is even greater than that of the first molar.[62] In general terms, its anatomy is very similar to that of the first molar; the only difference is that it is somewhat smaller, more symmetric, and has more closely-spaced roots.

Many times, however, its appearance may be bizarre, different from the usual morphology, as it may have various combinations:[23,25]

– One canal may be in the distal root, while two independent canals (Fig. 11.121) or two canals joining at a single apical foramen (Fig. 11.122) may be in the mesial root.
– In other cases, the mesial root may have only a centrally-situated canal, so that the tooth has a distal canal and only one mesial canal (Fig. 11.123). To be certain that the mesial root has a single canal, it is necessary to check the position of its orifice in the floor of the pulp chamber and obtain different radiographic views. Sometimes a perforation can be found in the lingual side of the access cavity, because the previous dentist was looking for the mesiolingual canal while the mesial root had only one mesial canal.
– The tooth can have the classical three canals, but they may be oriented unusually. For example, the orifice of the mesiolingual canal might be found much closer to the distal than to the mesiobuccal canal (Fig. 11.124). There may be a mesial root with a single canal, while the distal root contains two ca-

A B

Fig. 11.121. A lower second molar with one distal and two mesial canals with independent apices. **A**. Preoperative radiograph. **B**. Recall radiograph two years later.

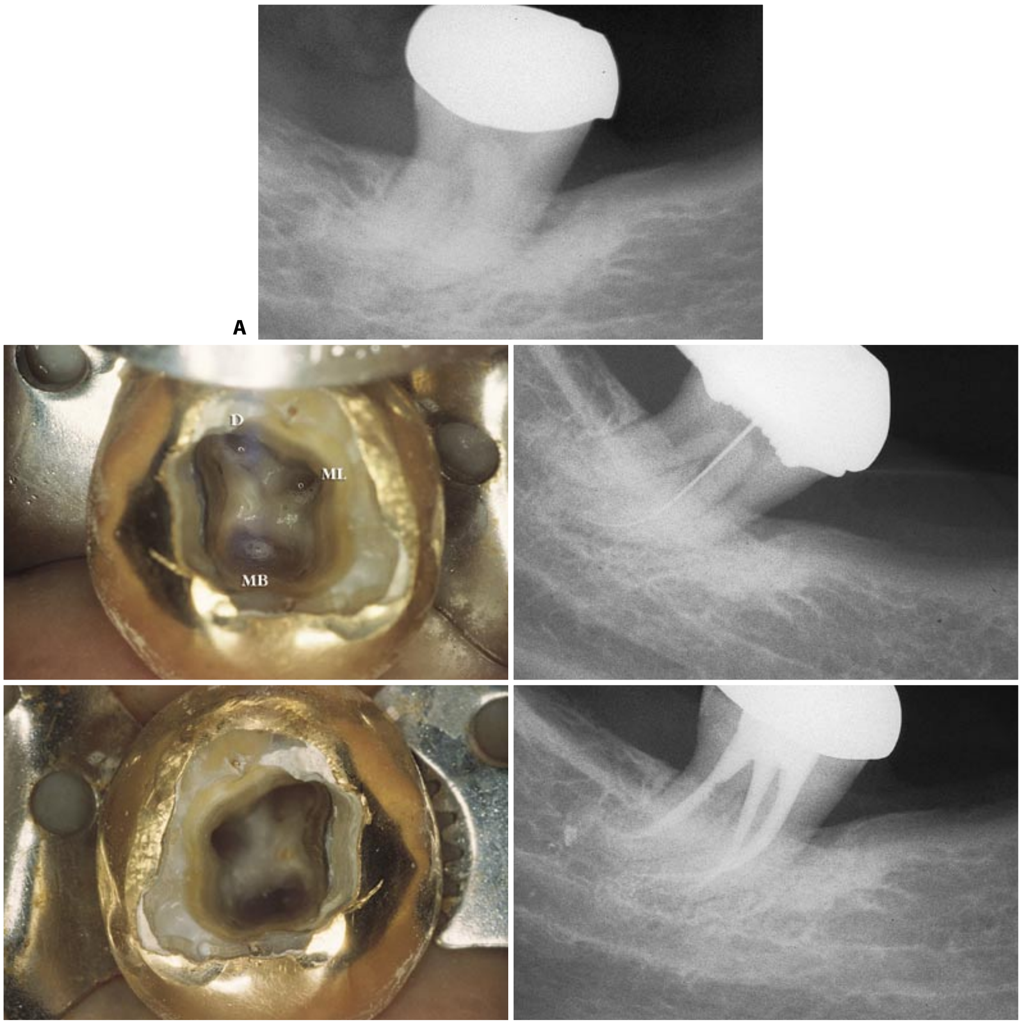


A B

Fig. 11.122. A lower second molar with a distal and two mesial canals joining together at a common apex. **A**. Preoperative radiograph. **B**. Postoperative radiograph.

A B

Fig. 11.123. A lower second molar with one canal in the distal root and a single canal in the mesial root. **A**. Access cavity: the two canals are at the two ends of the shallow groove in the floor of the pulp chamber. On the right, the impression of the bur is recognisable (in a lingual direction). The previous dentist was looking for the non-existing mesiolingual canal. **B**. Postoperative radiograph: the two canals lie in separate roots, which barely communicate near their apical foramina.



A B C D E

Fig. 11.124. A lower second molar with the three classical canals oriented a bit unusually: the mesiolingual canal is close to the distal canal. **A**. Preoperative radiograph. **B**. Access cavity: the opening of the mesiolingual canal is very close to that of the distal canal, so much so that it resembles a distolingual canal. D, distal canal; ML, mesiolingual canal; MB, mesiobuccal canal, **C**. Intraoperative radiograph demonstrating the course of the mesiolingual canal. **D**. Access cavity showing cleaned and shaped root canals. **E**. Postoperative radiograph.

nals, which join at the apex (Fig. 11.125). In this case, the tooth will have three canals, but will appear as though it was rotated 180 degrees.[25,98]

– The tooth may have a single root containing two canals, one mesial and one distal, which are independent (Fig. 11.126) or joined at the apex (Fig. 11.127).
– The molar may have a single root containing a single canal (Fig. 11.128).
– Quite rarely, the lower second molar may have three roots with three independent canals, one distal and two mesial,[92] (Fig. 11.129) or three roots with four canals, one distobuccal, one distolingual, and two mesial (Fig. 11.130).
– In some cases, the molars may appear clinically and radiographically unexceptional, but in fact have unusual canal communications, which one can find out in different phases of the root canal treatment:

1. Following preparation of the access cavity.

This is the case of the so-called "C-shaped canal", which Weine et al. have reported is present in 2.7% of cases.[95] It was described for the first time by Cook and Cox[27] in the lower second molar, but it may sometimes be found in the lower first molar.[7,13,45,74,94]

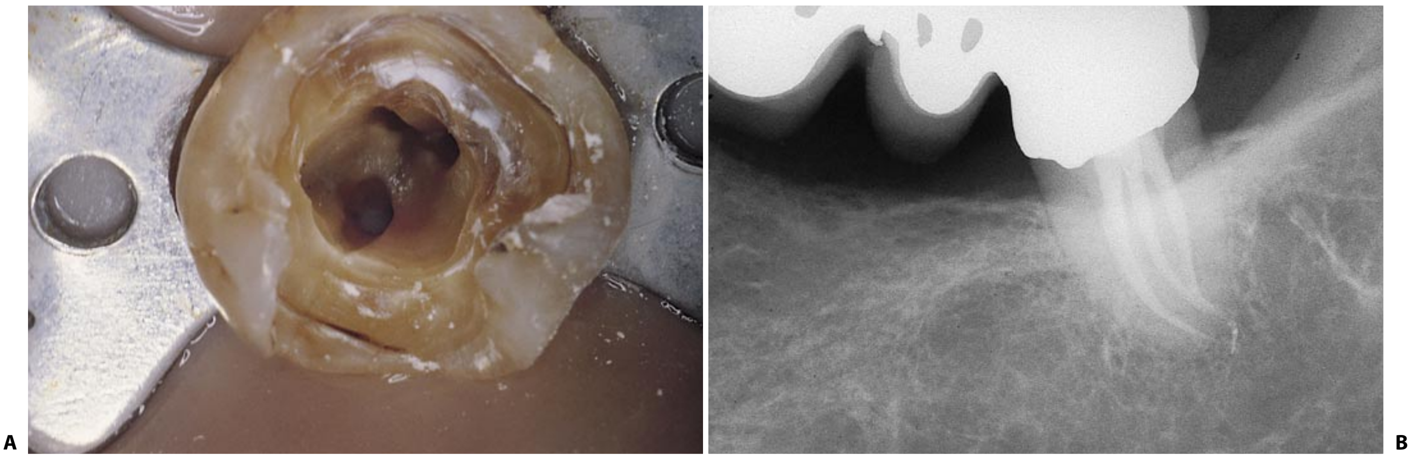


Fig. 11.125. A lower second molar with a single mesial canal and two distal canals, joining at a common apex. **A.** Access cavity: the three openings are noted, but the tooth seems to be rotated 180°. **B.** Two year recall.

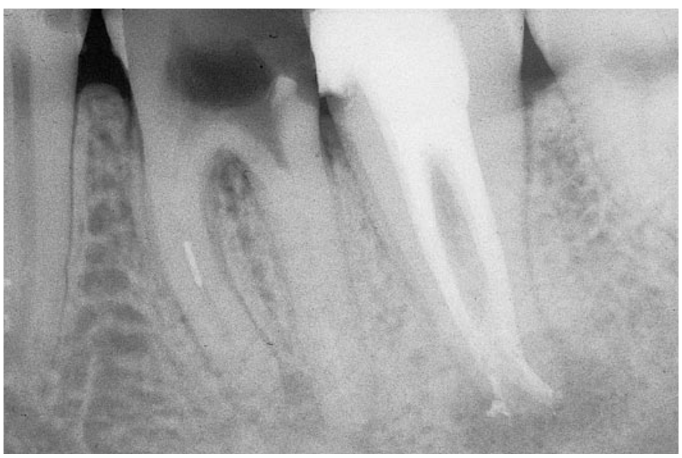


Fig. 11.126. Postoperative radiograph of a lower left second molar with two independent canals in a single root.

Fig. 11.127. Postoperative radiograph of a lower left second molar with two merging root canals in a single root.

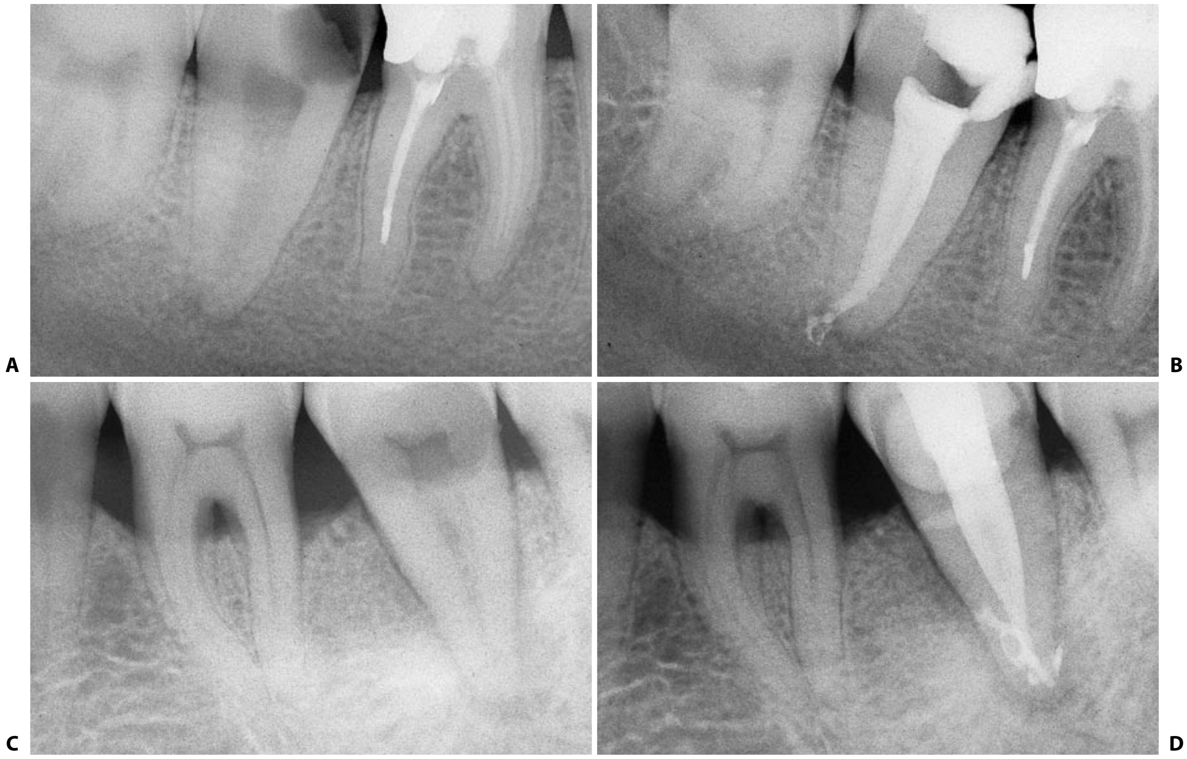


Fig. 11.128. Lower second molars with a single root and a single canal. **A**. Preoperative radiograph. **B**. Postoperative radiograph. **C**. In this other case, from the preoperative radiograph the second molar seems to have two fused roots with the three classical root canals. **D**. After cleaning and shaping, the tooth reveals a single root containing a single canal. Note the bizarre endodontic anatomy.

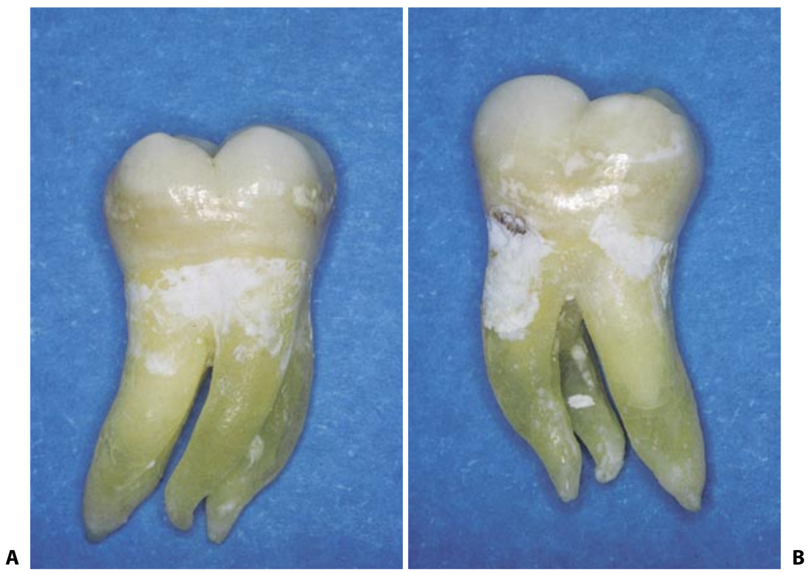


Fig. 11.129. The two mesial canals of this extracted second molar are in independent roots. **A**. Lingual view. **B**. Buccal view.

This anatomy is quite common among oriental patients.[91,99]
Instead of having three separate orifices, the three canals have a single "C-shaped" one, the convexity facing buccally (Fig. 11.131).
The introduction of an instrument into the mesiobuccal portion causes an unusual radiographic image, which may lead one to suspect a perforation; in fact, it is the mesiobuccal canal, which can join the

A
B
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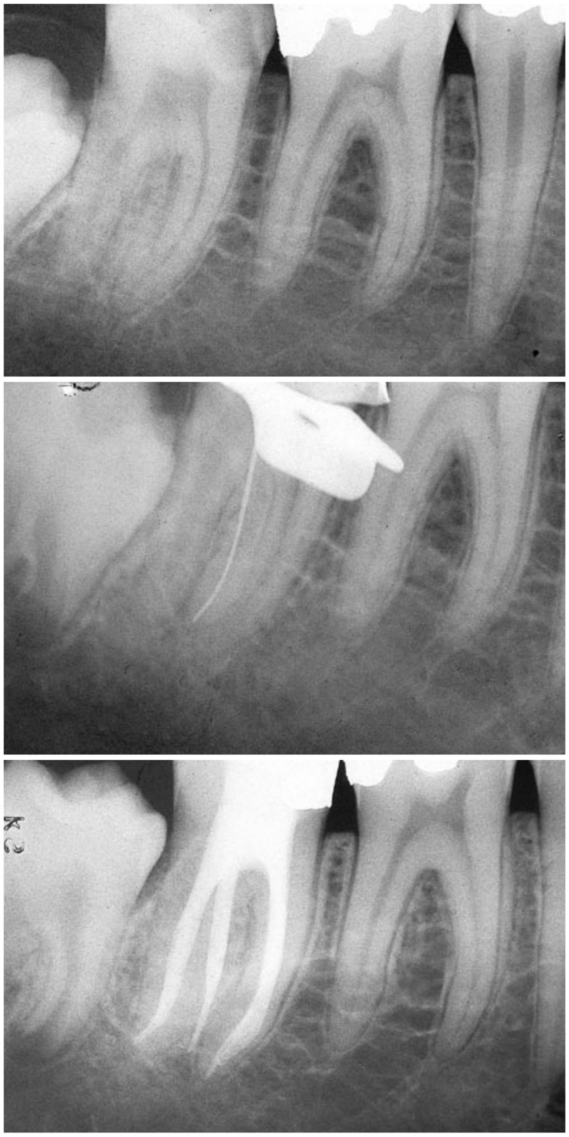

Fig. 11.130. A lower right second molar with two distal canals in two separate roots. **A**. The preoperative radiograph reveals the presence of one root, the distolingual root, within the bifurcation. **B**. The instrument that simulates a perforation of the floor is in fact within the distolingual canal. **C**. Two year recall.

A
B
C
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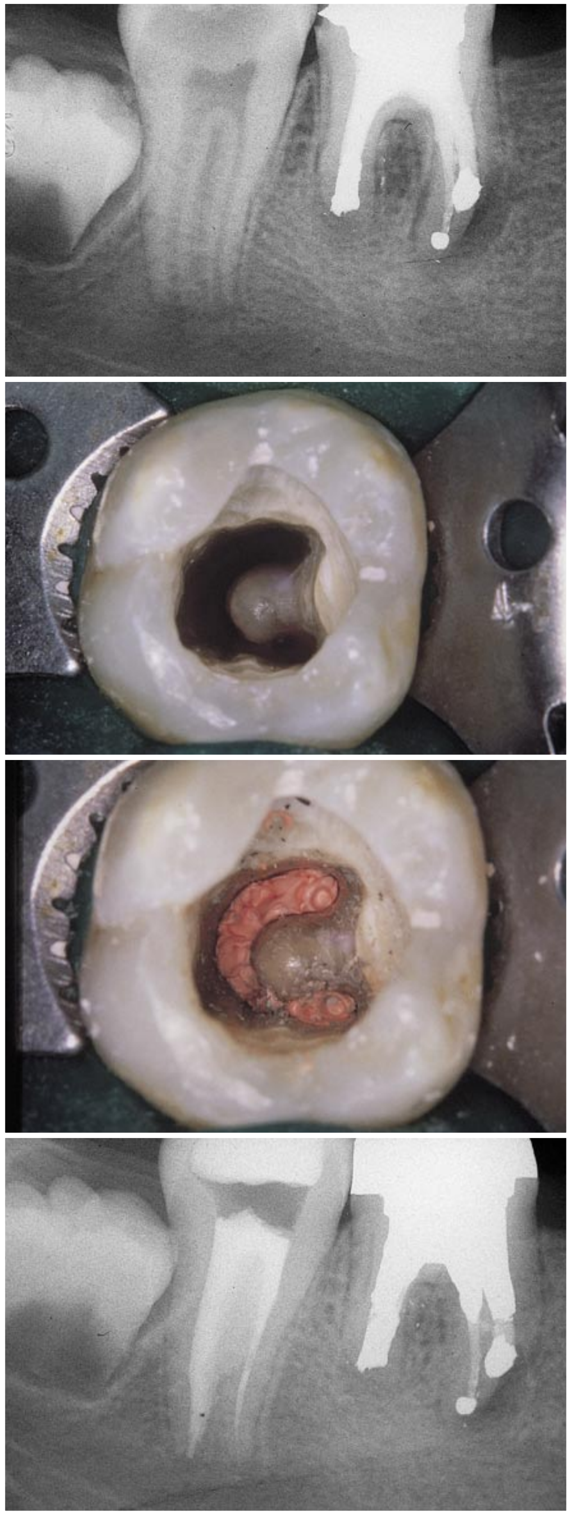


Fig. 11.131. A lower right second molar with a C-shaped canal. **A**. Preoperative radiograph. **B**. Access cavity. Note the typical C-shaped appearance of the three connected canal openings. **C**. Three-dimensional obturation with warm gutta-percha has been completed. **D**. Postoperative radiograph. The C-shaped communication extends to the level of the apical one third.

distal[7] (Fig. 11.132) or the mesiolingual canal[23] (Fig. 11.133). The "C-shaped" communication among the various canal openings can extend apically to a variable depth, and this can be visualized only by the root canal filling (Figs. 11.134-11.136).

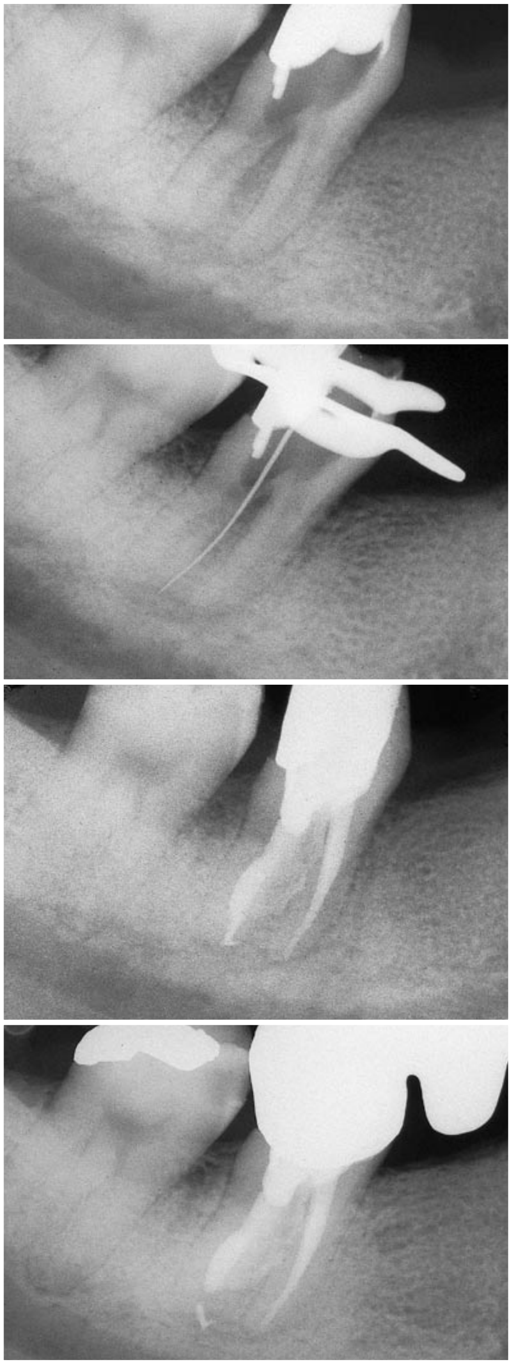


Fig. 11.132. A lower second molar with a C-shaped canal, in which the mesiobuccal canal runs into the distal canal. **A**. Preoperative radiograph. **B**. An instrument introduced into the convexity of the "C" simulates a perforation of the floor; actually, it is negotiating the mesiobuccal canal which, in this case, runs into the distal canal. **C**. Postoperative radiograph. **D**. Three year recall.

