ENDODONTIC CAVITY PREPARATION

The chapter on success and failure (chapter 13) substantiates the endodontic dogma of careful cavity preparation and canal obturation as the keystones to successful root canal therapy. Apical moisture-proof seal, the first essential for success, is not possible unless the space to be filled is carefully prepared and débrided to receive the restoration. As in restorative dentistry, the final restoration is rarely better than the initial cavity preparation.

Endodontic cavity preparation begins the instant the involved tooth is approached with a cutting instrument, and the final obturation of the canal space will depend in great measure on the care and accuracy exercised in this initial preparation.

DIVISIONS OF CAVITY PREPARATION

For descriptive convenience, endodontic cavity preparation may be separated into two anatomic divisions: (a) coronal preparation and (b) radicular preparation. Actually, coronal preparation is merely a means to an end, but to accurately prepare and properly fill the radicular pulp space, intracoronal preparation must be correct in size, shape, and inclination.

If one thinks of an endodontic preparation as a continuum from enamel surface to apex, Black’s principles of cavity preparation—Outline, Convenience, Retention, and Resistance Forms—may be applied (Figure 10-1). The entire length of the preparation is the full outline form. In turn, this outline may have to be modified for the sake of convenience to accommodate canal anatomy or curvature and/or instruments. In some techniques, the canal may be prepared for slight retention of a primary gutta-percha point. But most important, resistance must be developed at the apical terminus of the preparation, the so-called “apical stop,” the barrier against which virtually every canal filling must be compacted.

CORONAL CAVITY PREPARATION

Basic Coronal Instruments

Preparations on and within the crown are completed with power-driven rotary instruments. For optimal operating efficiency, separate ranges of bur speed are needed. Although two handpieces are usually required, developments in electric handpiece engineering allow one motor to provide both low- and high-speed ranges of rpm. Handpieces are also being developed that automatically reverse on lockage of the file.

The correct burs are mounted by the dental assistant prior to their use. Rarely should a bur have to be placed or changed during the operation. For initial entrance through the enamel surface or through a restoration, the ideal cutting instrument is the round-end carbide fissure bur such as the Maillefer Transmetal bur or Endo Access diamond stone (Dentsply/Maillefer, Tulsa, Okla.), mounted in a contra-angle handpiece operating at accelerated speed. With this instrument, enamel, resin, ceramic, or metal perforation is easily accomplished, and surface extensions may be rapidly completed.

Porcelain-fused-to-metal restorations, however, are something else. Stokes and Tidmarsh have shown the effectiveness of various bur types in cutting through different types of crowns (Figure 10-2). Precious metal alloys are relatively easy to penetrate, whereas nonprecious metals present considerable difficulty. Although nonprecious alloys can be cut with tungsten carbide burs, they “chatter” severely. This vibration results in patient discomfort and tends to loosen the crown from the luting cement. “The extra coarse, dome-ended cylinder…was the only bur type that cut smoothly and remained clinically effective during the cutting of five successive access cavities in the nonprecious metal” found frequently under metal-ceramic crowns. Tepelitsky and Sutherland also found diamond instrumentation perfect for access
openings in Cerestone (cast ceramic) crowns, as did Cohen and Wallace with Dicor crowns. In Teplitzky and Sutherland’s study, not a single crown fractured of 56 prepared with diamonds. Carbide burs were ineffective.

Tapered instruments should never be forced but should be allowed to cut their own way with a light touch by the operator. If a tapered instrument is forced, it will act as a wedge. This causes the enamel to “check” or “craze” and will materially weaken the tooth.

As soon as the enamel or restorative penetration and minor surface extensions are complete, the accelerated handpiece is put aside, and the slow-speed (3,000 to 8,000 rpm) contra-angle handpiece is used, mounted with a round bur. Three sizes of round burs, Nos. 2, 4, and 6, and two lengths, regular and surgical, are routinely used. The regular-length round bur in a conventional latch-type contra-angle handpiece will “reach” 9.0 mm from the nose of the contra-angle. The surgical-length bur will “reach” 14 or 15 mm and is necessary in some deep preparations (Figure 10-4).

The round burs are for dentin removal in both anterior and posterior teeth. These burs are first used to drill through the dentin and “drop” into the pulp chamber. The same bur is then employed in the removal of the roof of the pulp chamber. The choice of the size of the round bur is made by estimating the canal width and chamber size and depth apparent in the initial radiograph.

The No. 2 round bur is generally used in preparing mandibular anterior teeth and most maxillary premolar teeth with narrow chambers and canals. It is also occasionally used in the incisal pulp horn area of maxillary anterior teeth. The No. 4 round bur is generally used in the maxillary anterior teeth and the mandibular premolar teeth. It is also occasionally used in “young” maxillary premolars and “adult” molars in both arches, that is, molars with extensive secondary dentin. The No. 6 round bur is used only in molars with large pulp chambers. A No. 1 round bur is also occasionally used in the floor of the pulp chamber to seek additional canal orifices. In addition, sonic and ultrasonic units, with specially designed endodontic tips, allow clinicians to more precisely remove dentin and expose orifices. In conjunction with magnification (loupes, fiber-optic endoscope, or microscope), the operator is better able to visualize the pulp chamber floor.

As soon as the bulk of the overhanging dentin is removed from the roof of the chamber, the slower operating round burs are put aside, and, once again, the high-speed fissure bur is used to finish and slope the side walls in the visible portions of the preparation. Again, the Maillefer Endo-Z carbide fissure bur (Dentsply/Maillefer, Tulsa, Okla.) is recommended. It is safe-ended and will not scar the pulpal floor. Moreover, it is longer bladed (9 mm) for sloping and funneling the access cavity.

Rotary cutting instruments, operating at greatly accelerated speeds, play a most important role in endodontic cavity preparation, especially for the patient with discomfort. At the same time, a good deal of damage may be rendered with these instruments because of the loss of tactile sense in their use. High-speed burs should not be used to penetrate into, or initially enlarge, the pulp chamber unless the operator is skilled in endodontic preparations. In this operation, the clinician depends almost entirely on the “feel” of the bur deep inside the tooth, against the roof and walls of the pulp chamber, to judge the extensions that are necessary. High-speed equipment is operated...
by sight alone and is not generally employed in a blind area where reliance on tactile sensation is necessary.

Pulp Anatomy in Relation to Cavity Preparation
The alliance between endodontic cavity preparation and pulp anatomy is inflexible and inseparable. To master the anatomic concept of cavity preparation, the operator must develop a mental, three-dimensional image of the inside of the tooth, from pulp horn to apical foramen. Unfortunately, radiographs provide only a two-dimensional “blueprint” of pulp anatomy. It is the third dimension that the clinician must visualize, as a supplement to two-dimensional thinking, if one is to clean and shape accurately and fill the total pulp space (Plate 1, A).

Often the number or anatomy of the canals dictates modifications of the cavity preparation. If, for example, a fourth canal is found or suspected in a molar tooth, the preparation outline will have to be expanded to allow for easy, unrestrained access into the extra canal.
On the other hand, it became quite fashionable to grossly expand cavity preparations to accommodate large instruments used in canal preparation or filling. This violates the basic tenets of endodontic cavity preparation—gross modifications made for the sake of the clinician and the method rather than the more modest convenience modifications that may be dictated by the pulp anatomy itself.

**PRINCIPLES OF ENDODONTIC CAVITY PREPARATION**

Any discussion of cavity preparation must ultimately revert to the basic Principles of Cavity Preparation established by G. V. Black. By slightly modifying Black’s principles, a list of principles of endodontic cavity preparation may be established. In laying down his principles, Black dealt completely with cavity preparations limited to the crowns of teeth; however, his principles can be applied to radicular preparations as well. Endodontic preparations deal with both coronal and radicular cohorts—each prepared separately but ultimately flowing together into a single preparation. For convenience of description, Black’s principles are therefore divided into the following:

**Endodontic Coronal Cavity Preparation**

I. Outline Form
II. Convenience Form
III. Removal of the remaining carious dentin (and defective restorations)
IV. Toilet of the cavity

**Endodontic Radicular Cavity Preparation**

I and II. Outline Form and Convenience Form (continued)
IV. Toilet of the cavity (continued)
V. Retention Form
VI. Resistance Form

In the first half of this chapter, endodontic coronal cavity preparation will be discussed; the second half will be devoted to radicular preparation. A similar approach to coronal preparation was suggested by Pucci and Reig in 1944.

**Principle I: Outline Form**

The outline form of the endodontic cavity must be correctly shaped and positioned to establish complete access for instrumentation, from cavity margin to apical foramen. Moreover, external outline form evolves from the internal anatomy of the tooth established by the pulp. Because of this internal-external relationship, endodontic preparations must of necessity be done in a reverse manner, from the inside of the tooth to the outside. That is to say, external outline form is established by mechanically projecting the internal anatomy of the pulp onto the external surface. This may be accomplished only by drilling into the open space of the pulp chamber and then working with the bur from the inside of the tooth to the outside, cutting away the...
dentin of the pulpal roof and walls overhanging the floor of the chamber (Plate 1, B).

This intracoronal preparation is contrasted to the extracoronal preparation of operative dentistry, in which outline form is always related to the external anatomy of the tooth. The tendency to establish endodontic outline form in the conventional operative manner and shape must be resisted (Plate 1, C).

To achieve optimal preparation, three factors of internal anatomy must be considered: (1) the size of the pulp chamber, (2) the shape of the pulp chamber, and (3) the number of individual root canals, their curvature, and their position.

Size of Pulp Chamber. The outline form of endodontic access cavities is materially affected by the size of the pulp chamber. In young patients, these preparations must be more extensive than in older patients, in whom the pulp has receded and the pulp chamber is smaller in all three dimensions (Plate 1, D). This becomes quite apparent in preparing the anterior teeth of youngsters, whose larger root canals require larger instruments and filling materials—materials that, in turn, will not pass through a small orifice in the crown (Plate 1, E).

Shape of Pulp Chamber. The finished outline form should accurately reflect the shape of the pulp chamber. For example, the floor of the pulp chamber in a molar tooth is usually triangular in shape, owing to the triangular position of the orifices of the canals. This triangular shape is extended up the walls of the cavity and out onto the occlusal surface; hence, the final occlusal cavity outline form is generally triangular (Plate 1, C). As another example, the coronal pulp of a maxillary premolar is flat mesiodistally but is elongated buccolingually. The outline form is, therefore, an elongated oval that extends buccolingually rather than mesiodistally, as does Black’s operative cavity preparation (Plate 1, F).

Number, Position, and Curvature of Root Canals. The third factor regulating outline form is the number, position, and curvature or direction of the root canals. To prepare each canal efficiently without interference, the cavity walls often have to be extended to allow an unstrained instrument approach to the apical foramen. When cavity walls are extended to improve instrumentation, the outline form is materially affected (Plate 1, G). This change is for convenience in preparation; hence, convenience form partly regulates the ultimate outline form.

Principle II: Convenience Form

Convenience form was conceived by Black as a modification of the cavity outline form to establish greater convenience in the placement of intracoronal restorations. In endodontic therapy, however, convenience form makes more convenient (and accurate) the preparation and filling of the root canal. Four important benefits are gained through convenience form modifications: (1) unobstructed access to the canal orifice, (2) direct access to the apical foramen, (3) cavity expansion to accommodate filling techniques, and (4) complete authority over the enlarging instrument.

Unobstructed Access to the Canal Orifice. In endodontic cavity preparations of all teeth, enough tooth structure must be removed to allow instruments to be placed easily into the orifice of each canal without interference from overhanging walls. The clinician must be able to see each orifice and easily reach it with the instrument points. Failure to observe this principle not only endangers the successful outcome of the case but also adds materially to the duration of treatment (Plate 2, A to D).

In certain teeth, extra precautions must be taken to search for additional canals. The lower incisors are a case in point. Even more important is the high incidence of a second separate canal in the mesiobuccal root of maxillary molars. A second canal often is found in the distal root of mandibular molars as well. The premolars, both maxillary and mandibular, can also be counted on to have extra canals. During preparation, the operator, mindful of these variations from the norm, searches conscientiously for additional canals. In many cases, the outline form has to be modified to facilitate this search and the ultimate cleaning, shaping, and filling of the extra canals (Figure 10-5).

Luebke has made the important point that an entire wall need not be extended in the event that instrument impingement occurs owing to a severely curved root or an extra canal (personal communication, April 1983) (Plate 1, G). In extending only that portion of the wall needed to free the instrument, a cloverleaf appearance may evolve as the outline form. Hence, Luebke has termed this a “shamrock preparation” (Plate 1, H).

It is most important that as much crown structure be maintained as possible. MOD cavity preparations reduce tooth “stiffness” by more than 60%, and the “loss of marginal ridge integrity was the greatest contribution to loss of tooth strength.”7

Direct Access to the Apical Foramen. To provide direct access to the apical foramen, enough tooth structure must be removed to allow the endodontic instruments freedom within the coronal cavity so they can extend down the canal in an unstrained position. This is especially true when the canal is severely curved or
A. A standard radiograph (left) in buccolingual projection provides only a two-dimensional view of what is actually a three-dimensional problem. If a mesiodistal x-ray projection could be made (right), one would find the pulp of the maxillary second premolar to be flat tapering “ribbon” rather than round “thread” visualized on the initial radiograph. The final ovoid occlusal cavity preparation (F) will mirror the internal anatomy rather than the buccolingual x-ray image.

B. Coronal preparation of a maxillary first molar illustrating the major principle of endodontic cavity outline form: the internal anatomy of the tooth (pulp) dictates the external outline form. This is accomplished by extending preparation from inside of the tooth to the outside surface, that is, working from inside to outside.

C. Endodontic cavity preparation, mandibular first molar, superimposed on inlay, restoring proximal-occlusal surfaces. Black’s outline form of inlay is related to the external anatomy and environment of the tooth, that is, the extent of carious lesions, grooves, and fissures and the position of the approximating premolar. A triangular or rhomboidal outline form of endodontic preparation, on the other hand, is related to the internal anatomy of the pulp. No relationship exists between the two outline forms.

D. Size and shape of endodontic coronal preparations in mandibular incisors related to size and shape of the pulp and chamber. A contrast in outline form between a “young” incisor (left) with a large pulp and an adult incisor (right) is apparent. The large triangular preparation in a youngster reflects pulpal horn extension and size of the pulp chamber, whereas ovoid preparation in an adult relates to a grossly receded pulp. Extension toward the incisal allows central-axis access for instruments.

E. Large size and shape of coronal preparation in a recently calcified incisor relate to huge pulp housing. To remove all pulp remnants and to accommodate large endodontic instruments and filling materials, coronal preparation must be an extensive, triangular, funnel-shaped opening. Actually, no more than the lingual wall of pulp chamber has been removed. In lower incisors, the outline form may well be extended into the incisal edge. This preparation allows absolutely direct access to apex.

F. The outline form of the endodontic coronal cavity in the maxillary first premolar is a narrow, elongated oval in buccolingual projection (bottom), which reflects the size and shape of a broad, flat pulp chamber of this particular tooth.

G. Buccal view of an inadequate coronal preparation in a maxillary molar with a defalcated mesiobuccal root. There has been no compensation in cavity preparation for severe curvature of the mesial canal or for the obtuse direction by which the canal leaves the chamber. The operator can no longer maintain control of the instrument, and a ledge has been produced (arrow). Extension of the outline form and internal preparation to the mesial (dotted line) would have obviated this failure.

H. “Shamrock preparation.” Modified outline form to accommodate the instrument unrestrained in the severely curved mesial canal seen in G.
leaves the chamber at an obtuse angle (Plate 2, E). Infrequently, total decuspatation is necessary.

**Extension to Accommodate Filling Techniques.** It is often necessary to expand the outline form to make certain filling techniques more convenient or practical. If a softened gutta-percha technique is used for filling, wherein rather rigid pluggers are used in a vertical thrust, then the outline form may have to be widely extended to accommodate these heavier instruments.

**Complete Authority over the Enlarging Instrument.** It is imperative that the clinician maintain complete control over the root canal instrument. If the instrument is impinged at the canal orifice by tooth structure that should have been removed, the dentist will have lost control of the direction of the tip of the instrument, and the intervening tooth structure will dictate the control of the instrument (Plate 2, G).

If, on the other hand, the tooth structure is removed around the orifice so that the instrument stands free in this area of the canal (Plate 2, H), the instrument will then be controlled by only two factors: the clinician’s fingers on the handle of the instrument and the walls of the canal at the tip of the instrument. Nothing is to intervene between these two points (Plate 2, F).

Failure to properly modify the access cavity outline by extending the convenience form will ultimately lead to failure by either root perforation, “ledge” or “shelf” formation within the canal, instrument breakage, or the incorrect shape of the completed canal preparation, often termed “zipping” or apical transportation.

**Principle III: Removal of the Remaining Carious Dentin and Defective Restorations**

Caries and defective restorations remaining in an endodontic cavity preparation must be removed for three reasons: (1) to eliminate mechanically as many bacteria as possible from the interior of the tooth, (2) to eliminate the discolored tooth structure, that may ultimately lead to staining of the crown, and (3) to eliminate the possibility of any bacteria-laden saliva leaking into the prepared cavity. The last point is especially true of proximal or buccal caries that extend into the prepared cavity.

After the caries are removed, if a carious perforation of the wall is allowing salivary leakage, the area must be repaired with cement, preferably from inside the cavity. A small piece of premixed temporary cement, Cavit or Cavit G (Premier Dental Products; Plymouth, Pa.), may be forced through the perforation and applied to the

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**Figure 10-5** “Rogues’ Gallery” of aberrant canals, bifurcations, and foramina, all cleaned, shaped, and obturated successfully. (Courtesy of Drs. L. Stephen Buchanan and Clifford J. Ruddle.)
dry walls of the cavity, while care is taken to avoid forcing the cement into a canal orifice. A cotton pellet, moistened with any sterile aqueous solution such as saline or a local anesthetic, will cause the Cavit to set. Coronal perforations may also be repaired with adhesive composite resins placed by the acid-etch technique in a perfectly dry milieu.

If the caries is so extensive that the lateral walls are destroyed, or if a defective restoration is in place that is loose and leaking, then the entire wall or restoration should be removed and later restored. It is important that restoration be postponed until the radicular preparation has been completed. It is much easier to complete the radicular preparation through an open cavity than through a restored crown. As a matter of fact, the more crown that is missing, the easier the radicular preparation becomes. The ultimate in ease of operation is the molar tooth broken off at the gingival level (Figure 10-6). As long as a rubber dam can be placed on the tooth, it need not be built up with amalgam, cement, or an orthodontic band; having to work through a hole only complicates the endodontic procedures. In addition, if the band comes off, the length of tooth measurements is invalidated and must be re-established. An adequate temporary filling can always be placed in the remaining pulp chamber.

If enough tooth does not remain above the gingiva to place a rubber dam clamp and seal against saliva, and if it is imperative that the tooth be retained, a simple gingivoplasty will establish the required “crown” length. In any case, this procedure is usually necessary before the tooth can be restored. In this case, the occlusal cavity may be sealed and the incised gingiva protected with the placement of a putty-like periodontal dressing over the entire stump and gingiva. Cotton, and then a thin layer of Cavit, should first cover the canal orifices.

**Principle IV: Toilet of the Cavity**

All of the caries, debris, and necrotic material must be removed from the chamber before the radicular preparation is begun. If the calcified or metallic debris is left in the chamber and carried into the canal, it may act as an obstruction during canal enlargement. Soft debris carried from the chamber might increase the bacterial population in the canal. Coronal debris may also stain the crown, particularly in anterior teeth.

Round burs, of course, are most helpful in cavity toilet. The long-blade, endodontic spoon excavator is ideal for debris removal (Figure 10-7). Irrigation with sodium hypochlorite is also an excellent measure for cleansing the chamber and canals of persistent debris. The chamber may finally be wiped out with cotton, and a careful flush of air will eliminate the remaining debris. However, air must never be aimed down the canals. Emphysema of the oral tissues has been pro-
A. **Obstructed access** to mesial canals in a mandibular first molar. The overhanging roof of the pulp chamber misdirects the instrument mesially, with resulting ledge formation in the canal. It is virtually impossible to see and difficult to locate mesial canal orifices each time the instrument is introduced.

B. **Internal cavity preparation.** Removing the roof completely from the pulp chamber will bring canal orifices into view and allow immediate access to each orifice. Using a round bur and working from the inside out will accomplish this end.

C. **Final finish of the convenience form** is completed with a fissure bur, diamond point, or non-end-cutting batt bur. The entire cavity slopes toward the mesial direction of approach, which greatly simplifies instrument placement.

D. **Unobstructed access to canal orifices.** The mesial wall has been sloped to mesial for the approach to the mandibular molar is from the mesial. The tip of the instrument follows down the mesial wall at each corner of the triangular preparation and literally “falls” into orifices. After the position of each orifice has been determined, the mouth mirror may be laid aside.

The distal wall of preparation also slopes to the mesial and is easily entered from the mesial approach.

E. **Direct access to apical foramen.** Extensive removal of coronal tooth structure is necessary to allow complete freedom of endodontic instruments in the coronal cavity and direct access to the apical canal. This is especially true when the root is severely curved or leaves the chamber at an obtuse angle.

Walls are generally reduced with burs or long, thin diamond points (see B and C above) and with endodontic files, Gates-Glidden drills, or orifice openers. Burs are rarely used in the floor or immediate orifice area. In the event that a second canal is suspected in the mesiobuccal root of the maxillary molar, the cavity outline would be extended in both of these directions to broaden the search.

Depending on the technique used to fill the canal, the outline form may also be expanded somewhat to accommodate pluggers used in obturation.

F. **The complete authority of the enlarging instrument is maintained** when all intervening tooth structure is removed and the instrument is controlled by the clinician’s fingers on the handle of the instrument and the tip of the instrument is free in the lumen of the canal.

G. **Complete authority of enlarging instrument.** If the lateral wall of the cavity has not been sufficiently extended and the pulpal horn portion of the orifice still remains in the wall, the orifice will have the appearance of a tiny “mouse hole.” This lateral wall will then impinge on enlarging the instrument and will dictate the direction of the instrument tip. The operator will have lost control of the instrument and the situation.

H. **By extending the lateral wall** of the cavity, thus removing all intervening dentin from the orifice, the “mouse hole” in the wall will be eliminated and the orifice will appear **completely in the floor.** Now the enlarging instrument will stand free of the walls, and the **operator will regain control of the instrument** (see F above).
duced by a blast of air escaping out of the apex. In an in vitro study, Eleazer and Eleazer found a direct relation between the size of the apical foramen and the likelihood of expressing air into the periapical tissues. Additional risks are incurred as air from these syringes is not sterile. Some dental schools do not allow the use of the three-way air/water syringe once access into the chamber has been achieved.

As previously stated, toilet of the cavity makes up a significant portion of the radicular preparations.

DETAILED CORONAL CAVITY PREPARATION

Descriptions and Caveats

With the basic principles of endodontic cavity preparation in mind, the student is urged to study the detailed plates that follow, each dealing with coronal preparation. Again, keep in mind the importance of the intracoronal preparation to the ultimate radicular preparation and filling.

For each group of teeth—for example, maxillary anterior teeth, mandibular premolar teeth—there is a plate showing in detail the suggested cavity preparation and operative technique applicable to that particular group of teeth. The technique plate is followed by plates of the individual teeth within the group. Four separate views of each tooth are presented: (1) the facial-lingual view as seen in the radiograph; (2) the mesiodistal view, impossible to obtain radiographically but necessary to the three-dimensional mental image of the pulp anatomy; (3) a cross-sectional view at three levels; and (4) a view of the occlusal or lingual surface with cavity outline form.

Detailed variations in preparation related to each particular tooth, as well as information about tooth length, root curvature, and canal anatomy variations, are presented. These plates are followed by a plate of errors commonly committed in the preparation of this group of teeth.

The mandibular incisors—centrals and laterals—are so anatomically similar that they are confined to one plate.

The reader is reminded that the preparations illustrated here are minimal preparations, that the outline form is a direct reflection of the pulp anatomy. If the pulp is expansive, the outline form will also be expansive. Furthermore, the outline form may have to be greatly enlarged to accept heavier instruments or rigid filling materials.

Generally speaking, the length-of-tooth measurements are approximations. Nonetheless, they are helpful and should alert the dentist to what to expect as “normal.” When there is a lack of agreement between authors, we have chosen the larger figures, that is, the figures furthest from normal. We have also adapted liberally from the important work by Dempster et al. on the angulation of the teeth in the alveolar process.

In addition, new information on multiple canals has been brought to light.

Multiple and Extra Canals

Although it should come as no surprise, the high incidence of additional canals in molars, premolars, and mandibular incisors is significant. Hess, as early as 1925, pointed out that 54% of his 513 maxillary molar specimens had four canals. For years these facts were generally ignored.

At this juncture, however, one cannot help but be struck by the magnitude of the numbers of additional versus traditional canals. For example, maxillary molars may have four canals rather than three canals as much as 95% of the time. Using a No. 1 round bur and/or ultrasonic instruments to remove secondary dentin from the pulpal floor along the mesiobuccal-palatal leg of the molar triangle will uncover an additional 31% of these orifices. An earlier study found these secondary canals 69% of the time in vivo but only 31% in vitro. Another in vivo study found two canals in the mesiobuccal roots of maxillary first molars 77% of the time, and, of these, 62% had two apical foramina. Although a fourth root in maxillary molars is rare (0.4%), single-canal taurodontism (“bull-tooth”) was found in 11.3% of one patient cohort.

The incidence of accessory canals in the furcation of maxillary molars, canals that extend all the way from the pulpal floor to the furcation area, is 48% in one study and 68% in another. These accessory canals are only about twice the size of a dentinal tubule and are rarely mistaken for a canal orifice even though they are large enough to admit bacteria to the pulp from a furcal periodontal lesion.

In mandibular molars, through-and-through furcal accessory canals are found 56% of the time in one study and 48% in another. Mandibular molars also exhibit secondary root canals, over and above the traditional three. Although as many as five canals and as few as one and two canals rarely occur in mandibular molars, four canals are not unusual. Bjornsdal and Skidmore reported this occurrence 29% of the time in a US cohort, a second distal canal being the usual anomaly. The Chinese found four canals in 31.5% of their cases. Weine et al. however, reported that only 12.5% of their second molar specimens had a second distal canal and that only one had two separate apical foramina. Anomalies also occur in the mesial root.
Premolar teeth are also prone to secondary canals. Maxillary first premolars, which generally have two canals, have three canals 5 to 6% of the time.\textsuperscript{14,39} Twenty-four percent of maxillary second premolars have second root canals and occasionally three canals.\textsuperscript{15} In Brazil, two canals were found 32.4% of the time and three canals in 0.3% of the cases.\textsuperscript{40}

Mandibular premolars are notorious for having extra canals—26.5% in first premolars and 13.5% in second premolars.\textsuperscript{21} A US Army group reported canal bifurcations as deep as 6 to 9 mm from the coronal orifice 74% of the time in mandibular first premolars.\textsuperscript{22}

Almost one-third of all mandibular lateral incisors have two canals with two foramina.\textsuperscript{11} A Turkish report lists two newly defined canal configurations, one that ends in three separate foramina.\textsuperscript{12}

Every dentist who has done considerable root canal therapy must ask, “How many of these extra canals have I failed to find in the past?” Also, there appears to be a wide discrepancy between the figures quoted above, which are based on laboratory studies, and those found under clinical conditions. Hartwell and Bellizi found four canals in maxillary first molars only 18% of the time \textit{in vivo} (in comparison to the figure of 85% found \textit{in vitro}, cited above).\textsuperscript{41} In mandibular first molars, the reverse was true: they actually filled a fourth canal 35% of the time, whereas 29% of extracted teeth had a fourth canal.\textsuperscript{41}

How may one account for the wide discrepancy between these figures of incidence of additional canals? Ethnic variance may be one part of the equation. African Americans have more than twice as many two-canal mandibular premolars (32.8% versus 13.7%) than do Caucasian patients: “Four out of ten black patients had at least one lower premolar with two or more canals.”\textsuperscript{42} In a southern Chinese population, however, the roots of mandibular second molars are fused 52% of the time and only have two canals, rather than three, 55% of the time.\textsuperscript{36} The Chinese also have two canal lower incisors 27% of the time, but only 1% terminate in two foramina,\textsuperscript{43} compared to two foramina terminations 30% of the time in a US study.\textsuperscript{11} A Brazilian study reports two canals with two foramina in 1.2% of mandibular canines.\textsuperscript{44}

The incidence of taurodontism varies all over the world. In Saudi Arabia, 43.2% of adult molars studied were taurodents in 11.3% of the patient cohort.\textsuperscript{31} In Brazil, 11 cases of taurodontism in mandibular premolars, a very rare occurrence, were described.\textsuperscript{45} The seminal studies of Pineda and Kuttler were done in Mexico on extracted teeth, many presumably from a native cohort.\textsuperscript{14,18}

In any event, anomalous and multiple canals are a worldwide problem, a fact that makes imperative a careful search in every tooth for additional canals. Just as important, the facts emphasize the necessity of choosing a method of preparation and filling that will ensure the obturations of these additional canals (see Figure 10-5).
Plates 3 to 27

Folio of
CORONAL ENDODONTIC
CAVITY PREPARATIONS

Originally Illustrated by
VIRGINIA E. BROOKS
Modified by
PHYLLIS WOOD
A. Entrance is always gained through the lingual surface of all anterior teeth. Initial penetration is made in the exact center of the lingual surface at the position marked “X.” A common error is to begin the cavity too far gingivally.

B. Initial entrance is prepared with a round-point tapering fissure bur in an accelerated-speed contra-angle handpiece with air coolant, operated at a right angle to the long axis of the tooth. Only enamel is penetrated at this time. Do not force the bur; allow it to cut its own way.

C. Convenience extension toward the incisal continues the initial penetrating cavity preparation. Maintain the point of the bur in the central cavity and rotate the handpiece toward the incisal so that the bur parallels the long axis of the tooth. Enamel and dentin are beveled toward the incisal. Entrance into the pulp chamber should not be made with an accelerated-speed instrument. Lack of tactile sensation with these instruments precludes their use inside the tooth.

D. The preliminary cavity outline is funneled and fanned incisally with a fissure bur. Enamel has a short bevel toward the incisal, and a “nest” is prepared in the dentin to receive the round bur to be used for penetration.

E. A surgical-length No. 2 or 4 round bur in a slow-speed contra-angle handpiece is used to penetrate the pulp chamber. If the pulp has greatly receded, a No. 2 round bur is used for initial penetration. Take advantage of convenience extension toward the incisal to allow for the shaft of the penetrating bur, operated nearly parallel to the long axis of the tooth.

F. Working from inside the chamber to outside, a round bur is used to remove the lingual and labial walls of the pulp chamber. The resulting cavity is smooth, continuous, and flowing from cavity margin to canal orifice.

G. After the outline form is completed, the surgical-length bur is carefully passed into the canal. Working from inside to outside, the lingual “shoulder” is removed to give continuous, smooth-flowing preparation. Often a long, tapering diamond point will better remove the lingual “shoulder.”

H. Occasionally, a No. 1 or 2 round bur must be used laterally and incisally to eliminate pulpal horn debris and bacteria. This also prevents future discoloration.

I. Final preparation relates to the internal anatomy of the chamber and canal. In a “young” tooth with a large pulp, the outline form reflects a large triangular internal anatomy—an extensive cavity that allows thorough cleansing of the chamber as well as passage of large instruments and filling materials needed to prepare and fill a large canal. Cavity extension toward the incisal allows greater access to the midline of the canal.

J. Cavity preparations in “adult” teeth, with the chamber obturated with secondary dentin, are ovoid in shape. Preparation funnels down to the orifice of the canal. The further the pulp has receded, the more difficult it is to reach to this depth with a round bur. Therefore, when the radiograph reveals advanced pulpal recession, convenience extension must be advanced further incisally to allow the bur shaft and instruments to operate in the central axis.

K. Final preparation with the reamer in place. The instrument shaft clears the incisal cavity margin and reduced lingual “shoulder,” allowing an unrestrained approach to the apical third of the canal. The instrument remains under the complete control of the clinician. An optimal, round, tapered cavity may be prepared in the apical third, tailored to the requirements of round, tapered filling materials to follow. The remaining ovoid part of the canal is cleaned and shaped by circumferential filing or Gates-Glidden drills.
A. **Lingual** view of a recently calcified incisor with a large pulp. A radiograph will reveal
1. extent of the pulp horns
2. mesiodistal width of the pulp
3. apical-distal curvature (8% of the time)
4. 2-degree mesial-axial inclination of the tooth
These factors seen in the radiograph are borne in mind when preparation is begun.

B. **Distal** view of the same tooth demonstrating details **not apparent in the radiograph:**
1. presence of a lingual “shoulder” at the point where the chamber and canal join
2. broad labiolingual extent of the pulp
3. 29-degree lingual-axial angulation of the tooth

The operator must recognize that
a. the lingual “shoulder” must be removed with a tapered diamond point to allow better access to the canal.
b. these “unseen” factors affect the size, shape, and inclination of final preparation.

C. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. **Cervical** level: the pulp is enormous in a young tooth, wider in the mesiodistal dimension. Débridement in this area is accomplished by **extensive perimeter filing.**
2. **Midroot** level: the canal continues ovoid and requires perimeter filing and multiple point filling.
3. **Apical third** level: the canal, generally round in shape, is enlarged by reshaping the cavity into a **round tapered** preparation. Preparation terminates at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex. An unusually large apical third canal is more ovoid in shape, must be prepared with **perimeter filing** rather than reaming, and must be obturated with multiple points or warm gutta-percha.

D. Large, triangular, funnel-shaped **coronal preparation** is necessary to adequately débride the chamber of all pulp remnants. (The pulp is “ghosted” in the background.) Note the beveled extension toward the incisal that will carry the preparation labially and thus nearer the central axis. Incisal extension allows better access for large instruments and filling materials used in the apical third canal.

E. **Lingual** view of an **adult** incisor with extensive secondary dentin formation.
A radiograph will reveal
1. full pulpal recession
2. apparently straight canal
3. 2-degree mesial-axial inclination of the tooth

The operator must recognize that
a. a small canal orifice is difficult to find.
b. **apical-labial curvature, not usually seen radiographically,** can be determined by exploration with a fine curved file and mesially oriented radiographs.
c. axial inclination of the root calls for careful orientation and alignment of the bur to prevent “gouging.”

G. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. **Cervical** level: the canal, only slightly ovoid, becomes progressively more round.
2. **Midroot** level: the canal varies from slightly ovoid to round.
3. **Apical third** level: the canal is generally round in the older patient.

H. Ovoid, funnel-shaped coronal preparation provides adequate access to the root canal. The pulp chamber, obturated by secondary dentin, need not be extended for coronal débridement. “Adult” cavity preparation is narrow in the mesiodistal width but is almost as extensive in the incisogingival direction as preparation in a young tooth. This beveled incisal extension carries preparation nearer the central axis, allowing better access to the curved apical third.
### Maxillary Central Incisors

<table>
<thead>
<tr>
<th>Length of tooth</th>
<th>Canal</th>
<th>Lateral canals</th>
<th>Apical ramifications</th>
<th>Root curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Length 23.3 mm</td>
<td>One canal 23%</td>
<td>13%</td>
<td></td>
<td>Straight 75%</td>
</tr>
<tr>
<td>Maximum Length 25.6 mm</td>
<td></td>
<td></td>
<td></td>
<td>Distal Curve 8%</td>
</tr>
<tr>
<td>Minimum Length 21.0 mm</td>
<td></td>
<td></td>
<td></td>
<td>Mesial Curve 4%</td>
</tr>
<tr>
<td>Range 4.6 mm</td>
<td></td>
<td></td>
<td></td>
<td>*Labial Curve 9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*Lingual Curve 4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*Not apparent in radiograph</td>
</tr>
</tbody>
</table>

![Illustrations of Maxillary Central Incisors](image-url)
A. Lingual view of a recently calcified incisor with a large pulp. A radiograph will reveal
1. extent of the pulp horns
2. mesiodistal width of the pulp
3. apical-distal curvature (53% of the time)
4. 16-degree mesial-axial inclination of the tooth
Factors seen in the radiograph are borne in mind when preparation is begun.

B. Distal view of the same tooth demonstrating details not apparent in the radiograph:
1. presence of a lingual “shoulder” at the point where the chamber and canal join
2. broad labiolingual extent of the pulp
3. 29-degree lingual-axial angulation of tooth
The operator must recognize that
a. the lingual “shoulder” must be removed with a tapered diamond point to allow better access to the canal.
b. these “unseen” factors will affect the size, shape, and inclination of final preparation.

C. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. Cervical level: the pulp is large in a young tooth and wider in the labiolingual dimension. Débridement in this area is accomplished by extensive perimeter filing.
2. Midroot level: the canal continues ovoid and requires additional filing to straighten the gradual curve. Multiple point filling is necessary.
3. Apical third level: the canal, generally round and gradually curved, is enlarged by filing to a straightened trajectory. Preparation is completed by shaping the cavity into a round, tapered preparation. Preparation terminates at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex.

D. Large, triangular, funnel-shaped coronal preparation is necessary to adequately débride the chamber of all pulpal remnants. (The pulp is “ghosted” in the background.) Note the beveled extension toward the incisal, which will carry the preparation labially and thus nearer the central axis. Incisal extension allows better access to the apical third of the canal.

E. Lingual view of an adult incisor with extensive secondary dentin formation.
A radiograph will reveal
1. full pulp recession
2. severe apical curve to the distal
3. 16-degree mesial-axial inclination of the tooth

F. Distal view of the same tooth demonstrating details not apparent in the radiograph:
1. narrow labiolingual width of the pulp
2. reduced size of the lingual shoulder
3. apical-lingual curvature (4% of the time)
4. 29-degree lingual-axial angulation of the tooth
The operator must recognize that
a. a small canal orifice is difficult to find.
b. apical-lingual curvature, not usually seen radiographically, can be determined by exploration with a fine curved file and mesially oriented radiographs.
c. axial inclination of the root calls for careful orientation and alignment of the bur to prevent labial “gouging.” A “corkscrew” curve, to the distal and lingual, complicates preparation of the apical third of the canal.

G. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. Cervical level: the canal is only slightly ovoid and becomes progressively rounder.
2. Midroot level: the canal varies from slightly ovoid to round.
3. Apical third level: the canal is generally round in the older patient.
A curved canal is enlarged by alternate reaming and filing. Ovoid preparation will require multiple point filling.

H. Ovoid, funnel-shaped coronal preparation should be only slightly skewed toward the mesial to prevent better access to the apical-distal. It is not necessary to extend preparation for coronal débridement, but an extensive bevel is necessary toward the incisal to carry preparation nearer the central axis, allowing better access to the apical third.
PLATE 5

Maxillary Lateral Incisors

<table>
<thead>
<tr>
<th>Length of tooth</th>
<th>Canal</th>
<th>Lateral canals</th>
<th>Apical ramifications</th>
<th>Root curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Length</td>
<td>22.8 mm</td>
<td>One canal</td>
<td>10%</td>
<td>Straight 30%</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>25.1 mm</td>
<td></td>
<td>99.9%</td>
<td>Distal Curve 53%</td>
</tr>
<tr>
<td>Minimum Length</td>
<td>20.5 mm</td>
<td></td>
<td></td>
<td>Mesial Curve 3%</td>
</tr>
<tr>
<td>Range</td>
<td>4.6 mm</td>
<td></td>
<td></td>
<td>*Labial Curve 4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*Bayonet and 6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gradual Curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*Not apparent in radiograph</td>
</tr>
</tbody>
</table>
A. **Lingual** view of a recently calcified canine with a large pulp. A radiograph will reveal
1. coronal extent of the pulp
2. narrow mesiodistal width of the pulp
3. apical-distal curvature (32% of the time)
4. 6-degree distal-axial inclination of the tooth

These factors, *seen* in the radiograph, are borne in mind when preparation is begun, particularly the severe apical curve.

B. **Distal** view of the same tooth demonstrating details *not apparent in the radiograph*:
1. huge ovoid pulp, larger labiolingually than the radiograph would indicate
2. presence of a *labial* “shoulder” just below the cervical
3. narrow canal in the apical third of the root
4. 21-degree lingual-axial angulation of the tooth

These “unseen” factors will affect the *size, shape, and inclination* of the final preparation.

C. Cross-section is at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. **Cervical** level: the pulp is enormous in a young tooth, much wider in the labiolingual direction. Débride ment in this area is accomplished with a long, tapered diamond point and extensive perimeter filing.
2. **Midroot** level: the canal continues ovoid in shape and requires perimeter filing and multiple point filling.
3. **Apical third** level: the straight canal (39% of time), generally round in shape, is prepared by shaping the cavity into *round tapered* preparation. Preparation should terminate at the cementodental junction, 0.5 to 1.0 mm from the radiographic apex. If unusually large or curved, the apical canal requires perimeter filing and multiple point or warm gutta-percha filling.

D. Extensive, *ovoid*, funnel-shaped *coronal preparation* is necessary to adequately débride the chamber of all pulpal remnants. *(The pulp is “ghosted” in the background.)* Note the long, beveled extension toward the incisal, which will carry the preparation labially and thus nearer the central axis. Incisal extension allows better access for large instruments and filling materials used in the apical third of the canal.

E. **Lingual** view of an *adult* canine with extensive secondary dentin formation. A radiograph will reveal
1. full pulp recession
2. straight canal (39% of the time)
3. 6-degree distal-axial inclination of the tooth

F. **Distal** view of the same tooth demonstrating details *not apparent in the radiograph*:
1. narrow labiolingual width of the pulp
2. apical *labial* curvature (13% of the time)
3. 21-degree lingual-axial angulation of the tooth

The operator should recognize that
a. a small canal orifice is difficult to find.
b. apical *labial* curvature, not seen radiographically, can be determined only by exploration with a fine curved file and mesially oriented radiographs.
c. distal-lingual axial inclination of the root calls for careful orientation and alignment of the bur to prevent “gouging.”
d. **apical foramen** toward the labial is a problem.

G. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. **Cervical** level: the canal is slightly ovoid.
2. **Midroot** level: the canal is smaller but remains ovoid.
3. **Apical third** level: the canal becomes progressively rounder.

H. Extensive, ovoid, funnel-shaped preparation must be *nearly as large* as for a young tooth. A beveled incisal extension carries preparation nearer the central axis, allowing better access to the curved apical third. Discovery by exploration of an *apical-labial* curve calls for even greater incisal extension.
### Maxillary Canines

<table>
<thead>
<tr>
<th>Length of tooth</th>
<th>Canal</th>
<th>Lateral canals</th>
<th>Apical ramifications</th>
<th>Root curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Length</td>
<td>One canal</td>
<td>24%</td>
<td>8%</td>
<td>Straight</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>100%</td>
<td></td>
<td></td>
<td>Distal Curve</td>
</tr>
<tr>
<td>Minimum Length</td>
<td>24%</td>
<td></td>
<td></td>
<td>Mesial Curve</td>
</tr>
<tr>
<td>Range</td>
<td>5.8 mm</td>
<td></td>
<td></td>
<td>*Labial Curve</td>
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<td></td>
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<td></td>
<td>*Lingual Curve</td>
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<td>Bayonet and</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gradual Curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*Not apparent in radiograph</td>
</tr>
</tbody>
</table>

Average Length: 26.0 mm
Maximum Length: 28.9 mm
Minimum Length: 23.1 mm
Range: 5.8 mm
PLATE 7

Maxillary Anterior Teeth

ERRORS in Cavity Preparation

A. PERFORATION at the labiocervical caused by failure to complete convenience extension toward the incisal, prior to the entrance of the shaft of the bur.

B. GOUGING of the labial wall caused by failure to recognize the 29-degree lingual-axial angulation of the tooth.

C. GOUGING of the distal wall caused by failure to recognize the 16-degree mesial-axial inclination of the tooth.

D. PEAR-SHAPED PREPARATION of the apical canal caused by failure to complete convenience extensions. The shaft of the instrument rides on the cavity margin and lingual “shoulder.” Inadequate débridement and obturation ensure failure.

E. DISCOLORATION of the crown caused by failure to remove pulp debris. The access cavity is too far to the gingival with no incisal extension.

F. LEDGE formation at the apical-distal curve caused by using an uncurved instrument too large for the canal. The cavity is adequate.

G. PERFORATION at the apical-distal curve caused by using too large an instrument through an inadequate preparation placed too far gingivally.

H. LEDGE formation at the apical-labial curve caused by failure to complete the convenience extension. The shaft of the instrument rides on the cavity margin and “shoulder.”
A. Entrance is always gained through the lingual sur-
face of all anterior teeth. Initial penetration is made
in the exact center of the lingual surface at the posi-
tion marked “X.” A common error is to begin too
far gingivally.

B. The initial entrance cavity is prepared with a 701 U
tapering fissure bur in an accelerated-speed con-
tra-angle handpiece with air coolant, operated at a
right angle to the long axis of the tooth. Only
enamel is penetrated at this time. Do not force the
bur; allow it to cut its own way.

C. Convenience extension toward the incisal continues
initial penetrating cavity. Maintain the point of the
bur in the central cavity and rotate the handpiece
toward the incisal so that the bur parallels the long
axis of the tooth. Enamel and dentin are beveled
toward the incisal. Entrance into the pulp chamber
should not be made with an accelerated-speed
instrument. Lack of tactile sensation with these
instruments precludes their use inside the tooth.

D. The preliminary cavity outline is funneled and
fanned incisally with a fissure bur. The enamel has
a short bevel toward the incisal, and a “nest” is pre-
pared in the dentin to receive the round bur to be
used for penetration.

E. A surgical-length No. 2 round bur in a slow-speed
contra-angle handpiece is used to penetrate into the
pulp chamber. If the pulp has greatly receded, the
No. 2 round bur is used for initial penetration. Take
advantage of convenience extension toward the incisal to allow for the shaft of the penetrating bur,
operated nearly parallel to the long axis of the tooth.

F. Working from inside the chamber to the outside, a
round bur is used to remove the lingual and labial
walls of the pulp chamber. The resulting cavity is
smooth, continuous, and flowing from cavity mar-
gin to canal orifice.

G. After the outline form is completed, a surgical-length
bur is carefully passed down into the canal. Working
from inside to outside, the lingual “shoulder” is
removed with a long, fine, tapered diamond point to
give a continuous, smooth-flowing preparation.

H. Occasionally, a No. 1 round bur must be used lat-
erally and incisally in the cavity to eliminate pulpal
horn debris and bacteria. This also prevents future
discoloration.

I. Final preparation related to the internal anatomy
of the chamber and canal. In a “young” tooth with
a large pulp, the outline form reflects triangular
internal anatomy—an extensive cavity that allows
thorough cleansing of the chamber as well as pas-
sage of large instruments and filling materials
needed to prepare and fill the large canal. Note
extension toward the incisal to allow better access
to the central axis.

J. Cavity preparations in an “adult” tooth with the
chamber obliterated with secondary dentin are
ovoid. Preparation funnels down to the orifice of
the canal. The further the pulp has receded, the
more difficult it is to reach to this depth with a
round bur. Therefore, when a radiograph reveals
advanced pulpal recession, convenience exten-
sion must be advanced further incisally to allow
the bur shaft to operate in the central axis. The
incisal edge may even be invaded and later
restored by composites.

K. Final preparation showing the reamer in place.
The instrument shaft clears the incisal cavity
margin and reduced lingual shoulder, allowing an
unrestrained approach to the apical third of the
canal. The instruments remain under the com-
plete control of the clinician. Great care must be
taken to explore for additional canals, particu-
larly to the lingual of the pulp chamber. An optimal
round, tapered cavity may be prepared in the api-
cal third, tailored to requirements of round,
tapered filling materials to follow. The remaining
ovoid part of the canal is cleaned and shaped by
extensive filing.
A. **Lingual** view of a recently calcified incisor with a large pulp. A radiograph will reveal:
   1. extent of the pulp horns
   2. mesiodistal width of the pulp
   3. slight apical-distal curvature of the canal (23% of the time)
   4. mesial-axial inclination of the tooth (central incisor 2 degrees, lateral incisor 17 degrees).
   These factors, seen in the radiograph, are borne in mind when preparation is begun.

B. **Distal** view of the same tooth demonstrating details not apparent in the radiograph:
   1. presence of a lingual "shoulder" at the point where the chamber and canal join
   2. broad labiolingual extent of the pulp
   3. 20-degree lingual-axial angulation of the tooth

The operator must recognize that
   a. the lingual "shoulder" must be removed with a fine, tapered diamond point to allow better access to the canal.
   b. these "unseen" factors affect the size, shape, and inclination of the final preparation.

C. Cross-sections at three levels: 1, cervical; 2, mid-root; 3, apical third:
   1. **Cervical** level: the pulp is enormous in a young tooth, wider in the labiolingual dimension. Débridement in this area is accomplished by extensive perimeter filing.
   2. **Midroot** level: the canal continues ovoid and requires perimeter filing and multiple point filling.
   3. **Apical third** level: the canal, generally round in shape, is enlarged by shaping the cavity into a round, tapered preparation. Preparation terminates at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex.

D. Large, triangular, funnel-shaped coronal preparation is necessary to adequately debride the chamber of all pulp remnants. (The pulp is “ghosted” in the background.) Note the beveled extension toward the incisal, which will carry the preparation labially and thus nearer the central axis. Incisal extension allows better access for instruments and filling materials used in the apical third of the canal.

E. **Lingual** view of an adult incisor with extensive secondary dentin formation.
A radiograph will reveal:
   1. full pulp recession
   2. an apparently straight canal
   3. mesial-axial inclination of the tooth (central incisor 2 degrees, lateral incisor 17 degrees).

F. **Distal** view of the same tooth demonstrating details not apparent in the radiograph:
   1. labiolingual width of the pulp
   2. reduced size of the lingual shoulder
   3. unsuspected presence of bifurcation of pulp into the labial and lingual canals nearly 30% of the time
   4. 20-degree lingual-axial angulation of the tooth

The operator must recognize that
   a. smaller canal orifices are more difficult to find.
   b. labial and lingual canals are discovered by exploration with a fine curved file to both labial and lingual.
   c. axial inclination of the root calls for careful orientation and alignment of the bur to prevent “gouging.”

G. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
   1. **Cervical** level: the canal is only slightly ovoid.
   2. **Midroot** level: the two canals are essentially round.
   3. **Apical third** level: the canals are round and curve toward the labial.

*It is important that all mandibular anterior teeth be explored to both labial and lingual for the possibility of two canals.*

H. Ovoid, funnel-shaped coronal preparation provides adequate access to the root canal. An “adult” cavity is narrow in the mesiodistal width but is as extensive in the incisogingival direction as preparation in a young tooth. This beveled incisal extension carries preparation nearer to the central axis. The incisal edge may even be invaded. This will allow better access to both canals and the curved apical third. Ideal lingual extension and better access will often lead to discovery of the second canal.
### Mandibular Central and Lateral Incisors

<table>
<thead>
<tr>
<th>Length of tooth</th>
<th>Central Incisors</th>
<th>Lateral Incisors</th>
<th>Canals</th>
<th>Central Incisors</th>
<th>Lateral Incisors</th>
<th>Root curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Length</td>
<td>21.5 mm</td>
<td>22.4 mm</td>
<td>One canal</td>
<td>70.1%</td>
<td>56.9%</td>
<td>Straight 60%</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>23.4 mm</td>
<td>24.6 mm</td>
<td>Two canals</td>
<td>23.4%</td>
<td>14.7%</td>
<td>Distal Curve 23%</td>
</tr>
<tr>
<td>Minimum Length</td>
<td>19.6 mm</td>
<td>20.2 mm</td>
<td>Two canals</td>
<td>6.5%</td>
<td>29.4%</td>
<td>Mesial Curve 0%</td>
</tr>
<tr>
<td>Range</td>
<td>3.8 mm</td>
<td>4.4 mm</td>
<td>Lateral canals</td>
<td>5.2%</td>
<td>13.9%</td>
<td>*Labial Curve 13%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*Lingual Curve 0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*Not apparent in radiograph</td>
</tr>
</tbody>
</table>

![Images of dental structures](Image)
A. **Lingual** view of a recently calcified canine with a large pulp. A radiograph will reveal
1. coronal extent of the pulp
2. narrow mesiodistal width of the pulp
3. apical-distal curvature (20% of the time)
4. 13-degree mesial-axial inclination of tooth
These factors, *seen* in the radiograph, are borne in mind when preparation is begun.

B. **Distal** view of the same tooth demonstrating details **not apparent in the radiograph**:
1. broad labiolingual extent of the pulp
2. narrow canal in the apical third of the root
3. apical-labial curvature (7% of time)
4. 15-degree lingual-axial angulation of the tooth
These “unseen factors” affect the **size, shape, and inclination** of the final preparation.

C. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. **Cervical** level: the pulp is enormous in a young tooth, wider in the labiobuccal direction. Débridement in this area is accomplished with **extensive perimeter filing**.
2. Midroot level: the canal continues ovoid and requires perimeter filing and multiple gutta-percha point filling.
3. **Apical third** level: the canal, generally round, is enlarged by filing to reduce the curve to a relatively straight canal. This canal is then completed by shaping action into **round, tapered** preparation. Preparation terminates at the cemento-dentinal junction, 0.5 to 1.0 mm from the radiograph apex. If unusually large or ovoid, the apical canal requires perimeter filing.

D. Extensive ovoid, funnel-shaped **coronal preparation** is necessary to adequately débride the chamber of all pulp remnants. (The pulp is “ghosted” in the background.) Note the beveled extension toward the incisal, which will carry the preparation labially and thus nearer the central axis. Incisal extension allows better access for large instruments and filling materials used in the apical third canal.

E. **Lingual** view of an **adult** canine with extensive secondary dentin formation. A radiograph will reveal
1. full pulp recession
2. slight distal curve of the canal (20% of the time)
3. 13-degree mesial-axial inclination of the tooth

F. Distal view of the same tooth demonstrating details **not apparent in the radiograph**:
1. labiobuccal width of the pulp
2. 15-degree lingual-axial angulation of the tooth
The operator must recognize that
a. a small canal orifice, positioned well to the **labial**, is difficult to find.
b. lingual-axial angulation calls for careful orientation of the bur to prevent “gouging.”
c. apical-labial curvature (7% of the time).

G. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. **Cervical** level: the canal is slightly ovoid.
2. **Mid-root** level: the canal is smaller but remains ovoid.
3. **Apical third** level: the canal becomes progressively rounder.
The canal is enlarged by filing and is filled.

H. Extensive ovoid, funnel-shaped preparations must be as large as preparation for a young tooth. The cavity should be extended incisogingivally for room to find the orifice and enlarge the apical third without interference. An apical-labial curve would call for increased extension incisally.
## PLATE 10

**Mandibular Canines**

<table>
<thead>
<tr>
<th>Length of tooth</th>
<th>Canals</th>
<th>Lateral canals</th>
<th>Root curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Length</td>
<td>25.2 mm</td>
<td>One canal</td>
<td>94%</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>27.5 mm</td>
<td>Two canals</td>
<td>9.5%</td>
</tr>
<tr>
<td>Minimum Length</td>
<td>22.9 mm</td>
<td>Two foramina</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>4.6 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Canals**
  - One canal: 94%
  - Two canals: 6%
  - Two foramina: 6%

- **Root curvature**
  - Straight: 68%
  - Distal Curve: 20%
  - Mesial Curve: 1%
  - *Labial Curve: 7%
  - *Lingual Curve: 0%
  - Bayonet Curve: 2%

*Not apparent in radiograph*
A. GOUISING at the labiocervical caused by failure to complete convenience extension toward the incisal prior to entrance of the shaft of the bur.

B. GOUISING of the labial wall caused by failure to recognize the 20-degree lingual-axial angulation of the tooth.

C. GOUISING of the distal wall caused by failure to recognize the 17-degree mesial-axial angulation of the tooth.

D. FAILURE to explore, débride, or fill the second canal caused by inadequate incisogingival extension of the access cavity.

E. DISCOLORATION of the crown caused by failure to remove pulp debris. The access cavity is too far to the gingival with no incisal extension.

F. LEDGE formation caused by complete loss of control of the instrument passing through the access cavity prepared in proximal restoration.
A. Entrance is always gained through the occlusal surface of all posterior teeth. Initial penetration is made parallel to the long axis of the tooth in the exact center of the central groove of the maxillary premolars. The 701 U tapering fissure bur in an accelerated-speed contra-angle handpiece is ideal for penetrating gold casting or virgin enamel surface to the depth of the dentin. Amalgam fillings are opened with a No. 4 round bur in a slow-speed contra-angle handpiece.

B. A regular-length No. 2 or 4 round bur is used to open into the pulp chamber. The bur will be felt to “drop” when the pulp chamber is reached. If the chamber is well calcified and the “drop” is not felt, vertical penetration is made until the contra-angle handpiece rests against the occlusal surface. This depth is approximately 9 mm, the position of the floor of the pulp chamber that lies at the cervical level. In removing the bur, the orifice is widened buccolingually to twice the width of the bur to allow room for exploration for canal orifices. If a surgical-length bur is used, care must be exercised not to perforate the furca.

C. An endodontic explorer is used to locate orifices to the buccal and lingual canals in the first premolar or the central canal in the second premolar. Tension of the explorer shaft against the walls of preparation will indicate the amount and direction of extension necessary.

D. Working from inside the pulp chamber to outside, a round bur is used at low speed to extend the cavity buccolingually by removing the roof of the pulp chamber.

E. Buccolingual extension and finish of cavity walls are completed with a 701 U fissure bur at accelerated speed.

F. Final preparation should provide unobstructed access to canal orifices. Cavity walls should not impede complete authority over enlarging instruments.

G. Outline form of final preparation will be identical for both newly erupted and “adult” teeth. Buccolingual ovoid preparation reflects the anatomy of the pulp chamber and the position of the buccal and lingual canal orifices. The cavity must be extensive enough to allow for instruments and filling materials needed to enlarge and fill canals. Further exploration at this time is imperative. It may reveal the orifice to an additional canal, a second canal in the second premolar, or a third canal in the first premolar.
PLATE 13
Maxillary First Premolar
Pulp Anatomy and Coronal Preparation

A. Buccal view of a recently calcified first premolar with a large pulp.
   A radiograph, if exposed slightly from the mesial, will reveal
   1. mesiodistal width of the pulp
   2. presence of two pulp canals
   3. apparently straight canals
   4. 10-degree distal-axial inclination of the tooth
   These factors, seen in the radiograph, are borne in mind when preparation is begun. One should always expect two and occasionally three canals.

B. Mesial view of the same tooth demonstrating details not apparent in the radiograph:
   1. height of the pulp horns
   2. broad buccolingual dimension of the pulp
   3. two widespread and separate roots, each with a single straight canal
   4. 6-degree buccal-axial angulation of the tooth
   These “unseen” factors will affect the size and shape of the final preparation. Pulp horns in the roof of the pulp chamber are not to be confused with true canal orifices in the cavity floor. Verticality of the tooth simplifies orientation and bur alignment.

C. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
   1. Cervical level: the pulp is enormous in a young tooth, very wide in the buccolingual direction. Débridement of the chamber is completed in coronal cavity preparation with a round bur. Canal orifices are found well to the buccal and lingual.
   2. Midroot level: the canals are only lightly ovoid and may be enlarged to a round, tapered cavity.
   3. Apical third level: the canals are round and are shaped into round, tapered preparations. Preparations terminate at the cementodental junction, 0.5 to 1.0 mm from the radiographic apex.

D. Ovoid coronal preparation need not be as long buccolingually as the pulp chamber. However, the outline form must be large enough to provide two filling points at same time. Buccal and lingual walls smoothly flow to orifices.

E. Buccal view of an adult first premolar with extensive secondary dentin formation. A radiograph will reveal
   1. full pulp recession and thread-like appearance of the pulp
   2. radiographic appearance of only one canal
   3. 10-degree distal-axial inclination of the tooth
   Owing to misalignment of the bur, perforation of the mesiocervical, at the point of mesial indenta-
   tion, may occur.

F. Mesial view of the same tooth demonstrating details not apparent in the radiograph:
   1. pulp recession and a greatly flattened pulp chamber
   2. buccolingual width revealing the pulp to be “ribbon shaped” rather than “thread-like”
   3. single root with parallel canals and a single apical foramen
   4. 6-degree buccal-axial angulation of the tooth
   The operator must recognize that
   a. small canal orifices are found well to the buccal and lingual and are difficult to locate.
   b. the direction of each canal is determined only by exploration with a fine curved instrument.
   c. a single apical foramen cannot be determined; therefore, two canals must be managed as two separate canals.
   d. virtually always there will be two and occasionally three canals.

G. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
   1. Cervical level: the chamber is very narrow ovoid, and canal orifices are at the buccal and lingual termination of the floor.
   2. Midroot level: the canals are round.
   3. Apical third level: the canals are round.

H. Ovoid coronal preparation must be more extensive in the buccolingual direction because of parallel canals. More extensive preparation allows instrumentation without interference.
### Maxillary First Premolars

<table>
<thead>
<tr>
<th>Length of Tooth</th>
<th>Canals</th>
<th>Direction</th>
<th>Single Root</th>
<th>Buccal</th>
<th>Palatal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Length</strong> 21.8 mm</td>
<td>One canal</td>
<td>Straight</td>
<td>9%</td>
<td>38%</td>
<td>28%</td>
</tr>
<tr>
<td><strong>Maximum Length</strong> 23.8 mm</td>
<td>One foramen</td>
<td>Distal Curve</td>
<td>37%</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td><strong>Minimum Length</strong> 18.8 mm</td>
<td>Two canals</td>
<td>Mesial Curve</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Range</strong> 5 mm</td>
<td>One foramen</td>
<td>*Buccal Curve</td>
<td>15%</td>
<td>14%</td>
<td>28%</td>
</tr>
<tr>
<td></td>
<td>Two canals</td>
<td>*Lingual Curve</td>
<td>3%</td>
<td>36%</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>Two foramina</td>
<td>Bayonet Curve</td>
<td>0%</td>
<td>8%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Three canals</td>
<td></td>
<td>6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Three foramina</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Not apparent in radiograph*
A. **Buccal** view of a recently calcified second premolar with a large pulp. A radiograph will reveal
1. narrow mesiodistal width of the pulp
2. apical-distal curvature (34% of the time)
3. 19-degree distal-axial inclination of the tooth
These factors, seen in the radiograph, are borne in mind when preparation is begun.

B. **Mesial** view of the same tooth demonstrating details not apparent in the radiograph:
1. broad buccolingual width revealing the pulp to be “ribbon shaped”
2. single root with a large single canal
3. 9-degree lingual-axial angulation of the tooth
The pulp is shown to be a broad “ribbon” rather than a “thread” as it appears from radiograph. These “unseen” factors affect the size, shape, and inclination of the final preparation.

C. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. **Cervical** level: the pulp is enormous in a young tooth, very wide in the buccolingual direction. Débridement of the chamber is completed during coronal cavity preparation with a round bur. The canal orifice is directly in the center of the tooth.
2. **Midroot** level: the canal remains ovoid in shape and requires perimeter filing.
3. **Apical third** level: the canal, round in shape, is filed and then shaped into a round, tapered preparation. Preparation terminates at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex.

D. Ovoid preparation allows débridement of the entire pulp chamber and funnels down to the ovoid midcanal.

E. **Buccal** view of an adult second premolar with extensive secondary dentin formation. A radiograph, if exposed slightly from the mesial, will reveal
1. pulp recession and the “thread-like” appearance of the pulp
2. roentgen appearance of two roots (2% of the time)
3. bayonet curve of the roots (20% of the time)
4. 19-degree distal-axial inclination of the tooth

F. **Mesial** view of the same tooth demonstrating details not apparent in the radiograph:
1. buccolingual width revealing the coronal pulp to be “ribbon shaped” rather than “thread-like”
2. high bifurcation and two separate apical third roots
3. 9-degree lingual-axial angulation of the tooth
The operator must recognize that
a. small canal orifices are deeply placed in the root and will be difficult to locate.
b. the direction of each canal is determined by exploration with a fine curved file carried down the wall until the orifice is engaged. Then, by half-rotation, the file is turned to match the first curve of the canal, followed by penetration until the tip again catches on the curved wall. A second half-turn and further penetration will carry the tip of the instrument to within 0.5 to 1.0 mm of the radiographic apex. Retraction will remove dentin at both curves.

G. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. **Cervical** level: the chamber, very narrow ovoid, extends deeply into the root.
2. **Midroot** level: the bayonet curve and round canal orifices are apparent.
3. **Apical third** level: the canals are round. The severe curve at the “bayonet” is reduced by filing action into a gradual curve.

H. An ovoid coronal cavity is prepared well to the mesial of the occlusal surface, with a depth of penetration skewed toward the bayonet curvature. **Skewing the cavity** allows an unrestrained approach to the first curve.
Maxillary Second Premolars

<table>
<thead>
<tr>
<th>Length of tooth</th>
<th>Canals</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Length</td>
<td>One canal</td>
<td>Straight 9.5%</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>One foramen</td>
<td>Distal Curve 27.0%</td>
</tr>
<tr>
<td>Minimum Length</td>
<td>Two canals</td>
<td>Mesial Curve 1.6%</td>
</tr>
<tr>
<td>Range</td>
<td>Two foramina</td>
<td>Buccal Curve 12.7%</td>
</tr>
<tr>
<td></td>
<td>Three canals</td>
<td>*Lingual Curve 4.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bayonet Curve 20.6%</td>
</tr>
</tbody>
</table>

*Not apparent in radiograph
A. UNDEREXTENDED preparation exposing only pulp horns. Control of enlarging instruments is abdicated to cavity walls. The **white color** of the **roof** of the **chamber** is a clue to a shallow cavity.

B. OVEREXTENDED preparation from a fruitless search for a receded pulp. The enamel walls have been completely undermined. Gouging relates to failure to refer to the radiograph, which clearly indicates pulp recession.

C. **PERFORATION** at the mesiocervical indentation. Failure to observe the distal-axial inclination of the tooth led to **bypassing** receded pulp and perforation. The maxillary first premolar is one of the most commonly perforated teeth.

D. **FAULTY ALIGNMENT** of the access cavity through **full veneer restoration** placed to “straighten” the crown of a rotated tooth. Careful examination of the radiograph would reveal the rotated body of the tooth.

E. **BROKEN INSTRUMENT** twisted off in a “cross-over” canal. This frequent occurrence may be obviated by extending the internal preparation to straighten the canals (**dotted line**).

F. **FAILURE** to explore, débride, and obturate the third canal of the maxillary **first** premolar (6% of the time).

G. **FAILURE** to explore, débride, and obturate the second canal of the maxillary **second** premolar (24% of the time).

---

**PLATE 15**

**Maxillary Premolar Teeth**

**ERRORS** in Cavity Preparation
A. Entrance is always gained through the occlusal surface of all posterior teeth. Initial penetration is made in the exact center of the central groove of mandibular premolars. The bur is directed parallel to the long axis of the tooth. The 702 U taper fissure bur in an accelerated-speed contra-angle handpiece is ideal for perforating gold casting or virgin enamel surface to the depth of the dentin. Amalgam fillings are penetrated with a round bur in a high-speed contra-angle handpiece.

B. A regular-length No. 4 round bur is used to open vertically into the pulp chamber. The bur will be felt to “drop” when the pulp chamber is reached. If the chamber is well calcified, initial penetration is continued until the contra-angle handpiece rests against the occlusal surface. This depth of 9 mm is the usual position of the canal orifice that lies at the cervical level. In removing the bur, the occlusal opening is widened buccolingually to twice the width of the bur to allow room for exploration.

C. An endodontic explorer is used to locate the central canal. Tension of the explorer against the walls of preparation will indicate the amount and direction of extension necessary.

D. Working from inside the pulp chamber to outside, a regular-length No. 2 or 4 round bur is used to extend the cavity buccolingually by removing the roof of the pulp chamber.

E. Buccolingual extension and finish of cavity walls are completed with a 702 U fissure bur at accelerated speed.

F. Final ovoid preparation is a tapered funnel from the occlusal to the canal, providing unobstructed access to the canal. No overhanging tooth structure should impede complete authority over enlarging instruments.

G. Buccolingual ovoid outline form reflects the anatomy of the pulp chamber and position of the centrally located canal. The cavity is extensive enough to allow for instruments and filling the materials needed to enlarge and fill canals. Further exploration at this time may reveal the orifice to an additional canal, especially a second canal in the first premolar. The outline form of the final preparation will be identical for both newly erupted and “adult” teeth.
A. Buccal view of a recently calcified first premolar with a large pulp. A radiograph, if exposed slightly from the mesial, will reveal:
   1. narrow mesiodistal width of the pulp
   2. presence of one pulp canal
   3. relatively straight canal
   4. 14-degree distal-axial inclination of the root
   All of these factors, seen in radiograph, are borne in mind when preparation is begun.

B. Mesial view of the same tooth demonstrating details not apparent from the radiograph:
   1. height of the pulp horn
   2. broad buccolingual extent of the pulp
   3. apical-buccal curvature (2% of the time)
   4. 10-degree lingual-axial angulation of the root
   These “unseen” factors will affect the size, shape, and inclination of the final preparation. Severe apical curvature can be detected only by exploration with a fine curved file. Near-verticality of the tooth simplifies orientation and bur alignment.

C. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
   1. Cervical level: the pulp is enormous in a young tooth, very wide in the buccolinguinal dimension. Débride ment of the ovoid chamber is completed during coronal cavity preparation with a round bur.
   2. Midroot level: the canal continues ovoid and requires perimeter filing.
   3. Apical third level: the canal, generally round in shape, is enlarged by shaping into a round, tapered preparation. Preparation terminates at the cemento-dentinal junction, 0.5 to 1.0 mm from the radiographic apex.

D. Ovoid coronal preparation allows débride ment of the entire pulp chamber, funnels down to the ovoid midcanal, and is large enough buccolingually to allow passage of instruments used to enlarge and fill the canal space.

E. Buccal view of an adult first premolar with extensive secondary dentin formation. A radiograph will reveal
   1. pulp recession and “thread-like” appearance of the pulp
   2. radiographic appearance of only one canal
   3. 14-degree distal-axial inclination of the root

F. Mesial view of the same tooth demonstrating details not apparent in the radiograph:
   1. buccolingual “ribbon-shaped” coronal pulp
   2. single-root, bifurcated canal at the midroot level and a single apical foramen
   3. 10-degree lingual-axial angulation of the root
   The operator must recognize that
   a. small orifices are difficult to locate.
   b. the presence of a bifurcated canal is determined only by exploration with a fine curved file.
   c. a single apical foramen can be determined by placing instruments in both canals at the same time. The instruments will be heard and felt to grate against each other.

G. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
   1. Cervical level: the chamber is very narrow ovoid.
   2. Midroot level: the two branches of the canal are round.
   3. Apical third level: the canal is round.
   Divisions of the canal are enlarged by filing. The buccal canal would be filled to the apex and the lingual canal to the point where the canals rejoin.

H. Ovoid funnel-shaped coronal preparation must be extensive enough buccolingually to allow for enlarging and filling both canals.
### Mandibular First Premolar

<table>
<thead>
<tr>
<th>Length of tooth</th>
<th>Canals</th>
<th>Curvature of root</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Length</strong></td>
<td>One canal 73.5%</td>
<td>Straight 48%</td>
</tr>
<tr>
<td>22.1 mm</td>
<td>One foramen 6.5%</td>
<td>†Buccal Curve 2%</td>
</tr>
<tr>
<td><strong>Maximum Length</strong></td>
<td>Two canals* 6.5%</td>
<td>Distal Curve 35%</td>
</tr>
<tr>
<td>24.1 mm</td>
<td>One foramen 19.5%</td>
<td>†Lingual Curve 7%</td>
</tr>
<tr>
<td><strong>Minimum Length</strong></td>
<td>Two canals* 19.5%</td>
<td>Mesial Curve 0%</td>
</tr>
<tr>
<td>20.1 mm</td>
<td>Two foramina 0.5%</td>
<td>Bayonet Curve 7%</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>Three canals 0.5%</td>
<td></td>
</tr>
<tr>
<td>4.0 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Incidence higher in black persons than in white persons

†Not apparent in radiograph
A. **Buccal** view of a recently calcified second premolar with a large pulp. A radiograph will reveal
1. mesiodistal width of the pulp
2. apical-distal curvature (40% of the time)
3. 10-degree distal-axial inclination of the root
 These factors, **seen** in the radiograph, are borne in mind when preparation is begun.