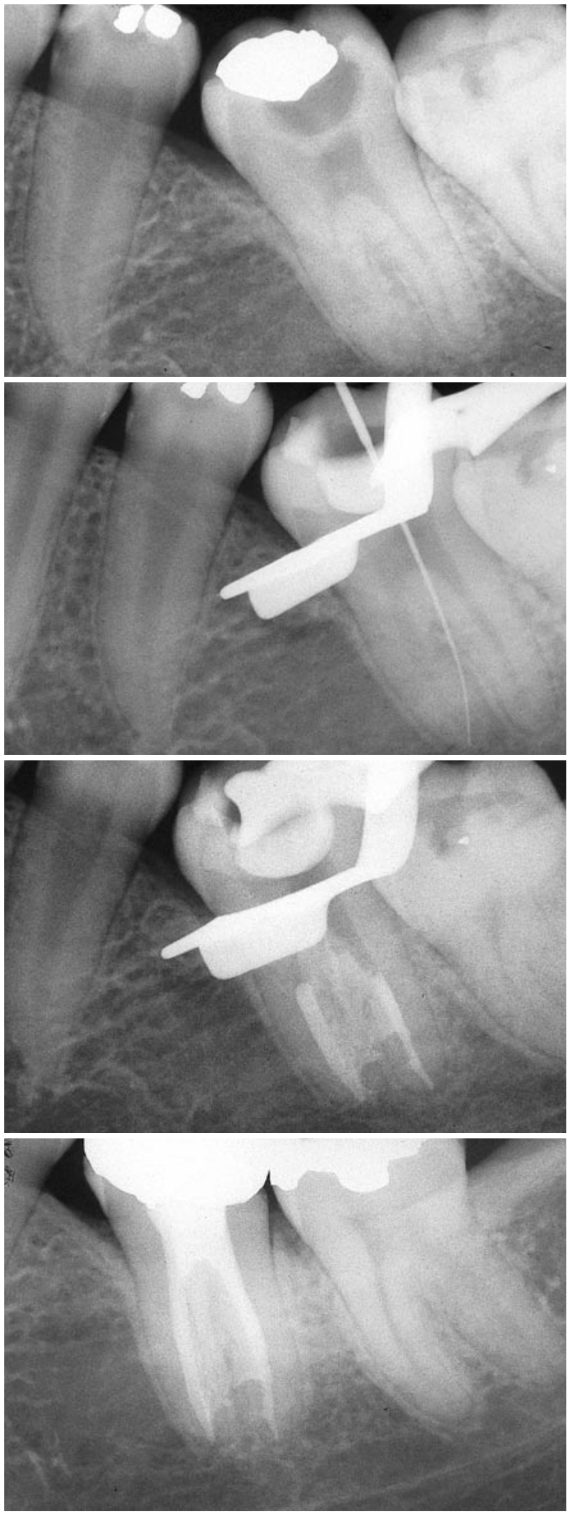


Fig. 11.133. A lower left second molar with a C-shaped canal, in which the mesiobuccal canal runs into the mesiolingual canal. **A**. Preoperative radiograph in which the presence of a C-shaped canal cannot be detected. **B**. Intraoperative radiograph: an instrument introduced in the convexity of the "C" simulates a perforation of the floor; actually, it negotiates the mesiobuccal canal which, in this case, runs into the mesiolingual canal. **C**. Intraoperative radiograph of the apical condensation: only with a technique that includes the condensation of the heat-softened gutta-percha is it possible to three-dimensionally obturate the entire extent of the "C". **D**. Three year recall.

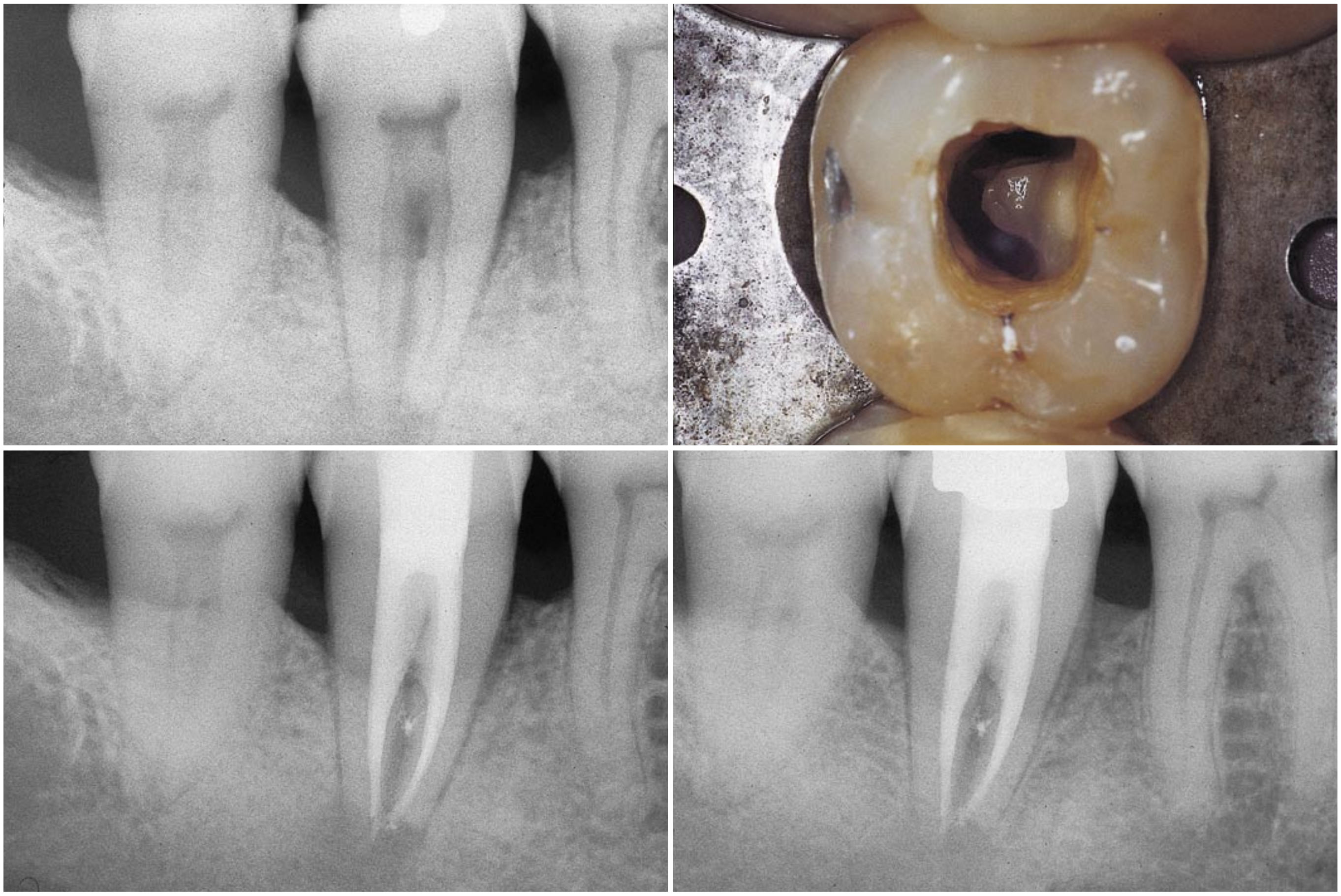

A B C D

Fig. 11.134. A lower right second molar with a C-shaped canal. The ribbon shaped communication among the three canals extends apically as far as the middle one third. **A**. Preoperative radiograph. **B**. Access cavity with a typical ribbon shaped opening. **C**. Postoperative radiograph. **D**. Recall radiograph 18 months later.

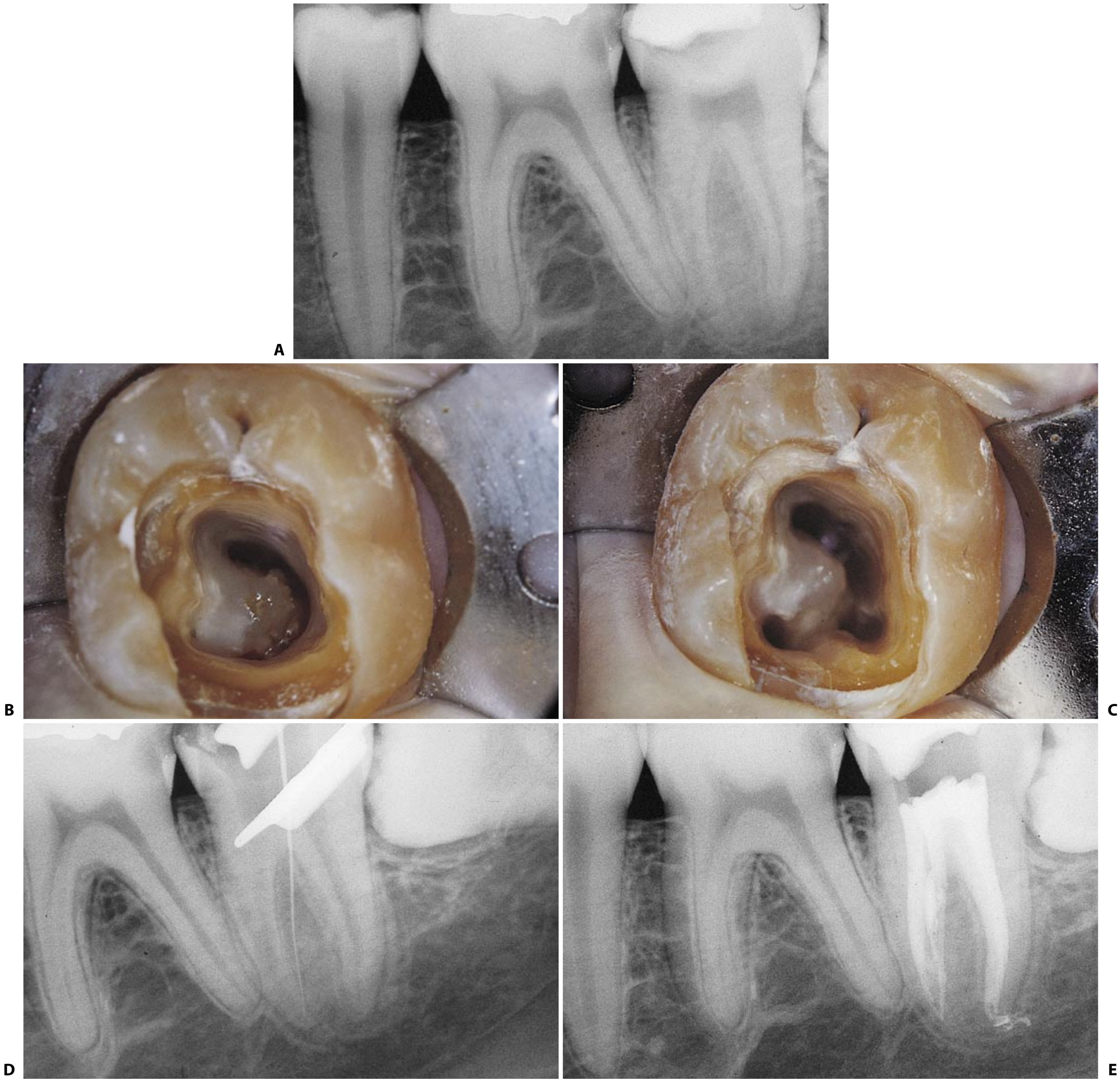


Fig. 11.135. A lower left second molar with an incomplete C-shaped canal. **A**. Preoperative radiograph. **B**. Access cavity: the three canals appear to be joined by a groove with a buccal convexity. A C-shaped canal was diagnosed. **C**. After completing the cleaning and shaping phases, the "C" appears incomplete, as it involves only the distal and mesiobuccal canals. **D**. An instrument introduced into the mesiobuccal canal indicates the confluence of this canal with the mesiolingual canal. **E**. Postoperative radiograph.

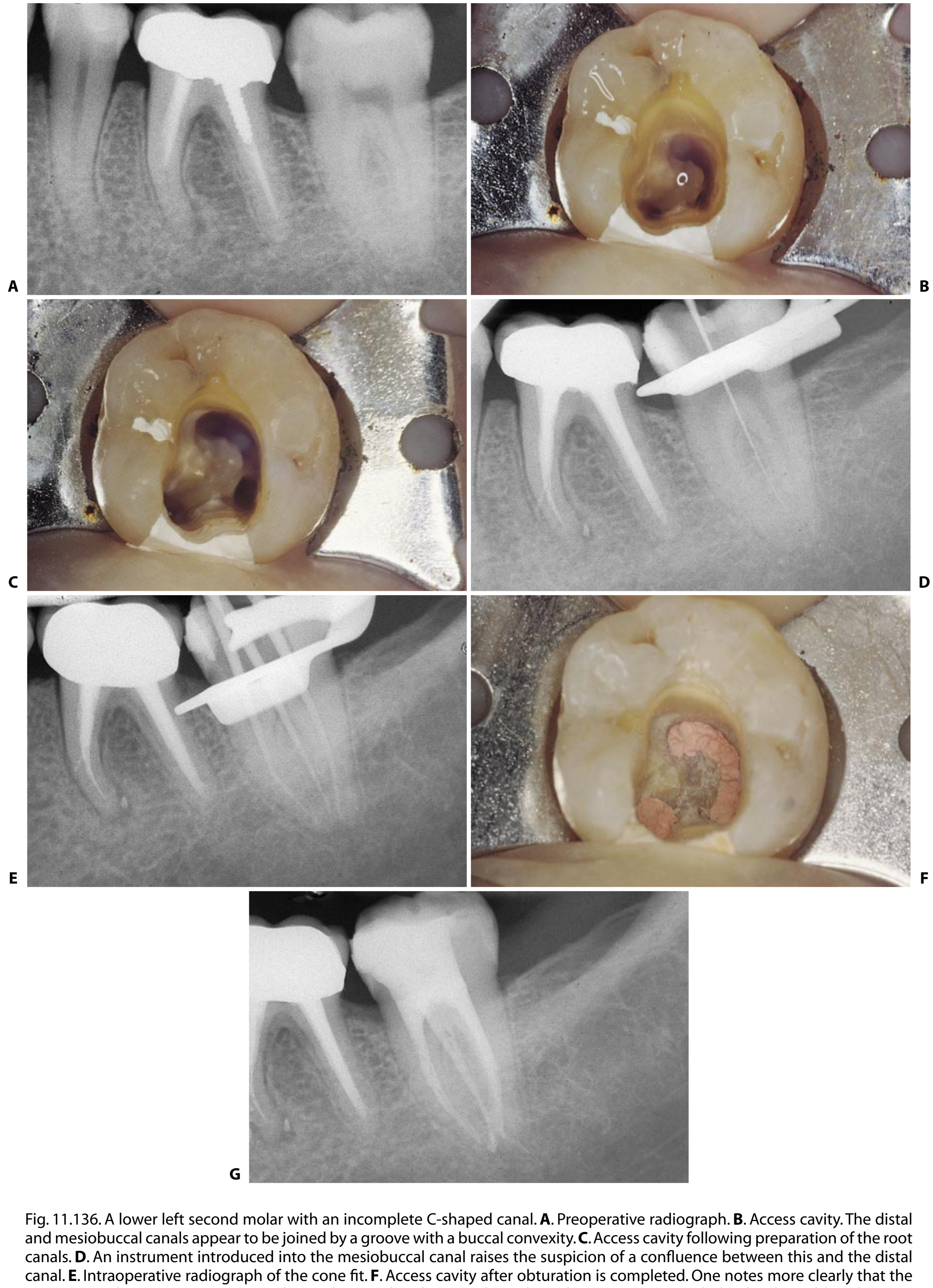
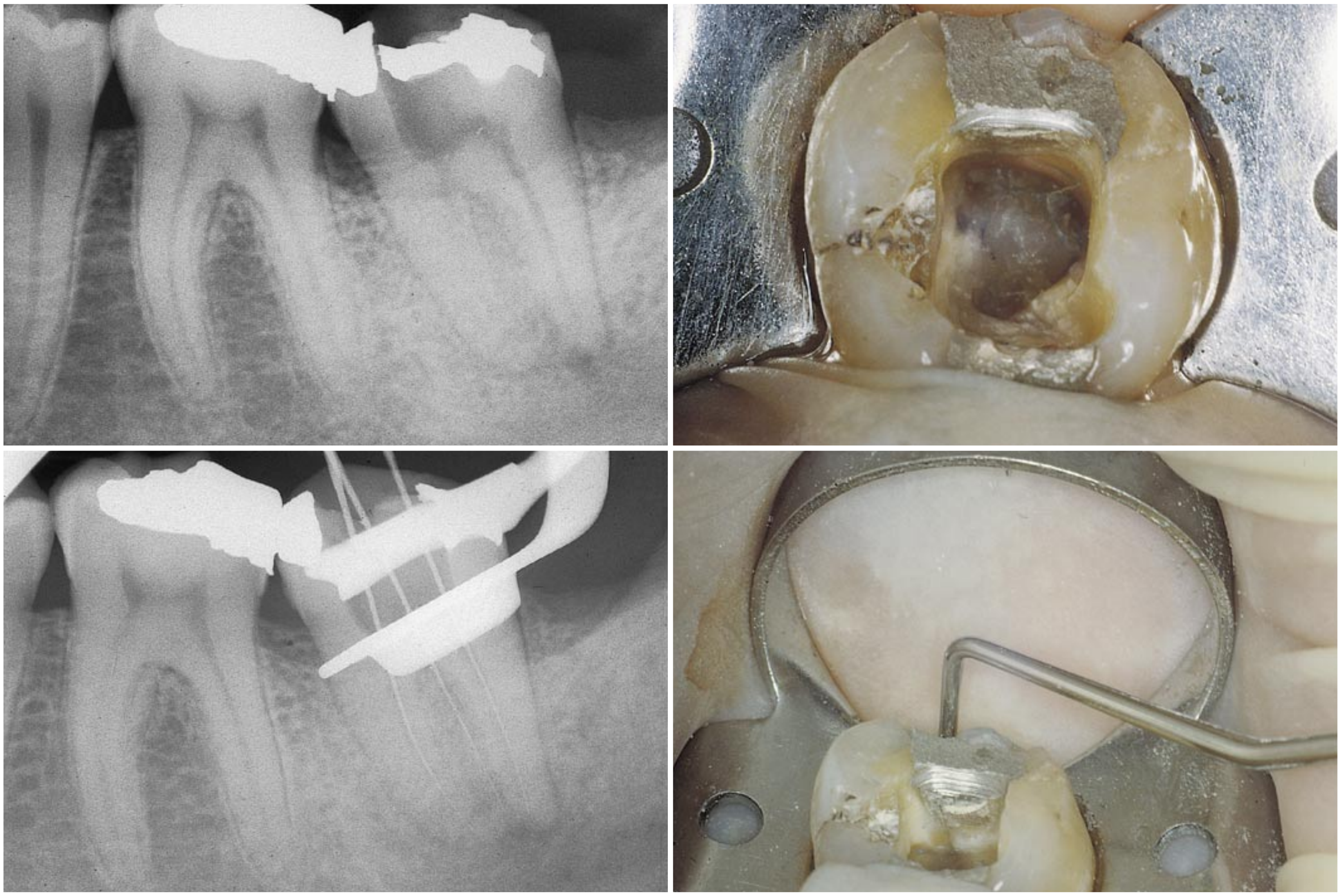


Fig. 11.136. A lower left second molar with an incomplete C-shaped canal. **A**. Preoperative radiograph. **B**. Access cavity. The distal and mesiobuccal canals appear to be joined by a groove with a buccal convexity. **C**. Access cavity following preparation of the root canals. **D**. An instrument introduced into the mesiobuccal canal raises the suspicion of a confluence between this and the distal canal. **E**. Intraoperative radiograph of the cone fit. **F**. Access cavity after obturation is completed. One notes more clearly that the "C" is incomplete. **G**. Postoperative radiograph. Note that the mesiobuccal canal communicates with the distal canal, but does not flow into it, as it has an independent apical foramen.

This bizarre type of endodontic anatomy is easily explained by examining an extracted tooth (Fig. 11.137). Seen from the buccal side (Fig. 11.137 E), the tooth appears singlerooted, while from the lingual side (Fig. 11.137 F) the tooth demonstrates the normal anatomy of a lower molar: two roots, one of which is mesial, the other distal, separated by a variable interradicular bony septum. The molar with a "C-shaped" canal is therefore a singlerooted tooth with a kidney shaped root. The canal contained within also has a kidney shaped appearance which can be preserved unaltered throughout its corono-apical length or which can branch into individual canals at various levels.



A B C D

Fig. 11.137. **A**. Radiographically, the lower second molar seems to have the classical endodontic anatomy. **B**. Careful examination of the pulp chamber floor indicates a C-shaped canal. **C**. The introduction of instruments into the respective canals confirms the diagnosis. Note that the instrument in the mesiobuccal canal simulates a perforation of the floor. **D**. This tooth had a vertical root fracture distally and was therefore extracted (continued).

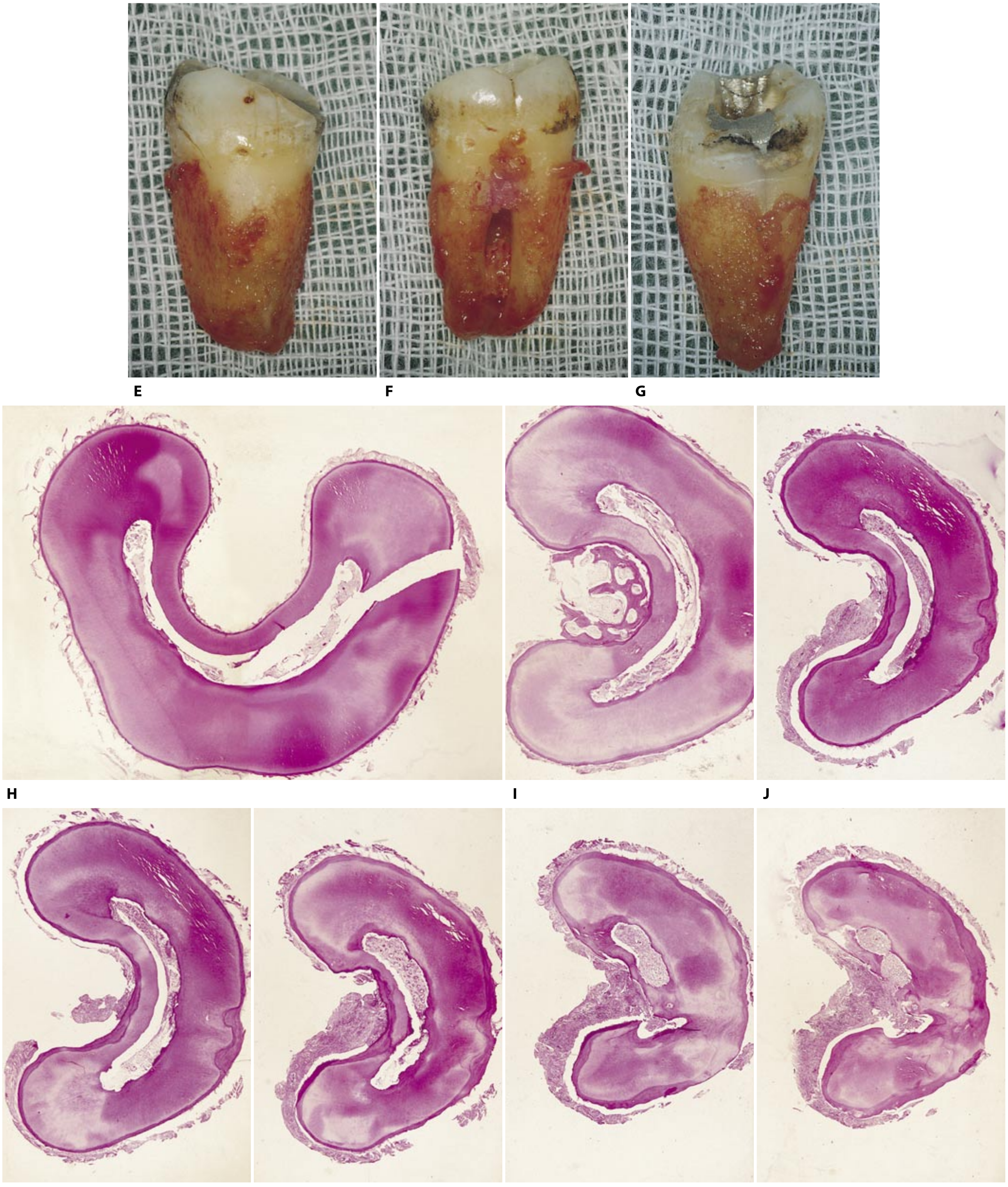


Fig. 11.137. (continued) **E**. Buccal aspect: the tooth is actually a singlerooted tooth, with a kidney shaped root. **F**. Lingual aspect: two roots separated by a bony septum are seen. **G**. The distal aspect shows the vertical root fracture with associated the granulation tissue. **H-N**. Histologic sections of the same tooth. Sections are about 1-2 millimeters from each other.