B. **Mesial** view of the same tooth demonstrating details **not apparent in the radiograph**:
1. broad buccolingual “ribbon-shaped” coronal pulp
2. single root with pulpal bifurcation in the apical third
3. 34-degree buccal-axial angulation of the root
 **These “unseen” factors affect the size, shape, and inclination** of the final preparation. Apical third bifurcation, **unseen in the radiograph**, emphasizes the necessity of careful canal exploration.

C. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. **Cervical** level: the pulp is large in a young tooth, very wide in the buccolingual dimension. Débridement of the chamber is completed during coronal cavity preparation with a round bur.
2. **Midroot** level: the canal continues to be long ovoid and requires perimeter filing.
3. **Apical third** level: the canals, generally round, are shaped into **round, tapered** preparations. Preparation terminates at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex.

D. **Ovoid**, coronal funnel-shaped preparation allows débridement of the entire pulp chamber down to the ovoid midcanal. The cavity is large enough buccolingually to allow enlarging and filling of both canals.

E. **Buccal** view of an **adult** second premolar with extensive secondary dentin formation. A radiograph, if exposed slightly from the mesial, will reveal
1. pulp recession and “thread-like” appearance of the pulp
2. sweeping distal curve of the apical third of the root of the tooth (40% of the time)
3. 10-degree distal-axial angulation of the root

F. **Mesial** view of the same tooth demonstrating details **not apparent in the radiograph**:
1. buccolingual “ribbon-shaped” pulp
2. minus 34-degree buccal-axial angulation of the root

The operator should recognize that
a. a small canal orifice will be difficult to locate.
b. the direction of the canal is best explored with a fine curved file that is carried to within 0.5 to 1.0 mm of the radiographic apex. Retraction will then remove dentin at the curve.

G. Cross-sections at three levels: 1, cervical; 2, mid-root; and 3, apical third:
1. **Cervical** level: the chamber is very narrow ovoid.
2. **Midroot** level: the canal is less ovoid.
3. **Apical third** level: the canal is round.
 **The sweeping curve at the apical third is filed to a gradual curve.**

H. **Ovoid** funnel-shaped coronal cavity is modest in size and skewed slightly to the mesial, allowing adequate room to instrument and fill the curved apical third.
### Mandibular Second Premolars

<table>
<thead>
<tr>
<th>Length of tooth</th>
<th>Canals</th>
<th>Curvature of root</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Length</td>
<td>One canal</td>
<td>Straight 39%</td>
</tr>
<tr>
<td>21.4 mm</td>
<td>One foramen</td>
<td>Lingual Curve 3%</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>Two canals*</td>
<td>Distal Curve 40%</td>
</tr>
<tr>
<td>23.7 mm</td>
<td>One foramen</td>
<td>Bayonet Curve 7%</td>
</tr>
<tr>
<td>Minimum Length</td>
<td>Two canals*</td>
<td>Mesial Curve 0%</td>
</tr>
<tr>
<td>19.1 mm</td>
<td>One foramen</td>
<td>Trifurcation Curve 1%</td>
</tr>
<tr>
<td>Range</td>
<td>Two foramina</td>
<td></td>
</tr>
<tr>
<td>4.6 mm</td>
<td>Three canals</td>
<td></td>
</tr>
</tbody>
</table>

*Incidence much higher in black persons than in white persons

†Not apparent in radiograph
PLATE 19

Mandibular Premolar Teeth

ERRORS in Cavity Preparation

A. PERFORATION at the distogingival caused by failure to recognize that the premolar has tilted to the distal.

B. INCOMPLETE preparation and possible instrument breakage caused by total loss of instrument control. Use only occlusal access, never buccal or proximal access.

C. BIFURCATION of a canal completely missed, caused by failure to adequately explore the canal with a curved instrument.

D. APICAL PERFORATION of an invitingly straight conical canal. Failure to establish the exact length of the tooth leads to trephination of the foramen.

E. PERFORATION at the apical curvature caused by failure to recognize, by exploration, buccal curvature. A standard buccolingual radiograph will not show buccal or lingual curvature.
PLATE 20

Endodontic Preparation of Maxillary Molar Teeth

A. Entrance is always gained through the occlusal surface of all posterior teeth. Initial penetration is made in the exact center of the mesial pit, with the bur directed toward the lingual. The 702 U tapering fissure bur in an accelerated-speed contra-angle handpiece is ideal for perforating gold casting or virgin enamel surface to the depth of dentin. Amalgam fillings are penetrated with a No. 4 or 6 round bur operating in a slow-speed contra-angle handpiece.

B. According to the size of the chamber, a regular-length No. 4 round bur is used to open into the pulp chamber. The bur should be directed toward the orifice of the palatal canal or toward the mesiobuccal canal orifice, where the greatest space in the chamber exists. It will be felt to “drop” when the pulp chamber is reached. If the chamber is well calcified, initial penetration is continued until the contra-angle rests against the occlusal surface. This depth of 9 mm is the usual position of the floor of the pulp chamber, which lies at the cervical level. Working from inside out, back toward the buccal, the bur removes enough roof of the pulp chamber for exploration.

C. An endodontic explorer is used to locate orifices of the palatal, mesiobuccal, and distobuccal canals. Tension of the explorer against the walls of preparation will indicate the amount and direction of extension necessary. Orifices of canals form the perimeter of preparation. Special care must be taken to explore for a second canal in the mesiobuccal root.

D. Again, working at slow speed from inside to outside, a round bur is used to remove the roof of the pulp chamber. Internal walls and floor of preparation should not be cut into unless difficulty is encountered in locating orifices. In that case, surgical-length No. 2 round burs are necessary to explore the floor of the chamber.

E. Final finish and funneling of cavity walls are completed with a 702 U fissure bur or tapered diamond points at accelerated speed.

F. Final preparation provides unobstructed access to canal orifices and should not impede complete authority of enlarging instruments. Improve ease of access by “leaning” the entire preparation toward the buccal, for all instrumentation is introduced from the buccal. Notice that the preparation extends almost to the height of the buccal cusps. The walls are perfectly smooth, and the orifices are located at the exact pulpal-axial angles of the cavity floor.

G. Extended outline form reflects the anatomy of the pulp chamber. The base is toward the buccal and the apex is to the lingual, with the canal orifice positioned at each angle of the triangle. The cavity is entirely within the mesial half of the tooth and need not invade the transverse ridge but is extensive enough, buccal to lingual, to allow positioning of instruments and filling materials. Outline form of final preparation is identical for both a newly erupted and an “adult” tooth. Note the orifice to the fourth canal.
PLATE 21

Maxillary First Molar
Pulp Anatomy and Coronal Preparation

A. **Buccal** view of a recently calcified first molar with large pulp. A radiograph will reveal
   1. large pulp chamber
   2. mesiobuccal root with two separate canals, distobuccal, and palatal roots, each with one canal
   3. slightly curved buccal roots
   4. slightly curved palatal root
   5. vertical axial alignment of the **tooth**

   These factors, **seen** in radiograph, are borne in mind when preparation is begun. Care must be taken to explore for an additional mesiobuccal canal.

B. **Mesial** view of the same tooth demonstrating **details not apparent in the radiograph:**
   1. buccolingual width of the pulp chamber
   2. apical-buccal curvature of the palatal root (55% of the time)
   3. buccal inclination of buccal roots
   4. vertical axial alignment of the **tooth**

   These “unseen” factors will affect the **size, shape, and inclination** of the final preparation. Sharp buccal curvature of the palatal canal requires **great care** in exploration and instrumentation. Canals must be carefully explored with **fine curved files.** Enlargement of buccal canals is accomplished by reaming and filing and of the palatal canal by step-back filing.

C. Cross-section at two levels: 1, cervical; and 2, apical third:
   1. **Cervical** level: the pulp is enormous in a young tooth. Débridement of a triangular chamber is completed with a round bur. A **dark** cavity floor with “**lines**” connecting orifices is in marked contrast to white walls. A palatal canal requires perimeter filing.
   2. **Apical third** level: the canals are essentially round. Buccal canals are shaped into **round, tapered** preparations. Preparations terminate at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex.

D. **Triangular outline form,** with the base toward the buccal and the apex toward the lingual, reflects the anatomy of the pulp chamber, with the orifice positioned at each angle of the triangle. Both **buccal and lingual walls slope Buccally.** The **mesial wall slopes mesially** to allow for instrumentation of a severely curved mesiobuccal canal. If an **additional canal is found in the mesiobuccal root,** its orifice will usually be in the groove leading to the palatal canal.

E. **Buccal** view of an adult first molar with extensive secondary dentin formation. A radiograph will reveal
   1. pulp recession and “thread-like” pulp
   2. mesiobuccal, distobuccal, and palatal roots, each with one canal
   3. straight palatal root, apical curve, distal root
   4. apical-distal curvature of the mesial root (78% of the time)
   5. vertical axial alignment of the **tooth**

F. **Mesial** view of the same tooth demonstrating **details not apparent in the radiograph:**
   1. pulp recession
   2. relatively straight palatal root
   3. buccal inclination of the buccal roots
   4. vertical axial alignment of the **tooth**

   The operator must recognize that
   a. careful exploration for orifices and canals is imperative.
   b. severe curvature of buccal roots will require careful enlargement with curved instruments.

G. Cross-section at two levels: 1, cervical; and 2, apical third:
   1. **Cervical** level: a triangular chamber constricted from secondary dentin formation is débrided during coronal cavity preparation with a round bur. Round palatal and distobuccal canals will be shaped to a **round, tapered** preparation.
   2. **Apical third** level: the canals are round. A curved mesiobuccal canal is enlarged by step-back filing. Preparations terminate at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex.

H. **Triangular outline form** reflects the anatomy of the pulp chamber. Both **buccal and lingual walls slope Buccally.** The **mesial wall slopes mesially** to allow for instrumentation of a severely curved mesiobuccal canal. If an **additional canal is found in the mesiobuccal root,** its orifice will usually be in the groove leading to the palatal canal.
### Maxillary First Molars

#### Curvature of roots

<table>
<thead>
<tr>
<th>Length of Tooth</th>
<th>Mesiobuccal</th>
<th>Distobuccal</th>
<th>Palatal</th>
<th>Canal</th>
<th>Direction</th>
<th>Palatal</th>
<th>Mesial</th>
<th>Distal</th>
<th>Canals in the mesiobuccal root</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Length</td>
<td>19.9 mm</td>
<td>19.4 mm</td>
<td>20.6 mm</td>
<td>Three canals</td>
<td>41.1%</td>
<td>21%</td>
<td>54%</td>
<td>41.1%</td>
<td>One canal</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>21.6 mm</td>
<td>21.2 mm</td>
<td>22.5 mm</td>
<td>Four canals</td>
<td>56.5%</td>
<td>1%</td>
<td>17%</td>
<td>One foramen</td>
<td></td>
</tr>
<tr>
<td>Minimum Length</td>
<td>18.2 mm</td>
<td>17.6 mm</td>
<td>17.6 mm</td>
<td>Five canals</td>
<td>2.4%</td>
<td>4%</td>
<td>19%</td>
<td>Two canals</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>3.4 mm</td>
<td>3.6 mm</td>
<td>3.8 mm</td>
<td><em>Buccal Curve</em></td>
<td><em>55%</em></td>
<td>0%</td>
<td>0%</td>
<td>One foramen</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><em>Lingual Curve</em></td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>Two canals</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bayonet Curve</td>
<td>0%</td>
<td>1%</td>
<td>10%</td>
<td>Two foramina</td>
<td></td>
</tr>
</tbody>
</table>

*Not apparent in radiograph*
A. **Buccal** view of a recently calcified second molar with a large pulp. A radiograph will reveal
1. large pulp chamber
2. mesiobuccal, distobuccal, and palatal roots, each with one canal
3. gradual curvature of all three canals
4. vertical axial alignment of the **tooth**

These factors, seen in radiograph, are borne in mind when preparation is begun.

B. **Mesial** view of the same tooth demonstrating details **not apparent in the radiograph**:
1. buccolingual width of the pulp chamber
2. gradual curvature in two directions of all three canals
3. buccal inclination of the buccal roots
4. vertical axial alignment of the **tooth**

These “unseen” factors will affect the **size, shape, and inclination** of the final preparation.

C. Cross-section at two levels: 1, cervical; and 2, apical third:
1. **Cervical** level: the pulp is enormous in a young tooth. Debride ment of a **triangular** chamber is completed with round burs. The **dark** cavity floor with “**lines**” connecting orifices is in marked contrast to white walls.
2. **Apical third** level: the canals are essentially round and are shaped into a **round, tapered** preparation. Preparations terminate at the cementodentinal junction, 0.5 to 1.0 from the radiographic apex.

D. **Triangular outline form** is “flattened” as it reflects the internal anatomy of the chamber. Note that the distobuccal canal orifice is nearer the center of the cavity floor. The entire preparation sharply slopes to the buccal and is extensive enough to allow positioning of instruments and filling materials needed to enlarge and fill canals.

E. **Buccal** view of an adult second molar with extensive secondary dentin formation. A radiograph will reveal
1. pulp recession and “**thread-like**” pulp
2. **anomalous** appearance of only **one root** and **two canals**
3. vertical axial alignment of the **tooth**

F. **Mesial** view of the same tooth demonstrating details **not apparent in the radiograph**:
1. pulp recession
2. **anomalous** appearance of only **one root** and **two canals**
3. sweeping curvature of the lingual canal
4. vertical axial alignment of the **tooth**

The operator must recognize that
a. canal orifices are difficult to find by exploration.

b. a **detailed search must be made for the third canal**.

G. Cross-sections at two levels: 1, cervical; and 2, apical third.
1. **Cervical** level: **ovoid** pulp chamber is debrided during cavity preparation with a round bur.
2. **Apical third** level: canals are round. Preparations terminate at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex.

H. **Ovoid outline form** reflects the internal anatomy of the pulp chamber and elongated parallelogram shape of the occlusal surface. The entire preparation slopes sharply to the buccal.
### Maxillary Second Molars

<table>
<thead>
<tr>
<th>Length of Tooth</th>
<th>Mesiobuccal</th>
<th>Distobuccal</th>
<th>Palatal</th>
<th>Number of Roots</th>
<th>Direction</th>
<th>Palatal</th>
<th>Mesial</th>
<th>Distal</th>
<th>Canals in the mesiobuccal root</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Length</td>
<td>20.2 mm</td>
<td>19.4 mm</td>
<td>20.8 mm</td>
<td>Three</td>
<td>Straight</td>
<td>63%</td>
<td>22%</td>
<td>54%</td>
<td>One canal</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>22.2 mm</td>
<td>21.3 mm</td>
<td>22.6 mm</td>
<td>Fused</td>
<td>Distal</td>
<td>0%</td>
<td>54%</td>
<td>?</td>
<td>One foramen</td>
</tr>
<tr>
<td>Minimum Length</td>
<td>18.2 mm</td>
<td>17.5 mm</td>
<td>19.0 mm</td>
<td></td>
<td>Mesial</td>
<td>0%</td>
<td>0%</td>
<td>17%</td>
<td>Two canals</td>
</tr>
<tr>
<td>Range</td>
<td>4.0 mm</td>
<td>3.8 mm</td>
<td>3.6 mm</td>
<td></td>
<td>*Buccal</td>
<td>37%</td>
<td></td>
<td></td>
<td>One foramen</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lingual</td>
<td>0%</td>
<td></td>
<td></td>
<td>Two canals</td>
</tr>
</tbody>
</table>

*Not apparent in radiograph*
A. UNDEREXTENDED preparation. Pulp horns have merely been “nicked,” and the entire roof of the pulp chamber remains. “White” color dentin of the roof is a clue to underextension (A1). Instrument control is lost.

B. OVEREXTENDED preparation undermining enamel walls. The crown is badly gouged owing to failure to observe pulp recession in the radiograph.

C. PERFORATION into furca using a surgical-length bur and failing to realize that the narrow pulp chamber had been passed. Operator error in failure to compare the length of the bur to the depth of the pulp canal floor. Length should be marked on the bur shank with Dycal.

D. INADEQUATE vertical preparation related to failure to recognize severe buccal inclination of an unopposed molar.

E. DISORIENTED occlusal outline form exposing only the palatal canal. A faulty cavity has been prepared in full crown, which was placed to “straighten” a rotated molar (E1). Palpating for mesiobuccal root prominence would reveal the severity of the rotation.

F. LEDGE FORMATION caused by using a large straight instrument in a curved canal.

G. PERFORATION of a palatal root commonly caused by assuming the canal to be straight and failing to explore and enlarge the canal with a fine curved instrument.
A. Entrance is always gained through the occlusal surface of all posterior teeth. Initial penetration is made in the exact center of the mesial pit, with the bur directed toward the distal. The 702 U tapering fissure bur in an accelerated-speed contra-angle handpiece is ideal for perforating gold casting or virgin enamel surface to the depth of dentin. Amalgam fillings are penetrated with a No. 4 round bur operating in a high-speed contra-angle handpiece.

B. According to the size of the chamber, a regular-length No. 4 or 6 round bur is used to open into the pulp chamber. The bur should be directed toward the orifice of the mesiobuccal or distal canal, where the greatest space in the chamber exists. It will be felt to “drop” when the pulp chamber is reached. If the chamber is well calcified, initial penetration is continued until the contra-angle handpiece rests against the occlusal surface. This depth of 9 mm is the usual position of the floor of the pulp chamber, which lies at the cervical level. Working from inside out, back toward the mesial, the bur removes enough roof of the pulp chamber for exploration.

C. An endodontic explorer is used to locate orifices of the distal, mesiobuccal, and mesiolingual canals. Tension of the explorer against the walls of preparation indicates the amount and direction of extension necessary. Orifices of the canals form the perimeter of preparation. Special care must be taken to explore for an additional canal in the distal root. The distal canal should form a triangle with two mesial canals. If it is asymmetric, always look for the fourth canal 29% of the time.

D. Again, working at slow speed from the inside to outside, a round bur is used to remove the roof of the pulp chamber. Internal walls and floor of preparation should not be cut into unless difficulty is encountered in locating orifices. In that case, surgical-length No. 2 or 4 round burs are necessary to explore the floor of the chamber.

E. Final finish and funneling of cavity walls are completed with a 702 U fissure bur or diamond point at accelerated speed.

F. Final preparation provides unobstructed access to canal orifices and should not impede the complete authority of enlarging instruments. Improve ease of access by “leaning” the entire preparation toward the mesial, for all instrumentation is introduced from the mesial. Notice that the cavity outline extends to the height of the mesial cusps. The walls are perfectly smooth and the orifices located at the exact pulpal-axial angle of the cavity floor.

G. “Square” outline form reflects the anatomy of the pulp chamber. Both mesial and distal walls slope mesially. The cavity is primarily within the mesial half of the tooth but is extensive enough to allow positioning of the instrument and filling materials. The outline form of the final preparation will be identical for both a newly erupted and an “adult” tooth. Further exploration should determine if a fourth canal can be found in the distal. If so, the outline is extended in that direction. In that case, an orifice will be positioned at each angle of the square.
A. **Buccal** view of a recently calcified first molar with large pulp. The initial radiograph will reveal
1. large pulp chamber
2. mesial and distal roots, each **apparently** containing one canal
3. vertical distal root with a severe apical curvature
4. curvature of the mesial root (84% of the time)
5. distal-axial inclination of the tooth
These factors, **seen** in radiograph, are borne in mind when preparation is begun.

B. **Mesial** view of the same tooth demonstrating details **not apparent in the radiograph**:
1. single mesial root with two canals
2. minus 58-degree buccal-axial inclination of the roots
All of these **unseen** factors will affect the size, shape, and inclination of the final preparation.

C. Cross-section at three levels: 1, cervical; 2, midroot; and 3, apical third:
1. **Cervical** level: the pulp, enormous in a young tooth, is débrided during coronal cavity preparation with a round bur.
2. **Midroot** level: the canals are ovoid. Severe indentation on the distal surface of the mesial root brings the canal within 1.5 mm of the external surface, an area frequently perforated by “stripping.”
3. **Apical third** level: the canals are round and are shaped into round, tapered preparations. Preparations terminate at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex.

D. **Distal** view of the same tooth demonstrating details **not apparent in the radiograph**:
1. height of distal pulp horns
2. “ribbon-shaped” distal canal

E. **Buccal** view of an **adult** first molar with extensive secondary dentin formation. A radiograph will reveal
1. pulp recession and “thread-like” pulp
2. mesial and distal roots, each **apparently** containing one canal
3. mesial curvature of the distal root (5% of the time) and distal curvature of the mesial root (84% of the time)
4. distal-axial inclination of the tooth

F. **Mesial** view of the same tooth demonstrating details **not apparent in the radiograph**:
1. pulp recession
2. mesial root, **two canals**, and a single foramen
3. minus 58-degree buccal-axial inclination of the roots

The operator must recognize that
a. careful exploration with two instruments at the same time reveals a common apical foramen.
b. mesial canals curve in two directions.

G. Cross-section at three levels: 1, cervical; 2, midroot; and 3, apical third:
1. **Cervical** level: the chamber is débrided during coronal cavity preparation with a round bur.
2. **Midroot** level: the canals are nearly round and are enlarged during reaming of an apical third.
3. **Apical third** level: the canals are round and are shaped into a round, tapered preparation. Preparations terminate at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex.

H. **Distal** view of the same tooth demonstrating details **not apparent in the radiograph**:
1. pulp recession
2. distal root with the usual single canal
3. buccal-axial inclination of the roots
4. distal canal curves in two directions

The operator should recognize that
a. the presence of a fourth canal can be determined only by careful exploration.

I. **Triangular outline form** reflects the anatomy of the pulp chamber. Both mesial and distal walls slope mesially. The cavity is primarily within the mesial half of the tooth but is extensive enough to allow positioning of instruments and filling materials. **Further exploration should determine whether a fourth canal can be found in the distal.** In that case, an orifice will be positioned at each angle of the rhomboid.
Mandibular First Molars

<table>
<thead>
<tr>
<th>Length of Tooth</th>
<th>Mesial</th>
<th>Distal</th>
<th>Roots</th>
<th>Canals</th>
<th>Canals</th>
<th>Curvature of Roots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Length</td>
<td>20.9 mm</td>
<td>20.9 mm</td>
<td>Two roots</td>
<td>97.8%</td>
<td>Two canals</td>
<td>6.7% Two canals</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>22.7 mm</td>
<td>22.6 mm</td>
<td>Three roots</td>
<td>2.2%</td>
<td>Three canals</td>
<td>64.4% Two canals</td>
</tr>
<tr>
<td>Minimum Length</td>
<td>19.1 mm</td>
<td>19.2 mm</td>
<td>Four canals</td>
<td></td>
<td>Four canals</td>
<td>28.9% Two canals</td>
</tr>
<tr>
<td>Range</td>
<td>3.6 mm</td>
<td>3.4 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PLATE 26

Mandibular Second Molar

Pulp Anatomy and Coronal Preparation

A. **Buccal** view of a recently calcified second molar with a large pulp. A radiograph will reveal
   1. large pulp chamber
   2. mesial and distal roots, each **apparently** containing one canal
   3. mesial curvature of the distal root (10%)
   4. bayonet curvature of the mesial root (7%)
   5. distal-axial inclination of the **tooth**
   These factors, **seen** in radiograph, are borne in mind when preparation is begun.

B. **Mesial** view of the same tooth demonstrating details not apparent in the radiograph:
   1. mesial root with two canals
   2. lingual curvature of the mesiobuccal canal
   3. “S” curvature of the mesiolingual canal
   4. minus 52-degree buccal-axial inclination of the roots
   These **unseen** factors will affect the **size**, **shape**, and **inclination** of the final preparation. Canals must be carefully explored with a fine curved file. The **double “S” curvature** of the mesiolingual canal is especially challenging. All three canals are enlarged by step-back or step-down filing.

C. Cross-section at three levels: 1, cervical; 2, midroot; and 3, apical third:
   1. **Cervical** level: the pulp, enormous in a young tooth, is debrided during coronal cavity preparation with a round bur.
   2. **Midroot** level: the canals are ovoid. Carefully avoid filing against the distal surface of the mesial root, where “stripping” perforation often occurs.
   3. **Apical third** level: the canals are round and are shaped into **round, tapered** preparations. Preparations terminate at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex.

D. **Distal** view of the same tooth demonstrating details not apparent in the radiograph:
   1. height of the distal pulp horns
   2. “ribbon-shaped” distal canal

E. **Buccal** view of an **adult** second molar with extensive secondary dentin formation. A radiograph will reveal:
   1. pulp recession and a “thread-like” pulp
   2. mesial and distal roots, each **apparently** containing one canal
   3. “straight” distal root (58%) and distal curvature of the mesial root (84%)
   4. distal-axial inclination of the **tooth**

F. **Mesial** view of the same tooth demonstrating details not apparent in the original radiograph:
   1. pulp recession
   2. **mesial** root with **two** canals that join and “cross over”
   3. minus 52-degree buccal-axial inclination of the roots

The operator should recognize that
   a. careful exploration with curved instruments is imperative.
   b. mesial canals curve in two directions.

G. Cross-section at three levels: 1, cervical; 2, midroot; and 3, apical third:
   1. **Cervical** level: the chamber is debrided during coronal cavity preparation with a round bur.
   2. **Midroot** level: the canals, only slightly ovoid in shape, will be enlarged by step-back filing of the apical third of the canals.
   3. **Apical third** level: the canals are round and are shaped into **round, tapered** preparations. Preparations terminate at the cementodentinal junction, 0.5 to 1.0 mm from the radiographic apex.

H. **Distal** view of the same tooth demonstrating details not apparent in the radiograph:
   1. pulp recession
   2. single distal root with a usual single canal
   3. buccal-axial inclination of the **tooth**

I. Triangular outline form reflects the anatomy of the pulp chamber. Both mesial and distal walls slope mesially. The cavity is primarily within the mesial half of the tooth but is extensive enough to allow positioning of instruments and filling materials. Further exploration should determine whether a fourth canal can be found in the distal. In that case, an orifice will be found at each angle of the rhomboid.
### Mandibular Second Molars

<table>
<thead>
<tr>
<th>Length of Tooth</th>
<th>Mesial</th>
<th>Distal</th>
<th>Canals</th>
<th>Direction</th>
<th>Curvature of roots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Length</td>
<td>20.9 mm</td>
<td>20.8 mm</td>
<td>One canal</td>
<td>Mesial</td>
<td>Single Root</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Distal</td>
<td>Double Root</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>22.6 mm</td>
<td>22.6 mm</td>
<td>One canal</td>
<td>Straight</td>
<td></td>
</tr>
<tr>
<td>Minimum Length</td>
<td>19.2 mm</td>
<td>19.0 mm</td>
<td>Two canals</td>
<td>Distal Curve</td>
<td></td>
</tr>
<tr>
<td>Root</td>
<td>3.4 mm</td>
<td>3.6 mm</td>
<td>One canal</td>
<td>Mesial Curve</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td></td>
<td>Two canals</td>
<td>Distal Curve</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Two canals</td>
<td>*Buccal Curve</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Two canals</td>
<td>*Lingual Curve</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Two canals</td>
<td>Bayonet Curve</td>
<td></td>
</tr>
</tbody>
</table>

*Not apparent in radiograph*
A. OVEREXTENDED preparation undermining enamel walls. The crown is badly gouged owing to failure to observe pulp recession in the radiograph.

B. PERFORATION into furca caused by using a longer bur and failing to realize that the narrow pulp chamber had been passed. The bur should be measured against the radiograph and the depth to the pulpal floor marked on the shaft with Dycal.

C. PERFORATION at the mesial-cervical caused by failure to orient the bur with the long axis of the molar severely tipped to the mesial.

D. DISORIENTED occlusal outline form exposing only the mesiobuccal canal. A faulty cavity has been prepared in full crown, which was placed to “straighten up” a lingually tipped molar (D1).

E. FAILURE to find a second distal canal owing to lack of exploration for a fourth canal.

F. LEDGE FORMATION caused by faulty exploration and using too large of an instrument.

G. PERFORATION of the curved distal root caused by using a large straight instrument in a severely curved canal.
RADICULAR CAVITY PREPARATION

Objectives
With the completion of the coronal access cavity, preparation of the radicular cavity may be started. Root canal preparation has two objectives: thorough débridement of the root canal system and the specific shaping of the root canal preparation to receive a specific type of filling. A major objective, of course, is the total obturation of this designed space. The ultimate objective, however, should be to create an environment in which the body’s immune system can produce healing of the apical periodontal attachment apparatus.

Cleaning and Débridement of the Root Canal
The first objective is achieved by skillful instrumentation coupled with liberal irrigation. This double-pronged attack will eliminate most of the bacterial contaminants of the canal as well as the necrotic debris and dentin. In addition to débridement, remaining bacteria have long been controlled by intracanal medication. This is still true today even though many dentists, as well as endodontists, merely seal a dry cotton pellet in the chamber in multiappointment cases. This practice cannot be recommended, and the reader is urged to read chapter 2, which deals in detail with the importance of intracanal medication. Single-appointment treatment, of course, precludes interappointment medication.

Cleaning and sanitizing the root canal have been likened to the removal of carious dentin in a restorative preparation—that is, enough of the dentin wall of the canal must be removed to eliminate the attached necrotic debris and, insofar as possible, the bacteria and debris found in the dentinal tubuli (Figure 10-8). Along with repeated irrigation, the débriding instruments must be constantly cleaned. A sterile 2 × 2 gauze square soaked in alcohol is used to wipe the instruments.

Preparing the Root Canal
Over the years, two different approaches to root canal cleaning and shaping have emerged: the “step-back” and the “step-down” preparations. The step-back preparation is based upon the traditional approach: beginning the preparation at the apex and working back up the canal coronally with larger and larger instruments. The step-down preparation, often called “the crown-down approach,” begins coronally and the preparation is advanced apically, using smaller and smaller instruments, finally terminating at the apical stop. All of the techniques of canal cleaning and shaping, including those modified by new instruments or devices, will use variations of either a step-back or a

Figure 10-8  A, Cross-section through pulp canal showing ideal round preparation to remove canal debris and enough dentin to eliminate virtually all bacteria in the tubuli. B, Serial section showing necrotic canal contents and debris-saturated dentin. Débridement of necrotic mass and instrumentation of the dentin to the black line are the goals of instrumentation.
Endodontic Cavity Preparation

step-down approach. In either event, certain principles of cavity preparation (in this case, radicular and coronal) must be followed to ensure thorough cleaning and proper shaping for obturation.

Principles
Once again, as expounded for coronal cavity preparation, a return to Black’s Principles of Cavity Preparation is in order.1 The root canal “cavity” is prepared with the same principles in mind:

- Outline Form
- Convenience Form
- Toilet of the cavity
- Retention Form
- Resistance Form
- Extension for prevention

Figure 10-9 repeats the entire endodontic cavity preparation, from Outline Form beginning at the enamel’s edge to Resistance Form at the apical foramen. In some preparations, Retention Form may be developed in the last 2 to 3 mm of the apical canal. Usually, however, the preparation is a continuous tapered preparation from crown to root end.

The entire length of the cavity falls under the rubric Outline Form and toilet of the cavity. At the coronal margin of the cavity, the Outline Form must be continually evaluated by monitoring the tension of the endodontic instruments against the margins of the cavity. Remember to retain control of the instruments; they must stand free and clear of all interference. Access may have to be expanded (Convenience Form) if instruments start to bind, especially as larger, less flexible instruments are used.

The size and shape of the entire preparation will be governed by the anatomy of the root canal. One attempts to retain this basic shape while thoroughly cleaning and flaring to accommodate the instruments and filling materials used in débridement and obturation.

The entire preparation, crown to apex, may be considered extension for prevention of future periradicular infection and inflammation.

Outline Form and Toilet of the Cavity
Meticulous cleaning of the walls of the cavity until they feel glassy-smooth, accompanied by continuous irrigation, will ensure, as far as possible, thorough débridement. One must realize, however, that total débridement is not possible in some cases, that some “nooks and crannies” of the root canal system are virtually impossible to reach with any device or system.48 One does the best one can, recognizing that in spite of microscopic remaining debris, success is possible. Success depends to a great extent on whether unreachable debris is laden with viable bacteria that have a source of substrate (accessory canal or microleakage) to survive—hence the importance of thorough douching through irrigation, toilet of the cavity.49

Retention Form
In some filling techniques, it is recommended that the initial primary gutta-percha point fit tightly in the apical 2 to 3 mm of the canal. These nearly parallel walls (Retention Form) ensure the firm seating of this principal point. Other techniques strive to achieve a continuously tapering funnel from the apical foramen to the cavosurface margin. Retention Form in these cases is gained with custom-fitted cones and warm compaction techniques.

These final 2 to 3 mm of the cavity are the most crucial and call for meticulous care in preparation. This is where the sealing against future leakage or percolation

Figure 10-9 Concept of total endodontic cavity preparation, coronal and radicular as a continuum, based on Black’s principles. Beginning at apex: A, Radiographic apex. B, Resistance Form, development of “apical stop” at the cementodentinal junction against which filling is to be compacted and to resist extrusion of canal debris and filling material. C, Retention Form, to retain primary filling point. D, Convenience Form, subject to revision as needed to accommodate larger, less flexible instruments. External modifications change the Outline Form. E, Outline Form, basic preparation throughout its length dictated by canal anatomy.
into the canal takes place. This is also the region where accessory or lateral canals are most apt to be present.

Coronally, from the area of retention, the cavity walls are deliberately flared. The degree of flare will vary according to the filling technique to be used—lateral compaction with cold or warm gutta-percha or vertical compaction of heat-softened gutta-percha.

**Resistance Form**

Resistance to overfilling is the primary objective of **Resistance Form**. Beyond that, however, maintaining the integrity of the natural constriction of the apical foramen is a key to successful therapy. Violating this integrity by overinstrumentation leads to complications: (1) acute inflammation of the periradicular tissue from the injury inflicted by the instruments or bacteria and/or canal debris forced into the tissue, (2) chronic inflammation of this tissue caused by the presence of a foreign body—the filling material forced there during obturation, and (3) the inability to compact the root canal filling because of the loss of the limiting apical termination of the cavity—the important **apical stop**. This could be compared to an attempt to place a Class II amalgam filling without the limiting presence of a proximal matrix band.

**Establishing Apical Patency**

Bearing in mind that canal preparations should terminate at the dentinocemental junction, slightly short of the apex, one is left with a tiny remaining portion of the canal that has not been properly cleaned and may contain bacteria and packed debris. It is this section of the canal that is finally cleaned, not shaped, with fine instruments—No. 10 or 15 files. This action is known as **establishing apical patency**. It should not be confused with overenlargement—destroying the apical foramen. Cailleteau and Mullaney surveyed all dental schools in the United States to determine the prevalence of teaching apical patency. They found that 50% of the 49 schools responding teach the concept.

In some cases—youngsters, root fractures, apical root resorption—the apical foramen is open, and these cases always present difficulties in instrumentation and obturation. Special techniques, to be discussed later, have been devised to overcome the loss of resistance form.

In Mexico, Kuttler has shown that the narrowest waist of the apical foramen often lies at the dentinocemental junction (Figure 10-10). He established this point at approximately 0.5 mm from the outer surface of the root in most cases. The older the patient, however, the greater this distance becomes because continued cemental formation builds up the apex. One is also reminded that the dentinocemental junction, where **Resistance Form** may be established, is the apical termination of the pulp. Beyond this point, one is dealing with the tissues of the periodontal ligament space, not the pulp.

The fact must also be established that the apical foramen does not always lie at the exact apex of the root. Most often, canals exit laterally, short of the radiographic apex. This may be revealed by careful scrutiny of the film with a magnifying glass or by placing a curved exploratory instrument to the exact canal length and repeating the radiograph examination. Japanese researchers reported from a native cohort that the apical foramen exits the exact apex only 16.7% of the time in maxillary anterior teeth.

**Extension for Prevention**

Seidler once described the **ideal** endodontic cavity as a round, evenly tapered space with a minimal opening at the foramen. Because one is working with round, tapered materials, one would think that this ideal is easily achieved, particularly when one thinks of root canals as naturally round and tapered. As seen in the anatomic drawings in this chapter, however, few canals are round throughout their length. Thus, one must usually compromise from the ideal, attempting to prepare the round, tapered cavity but knowing that filling techniques must be used to make up for the variance from ideal. This is why single-point fillings, whether silver or gutta-percha, are seldom used.

The extension of the cavity preparation throughout its entire length and breadth is necessary, however, to ensure prevention of future problems. Peripheral enlargement of the canal, to remove all of the debris, followed by total obturation is the primary preventive method.
INSTRUMENTS AND METHODS FOR RADICULAR CLEANING AND SHAPING

Before launching into a detailed or even a broad discussion of the methods and shapes of canal cavity preparation, a description of the instruments and methods used in cleaning and shaping the canal is necessary. “The order of their appearance” during preparation will also be discussed: basic endodontic instruments, irrigation, exploration for canal orifices, exploration of the canal, and length of tooth determination. Then the techniques of intraradicular cavity preparation will follow in detail. Pulpectomy is discussed later.

Basic Endodontic Instruments

After years of relative inactivity, a remarkable upsurge in endodontic instrument design and refinement has recently developed. Historically, very little was done to improve the quality or standardization of instruments until the 1950s, when two research groups started reporting on the sizing, strength, and materials that went into hand instruments. After the introduction of standardized instruments, about the only changes made were the universal use of stainless rather than carbon steel and the addition of smaller (Nos. 6 and 8) and larger (No. 110 to 140) sizes as well as color coding and the re-emergence of power-driven instruments.

By 1962, a working committee on standardization had been formed including manufacturers, the American Association of Endodontists (AAE), and the American Dental Association (ADA). This group evolved into the present-day International Standards Organization (ISO). It was not until 1976, however, that the first approved specification for root canal instruments was published (ADA Specification No. 28), 18 years after Ingle and Levine first proposed standardization in 1958:

1. A formula for the diameter and taper in each size of instrument and filling material was agreed on.
2. A formula for a graduated increment in size from one instrument to the next was developed.
3. A new instrument numbering system based on instrument metric diameter was established.

After initial resistance by many manufacturers, who felt that the change would entail a “considerable investment in new dies and machinery to produce them,” all manufacturers, worldwide, eventually accepted the new sizing.

This numbering system, last revised in 2002, using numbers from 6 to 140, was not just arbitrary but was based on the diameter of the instruments in hundredths of a millimeter at the beginning of the tip of the blades, a point called D0 (diameter 1) (Figure 10-11), and extending up the blades to the most coronal part of the cutting edge at D16 (diameter 2)—16 mm in length. Additional revisions are under way to cover instruments constructed with new materials, designs, and tapers greater than 0.02 mm/mm.

At the present time, instruments with a taper greater than the ISO 0.02 mm/mm have become popular: 0.04,

This means that for every millimeter gain in the length of the cutting blade, the width (taper) of the instrument increases in size by 0.04, 0.06, and 0.08 of a millimeter rather than the ISO standard of 0.02 mm/mm. These new instruments allow for greater coronal flaring than the 0.02 instruments.

In contrast to these widened-flare files, a number of manufacturers have issued half sizes in the 0.02 flare—2.5, 17.5, 22.5, 27.5, 32.5, and 37.5—to be used in shaping extremely fine canals.

The full extent of the shaft, up to the handle, comes in three lengths: standard, 25 mm; long, 31 mm; and short, 21 mm. The long instruments are often necessary when treating canines over 25 mm long. Shorter instruments are helpful in second and third molars or in the patient who cannot open widely. Other special lengths are available, such as the popular 19 mm instrument.

Ultimately, to maintain these standards, the AAE urged the ADA and the United States Bureau of Standards to appoint a committee for endodontic instrument standardization. A committee was formed and, after considerable work and several drafts, produced a specification package that slightly modified and embellished Ingle's original standardization. These pioneering efforts reached international proportions when a worldwide collaborative committee was formed: the ISO, consisting of the Fédération Dentaire International, the World Health Organization, and the ADA Instrument Committee. The ISO has now formulated international specifications using the ADA proposal as a model.

In 1989, the American National Standards Institute (ANSI) granted approval of "ADA Specification No. 28 for endodontic files and reamers" (Figure 10-12). It established the requirements for diameter, length, resistance to fracture, stiffness, and resistance to corrosion. It also included specifications for sampling, inspection, and test procedures. The revision to ADA Specification No. 28 for K-type files and reamers highlighted 30 years of work to achieve international standardization (Table 10-1). Since then, Specification No. 28 has been modified again (1996), and still another revision is in progress.

The ANSI/ADA standards have also been set for other instruments and filling materials: No. 58, Hedstrom files; No. 63, rasps and barbed broaches; No. 71, spreaders and condensers; No. 95, root canal enlargers; as well as No. 57, filling materials; No. 73, absorbent points; and No.78, obturating points. The ISO's standards are comparable with these specifications (N Luebke, personal communication, March 24, 1999).

Initially, manufacturers of endodontic instruments worldwide adhered rather closely to these specifications. Some variations have been noted, however, in size maintenance (both diameter and taper), surface debris, cutting flute character, torsional properties, stiffness, cross-sectional shape, cutting tip design, and type of metal and may also create more undesirable fluting defects. Since then, however, grinding has improved and gained importance since all nickel-titanium instruments must be machined, not twisted. Several recent studies have indicated that this type of manufacturing does not weaken instruments. In fact, most studies indicate that both manufacturing processes produce files that meet or exceed ADA standards.

It has also been found that autoclaving has no significant deleterious effects on stainless steel or nickel-titanium endodontic instruments.

**ISO Grouping of Instruments**

In due time, the ISO-Fédération Dentaire International committee grouped root canal instruments according to their method of use:
latch type
G
same design as
both
drills
First
or
reamers, K
gutta-percha, silver,
latch type
After having dominated the
P
a departure from the
Company (Figure 10-14), K-style
designed as early as 1904 by the Kerr Manufacturing
Group IV: Root canal points
• Group III: Engine-driven
Group II: Engine-driven
• Group I: Hand use only—files, both K type (Kerr)
and H type (Hedstroem); reamers, K type and U
type; and broaches, pluggers, and spreaders.
• Group II: Engine-driven latch type—same design as
Group I but made to be attached to a handpiece. Also
included are paste fillers.
• Group III: Engine-driven latch type—drills or
reamers such as Gates-Glidden (G type), Peeso (P
type), and a host of others—A-, D-, O-, KO-, T-, M-type reamers and the Kurer Root-Facer.
• Group IV: Root canal points—gutta-percha, silver,
paper.

The ISO grouping of endodontic instruments makes
convenient a discussion by group of their manufacture,
use, cutting ability, strengths, and weaknesses.

ISO Group I Instruments, Reamers, or Files. First
designed as early as 1904 by the Kerr Manufacturing
Company (Figure 10-14), K-style files and reamers are
the most widely copied and extensively manufactured
endodontic instruments worldwide. Now made universally
of nickel titanium and stainless steel rather than
carbon steel, K-type instruments are produced using one
of two techniques. The more traditional is produced by
grinding graduated sizes of round “piano” wire into
various shapes such as square, triangular, or rhomboid. A
second grinding operation properly tapers these pieces.
To give the instruments the spirals that provide the
cutting edges, the square or triangular stock is then
grasped by a machine that twists it counterclockwise a pro-
grammed number of times—tight spirals for files, loose
spirals for reamers. The cutting blades that are produced
are the sharp edges of either the square or the triangle. In
any instrument, these edges are known as the “rake”
of the blade. The more acute the angle of the rake, the
sharper the blade. There are approximately twice the
number of spirals on a file than on a reamer of a cor-
responding size (Figure 10-15, A, B).

The second and newer manufacturing method is to
grind the spirals into the tapered wire rather than twist
the wire to produce the cutting blades. Grinding is
totally necessary for nickel-titanium instruments.
Because of their superelasticity, they cannot be twisted.

Originally, the cross-section of the K file was square
and the reamer triangular. Recently, manufacturers
have started using many configurations to achieve bet-
ter cutting and/or flexibility. Cross-section is now the
prerogative of individual companies.

K-Style Modification. After having dominated the
market for 65 years, K-style endodontic instruments
came into a series of modifications beginning in the
1980s. Not wholly satisfied with the characteristics of
their time-honored K-type instrument, the Kerr
Manufacturing Company in 1982 introduced a new
instrument design that they termed the K-Flex File
(Sybron Endo/Kerr; Orange Calif.), a departure from
the square and triangular configurations (Figure 10-15, C).

The cross-section of the K-Flex is rhombus or dia-
mond shaped. The spirals or flutes are produced by
the same twisting procedure used to produce the cutting
dege of the standard K-type files; however, this new
cross-section presents significant changes in instru-
ment flexibility and cutting characteristics. The cutting
dges of the high flutes are formed by the two acute
angles of the rhombus and present increased sharpness
and cutting efficiency. The alternating low flutes
formed by the obtuse angles of the rhombus are meant
to act as an auger, providing more area for increased
debris removal. The decreased contact by the instru-
ment with the canal walls provides a space reservoir
that, with proper irrigation, further reduces the danger
of compacting dentinal filings in the canal.

| Table 10-1 Dimensions in Millimeters. Revision of ADA Specification No. 28 Added Instrument Sizes 08 and 110 to 150 to the Original Specification |
|---|---|---|---|---|
| Size | D1 mm | D2 mm | D3 mm | Handle Color Code |
| 08 | 0.08 | 0.40 | 0.14 | Gray |
| 10 | 0.10 | 0.42 | 0.16 | Purple |
| 15 | 0.15 | 0.47 | 0.21 | White |
| 20 | 0.20 | 0.52 | 0.26 | Yellow |
| 25 | 0.25 | 0.57 | 0.31 | Red |
| 30 | 0.30 | 0.62 | 0.36 | Blue |
| 35 | 0.35 | 0.67 | 0.41 | Green |
| 40 | 0.40 | 0.72 | 0.46 | Black |
| 45 | 0.45 | 0.77 | 0.51 | White |
| 50 | 0.50 | 0.82 | 0.56 | Yellow |
| 55 | 0.55 | 0.87 | 0.61 | Red |
| 60 | 0.60 | 0.92 | 0.66 | Blue |
| 70 | 0.70 | 1.02 | 0.76 | Green |
| 80 | 0.80 | 1.12 | 0.86 | Black |
| 90 | 0.90 | 1.22 | 0.96 | White |
| 100 | 1.00 | 1.32 | 1.06 | Yellow |
| 110 | 1.10 | 1.42 | 1.16 | Red |
| 120 | 1.20 | 1.52 | 1.26 | Blue |
| 130 | 1.30 | 1.62 | 1.36 | Green |
| 140 | 1.40 | 1.72 | 1.46 | Black |
| 150 | 1.50 | 1.82 | 1.56 | White |

*New diameter measurement point (D3) was added 3 mm from the tip of the cutting end of the instrument. Handle color coding is official.*
Figure 10-13 Comparisons of the condition of unused instruments from different manufacturers. A, New No. 30 K file with consistently sharp blades and point. B, New No. 35 K file, different brand, exhibiting dull blades. C, Cross-sectional profile of triangular No. 20 file showing consistency in angles. D, Cross-section of competing No. 20 file with dull, rounded angles of cutting blades. E, No. 15 file showing lack of consistency in the blade, reflecting poor quality control. F, New No. 08 file with no cutting blades at all.
Testing five brands of K-type files for stiffness, the San Antonio group found K-Flex files to be the most flexible. Moreover, not a single K-Flex fractured in torque testing, even when twisted twice the recommended level in the ADA specification.73

More recently, Kerr has introduced a hybrid instrument they call the Triple-Flex File (Kerr; Orange, Calif.) It has more spiral flutes than a K reamer but fewer than a K file. Made from triangular stainless steel and twisted, not ground, the company claims the instrument is more aggressive and flexible than the regular K-style instruments (see Figure 10-15, D).

Reamers. The clinician should understand the importance of differentiating endodontic files and reamers from drills. Drills are used for boring holes in solid materials such as gold, enamel, and dentin. Files, by definition, are used by rasping.

Reamers, on the other hand, are instruments that ream—specifically, a sharp-edged tool for enlarging or tapering holes (see Figure 10-15B). Traditional endodontic reamers cut by being tightly inserted into the canal, twisted clockwise one quarter- to one half-turn to engage their blades into the dentin, and then withdrawn—penetration, rotation, and retraction.6 The cut is made during retraction. The process is then repeated, penetrating deeper and deeper into the canal. When working length is reached, the next size instrument is used, and so on.

Reaming is the only method that produces a round, tapered preparation, and this only in perfectly straight canals. In such a situation, reamers can be rotated one half-turn before retracting. In a slightly curved canal, a reamer should be rotated only one quarter-turn. More stress may cause breakage. The heavier reamers, however, size 50 and above, can almost be turned with impunity.

Files. The tighter spiral of a file (see Figure 10-15, A) establishes a cutting angle (rake) that achieves its primary action on withdrawal, although it will cut in the push motion as well. The cutting action of the file can be effected in either a filing (rasping) or reaming (drilling) motion. In a filing motion, the instrument is placed into the canal at the desired length, pressure is exerted against the canal wall, and while this pressure is maintained, the rake of the flutes rasps the wall as the instrument is withdrawn without turning. The file need not contact all walls simultaneously. For example, the entire length and circumference of large-diameter canals can be filed by inserting the instrument to the desired working distance and filing circumferentially around all of the walls.

To use a file in a reaming action, the motion is the same as for a reamer—penetration, rotation, and retraction.6 The file tends to set in the dentin more readily than the reamer and must therefore be treated more gingerly. Withdrawing the file cuts away the engaged dentin.
The tactile sensation of an endodontic instrument “set” into the walls in the canal may be gained by pinching one index finger between the thumb and forefinger of the opposite hand and then rotating the extended finger (Figure 10-16).

To summarize the basic action of files and reamers, it may be stated that either files or reamers may be used to ream out a round, tapered apical cavity but that files are also used as push-pull instruments to enlarge by rasping certain curved canals as well as the ovoid portion of large canals. In addition, copious irrigation and constant cleansing of the instrument are necessary to clear the flutes and prevent packing debris at or through the apical foramen (Figure 10-17).

The subject addressed—how K-style files and reamers work—must logically be followed by asking how well they work. One is speaking here, primarily, about stainless steel instruments.

Oliet and Sorin evaluated endodontic reamers from four different manufacturers and found “considerable variation in the quality, sharpness of the cutting edges, cross sectional configuration, and number of flutes of the 147 different reamers tested.” They further found that “triangular cross sectional reamers cut with greater efficiency than do the square cross sectional reamers,” but the failure rate of the triangular instruments was considerably higher. Webber et al. found that “instruments with triangular cross sections were initially more efficient but lost sharpness more rapidly than square ones of the same size.”

Oliet and Sorin also found that “wear does not appear to be a factor in instrument function, but rather instruments generally fail because of deformation or fracture of the blades. Once an instrument became permanently distorted, additional rotation only caused additional distortion, with minimum cutting frequently leading to fracture.” A more recent in vitro study of stainless steel files at Connecticut demonstrated that significant wear and potential loss of efficiency occurred after only one use of 300 strokes. They proposed that endodontic instruments should be available in sterile packaging for single-patient use. Another study, from Brazil, concluded that stainless steel instruments, in small sizes, should be used once, and the No. 30 could be used three times. The No. 30 nickel-titanium instruments, however, “even after five times, did not show appreciable abnormalities in shape.” Most endodontists use the small instruments, 08 to 25 sizes only once.

Webber et al. used a linear cutting motion in moist bovine bone and found that “there was a wide range of cutting efficiency between each type of root canal instrument, both initially and after successive use.”

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Figure 10-16 Demonstration of sensation of an endodontic instrument, which is “set” into dentin walls during reaming action. Figure 10-17 “Worm” of necrotic debris forced from the apex during canal enlargement. This mass of material could contain millions of bacteria that act as a nidus for acute apical abscess.
Similar findings were made by a group at Marquette University, who compared K-type files with five recently introduced brands in three different sizes, Nos. 20, 25, and 30.\textsuperscript{78} Significant differences were noted in the \textit{in vitro} cutting efficiency among the seven brands. Wear was exhibited by all instruments after three successive 3-minute test periods. Depth of groove is also a significant factor in improving cutting ability (Figure 10-18).

A group of researchers in Michigan also studied the cutting ability of K-type files.\textsuperscript{79} They reported a wide variance in the cutting ability of individual files. This study appears to confirm what dentists have long noted—the wide variance in cutting ability among individual instruments, even from the same manufacturer. Contrary to the Marquette findings,\textsuperscript{78} this study reported an insignificant role played by wear in decreasing the cutting ability of regular K-type stainless steel files.\textsuperscript{79} This speaks of the strength of instruments, but what of their weaknesses?

The Oliet and Sorin,\textsuperscript{74} Webber et al.,\textsuperscript{75} and Neal et al.\textsuperscript{79} studies all alluded to certain weaknesses in K-style instruments. In addition, Luks has shown that the smaller reamers and files may be easily broken by twisting the blades beyond the limits of the metal until the metal separated.\textsuperscript{80} On the other hand, Gutierrez et al. found that although the instrument did not immediately break, a progression of undesirable features occurred.\textsuperscript{81} Locking and twisting clockwise led to unwinding and elongation as well as the loss of blade cutting edge and blunting of the tip. With continued clockwise twisting, a reverse “roll-up” occurred. Cracks in the metal eventually developed that finally resulted in breakage, with all of its attendant problems. These findings were unusual in that breakage would have normally resulted long before “roll-up” occurred. It may reflect a variance in the quality of metal used by the individual manufacturing companies. This point was borne out in a study by Lentine, in which he found a wide range of values within each brand of instrument as well as between brands.\textsuperscript{82}

An additional study of 360-degree clockwise rotation (ISO revision of ADA Specification No. 28) found

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**Figure 10-18** Comparison between two competing brands of endodontic instruments showing widely different cutting ability related to the depth of the blade groove.
only 5 K-style files failing of 100 instruments tested. They were sizes 30 to 50, all from one manufacturer.\textsuperscript{73}

Attempts to “unscrew” a locked endodontic file also present a problem. Researchers at Northwestern University demonstrated that “endodontic files twisted in a counterclockwise manner were extremely brittle in comparison to those twisted in a clockwise manner.”\textsuperscript{83} They warned that dentists “should exercise caution when ‘backing-off’ embedded root canal instruments.” This finding was strongly supported by Lautenschlager and colleagues, who found that “all commercial files and reamers showed adequate clockwise torque, but were prone to brittle fracture when placed in counterclockwise torsion.”\textsuperscript{84}

In contrast, Roane and Sabala at the University of Oklahoma found that clockwise rotation was more likely (91.5\%) to produce separation and/or distortion than counterclockwise rotation (8.5\%) when they examined 493 discarded instruments.\textsuperscript{85} In laboratory tests, the Washington group also found greater rotational failure in clockwise rotation and greater failure in machined stainless steel K files over twisted K files.\textsuperscript{63}

Sotokawa in Japan also studied discarded instruments and indicated metal fatigue as the culprit in breakage and distortion\textsuperscript{86}. “First a starting point crack develops on the file’s edge and then metal fatigue fans out from that point, spreading towards the file’s axial center” (Figure 10-19). Sotokawa also classified the types of damage to instruments (Figure 10-20). He found the No. 10 file to be the most frequently discarded.\textsuperscript{86}

Montgomery evaluated file damage and breakage from a sophomore endodontics laboratory and also found that most damage (87\%) “occurred while filing canals in posterior teeth with #10 stainless files. One file separated for every 3.91 posterior teeth that were filed,” and each student averaged over 5 (range 1 to 11) damaged files in the exercise.\textsuperscript{87}

A group in France compared instrument fracture between traditional K and H files and the newer “hybrid” instruments. They found that “the instruments with triangular cross sections, in particular the Flexofile (Dentsply/Maillefer; Tulsa, Okla.), were found to be the most resistant to fracture.” French researchers, like the Japanese researchers, found starting-point cracks and ductile fracture as well as plastic deformations and axial fractures\textsuperscript{88} (Figure 10-21).

A group at the University of Washington compared rotation and torque to failure of stainless steel and nickel-titanium files of various sizes. An interesting relation was noted. Stainless steel had greater rotations to failure in a clockwise direction, and the nickel titanium was superior in a counterclockwise direction. Despite these differences, the actual force to cause failure was the same.\textsuperscript{89}

Buchanan, among others, pointed out the importance of bending stainless steel files to conform to curved canals. He recommended the use of pliers to make the proper bend.\textsuperscript{90} Yesilsoy et al. on the other hand, observed damage (flattenining of the flutes) in cotton plier-bent files (Figure 10-22, A). The finger-bent files, however, although not damaged, were coated with accumulated debris-stratified squamous epithelium cells and nail keratin\textsuperscript{91} (Figure 10-22, B). Finger-bent files should be bent while wearing washed rubber gloves or between a sterile

Figure 10-19  Instrument breakage. A, Initial crack across the shaft near the edge of the blade, Type V (original magnification \times 1,000). B, Full fracture of file broken in a 30-degree twisting simulation, Type V1 (original magnification \times 230). Reproduced with permission from Sotokawa T.\textsuperscript{86}
Figure 10-20  A, Sotokawa’s classification of instrument damage. Type I, Bent instrument. Type II, Stretching or straightening of twist contour. Type III, Peeling-off metal at blade edges. Type IV, Partial clockwise twist. Type V, Cracking along axis. Type VI, Full fracture. B, Discarded rotary nickel-titanium files showing visible defects without fracture. All files show unwinding, indicating a torsional defect, and are very dangerous to be used further. A reproduced with permission from Sotokawa T.86 B reproduced with permission from Sattapan B, Nervo GJ, Palamara JEA, Messer HH. JOE 2000;26:161.

Figure 10-21  Instrument fracture by cracks and deformation. A, Broken Hedstroem file with starting point at i (far right) spreading to cracks (S) and ductile fracture (F). B, Broken K-Flex file with plastic deformations at D and axial fissure at Fs. Reproduced with permission from Haikel Y et al.88
gauze sponge. Maillefer manufactures a hand tool called a Flexobend (Dentsply/Maillefer; Tulsa, Okla.) for properly bending files without damage.

To overcome the problems chronicled above—distortion, fracture, and precurvature—a group at Marquette University suggested that nickel titanium, with a very low modulus of elasticity, be substituted for stainless steel in the manufacture of endodontic instruments.92 On the other hand, the cutting efficiency of the Nitinol #35 K files was only 60% that of matching stainless steel files.93

Tip Modification. Early interest in the cutting ability of endodontic instruments centered around the sharpness, pitch, and rake of the blades. By 1980, interest had also developed in the sharpness of the instrument tip and the tip’s effect in penetration and cutting as well as its possible deleterious potential for ledging and/or transportation—machining the preparation away from the natural canal anatomy.

The Northwestern University group noted that tip design, as much as flute sharpness, led to improved cutting efficiency.94 They later designed experiments to exclude tip design because the tip might “overshadow the cutting effects of flute design.”95 Somewhat later, they reported that “tips displayed better cutting efficiency than flutes” and that triangular pyramidal tips outperformed conical tips, which were least effective.96,97

At the same time that a pitch was being made for the importance of cutting tips, other researchers, centered around the University of Oklahoma, were redesigning tips that virtually eliminated their cutting ability. Powell et al. began modifying the tips of K files by “grinding to remove the transition angle” from tip to first blade.98,99 This was an outgrowth of Powell’s indoctrination at the University of Oklahoma by Roane et al.’s introduction of the Balanced Force concept of canal preparation.100 By 1988, Sabala et al. confirmed previous findings that the modified tip instruments exerted “less transportation and more inner curvature” preparation. The modified files maintained the original canal curvature better and more frequently than did the unmodified files.”101 These findings were essentially confirmed in vitro by Sepic et al.102 and in vivo by McKendry et al.103 Powell et al. noted that each stainless steel “file’s metallic memory to return to a straight position, increases the tendency to transport or ledge and eventually to perforate curved canals.”99 This action takes place on the outer wall, the convex curvature of the canal. They pointed out that when this tip “angle is reduced, the file stays centered within the original canal and cuts

Figure 10-22 Instruments precurved with cotton pliers or fingers. A, Cotton plier-precured No. 25 file with attached metal chips, left. Flutes are badly damaged. B, Finger-precured No. 25 file with accumulated cellular debris between flutes. Reproduced with permission from Yesilsoy C et al.91
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all sides (circumference) more evenly.” This modified-tip file has been marketed as the Flex-R-file (Moyco/Union Broach, Miller Dental; Bethpage, N.Y.) (Figure 10-23).

Recognizing the popularity of modified-tip instruments, other companies have introduced such instruments as Control Safe files (Dentsply/Maillefer; Tulsa, Okla.), the Anti-Ledging Tip file (Brasseler; Savannah, Ga.), and Safety Hedstrom file (Sybron Endo/Kerr; Orange, Calif.).

At the University of Wales, rounded-tipped files were compared with other files with triangular cross-sections and various forms of tip modification. Although the round-tipped files were the least efficient, they prepared canals more safely and with less destruction than did the other files.104

Hedstroem Files (aka Hedstrom). H-type files are made by cutting the spiraling flutes into the shaft of a piece of round, tapered, stainless steel wire. Actually, the machine used is similar to a screw-cutting machine. This accounts for the resemblance between the Hedstroem configuration and a wood screw (Figure 10-24, A).

It is impossible to ream or drill with this instrument. To do so locks the flutes into the dentin much as a screw is locked in wood. To continue the drilling action would fracture the instrument. Furthermore, the file is impossible to withdraw once it is locked in the dentin and can be withdrawn only by backing off until the flutes are free. This action also “separates” files.

Hedstroem files cut in one direction only—retraction. Because of the very positive rake of the flute design, they are also more efficient as files per se.105–110 French clinicians (Yguel-Henry et al.) reported on the importance of the lubricating effect of liquids on cutting efficiency, raising this efficiency by 30% with H-style files and 200% with K-files.108 Temple University researchers, however, reported the proclivity that H files have for packing debris at the apex.106 On the other hand, El Deeb and Boraas found that H files tended not to pack debris at the apex and were the most efficient.110

Owing to their inherent fragility, Hedstroem files are not to be used in a torquing action. For this reason, ADA Specification No. 28 could not apply, and a new specification, No. 58, has been approved by the ADA and the American National Standards Committee.111

H-Style File Modification. McSpadden was the first to modify the traditional Hedstroem file. Marketed as the Unifile and Dynatrak, these files were designed with two spirals for cutting blades, a double-helix design, if you will. In cross-section, the blades presented an “S” shape rather than the single-helix teardrop cross-sectional shape of the true Hedstroem file.

Unfortunately, breakage studies revealed that the Unifile generally failed the torque twisting test (as did the four other H files tested) based on ISO Specification No. 58.112 The authors concluded that the specification was unfair to H-style files, that they should not be twisted more than one quarter-turn.73,112 At this time, Unifiles and Dynatraks are no longer being marketed; however, the Hyflex file (Coltene/Whaledent/Hygenic, Mahwah,

Figure 10-23  Flex-R-file with noncutting tip. A, Note rounded tip. B, “Nose” view of a noncutting tip ensures less gouging of the external wall and reduced cavity transport. (Courtesy of Moyco Union Broach Co.)
The “S” File (J-S Dental; Ridgefield, Conn.) also appears to be a variation of the UniFile in its double-helix configuration. Reports on this instrument are very favorable. Buchanan has further modified the Hedstroem file, the Safety Hedstrom (Sybron Endo/Kerr; Orange, Calif.), which has a noncutting side to prevent ledging in curved canals (see Figure 10-24, B right).

The U-File. A new endodontic classification of instrument, for which there is no ISO or ANSI/ADA specification as yet, is the U-File, developed by Heath (personal communication, May 3, 1988) and marketed as ProFiles, GT Files (Dentsply/Tulsa Dental; Tulsa, Okla.), LIGHTSPEED (LightSpeed Technology Inc; San Antonio, Tex.), and Ultra-Flex files (Texeed Corp., USA).

The U-File’s cross-sectional configuration has two 90-degree cutting edges at each of the three points of the blade (Figure 10-25, A). The flat cutting surfaces act as a planing instrument and are referred to as radial lands. Heath pointed out that the new U shape adapts well to the curved canal, aggressively planing the external convex wall while avoiding the more dangerous internal concave wall, where perforation stripping occurs (Figure 10-25, B). A noncutting pilot tip ensures that the file remains in the lumen of the canal, thus avoiding transportation and “zipping” at the apex. The

Figure 10-24 ISO Group I, H-style instruments. A. Maillefer Hedstroem file resembling a wood screw. B. Modified Hedstroem file (left) with non-cutting tip. “Safety” Hedstroem (right) with flattened non-cutting side to prevent “stripping”. A. Reproduced with permission from Keate KC and Wong M.64

Figure 10-25 A, Cross-sectional view of a U File reveals six corners in cutting blades compared with four corners in square stock and three corners in triangular stock K files. B, Nickel-titanium U-shaped files in C-shaped molar canals. Note extreme flexibility (arrow) without separation. (A courtesy of Derek Heath, Quality Dental Products. B courtesy of Dr. John McSpadden.)
files are used in both a push-pull and rotary motion and are very adaptable to nickel-titanium rotary instruments. ProFiles are supplied in 0.04, 0.05, 0.06, 0.07, and 0.08 tapers and ISO tip sizes of 15 through 80.

GT ProFiles, developed by Buchanan in the U design, are unusual in that the cutting blades extend up the shaft only 6 to 8 mm rather than 16 mm, and the tapers start at 0.06 mm/mm (instead of 0.02), as well as 0.08 and 0.10, tapered instruments. They are made of nickel titanium and come as hand instruments and rotary files. GT instruments all start with a noncutting tip ISO size 20.

An unusual variation of the U-shaped design is the LIGHTSPEED instrument (Figure 10-26). Made only in nickel titanium, it resembles a Gates-Glidden drill in that it has only a small cutting head mounted on a long, noncutting shaft. It is strictly a rotary instrument but comes with a handle that may be added to the latch-type instrument for hand use in cleaning and shaping abrupt apical curvatures where rotary instruments may be in jeopardy. The instruments come in ISO sizes beginning with No. 20 up to No. 100. Half sizes begin at ISO 22.5 and range to size 65. The heads are very short—only 0.25 mm for the size 20 and up to 1.75 mm for the size 100.

It is recommended that the LIGHTSPEED be used at 1,300 to 2,000 rpm and that the selected rpm remain constant. As with many of the new rotary instruments, this speed calls for a controlled, preferably electric handpiece. One of LIGHTSPEED’s touted advantages is the ability to finish the apical-third preparation to a larger size if dictated by the canal diameter. It has been said that “canal diameter, particularly in the apical third, is a forgotten dimension in endodontics” (personal communication, Dr. Carl Hawrish, 1999).

Gates-Glidden Modification. A hand instrument also designed for apical preparation is the Flexogates, aka Handygates (Dentsply/Maillefer; Tulsa, Okla.). A safe-tipped variation of the traditional Gates-Glidden drill, the Flexogates is still to be tested clinically, although Briseno et al. compared Flexogates and Canal Master (Brasseler, Savannah, Ga.) in vitro and found Flexogates less likely to cause apical transportation (Figure 10-27).118

Quante “Files.” The newly designed Quantec instrument (Sybron-Endo/Kerr; Orange, Calif.), although called a “file,” is more like a reamer—a drill, if you will. It is not designed to be used in the file’s push-pull action but rather in the reamer’s rotary motion. Produced as both hand- and rotary-powered instruments, the Quantec has proved to be very effective as a powered instrument. First designed by McSpadden, the instrument has undergone a number of modifications that have improved its efficiency and safety. Quantec is produced in three different tapers—0.02, 0.04, and 0.06 mm/mm—as well as safe-cutting and noncutting tips (Figure 10-28). The instruments are sized at the tip and numbered according to the ISO system—15, 20, 25, etc. The radial lands of the Quantec are slightly relieved to reduce frictional contact with the canal wall, and the helix angle is configured to efficiently remove debris.

Hand Instrument Conclusions. The literature is replete with references to the superiority of one instrument or one method of preparation over all others.110,119–122 Quite true is the statement, “Regardless of the instrument type, none was able to reproduce ideal

![Figure 10-26](image1.png)

*Figure 10-26* The unusual LightSpeed instrument. "U" shaped in design with a noncutting tip, the LightSpeed cutting head terminates a 16 mm noncutting shaft. Made only in nickel titanium in ISO sizes 20 to 100 and in half sizes as well, they are used in rotary preparations at 2,000 rpm. (Courtesy of LightSpeed Technology Inc.)

![Figure 10-27](image2.png)

*Figure 10-27* Flexogates (aka "Handy Gates") hand-powered version of a Gates-Glidden drill used to perfect apical cavity preparation. Note the safe noncutting pilot tip. (Courtesy of Dentsply/Maillefer.)
results; however, clinically acceptable results could be obtained with all of them.’’ These German authors went on to say, ‘‘These observations were subjective and might differ from one operator to another.’’

All too often clinicians report success with the instruments and technique with which they are most comfortable. No ulterior motive is involved, but often a report reflects badly on an instrument when it is the clinician’s inexperience with an unfamiliar technique that is unknowingly being reported. Stenman and Spångberg said it best: it is difficult to assess, as results from published investigations often vary considerably.’’

**Barbed Broaches.** Barbed broaches are short-handled instruments used primarily for vital pulp extirpation. They are also used to loosen debris in necrotic canals or to remove paper points or cotton pellets. ISO Specification No. 63 sets the standards for barbed broaches. Rueggeberg and Powers tested all sizes of broaches from three manufacturers and found significant differences in shape, design, and size, as well as results from torsion and deflection tests. The authors warned that a ‘‘jammed broach’’ should be removed vertically without twisting.

Broaches are manufactured from round wire, the smooth surface of which has been notched to form barbs bent at an angle from the long axis (Figure 10-29, A). These barbs are used to engage the pulp as the broach is carefully rotated within the canal until it begins to meet resistance against the walls of the canal. The broach should never be forced into a canal beyond the length where it first begins to bind. Forcing it farther apically causes the barbs to be compressed by the canal walls. Subsequent efforts to withdraw the instrument will embed the barbs in the walls. Increased withdrawal pressure to retrieve the instrument results in breaking off the embedded barbs or the shaft of the instrument itself at the point of engagement (Figure 10-29, B). A broken barbed broach embedded in the canal wall is seldom retrievable. (Proper use of this instrument will be described in the section on pulpectomy.)

There is also a smooth broach, sometimes used as a pathfinder. The newly released Pathfinder CS (Sybron-Endo/Kerr; Orange, Calif.), made of carbon steel, is less likely to collapse when forced down a fine canal. Carbon steel will rust and cannot be left in sodium hypochlorite.

**NICKEL-TITANIUM ENDODONTIC INSTRUMENTS**

A new generation of endodontic instruments, made from a remarkable alloy, nickel titanium, has added a striking new dimension to the practice of endodontics. The superelasticity of nickel titanium, the property that allows it to return to its original shape following significant deformation, differentiates it from other metals, such as stainless steel, that sustain deformation and retain permanent shape change. These properties make nickel-titanium endodontic files more flexible and better able to conform to canal curvature, resist fracture, and wear less than stainless steel files.

**History.** In the early 1960s, the superelastic property of nickel-titanium alloy, also known as Nitinol, was discovered by Buehler and Wang at the US Naval Ordnance Laboratory. The name Nitinol was derived from the elements that make up the alloy, nickel and titanium, and “nol” for the Naval Ordnance Laboratory. The trademark Nitinol refers specifically to the first nickel-titanium wire marketed for orthodontics.

As early as 1975, Civjan and associates reported on potential applications of nickel-titanium alloys containing nickel 55% by weight (55-Nitinol) and nickel 60% by weight (60-Nitinol). They found that the characteristics of 60-Nitinol suggested its use in the fabrication of tough corrosion-resistant hand or rotary cutting instruments or files for operative dentistry, surgery, periodontics, and endodontics. Further, it was suggested that 55- or 60-Nitinol could be used for the manufacture of corrosion-resistant root canal points to replace silver points.

A first potential use of nickel titanium in endodontics was reported in 1988 by Walia and associates. Number 15 files fabricated from nickel-titanium orthodontic alloy were shown to have two or three times the elastic flexibility in bending and torsion, as well as supe-
rior resistance to torsional fractures, compared with No. 15 stainless steel files manufactured by the same process. The results suggested that Nitinol files might be promising for the instrumentation of curved canals.

In 1992, a collaborative group made a decision to examine and study the possibility of producing nickel-titanium instruments. The nickel-titanium revolution in endodontics followed, and in May 1992, Serene introduced these new files to students in the College of Dental Medicine at the Medical University of South Carolina. Later these and other similar files became available to the profession generally.