2. At the moment of canal obturation.

This is the case of confluence, albeit rare, between the mesiobuccal and the distal [73] canals (Fig. 11.138) or between the mesiobuccal and the distobuccal canals, in case two canals are found in the distal root (Fig. 11.139). At the moment of individually performing the obturation in the different canals, condensation of the material in the distal canal may push the sealer and gutta-percha into the mesiobuccal canal through the communication, which had pre-

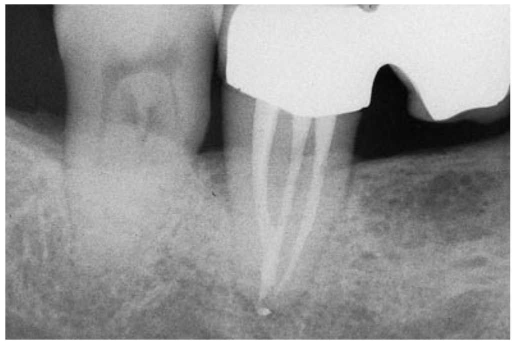


Fig. 11.138. The postoperative radiograph shows the mesiobuccal merging into the distal canals.

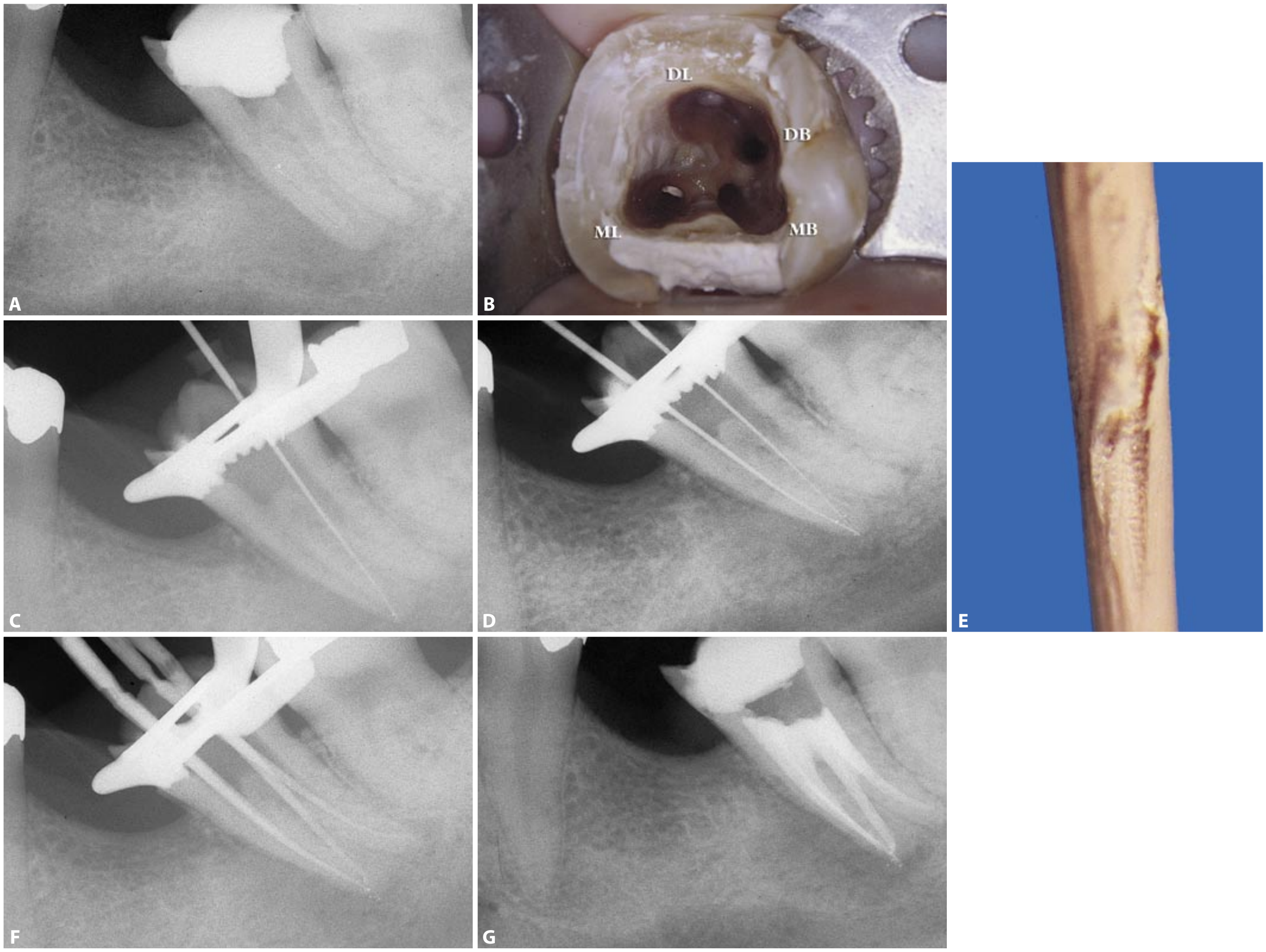


Fig. 11.139. A lower second molar with two distal and two mesial root canals. The distobuccal canal flows into the mesiobuccal canal. **A**. Preoperative radiograph. **B**. Access cavity. Note that the two orifices of the buccal canals, mesial and distal, are close together. **C**. An instrument introduced into the distobuccal canal reveals an unsuspected confluence in the mesiobuccal canal. **D**. Two thin instruments placed into two canals confirm the confluence. **E**. Impression left on the gutta-percha cone, which had been introduced into the distobuccal canal, by a # 08 file introduced in the mesiobuccal canal. **F**. Cone fit. **G**. Postoperative radiograph. **H**. Two year recall.

viously gone undetected. This, among other things, confirms that it is possible, with adequate technique, to prepare individually two confluent canals without any risk of obstructing either of them.[23]
This type of communication between the mesiobuccal and distal canals can and must be diagnosed in an earlier phase, namely during the cleaning and shaping of one of the two canals. Once one canal has been prepared, a gutta-percha cone is placed into it and a small instrument (e.g., a # 08 file) is introduced into the other canal, which has yet to be prepared. If the two canals join together, careful examination of the surface of the gutta-percha cone will reveal the imprint left by the file used in the other canal (Fig. 11.140).

The access cavity of this tooth is started from the central fossa, and it is created according to the same rules used for the first molar. Because of the slight distal angulation of its roots, the access cavity can, however, be less extensive in this case.[17]
The shape of the access cavity depends on whether there is one, two, three, or four canals; it may be round to oval, triangular, or quadrangular.
For this tooth as well, cusp protection is highly recommended.

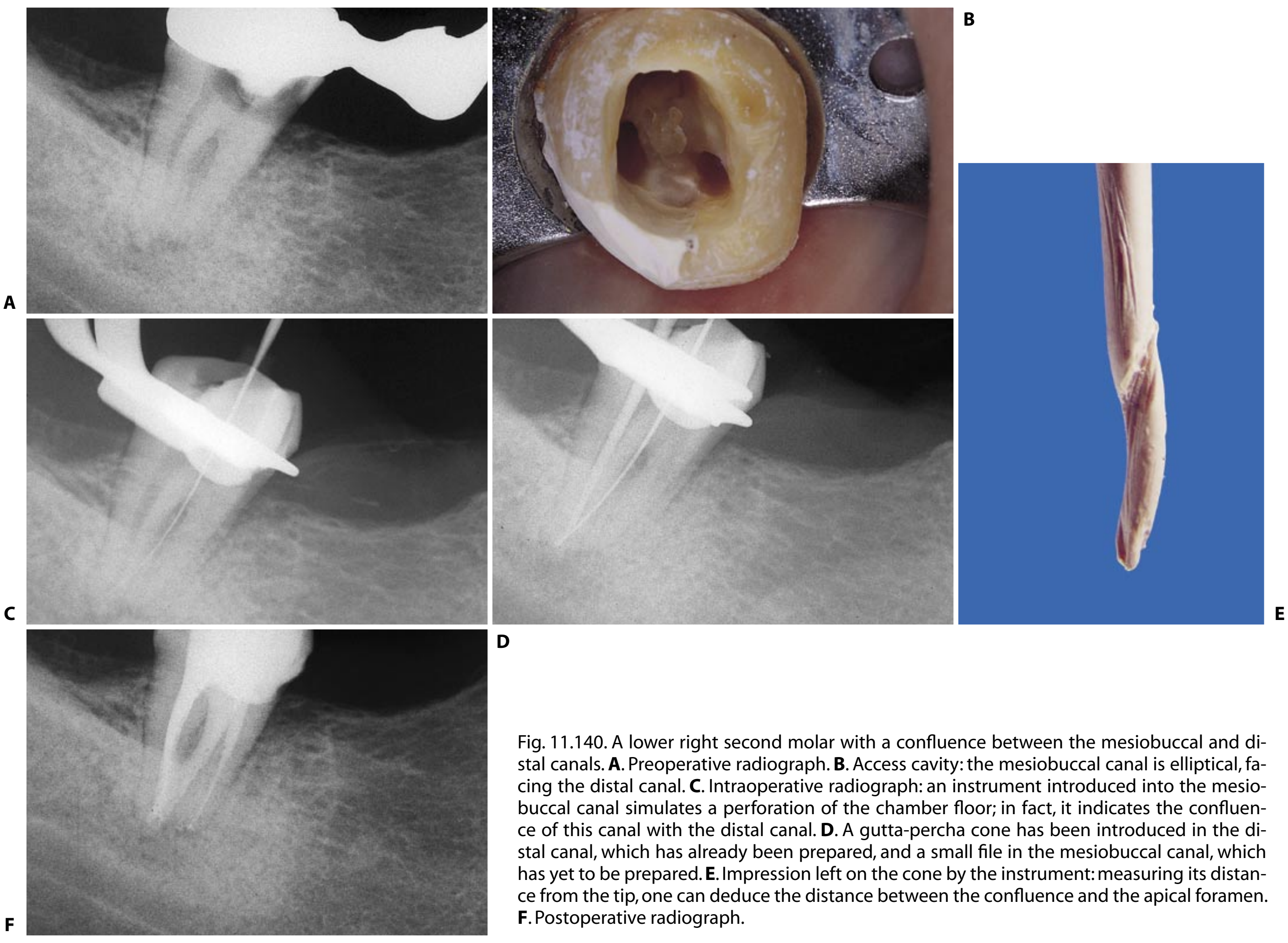


Fig. 11.140. A lower right second molar with a confluence between the mesiobuccal and distal canals. **A**. Preoperative radiograph. **B**. Access cavity: the mesiobuccal canal is elliptical, facing the distal canal. **C**. Intraoperative radiograph: an instrument introduced into the mesiobuccal canal simulates a perforation of the chamber floor; in fact, it indicates the confluence of this canal with the distal canal. **D**. A gutta-percha cone has been introduced in the distal canal, which has already been prepared, and a small file in the mesiobuccal canal, which has yet to be prepared. **E**. Impression left on the cone by the instrument: measuring its distance from the tip, one can deduce the distance between the confluence and the apical foramen. **F**. Postoperative radiograph.

LOWER THIRD MOLAR

The lower third molar may require endodontic therapy for the same reasons as the upper third molar.
When it is the last distal abutment, this tooth acquires great importance.
The most varied and bizarre root morphology can correspond to an almost normal coronal appearance (Figs. 11.141, 11.142).
Nonetheless, this tooth can also be treated successfully by endodontic means (Figs. 11.143, 11.144).
The same rules that apply to the other lower molars also hold for its access cavity.
Owing to the distal inclination of the roots, its treatment is often easier than one might think on a first look at the radiograph.

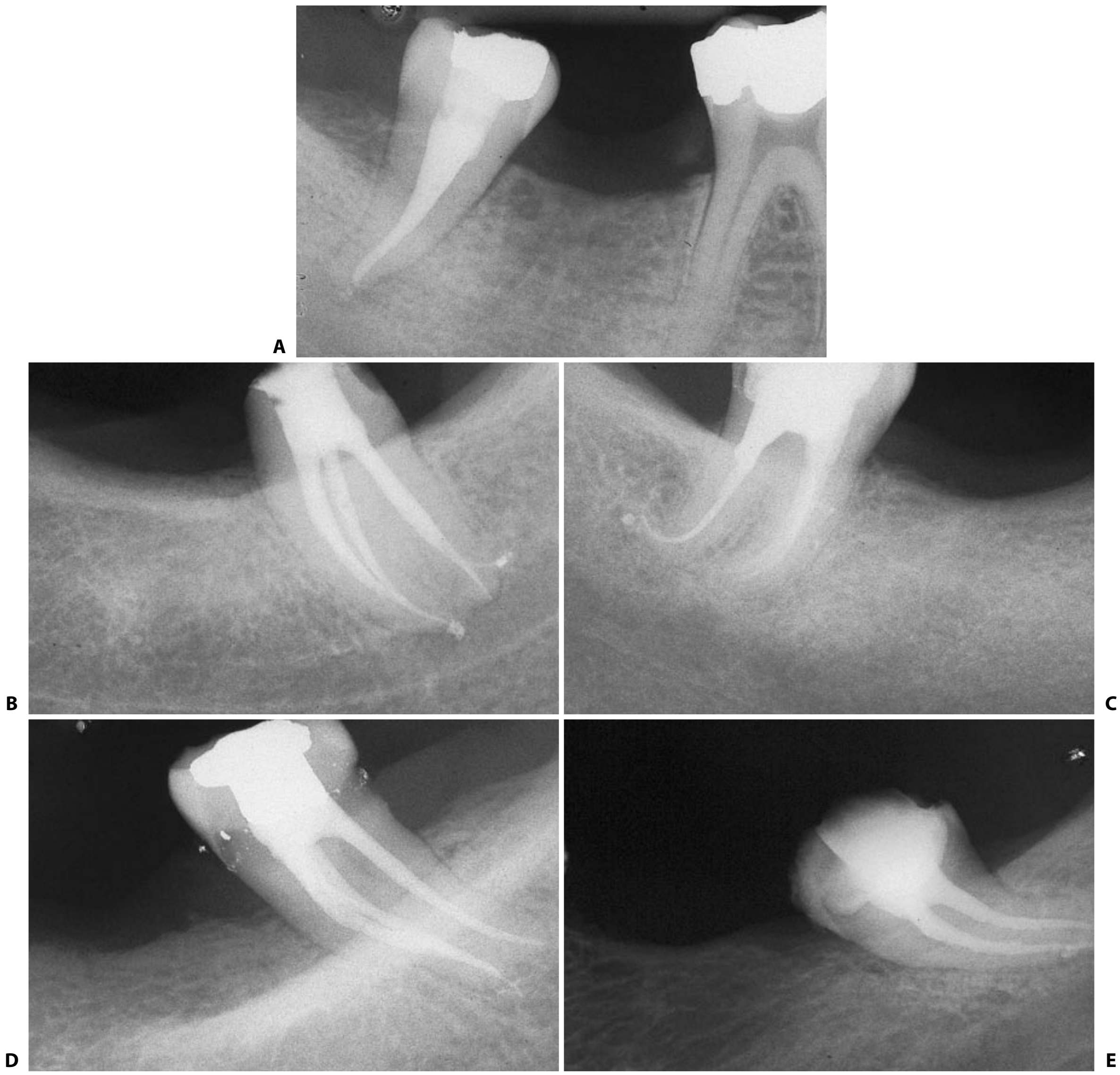


Fig. 11.141. **A-E.** Examples of the endodontic anatomy of lower third molars.

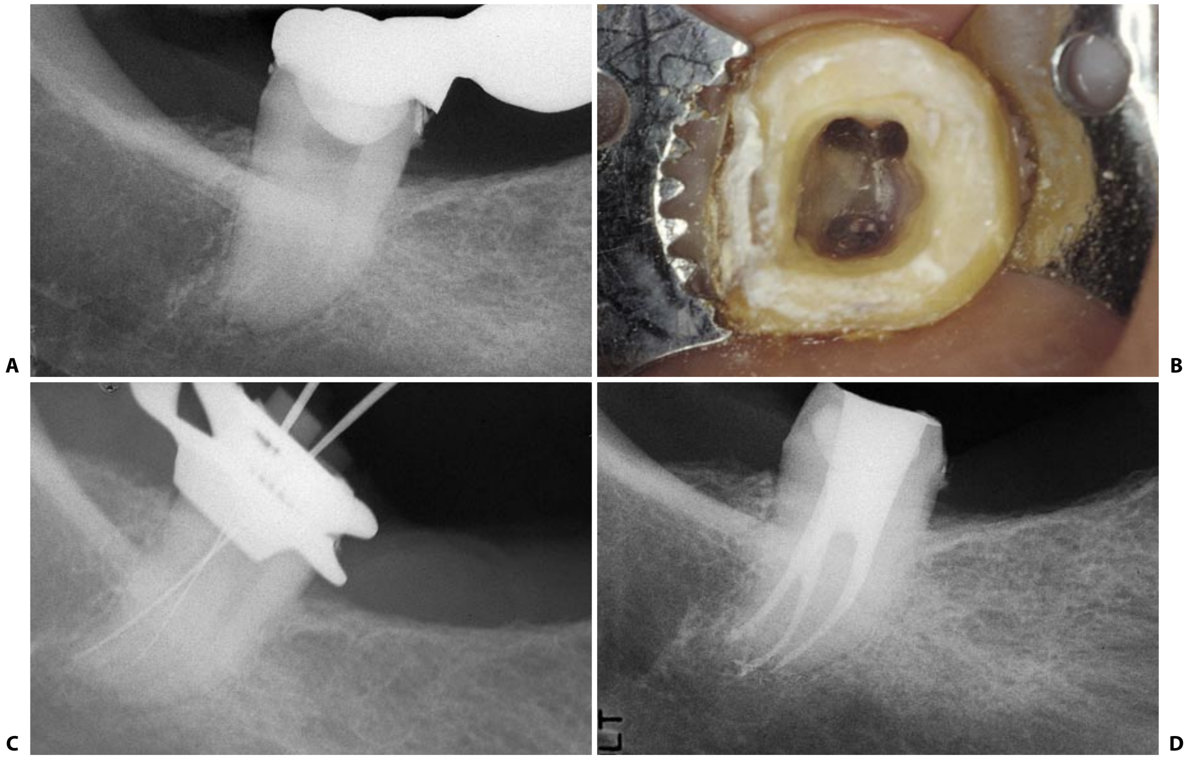


Fig. 11.142. A lower third molar with two distal canals and a single mesial canal. **A**. Preoperative radiograph. **B**. Access cavity. **C**. Intraoperative radiograph. **D**. Postoperative radiograph.

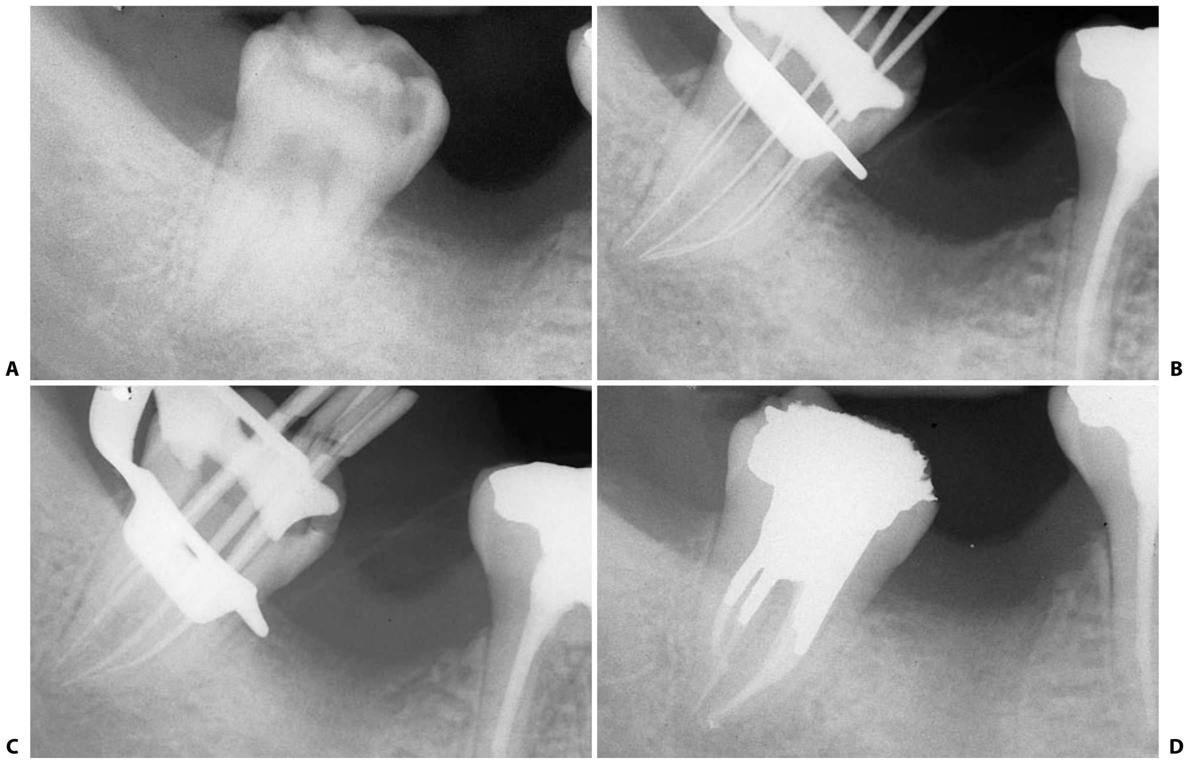


Fig. 11.143. A lower right third molar with five canals. **A**. Preoperative radiograph. **B**. Intraoperative radiograph: two canals are present in the distal and three in the mesial root. **C**. Cone fit. **D**. Postoperative radiograph.

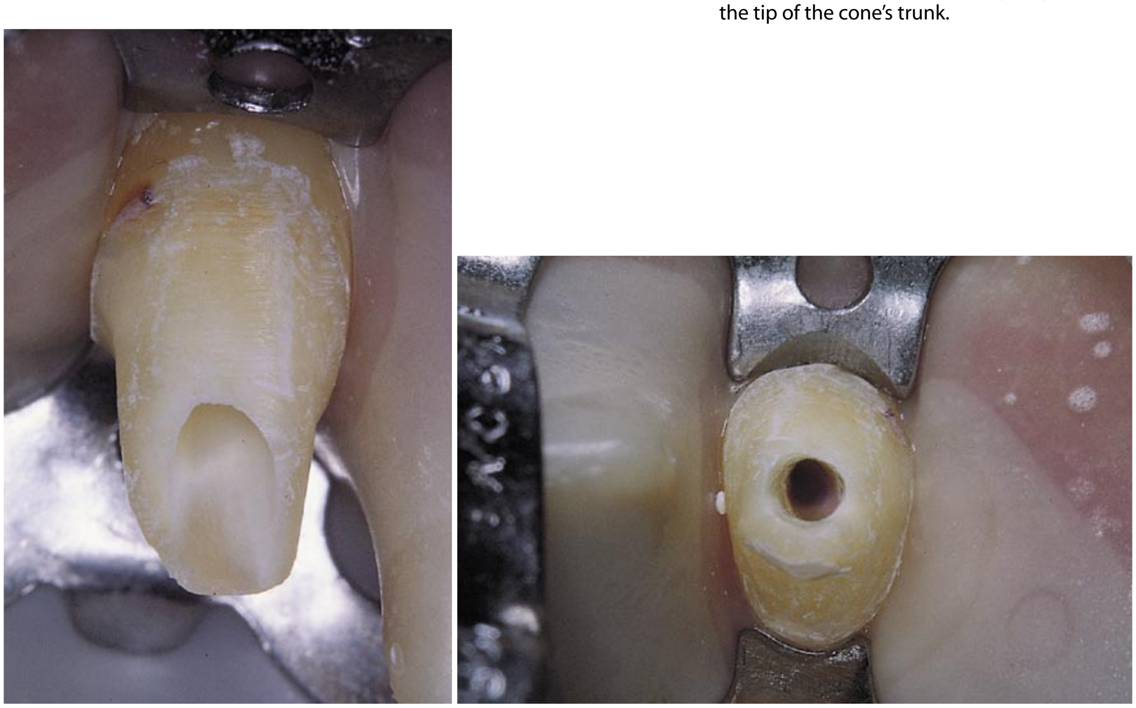
A B C

Fig. 11.144. Lower third molar with many lateral canals, responsible for the lesion mesial to the mesial root. **A**. Preoperative radiograph. **B**. Postoperative radiograph. **C**. The two year recall shows the complete healing.