**Superelasticity**

Alloys such as nickel titanium, that show superelasticity, undergo a stress-induced martensitic transformation from a parent structure, which is austenite. On release of the stress, the structure reverts back to austenite, recovering its original shape in the process. Deformations involving as much as a 10% strain can be completely recovered in these materials, as compared with a maximum of 1% in conventional alloys.

In a study comparing piano wire and a nickel-titanium wire, Stoeckel and Yu found that a stress of 2500 MPa was required to stretch a piano wire to 3% strain,
as compared with only 500 MPa for a nickel-titanium wire. At 3% strain, the music wire breaks. On the other hand, the nickel-titanium wire can be stretched much beyond 3% and can recover most of this deformation on the release of stress.

The superelastic behavior of nickel titanium also occurs over a limited temperature window. Minimum residual deformation occurs at approximately room temperature. A composition consisting of 50 atomic percent nickel and 50 atomic percent titanium seems ideal, both for instrumentation and manufacture.

Manufacture. Today, nickel-titanium instruments are precision ground into different designs (K style, Hedstrom, Flex-R, X-double fluted, S-double fluted, U files, and drills) and are made in different sizes and tapers. In addition, spreaders and pluggers are also available. Nickel-titanium instruments are as effective or better than comparable stainless steel instruments in machining dentin, and nickel-titanium instruments are more wear resistant. U and drill designs make it possible to use mechanical (i.e., rotary handpiece) instrumentation. Moreover, new prototype rotary motors now offer the potential for improved torque control with automatic reversal that may ultimately decrease rotary instrument breakage.

Finally, nickel-titanium files are biocompatible and appear to have excellent anticorrosive properties. In addition, implantation studies have verified that nickel titanium is biocompatible and acceptable as a surgical implant. In a 1997 AAE questionnaire, the endodontic membership answered the following question, “Do you think nickel-titanium instruments are here to stay and will become basic armamentaria for endodontic treatment?” The responses were quite positive: “yes,” 72%; “maybe,” 21%; and “no,” 4%. With the ability to machine flutes, many new designs such as radial lands have become available. Radial lands allow nickel-titanium files to be used as reamers in a 360-degree motion as opposed to the traditional reamers with more acute rake angles. Although the most common use of this new design has been as a rotary file, the identical instrument is available as a hand instrument. In addition, a converter handle is available that allows the operator to use the rotary file as a hand instrument.

Torsional Strength and Separation. The clinician switching from stainless to nickel-titanium hand instruments should not confuse nickel titanium’s superelastic characteristics with its torsional strength and so assume that it has super strength. This misconception has led to unnecessary file breakage when first using this new metal. Studies indicate that instruments, whether stainless steel or nickel titanium, meet or exceed ANSI/ADA Specification No. 28. However, when reviewing the literature on this subject the results seem to be mixed. Canalda and Berastequi found nickel-titanium files (Nitiflex and Naviflex) (Dentsply; Tulsa, Okla.) to be more flexible than the stainless files tested (Flexofile and Flex-R). However, the stainless steel files were found to be more resistant to fracture. Both types of metal exceeded all ANSI/ADA specifications. Canalda et al., in another study, compared identical instruments: CanalMaster (aka LIGHTSPEED) stainless steel and CanalMaster nickel titanium. Within these designs, the nickel-titanium values were superior in all aspects to those of stainless steel of the same design.

Tepel et al. looked at bending and torsional properties of 24 different types of nickel-titanium, titanium-aluminum, and stainless steel instruments. They found the nickel-titanium K files to be the most flexible, followed in descending order by titanium aluminum, flexible stainless steel, and conventional stainless steel. When testing for resistance to fracture for 21 brands, however, they found that No. 25 stainless steel files had a higher resistance to fracture than their nickel-titanium counterpart.

Wolcott and Himel, at the University of Tennessee, compared the torsional properties of stainless steel K-type and nickel-titanium U-type instruments. As in previous studies, all of the stainless steel instruments showed no significant difference between maximum torque and torque at failure, whereas the nickel-titanium instruments showed a significant difference between maximum torque and torque at failure. Essentially, this means that the time between “wind-up” and fracture in nickel-titanium instruments is extended, which could lead to a false sense of security.

While studying cyclic fatigue using nickel-titanium LIGHTSPEED instruments, Pruett et al. determined that canal curvature and the number of rotations determined file breakage. Separation occurred at the point of maximum curvature of the shaft. Cyclic fatigue should be considered a valid term, even for hand instrumentation, in light of the fact that many manufacturers are placing handles on files designed for rotational use.

From these studies, it seems that if the clinician is changing from a high-torque instrument, such as stainless steel, to a low-torque instrument, such as nickel titanium, it would be wise to know that nickel-titanium instruments are more efficient and safer when used passively.

Although instrument breakage should be rare, any instrument, hand or rotary, can break. It is the clinician’s knowledge and experience, along with the manu-
facturer’s quality control, that will ultimately minimize breakage. At both the University of Tennessee and University of California at Los Angeles, breakage has not increased with the routine use of nickel-titanium instruments. If breakage occurs, the fractured piece can occasionally be removed or bypassed using ultrasonics and hand instruments in conjunction with magnification. The dentist having problems with file breakage should seek help in evaluating his technique. One should practice on extracted teeth until a level of confidence is reached that will help ensure safe and efficient patient care.

The following is a list of situations that place nickel-titanium hand instruments at risk along with suggestions for avoiding problems:

**Nickel-Titanium Precautions and Prevention**

1. Often too much pressure is applied to the file. Never force a file! These instruments require a passive technique. If resistance is encountered, stop immediately, and before continuing, increase the coronal taper and negotiate additional length, using a smaller, 0.02 taper stainless steel hand file. Stainless steel files should be used in sizes smaller than a No. 15. If one is using more finger pressure than that required to break a No. 2 pencil lead, too much pressure is being used. Break a sharp No. 2 pencil lead and see how little pressure is required!

2. Canals that join abruptly at sharp angles are often found in roots such as the mesiobuccal root of maxillary molars, all premolars, and mandibular incisors and the mesial roots of mandibular molars. The straighter of the two canals should first be enlarged to working length and then the other canal, only to where they join. If not, a nickel-titanium file may reverse its direction at this juncture, bending back on itself and damaging the instrument.

3. Curved canals that have a high degree and small radius of curvature are dangerous. Such curvatures (over 60 degrees and found 3 to 4 mm from working length) are often seen in the distal canals of mandibular molars and the palatal roots of maxillary first molars.

4. Files should not be overused! All clinicians have experienced more fracture after files have been used a number of times. Remember that all uses of a file are not equal. A calcified canal stresses the file more than an uncalcified canal. A curved canal stresses the file more than a straight canal. One must also bear in mind operator variability and the use of lubricants, which will affect stress.

Consider discarding a file after abusive use in calcified or severely curved canals even though it has been used only in one tooth. Use new files in hard cases and older files in easier cases. No one knows the maximum or ideal number of times a file can be used. Follow manufacturers’ instructions and the rule of being “better safe than sorry.” Once only is the safest number.

5. Instrument fatigue occurs more often during the initial stages of the learning curve. The clinician changing from stainless steel to nickel titanium should take continuing education courses with experienced clinicians and educators, followed by *in vitro* practice on plastic blocks and extracted teeth. Break files in extracted teeth! Developing a level of skill and confidence allows one to use the technique clinically.

6. Ledges that develop in a canal allow space for deflection of a file. The nickel-titanium instrument can then curve back on itself. A nickel-titanium instrument should not be used to bypass ledges. Only a small curved stainless steel file should be used, as described, in another section of this text.

7. Teeth with “S”-type curves should be approached with caution! Adequate **flaring of the coronal third to half** of the canal, however, will decrease problems in these cases. It may also be necessary to go through a series of instruments an additional time or two in more difficult cases.

8. If the instrument is progressing easily in a canal and then feels as if it hits bottom, DO NOT APPLY ADDITIONAL PRESSURE! This will cause the instrument tip to bind. Additional pressure applied at this point may cause weakening or even breakage of the instrument. In this situation, remove the instrument and try a smaller, 0.02 taper hand instrument, either stainless steel or nickel-titanium, carefully flaring and enlarging the uninstrumented apical portion of the canal.

9. Avoid creating a canal the same size and taper of the instrument being used. The only exception is in the use of the Buchanan GT file concept (to be discussed later). On removal from the canal, the debris pattern on the file should be examined. Debris should appear on the middle portion of the file. Except for negotiating calcified canals and enlarging the apical portion of the canal, the tip and coronal section of the file should not carry debris. Avoid **cutting with the entire length of the file blade**. This total or frictional fit of the file in the canal will cause the instrument to lock.

If this occurs, rotate the instrument in a counterclockwise direction and remove it from the canal.
The greater the distance a single file is advanced into the canal, the greater will be the chance of files “locking up.” When the file feels tight throughout the length of blade, it is an indication that the orifice and coronal one-third to two-thirds of the canal need increased taper. Instruments of varying design and/or taper can be used to avoid frictional fit. Nickel-titanium instruments with tapers from 0.04, 0.06, and greater, as well as Gates-Glidden drills and sonic/ultrasonic instruments, serve this purpose well.

10. Sudden changes in the direction of an instrument caused by the operator (ie, jerky or jabbing movements) must be avoided. A smooth gentle reaming or rotary motion is most efficient.

11. As with any type of instrument, poor access preparation will lead to procedural errors.

12. Advancing or pushing an instrument into a canal in too large an increment causes it to act as a drill or piston and greatly increases stress on the metal. Except for the most difficult cases and the necessity of using small instruments, the tip should not be used to cut into or drill into the canal; it should act only as a guide. Regardless of the technique being used, nickel-titanium instruments should be advanced in small increments with a more passive pressure than that used with stainless steel.

13. Do not get in a hurry! Do not get greedy and try to make nickel titanium do more than it is designed to do.

14. Inspection of instruments, particularly used instruments, by staff and doctor is critical. Prior to insertion and on removal, look at the blade. Rotate the file, looking for deflections of light. This indicates a damaged instrument. Also remember that, unlike stainless steel, nickel-titanium has an excellent memory. The file should be straight. If any bend is present, the instrument is fatigued and should be replaced.

15. Do not assume that the length of files is always accurate; measure each file. Some files are longer from handle to tip than others. Files may also become longer or shorter if they are unraveled or twisted.

**Comparative Studies**

Nickel-titanium instruments function differently than those made of stainless steel, even when the cross-sectional design, taper, flutes, and tip are identical. In an effort to compare hand nickel-titanium to stainless steel files, a series of studies were initiated at The University of Tennessee. Eighty-two second-year dental students were required to instrument two epoxy blocks containing curved canals. The only variable was the use of stainless steel files in one block and nickel-titanium files in the second block. Standardized photographs were taken of the blocks before and after instrumentation. Overlay tracings were made of these photographs, and differences in the shapes of the before and after drawings were measured.

The nickel-titanium blocks received a higher grade of 67.9% of the time and the stainless steel blocks 14.8% of the time. Working length was maintained significantly more often (p < .05) in the nickel-titanium group than in the stainless steel group. There was no ledging of canals using the more flexible nickel-titanium files compared with 30.4% ledging when stainless steel files were used. When using nickel-titanium files, the students were short of working length in only 3% of the canals compared with 46% of the canals when using stainless steel files. Although the canals were instrumented beyond the intended working length in 25% of the nickel-titanium blocks, the students were able to develop an apical stop within 1 mm between working length and the end of the canal. In the stainless steel group, 6% of canals fell into this category. The degree of destruction around the foramen was significantly different (p < .05). Apical zipping occurred 31.7% less often with the Nitinol files. Stripping of the canal walls was less with the nickel-titanium files. A second study in which the blocks were instrumented by a member of the faculty had similar findings.

An observation from these studies was the creation of a smooth belly shape on the outer aspect of the apical third of the canals instrumented with nickel-titanium instruments. This seemed to replace the ledging that occurred with stainless steel. Other studies have shown that this may be attributable to the technique in which the files were used.

Are nickel-titanium hand instruments best used with a push-pull filing motion or with a reaming or rotary motion? In one study, nickel-titanium files used in a filing motion caused a significantly greater amount of the outer canal wall to be removed, between 3 and 6 mm short of working length. The stainless steel files, however, removed significantly more of the outer canal wall, at working length and in the danger zone, than did the rotary or hand nickel-titanium files. The rotary nickel-titanium files were significantly faster and maintained better canal shape than the other groups. The results of this study indicate that nickel-titanium instruments should be used with a rotational or reaming motion and are effective in shaping root canal systems.

Using computed tomography, Gambill et al. reamed extracted teeth with either stainless steel or nickel-titanium files and reported that the nickel-titanium files caused less canal transportation, removed
less dentin, were more efficient, and produced more centered canals.142

On the other hand, not all studies are in agreement concerning cutting efficiency. Tepel et al. tested 24 brands of hand instruments specifically for cutting efficiency. They found that flexible stainless steel files were more efficient than nickel titanium. However, they did not address the quality of the completed canal.143

Elliot et al., at Guy’s Hospital in London, used resin blocks to compare stainless steel (Flexo fi) and nickel-titanium (Nitiflex) instruments used with either a balanced force or stepback technique.144 The authors concluded that it is preferable to use nickel-titanium instruments in a balanced force technique and stainless steel in a filing technique because stainless steel files can be precurved. Considering the results from Tennessee and London, nickel-titanium instruments should be used as reamers, not files.

**ISO Groups II and III**

Engine-driven instruments can be used in three types of contra-angle handpieces: a full rotary handpiece, either latch or friction grip, a reciprocating/quarter-turn handpiece, or a special handpiece that imparts a vertical stroke but with an added reciprocating quarter-turn that “cuts in” when the instrument is stressed. In addition, there are battery-powered, slow-speed handpieces that are combined with an apex locator, designed to prevent apical perforations. Because the instruments used in these handpieces are generally designed for the type of action delivered, it is best to describe the handpiece before discussing their instruments.

**Rotary Contra-angle Handpiece Instruments.** Instrumentation with a full rotary handpiece is by straight-line drilling or side cutting. Mounted with round or tapered burs or diamond points, full rotary contra-angle handpieces can be used to develop coronal access to canal orifices. In addition, special reamers, listed under ISO Group II, may be used to funnel out orifices for easier access, to clean and shape canals with slow-turning nickel-titanium reamer-type instruments, and to prepare post channels for final restoration of the tooth.

Since some of these instruments (stainless) do not readily bend, they should be used in perfectly straight canals. Because they are often misdirected or forced beyond their limits, they notoriously cause perforations or break in the hands of neophytes.

One solution to these problems is to use a slower handpiece: the Medidenta/Micro Mega MM 324 reduction gear Handpieces (Medidenta/Micro Mega, Woodside, N.Y.), the Aseptico Electric Motor Handpiece (Aseptico International, Woodinville, Wash.), the Quantec ETM Electric torque control motor (Sybron-Endo; Irving, Calif.), and the Moyco/Union Broach Sprint EDM Electronic Digital Motor handpiece (Miller Dental; Bethpage, N.Y.). These electric motors are specifically designed to power the new nickel-titanium instruments in canal preparation. The speeds vary from 300 rpm suggested for the NiTi ProFiles (Tulsa Dental; Tulsa, Okla.) to 2,000 rpm recommended for the LightSpeed instruments.

Newer electric handpieces are available wherein not only the speed can be controlled but the torque as well, that is, the speed and torque can be set for a certain size instrument and the handpiece will “stall” and reverse if the torque limit is exceeded. Emerging as contenders in this field are the new Aseptico ITR Motor handpiece (Aseptico International; Woodinville, Wash.), the Nouvag TCM ENDO motor (Nouvag, Switzerland), the new Endo-Pro Electric (Medidenta/MicroMega; Woodside, N.Y.), and the new ProTorq motor handpiece (Micro Motors Inc; Santa Ana, Calif.).

An entirely new “wrinkle” in rotary handpieces is the Morita Tri Auto-ZX (J. Morita USA Inc. Irvine, CA), a cordless, battery-powered, endodontic, slow-speed (280 rpm) handpiece with a built-in apex locator. It uses rotary nickel-titanium instruments held by a push-button chuck. The Tri Auto-ZX has three automatic functions: The handpiece automatically starts when the file enters the canal and stops when the file is removed. If too much pressure is applied, the handpiece automatically stops and reverses rotation. It also automatically stops and reverses rotation when the file tip reaches the apical stop, as determined by the build-in apex locator. The Tri Auto-ZX will work in a moist canal.

**Reciprocating Handpiece.** A commonly used flat plane reciprocating handpiece is the Giromatic (Medidenta/MicroMega; Woodside, N.Y.). It accepts only latch-type instruments. In this device, the quarter-turn motion is delivered 3,000 times per minute. More recently, Kerr has introduced the M4 Safety Handpiece (Sybron-Kerr; Orange, Calif.), which has a 30-degree reciprocating motion and a unique chuck that locks regular hand files in place by their handles (Figure 10-30). The Kerr Company recommends that their Safety Hedstrom Instrument be used with the M4. Zakariasen et al. found the M4, mounted with Safety Hedstrom files, to be somewhat superior to “step-back hand preparations and a shorter time of preparation.”145,146 German researchers found much the same for both the M4 and the Giromatic.147

The Endo-Gripper (Moyco/Union Broach; Bethpage, N.Y.) is a similar handpiece, with a 10:1 gear ratio and a 45-degree turning motion. As with the Kerr M4, the Endo-Gripper also uses regular hand, not contra-angle,
instruments. Union Broach recommends their Flex-R and Onyx-R files.

The Giromatic handpiece probably got off to a bad start because of the instruments initially used. Broaches proved less than effective. Then Hedstroem-type files were introduced followed by K-style reamers. Today, Micro Mega recommends their RispiSonic or Triocut as the instruments of choice.

In any event, as the cutting instruments improved, a number of well-known endodontists “came out of the closet,” so to speak, admitting that they often used these reciprocating instruments. The reports were mixed, however, between “zipping” at the apical foramen versus round, tapered preparations.

Vertical Stroke Handpiece. Levy introduced a handpiece that is driven either by air or electrically that delivers a vertical stroke ranging from 0.3 to 1 mm. The more freely the instrument moves in the canal, the longer the stroke. The handpiece also has a quarter-turn reciprocating motion that “kicks in,” along with the vertical stroke, when the canal instrument is under bind in a tight canal. If it is too tight, the motion ceases, and the operator returns to a smaller file. Developed in France, the Canal Finder System (Marseille, France) uses the A file, a clever variation of the H file.

ROTARY INSTRUMENTS

Two of the most historic and popular engine-driven instruments are Gates-Glidden drills and Peeso reamers (drills) (Figure 10-31, A and B).

Gates-Glidden drills are an integral part of new instrumentation techniques for both initial opening of canal orifices and deeper penetration in both straight and curved canals. Gates-Glidden drills are designed to have a weak spot in the part of the shaft closest to the handpiece so that, if the instrument separates, the separated part can be easily removed from the canal. They come in sizes 1 through 6, although these sizes are being converted to the ISO instrument sizes and colors.

In a laboratory study, Leubke and Brantley tested two brands of Gates-Glidden drills by clamping the head of the drill and then twisting the handles either clockwise or counterclockwise. There was no specific pattern to their fracture except that some broke at the head and some high on the shaft near the shank. Luebke and Brantley later repeated the experiment, allowing the drill head to turn as it would in a clinical situation. This...
time, all of the drills fractured near the shank, “a major departure from the previous test.”¹⁵⁸,¹⁵⁹

The Peeso reamer (Dentsply/Maillefer; Tulsa, Okla.) is most often used in preparing the coronal portion of the root canal for a post and core. One must be careful to use the “safe-ended” Peeso drill to prevent lateral perforation. Gutta-percha should have previously been removed to post depth with a hot plugger. Round burs should never be used.

The use of rotary instruments will be described in the instrumentation section. If used correctly, they can be a tremendous help in facilitating instrumentation.

**Rotary K-Type, U-Type, H-Type, and Drill-Type Instruments**

As previously stated, the same instrument designs described for hand instruments are available as rotary-powered instruments. To think this a new idea, one has only to return to a year 1912 catalog to learn that rotary instruments were being used nearly a century ago, K-style rotary “broaches” (reamers) made of carbon steel (Figure 10-32). At that early time, the probability of their breakage was precluded by the very slow speed of the treadle-type, foot-powered handpieces.

Today, at speeds that vary from 300 to 2,500 rpm, and with the growing use of nickel-titanium instruments, rotary canal preparation is once again very much in vogue. Although the K-style configuration is still widely used, the rotary U-style (ProFile) and drill style (Quantec) instruments are proving ever more popular. The use of these instruments will be described later in the chapter.

**Ultrasonic and Sonic Handpieces**

Instruments used in the handpieces that move near or faster than the speed of sound range from standard K-type files to special broach-like instruments. “Ultrasonic endodontics is based on a system in which sound as an energy source (at 20 to 25 kHz) activates an endodontic file resulting in three-dimensional activation of the file in the surrounding medium.”¹⁶⁰ The main debriding action of ultrasonics was initially thought to be by cavitation, a process by which bubbles formed from the action of the file, become unstable, collapse, and cause a vacuum-like ‘implosion.’ A combined shock, shear and vacuum action results.¹⁶⁰

Ultrasonic handpieces use K files as a canal instrument. Before a size 15 file can fully function, however, the canal must be enlarged with hand instruments to at least a size 20.

Although Richman must be credited with the first use (1957) of ultrasonics in endodontics,¹⁶¹ Martin and Cunningham were the first to develop a device, test it, and see it marketed in 1976.¹⁶²–¹⁷¹ Ultimately named the

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**Kerr Engine Drills**

These Drills are made after the plan of our well known Universal Broach, with the exception that they are provided with a Special Drill Point, thus giving a most rapid and clean cutting instrument for enlarging or drilling in the root canal.

They clear themselves of all cuttings while drilling and do not clog.

Made from the toughest spring steel, they can be easily sharpened.

They are put up in sets on a neat wooden block where each drill has its place.

A set comprises twelve drills, six in straight shank for use in canals of the anterior teeth and six for use in the right angle attachment.

Price, each ...... $ .35
Full set as per cut 3.50

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Figure 10-32  Historical illustration of Kerr Engine Drills, circa 1912. The shape of the drills resembles present-day K-style reamers. Made of carbon steel, they were probably safe to use in straight canals with a slow, treadle-type, foot-powered handpiece. (Courtesy of Kerr Dental Manufacturing Co., 1912 catalog.)
Cavitron Endodontic System (Dentsply/Caulk; York, Pa.), (Figure 10-33), it was followed on the market by the Enac unit (Osada Electric Co., Los Angeles, Calif.) and the Piezon Master 400 (Electro Medical Systems, SA, Switzerland), as well as a number of “copycat” devices. These instruments all deliver an irrigant/coolant, usually sodium hypochlorite, into the canal space while cleaning and shaping are carried out by a vibrating K file.

The results achieved by the ultrasonic units have ranged from outstanding162–183 to disappointing.184–189 Surely, there must be an explanation for such wide variance in results.

The answer seems to lie in the extensive experimentation on ultrasonic instruments carried out, principally at Guy’s Hospital in London. They thoroughly studied the mechanisms involved and questioned the role that cavitation and implosion play in the cleansing process.190–192 They believe that a different physical phenomenon, “acoustic streaming,” is responsible for the debridement. They concluded that “transient cavitation does not play a role in canal cleaning with the CaviEndo unit; however, acoustic streaming does appear to be the main mechanism involved.”190 They pointed out that acoustic streaming “depends on free displacement amplitude of the file” and that the vibrating file is “dampened” in its action by the restraining walls of the canal.

The Guy’s Hospital group found that the smaller files generated greater acoustic streaming and hence much cleaner canals. After canals are fully prepared, by whatever means, they recommended returning with a fully oscillating No. 15 file for 5 minutes with a free flow of 1% sodium hypochlorite.191 In another study, the Guy’s Hospital group found that root canals had to be enlarged to the size of a No. 40 file to permit enough

Figure 10-33  A, CaviEndo unit with handpiece (right) and reservoir hatch (top right). Dials (front panel) regulate vibratory settings. Foot control not shown. B, CaviEndo handpiece mounted with an Endosonic diamond file. Irrigating solution emits through a jet in the head. (Courtesy of Dentsply/Cavitron.)
clearance for the free vibration of the No. 15 file at full amplitude. Others, including Martin, the developer, have recommended that the No. 15 file be used exclusively. The efficacy of ultrasonography to thoroughly débride canals following step-back preparation was dramatically demonstrated by an Ohio State/US Navy group. There was an enormous difference in cleanliness between canals merely needle-irrigated during preparation and those canals prepared and followed by 3 minutes of ultrasonic instrumentation with a No. 15 file and 5.25% sodium hypochlorite.

Another British group reached similar conclusions about the oscillatory pattern of endosonic files. These researchers pointed out that the greatest displacement amplitude occurs at the unconstrained tip and that the greatest restraint occurs when the instrument is negotiating the apical third of a curved canal. This is the damping effect noted by the Guy’s Hospital group, the lack of freedom for the tip to move freely to either cut or cause acoustic streaming to cleanse. Krell at The University of Iowa observed the same phenomenon, that the irrigant could not advance to the apex “until the file could freely vibrate.” The British researchers also reported better results if K files were precurved when used in curved canals.

At Guy’s Hospital, another interesting phenomenon was discovered about ultrasonic canal preparation—that, contrary to earlier reports, ultrasonics alone actually increased the viable counts of bacteria in simulated root canals. This was felt to be caused by the lack of cavitation and the dispersal effects of the bacteria by acoustic streaming. On substitution of sodium hypochlorite (2.5%) for water, however, all of the bacteria were killed, proving once again the importance of using an irrigating solution with bactericidal properties.

Ahmad and Pitt Ford also pitted one ultrasonic unit against the other—CaviEndo versus Enac. They evaluated canal shape and elbow formation: “There was no significant difference...in the amount of apical enlargement.” They did find, however, that the Enac unit had a greater propensity for producing “elbows,” as well as apical deviation and change of width.

Ahmad, at Guy’s Hospital, suggested that the manufacturers of ultrasonic units consider different file designs. She found the K-Flex to be more efficient than the regular K style.

Ultrasonic Conclusions

One can draw the conclusion that ultrasonic endodontics has added to the practice of root canal therapy. There is no question that canals are better débrided if ultrasonic oscillation with sodium hypochlorite is used at the conclusion of cavity preparation. But the files must be small and loose in the canal, particularly in curved canals, to achieve optimum cleansing.

Sonic Handpieces

The principal sonic endodontic handpiece available today is the Micro Mega 1500 (or 1400) Sonic Air Endo System (Medidenta/ Micro Mega) (Figure 10-34). Like the air rotor handpiece, it attaches to the regular airline at a pressure of 0.4 MPa. The air pressure may be varied with an adjustable ring on the handpiece to give an oscillatory range of 1,500 to 3,000 cycles per second.
Tap water irrigant/coolant is delivered into the preparation from the handpiece.

Walmsley et al., in England, studied the oscillatory pattern of sonically powered files. They found that out in the air, the sonic file oscillated in a large elliptical motion at the tip. When loaded, as in a canal, however, they were pleased to find that the oscillatory motion changed to a longitudinal motion, up and down, “a particularly efficient form of vibration for the preparation of root canals.”

The strength of the Micro Mega sonic handpiece lies in the special canal instruments used and the ability to control the air pressure and hence the oscillatory pattern. The three choices of file that are used with the Micro Mega 1500 are the RispiSonic, developed by Dr. Retano Spina in Italy, the Shaper Sonic (Medidenta; Woodside, N.Y.), developed by Dr. J. M. Laurichesse in France, and the Trio Sonic (Medidenta; Woodside, N.Y.) (also called in Europe the Heliosonic and the Triocut File) (Figure 10-35). The Rispi Sonic resembles the old rat-tail file. The Shaper Sonic resembles a husky barbed broach. The Trio Sonic resembles a triple-helix Hedstroem file. All of these instruments have safe-ended noncutting tips.

The RispiSonic has 8 cutting blades and the Shaper Sonic has 16. The ISO sizes range from 15 to 40. Because graduated-size instruments have varying shaft sizes, the instrument must be tuned with the unit’s tuning ring to an optimum tip amplitude of 0.5 mm.

As with the ultrasonic canal preparation, these instruments must be free to oscillate in the canal, to rasp away at the walls, and to remove necrotic debris and pulp remnants. To accommodate the smallest instrument, a size 15, the canal must be enlarged to the working length with hand instruments through size No. 20. The sonic instruments, with the 1.5 to 2.0 mm safe tips, begin their rasping action this far removed from the apical stop. This is known as the “sonic length.” As the instrument becomes loose in the canal, the next-size instrument is used, and then the next size, which develops a flaring preparation. The sonic instruments are primarily for step-down enlarging, not penetration.

Cohen and Burns emphasized the three objectives of shaping the root canal: “(a) developing a continuous tapering conical form; (b) making the canal narrow apically with the narrowest cross-sectional diameter at its terminus, and (c) leaving the apical foramen in its original position spatially.”

To satisfy these requirements, two of the sonic instruments have been quite successful. At the dental school in Wales, Dummer et al. found the Rispi Sonic and Shaper Sonic files to be the most successful, the Trio Sonic less so: “In general, the Shaper Sonic files widened the canals more effectively than the Rispi Sonic files, whilst the Heliosonic [Trio Sonic] files were particularly ineffective.”

The research group at Temple University found essentially the same results. They recommended that the Shaper Sonic files be used first and that the remaining two-thirds of the canal be finished with the Rispi Sonic. Ehrlich et al. compared canal apical transport using Rispi Sonic and Trio Sonic files versus hand instrumentation with K files. They found no difference in zipping among the three instruments. Even the worst transport was only 0.5 mm. Tronstad and Niemczyk also tested the Rispi and Shaper files against other instruments. They reported no complications (broken instruments, perforations, etc) with either of the sonic instruments. Miserendino et al. also found that the “Micro Mega sonic vibratory systems using Rispi Sonic and Shaper files were significantly more efficient than the other systems tested.”

Comparisons in Efficacy and Safety of Automated Canal Preparation Devices

Before making an investment in an automated endodontic device, one should know the comparative values of the different systems and their instruments.
Unfortunately, the ultimate device and instrument has not been produced and tested as yet. Some are better in cutting efficiency, some in following narrow curved canals, some in producing smooth canals, and some in irrigating and removing smear layer, but apparently none in mechanically reducing bacterial content.

As stated above, Miserendino et al. found that the cutting varied considerably. They ranked the RispiSonic file at the top, followed by the ShaperSonic, the Enac “U” file (Osada Electric), and the CaviEndo K file. Tronstad and Niemczyk’s comparative study favored the Canal Finder System in narrow, curved canals. On the other hand, the Rispi and Shaper files in the Micro Mega Sonic handpiece proved the most efficacious “in all types of root canals.” The Cavitron Endo System was a disappointment in that it was so slow, blocked and edged the canals, and fractured three files in severely curved canals. They also found the Giromatic with Rispi files to be effective in wide straight canals, less so in curved canals, where four Rispi files fractured.

Bolanos et al. also tested the Giromatic with Rispi files against the Micro Mega Sonic handpiece with Rispi and Shaper files. They found the RispiSonic best in straight canals, the ShaperSonic best in curved canals, and both better than the Giromatic/Rispi and/or hand instrumentation with K-Flex files. The Shaper files left the least debris and the Giromatic/Rispi left “an extensive amount of debris.”

Kielt and Montgomery also tested the Micro Mega Sonic unit with TrioSonic files against the ultrasonic Cavitron Endo and Enac units with K files. Even though others found the Trio Sonic files less effective (than the Rispi or Shaper files), Kielt and Montgomery concluded that “overall the Medidenta unit was superior to the other endosonic systems and to the hand technique (control).” The Zakariasen group at Dalhousie University reported unusual success in combining hand instrumentation with sonic enlargements using the Micro Mega 1500.

Walker and del Río also compared the efficacy of the Cavitron Endo and Enac ultrasonic units against the Micro Mega Sonic unit and found “no statistically significant difference among the groups, however, liquid extruded from the apical foramen in 84% of their test teeth. They felt that “sodium hypochlorite may improve the debridement of the canal.” They also did not test the Rispi or Shaper Sonic files.

At the University of Minnesota, the ultrasonic units were again tested against the sonic unit. The researchers found the Micro Mega Sonic to be the fastest in preparation time and caused the “least amount of straightening of the canals.” On the other hand, Reynolds et al., at Iowa, found hand preparation with the step-back technique superior to sonic and ultrasonic preparation except in the important apical area, where they were similar. The Iowa group also found that ultrasonic and sonic files best cleaned ovoid canals.

Lev et al. prepared the cleanest canals using the step-back technique followed by 3-minute use of a CaviEndo ultrasonic file with sodium hypochlorite. This approach has become an optimum and standard procedure for many endodontists.

Stamos et al. also compared cleanliness following ultrasonic débridement with sodium hypochlorite or tap water. Using water alone, the Enac system was more effective, but when sodium hypochlorite was used, the CaviEndo unit (which has a built-in tank) was superior. They also reported ultrasonic preparation to be “significantly faster” than hand instrumentation.

A US Army research group tested sonic versus ultrasonic units and concluded that they were all effective in canal preparation but judged the Micro Mega Sonic Air System, using Rispi and Shaper Sonic files, “as the best system tested.”

Fairbourn et al. compared four techniques according to the amount of debris extruded from the apex. The sonic technique extruded the least and hand instrumentation the most debris. Ultrasonic was halfway between. Whether the debris discharged into the apical tissue contains bacteria was of the utmost importance. Using sterile saline as an irrigant, Barnett et al. found sodium hypochlorite to be four times more effective than sterile saline. A US Navy group found essentially the same thing.

Comparative Conclusion of Automated Devices. It appears safe to say that no one automated device will answer all needs in canal cleaning and shaping. Hand instrumentation is essential to prepare and cleanse the apical canal, no matter which device, sonic or ultrasonic, is used. The sonic unit Micro Mega 1500 reportedly enlarges the canal the fastest when Rispi or Shaper files are used, whereas the Canal Finder System, using A-style files, leads in instrumenting narrow curved canals. Finally, the ultrasonic CaviEndo and Enac units, using small K files and half-strength sodium hypochlorite for an extended time (3 minutes), seem to debride the canal best. No technique without sodium hypochlorite kills bacteria, however.

One must evaluate one’s practice and decide which device, no device, or all three best suit one’s needs.

ISO Group IV Filling Materials
An ADA specification has also been written for filling materials—core materials such as gutta-percha and sil-
ver points, as well as sealer cements classified by their chemical make-up and mode of delivery.

**IRRIGATION**

**Chemomechanical Débridement**

The pulp chamber and root canals of untreated nonvital teeth are filled with a gelatinous mass of necrotic pulp remnants and tissue fluid (Figure 10-36). Essential to endodontic success is the careful removal of these remnants, microbes, and dentinal filings from the root canal system. The apical portion of the root canal is especially important because of its relationship to the periradicular tissue. Although instrumentation of the root canal is the primary method of canal débridement, irrigation is a critical adjunct. Irregularities in canal systems such as narrow isthmi and apical deltas prevent complete débridement by mechanical instrumentation alone. Irrigation serves as a physical flush to remove debris as well as serving as a bactericidal agent, tissue solvent, and lubricant. Furthermore, some irrigants are effective in eliminating the smear layer.

A potential complication of irrigation is the forced extrusion of the irrigant and debris through the apex. This raises questions concerning the choice of irrigating solution, the best method of delivering the irrigant, and the volume of irrigant used. Other variables include how long the solution is left in the canal, ultrasonic activation, temperature of the irrigant, and the effect of combining different types of solutions. Although the presence of an irrigant in the canal throughout instrumentation facilitates the procedure, there are specific lubricating agents designed for that purpose: examples are RC Prep (Premier Dental; King of Prussia, Pa.), GlyOxide (Smith Kline Beecham, Pittsburgh, Pa.), REDTAC (Roth International, Chicago, Ill.), and Glyde File Prep (Dentsply/Maillefer; Tulsa, Okla.). It is highly recommended that canals always be instrumented while containing an irrigant and/or a lubricating agent. Instrumentation in this manner may prevent the complicity of losing contact with the measurement control owing to an accumulation of debris in the apical segment of the canal.

**Root Canal Irrigants**

A wide variety of irrigating agents are available. It is recommended that the practitioner understands the potential advantages and disadvantages of the agent to be used.

**Sodium Hypochlorite.** Sodium hypochlorite is one of the most widely used irrigating solutions. Household bleach such as Chlorox contains 5.25% sodium hypochlorite. Some suggest that it be used at that concentration, whereas others suggest diluting it with water, and still others alternate it with other agents, such as ethylenediaminetetraacetic acid with centrimide (EDTAC) (Roydent Products; Rochester Hills, Mich.) or chlorhexidine (Proctor & Gamble, Cincinnati, Ohio). Sodium hypochlorite is an effective antimicrobial agent, serves as a lubricant during instrumentation, and dissolves vital and nonvital tissue. Questions concerning the use of sodium hypochlorite are often focused on the appropriate concentration, method of delivery, and concern with cellular damage caused by extrusion into the periradicular tissues. Researchers do not agree on the precise concentration of sodium hypochlorite that is advisable to use.

Baumgartner and Cuenin, in an *in vitro* study, found that 5.25%, 2.5%, and 1.0% solutions of sodium hypochlorite completely removed pulpal remnants and predentin from uninstrumented surfaces of single-canal premolars. Although 0.5% sodium hypochlorite removed most of the pulpal remnants and predentin from uninstrumented surfaces, it left some fibrils on the surface. They commented that “It seemed probable that
there would be a greater amount of organic residue present following irrigation of longer, narrower, more convoluted root canals that impede the delivery of the irrigant. This concern seems reasonable as the ability of an irrigant to be distributed to the apical portion of a canal is dependent on canal anatomy, size of instrumentation, and delivery system. Trepagnier et al. reported that either 5.25% or 2.5% sodium hypochlorite has the same effect when used in the root canal space for a period of 5 minutes.220

Spångberg et al. noted that 5% sodium hypochlorite may be too toxic for routine use.221 They found that 0.5% sodium hypochlorite solution dissolves necrotic but not vital tissue and has considerably less toxicity for HeLa cells than a 5% solution. They suggested that 0.5% sodium hypochlorite be used in endodontic therapy. Byström and Sundquist examined the bacteriologic effect of 0.5% sodium hypochlorite solution in endodontic therapy.222 In that in vivo study, using 0.5% sodium hypochlorite, no bacteria could be recovered from 12 of 15 root canals at the fifth appointment. This was compared with 8 of 15 root canals when saline solution was used as the irrigant. Baumgartner and Cuenin also commented that “The effectiveness of low concentrations of NaOCl may be improved by using larger volumes of irrigant or by the presence of replenished irrigant in the canals for longer periods of time.”219 On the other hand, a higher concentration of sodium hypochlorite might be equally effective in shorter periods of time.

Siqueira et al., in an in vitro study, evaluated the effect of endodontic irrigants against four black-pigmented gram-negative anaerobes and four facultative anaerobic bacteria by means of an agar diffusion test. A 4% sodium hypochlorite solution provided the largest average zone of bacterial inhibition and was significantly superior when compared with the other solutions, except 2.5% sodium hypochlorite (p < .05). Based on the averages of the diameters of the zones of bacterial growth inhibition, the antibacterial effects of the solution were ranked from strongest to weakest as follows: 4% sodium hypochlorite; 2.5% sodium hypochlorite; 2% chlorhexidine, 0.2% chlorhexidine EDTA, and citric acid; and 0.5% sodium hypochlorite.223

The question of whether sodium hypochlorite is equally effective in dissolving vital, nonvital, or fixed tissue is important since all three types of tissue may be encountered in the root canal system. Rosenfeld et al. demonstrated that 5.25% sodium hypochlorite dissolves vital tissue.224 In addition, as a necrotic tissue solvent, 5.25% sodium hypochlorite was found to be significantly better than 2.6%, 1%, or 0.5%.225 In another study, 3% sodium hypochlorite was found to be optimal for dissolving tissue fixed with paraphenol or formaldehyde.226 Clearly, the final word has not been written on this subject.

Sodium Hypochlorite Used in Combination with Other Medicaments. Whether sodium hypochlorite should be used alone or in combination with other agents is also a source of controversy. There is increasing evidence that the efficacy of sodium hypochlorite, as an antibacterial agent, is increased when it is used in combination with other solutions, such as calcium hydroxide, EDTAC, or chlorhexidine. Hasselgren et al. found that pretreatment of tissue with calcium hydroxide can enhance the tissue-dissolving effect of sodium hypochlorite.227

Wadachi et al., using 38 bovine freshly extracted teeth, studied the effect of calcium hydroxide on the dissolution of soft tissue on the root canal wall.228 They found that the combination of calcium hydroxide and sodium hypochlorite was more effective than using either medicament alone.

However, Yang et al., using 81 freshly extracted human molars, examined the cleanliness of main canals and inaccessible areas (isthmi and fins) at the apical, middle, and coronal thirds.229 Complete chemomechanical instrumentation combined with 2.5% sodium hypochlorite irrigation alone accounted for the removal of most tissue remnants in the main canal. Prolonged contact with calcium hydroxide to aid in dissolving main canal tissue remnants after complete instrumentation was ineffective. They also found that tissues in inaccessible areas (isthmi and fins) of root canals were not contacted by calcium hydroxide or sodium hypochlorite and were poorly debrided. As they noted, however, it could be that their study did not permit sufficient time (1 day or 7 days) for the tissue to be degraded. Hasselgren et al. reported that porcine muscle was completely dissolved after 12 days of exposure to calcium hydroxide.227 The contrasting results of some investigators may be explained by their different methodologies including varied tissues studied, as well as a variety of delivery systems and the vehicle included in the calcium hydroxide mix.

Other variables to be considered include temperature as well as shelf life of the solution.230–232 Raphael et al. tested 5.25% sodium hypochlorite on Streptococcus faecalis, Staphylococcus aureus, and Pseudomonas aeruginosa at 21°C and 37°C and found that increasing the temperature made no difference on antimicrobial efficacy and may even have decreased it.233 Pseudomonas aeruginosa was particularly difficult to eliminate. Buttler and Crawford, using Escherichia coli and Salmonella typhosa, studied 0.58%, 2.7%, and 5.20% sodium
hypochlorite for its ability to detoxify endotoxin. All three concentrations were equally effective; however, large amounts of *E. coli* endotoxin could not be detoxified by 1 mL of 0.58% or 2.7% sodium hypochlorite. How this relates to the clinical situation is uncertain.

Against most anaerobic bacteria, Byström and Sundqvist found 5.0% and 0.5% sodium hypochlorite equally effective. By combining 5.0% sodium hypochlorite with EDTA, however, the bactericidal effect was considerably enhanced. This could be related to the removal of the contaminated smear layer by EDTA.

Fischer and Huerta believe that it is the alkaline property (pH 11.0 to 11.5) of sodium hypochlorite that makes it effective against anaerobic microbes, and a US Army group found full-strength sodium hypochlorite to be effective in 5 minutes against obligate anaerobes.

Possibly, the bactericidal effect gained by combining sodium hypochlorite with other chemicals comes from the release of chlorine gas. This was especially true of citric acid and to some extent with EDTA, but not with peroxide.

Sodium hypochlorite is a tissue irritant, and this has deterred its use, particularly at full strength. There is no question that, forced out the apex, most irrigants can be destructive. This will be discussed in detail in chapter 14 on mishaps.

**Other Irrigants.** Salvizol (Ravensberg Konstanz, Germany) is a root canal chelating irrigant, N1-decamethylene-bis-4-aminoquinaldinium-diacetate. Kaufman et al. have suggested that Salvizol, with a neutral pH, has a broad spectrum of bactericidal activity and the ability to chelate calcium. This gives the product a cleansing potency while being biologically compatible (Figure 10-37). This applies to Tublicid (green, red, and blue) (Dental Therapeutics AB, Sweden) as well.

Chlorhexidine gluconate is an effective antimicrobial agent, and its use as an endodontic irrigant has been well documented. It possesses a broad-spectrum antimicrobial action, substantivity, and a relative absence of toxicity. However, chlorhexidine gluconate is not known to possess a tissue-dissolving property.

The results from the individual trial of chlorhexidine gluconate and sodium hypochlorite indicate that they are equally effective antibacterial agents. However, when Kuruvilla and Kamath combined the solutions within the root canal, the antibacterial action was suggestive of being augmented.

The results of their study indicate that the alternate use of sodium hypochlorite and chlorhexidine gluconate irrigants resulted in a greater reduction of microbial flora (84.6%) when compared with the individual use of sodium hypochlorite (59.4%) or chlorhexidine gluconate (70%) alone.

White et al. found that chlorhexidine instills effective antimicrobial activity for many hours after instrumentation. Although sodium hypochlorite is equal-

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**Figure 10-37** A, Coronal portion of a root canal of a tooth treated *in vivo* with Salvizol. The canal wall is clean, and very small pulpal tissue remnants are present; the tubules are open, and many intertubular connections with small side branches are visible. B, Middle portion of root canal treated with Salvizol. Note the tridimensional framework arrangement of tubular openings. Very little tissue debris is present. Intratubular connections are clearly seen. Reproduced with permission from Kaufman AY et al.
ly effective on initial exposure, it is not a substantive antimicrobial agent.

Kaufman reported the success of several cases using bis-dequalinium acetate (BDA) as a disinfectant and chemotherapeutic agent. He cited its low toxicity, lubrication action, disinfecting ability, and low surface tension, as well as its chelating properties and low incidence of post-treatment pain.

Others have pointed out the efficacy of BDA. In one report, it was rated superior to sodium hypochlorite in débriding the apical third. When marketed as Solvidont (Dentsply/DeTrey, Switzerland), the University of Malaysia reported a remarkable decrease in postoperative pain and swelling when BDA was used. They attributed these results to the chelation properties of BDA in removing the smear layer coated with bacteria and contaminants as well as the surfactant properties that allow BDA “to penetrate into areas inaccessible to instruments.” Bis-dequalinium acetate is recommended as an excellent substitute for sodium hypochlorite in those patients who are allergic to the latter. Outside North America, it enjoys widespread use.

A Loyola University in vitro study reported that full-strength Clorox (sodium hypochlorite) and Gly-Oxide (urea peroxide), used alternately, were 100% effective against Bacteroides melaninogenicus, which has been implicated as an endodontic pathogen. Alternating solutions of sodium hypochlorite and hydrogen peroxide cause a foaming action in the canal through the release of nascent oxygen. Hydrogen peroxide (3%) alone also effectively “bubbles” out debris and mildly disinfects the canal. In contrast, Harrison et al. have shown that using equal amounts of 3% hydrogen peroxide and 5.25% sodium hypochlorite inhibited the antibacterial action of the irrigants. Because of the potential for gaseous pressure from residual hydrogen peroxide, it must always be neutralized by the sodium hypochlorite and not sealed in the canal.

It must be understood that each of the studies cited above has examined limited test results concerning the use of various irrigants or combinations of irrigants. However, there are other factors aside from the solution used. For example, Ram pointed out that the irrigational removal of root canal debris seems to be more closely related to canal diameter than to the type of solution used. This, in turn, must be related to the viscosity or surface tension of the solution, the diameter and depth of penetration of the irrigating needle, the volume of the solution used, and the anatomy of the canal.

Ultrasonic Irrigation. As stated previously, the use of ultrasonic or sonic irrigation to better cleanse root canals of their fillings, debris, and bacteria, all the way to the apex, has been well documented by Cunningham et al. as well as others. More recently, they have been joined by a number of clinicians reporting favorable results with ultrasonic/sonic irrigation, from thoroughly cleansing the walls in necrotic open apex cases, to removing the smear layer. Griffiths and Stock preferred half-strength sodium hypochlorite to Solvidont in débriding canals with ultrasound. Sjögren and Sundqvist found that ultrasonography was best in eliminating canal bacteria but still recommended the “use of an antibacterial dressing between appointments.”

Others were not as impressed. In fact, one group found sodium hypochlorite somewhat better than tap water when used with ultrasonography but also noted that both irrigants were ineffective “in removing soft tissue from the main canal, the isthmus between canals, the canal fins, and the multiple branches or deltas.” However, they used ultrasonics for only 3 minutes with a No. 15 file and 1 minute with a No. 25 diamond file. As Druttman and Stock pointed out, “with the ultrasonic method, results depended on irrigation time.” As previously noted, the cleanest canals are achieved by irrigating with ultrasonics and sodium hypochlorite for 3 minutes after the canal has been totally prepared. Moreover, ultrasonics proved superior to syringe irrigation alone when the canal narrowed to 0.3 mm (size 30 instrument) or less. Buchanan noted that it is the irrigants alone that clean out the accessory canal. Instruments cannot reach back into these passages. Only the copious use of a tissue-dissolving irrigant left in place for 5 to 10 minutes repeatedly will ensure auxiliary canal cleaning.

Figure 10-38 Irrigating solution climbs the shaft of a CaviEndo vibrating No. 15 file to agitate and débride unreachable spaces in the canal. (Courtesy of Dentsply/Cavitron.)
Method of Use

Although the technique for irrigation is simple, the potential for serious complications exists. Regardless of the delivery system, the solution must be introduced slowly and the needle never wedged in the canal. The greatest danger exists from forcing the irrigant and canal debris into the periradicular tissue owing to a piston-like effect. Several types of plastic disposable syringes are available.

Usually, the irrigating solution is kept in a dappen dish that is kept filled. The syringe is filled by immersing the hub into the solution while withdrawing the plunger. The needle, or probe in the case of the ProRinse (Dentsply/Tulsa Dental; Tulsa, Okla.), is then attached. Care must be taken with irrigants like sodium hypochlorite to prevent accidents. Sodium hypochlorite can be irritating to the eyes, skin, and mucous membranes. Some practitioners provide protective glasses to their patients to protect their eyes. Also, it can ruin clothing.

The irrigating needle may be one of several types. It should be bent to allow easier delivery of the solution and to prevent deep penetration of the needle or probe (see Figure 10-38). A commonly used needle is the 27-gauge needle with a notched tip, allowing for solution flowback (see Figure 10-39, insert), or the blunt-end ProRinse. It is strongly recommended that the needle lie passively in the canal and not engage the walls. Severe complications have been reported from forcing irrigating solutions beyond the apex by wedging the needle in the canal and not allowing an adequate backflow.261 This is an important point in view of results suggesting that the proximity of the irrigation needle to the apex plays an important role in removing root canal debris.262 Moser and Heuer reported Monoject endodontic needles (Tyco/Kendall; Mansfield, Mass.) to be the most efficient delivery system in which longer needles of a blunted, open-end system were inserted to the full length of the canal.263 The point is that a larger volume of solution can be delivered by this method. However, the closer the needle tip is placed to the apex, the greater the potential for damage to the periradicular tissues. Druttman and Stock found much the same results, that with “conventional methods, irrigation performance varied with the size of the needle and volume of irrigant.”258

Walton and Torabinejad stated that “Perhaps the most important factor is the delivery system and not the irrigating solution per se.” Furthermore, it was found that the volume of the irrigant is more important than the concentration or type of irrigant.264 Chow found that there was little flushing beyond the depth of the needle, unless the needle was “bound” in the canal and the irrigant forcibly expressed.265 Wedging a needle in a canal is dangerous and can cause serious sequelae.

Canal size and shape are crucial to the penetration of the irrigant. The apical 5 mm are not flushed until they have been enlarged to size 30 and more often size 40 file.266,267 It is reported that “In order to be effective, the needle delivering the solution must come in close proximity to the material to be removed.”262 Small-diameter needles were found to be more effective in reaching adequate depth but were more prone to problems of possible breakage and difficulty in expressing the irrigant from the narrow needles.262 Of course, the closer the needle is to the apical foramen, the more likely it is that solution will be extended into the periradicular tissues.

Kahn, Rosenberg et al. at New York University, in an in vitro study, tested various methods of irrigating the canal. Evaluated were Becton-Dickinson (BD), (Franklin Lake, N.J.) 22-gauge needles; Monoject endodontic needles, 23 and 27 gauge (Tyco/Kendall, Mansfield, Mass.) (Figure 10-39); ProRinse 25-, 28-, and 30-gauge probes (Dentsply/Tulsa Dental; Tulsa, Okla); CaviEndo ultra-

![Figure 10-39](simplest_endodontic_irrigating_system_plastic_disposable_syringe_and_needle_note_that_the_needle_is_loose_in_the_canal_to_allow_backflow_notched_needle_tip_inset_elimination_pressure_monoject)
sonic handpiece (Dentsply/Caulk, York, Pa.); and the MicroMega 1500; Woodside, N.Y.). Canals in plastic blocks were filled with food dye and instrumented to progressively larger sizes.

ProRinse probes were highly effective in all gauges and in all sizes of canals tested. In canals instrumented to size 30 K file and size 35 K file, the smaller-lumen 27-gauge notch-tip needle was found to be highly effective. The larger 23-gauge notch-tip needle was found to be relatively ineffective, as was the standard 22-gauge beveled needle.

The Micromega 1500 and CaviEndo systems were highly effective at the size 20, 25, and 30 K-file levels. Recapitulation, with smaller-sized vibrating files, completely cleared dye from the few apical millimeters.

The zones of clearance beyond the tip of the ProRinse probes were significant in that they indicated that highly effective canal clearance occurred without having to place the tip of the probes at the apical foramina. The effectiveness of the ProRinse seemed related to its design. It has a blunt tip, with the lumen 2 mm from the tip. Expression of fluid through the lumen creates turbulence around and beyond the end of the probe (Figure 10-40).

This model system was created to enable the investigators, using a Sony camcorder, to observe the differences of different irrigating systems. However, there are inherent differences in the in vitro test model from the in vivo situation. In vivo variables that affect delivery of the irrigant are canal length and quality of instrumentation. In vitro results, although potentially valuable, cannot be directly extrapolated to the in vivo situation.

Removal of the Smear Layer

Organic Acid Irrigants. The use of organic acids to irrigate and débride root canals is as old as root canal therapy itself. More recently, though, it has been investigated by Tidmarsh, who felt that 50% citric acid gave the cleanest dentin walls without a smear layer (Figure 10-41). Wayman et al. also reported excellent filling results after preparation with citric acid (20%), followed by 2.6% sodium hypochlorite and a final flushing with 10% citric acid.

In two separate studies, the US Army reported essentially the same results. Both studies, however, emphasized the importance of recapitulation—re-instrumentation with a smaller instrument following each irrigation. Not to be outdone, the US Air Force tested both citric acid and sodium hypochlorite against anaerobic bacteria. They reported them equally effective as a bactericide in 5 to 15 minutes.
Other organic acids have been used to remove the smear layer: polyacrylic acid as Durelon and Fuji II liquids, both 40% polyacrylic acid.\textsuperscript{273}

Chelating Agents. The most common chelating solutions used for irrigation include Tublicid, EDTA, EDTAC, File-Eze, and RC Prep, in all of which EDTA is the active ingredient. Nygaard-\O stby first suggested the use of EDTA for cleaning and widening canals.\textsuperscript{274} Later, Fehr and Nygaard-\O stby introduced EDTAC (N-O Therapeutics Hd, Sweden), quaternary ammonium bromide, used to reduce surface tension and increase penetration.\textsuperscript{275} The optimal pH for the demineralizing efficacy of EDTA on dentin was shown by Valdrighi to be between 5.0 and 6.0.\textsuperscript{276}

Goldberg and Abramovich have shown that EDTAC increases permeability into dentinal tubules, accessory canals, and apical foramina\textsuperscript{277} (Figure 10-42). McComb and Smith found that EDTA (in its commer-
Endodontic Cavity Preparation

1. Cationic form (REDTA), when sealed in the canal for 24 hours, produced the cleanest dentinal walls. Goldman and colleagues have shown that the smear layer is not removed by sodium hypochlorite irrigation alone but is removed with the combined use of REDTA. This study helps answer the question of the composition of the smear layer since chelating agents remove only calcified tissue, whereas sodium hypochlorite removes organic material. Goldberg and Spielberg have shown that the optimal working time of EDTA is 15 minutes, after which time no more chelating action can be expected. This study indicates that EDTA solutions should perhaps be renewed in the canal each 15 minutes.

2. Since Goldman et al.’s landmark research in 1981, reporting the efficacy of EDTA and sodium hypochlorite to remove the smear layer, a host of confirming reports have been published. The US Army Institute of Dental Research, after first reporting the constituents, the thickness, and the layering of the smear layer, followed up with two reports detailing the importance of alternate use of 15% EDTA and 5.25% sodium hypochlorite. They introduced a total of 33 mL of irrigants into each canal, using 27 g blunt Monoject endodontic needles. The original Nygaard-Østby formula for 15% EDTA was used: disodium salt of EDTA, 17 g; distilled water, 100 mL; and 5 N sodium hydroxide, 9.25 mL.

3. Developed by Stewart and others in 1969, RC-Prep is composed of EDTA and urea peroxide in a base of Carbowax. It is not water soluble. Its popularity, in combination with sodium hypochlorite, is enhanced by the interaction of the urea peroxide in RC-Prep with sodium hypochlorite, producing a bubbling action thought to loosen and help float out dentinal debris.

4. Zubriggen et al., however, reported that a residue of RC-Prep remains in the canals in spite of further irrigation and cleansing. This led to the question of the effect of RC-Prep residue on apical seal. Cooke et al. showed that RC-Prep allowed maximum leakage into filled canals—over 2.6 times the leakage of the controls.

**EXPLORATION FOR THE CANAL ORIFICE**

Before the canals can be entered, their orifices must be found. In older patients, finding a canal orifice may be the most difficult and time-consuming operation.

Obviously, a knowledge of pulp anatomy (knowing where to look and expect to find the orifices) is of first importance. Perseverance is the second requirement, followed by a calm resolve not to become desperate and decimate the internal tooth when the orifice does not appear.

The endodontic explorer is the greatest aid in finding a minute canal entrance (Figure 10-43), feeling along the walls and into the floor of the chamber in the area where the orifices are expected to be. Extension of the walls toward these points forms the basic perimeter of the preparation.
A new addition to finding and enlarging canal orifices is the Micro-Opener (Dentsply/Maillefer; Tulsa, Okla.) (Figure 10-44, A), with K-type flutes in 0.04 and 0.06 tapers, mounted like a spreader, that can be used to uncover, enlarge, and flare orifices. This can be followed by the Micro-Debrider in ISO 0.02 taper, Hedstroem-type flutes (Figure 10-44, B) to further flare down the canal.

The radiograph is invaluable in determining just where and in which direction canals enter into the pulp chamber. This is especially true in the maxillary molars. The initial radiograph is one of the most important aids available to the clinician but, unfortunately, one of the least used during cavity preparation. A bite-wing radiograph is particularly helpful in providing an undistorted view of the pulp chamber. The handpiece and bur may be held up to the radiograph to estimate the correct depth of penetration and direction to the orifices (Figure 10-45).

Color is another invaluable aid in finding a canal orifice. The floor of the pulp chamber and the continuous anatomic line that connects the orifices (the so-called molar triangle) are dark (Figure 10-46, A)—dark gray or sometimes brown in contrast to the white or light yellow of the walls of the chamber (Figure 10-46, B). Using a No. 1 or 2 bur and “following out” the colored pathway from one orifice often leads to the elusive second, third, or even fourth orifice.

Canal orifices are often so restrictive that they need to be flared so that instruments may enter easily. Orifice openers, from hand-operated Micro-Openers to contra-angle powered reamers with a greater taper (.0.04, 0.06), and Gates-Glidden drills are de rigueur.

More recent is the development of endodontic ultrasonic units for surgical procedures, that has resulted in attachments for use in the pulp chamber, orifice, and canal. One of these attachments is a “cutting explorer.” These tips allow the clinician not only to pick at the orifice but also to cut into the orifice without removing excessive amounts of dentin. Using magnification (loupes, Orascope [Spectrum Dental, Inc. North
Attlebora, Mass.), or a microscope) can also be a tremendous help in finding and negotiating these canals.

Sometimes a greatly receded pulp has to be followed well down into the root to find the orifice to the remaining canal. Measurements on the radiograph indicate how many millimeters to drill before the orifice is encountered. The use of surgical-length burs, even in a miniature handpiece, will extend the depth of cut to well beyond 15 mm.

It is most important to enlarge the occlusal opening so complete authority over the direction of the instrument can be maintained (Figure 10-47). Repeated radiographs to verify the depth and direction of the cut are also invaluable.

**Axioms of Pulp Anatomy**

Remembering the following axioms of pulp anatomy can be most helpful:

1. The two orifices of the **maxillary** first premolar are further to the buccal and the lingual than is usually suspected (Plate 13).
2. The orifices of the mesiobuccal canals in both the maxillary and mandibular molars are well up under the mesiobuccal cusp, and the outline form must often be widely extended into the cusp (Plates 21 and 22).
3. The orifice to the lingual canal in the **maxillary** molars is **not far** to the lingual but is actually in the center of the mesial half of the tooth (Plates 21 and 22).
4. The orifice to the distobuccal canal of the **maxillary** molars is **not far** to the distobuccal but is actually almost directly buccal from the lingual orifice (Plates 21 and 22).
5. The orifice to the distal canal in **mandibular** molars is **not far** to the distal but is actually in almost the exact center of the tooth (Plates 25 and 26).
6. The orifice to the mesiolingual canal of the **mandibular** molars is **not far** to the mesiolingual but is actually almost directly mesial from the distal orifice (Plates 25 and 26).
7. Certain anatomic variations occur with enough frequency to warrant mention here:
   a. The mesiobuccal root of the **maxillary first molar** may often have an extra mesiolingual canal just lingual to the mesiobuccal orifice (Figure 10-48). It is found in the groove that comes off the mesiobuccal orifice like the tail on a comma. This entire groove should be explored for the mesiolingual canal; 62% of the time, the two mesial canals exit through two separate foramina.28
   b. **Mandibular second** molars frequently have a common mesial orifice that divides about 1 mm...
below the floor of the pulp chamber into a mesiobuccal and a mesiolingual canal.

c. **Mandibular** first and second molars may have two distal canals, with either separate orifices, or a common orifice as described for the mesial.

d. **Mandibular first** premolars frequently have a second canal branching off the main canal to the buccal or lingual, several millimeters below the pulp chamber floor.

e. **Mandibular** incisors frequently have two canals. The lingual canal is hidden beneath the internal “shoulder” that corresponds to the lingual cingulum. This “shoulder” prominence must be removed with a No. 2 long-shank round bur or a fine tapered diamond “stone” to permit proper exploration.

In summary, the unexpected should always be anticipated, and the operator must be prepared to expand the access cavity for convenience in enlarging one of these canals or even just to increase visual examination of the pulp chamber floor in searching for such anatomic variance.

**EXPLORATION OF THE CANAL**

Besides the use of radiographs, the use of a fine curved reamer or file is a method available to determine curvature in canals. Stainless steel instruments are better suited for this purpose. The superelastic properties of nickel titanium, which make them desirous during the cleaning and shaping phase, are not helpful in the smaller sizes (6, 8, 10) when used for pathfinding. Many times, however, it cannot be determined that the canal is curved until enlargement begins and resistance develops to instrument placement above the No. 25 or No. 30 file owing to a lack of file flexibility. This will be discussed later in the chapter.
A curved pathfinder file should be used to explore the walls and direction of the canal. The argument against using a straight instrument is that it may tend to engage the wall at the curve or pivot on a catch on the walls (Figure 10-49). The curved tip of the instrument will scribe a circle when the instrument is turned on its axis, whereas the perfectly straight instrument will rotate only on the central axis of the instrument (Figure 10-50).

A curved pathfinding instrument can be rotated away from a catch or curve on the wall and advanced down the canal to the apical region (see Figure 10-49). From the initial pathfinding instrument, the length of the tooth may be established. With control of probing, poking, twisting, and turning, the fine pathfinder can almost always be penetrated to working length. The action can best be described as a "watch-winding" type of finger action.

If unable to reach the apex with reasonable effort, however, the clinician should increase the taper of the coronal part of the canal. Nickel-titanium files, with tapers greater than the standard ISO 0.02 mm/mm, have proved to make this process safe and more efficient. Once this has been achieved, it becomes possible to advance the pathfinder to working length.

When tentative working length is reached with a curved pathfinder file, the operator can determine the direction of curvature by noting the direction of the tip of the file when it is withdrawn. This is a valuable clue for now the clinician knows the direction in which the canal curves and may guide the instrument accordingly. Valuable time is saved by eliminating exploration each time the instrument is placed in the canal. If a teardrop-shaped silicone stop is placed on the files, the pointed end indicates the direction of the file curvature.

One method to curve an instrument is to insert the tip into the end of a sterile cotton roll or gauze sponge and bend the instrument under the pressure of the thumbnail (Figure 10-51). Cotton pliers used to make this bend damage the flutes of fine instruments. The Buchanan Endo-Bender is better for this task (Sybron Endo/Analytic; Orange, Calif.).

In exploring a canal with a curved instrument, the clinician should always expect the worst. One should probe with the point toward the buccal and lingual, that is, toward the direction of the x-ray beam, always searching for the unusual curvature that does not show on the radiograph. As mentioned previously, the palatal canals of maxillary molars, and the maxillary lateral
incisors and canines, are always suspect. In mandibular premolars, curvature of the canal toward the buccal or lingual is a common occurrence as well (Figure 10-52). In these teeth, particularly the mandibular first premolar, anomalies of the canals frequently exist: double canals, bifurcated canals, and apical deltas are common. This also applies to the mandibular anterior teeth, where a search with the curved pathfinder should always be made for two canals, toward the labial and the lingual (Plates 9, F and 11, D).

Extra canals, such as three canals in the maxillary first premolar, two canals in the maxillary second premolar, or two canals in the mesiobuccal root of the maxillary first molar, should also be searched for (Plates 13, 14, 21). The fourth canal toward the distal in a mandibular molar is occasionally found by careful exploration, first with the endodontic explorer and then with the curved instrument. Finding the extra or unusual canal spells the difference between success and failure.

DETERMINATION OF WORKING LENGTH
The determination of an accurate working length is one of the most critical steps of endodontic therapy. The cleaning, shaping, and obturation of the root canal system cannot be accomplished accurately unless the working length is determined precisely.\(^\text{294–296}\)

Anatomic Considerations and Terminology
Simon has stressed the need for clarification and consistency in the use of terms related to working length determination.\(^\text{297}\) Working length (Figure 10-53) is defined in

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Figure 10-51  Curving point of an instrument. The tip is introduced into the end of a sterile cotton roll and is bent under a thumbnail padded by cotton.

Figure 10-52  A, Working length film, mandibular premolar. The patient experienced sensitivity even though the instrument appears approximately 3 mm short of the radiographic apex. B, Preoperative mesio-angled radiograph of the same tooth showing canal curvature and the labial exit of the foramen (arrow) not evident on the working length film. (Courtesy of Dr. Thomas P. Mullaney.)
The apical foramen is the main apical opening of the root canal. It is frequently eccentrically located away from the anatomic or radiographic apex.\textsuperscript{299–301} Kuttler’s investigation showed that this deviation occurred in 68 to 80\% of teeth in his study.\textsuperscript{301} An accessory foramen is an orifice on the surface of the root communicating with a lateral or accessory canal.\textsuperscript{298} They may exist as a single foramen or as multiple foramina.

The apical constriction (minor apical diameter) (Figure 10–54) is the apical portion of the root canal having the narrowest diameter. This position may vary but is usually 0.5 to 1.0 mm short of the center of the apical foramen.\textsuperscript{298–300} The minor diameter widens apically to the foramen (major diameter) and assumes a funnel shape.

The apical third is the most studied region of the root canal.\textsuperscript{299,300,302–307} Dummer and his coworkers reported many variations in the apical constriction.\textsuperscript{300} In 6\% of cases, the constriction may be blocked by cementum.\textsuperscript{300} The cementodentinal junction is the region where the dentin and cementum are united, the point at which the cemental surface terminates at or near the apex of a tooth.\textsuperscript{298} It must be pointed out, however, that the cementodentinal junction is a histologic landmark that cannot be located clinically or radiographically. Langeland reported that the cementodentinal junction does not always coincide with the apical constriction.\textsuperscript{308} The location of the cementodentinal junction also ranges from 0.5 to 3.0 mm short of the anatomic apex.\textsuperscript{298–305,309–313} Therefore, it is generally accepted that the apical constriction is most frequently located...
0.5 to 1.0 mm short of the radiographic apex, but with variations. Problems exist in locating apical landmarks and in interpreting their positions on radiographs.

Clinical Considerations

Before determining a definitive working length, the coronal access to the pulp chamber must provide a straight-line pathway into the canal orifice. Modifications in access preparation may be required to permit the instrument to penetrate, unimpeded, to the apical constriction. As stated above, a small stainless steel K file facilitates the process and the exploration of the canal.

Loss of working length during cleaning and shaping can be a frustrating procedural error. Once the apical restriction is established, it is extremely important to monitor the working length periodically since the working length may change as a curved canal is straightened ("a straight line is the shortest distance between two points"). The loss may also be related to the accumulation of dentinal and pulpal debris in the apical 2 to 3 mm of the canal or other factors such as failing to maintain foramen patency, skipping instrument sizes, or failing to irrigate the apical one-third adequately. Occasionally, working length is lost owing to ledge formation or to instrument separation and blockage of the canal.

Two in vivo studies measured the effect of canal preparation on working length. The mean shortening of all canals in these studies was found to range from 0.40 mm to 0.63 mm.

There has been debate as to the optimal length of canal preparation and the optimal level of canal obturation. Most dentists agree that the desired end point is the apical constriction, which is not only the narrowest part of the canal but a morphologic landmark that can help to improve the apical seal when the canal is obturated.

Failure to accurately determine and maintain working length may result in the length being too long and may lead to perforation through the apical constriction. Destruction of the constriction may lead to overfilling or overextension and an increased incidence of postoperative pain. In addition, one might expect a prolonged healing period and lower success rate owing to incomplete regeneration of cementum, periodontal ligament, and alveolar bone.

Failure to determine and maintain working length accurately may also lead to shaping and cleaning short of the apical constriction. Incomplete cleaning and underfilling may cause persistent discomfort, often associated with an incomplete apical seal. Also, apical leakage may occur into the uncleared and unfilled space short of the apical constriction. Such leakage supports the continued existence of viable bacteria and contributes to a continued periradicular lesion and lowered rate of success.

In this era of improved illumination and magnification, working length determination should be to the nearest one-half millimeter. The measurement should be made from a secure reference point on the crown, in close proximity to the straight-line path of the instrument, a point that can be identified and monitored accurately.

Stop Attachments. A variety of stop attachments are available. Among the least expensive and simplest to use are silicone rubber stops. Several brands of instruments are now supplied with the stop attachments already in place on the shaft. Special tear-shaped or marked rubber stops can be positioned to align with the direction of the curve placed in a precurved stainless steel instrument.

The length adjustment of the stop attachments should be made against the edge of a sterile metric ruler or a gauge made specifically for endodontics. Devices have been developed that assist in adjusting rubber stops on instruments (Figure 10-55). It is critical that the stop attachment be perpendicular and not oblique to the shaft of the instrument (Figure 10-56).

There are several disadvantages to using rubber stops. Not only is it time consuming, but rubber stops may move up or down the shaft, which may lead to preparations short or past the apical constriction.

The clinician should develop a mental image of the position of the rubber stop on the instrument shaft in relation to the base of the handle. Any movement from that position should be immediately detected and corrected. One should also develop a habit of looking directly at the rubber stop where it meets the reference point.

Figure 10-55 Guldener Endo-M-Bloc has 32 depth guides in two rows. Front row indicators from 10 to 30 mm in 1 mm increments. Back row indicators are 0.5 mm deeper. Helpful ruler at end. The device is invaluable in step-back or step-down techniques. (Courtesy of Dentsply/Maillefer).
Endodontic Cavity Preparation

It is imperative that teeth with fractured cusps or cusps severely weakened by caries or restoration be reduced to a flattened surface, supported by dentin. Failure to do so may result in cusps or weak enamel walls being fractured between appointments (Figure 10-57). Thus, the original site of reference is lost. If this fracture goes unobserved, there is the probability of overinstrumentation and overfilling, particularly when anesthesia is used.