THE ACCESS CAVITY IN PROSTHETICALLY PREPARED TEETH

When endodontic treatment is required for a tooth whose crown has been prosthetically prepared, the opening of the access cavity need not take into consideration the geometry of the prepared crown, but, as always, a straight-line access to the apical one third of the canal must be provided. Therefore, if possible, one must try to save the walls of the preparation by opening the tooth at the flattened tip of the cone (Fig. 11.145). However, if the surface of the dental crown has been removed asymmetrically with respect to the underlying pulp for the purposes of parallelism, in this case the access cavity will also have to involve one side of the preparation (Fig. 11.146) or even be performed entirely at the expense of this surface (Fig. 11.147).

Fig. 11.145. The prosthetic preparation has been concentrically performed on the pulp chamber and canal; therefore, the access cavity may be created at the tip of the cone's trunk.



A B

Fig. 11.146. **A.** The tooth has been prepared for the most part at the expense of the buccal portion for purposes of parallelism. Thus, the access cavity must also affect the buccal surface of the preparation. **B.** The same tooth photographed from the incisal side. The access cavity must always provide a straight-line access to the apical one third of the root canal.

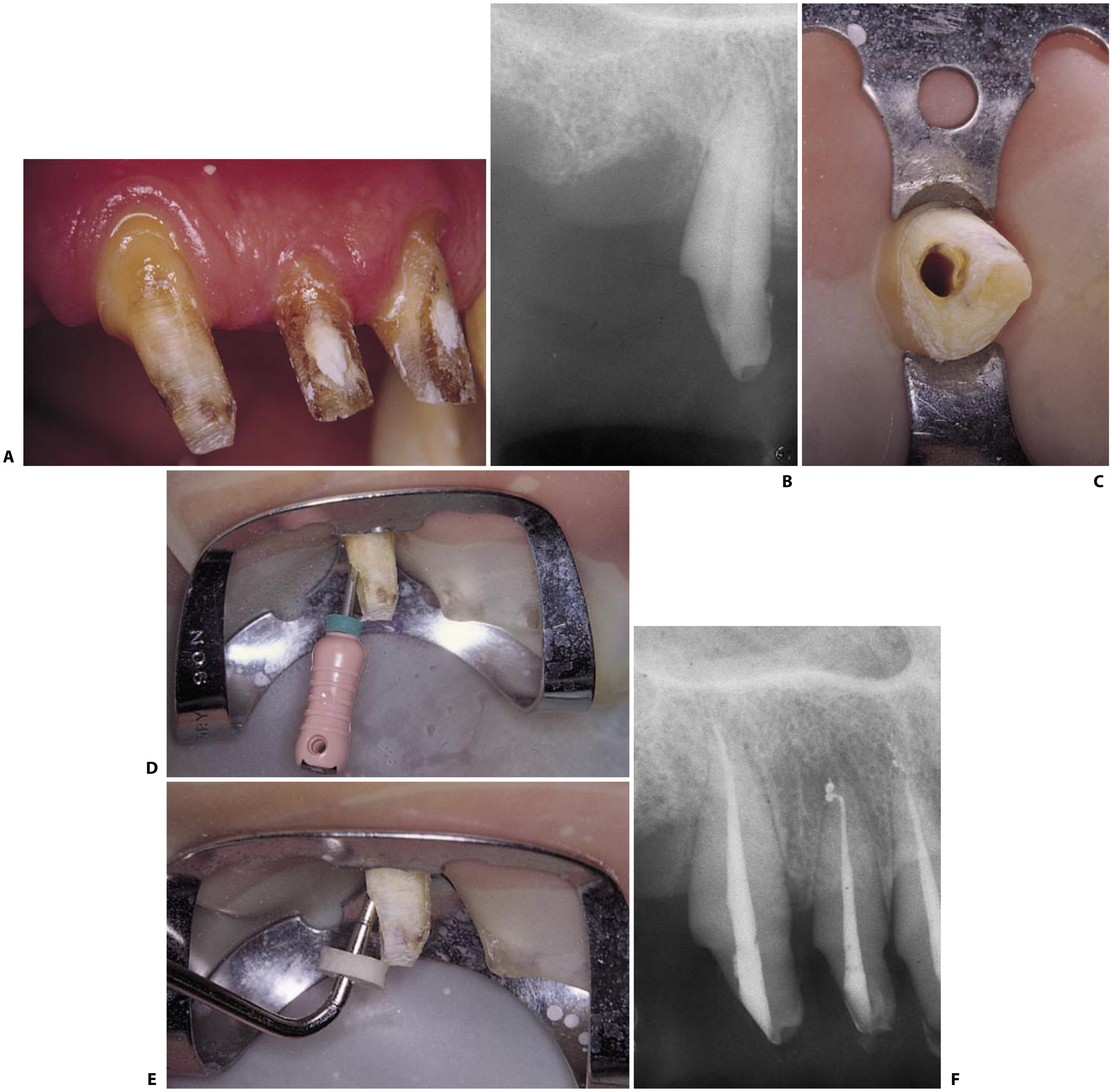
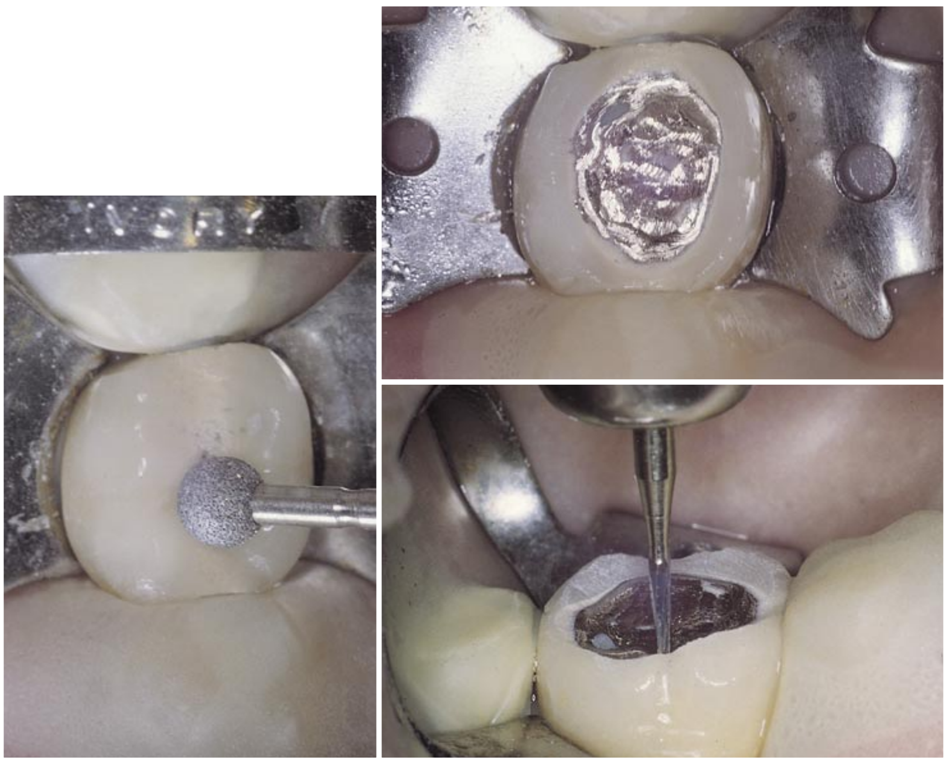


Fig. 11.147. **A**. The prosthetic preparation has particularly involved the distal aspect of this upper right canine, which mesially has been reduced by only a minimum amount. **B**. The preoperative radiograph confirms the asymmetry of the prosthetic preparation and indicates the site and inclination of the root canal with respect to the preparation. **C**. The access cavity has been entirely created at the level of the distal surface. **D**. Although the instruments take this apparently absurd inclination, they have straight-line access to the apical one third of the root canal. **E**. The access cavity must also allow easy introduction to materials and instruments used for obturation. **F**. Postoperative radiograph.

THE ACCESS CAVITY THROUGH PROSTHETIC CROWNS

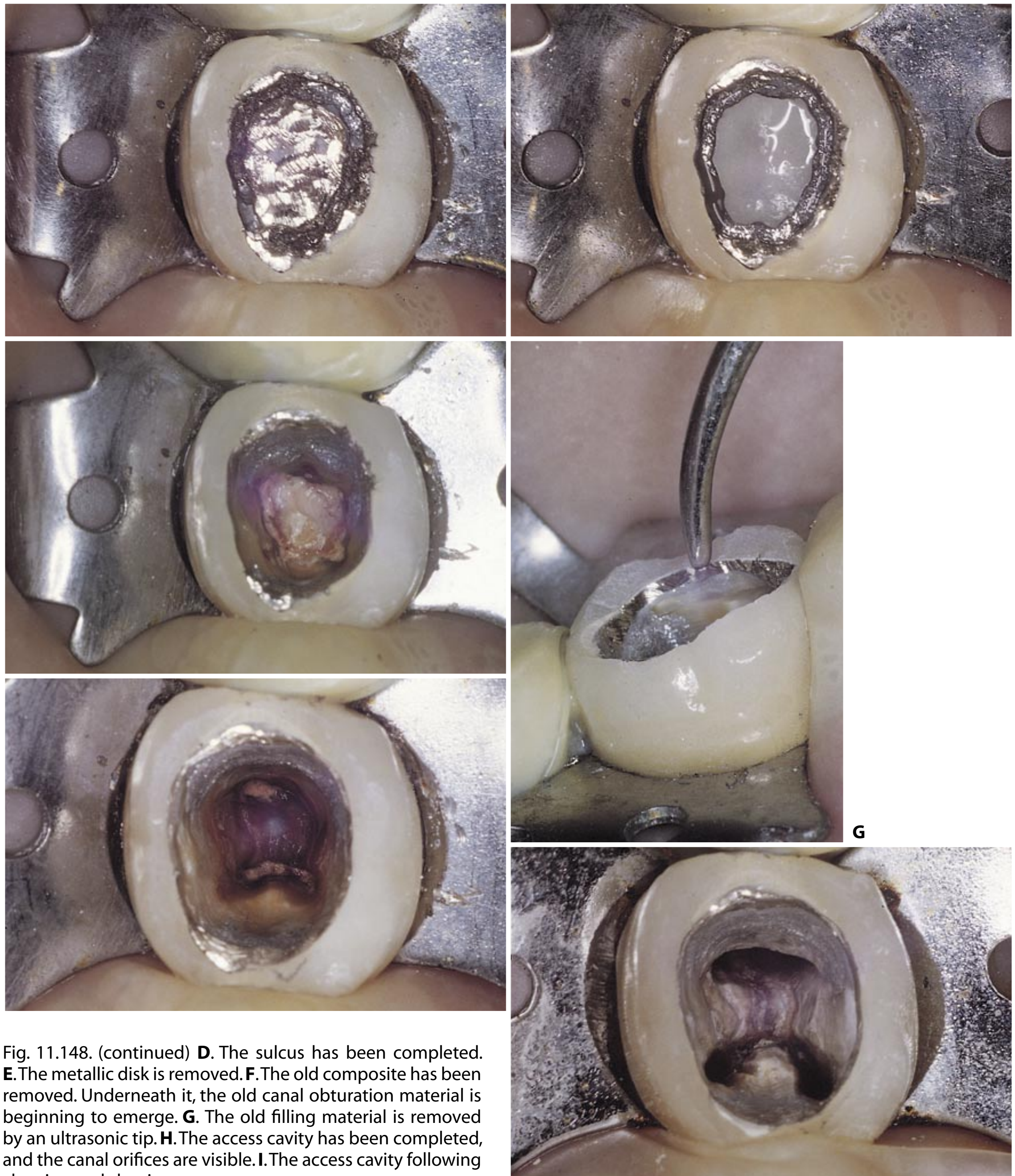
In the case of a patient with a prosthetic crown, two situations arise, depending on whether the prosthetic crown must be kept in the patient's mouth or has to be replaced.
In the first circumstance, one must create a more conservative access cavity, though one must recall that if it is necessary to extend it for the purpose of improved visibility, this should be done without any regret. The crown can always be re-made, while a mistake in the cleaning and shaping procedure of the root canals cannot be corrected.
In the case in which the crown must, for some reason, be substituted after therapy, it is always preferable, for the stability of the rubber dam clamp, as well as esthetics and function, to perform the endodontic treatment through the prosthesis, which can be removed and substituted once the therapy has been completed.
Obviously, the access cavity should be as wide as possible to permit easier orientation through the prosthesis, which can conceal or, in any case, mask, the tooth's true position in the arch.
It is therefore advisable to remove as much as possible, if not indeed completely, the occlusal surface of the metal crown, thus transforming the crown into a "band" before sinking the bur in search of the pulp chamber and canal openings.
In the case of a gold-porcelain crown, one can use the head of a large, round diamond bur (Fig. 11.148 A) to remove the esthetic surface until a large part of the underlying metal has been uncovered (Fig. 11.148 B). Then, with a tungsten fissure bur (Fig. 11.148 C), a groove is cut at the periphery of the metal surface (Fig. 11.148 D), and the diskette thus obtained is removed (Fig. 11.148 E). Once the thin layer of underlying oxyphosphate has been removed, it will be possible to see whether any old amalgam or composite restoration has been left. In such cases, the access cavity will have to be initiated at the expense of these materials, whose gradual removal permits even better orientation.
One then begins carefully to drill into the dentin, di-



A B C

Fig. 11.148. An access cavity in a molar covered by a gold-porcelain crown requiring endodontic retreatment. **A**. Using a large, round diamond bur, the porcelain is removed. **B**. The underlying metal has been exposed. **C**. With a fissure bur, a groove is incised at the periphery of the metal (continued).

recting the bur toward the horn that one suspects is closest to the dentist.
If the tooth has already been treated endodontically (Fig. 11.148 F), the use of ultrasonics may help remove the old endodontic filling material from the pulp chamber (Fig. 11.148 G) to permit a clearer, more complete view of the floor of the pulp chamber (Figs. 11.148 H, I).
The access cavity dug in the dentin may be smaller than the opening created in the metal of the crown. However, it is not the dentist who decides its extent, but as usual, the anatomy of the underlying pulp chamber.
Having prepared a generous opening in the metal of the prosthesis has another advantage: in the case in which, intraoperatively, an extension of the aperture of the access cavity becomes necessary, one will not run the risk of pushing metallic filings into the canals (Fig. 11.8).



D E F G H I

Fig. 11.148. (continued) **D**. The sulcus has been completed. **E**. The metallic disk is removed. **F**. The old composite has been removed. Underneath it, the old canal obturation material is beginning to emerge. **G**. The old filling material is removed by an ultrasonic tip. **H**. The access cavity has been completed, and the canal orifices are visible. **I**. The access cavity following cleaning and shaping.

COMMON ERRORS IN THE PREPARATION OF THE ACCESS CAVITY

Errors Related to Inadequate Preparation

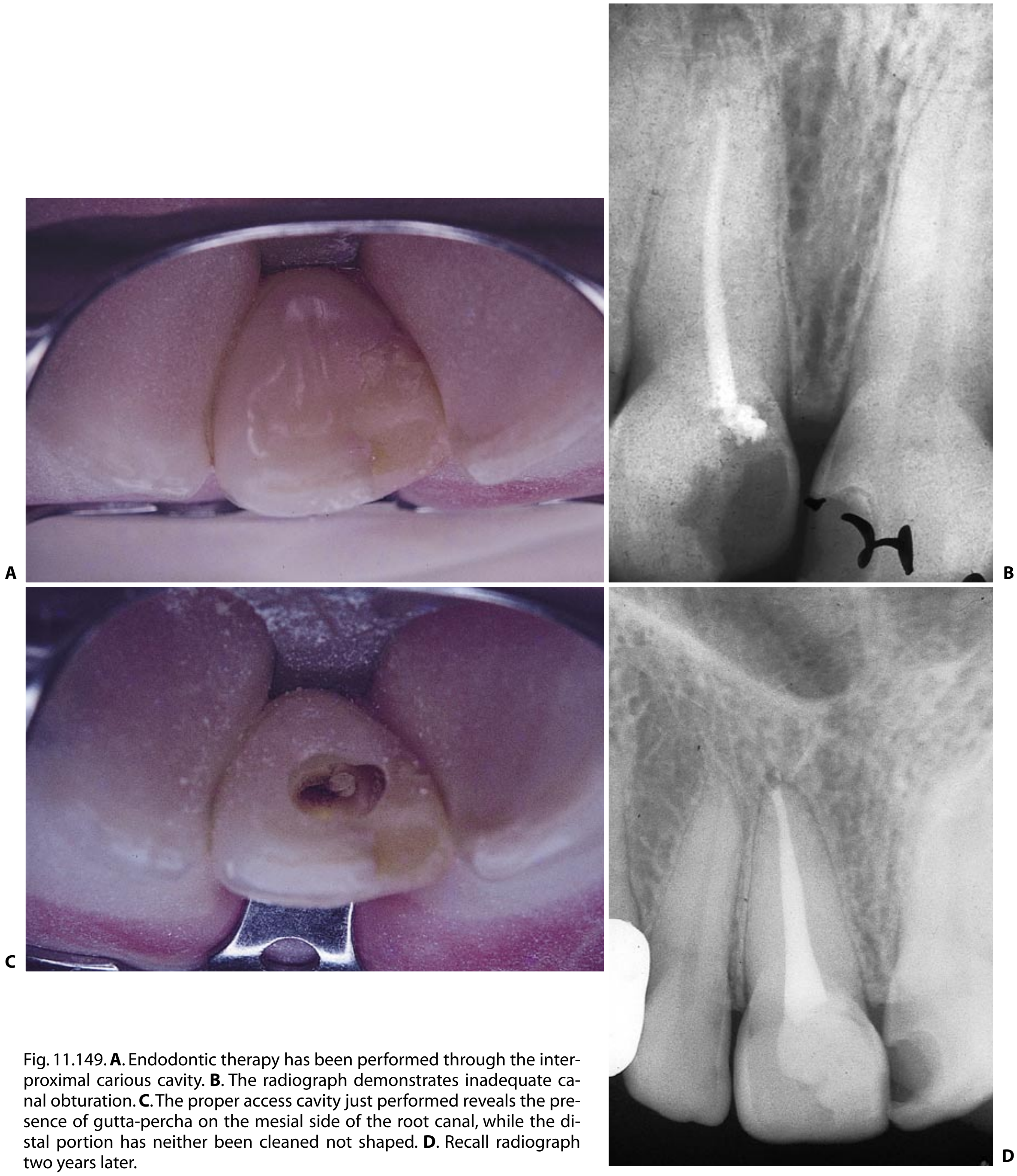
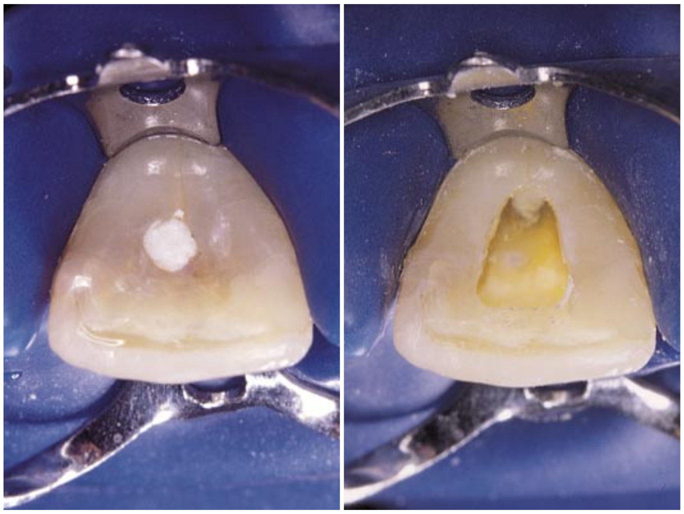
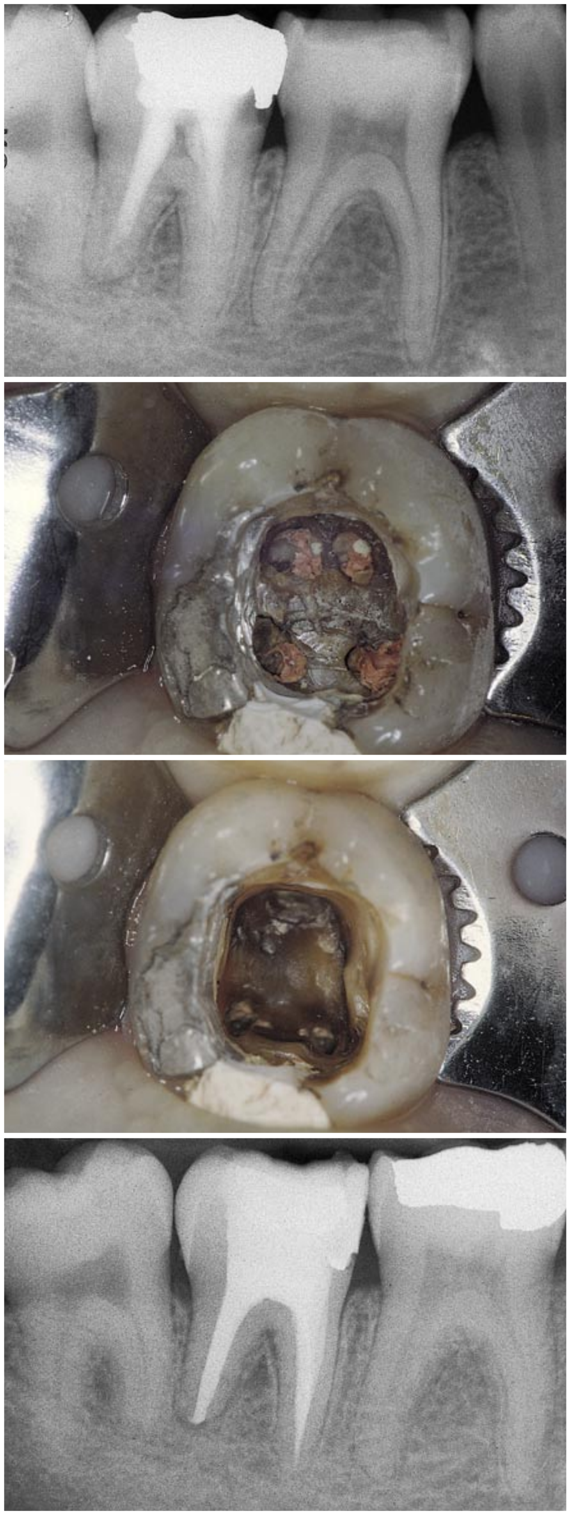


Fig. 11.149. **A**. Endodontic therapy has been performed through the interproximal carious cavity. **B**. The radiograph demonstrates inadequate canal obturation. **C**. The proper access cavity just performed reveals the presence of gutta-percha on the mesial side of the root canal, while the distal portion has neither been cleaned not shaped. **D**. Recall radiograph two years later.



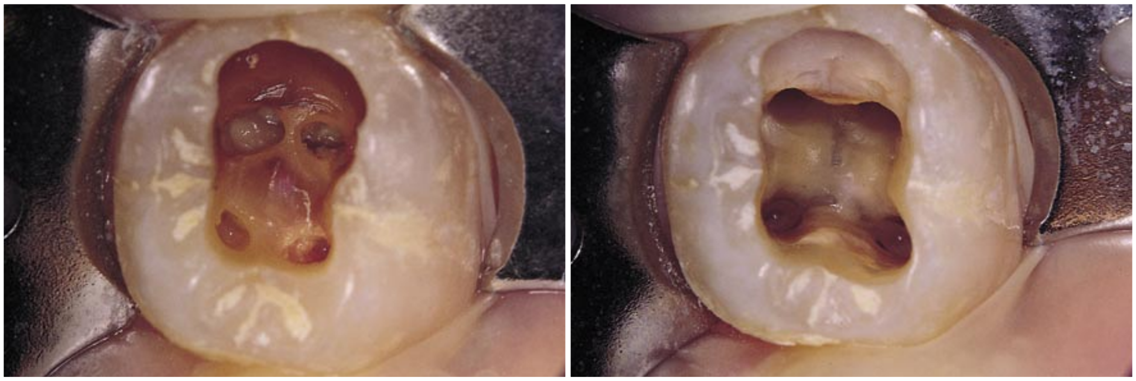
A B

Fig. 11.150. **A**. Inadequate access cavity in an upper central incisor. **B**. Same tooth with a proper access cavity.



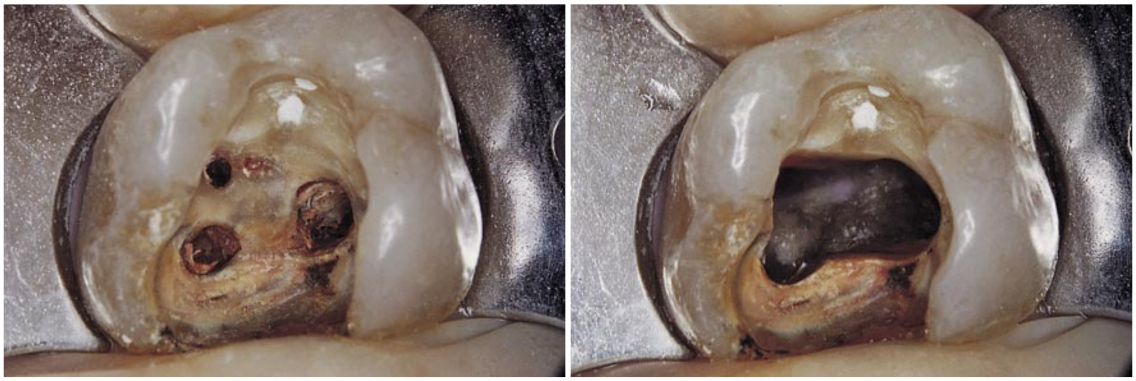

A B C D E F

Fig. 11.151. **A**. Preoperative radiograph. The relatively radiolucent space between the base of the canal obturation and the pulp chamber raises the suspicion of the presence of a residuum of the pulp chamber roof. **B**. The previous endodontic therapy had been performed through four small holes made in the roof of the pulp chamber. The four pulp horn were interpreted as canal orifices. **C**. Once the obturating material has been removed with the help of ultrasonics, the chamber roof left in place is better visualized. **D**. The access cavity has been corrected with the complete removal of the roof of the pulp chamber. **E**. The same access cavity after preparation of the root canals. **F**. Post-operative radiograph.



A B

Fig. 11.152. **A**. The same error as that in the preceding figure has been committed: the tooth had been opened to establish a drainage, but part of the roof of the pulp chamber was left. **B**. The access cavity has been corrected, and the canals have been prepared.

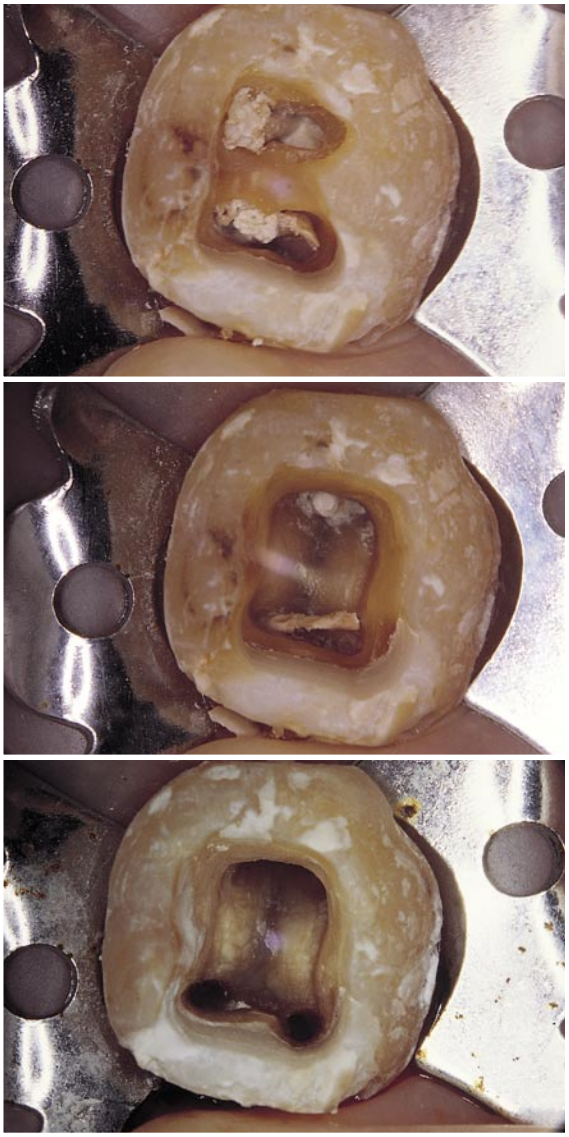


A B

Fig. 11.153. **A**. The same error has been committed in an upper first molar. **B**. The access cavity as it appeared after complete removal of the chamber roof.

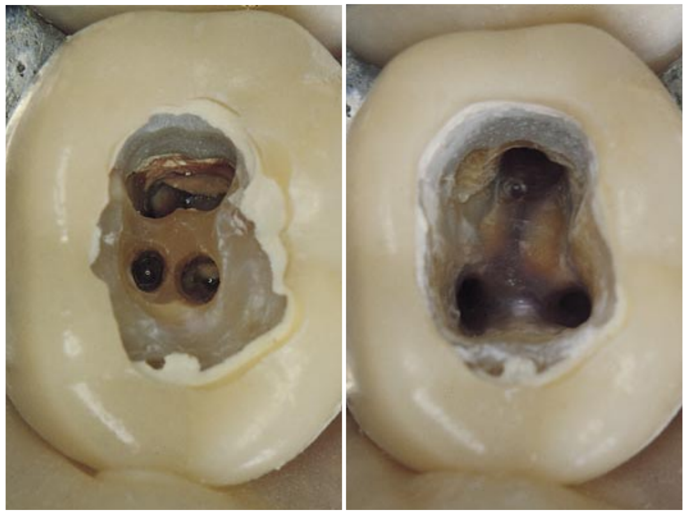
A B C D

Fig. 11.154. **A**. Preoperative radiograph of the lower left second molar which necessitates retreatment. **B**. After the removal of the old composite filling, the access cavity made by the previous dentist is evident. **C**. The residual roof has been removed. **D**. One year recall.



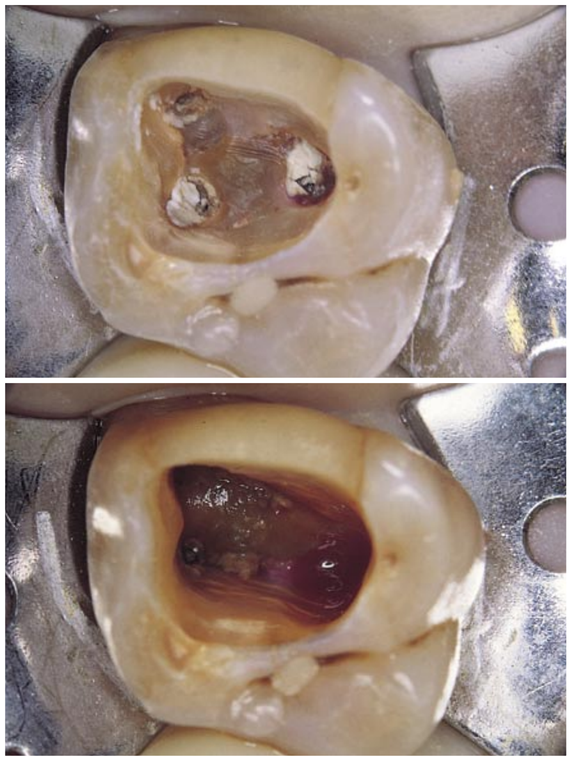
A B C

Fig. 11.155. **A**. Part of the roof of the pulp chamber is still in place. **B**. The roof has been removed. **C**. Access cavity after cleaning and shaping the root canals.



A B

Fig. 11.156. **A**. The previous dentist forgot to remove part of the pulp chamber roof. **B**. Now the root canals are ready for packing.



A B

Fig. 11.157. **A**. The root canal treatment of this upper first molar has been made through three holes made in the pulp chamber roof. **B**. The bleeding from the palatal canal is caused by some remaining vital pulp tissue!

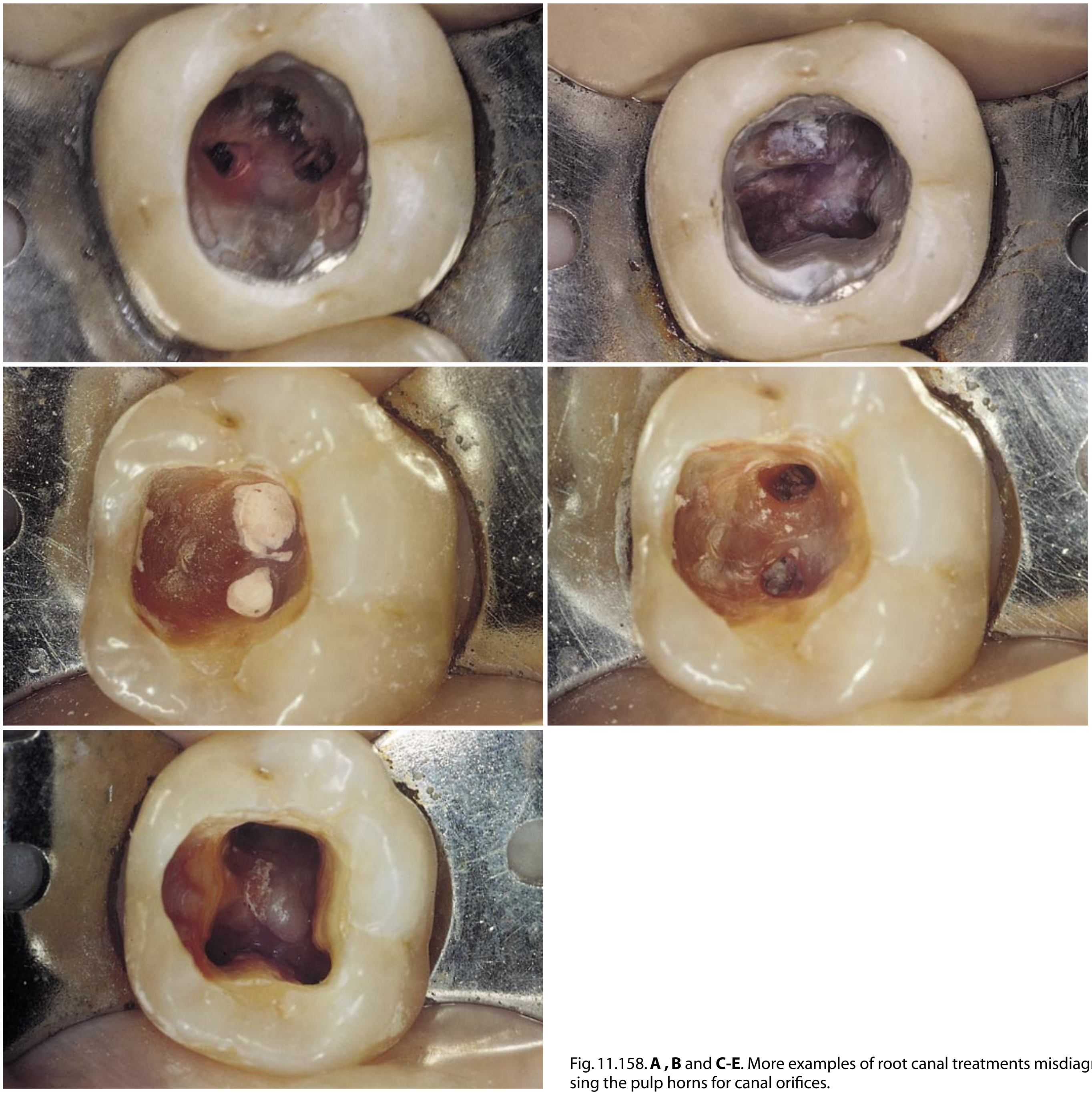


Fig. 11.158. **A , B** and **C-E**. More examples of root canal treatments misdiagnosing the pulp horns for canal orifices.

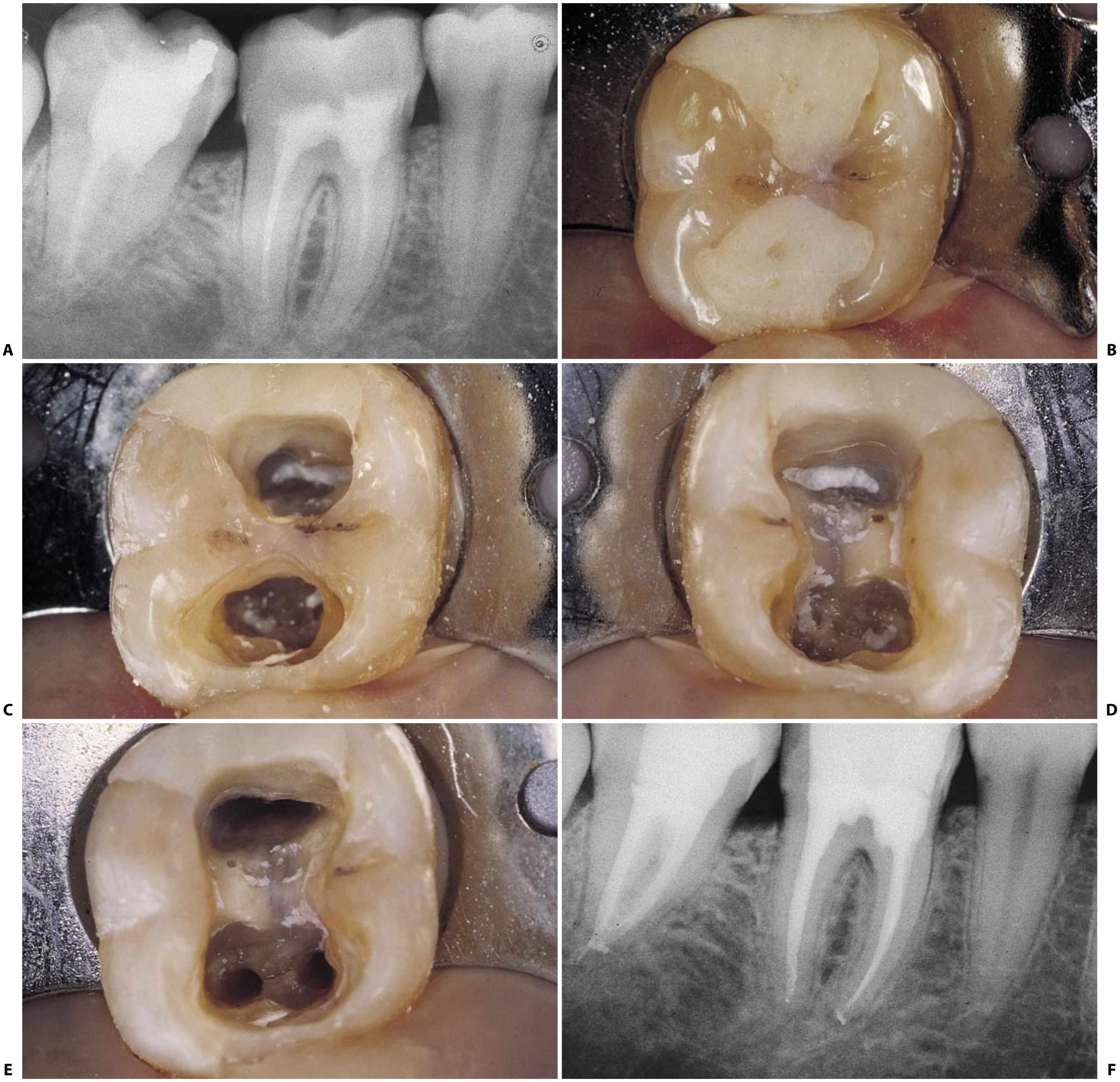


Fig. 11.159. **A**. This radiograph demonstrates a lower right first molar treated endodontically, with the occlusal surface apparently intact. **B**. The occlusal surface reveals the presence of two composite obturations, one mesial and one distal, separated by an enamel bridge. **C**. Careful removal of the composite reveals the bridge of enamel and dentin: the tooth has been treated endodontically through two distinct access cavities, one mesial for the two mesial root canals, the other distal for the distal root canal! **D**. The bridge has been chipped away, so as to allow visualization of the pulp chamber floor. **E**. Access cavity with cleaned and shaped root canals. **F**. Postoperative radiograph.

Errors Related to Over-Aggressive Preparation

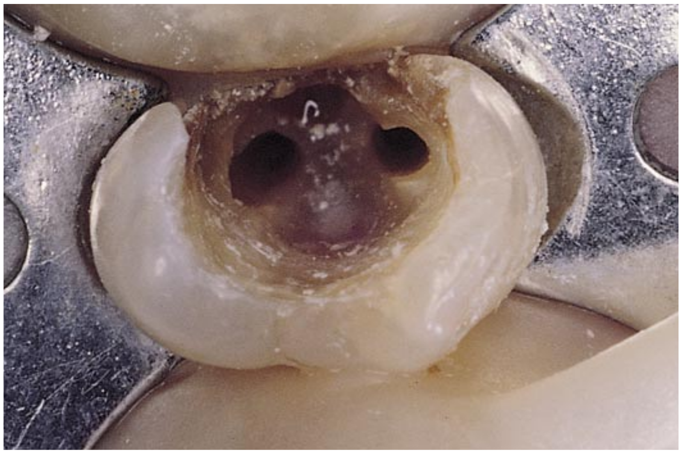
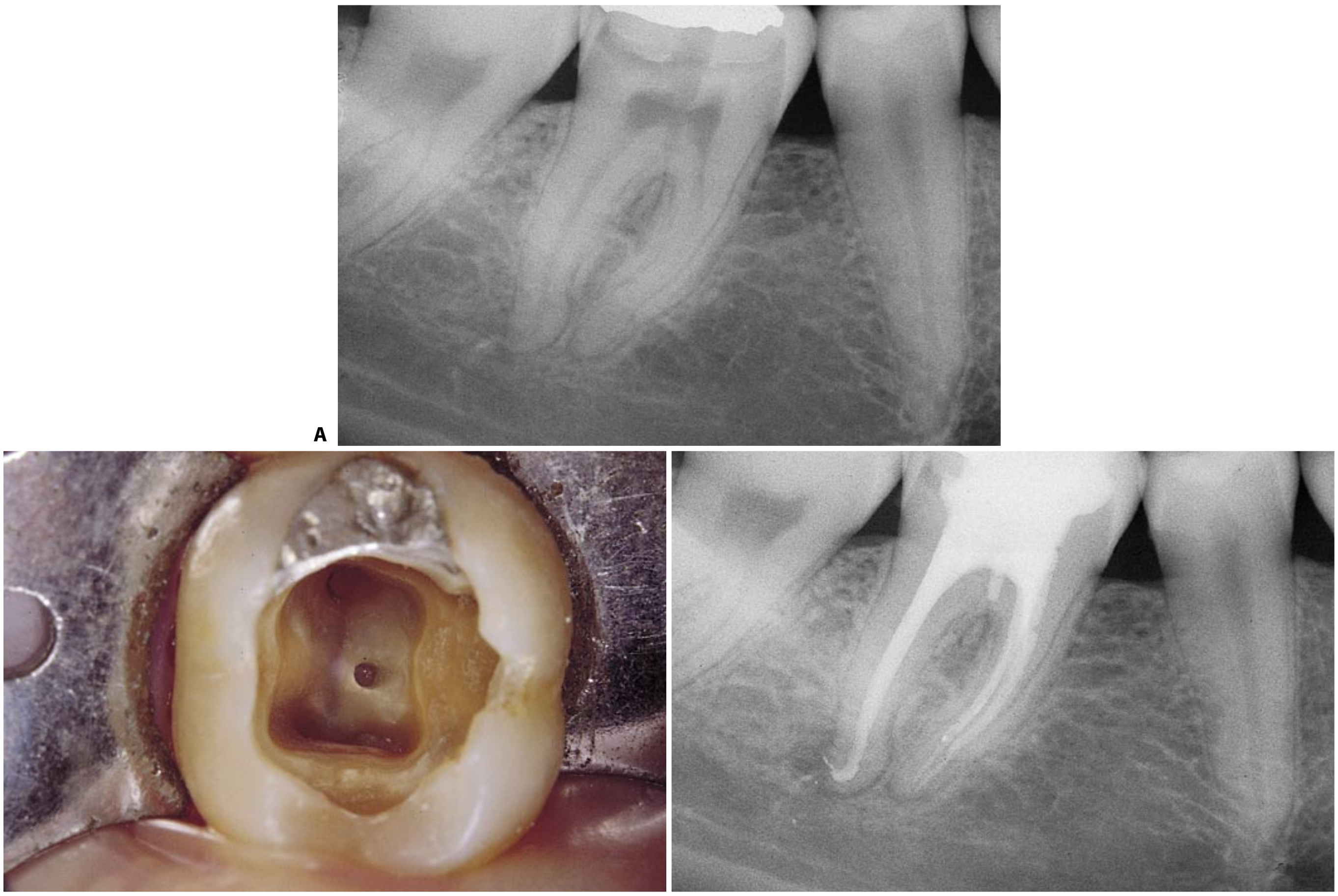


Fig. 11.160. Two perforations are visible, one mesial and one distal, caused by a fruitless search for the canal orifices, in this upper right first premolar.

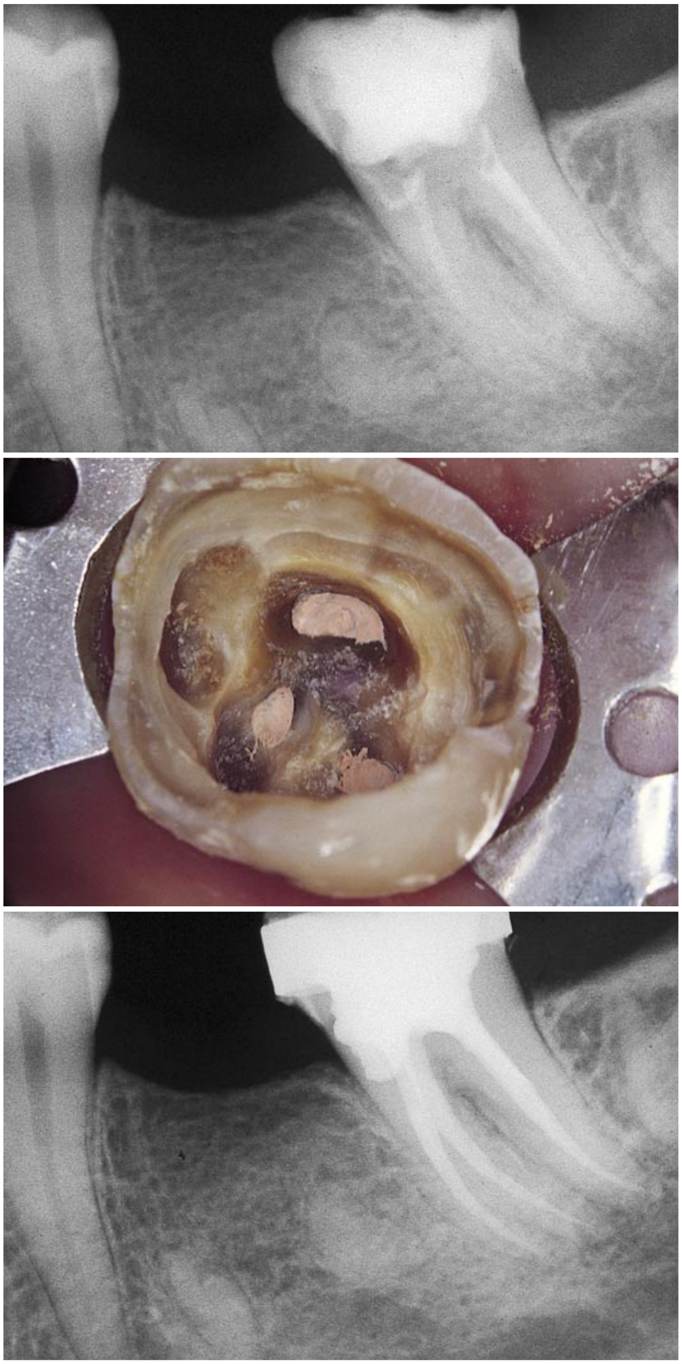
Fig. 11.161. A lower left first molar. A too-limited access cavity had concealed the mesiobuccal canal. The mesiolingual canal had been taken to be the mesiobuccal, and the cut of the bur visible lingually had been created in the futile search for the orifice of the mesiolingual canal in the wrong place.

A



B C

Fig. 11.162. **A**. Preoperative radiograph of a lower right first molar. The tooth had been "opened" with a conical bur, which has left an easily visible impression as far as the floor of the pulp chamber. **B**. Proper access cavity. **C**. Postoperative radiograph. Obturation of the small perforation created in the thickness of the chamber floor is visible.