To establish the length of the tooth, a stainless steel reamer or file with an instrument stop on the shaft is needed. The exploring instrument size must be small enough to negotiate the total length of the canal but large enough not to be loose in the canal. A loose instrument may move in or out of the canal after the radi-
ograph and cause serious error in determining the length of tooth. Moreover, fine instruments (Nos. 08 and 10) are often difficult to see in their entirety in a radiograph,\textsuperscript{330} as are nickel-titanium instruments. Once again, in a curved canal, a curved instrument is essential.

**Method**

1. Measure the tooth on the preoperative radiograph (Figure 10-58, A).
2. Subtract at least 1.0 mm “safety allowance” for possible image distortion or magnification.\textsuperscript{331}
3. Set the endodontic ruler at this tentative working length and adjust the stop on the instrument at that level (Figure 10-58, B).
4. Place the instrument in the canal until the stop is at the plane of reference unless pain is felt (if anesthesia has not been used), in which case, the instrument is left at that level and the rubber stop readjusted to this new point of reference.
5. Expose, develop, and clear the radiograph.
6. On the radiograph, measure the difference between the end of the instrument and the end of the root and add this amount to the original measured length the instrument extended into the tooth (Figure 10-58, C). If, through some oversight, the exploring instrument has gone beyond the apex, subtract this difference.
7. From this adjusted length of tooth, subtract a 1.0 mm “safety factor” to conform with the apical termination of the root canal at the apical constriction (see Figure 10-58, C).\textsuperscript{332}

Weine has made a sensible improvement in this determination: If, radiographically, there is no resorption of the root end or bone, shorten the length by the standard 1.0 mm.\textsuperscript{332} If periapical bone resorption is apparent, shorten by 1.5 mm, and if both root and bone resorption are apparent, shorten by 2.0 mm (Figure 10-59). The reasoning behind this suggestion is thoughtful. If there is root resorption, the apical constriction is probably destroyed—hence the shorter move back up the canal. Also, when bone resorption is apparent, there probably is also root resorption, even though it may not be apparent radiographically.

8. Set the endodontic ruler at this new corrected length and readjust the stop on the exploring instrument (Figure 10-58, D).
9. Because of the possibility of radiographic distortion, sharply curving roots, and operator measuring error, a confirmatory radiograph of the adjusted length is highly desirable. In many instances, an added investment of a few minutes will prevent the discomfort and failure that stem from inaccuracy.
10. When the length of the tooth has been accurately confirmed, reset the endodontic ruler at this measurement.
11. Record this final working length and the coronal point of reference on the patient’s record.
12. Once again, it is important to emphasize that the final working length may shorten by as much as 1 mm as a curved canal is straightened out by instrumentation.\textsuperscript{314,315} It is therefore recommended that the “length of the tooth” in a curved canal be reconfirmed after instrumentation is completed.

**Variations.** When the two canals of a maxillary first premolar appear to be superimposed, much confusion and lost time may be saved by several simple means. Occasionally, it is advantageous to take individual radiographs of each canal with its length-of-tooth
Endodontic Cavity Preparation

Figure 10-58  A, Initial measurement. The tooth is measured on a good preoperative radiograph using the long cone technique. In this case, the tooth appears to be 23 mm long on the radiograph. B, Tentative working length. As a safety factor, allowing for image distortion or magnification, subtract at least 1 mm from the initial measurement for a tentative working length of 22 mm. The instrument is set with a stop at this length. C, Final working length. The instrument is inserted into the tooth to this length and a radiograph is taken. Radiograph shows that the image of the instrument appears to be 1.5 mm from the radiographic end of the root. This is added to the tentative working length, giving a total length of 23.5 mm. From this, subtract 1.0 mm as adjustment for apical termination short of the cementodentinal junction (see Anatomic Considerations). The final working length is 22.5 mm. D, Setting instruments. The final working length of 22.5 mm is used to set stops on instruments used to enlarge the root canal.

Figure 10-59  Weine’s recommendations for determining working length based on radiographic evidence of root/bone resorption. A, If no root or bone resorption is evident, preparation should terminate 1.0 mm from the apical foramen. B, If bone resorption is apparent but there is no root resorption, shorten the length by 1.5 mm. C, If both root and bone resorption are apparent, shorten the length by 2.0 mm. (Courtesy of Dr. Franklin Weine.)
in dental radiography (see Chapter 9).

The results of the studies indicate that there is no statistically significant difference in working length estimation accuracy between conventional film, direct digital radiography, and xeroradiography. On the other hand, rapid imaging and reduction in radiation by these techniques represent a significant advancement in dental radiography (see Chapter 9).

### Determination of Working Length by Digital Tactile Sense

If the coronal portion of the canal is not constricted, an experienced clinician may detect an increase in resistance as the file approaches the apical 2 to 3 mm. This detection is by tactile sense. In this region, the canal frequently constricts (minor diameter) before exiting the root. There is also a tendency for the canal to deviate from the radiographic apex in this region.

Seidberg et al. reported an accuracy of just 64% using digital tactile sense. Another in vivo study found that the exact position of the apical constriction could be located accurately by tactile sense in only 25% of canals in their study.

If the canals were prefurred, it was possible for an expert to detect the apical constriction in about 75% of the cases. If the canals were not prefurred, determination of the apical constriction by tactile sensation was possible in only about one-third of the cases.

All clinicians should be aware that this method, by itself, is often inexact. It is ineffective in root canals with an immature apex and is highly inaccurate if the canal is constricted throughout its entire length or if the canal has excessive curvature. This method should be considered as supplementary to high-quality, carefully aligned, parallel, working length radiographs and/or an apex locator.

A survey found that few general practice dentists and no endodontists trust the digital tactile sense method of determining working length by itself. Even the most experienced specialist would be prudent to use two or more methods to determine accurate working lengths in every canal.

### Determination of Working Length by Apical Periodontal Sensitivity

Any method of working length determination, based on the patient’s response to pain, does not meet the ideal method of determining working length. Working length determination should be painless. Endodontic therapy has gained a notorious reputation for being painful, and it is incumbent on dentists to avoid perpetuating the fear of endodontics by inserting an endodontic instrument and using the patient’s pain reaction to determine working length.

If an instrument is advanced in the canal toward inflamed tissue, the hydrostatic pressure developed inside the canal may cause moderate to severe, instantaneous pain. At the onset of the pain, the instrument tip may still be several millimeters short of the apical constriction. When pain is inflicted in this manner, little useful information is gained by the clinician, and considerable damage is done to the patient’s trust.

When the canal contents are totally necrotic, however, the passage of an instrument into the canal and past the apical constriction may evoke only a mild awareness or possibly no reaction at all. The latter is common...
when a periradicular lesion is present because the tissue is not richly innervated. On the other hand, Langeland and associates reported that vital pulp tissue with nerves and vessels may remain in the most apical part of the main canal even in the presence of a large periapical lesion. This suggests that a painful response may be obtained inside the canal even though the canal contents are “necrotic” and there is a periapical lesion.

It would appear that any response from the patient, even an eye squint or wrinkling of the forehead, calls for reconfirmation of working length by other methods available and/or profound supplementary anesthesia.

**Determination of Working Length by Paper Point Measurement**

In a root canal with an immature (wide open) apex, the most reliable means of determining working length is to gently pass the blunt end of a paper point into the canal after profound anesthesia has been achieved. The moisture or blood on the portion of the paper point that passes beyond the apex may be an estimation of working length or the junction between the root apex and the bone. In cases in which the apical constriction has been lost owing to resorption or perforation, and in which there is no free bleeding or suppuration into the canal, the moisture or blood on the paper point is an estimate of the amount the preparation is overextended. This paper point measurement method is a supplementary one.

A new dimension has recently been added to paper points by the addition of millimeter markings (Figure 10-60). These paper points have markings at 18, 19, 20, 22, and 24 mm from the tip and can be used to estimate the point at which the paper point passes out of the apex. These paper points were designed to ensure that they be inserted fully to the apical constriction. The accuracy of these markings should be checked on a millimeter ruler.

**Determination of Working Length by Electronics**

**Evolution of Apex Locators.** Although the term “apex locator” is commonly used and has become accepted terminology, it is a misnomer. Some authors have used other terms to be more precise. These devices all attempt to locate the apical constriction, the cementodentinal junction, or the apical foramen. They are not capable of routinely locating the radiographic apex. In 1918, Custer was the first to report the use of electric current to determine working length. The scientific basis for apex locators originated with research conducted by Suzuki in 1942.

His *in vivo* research on dogs using direct current discovered that the electrical resistance between the periodontal ligament and the oral mucosa was a constant value of 6.5 kilo-ohms. In 1960, Gordon was the second to report the use of a clinical device for electrical measurement of root canals. Sunada adopted the principle reported by Suzuki and was the first to describe the detail of a simple clinical device to measure working length in patients. He used a simple direct current ohmmeter to measure a constant resistance of 6.5 kilo-ohms between oral mucous membrane and the periodontum regardless of the size or shape of the teeth. The device used by Sunada in his research became the basis for most apex locators.

Inoue made significant contributions to the evolution of apex locators in North America with his reports on the Sono-Explorer. In recent years, several advancements and modification in the electronic design of apex locators have been reported. All apex locators function by using the human body to complete an electrical circuit. One side of the apex locator’s circuitry is connected to an endodontic instrument. The other side is connected to the patient’s body, either by a contact to the patient’s lip or by an electrode held in the patient’s hand. The electrical circuit is complete when the endodontic instrument is advanced apically inside the root canal until it touches periodontal tissue (Figure 10-61). The display on the apex locator indicates that the apical area has been reached.

This simple and commonly accepted explanation for the electronic phenomenon has been challenged.
There is evidence that electronic devices measure mainly the impedance of the probing electrode (contact impedance with the tissue fluid) rather than tissue impedance itself. Huang reported that the principle of electronic root canal measurement can be explained by physical principles of electricity alone. Ushiyama and colleagues presented this as the "voltage gradient method" that could accurately measure working length in root canals filled with electrolyte. A major disadvantage with this method was that it used a special bipolar electrode that was too large to pass into narrow root canals.

**Experimental Design and Parameters of Accuracy Studies.** In *in vitro* accuracy studies may be conducted on models using an extracted tooth in an electrolyte to simulate clinical conditions. The ideal conditions in *in vitro* testing may give accuracy results higher than those obtainable in clinical practice. Alternatively, in the fabrication of the *in vitro* model, electrolyte may be inadvertently forced into the canal space and give rise to an inaccuracy.

*In vivo* accuracy studies more closely reflect the reality of conditions in clinical practice. The best studies are those that use an apex locator to determine the working length of a canal followed by "locking" the measuring instrument at the electronic length. The tooth is extracted, and the exact relationship between the electronic length and the apical constriction is determined. Unfortunately, this design is not a viable alternative in most studies. Even when the design is used, the studies might be improved by prior shaping and cleaning of the canal followed by multiple electronic working length determinations.

In *in vivo* comparative studies in which the electronic file tip to apical constriction is also assessed by radiographs, the validity of the results is open to question. The comparisons are only as accurate as the accuracy of the radiographic method of estimating working length. Current information places this accuracy in the 39 to 86% range.

Using cadavers, Pratten and McDonald compared the accuracy of three parallel radiographs of each canal at three horizontal angles with the accuracy of the Endex apex locator. Even in these ideal conditions, radiographic estimation was no more accurate than electronic determination.

Another important point in accuracy studies is the error tolerance that is accepted in the experimental design. There appears to be a growing concern that either a +0.5 error or a −0.5 error may give rise to clinical problems and that the ±0.5 tolerance may be unacceptable. It would be useful clinically to use the apical constriction as the ideal apical reference point in the canal rather than the apical foramen. Consideration should also be given to using −0.5 to 0.0 mm as the most clinically ideal error tolerance.

**Classification and Accuracy of Apex Locators.** The classification of apex locators presented here is a modification of the classification presented by
McDonald. This classification is based on the type of current flow and the opposition to the current flow, as well as the number of frequencies involved.

First-Generation Apex Locators. First-generation apex location devices, also known as resistance apex locators, measure opposition to the flow of direct current or resistance. When the tip of the reamer reaches the apex in the canal, the resistance value is 6.5 kilo-ohms (current 40 mA). Although it had some problems, the original device was reported to be most accurate in palatal canals of maxillary molars and premolars. Initially, the Sono-Explorer (Satalec, Inc, Mount Laurel, N.J.) was imported from Japan by Amadent. Today, most first-generation apex location devices are off the market.

Second-Generation Apex Locators. Second-generation apex locators, also known as impedance apex locators, measure opposition to the flow of alternating current or impedance. Inoue developed the Sono-Explorer, one of the earliest of the second-generation apex locators. Several other second-generation apex locators then became available, including a number of improvements in the Sono-Explorer.

The major disadvantage of second-generation apex locators is that the root canal has to be reasonably free of electroconductive materials to obtain accurate readings. The presence of tissue and electroconductive irrigants in the canal changes the electrical characteristics and leads to inaccurate, usually shorter measurements. This created a “catch-22” situation. Should canals be cleaned and dried to measure working length, or should working length be measured to clean and dry canals?

There is another issue: not all apex locators incorporate the same degree of sophistication in electronic circuitry that adjusts its sensitivity to compensate for the intracanal environment or indicates on its display that it should be switched from a “wet” to a “dry” mode or vice versa. Pilot and Pitts reported that 5.25% sodium hypochlorite solution, 14.45% EDTA solution, and normal saline were conductive, whereas RC Prep and isopropyl alcohol were not.

The Apex Finder (Sybron Endo/Analytic; Orange, Calif.) has a visual LED digital indicator and is self-calibrating. The Endo Analyzer (Analytic/Endo; Orange, Calif.) is a combined apex locator and pulp vitality tester. The Apex Finder has been subjected to several in vivo studies. Compared to radiographic working length estimations, one study placed the accuracy at 67% (± 0.5 mm from the radiographic apex). In a study in which Apex Finder working length determinations were compared with direct anatomic working length measurements, only 20% of the determinations were “coincident,” and 53% were short.

The Digipex (Mada Equipment Co., Carlstadt, N.J.) has a visual LED digital indicator and an audible indicator. It requires calibration. The Digipex II is a combination apex locator and pulp vitality tester. The Exact-A-Pex (Ellman International, Hewlett, N.Y.) has an LED bar graph display and an audio indicator. An in vivo study reported an accuracy of 55% (± 0.5 mm from the apical foramen).

The Foramatron IV (Parkell Dental, Farmingdale, N.Y.) has a flashing LED light and a digital LED display and does not require calibration. Two in vivo studies were reported on the Foramatron IV (Figure 10-62). Electronic determinations in one study were found to be accurate (± 0.5 mm from the radiographic apex) in 65% of the cases. In the other study, 32% of the cases were “coincident” with the radiographic apex and 36% were short. None were long. This device is small, lightweight, and inexpensive.

The Pio (Denterials Ltd., St. Louis, Mo.) apex locator has an analog meter display and an audio indicator. It has an adjusting knob for calibration.

Third-Generation Apex Locators. The principle on which “third-generation” apex locators are based requires a short introduction. In biologic settings, the reactive component facilitates the flow of alternating current, more for higher than for lower frequencies. Thus, a tissue through which two alternating currents of differing frequencies are flowing will impede the lower-frequency current more than the higher-frequency current. The reactive component of the circuit may change, for example, as the position of a file changes in a canal. When this occurs, the impedances offered by the circuit to currents of differing frequencies will change relative to each other. This is the principle on which the operation of the “third-generation” apex locators is based (SM Weeks, personal communication, 1999).

Since the impedance of a given circuit may be substantially influenced by the frequency of the current flow, these devices have been called “frequency dependent” (SM Weeks, personal communication, 1999). Since it is impedance, not frequency, that is measured by these devices, and since the relative magnitudes of the impedances are converted into “length” information, the term “comparative impedance” may be more appropriate (SM Weeks, personal communication, 1999).

Endex (Osada Electric Co., Los Angeles, Calif. and Japan), the original third-generation apex locator, was described by Yamaoka et al. (Figure 10-63). In Europe and Asia, this device is available as the APIT. It uses a very low alternating current. The signals of
two frequencies (5 and 1 kHz) are applied as a composite waveform of both frequencies. As the attached endodontic reamer enters the coronal part of the canal, the difference in the impedances at the two frequencies is small. As the instrument is advanced apically, the difference in impedance values begins to change. As the apical constriction is reached, the impedance values are at their maximum difference, and these differences are indicated on the analog meter and audio alarm. This impedance difference is the basis of the “difference method.” The unit must then be “reset” (calibrated) for each canal.

The device operates most accurately when the canal is filled with electrolyte (ie, normal saline or sodium hypochlorite). Gutta-percha must be removed from the canals in re-treatment cases before electronic working length determination is made with this device. The manufacturer indicates that the size of the endodontic instrument does not affect the measurement.

The Endex has been the subject of several accuracy studies. One in vitro study reported that the Endex was superior to second-generation devices when there was conductive fluid in the canals and when the apical foramen was widened. Other in vitro studies compared the Endex electronic working length determination with direct anatomic working length measurement. One study reported an accuracy of 96.5% (−0.5 to 0.0 mm from the apical foramen). Another study reported an accuracy of 85% (± 0.5 mm from the apical foramen).
The Pratten and McDonald *in vitro* study of teeth in human cadavers compared Endex determinations to radiograph estimations and direct anatomic working length measurements. The Endex was slightly more reliable than the radiographic technique: 81% of the Endex determinations were −0.5 to 0.0 mm from the apical constriction in the study.399

Two *in vivo* studies compared the Endex determinations to radiographic working length estimations. One study reported that 63% of the determinations were −1.0 to 0.0 mm from the radiographic apex,409 whereas the other study reported an accuracy of 89.6% (± 0.5 mm from the apical constriction) in moist canals.415 One *in vivo* study reported that the Endex could be used to determine working length under various conditions, such as bleeding, exudate, and hypochlorite in the canals.420 Four studies reported on the comparison of Endex determinations and direct anatomic measurements. Two of the studies reported an accuracy of 72% and 93%, respectively (± 0.5 mm from the apical foramen).364,418 A third study reported that about 66% of the determinations were −0.75 to 0.0 mm from the apical constriction and the determinations were unaffected by pulp status.417 The fourth study reported that the determinations were “coincident” with the minor foramen in 37% of the canals and short in 47%.397

The Neosono Ultima Ez Apex Locator (Satelec Inc; Mount Laurel, N.J.) is a third-generation device that supersedes the second-generation Sono-Explorer line. To circumvent the Japanese patents of two alternating current frequencies, Amadent developed a device with multiple frequencies and implanted a microchip that sorts out two of the many frequencies to give an accurate reading in either wet or dry canals. It works best in the presence of sodium hypochlorite. The Ultima-Ez is mounted with a root canal graphic showing file position as well as an audible signal. The ability to “set” the digital readout at 0.5 or 1.0 mm allows measurements of wide open canals as well. The Ultima-Ez also comes with an attached pulp tester, called the Co-Pilot (Amadent; Cherry Hill, N.J.). To date, the Dental Advisor (Ogden, Utah) has had five consultants who used the device 26 times and reported its reliability to be better in wet canals than in dry. They also stated that it was “Quick and easy to use.”

The Mark V Plus (Moyco/Union Broach, Miller Dental, Bethpage, N.Y.) is identical in circuitry and performance to the Neosono Ultima Ez. To date, no evaluations of the device have been published.

The JUSTWO or JUSTY II (Toesco Toei Engineering Co./Medidenta, Woodside, N.Y. and Japan) is another third-generation apex locator. The device uses frequencies of 500 and 2,000 Hz in a “relative value method.”421 Two electric potentials are obtained that correspond to two impedances of the root canal. These two potentials are converted to logarithmic values, and one is subtracted from the other. The result drives the meter. The rationale of the JUSTWO resembles that of the Root ZX.422 The analog meter and audio indicator display the position of the instrument tip inside the canal. The unit determines working length in the presence of electrolytes. Although no calibration is required, a calibration check is recommended.

Two *in vitro* studies have been reported on this device. In one, in which electronic measurements were compared to radiographic working length, the mean distance from the radiographic apex was 0.98 ± 0.44 mm. In the other study, the device showed an average deviation of 0.04 ± 0.05 mm from the direct anatomic working length measurement.423

The APEX FINDER A.F.A. (“All Fluids Allowed”—Model 7005, Sybron Endo/Analytic; Orange, Calif.) uses multiple frequencies and comparative impedance principles in its electronic circuitry (Figure 10-64). It is reported to be accurate regardless of irrigants or fluids in the canals being measured. It has a liquid crystal display (LCD) panel that indicates the distance of the instrument tip from the apical foramen in 0.1 mm increments. It also has an audio chime indicator. The display has a bar graph “canal condition indicator” that reflects canal wetness/dryness and allows the user to

![Figure 10-64 The Apex Finder A.F.A. (All Fluids Allowed) third-generation apex locator. It functions best with an electrolyte present and displays, on an LCD panel, the distance of the file tip from the apex in 0.1 mm increments. (Courtesy of Sybron Endo/Analytic.)](image)
improve canal conditions for electronic working length determination. The Endo Analyzer 8005 combines electronic apex location and pulp testing in one unit.

McDonald et al. reported an in vitro study of the Apex Finder A.F.A. The device was able to locate the cementodentinal junction or a point 0.5 mm coronal to it with 95% accuracy.

The ROOT ZX (J. Morita Mfg. Co.; Irvine, Calif. and Japan), a third-generation apex locator that uses dual-frequency and comparative impedance principles, was described by Kobayashi (Figure 10-65). The electronic method employed was the “ratio method” or “division method.” The Root ZX simultaneously measures the two impedances at two frequencies (8 and 0.4 kHz) inside the canal. A microprocessor in the device calculates the ratio of the two impedances. The quotient of the impedances is displayed on an LCD meter panel and represents the position of the instrument tip inside the canal. The quotient “was hardly influenced by the electrical conditions of the canal but changed considerably near the apical foramen.”

The Root ZX is mainly based on detecting the change in electrical capacitance that occurs near the apical constriction. Some of the advantages of the Root ZX are that it requires no adjustment or calibration and can be used when the canal is filled with strong electrolyte or when the canal is “empty” and moist. The meter is an easy-to-read LCD. The position of the instrument tip inside the canal is indicated on the LCD meter and by the monitor’s audible signals. The Root ZX, as well as several other apex locators, allows shaping and cleaning of the root canal with simultaneous, continuous monitoring of the working length.

Several studies have reported on the accuracy and reliability of the Root ZX. In these studies, electronic working length determinations made by the Root ZX were compared with direct anatomic working length measurements after extraction of the teeth in the study. Four studies indicated an accuracy for the Root ZX in the range of 82 to 100% (± 0.5 mm from the apical foramen). One study reported an accuracy of 82% (± 0.5 mm from the apical constriction). McDonald et al. reported that the Root ZX demonstrated 95% accuracy in their study when the parameters were −0.5 to 0.0 mm from the cementodentinal junction.

Combination Apex Locator and Endodontic Handpiece. The Tri Auto ZX (J. Morita Mfg. Corp. USA; Irvine, Calif.) is a cordless electric handpiece with a built-in Root ZX apex locator (Figure 10-66). The handpiece uses nickel-titanium rotary instruments that rotate at 280 ± 50 rpm. The position of the tip of the rotary instrument is continuously monitored on the LED control panel of the handpiece during the shaping and cleaning of the canal. The Tri Auto ZX has three automatic safety mechanisms. The handpiece automatically starts rotation when the instrument enters the canal and stops when the instrument is removed (auto-start-stop mechanism). The handpiece also automatically stops and reverses the rotation of the instrument when the torque threshold (30 grams/centimeter) is exceeded (auto-torque-reverse mechanism), a mechanism developed to prevent instrument breakage. In addition, the handpiece automatically stops and reverses rotation when the instrument tip reaches a distance from the apical constriction that has been preset by the clinician (auto-apical-reverse mechanism), a mechanism controlled by the built-in Root ZX apex locator and developed to prevent instrumentation beyond the apical constriction.
The Tri Auto ZX has four modes. In the Electronic Measurement of Root (EMR) mode, a lip clip, hand file, and file holder are used with the apex locator in the handpiece to determine working length. The handpiece motor does not operate in this mode. In LOW mode, the torque threshold is lower than in the HIGH mode. The LOW mode is used with small to mid-sized instruments for shaping and cleaning the apical and mid-third sections of the root canal. All three automatic safety mechanisms are functional in this mode. In HIGH mode, the torque threshold is higher than the LOW mode but lower than the MANUAL mode. The HIGH mode is used with mid-size to large instruments for shaping and cleaning in the mid-third and coronal-third sections of the root canal. All three automatic safety mechanisms are functional in this mode. MANUAL mode offers the highest threshold of torque. In MANUAL mode, the auto-start-stop and the auto-torque-reverse mechanisms do not function. The auto-apical-reverse mechanism does function. MANUAL mode is generally used with large instruments for coronal flaring.

Kobayashi et al. suggested that “to get the best results, it may be necessary to use some hand instrumentation” in combination with the Tri Auto ZX, depending on the difficulty and morphology of the root canal being treated.439

In vitro, the accuracy of the EMR mode of the Tri Auto ZX to determine working length to the apical constriction has been reported at 0.02 ± 0.06 mm.441 Another in vitro study reported that about half of the canals studied were short (–0.48 ± 0.10 mm) and half were long (+ 0.56 ± 0.05).431 A second study concluded that shaping and cleaning with the Tri Auto ZX (AAR mechanism set at 1.0) consistently approximated

Figure 10-65  Root ZX third-generation apex locator with accessories (left) and extra accessories (right). The Root ZX microprocessor calculates the ratio of two impedances and displays a file’s approach to the apex on a liquid crystal display. It functions in both a “dry” or canal “wet” with electrolyte. (Courtesy of J. Morita Mfg. Co.)

Figure 10-66  The Tri-Auto ZX is primarily a cordless, automatic, endodontic handpiece with a built-in Root ZX apex locator. The position of the nickel-titanium rotary instrument tip is constantly being monitored and displayed on the LED control panel. A built-in safety feature stops and reverses the motor when the apex is approached by the tip of the file. Accessories include (left) an AR contra-angle lubricant with a dispensing cap and apex locator attachments. Additional accessories (right). (Courtesy of J. Morita Mfg. Co.)
the apical constriction. The accuracy was reported to have 95% “acceptable” measurements (± 0.5 mm) in a study that compared the direct anatomic working length with the electronic working length.443

The accuracy of the level of instrumentation with the Tri Auto ZX (J. Morita Mfg. Corp.; Irvine, Calif.) was reported in an in vivo study.444 The canals were shaped and cleaned with the Tri Auto ZX (low mode) with the auto-apical-reverse mechanism set at 1.0. In all cases, radiographs showed that the preinstrumentation working length was within 0.5 mm of the final instrument working length and without overextension of gutta-percha, instrument breakage, or canal transportation.

Other Apex-Locating Handpieces. Kobayashi et al. reported the development of a new ultrasonic root canal system called the SOFY ZX (J. Morita Mfg. Corp.; Irvine, Calif.), which uses the Root ZX to electronically monitor the location of the file tip during all instrumentation procedures.445,446 The device minimizes the danger of overinstrumentation.

The Endy 7000 (Ionyx SA, Blanquefort Cedex, France) is available in Europe. It is an endodontic hand-piece connected to an Endy apex locator that reverses the rotation of the endodontic instrument when it reaches a point in the apical region preset by the clinician.

Other Uses of Apex Locators. Sunada suggested the possibility of using apex locators to detect root perforations.437 It was later reported that Electronic Apex Locators (EALs) could accurately determine the location of root or pulpal floor perforations.447,448 The method also aided in the diagnosis of external resorption that had invaded the dental pulp space or internal resorption that had perforated to the external root surface.450 A method for conservative treatment of root perforations using an apex locator and thermal compaction has been reported.449

An in vitro study to test the accuracy of the Root ZX to detect root perforations compared with other types of apex locators tested that all of the apex locators tested were acceptable for detection of root perforations.450 No statistical significance was found between large perforations and small perforations. Prepared pin holes can be checked by apex locators to detect perforation into the pulp or into the periodontal ligament.451 Horizontal or vertical root fractures could also be detected as well as post perforations.

In this latter case, the EAL file holder is connected to a large file, and the file then contacts the top of the post. The Root ZX will sound a single sustained beep, and the word “APEX” will begin flashing.

An in vivo study has evaluated the usefulness of an apex locator in endodontic treatment of teeth with incomplete root formation requiring apexification.452 They reported that in all cases, the EAL was 2 to 3 mm short of the radiographic apex at the beginning of apexification therapy. When the apical closure was complete, the apex locator was then 100% accurate. In cases of immature teeth with open apices, a study reported that apex locators were inaccurate.453 In contrast, an in vivo study using absorbent paper points for estimating the working lengths of immature teeth has been described.454 They reported that in 95% of the cases for which the working length was estimated by paper points, they were within 1 mm of the working length estimated by radiographs.

An in vitro study evaluated the accuracy of the Root ZX in determining working length in primary teeth.455 Electronic determinations were compared with direct anatomic and radiographic working lengths. They reported that the electronic determinations were similar to the direct anatomic measurements (± 0.5 mm). Radiographic measurements were longer (0.4 to 0.7 mm) than electronic determinations.

Apex locators can be very useful in management of inpatients and outpatients. For example, they can be an important tool in endodontic treatment in the operating room. They also reduce the number of radiographs, which may be important for those who are very concerned about radiation hygiene. In some patients, such concern is so strong that dental radiographs are refused. An apex locator can be of enormous value in such situations.

Contraindications. The use of apex locators, and other electrical devices such as pulp testers, electrosurgical instruments, and desensitizing equipment, is contraindicated for patients who have cardiac pacemakers. Electrical stimulation to the pacemaker patient can interfere with pacemaker function. The severity of the interference depends on the specific type of pacemaker and the patient’s dependence on it.456 In special cases, an apex locator may be used on a patient with a pacemaker when it is done in close consultation with the patient’s cardiologist.457

The Future. The future of apex locators is very bright. Significant improvement in the reliability and accuracy of apex locators took place with the development of third-generation models. It is probable that more dentists will now use apex locators in the management of endodontic cases. At this time, however, the conclusions of studies have not demonstrated that apex locators are clearly superior to radiographic techniques, nor can they routinely replace radiographs in working length determination. It has been demonstrated that they are at least equally accurate.459
Studies have concluded that when apex locators are used in conjunction with radiographs, there is a reduction in the number of radiographs required and that some of the problems associated with radiographic working length estimation can be eliminated.459

An understanding of the morphology in the apical one-third of the canal is essential.299–308,311,312 Consideration should be given to adopting the parameter of 0.5 to 0.0 mm (from the apical constriction) as the most ideal apical reference point in the canal. Electronic working length determinations should be accomplished with multiple measurements and should be done in conjunction with the shaping and cleaning procedure. Consideration should be given to the evaluation of the accuracy of obturation as an indicator of the accuracy of the working length determination. Future apex locators should be able to determine working length in all electric conditions of the root canal without calibration. The meter display on future apex locators should accurately indicate how many millimeters the endodontic instrument tip is from the apical constriction.371

TECHNIQUES OF RADICULAR CAVITY PREPARATION

Over the years, there has been a gradual change in the ideal configuration of a prepared root canal. At one time, the suggested shape was round and tapered, almost parallel, resembling in silhouette an obelisk like the Washington Monument, ending in a pyramid matching the 75-degree point of the preparatory instruments. After Schilder’s classic description of “cleaning and shaping,” the more accepted shape for the finished canal has become a gradually increasing taper, with the smallest diameter at the apical constriction, terminating larger at the coronal orifice.460

This gradually increasing taper is effective in final filling for as Buchanan pointed out, the “apical movement of the cone into a tapered apical preparation...only tightens the apical seal.”461 But, as Buchanan further noted, “overzealous canal shaping to achieve this taper has been at the expense of tooth structure in the coronal two-thirds of the preparation leading to perforations,” and, one might add, materially weakening the tooth.461 Grossly tapered preparations may well go back to Berg, an early Boston endodontist, who enlarged canals to enormous size to accommodate large heated pluggers used to condense warm sectional gutta-percha.462

Step-Back or Step-Down?

As previously stated, two approaches to debriding and shaping the canal have finally emerged: either starting at the apex with fine instruments and working one’s way back up (or down) the canal with progressively larger instruments—the “step-back” or serial technique—or the opposite, starting at the cervical orifice with larger instruments and gradually progressing toward the apex with smaller and smaller instruments—the “step-down” technique, also called “crown-down” filing.

Hybrid approaches have also developed out of the two methods. Starting coronally with larger instruments, often power driven, one works down the straight coronal portion of the canal with progressively smaller instruments—the step-down approach. Then, at this point, the procedure is reversed, starting at the apex with small instruments and gradually increasing in size as one works back up the canal—the step-back approach. This hybrid approach could be called, quite clumsily, the step-down-step-back technique or “modified double-flared technique.”463

Any one of these methods of preparing the root canal will ensure staying within the confines of the canal and delivering a continuously tapered preparation and, as Buchanan noted, eliminate blocking, “apical ledging, transportation, ripping, zipping and perforation.”464

Step-Back Preparation. Weine, Martin, Walton, and Mullaney were early advocates of step-back, also called telescopic or serial root canal preparation.465–468 Designed to overcome instrument transportation in the apical-third canal, as described earlier (Figure 10-67), it has proved quite successful. When Weine coined the term “zip” to describe this error of commission, it became a “buzz word,” directing attention to apical aberrant preparations, principally in curved canals. Walton has depicted these variations, ranging from ledge to perforation to zip (Figure 10-68). The damage not only destroys the apical constriction, so important to the compaction of the root canal filling, but also produces an hourglass-shaped canal.469 In this, the narrowest width of the canal is transported far away from the apex and prevents the proper cleansing and filling of the apical region (see Figure 10-68). In the case of severely curved canals, perforation at the curve’s elbow leads to disastrous results (Figure 10-69).

Step-Back Preparation and Curved Canals. This method of preparation has been well described by Mullaney.468 His approach has been modified, however, to deliver a continuing tapered preparation.461 Mullaney divided the step-back preparation into two phases. Phase I is the apical preparation starting at the apical constriction. Phase II is the preparation of the remainder of the canal, gradually stepping back while increasing in size. The completion of the preparation is the Refining Phase IIA and IIB to produce the continuing taper from apex to cervical (Figure 10-70).
Although the step-back technique was designed to avoid zipping the apical area in curved canals, it applies as well to straight canal preparation. As Buchanan noted, “all root canals have some curvature. Even apparently straight canals are usually curved to some degree.”

Canals that appear to curve in one direction often curve in other directions as well (Figure 10-71).

Prior to the introduction of nickel-titanium files, one of the first axioms of endodontics has been to “always use a curved instrument in a curved canal.” The degree and direction of the curve are determined by the canal shadow in the radiograph. Buchanan has made an art of properly curving instruments to match the

Figure 10-67  A, Incorrect enlargement of the apical curve leads to cavitation. Larger, stiffer instruments transport preparation at the external wall. B, Ovoid cavitation (arrow) developed by incorrect cleaning and shaping.

Figure 10-68  Hazards of overenlarging the apical curve. A, Small flexible instruments (No. 10 to No. 25) readily negotiate the curve. B, Larger instruments (No. 30 and above) markedly increase in stiffness and cutting efficiency, causing ledge formation. C, Persistent enlargement with larger instruments results in perforation. D, A “zip” is formed when the working length is fully maintained and larger instruments are used. (Courtesy of Dr. Richard E. Walton.)

Figure 10-69  Apical curve to the buccal of the palatal root went undetected and was perforated by heavy instruments and then overfilled. Right-angle radiographs failed to reveal buccal or lingual curves. Step-back preparation could have prevented perforation. (Courtesy of Dr. Richard E. Walton.)
He made the point that the bladed part of the file must be bent all the way, even up to the last half millimeter, remembering that canals curve most in the apical one-third. \(^{470}\) (Figure 10-72). One must also remember that the most difficult curves to deal with are to the buccal and/or the lingual for they are directly in line with the x-ray beam. Their apical orifices appear on the film well short of the root apex. So, curving the file to match the canal is paramount to success in the step-back maneuver unless nickel-titanium files are used. Attempting to curve nickel-titanium files can introduce metal fatigue.

Phase I. To start Phase I instrumentation, it must be assumed that the canal has been explored with a fine pathfinder or instrument and that the working length has been established—that is, the apical constriction identified. The first active instrument to be inserted should be a fine (No. 08, 10, or 15) 0.02, tapered, stainless steel file, curved and coated with a lubricant, such as Gly-Oxide, R.C. Prep, File-Eze, Glyde, K-Y Jelly, or liquid soap. The flexibility of nickel titanium does not lend itself to this pathfinding function in sizes smaller than No. 15.