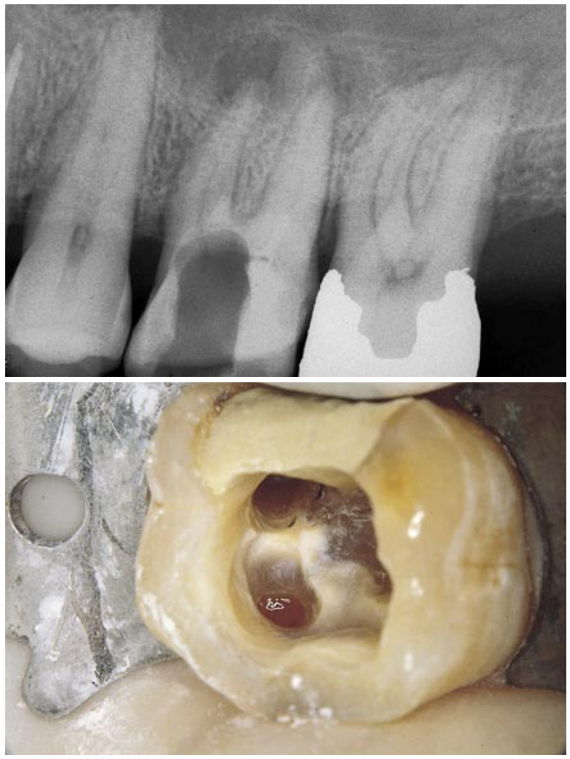


A

B

C

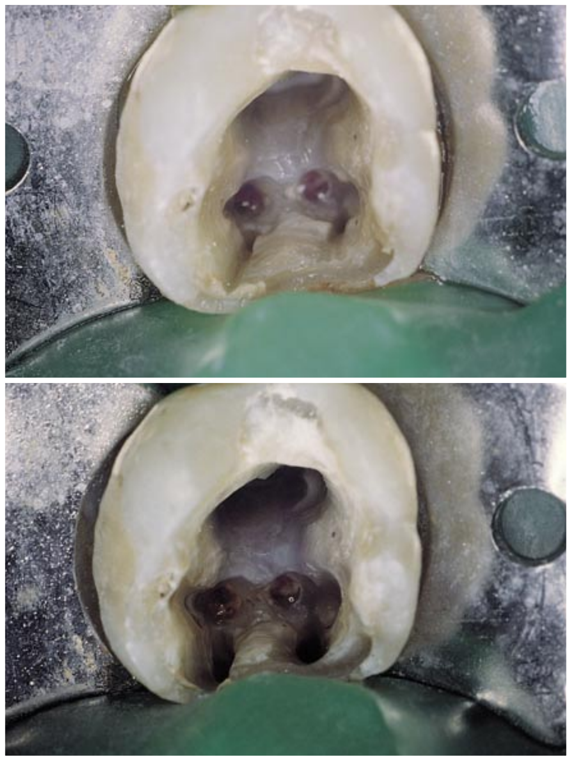
Fig. 11.163. A lower left second molar with an endodontic anatomy of the type illustrated in Fig. 11.124. **A**. Preoperative radiograph: note the bur cuts created in the search for the lingual canal. **B**. Access cavity at completion of obturation: the mesiolingual canal is distally displaced. The signs of a desperate search for the mesiolingual canal are visible. **C**. Postoperative radiograph.



A

B

Fig. 11.164. **A**. The access cavity has been made too mesially. **B**. Perforation of the floor at the orifice of the mesiobuccal canal is evident.



A

B

Fig. 11.165. **A**. In this lower left first molar, two perforations of the floor have been made in the attempt to find the orifices of the mesial canals, which are spotted on the mesial wall of the access cavity. **B**. The mesial canals have been prepared.

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12

Pretreatment: Preparation Techniques for Endodontic Theraphy

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INTRODUCTION

To perform endodontic therapy properly, the operative field must be adequately isolated with a rubber dam. Positioning the dam is not always easy.

More often than not, the dentist is confronted with the need to treat teeth destroyed by large carious lesions. He must therefore know how to anticipate and deal with any problems that may arise in the course of isolating the operative field.

Root canal therapy does not begin with the positioning of the dam, but rather with the restorative and periodontal procedures required to simplify and enable the positioning of the rubber dam.[16]

An early problem that can arise relates to the characteristics of the tooth requiring endodontic treatment. These can be analyzed in detail. Based on clinical and radiographic examinations, one can determine whether the tooth is endodontically intact – that is virgin - or whether intervention in fact amounts to retreatment of a previously devitalized tooth (Tab. I).

Table I

Diagnostic scheme

- virgin tooth
  - healthy
  - previously restored
- tooth requiring retreatment

While it is true that endodontic therapy is rarely required in anatomically intact virgin teeth, it may be necessary in two situations:

1) when a healthy tooth has to be treated endodontically for periodontal (e.g., root amputation) and/or prosthetic reasons (since the preparation of the crown would involve the pulp)
2) when a healthy, preserved tooth presents a lesion of endodontic origin associated with pulp (e.g., secondary to trauma).

The first situation occurs quite frequently, since periodontics more often succeeds in maintaining the individual roots of teeth that have been subjected to a serious loss of periodontal support. The second situation is quite rare.

In these cases, no preparation ("pretreatment") is required for endodontic therapy. One may simply position the rubber dam, disinfect the occlusal surface of the isolated tooth, and proceed directly to the preparation of the access cavity.

The only possible procedure that might be considered to be part of the preparation for endodontic therapy is ensuring that the dam clamp "grips" the tooth tightly. This may be required when one is called upon to treat intact teeth that have barely erupted, when the height of contour is apical to the gingival crest.[15] In such a case, it might be helpful to apply small ribbons of composite to the buccal and lingual cervical areas of the teeth after acid-etching so as to create an undercut to which the clamp may be anchored securely and stably (Fig. 10.25).

Normally, one finds oneself intervening for the first time on endodontically virgin teeth that have previously been reconstructed or that have large carious lesions involving the pulp.

If one must retreat a tooth that has already been subjected to endodontic therapy, one is dealing with a tooth with a partial or complete reconstruction of variable extent in its no-longer-intact coronal portion.

The smallest restoration which one might face is one

which solely reconstructs and obturates the endodontic access cavity that had been created previously.
At this point, one must ask oneself whether it is necessary to remove the existing restoration *in toto* or in part, whether the tooth is endodontically virginal but has a previous reconstruction, and whether the tooth requires retreatment (and therefore obviously has already been reconstructed to some degree).
The various clinical situations that may present can be simply described as follows:

a) Cases in which it is prudent to completely remove the existing restoration before beginning endodontic therapy:
   - when the restoration (restorative or prosthetic) does not seal adequately
   - when there is a carious lesion beneath the previous restoration
   - when there are posts or screw posts (in this case, the restoration must be removed in an early phase and the means of anchorage in a second one)
   - if, following the establishment of the access cavity, the obturation or crown do not remain in place.
b) Cases in which it is not necessary to completely remove the existing restoration before beginning endodontic therapy:
   - when one is certain that there is no carious lesion below the existing reconstruction (e.g., after having performed a complex amalgam restoration on a tooth with a vital pulp, it becomes necessary to treat it endodontically for symptomatic or other reasons; in this case, having performed the reconstruction and "ensuring" that no carious tissue has been left, it may be convenient to leave the restoration in place)
   - when, in a retreatment, there are no radicular anchorages and the pulp chamber is not obturated with amalgam, composite, or glass-ionomer cement
   - when one has to try to preserve a properly-performed prosthetic restoration (e.g., crown or onlay): in this case, the restoration is preserved by trying as much as possible to limit the preparation of the access cavity
   - this situation can occur when, for instance, one must endodontically treat a prosthetically-treated tooth that presents symptoms of pulpitis shortly after cementation of the prosthesis.

The sole purpose of this list of possibilities is to describe the various situations that may present clinically.
It goes without saying, however, that good clinical sense and experience should indicate whether previous restorations need to be removed. One need not necessarily follow rigid, pre-established criteria.

PRETREATMENT

The necessary prerequisite for proper endodontic therapy is the preparation of an adequate access cavity and restoration of the tooth so as to enable isolation of the field with a rubber dam. The teeth that one is called to treat almost never have an intact crown; more often than not they have cavities due to carious lesions or have old, leaking, and often not very retentive restorations.[18] In these cases, it is often difficult, if not impossible, to undertake endodontic therapy and complete it *lege artis*, both because of the impossibility of positioning the rubber dam – the necessary protection for acceptable endodontic therapy – and because of the difficulty of achieving a hermetic temporary filling between the various visits. Therefore, it is necessary to "pretreat" the tooth, so as to make the therapy possible.
What is normally called "pretreatment" in Endodontics may be defined thus: "The whole of all those techniques that prepare for endodontic therapy and that make possible and/or simplify optimal isolation of the operative field".[28]
In short, what must be done prior to beginning definitive endodontic therapy can be summarized by three points:[28]

- remove all carious tissue
- remove inadequate restorations
- restore the contour of the tooth.

These three procedures have the following six objectives:[18,19]

1. Prevent contamination of the endodontic space by the bacteria present in the carious tissues.
2. Ensure that the walls of the endodontic cavity do not let any liquid leak through and that there is no chance of infiltration of saliva from the oral cavity to the endodontic cavity or, vice versa, of percolation of medications or irrigating solutions from the endodontic space to the oral cavity.
3. Enable and facilitate the positioning of the rubber dam.
4. Reconstruct the pulp chamber so that there is an adequate space for the irrigating solutions and temporary medications. One must recall that, during the cleaning and shaping procedure, the pulp chamber must never be dry; on the contrary, it

must contain as much irrigating solution as possible. The access cavity therefore must function as a basin, which is possible only if there are four walls. The temporary medication must never be placed within the canal, but in the pulp chamber; for this reason, it requires space.

5. Re-establish a regular and stable contour of the tooth, to provide regular and easily locatable reference points by which one can determine, with the use of rubber stops, the working length of the instruments.
6. Prevent postoperative discomfort as much as possible and avoid fracturing the tooth in the course of therapy.

After the completion of root canal therapy, the patient sometimes complains of a pronounced periodontal type of sensitivity, which occurs on mastication and percussion. To preclude this pain and, especially, to avoid any possibility of fracture, it is necessary to releave the occlusion by reducing its occlusal surface so that there is no contact, either in maximal intercuspation or on lateral or protrusive movements. A beveled crown fracture is to be greatly feared and occurs frequently in posterior teeth treated endodontically, especially if the teeth are largely destroyed and reconstructed without protection of the cusps.

There are two reasons why the above mentioned occlusal reduction must be completed before the rubber dam is placed in position:

1) So that it is possible to confirm the absence of any contact on maximal closure, lateral movement, or protrusion with the articulating paper. Obviously, this procedure could not be performed if the rubber dam was in position.
2) So that the reference points used to define the working length remain fixed from the beginning to the end of the endodontic therapy, especially if this is performed in several visits.

Exceptions to this rule can occur in two situations:

1) when treating posterior teeth whose cusps are already protected (e.g., teeth prosthetically treated with crowns or onlays)
2) when treating anterior teeth.

Modern indications for Endodontic Pre-Treatment

The recent and continually more sofisticated progress in the endodontic sector (operative microscope, rotary instruments in nickel titanium and new materials like MTA) are enormously modifying and speeding up many root canal treatment procedures. More and more frequently, especially in single and double rooted teeth we are able to combine and complete the endodontic and reconstructive procedure in a single visit.

In the light of the many modern endodontic approaches, it would seem opportune to re-evaluate the ideal indications and necessity for pre-treatment. The six fundamental principles analized at the beginning of this chapter are considered irrefutable and beyond discussion for their didactical and clinical value (thereby applying them to all situations one can avoid mistakes!)

The essential prerequisites for undertaking endodontic treatment are always the correct isolation of the operative field with rubber dam, the removal of caries as well as inadequate restorations, which do not hermetically seal the tooth. Admittedly though the final decision whether pre-endodontic reconstruction is necessary could be determined by the evaluation of some parameters such as the amount of coronal destruction coupled to the occlusal conditions of the tooth, the depth and size of the pulp chamber and the time that will elapse before definitive reconstruction is completed. Therefore in the case of moderate coronal destruction (ie. loss of a cavity wall) with a fairly deep pulp chamber (capable of acting as a natural reservoir for the irrigating solution) and with a short term provision for the final reconstruction, subject to placing rubber dam and removing infected tissue, it is possible to start the endodontic procedure without any pretreatment (Figs. 12.1 A-D). The case in which the above listed conditions are not altogether present, one is necessarily compelled to reconstruct the tooth before endodontic treatment. Many procedures, apart form being essential to correctly undertake the endodontic treatment, also prove advantageous for the clinician having to reconstruct the treated tooth, who has the certainty of being able to have stable application of the rubber dam during successive sessions.

CLASSIFICATION

Schematizing the various possibilities that may face the dentist in the pre-endodontic phase for purposes of simplification, the pretreatment can be classified in several ways.

According to their length, one may refer to temporary and semi-definitive pretreatments. Depending on the type of therapy, one may also refer to restorative or periodontal pretreatment (see Tab. II).

More often than not, the preparation techniques for

A B C D

Fig. 12.1. Upper right first premolar needs retreatment. **A**. Pre-operative radiograph. **B**. Isolation of the operative field with rubber dam and removal of the old metallic restoration. Note the absence of only the distal wall. **C**. Irrigation with sodium hypochlorite. Note the depth of the pulp chamber, which is able to contain a large quantity of irrigant. **D**. Postoperative radiograph.

endodontic therapy are of limited duration, ending with the endodontic therapy itself (temporary pretreatment).
For example, a copper band used to pretreat a posterior tooth is removed by the prosthodontist when the tooth is definitively reconstructed.
In other situations, the techniques of pre-endodontic reconstruction may result in a durable restoration (semi-definitive pretreatment). For example, a pre-endodontic amalgam cusp covering may be considered a semi-definitive restoration, inasmuch as it can be re-restored in amalgam once the access cavity has been created in it; further, the entire entity may be prosthetically prepared.
One can also distinguish techniques of preparation for endodontic therapy (Tab. III) the aim of which is the

Table II

Pretreatment:
- temporary
- semi-definitive

Pretreatment:
- periodontal
- restorative
  - -prosthetic
  - -conservative
- other (special cases)

Table III - **Approaches that may be employed in restorative pretreatment:**

- prosthetic:	- temporary crown and hollow post - temporary crown and removable post - temporary crown in posterior teeth
- conservative:	- reconstruction of the 4th wall (various cements, composite, etc.) - copper band - orthodontic band - small amalgam pins or dentinal pins - composite (e.g., for well-conserved anterior teeth)

reconstruction of the individual tooth (restorative pretreatment) and others that aim at exposing the roots (Tab. II) destroyed and submersed in the periodontium (periodontal pretreatment).

PERIODONTAL PRETREATMENT

It is obvious and taken for granted that, prior to undertaking endodontic therapy, initial periodontal therapy has been performed properly.
If this is not possible for mere reasons of urgency and the dentist is obliged to intervene immediately without the opportunity of starting the patient on a proper program of preliminary hygiene, before positioning the rubber dam it is essential at the very least to remove the plaque and calculus from the tooth requiring treatment and from the two approximal teeth.
It would not be possible to isolate and correctly seal the operative field if, for example, a piece of calculus were found to interfere with the dam margin. It would be no less desirable to have plaque in proximity to a "sterile" access cavity.
As stated above, the tooth that is the object of endodontic treatment is almost never intact but almost always largely destroyed. Indeed, there may almost always be large, rapidly destructive carious lesions, large amalgam reconstructions, or infiltrated and worn composite, and even completely inadequate prosthetic reconstructions.
The tooth requiring definitive endodontic treatment very frequently presents partially or, more seldom, even completely concealed by the surrounding periodontium.
The principal aim of periodontal pretreatment is therefore to expose enough healthy dental tissue so that it is possible to isolate the operative field adequately and later reconstruct the tooth definitively.
When possible, the periodontal pretreatment is not simply limited to exposing healthy tissue in the tooth in question, but takes into consideration all the possible surgical problems, periodontal and other, in the same quadrant, so as not to subject the patient to repeated surgical procedures in the same area.
There are two surgical periodontic techniques that can be helpful in reestablishing a good tooth-periodontium relationship:
– gingivectomy-gingivoplasty [12-14]
– the apically repositioned flap [1,10,23] with or without resective bony surgery.

Gingivectomy-Gingivoplasty

Gingivectomy-gingivoplasty may be indicated when dealing with a wide band of keratinized gingiva, a subgingival cavity far away from the alveolar crest, and gingival hypertrophy that so insinuates itself that it occupies the space created as a consequence of carious destruction.
In the latter case, it is especially the gingiva that hypertrophies as a response to repeated inflammatory stimuli. It proliferates into a carious cavity which is at the gingival margin rather than truly subgingival ("false pocket").
This situation is encountered frequently, especially in young patients.
Numerous causal factors combine to cause large caries near the marginal periodontium. Poor hygiene and a carbohydrate-rich diet cause large, rapidly-evolving carious lesions that are easily found near the marginal periodontium, since at this stage the tooth is only partially erupted.
In short, gingivectomy is indicated in cases of pseudo-pockets and hyperplastic-hypertrophic gingival tissues, which are particularly frequent in interproximal sites. One therefore speaks of "papillectomy" rather than gingivectomy.

The apically repositioned flap

This procedure is necessary when the crown is largely destroyed and/or fractured below the gingival margin as far as the alveolar crest or when there is not enough attached gingiva to permit partial excision.
This procedure is certainly preferable to gingivectomy, unless the latter is reduced to a simple "papillectomy," which is performed only when the indications listed above are present.
It is necessary to proceed to osteotomy-osteoplasty during the procedure if the margins of the future cavity or of the preparation are not situated at least 2-3 mm from the alveolar crest (which is not to be understood as the "physiologic dimension" in the strict sense of the term, but rather as the minimum space necessary to restore the tooth [20]). If this space had already been present, it suffices to raise an internally beveled flap (45°) and reposition it more apically, thinning the soft tissues.
It is obvious that if, as often happens, other than having to endodontically treat the tooth or the radicular residue, one also has to resolve periodontal and/or

prosthetic problems (e.g., lengthening of the crown), the flap will provide free access to the root surface and periodontium. In this way, it is possible, obviously in the absence of endo-periodontal lesions, to restore health to pockets and craters, and to correct angular defects according to the usual techniques.
Endodontic treatment can be completed shortly thereafter, since, even in the healing phase, the dam clamp will not interfere with the healing and maturation of the marginal tissues.

PROSTHETIC RESTORATIVE PRETREATMENT

A number of techniques maybe employed to reconstruct the tooth prior to endodontic treatment. Some are used frequently, others are indicated more rarely.
We will consider in detail the various techniques that can be grouped under the heading of prosthetic restorative pretreatment (Tab. III), in particular temporary resin restoration in the anterior or posterior quadrants.
In the posterior quadrants, a temporary prosthetic restoration such as a temporary crown is required each time one intervenes in a tooth that had previously been prosthetically treated but where the restoration – a crown, in this case – has for some reason been removed. In this case, it may require one to reconstruct the coronal morphology using a temporary resin crown pre-made in the laboratory (e.g., a temporary shell crown or an acrilic temporary crown with cast frame work) or a pre-formed commercial aluminum crown applied to the abutment with autopolimerizing resin.
If the anchorage provided by the residual tissues is sufficient, such a restoration can then be perforated occlusally once it is cemented. The endodontic therapy is performed as if the tooth were reconstructed with a definitive crown.
If the residual dental tissues are insufficient to allow the use of such a method, it will be necessary to employ other techniques, which will be discussed below.
Endodontic therapy of the anterior quadrants may be necessary in the following two clinically different situations:

a) The clinical crown of the tooth to be treated is at least partially preserved. The remaining hard tissues make the isolation of the operative field possible.
b) The clinical crown no longer exists, and all that remains is the root.

While in the first case the only pre-endodontic intervention to consider regards the reconstruction of the fourth wall of the access cavity using zinc oxyphosphate cements or composite materials (Fig. 12.2), in the second case, in addition to having to resolve problems of pretreatment that are not always easy, one faces immediate esthetic needs.
Messing[22] suggests reconstruction of the crown using composite resin held in place by self-threading pins.
Abdullah Samani[26] confirms, though with some variations, the concept already expressed by Messing; in fact, he uses self-threading pins as a means of anchorage, but substitutes the composite with a resin temporary crown.
Today, recourse to such techniques certainly seems that much more inappropriate.
The risks of dentinal microfracture associated with the use of self-threading pins are too high, especially in teeth as fragile as the anterior teeth.
Nor should one forget that the presence of self-threading pins definitely complicates the work of the prosthodontist who will be the last to intervene on the treated root to restore it with a definitive and durable crown.
In our opinion, a good resolution of the problem is to employ temporary crowns anchored to the tooth, not with self-threading pins, as Abdullah Samani proposes, but rather with hollow radicular posts,[21,24,25] which are certainly the least risky means of anchorage.
In short, one must anticipate, albeit partially and temporarily, what will be performed afterward when the root canal is prepared for the definitive prosthetic post.

Fig. 12.2. The fourth wall of the canine access cavity has been reconstructed with zinc oxyphosphate cement.

Hollow posts

After having cleaned the residual dentin and re-established a proper relationship with the surrounding marginal periodontium, the abutment is prepared (Figs. 12.3 A-C) for the future definitive prosthetic restoration (e.g., a cast gold post and core).
Once the abutment has been prepared, one proceeds to the mechanical reaming of the most coronal one third of the canal using calibrated canal wideners mounted on a low-speed handpiece (Figs. 12.3 D, E).
It is obvious that the canal can already be quite wide if the post is a substitute for another one that has just been removed.
If the canal has not been prepared, it will obviously be difficult to calibrate it adequately. In this case, one must pay maximum attention to avoiding the formation of ledges, false paths, or perforations.
Once the canal has been prepared, one proceeds with a trial placement of the post in the root canal (Fig. 12.3 F); if this is satisfactory, it is positioned in the canal.

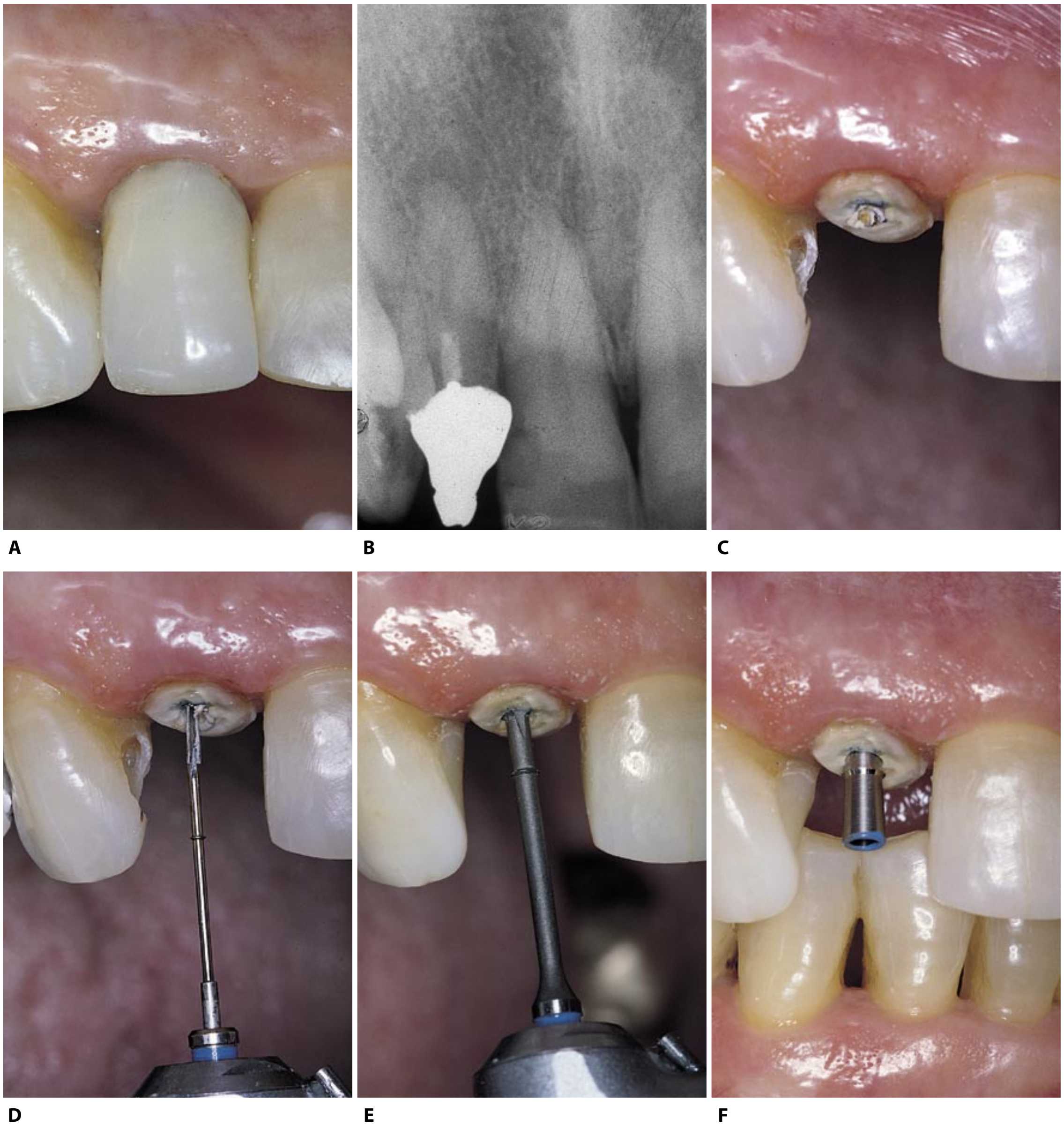


Fig. 12.3. Clinical (**A**) and radiographic (**B**) appearance of an upper right lateral incisor that requires endodontic retreatment after the removal of the existing prosthetic restoration. **C.** With the use of ultrasound, the crown has been removed, and the root have been regularized and cleaned of carious tissue. **D, E.** The coronal one third of the root canal is widened with calibrated burs. **F.** The hollow post is tried in place, checking that there is no interference in maximal intercuspidation (continued).

At this point, one must choose among three possible alternatives in the preparation of the resin temporary crown:
1) use pre-formed polycarbonate crowns
2) use acrilic resin provisionals previously polimerized under pressure in the laboratory
3) use previously-obtained silicone or alginate partial impressions.

This method is particularly indicated when one must intervene in previously prosthetically-treated teeth when the removal of the preceding prosthetic restoration is necessary prior to endodontic treatment. Once the type of temporary crown is chosen, it is filled with cold, self-polymerizing resin and relined. It is positioned on the abutment with the post in place (Figs. 12.3 H, I). The result is nothing more than a temporary crown with a post entrapped within in the hardened resin.

Everything is cemented with zinc oxyphosphate, making certain that the cement does not obstruct the most apical part of the canal (Figs. 12.3 J, K). To prevent this, one uses a paper or gutta percha cone (Fig.

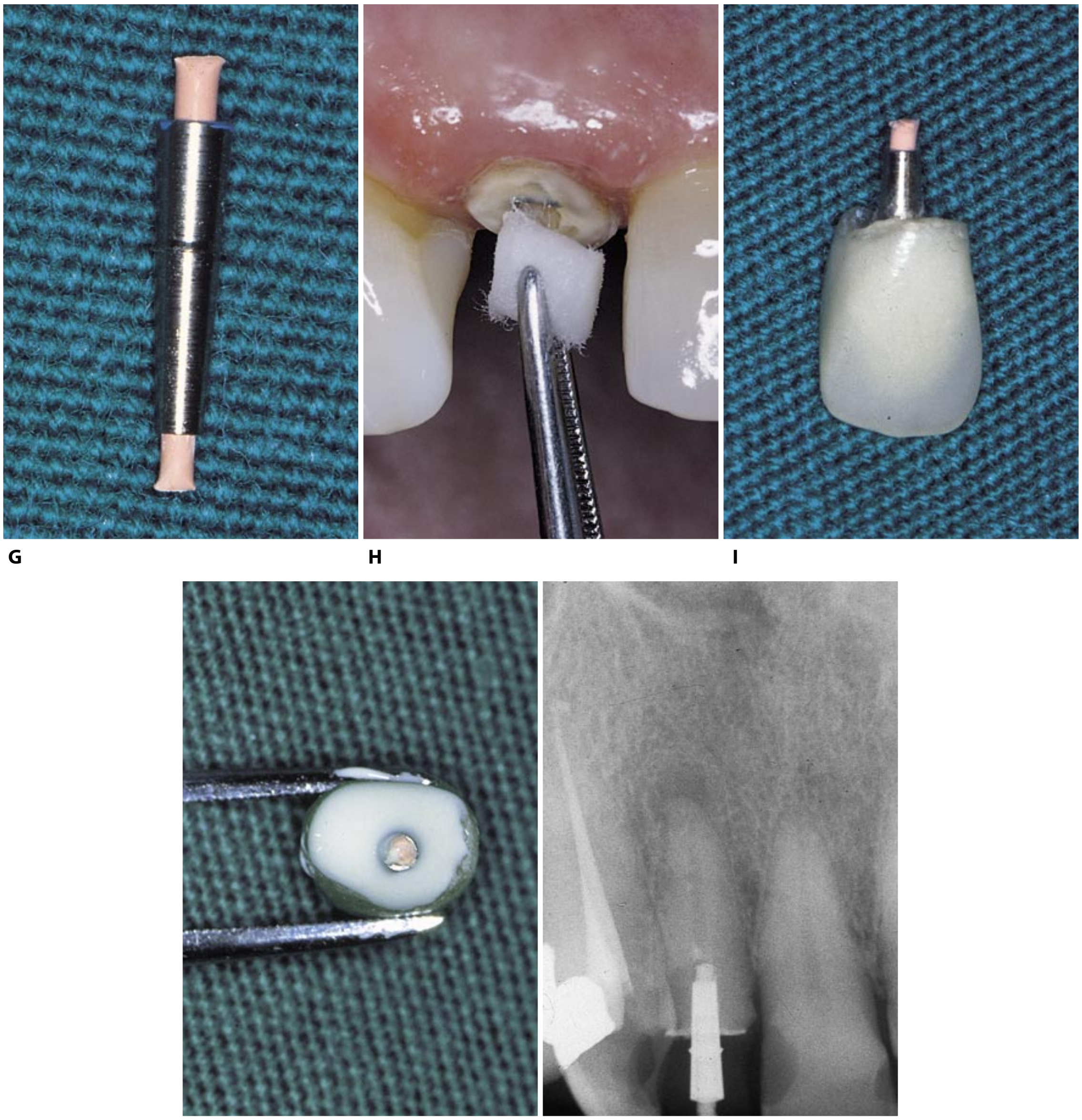

G H I
J K

Fig. 12.3. (continued) **G.** The hollow post before re-lining and cementation of the temporary crown. Note that the gutta-percha cone is encased in the resin; this not only helps in finding the access cavity but in preventing obstruction of the root canal by the definitive cement. **H.** The abutment is lubricated with paraffin oil before re-lining of the temporary crown. **I.** The temporary crown previously made in the laboratory has been re-lined with the hollow post encased within. **J.** The temporary crown filled with oxyphosphate cement ready for cementation: note the gutta-percha cone within the hollow post. **K.** Radiograph at completion of cementation (continued).

12.3 G) adequately inserted within the hollow post. After having removed the excess cement, one waits several minutes. Once the cement has completely hardened, the rubber dam is positioned by anchoring it with the clamp to the resin temporary crown, and one performs the access cavity *lege artis* until the post is encountered (Fig. 12.3 L).

When the bur reaches the artificially re-created "pulp chamber," the paper or gutta-percha cone is located and removed very easily.

Only cleaning and shaping of the canal as usual under optimal operating conditions remains to be done (Figg. 11.3 M-O).

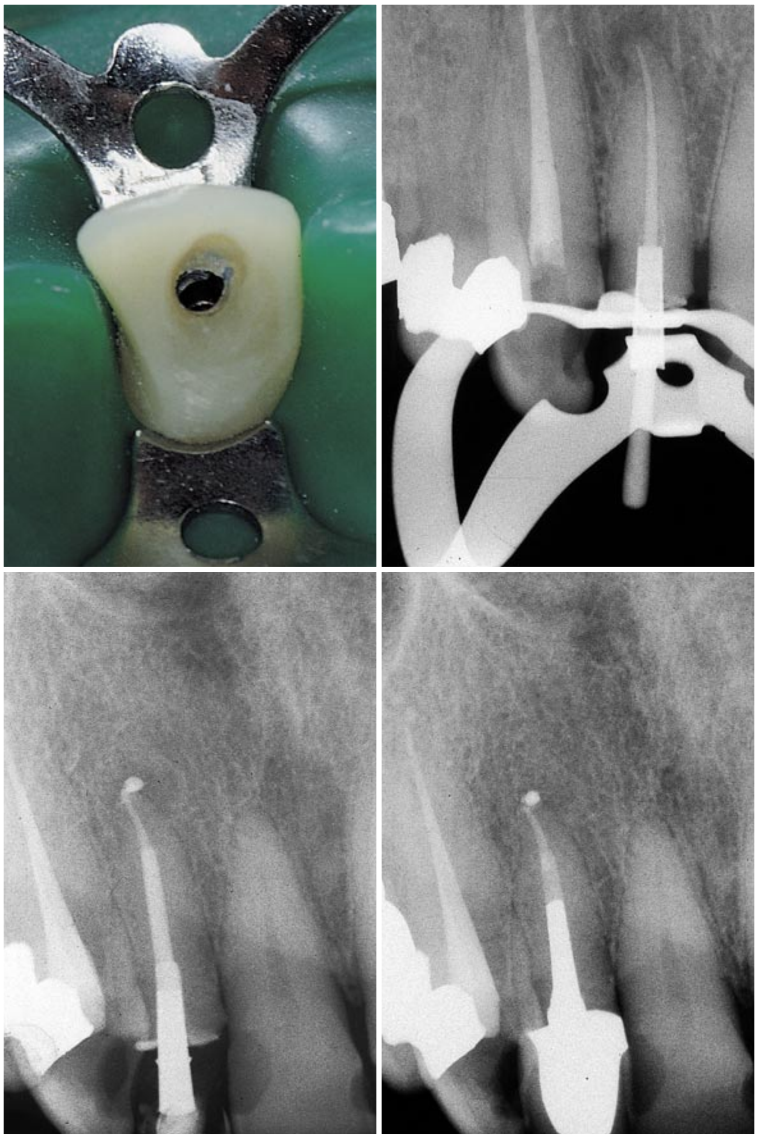

L M N O

Fig. 12.3. (continued) **L.** The access cavity prepared as far as finding of the hollow post within the temporary, after having removed the gutta-percha cone. **M.** Intraoperative radiograph of the cone fit. **N.** Postoperative radiograph. **O.** Recall radiograph one year later.

CONSERVATIVE RESTORATIVE PRETREATMENT

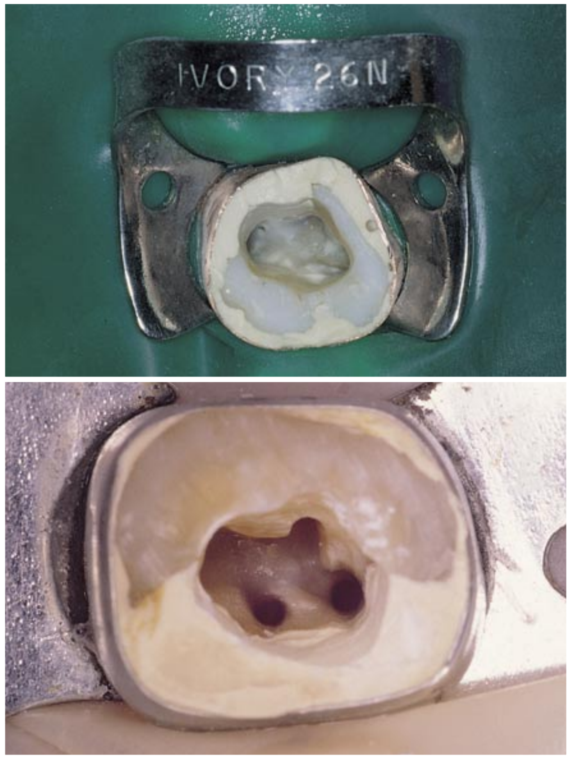
Reconstruction of the fourth wall

When the tooth to be treated is well-preserved and it is only necessary to reconstruct the fourth wall for completion of the access cavity, many relatively easy methods are at one's disposal.
In the case of the anterior teeth, as already seen, it is preferable to use composite materials. Certainly, this is esthetically acceptable.
Regarding the posterior teeth, it is possible to reconstruct the fourth wall using materials such as temporary cement, amalgam, glass ionomers, or composite materials.
If one uses composites,[3,4] it is a good idea to use materials that have a color which distinguishes them from the tooth, so that they may be more easily identified at the time of their removal and execution of the definitive restoration.
Obviously, this method does not protect the tooth from the risks of fracture.

Copper and orthodontic bands

If it is necessary to treat a very severely damaged posterior tooth lacking one or more walls of the future access cavity, it is advisable to reconstruct the perimeter of the tooth with a copper band (Fig. 12.4 A) or with an orthodontic band (Fig. 12.4 B).[5,29]
The choice of a copper band or orthodontic band depends particularly on the presence of asymmetrical hard tissue destruction that extends sub-gingivally at the varying levels.
Should one have to treat a tooth with subgingival interproximal caries, mesially and/or distally (Fig. 12.5 A), then the use of a copper band provides better adaptation than an orthodontic band.
It is possible to model and trim a copper band as needed to be able to hermetically seal cavities with irregular subgingival contour (Figs. 12.5 B-F). Any time the band must have an irregular contour, as in the case of mesio-occlusal caries and mesio-occlusal-distal caries extending subgingivally, it is advisable to use a copper band.
If cavity that needs to be enclosed extends completely above the gingiva and the band need be neither particularly high nor very contoured, one can use orthodontic bands which, being pre-formed, require less operative time to be applied (Fig. 12.4 B).
A tray prepared for positioning of copper bands or orthodontic bands must contain:

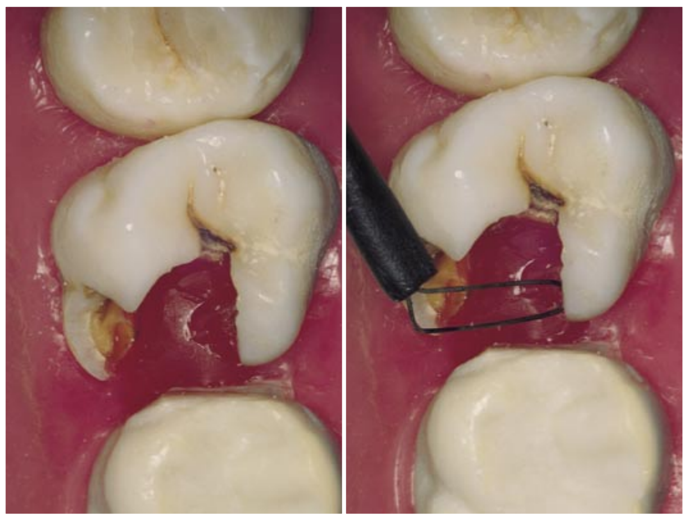
– a complete series of copper bands
– orthodontic bands for molars and premolars, upper and lower



A

B

Fig. 12.4. **A**. Pretreatment of a lower molar with a copper band cemented with zinc oxyphosphate. **B**. Reconstruction of a molar crown using an orthodontic band.



A B

Fig. 12.5. **A**. This photograph in a mannequin mouth shows a tooth requiring pretreatment using a copper band. Note that distally the carious lesion descends below the gingival margin, and that the gingiva reconstructed here in wax has proliferated into the cavity. **B**. Through the careful use of the electrosurgery, the gingival tissue that has invaded the carious cavity is removed (continued).

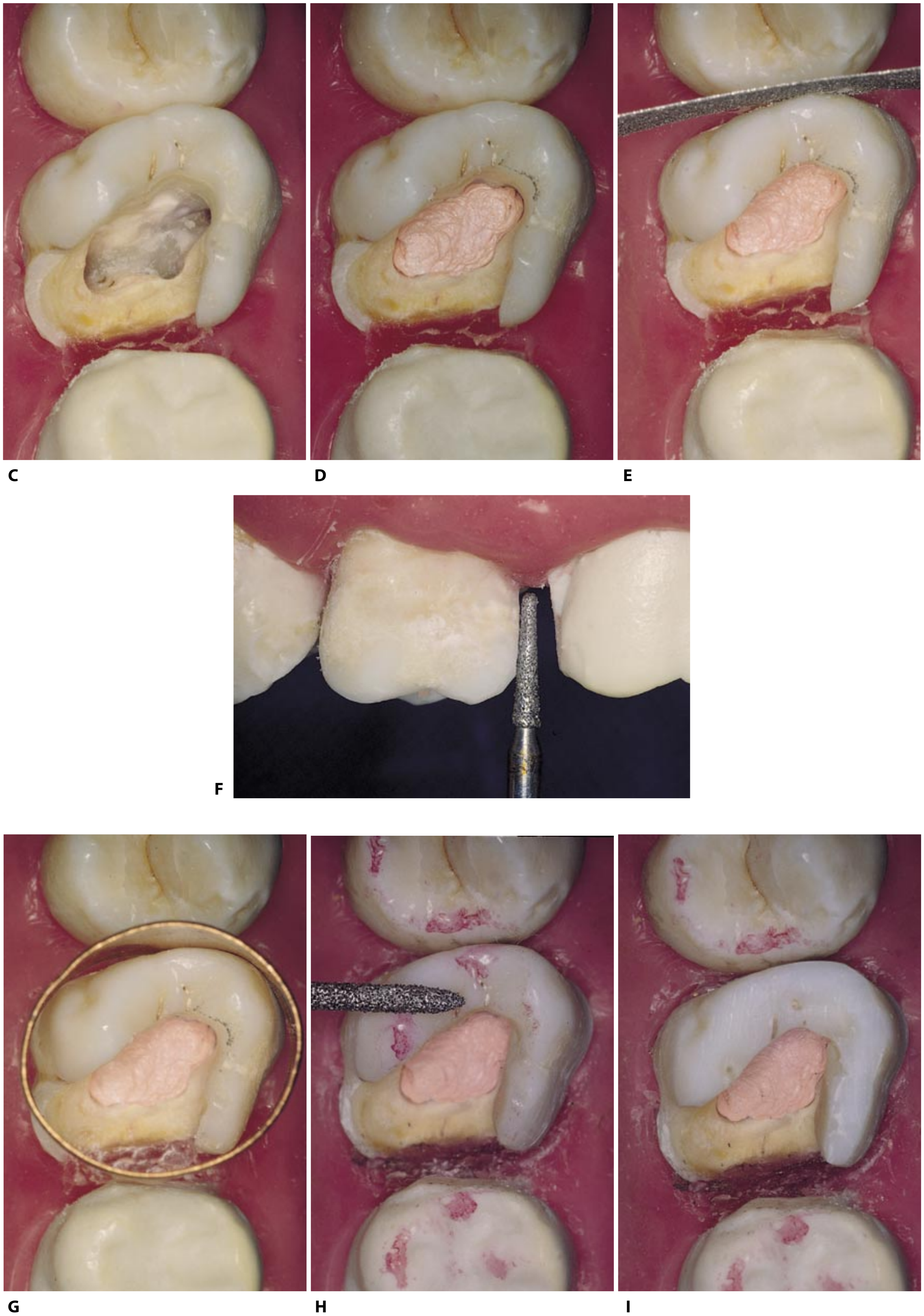


Fig. 12.5. (continued) **C.** The cavity as it appears once it has been cleansed of carious tissue and the pulp chamber has been opened. **D.** The pulp chamber has been filled with thermoplastic gutta-percha to avoid obstruction of the orifice of the root canals by zinc oxyphosphate cement. **E.** Using a diamond abrasive strip, the contact point with the approximal tooth is eliminated to permit the ring to be slipped into place. **F.** With a diamond bur, the largest undercuts on the tooth surface are removed. **G.** The band corresponding to the size of the tooth is tried. Before being softened, the band must always be a bit smaller. **H, I.** After having identified the occlusal contact points, the occlusal surface of the tooth is reduced to avoid contact with the opposing arch (continued).

– a strong pair of scissors to cut the bands
– orthodontic pliers for modelling
– a condensor for pushing the bands into place
– universal pliers
– articulating paper
– Arkansas stone, discs and rubber disks for finishing
– a dappen dish with alcohol to cool the flame-softened rings
– an abrasive metallic strip to reduce, obviously at the expense of the affected tooth, very tight contact points with neighboring teeth.

If a copper band is indicated, one must first of all choose the correct ring for the tooth.
It is advisable to choose a band slightly smaller than the tooth (Fig. 12.5 G). Copper is a ductile metal that can be modelled and enlarged to a certain degree, but it cannot be reduced in size (Figs. 12.5 H-K).
Furthermore, if one has to cut the band so that it is asymmetrical, it will have to be cut with a bevel; thus, its circumference will be increased with respect to its initial circumference (Figs. 12.5 L, M).

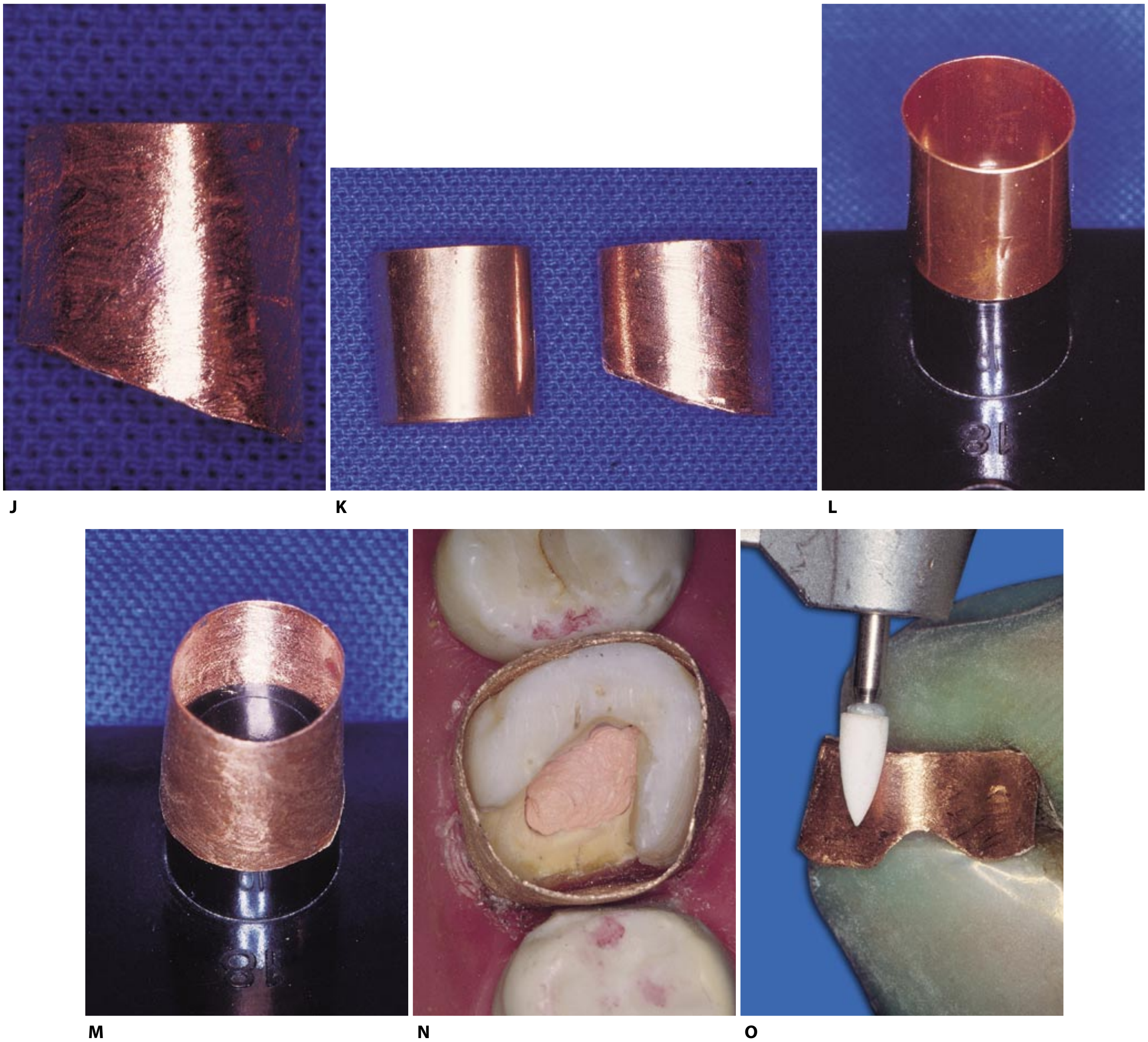


Fig. 12.5. (continued) **J, K.** Once the band has been flame-softened, it is cut, following the gingival margin described by the cavity. **L, M.** Note that two bands of the same diameter descend quite differently on the trial cylinder. This is because the ring on the right has been cut obliquely, presenting a larger circumference than that on the left. **N.** The softened, cut band is tried in place and modelled prior to cementation. **O.** The band is now finished with stones (continued).

When a copper band is adapted to a tooth, it is necessary to carefully check:

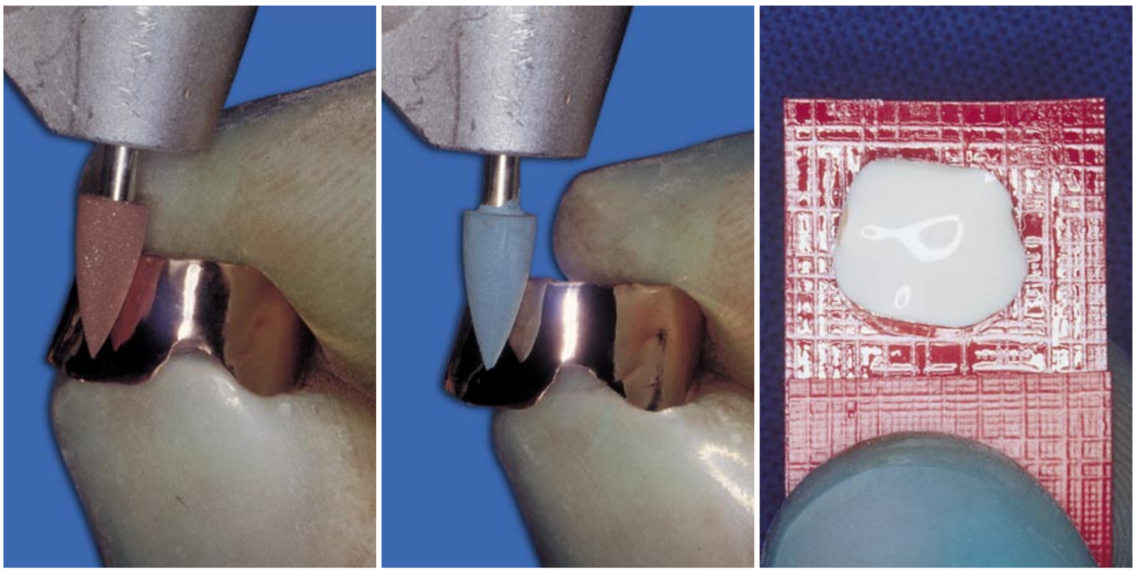
a) The gingival contour.
   The copper band must embrace the tooth well, making good contact with the surface (Fig. 12.5 N). If the interproximal cavity is subgingival, the band will also have to be so to assure a good, hermetic seal of the margin before cementation. This obviously must be done with the maximum respect for the marginal periodontium, and one is sure that the pretreatment will have a very limited duration.
b) The occlusal contour.
   The band should never be in contact with the opposing tooth, both to avoid occlusal interference and to avoid decementation between one appointment and the next.
   It is a good idea to make a small "V-shaped" cut on the occlusal surface, both to distinguish the buccal from the lingual side and to allow burnishing of the margins, while it is cemented, toward the interior of the occlusal surface, thus obtaining an occlusal contour that is smaller than the gingival contour.
c) The technique of cementation.
   The biggest problem that the copper band presents is not so much correct contouring as difficulty in working free of saliva.

Obviously, it is almost never possible to use the dam, but the band serves its purpose. Therefore, isolation of the field must be achieved with the help of cotton rolls and high-volume surgical aspiration.

A completely dry field is an essential requirement for proceeding to the cementation phase and achieving a stable band, which theoretically could remain in place for up to one year. A small cotton ball barely moistened in alcohol or, even better, thermoplastic gutta-percha is positioned in the pulp chamber (Fig. 12.5 D) so that this material, which is easily removable, hinders the oxyphosphate cement from obstructing the openings of the root canals.

The tooth is filled with oxyphosphate, making certain not to entrap air bubbles, and the ring is also filled after a small strip of adhesive tape is attached to its occlusal margin. In this way, the ring is transformed into a crown, and one's finger does not attach to the cement (Figs. 12.5 R-T).

One then positions the band, checking the side of insertion and its marginal fit. To do this, one exerts homogeneous pressure on the surface of the adhesive tape with the fingertip for a couple of seconds, using a small condenser kept within reach with which one also folds the previously made "V-cut" sides.



P Q R

Fig. 12.5. (continued) **P, Q.** The band is then finished with abrasive rubbers to prevent it, as much as possible, from harboring bacterial plaque. **R.** The band is cemented with the help of an adhesive strip that facilitates its manipulation.

S T U

Fig. 12.5. (continued) **S.** The band in now ready to be cemented. **T.** Omogeneous pressure is applied for a few seconds. **U.** At this point, the rubber dam clamp can be positioned, and the access cavity can be created.

d) The final finishing.
 Once the cement has set, the excess is removed, and the occlusion is re-checked. The occlusal surface is finished off with a bur.
 At this point, it is possible to position the rubber dam and begin the endodontic treatment (Fig. 12.5 U).

If an orthodontic band is employed in place of a copper band, all the steps described above regarding cementation are the same. In this case, however, it will not be necessary to model the band, but only to choose the diameter appropriate to the situation.

In both cases, one creates an unfavorable hygienic situation with consequent irritation of the marginal periodontium. It is therefore desirable that pretreatment of this type is of limited duration and that the band is removed as early as possible to avoid more serious periodontal problems.[11]

Amalgam anchored with posts or amalgam pins

When a tooth of the posterior quadrants, particularly a molar, is markedly destroyed and one anticipates protracted endodontic therapy (see apexification), a very good means of reconstruction in pre-endodontic function is one which anticipates the use of a direct amalgam restoration.[2]

When dealing with a tooth with an extensively broken crown, it is advisable to anchor the amalgam restoration to the residual healthy tissues, either through the use of small dentinal pins or – better – self-anchoring the restoration with amalgam pins.[6,27]

Success in reconstructing the correct coronal morphology of the tooth under examination will not entail all the negative consequences that could arise in the several months necessary for the maturation of the root apex in the case of apexification therapy.

Even if it is possible to position the rubber dam during the several visits required for apexification, by leaving a destroyed tooth for a prolonged period in the condition in which it is found, one inevitably encounters further problems after the apexification is completed.

As there are neither occlusal nor interproximal contacts, the tooth itself, like its antagonist, will be subjected to extrusion and the element more distal to the tooth to be apexified will mesialize. The consequences that will have to be faced when this has to be reconstructed are easily imaginable.

What means other than amalgam can one use to reconstruct such a destroyed tooth over such a long period of time?

A copper band would provoke serious, prolonged periodontal irritation the consequence of which can be easily predicted, and it would not prevent the extrusion of the opposing tooth.

In our judgement, the only alternative to amalgam restoration is a temporary crown in cases in which it can be anchored to sufficient remaining healthy tissue.

An important caveat related to the self-anchored amalgam restoration is that one must make certain that amalgam particles and/or dust do not obstruct the orifices of the root canals.

Thus, two rules must be observed:

a) when the amalgam restoration is performed, it is advisable to obturate the pulp chamber temporarily with a cement resistant to the forces of conden-

sation (e.g., IRM), obturating the openings of the root canals one at a time with a small pellet of cotton or thermoplastic gutta-percha
b) when the endodontic access cavity is created, it is important not to shed silver dust into the orifice of the root canals, as this could preclude correct execution of the endodontic therapy.

It is always desirable to open the access cavity a little in excess before introducing the temporary cement (e.g., IRM), and in the case of a correction of its perimeter in the course of therapy, it is necessary to adequately protect the canal entrance with cotton pellets or with gutta-percha.

Once the endodontic therapy with prior apexification is completed, the circumferential amalgam restoration can be re-used as a matrix, creating the restoration of the access cavity and anchoring it adequately to the root canals and pulp chamber in the most appropriate way.

Pre-endodontic Composite

The recent evolution of adhesive aesthetic materials, apart for revolutionising the restorative techniques on the posterior teeth with progressive change from the use of traditionally metallic materials, also allows one, nowadays a rapid and reliable technique for pre-endodontic reconstruction.[7-9]

The modern composites and the latest generations of enamel and dentine adhesives by virtue of their optimal physical and mechanical properties, the proven good longterm results and the semplicity of application (one should remember that the resin composites and their derivatives are at the moment the only materials that are able to "reinforce", even if only minimally, the residual tooth structure as well as allowing buildup without the use of a matrix band) can be considered the material of choice for restorative pre-treatment.

The advantages of this technique are the excellent sealing properties, the ease and speed of use without the necessity for added mechanical retention with subsequent healthy tissue loss and the possibility to start endodontic treatment at the same visit.[3]

Another advantage of this method especially considering the recent tendency to use resinous cements and non metallic fibre posts for adhesive pre-prosthetic reconstruction, and the modern evolution in the already mentioned endodontic field, is the transformation of the reconstructed tooth walls into a retaining matrix to simplify and speed up the successive pre-prosthetic procedure. In this regard it is advisable to use a material chromatically different to the dental tissue to aid the removal in the prosthetic phase (during tooth preparation). The immediate recognition cal also be useful during periodontal surgery to enable the correct positioning of the tissue with respect to the biological width during osteoplasty and osteotomy procedures.

During the pretreatment phase, after removal of caries and especially in particularly difficult operative conditions (absolute impossibility to place rubber dam due to inaccessible sub-gingival margins) the authors recommend the use of enamel-dentine adhesives with the minimum number of steps i.e. single bottle adhesives requiring one step applications ("all in one"), ultimately to help speed up the placement of the restoration avoiding the possible contamination of the area with blood and saliva.

The adhesive pretreatment phases therefore are (Figs. 12.6, 12.7):

1) Establishing a dry operative field and isolation with rubber dam (it may not be possible immediately).
2) Removal of caries and inadequate restorations (Fig. 12.6 A).
3) Placement of a matrix band.
4) Protection of the pulp chamber with cotton or gutta percha (to prevent the obstruction of the canals with restorative material).
5) Etching and bonding of enamel and dentine.
6) Composite buildup (Figs. 12.6 B-D).
7) Rubber dam placement if not possible before.
8) Endodontic treatment (Fig. 12.6 E).
9) Thinning of pre-treatment composite walls (0,5 – 1 mm thickness). The remaining material is used as a "matrix band" for the successive reconstruction (Fig. 12.6 F).
10) Preprosthetic restoration of the treated tooth (Fig. 12.6 G).
11) Prosthetic preparation: axial reduction of the walls with complete removal of the pre-endodontic composite (0,5 – 1 mm thickness) used as a "matrix band" to create a prosthetic core consisting of a homogeneous block of composite avoiding therefore the presence of a zone of adhesion between two materials placed at different times inside the prepared core (Fig. 12.6 H).

Fig. 12.6. Pretreatment using the adhesive technique: in vitro steps. **A**. Elimination of the inadequate restoration and caries. **B**. Etching of enamel and dentine (35% orthophosphoric acid). **C**. Isolation of the pulp chamber and canal orifices with a cotton pledget and application of adhesive to dentine and enamel and reconstruction in composite material (chromatically different). **D**. Elimination of the cotton pledget from the pulp chamber and modification of the access cavity if required. **E**. Completion of endodontic treatment. **F**. Thinning of the reconstructed walls (0,5 – 1 mm) to be used as a matrix. **G**. Preprosthetic adhesive reconstruction with fibre posts and composite resin. **H**. Prosthetic preparation (complete removal of composite material used in the pre-endodontic reconstruction at the first visit).

Fig. 12.7. Upper left first premolar. Adhesive pretreatment. **A**. Pre-operative view: note the coronal destruction. **B**. Pre-operative radiograph. **C**. Removal of caries. Note the weakening of the remaining walls. **D**. Adhesive pretreatment with composite material. **E**. Attainment of the prerequisites to correctly undertake endodontic treatment. **F**. Intra-operative radiograph to determine working length. **G**. Postoperative radiograph. **H**. Reconstructive phase (continued).

I J K

Fig. 12.7. (continued) **I**. Thinning of walls reconstructed at the beginning of treatment. **J**. Preprosthetic reconstruction with fibre posts and composite resin. **K**. Radiograph after completing prosthetic treatment.

ORTHODONTIC PRETREATMENT

On rare occasions, teeth that have to be treated endodontically and that require orthodontic pretreatment may require to one's attention.
In the case illustrated by Fig. 12.8, for example, mesialization of the second molar precluded both hygienic toilet of the carious cavity of the first molar and, even more, any endodontic therapy which could have become necessary in the course of the preparation of the second-class cavity.

A B C

Fig. 12.8. Radiographs obtained before (**A**) and after (**B**) orthodontic pretreatment. **C.** Postoperative radiograph.

Another special case is illustrated in Fig. 12.9, in which the upper left canine was destroyed by caries apically to the alveolar crest. In this situation, it was impossible to treat the root endodontically.

A procedure to salvage the root was planned as follows:

- endodontic access surgery
- open-flap endodontic therapy
- endocanal anchoring and orthodontic extrusion of the root
- periodontal surgery with apically repositioned flap.

A flap was first raised to enable access for removal of the root caries.

With an open flap, it was possible to place the rubber dam clamp (thanks also to a very small osteotomy), and endodontic therapy was performed (Figs. 12.9 A-E).

Once the canal treatment was completed, it was possible to anchor a small post in the treated canal and perform a very simplified orthodontic extrusive therapy, which met the needs of the patient (Figs. 12.9 F-H).

Once the phase of orthodontic extrusion was completed, it was necessary to proceed to a further intervention to correct the “inverse bony” architecture caused by the traction exerted by the fibers “inserted” in the alveolar bone, and also to re-establish adequate “physiological dimension” (Figs. 12.9 I-K).

Once the maturation of the tissues was complete, the therapy proceeded with the prosthetic reconstruction of the tooth (Figs. 12.9 L-N).

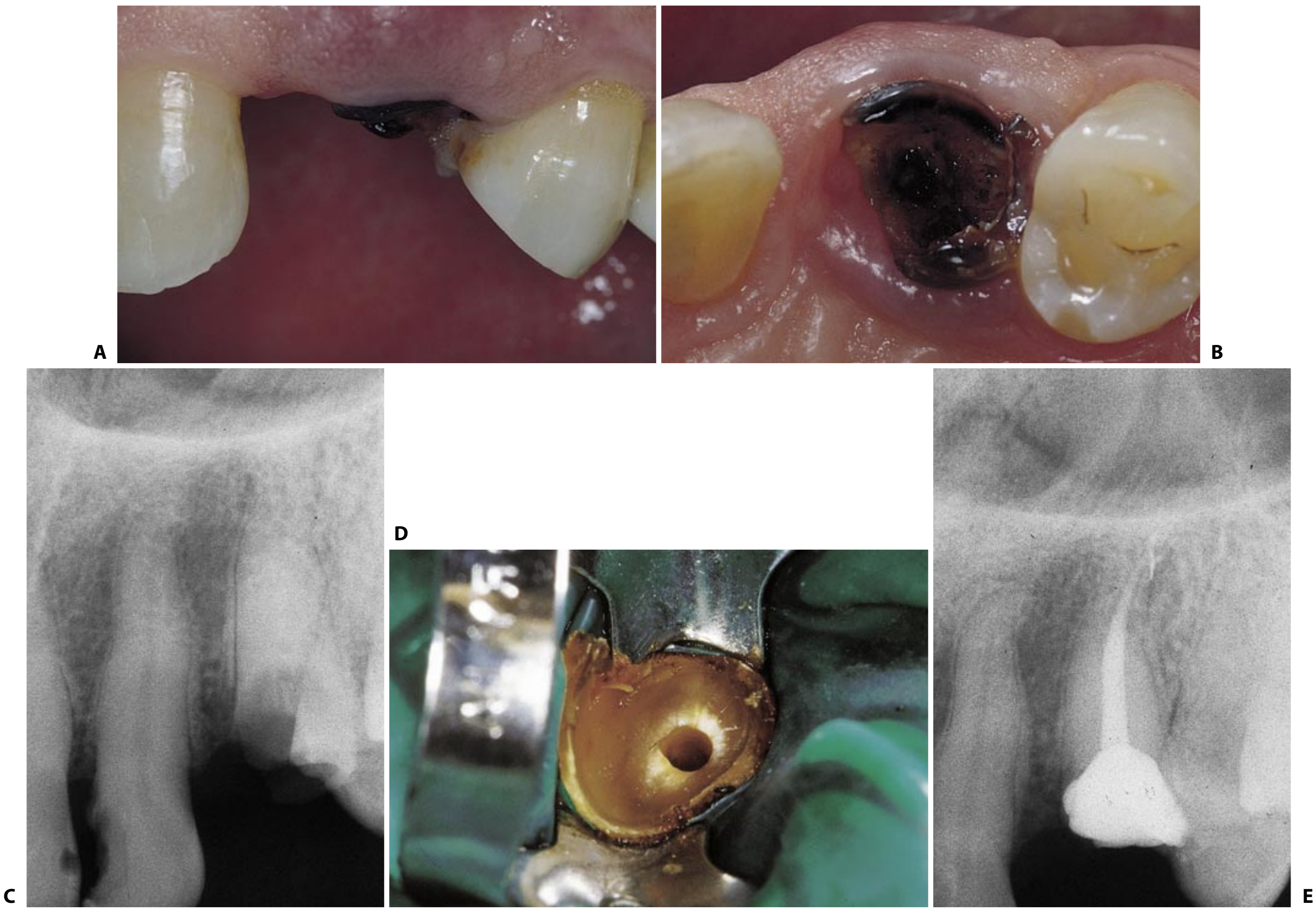


Fig. 12.9. **A, E.** Clinical case of a canine, in which any type of reconstructive therapy is impossible before carrying out endodontic therapy (continued).

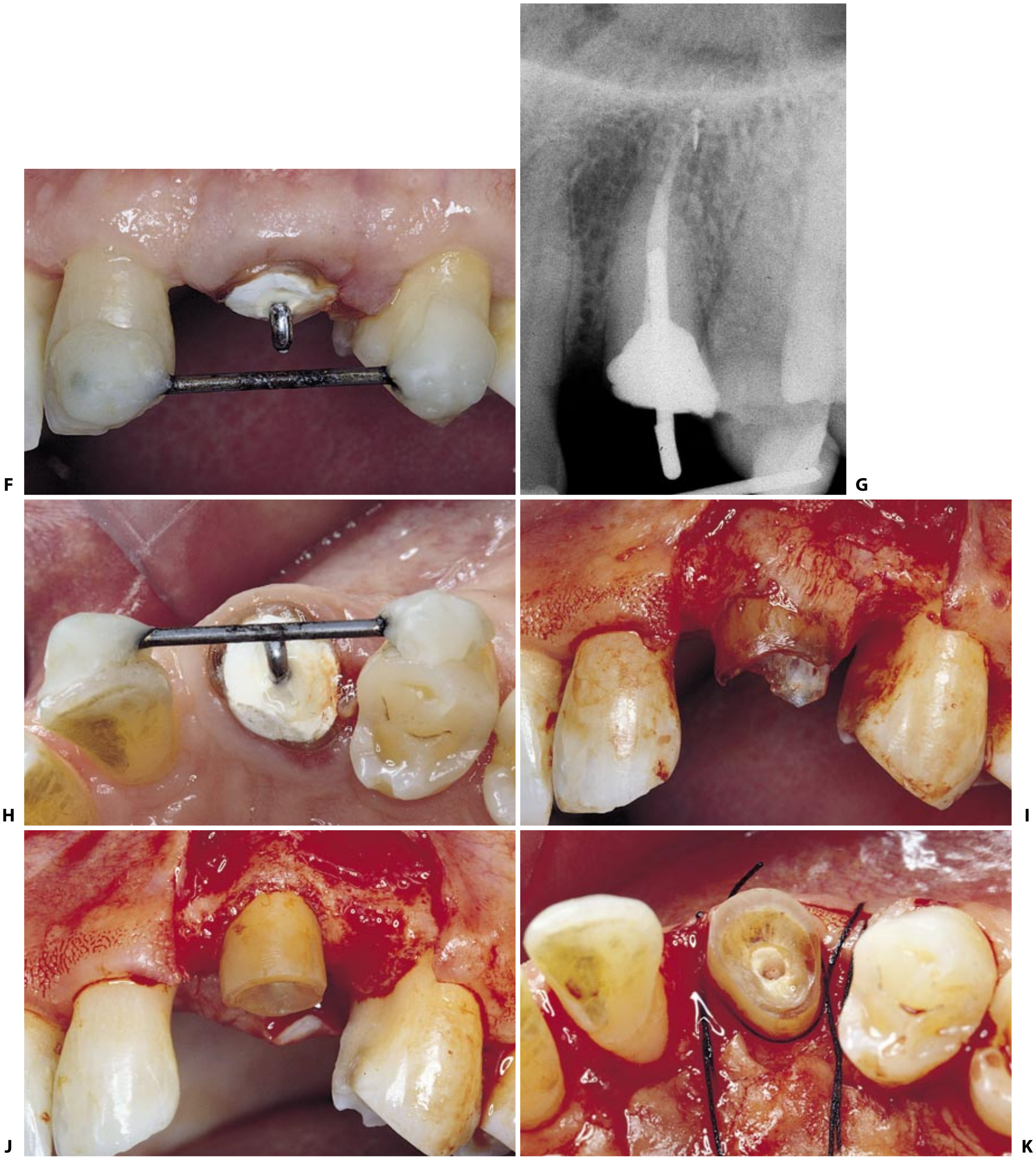


Fig. 12.9. (continued) **F-H**. The phases of orthodontic extrusion. **I, J**. At the conclusion of the orthodontic phase, a flap positioned apically is lifted, and osteotomy-osteoplasty of the bony crest that has "followed" the root extrusion is performed. **K**. The suture of the flap (continued).

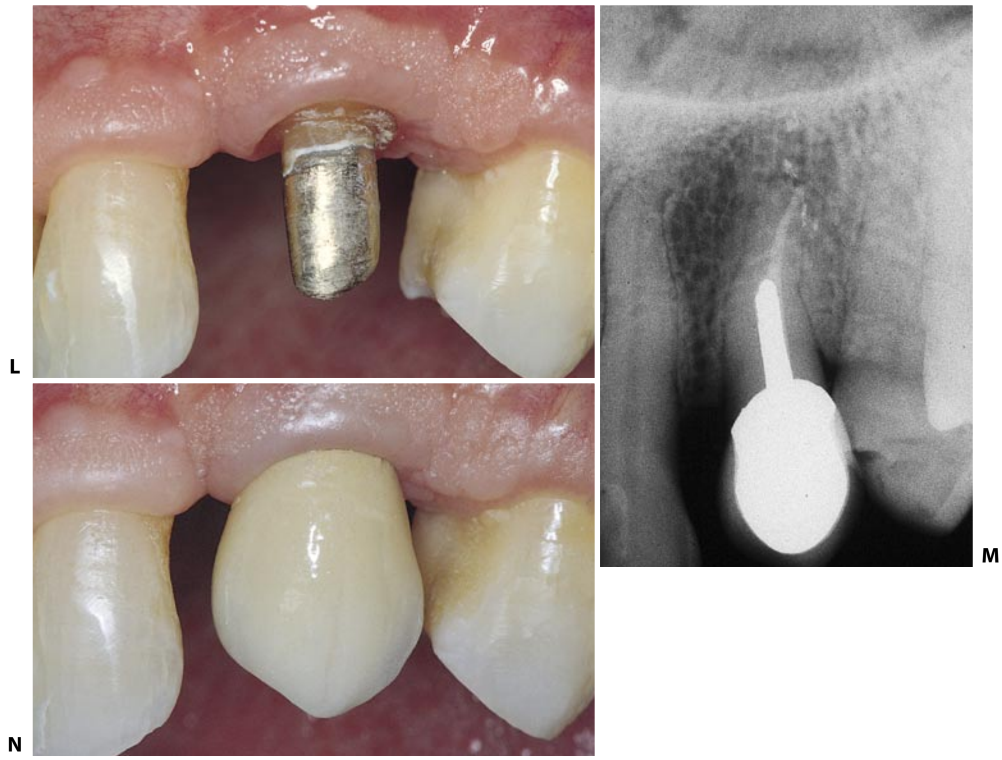


Fig. 12.9. (continued) **L**. Reconstruction of the abutment with a cast gold post and core during the phase of tissue maturation. **M**. Final radiograph at completion of restoration. **N**. The completed prosthetic restoration.

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