The motion of the instrument is “watch winding,” two or three quarter-turns clockwise-counterclockwise and then retraction. On removal, the instrument is wiped clean, recurved, relubricated, and repositioned. “Watch winding” is then repeated. Remember that the instrument must be to full depth when the cutting action is made. This procedure is repeated until the instrument is loose in position. Then the next size K file is used—length established, precurved, lubricated, and positioned. Again, the watch-winding action and retraction are repeated. Very short (1.0 mm) filing strokes can also be used at the apex. At the University of Tennessee, nickel-titanium 0.02 tapered instruments were shown to be effective when used with this technique. Nickel-titanium files were not curved and maintained the canal shape better than stainless steel.

It is most important that a lubricant be used in this area. As Berg and Buchanan pointed out, it is often fibrous pulp stumps, compacted into the constriction, that cause apical blockage. In very fine canals, the irrigant that will reach this area will be insufficient to dissolve tissue. Lubrication, on the other hand, emulsifies tissue, allowing instrument tips to macerate and remove this tissue. It is only later in canal filing that dentin chips pack apically, blocking the constriction. By then the apical area has been enlarged enough that sodium hypochlorite can reach the debris to douche it clear.

By the time a size 25 K file has been used to full working length, Phase I is complete. The 1.0 to 2.0 mm space back from the apical constriction should be clean of debris (Figure 10-73) unless this area of the canal was large to begin with, as in a youngster. Then, of course, larger instruments are used to start with.

Using a number 25 file here as an example is not to imply that all canals should be shaped at the apical...
Endodontic Cavity Preparation

restriction only to size 25. Hawrish pointed out the apparent lack of interest in canal diameter versus the great interest in the proper canal length (personal communication, 1999). Many, in fact most, canals should be enlarged beyond size 25 at the apical constriction in order to round out the preparation at this point and remove as much of the extraneous tissue, debris, and lateral canals as possible. A size 25 file is used here as an example and as a danger point for beyond No. 25 lies danger!

As stainless steel instruments become larger, they become stiffer. Metal “memory” plus stress on the instrument starts its straightening. It will no longer stay curved and starts to dig, to zip the outside (convex) wall of the canal.

It must be emphasized here that irrigation between each instrument use is now in order, as well as recapitulation with the previous smaller instrument carried to full depth and watch wound. This breaks up the apical debris so that it may be washed away by the sodium hypochlorite. All of these maneuvers (curved instruments, lubrication, cleaning debris from the used instrument, copious irrigation, and recapitulation) will ensure patency of the canal to the apical constriction.

Phase II. In a fine canal (and in this example), the step-back process begins with a No. 30 K-style file. Its working length is set 1 mm short of the full working length. It is precurved, lubricated, carried down the canal to the new shortened depth, watch wound, and retracted. The same process is repeated until the No. 30 is loose at this adjusted length (Figure 10-74). Recapitulation to full length with a No. 25 file follows to ensure patency to the constriction. This is followed by copious irrigation before the next curved instrument is introduced. In this case, it is a No. 35, again shortened by 1.0 mm from the No. 30 (2.0 mm from the apical No. 25). It is curved, lubricated, inserted, watch wound, and retracted followed by recapitulation and irrigation.

Thus, the preparation steps back up the canal 1 mm and one larger instrument at a time. When that portion of the canal is reached, usually the straight midcanal, where the instruments no longer fit tightly, then perimeter filing may begin, along with plenty of irrigation (Figure 10-75).

It is at this point that Hedstroem files are most effective. They are much more aggressive rasps than the K files. The canal is shaped into the continuous taper so conducive to optimum obturation. Care must be taken to recapitulate between each instrument with the original No. 25 file along with ample irrigation.

This midcanal area is the region where reshaping can also be done with power-driven instruments: Gates-Glidden drills, starting with the smaller drills (Nos. 1 and 2) and gradually increasing in size to No. 4, 5, or 6. Proper continuing taper is developed to finish Phase IIA preparation. Gates-Glidden drills must be used with great care because they tend to “screw” themselves into the canal, binding and then breaking. To avoid this, it has been recommended that the larger sizes be run in reverse. But, unfortunately, they do not cut as well when reversed. A better suggestion is to lubricate the drill heavily with RC-Prep or Glyde, which will prevent binding and the rapid advance problem.” Lubrication also suspends the chips and allows for a better “feel” of the cutting as well as the first canal curvature. Used Gates-Glidden drills are also less aggressive than new ones.
Newer instruments with various tapers from 0.04 to 0.08 mm/mm of taper are now available for this purpose as well and can be used as power-driven or hand instruments. With any of the power-driven instruments, using them in a passive pecking motion will decrease the chances of binding or screwing into the canal.

Refining Phase IIB is a return to a size No. 25 (or the last apical instrument used), smoothing all around the walls with vertical push-pull strokes, to perfect the taper from the apical constriction to the cervical canal orifice. In this case, a safe-ended, noncutting-tip Hedstroem file is the most efficient. It produces a good deal of dentin chips, however, that must be broken up at the apex with a cutting-tip K file and then flushed out with abundant sodium hypochlorite.

At this point, Buchanan recommended that sodium hypochlorite be left in place to the apex for 5 to 10 minutes. This is the only way in which the auxiliary canals can be cleaned. Hand-powered Gates-Glidden drills (Handy Gates) or LIGHTSPEED instruments may be used for this final finish, as well as the new handpiece Orifice Openers or Gates-Glidden drills. Gutmann and Rakusin pointed out that the “final preparation should be an exact replica of the original canal configuration—shape, taper, and flow, only larger”471 (Figure 10-76, A). So-called “Coke-bottle” preparations should be avoided at all cost (Figure 10-76, B).

This completes the chemomechanical step-back preparation of the continuing taper canal. It is now ready to be filled or medicated and sealed at the coronal cavity until the next appointment. If it is to be filled, the smear layer should first be removed. This procedure is detailed in chapter 11.

**Modified Step-Back Technique.** One variation of the step-back technique is more traditional. The preparation is completed in the apical area, and then the step-back procedure begins 2 to 3 mm up the canal. This gives a short, almost parallel retention form to receive the primary gutta-percha point when lateral condensation is being used to fill the canal. The gutta-percha trial point should go fully to the constriction, and a slight tug-back should be felt when the point is removed (retention form). This shows that it fits tightly into the last 2 to 3 mm of the prepared canal.

**Efficacy of the Step-Back Technique.** Three research groups tested the efficacy of the step-back maneuver. Using the techniques detailed here (precurving, watch winding, and step-back), a Swiss group stated that the “step back shapings consistently presented the best taper and apical stop design…”472 In marked contrast, two groups from Great Britain used straight, not precurved, instruments in “simple in/out filling…with no attempt at rotation or twisting.”473 Both British groups reported preparations that were hour-glass in shape, and one had a deformation and instrument breakage as well as severe zipping in the apical area473–475 (Figure 10-77).

These findings, using stainless steel files, emphasize the necessity of precurving instruments and using limited rotation for enlargement in the apical region. Vessey found that a limited reaming action (as recommended above) produced a circular preparation, whereas files used vertically as files (rasps) produced ovoid preparations.476 Others found essentially the same477,478 (Figure 10-78). In Scotland, W. P. and E. M. Saunders achieved better results using a step-down/step-back approach rather than straight step-back instrumentation. On the other hand, they broke a number of files using the modified approach.463 Positive findings have been noted using nickel-titanium instruments. They seem to maintain canal shape better and improved cutting efficiency when used as a reamer.

![Figure 10-75 A, Perimeter filing action used to débride and shape larger ovoid portions of the canal. The file is used in an up-and-down rasping action with pressure exerted cross-canal against all walls. B, Cross-section showing shaping of an ovoid canal. This “multiple exposure” illustration shows how the file is used as a rasp against walls around the entire perimeter of the canal. Only a small area remains to be cleaned and shaped. A stainless steel Hedstroem file is best suited for this purpose.](image)
Figure 10-76 Preparation configurations. A, Original canal shape, taper and flow, only larger. B (right), "Coke bottle" preparation from overuse of Gates-Glidden drills or Peeso reamers negates the efficient flow of gutta-percha. Reproduced with permission from Gutmann JL and Rakusin H.471

Figure 10-77 Composite print of an original curved canal (dark). Overlay details areas of instrument divergence (white). Note the hourglass shape, apical zip, and apical elbow as a result of straight filing with straight instruments. Reproduced with permission from Alodeh MHA et al.475
Chelation and Enlargement. A number of canals, particularly fine curved canals, will appear to be almost calcified or blocked by attached pulp stones. They may still be negotiated if the clinician uses a chelating agent and the utmost patience.

Ethylenediaminetetraacetic acid buffered to a pH of 7.3 was long ago advocated by Nygaard-Østby to “dissolve” a pathway for exploring instruments. When the mineral salts have been removed from the obstructing dentin by chelation, only the softened matrix remains. This may be removed by careful watch-winding action to “drill” past the obstruction. This maneuver may be improved if the coronal portion of the canal is widened so that only the instrument tip is cutting.

Files with tapers greater than the traditional 0.02 mm/mm have made negotiating these “calcified” canals more predictable. Calcification occurs nearest the irritant to which the pulp is reacting. Since most irritants are in the coronal region of the pulp, the farther apical one goes into the canal, the more unlikely it is to be calcified. When files bind in these canals, it may be from small constrictions in the coronal part of the canal. If working length is estimated to be 20 mm but the clinician can negotiate only 10 mm of canal, increasing the taper of the canal to the 10 mm level often removes the constrictions and allows a small file to negotiate farther into the canal. This is one of the strengths of following the step-down or crown-down technique.

Fraser has shown that, contrary to popular belief, chelating agents “do not soften dentin in the narrow parts of the canal,” although softening can occur in the cervical and middle portions. Ethylenediaminetetraacetic acid must be concentrated enough in an area to be effective.

R C Prep, File-Eze, and Glyde, which contain EDTA, act more as lubricating agents since the concentration of EDTA contained therein is very modest. The Canal Finder System, using No. 08 files, has been very effective in opening curved calcified canals in the presence of an EDTA lubricant.

Selden and McSpadden have recommended the use of a dental operating microscope for peering down
“calcified” canals. More recently, the fiber-optic endoscope, such as used in abdominal and brain surgery, has given dentists a whole new look at the pulpal floor and the root canal. The OraScope (Spectrum Dental Inc; North Attleboro, Mass.), for example, has a 0.9 mm fiber-optic probe that will penetrate down the root canal, displaying its view, enormously magnified, on a computer screen. Incidentally, there is recent evidence that root canal calcification may be associated with long-term prednisone therapy (60 mg per day over 8 years to treat lupus erythematosus).

**Step-Down Technique—Hand Instrumentation**

Initially, Marshall and Pappin advocated a “Crown-Down Pressureless Preparation” in which Gates-Glidden drills and larger files are first used in the coronal two-thirds of the canals and then progressively smaller files are used from the “crown down” until the desired length is reached. This has become known as the step-down or crown-down technique of cleaning and shaping. It has risen in popularity, especially among those using nickel-titanium instruments with varying tapers.

A primary purpose of this technique is to minimize or eliminate the amount of necrotic debris that could be extruded through the apical foramen during instrumentation. This would help prevent post-treatment discomfort, incomplete cleansing, and difficulty in achieving a biocompatible seal at the apical constriction. One of the major advantages of step-down preparation is the freedom from constraint of the apical enlarging instruments. By first flaring the coronal two-thirds of the canal, the final apical instruments are unencumbered through most of their length. This increased access allows greater control and less chance of stripping near the apical constriction. In addition, it “provides a coronal escapeway that reduces the ‘piston in a cylinder effect’ responsible for debris extrusion from the apex.”

**Step-Down, Step-by-Step.** In this method, the access cavity is filled with sodium hypochlorite, and the first instrument is introduced into the canal. At this point, there is a divergence in technique dictated by the instrument design and the protocol for proceeding recommended by each instrument manufacturer. All of the directions, however, start with exploration of the canal with a fine, stainless steel, .02 taper (No. 8, 10, 15, or 20 file, determined by the canal width), curved instrument. It is important that the canal be patent to the apical constriction before cleaning and shaping begin. Sometimes the chosen file will not reach the apical constriction, and one assumes that the file is binding at the apex. But, more often than not, the file is binding in the coronal canal. In this case, one should start with a wider (.04 or .06 taper) instrument or a Gates-Glidden drill to free up the canal so that a fine instrument may reach the mid- and apical canal. This would be the beginning of step-down preparation. Buchanan has also emphasized the importance of removing all pulp remnants before shaping begins to ensure that this tissue does not “pile up” at the constriction and impede full cleaning and shaping to that point.

**K-File Series Step-Down Technique.** As stated above, the initial penetrating instrument is a small, curved, stainless steel K file, exploring to the apical constriction and establishing working length. To ensure this penetration, one may have to enlarge the coronal third of the canal with progressively smaller Gates-Glidden drills or with instruments of larger taper such as the .04 or the .06 instruments. At this point, and in the presence of sodium hypochlorite and/or a lubricant such as Glyde, step-down cleaning and shaping begins with K-Flex, Triple-Flex, or Safety Hedstrom (Sybron Endo/Kerr; Orange, Calif.) instruments in either the 0.02, 0.04, or 0.06 taper configuration depending on the canal size to begin with. Starting with a No. 50 instrument (for example) and working down the canal to, say, a size No. 15, the instruments are used in a watch-winding motion until the apical constriction (or working length) is reached. When resistance is met to further penetration, the next smallest size is used. Irrigation should follow the use of each instrument and recapitulation after every other instrument. To properly enlarge the apical third, and to round out ovoid shape and lateral canal orifices, a reverse order of instruments may be used starting with a No. 20 (for example) and enlarging this region to a No. 40 or 50 (for example). The tapered shape can be improved by stepping back up the canal with ever larger instruments, bearing in mind all the time the importance of lubrication, irrigation, and recapitulation. At this point, the canal should be ready for smear layer removal, drying, and either medication or obturation.

**Modified Technique.** There have been a number of modifications of the step-down technique since it was first promulgated. One of the most recent was by Ruddle (personal communication, 2001). Following complete access, he suggested that clinicians “face-off” the orifices with an appropriately sized Gates-Glidden drill. This creates a smooth guide path to facilitate the placement of subsequent instruments. Certain canal systems contain deep divisions and may be initially opened at their coronal ends with Micro Openers (Dentsply Maillefer; Tulsa, Okla.).
If the pulp is vital, a broach may be selected to quickly extirpate it if space permits. At this stage of treatment, the coronal two-thirds of any canal should be “scouted” with a No. 10 or 15 curved, stainless steel K file in the presence of a lubricant and/or sodium hypochlorite. Exploration of this portion of the canal will confirm straight-line access, cross-sectional diameter, and root canal system anatomy. Files are used serially to flare the canal until sufficient space is generated to safely introduce either Gates-Gliddens or nickel-titanium rotary shaping files. Frequent irrigation with sodium hypochlorite and recapitulation with a No. 10 file will discourage canal blockage and move debris into solution, where it can be liberated from the root canal system. One way to accomplish pre-enlargement of the canal is with Gates-Glidden drills that are used at approximately 800 rpm, serially, passively, and like a brush to remove restrictive dentin. Initially, one should start with a Gates-Glidden drill No. 1 and carry each larger instrument short of the previous instrument to promote a smooth, flowing, tapered preparation. Frequent irrigation with sodium hypochlorite and recapitulation with a small clearing file to prevent blockage are in order.

Following pre-enlargement, Ruddle believes in negotiating the apical one-third last, establishing patency, and confirming working length. He then recommends finishing the apical zone so that there is a smooth uniform taper from the orifice level to the radiographic terminus. He emphasized that a variety of instruments may be used to create the “deep shape.” If the clinician chooses 0.02 tapered files to “finish” the apical one-third, Ruddle uses a concept he calls “Gauging and Tuning.” “Gauging” is knowing the cross-sectional diameter of the foramen that is confirmed by the size of instrument that “snugs in” at working length. “Tuning” is ensuring that each sequentially larger instrument uniformly backs out of the canal ½ mm.

After removing the sodium hypochlorite, the canal is rinsed with 17% aqueous EDTA to remove the smear layer in preparation for obturation. Dentsply Maillefer has developed a “Clean & Shape” Kit that contains all of the instruments necessary for this technique.

PROFILE GT (Greater Taper) Technique. If these instruments (Dentsply/Tulsa Dental; Tulsa, Okla.) are used, Buchanan, the developer, recommends that one start with a 0.10 GT instrument to flare out the coronal third of the canal. This means that this instrument is an ISO size 20 at the tip, but the taper is 0.10 mm/mm, that establishes a wider freedom for those instruments to follow. The instrument is used in a twisting motion, first counterclockwise and then clockwise with apical pressure, before retraction. The instrument is cleaned and the operation repeated until the instrument is loose. A lubricant such as RC PREP or GLYDE should be used. At this point, the canal should be flooded with EDTA and the next smaller-size GT file is used, number 0.08, in the same manner—counterclockwise, engage, twist clockwise, and retract. One continues down the canal using the 0.08, and 0.06 taper instruments until the apical restriction is reached. Constant irrigation with sodium hypochlorite is most important! This constitutes what Buchanan terms the “Second Shaping Wave,” and it should be completed in a matter of minutes.

The second wave is followed by the “Third Shaping Wave,” in which regular ISO instruments are used to the constriction to enlarge the apical canal diameter beyond size 20, the tip diameter of the GT files. Beginning with fine instruments, and then stepping back 1 or 2 mm with instruments, up to size 35 or 40, the apical region is “rounded out.” The final shaping is a return of the last GT file used in the canal.

Buchanan pointed out that the GT instruments are sized to fit certain size canals. The 0.06 file, for instance, is recommended for “extremely thin or curved roots.” The 0.08 file is best for lower anterior teeth, multirooted premolars, and the buccal roots of maxillary molars. The 0.10 file better matches the distal canal of mandibular molars, the palatal roots of maxillary molars, single-canal premolars, mandibular canines, and maxillary anterior teeth. The 0.12 instrument is for larger canals.

Buchanan is a great believer in the necessity of cleaning what he terms the “patency zone,” that tiny space between the apical constriction and the apical terminus. For this, in the presence of sodium hypochlorite, he carefully instruments this space with a regular No. 10 file. He also believes that sodium hypochlorite should be present in this region for a total of 30 minutes. If preparation time has been less than 30 minutes, he recommends that a final lavage should remain in the canal until 30 minutes have passed. This, in his view, dissolves the final debris and tissue packed there, even in the accessory canals (personal communication, 2001).

Quantec Instrument Technique. Using Quantec instruments (Sybron Endo/Analytic; Orange, Calif.), which are more reamer like than files, the recommended technique for hand instrumentation is divided into three phases: negotiation, shaping, and apical preparation.

NEGOTIATION: As is standard with virtually all cleaning and shaping techniques, the canal, in the presence of sodium hypochlorite, is first explored with a standard No. 10 or 15 0.02 taper, curved, stainless steel K file and working length is established (Figure 10-79, A). Exploration is followed by a Quantec No. 25, 0.06
taper, nickel-titanium instrument, advanced in a reaming action, from the canal orifice to just short of the apical third, and followed by irrigation with sodium hypochlorite (Figure 10-79, B and C).

With a standard ISO 0.02, stainless steel, No. 10 or 15 file, a “Glide Path” for the instruments to follow is developed to working length (Figure 10-79, D). The canal is then irrigated with EDTA (Figure 10-79, E), and the No. 20 and 25 stainless steel, 0.02 instruments are used to clean and shape the apical third to the apical constriction. This is followed again by copious irrigation (Figure 10-79, F).

**SHAPING:** Using lubricants and sodium hypochlorite, one returns to the Quantec instruments, all with an ISO size No. 25 tip. Returning to the No. 25, 0.06 taper instrument, it is used in a reaming action, as far down the canal as it will comfortably go (Figure 10-79, G). It is followed in succession by the No. 0.05 taper Quantec and then the 0.04 and 0.03 tapers until the apical stop is reached (Figure 10-79, H to J). Copious irrigation follows the use of each instrument.

**QUANTEC APICAL PREPARATION:** To ensure accuracy, the working length should be rechecked. If an apical preparation larger in diameter than a No. 25 is desired, one may return to the 0.02 taper Quantec instruments (which will now be quite loose in the midcanal), and the diameter of the apical third can then be enlarged up to a size No. 40, 45, or 50, depending on the original size of the canal (Figure 10-79, K). Final irrigation to remove the smear layer with EDTA and sodium hypochlorite prepares the tapered canal for medication or filling (Figure 10-79, L).

**Efficacy of the Step-Down Technique.** Compared to the step-back “circumferential filing technique with precurved files as described by Weine,” Morgan and Montgomery found the step-down technique significantly better in shape and terminus.489

Another in vitro study found significantly less debris extruded from the apical orifice when step-down procedures were used compared to step-back procedures. Neither technique was totally effective, however, in preventing total debris extrusion.490

**Variation of the Three Basic Preparations**

A variety of techniques have been developed, all based on the step-down, step-back, or hybrid approach to preparation. Most are inspired by new canal instruments and/or vibratory devices.

**Balanced Force Concept Using Flex-R Files.** After many years of experimentation, Roane et al. introduced their Balanced Force concept of canal preparation in 1985.100 The concept came to fruition, they claimed, with the development and introduction of a new K-type file design, the Flex-R File100,101 (Moyco Union Broach). The technique can be described as “positioning and pre-loading an instrument through a clockwise rotation and then shaping the canal with a counterclockwise rotation.”100 The authors evaluated damaged instruments produced by the use of this technique. They discovered that a greater risk of instrument damage was associated with clockwise movement.85

For the best results, preparation is completed in a step-down approach. The coronal and mid-thirds of a canal are flared with Gates-Glidden drills, sizes 2 through 6, and then instrument shaping is carried into the apical areas. This approach is less difficult than the conventional step-back technique. Increasing the diameter of the coronal and mid-thirds of a canal removes most of the contamination and provides access for a more passive movement of hand instruments into the apical third. Shaping becomes less difficult: the radius of curvature is increased as the arc is decreased. In other words, the canal becomes straighter and the apex accessible with less flexing of the shaping instruments (Figure 10-80).

After mechanical shaping with Gates-Glidden drills, balanced force hand instrumentation begins: placing, cutting, and removing instruments using only rotary motions (Figure 10-80, C). Insertion is done with a quarter-turn clockwise rotation while slight apical pressure is applied (Figure 10-81, 1). Cutting is accomplished by making a counterclockwise rotation, “again while applying a light apical pressure (Figure 10-81, 2). The amount of apical pressure must be adjusted to match the file size (ie, very light for fine instruments to fairly heavy for large instruments).”100 Pressure should maintain the instrument at or near its clockwise insertion depth. Then counterclockwise rotation and apical pressure act together to enlarge and shape the canal to the diameter of the instrument. Counterclockwise motion must be 120 degrees or greater. It must rotate the instrument sufficiently to move the next larger cutting edge into the location of the blade that precede it, in order to shape the full circumference of a canal. A greater degree of rotation is preferred and will more completely shape the canal to provide a diameter equal to or greater than that established by the counterclockwise instrument twisting during manufacture.

It is important to understand that clockwise rotation “sets” the instrument, and this motion should not exceed 90 degrees. If excess clockwise rotation is used, the instrument tip can become locked into place and the file may unwind. If continued, when twisted counterclockwise, the file may fail unexpectedly. The process
Figure 10-79  Step-down technique, with Quantec hand instruments, cleaning and shaping. A, Explore to the apex and establish working length (WL) with a stainless steel (SS) No. 10 or 15 0.02 taper file. B, Enlarge the orifices and two-thirds of the way down the canal with a nickel-titanium (NiTi) No. 25 0.06 taper file. C, Irrigate all of the canals with sodium hypochlorite (NaOCl). D, Establish a "glide path" to WL with SS No. 15, 0.02 taper file. E, Irrigate with ethylenediaminetetraacetic acid (EDTA). F, Enlarge to WL with SS No. 20 and 25 0.02 files. Irrigate with NaOCl. G, With Glyde and NaOCl, enlarge down the canal as far as possible with NiTi No. 25 0.06 file. Irrigate. H, Continue further down the canal with a NiTi No. 25 0.05 file. I, Continue further with a No. 25 0.04 file. J, Continue to WL with a NiTi No. 25 0.03 file. K, Enlarge apical one-third up to size Nos. 40, 45, or 50 with 0.02 taper files. L, Final irrigation with EDTA and NaOCl to remove smear layer. Dry.
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is repeated (clockwise insertion and counterclockwise cutting), and the instrument is advanced toward the apex in shallow steps. After the working depth is obtained, the instrument is freed by one or more counterclockwise rotations made while the depth is held constant. The file is then removed from the canal with a slow clockwise rotation that loads debris into the flutes and elevates it away from the apical foramen. Generous irrigation follows each shaping instrument since residual debris will cause transportation of the shape. Debris applies supplemental pressures against the next shaping instrument and tends to cause straightening of the curvature.

Repeating the previously described steps, the clinician gradually enlarges the apical third of the canal by advancing to larger and larger instruments. Working depths are changed between instruments to produce an apical taper. The working loads can and should be kept very light by limiting the clockwise motion and thereby reducing the amount of tooth structure removed by each counterclockwise shaping movement. This technique can and should be used with minimal force.

The balanced force technique can be used with any K-type file; however, the shaping and transportation control are maximum when a Flex-R file is used. The Flex-R file design incorporates a guiding plane and removes the transition angles inherent on the tip of standard K-type files (see Figure 10-23). Those angles, if present, enable the tip to cut in an outward direction and give it the ability to cut a ledge into the canal wall. Lacking a

Figure 10-80  a. File displays full curvature of the canal before radicular access is modified. b. Radicular access is completed with a descending series of Gates-Glidden drills progressing toward the apex in 2.0 mm or less increments. c. The dotted line indicates the original curvature, whereas the file displays the affective curvature after radicular access is improved. This modification materially reduces the difficulty of apical shaping. (Courtesy of Dr. James B. Roane.)

Figure 10-81  1. For a balanced force motion, the file is pushed inwardly and rotated one quarter-turn clockwise. 2. It is then rotated more than one half-turn counterclockwise. The inward pressure must be enough to cause the instrument to maintain depth and strip away dentin as it rotates counterclockwise. These alternate motions are repeated until the file reaches working length. (Courtesy of Dr. James B. Roane.)
sharp transition angle, Flex-R files follow the canal and are prevented from gouging into the walls. The tip design causes a Flex-R file to hug the inside of a curve and prevents tip transport into the external wall of that curve. \(493\)

Balanced force instrumentation was born out of necessity because Roane firmly believes in enlarging the apical area to sizes larger than generally practiced. He expects a minimum enlargement of size 45, 1.5 mm short of the foramen in curved canals, and size 80 in larger single-rooted teeth (Figure 10-82). These sizes, of course, depend on root bulk, fragility, and the extent of curvature. Sabala and Roane also believe in carrying the preparation through to “full length,” the radiographic apex of the root. They “purposely” shape the foraminal area, and yet patients rarely experience flareups. \(494\) A step-back in \(\frac{1}{2}\)-mm increments is used with at least two groups of instruments to form an apical control zone.

This shaping provides a minimum diameter at a known depth within the canal. A size 45 control zone is shaped by first expending a size 15 and 20 file to the periodontal ligament and then reducing the working depth by 0.5 mm for sizes 25, 30, and 35 and completing the apical shape 1 mm short using sizes 40 and 45. It goes without saying that sodium hypochlorite irrigation is used. Single-appointment preparation and obturation are \textit{de rigueur} and also play an important role in the formation of these shaping concepts.

The success of this shaping technique and enlarging scheme has been closely evaluated in both clinical practice and student clinics. Clinical responsiveness is impressive, and the efficiency has been unmatched until rotary shaping (Figure 10-83).

\textbf{Efficacy of Balanced Force Preparation.} Sabala and Roane reported that, using the balanced force concept,
students at the University of Oklahoma could enlarge canals (in a laboratory exercise) with no measurable apical transportation.\textsuperscript{494} Moreover, the modified-tip instrument (Flex-R file) developed a nontransported preparation more frequently and predictably. Procedural accidents occurred in 16.7\% of the samples.\textsuperscript{493} In a previous publication, the authors concluded that most instruments damaged by students (91.5\%) using balanced force technique were damaged by overzealous clockwise rotation.\textsuperscript{85}

A University of Washington balanced force study, using standard K-type files, concluded that “effective instrumentation of curved root canals may be accomplished with straight instruments of fairly large size without significant deviation from the original canal position.” The original canal position was maintained 80\% of the time after shaping with a No. 40 file. Original position was maintained in only 40\% when a size 45 file was the final apical instrument.\textsuperscript{491} A second University of Washington study compared balanced force and step-back techniques. This study disclosed that Balanced Force using Flex-R prototype files produced significantly less deviation from the center of the original canal than did the step-back method using conventional K-type and Hedstroem files.\textsuperscript{492} The authors noted that no instrument separations were experienced in this study.

McKendry at the University of Iowa reported that the Balanced Force technique débrided the apical canal at least as adequately as the step-back filing technique and as well as the CaviEndo ultrasonic method. Furthermore, significantly less debris was extruded apically using balanced force compared to sonic or step-back preparations.\textsuperscript{495,496} While testing the Balanced Force method at Georgia, the investigators found that early radicular flaring (step-back) made instrumentation much easier but did not necessarily improve the quality of the apical shape.\textsuperscript{497}

It has been well established that the Balanced Force technique using guiding-tip files is fast and efficient. However, Balanced Force, like any new technique, should be practiced before it is used clinically. If excessive pressure is used, instrument separation may result. The large radicular shaping provided by use of Gates-Glidden drills, if improperly guided, might cause a strip perforation into the furcation. Use in undergraduate clinics has proven this technique reliable and safe for routine use. Once mastered, Balanced Force technique expands the shaping possibilities and extends one’s operative abilities.

**Ultrasonic and Sonic Preparations.** *Ultrasonic.* As stated before, ultrasonic instrumentation today is used primarily in final canal débridement. For canal cleanliness, ultrasonic activation with a No. 15 file for 3 full minutes in the presence of 5\% sodium hypochlorite produced “smooth, clean canals, free of the smear layer and superficial debris along their entire length.”\textsuperscript{498} This is exactly the technique used by a number of dentists seeking the cleanest canals in spite of which clean and shape technique they might have used. This should be done after the smear layer has been removed to ensure that all of the detritus, including bacteria, is all flushed out.

Concern over the possible harmful effects of sodium hypochlorite spilling out of the apical foramen was dealt with at the State University of Louisiana. Investigators intentionally overinstrumented past the apex in a monkey study and then evaluated the tissue response when sodium hypochlorite was used with conventional filing versus ultrasonic filing/irrigation. They were pleased to find no significant difference between the two methods and a low to moderate inflammatory response.\textsuperscript{499}

**Sonic.** Sonic canal preparation and débridement with the Micro Mega 1500 Sonic Air (Micro Mega/MediDenta, France/USA) handpiece has been quite popular, particularly with the military. Camp has considerable experience with the Sonic handpiece and instruments and recommended that stainless steel hand files size 10 or 15 first be used to establish a pathway down the canals until resistance is met, usually about two-thirds of the canal length. He then begins the step-down approach with the sonic instruments—the No. 15 Shaper or Rispisonic file (see Figure 10-34), their length set 2 mm shy of the length reached with the previous instrument. About 30 seconds are spent in each canal using a quick up and down, 2 to 3 mm stroke and circumferentially filing under water irrigation supplied by the handpiece. This is the time to remove any isthmus or fins between canals. The use of each instrument is followed by copious sodium hypochlorite irrigation. The water from the handpiece is turned off and the irrigant is agitated in the canal with the fine Sonic file.

At this point, working length is established by a radiograph or an electric apex locator, and the extension to the apical constriction is carried out with stainless steel hand files to full working length—Nos. 15, 20, 25, and 30. Following sodium hypochlorite irrigation, Camp returns to the Sonic No. 15 (or a 20 or 25 in larger canals) Shaper or Rispisonic file for 30 seconds in each canal. After irrigation, No. 30, 35, and 40 hand files are again used followed by a larger Sonic instrument, and then No. 50 to 60 hand files are used to step-back up the canal to ensure a tapered preparation. Final use of the
small Sonic file, with copious sodium hypochlorite to the constriction, removes the remaining debris and fillings. Recapitulation with a No. 20 hand file will check the correct length of tooth and the apical stop at the constriction. After final irrigation, the canal is dried with paper points and is ready for medication or filling as the case may be (personal communication, 2001).

**Efficacy and Safety of Ultrasonic/Sonic Preparations.** The Iowa faculty tested step-back versus step-down approach with ultrasonic and sonic devices. They found that the ultrasonic instruments produced a better preparation when the step-back approach was used. The step-down preparation was preferred for sonic preparation.\(^{500}\)

Another group of clinicians compared step-down, step-back hand instrumentation versus ultrasonic and sonic preparations. Both hand methods, as well as sonic enlargement, caused the extrusion of debris apically. In ranking from least to worst extrusion, Sonic was 1, best; step-down was 2; ultrasonic was 3; and conventional, circumferential, step-back preparation was 4, worst.\(^{216}\)

Finally, a French group evaluated the degree of leakage following obturation of canals prepared with the Sonic Air unit using Shaper Sonic files versus hand preparation. The researchers found that the highest degree of leakage occurred overall with the manual method; however, both methods leaked apically. They felt that the smear layer present might have been responsible.\(^{501}\)

**ROTARY INSTRUMENTATION USING NICKEL TITANIUM**

Over the past few years, the movement toward using rotary nickel-titanium instruments for root canal preparation has resulted in a multitude of instrumentation systems in the marketplace. The manufacture of variably tapered and “Gates-Glidden-like,” flexible nickel-titanium instruments, for use in gear-reduction, slow-speed handpieces, either air driven or electric, has enabled the skilled clinician to deliver predictable canal shapes (Figure 10-84) with enhanced speed and increased efficiency.\(^{502-510}\)

Problems associated with hand and rotary instrumentation with stainless steel have plagued both generalists and endodontists for years; these include (1) too many instruments and steps needed to generate the desired shape, thus increasing the time of canal preparation; (2) each resultant shape will be different, making obturation less predictable; (3) canal transportation naturally results as instruments increase in diameter and stiffness; and (4) the use of traditional coronal enlargement burs such as Gates-Glidden drills can cause excessive dentin removal.

Although nickel-titanium endodontic rotary instruments do overcome some of these shortcomings associated with stainless steel instruments, the clinician must also understand that nickel-titanium is not completely “fail-safe”; one must be aware of the fact that although nickel-titanium files are flexible, nickel-titanium metal, like any other metal, will eventually fatigue and fail when it becomes overstressed, especially during rotation in curved root canals\(^{511-514}\) or if improperly used or abused (see Figure 10-20, B). In turn, strict monitoring of instrument use in all systems should be maintained so that nickel-titanium files can be periodically disposed of prior to failure.\(^{512}\) In fact, single use (ie, use one time per case) in severely curved or calcified canals should be the rule. In addition, care must be taken to use these systems as per the manufacturer’s instructions (eg, a step-down approach with light pressure is essential when using nickel-titanium rotary instruments).

It is also important to understand that these systems require a significant learning curve to achieve mastery and are not deemed to be a panacea.

**ProFile 0.04 and 0.06 Taper Rotary Instruments and ProFile Orifice Shapers**

**ProFile 0.04 and 0.06 Taper Rotary Instruments and ProFile Orifice Shapers** (Dentsply/Tulsa Dental; Tulsa, Okla.) are proportionately sized nickel-titanium U-shaped instruments (Figure 10-85) designed for use in a controlled, slow-speed, high-torque, rotary handpiece.\(^{504,509,510,515}\) Although a study by Gabel et al. demonstrated four times more file separation/distortion at 333 rpm than at 166 rpm, the preferred speed...
range is still from 275 to 325 rpm. As these more tapered instruments are rotated, they produce an accelerated step-down preparation, resulting in a funnel-form taper from orifice to apex. As these “reamers” rotate clockwise, pulp tissue and dentinal debris are removed and travel counterclockwise back up the shaft. As a result, these instruments require periodic removal of dentin “mud” that has filled the “U” portion of the file.

The U-blade design, similar in cross-section to the LightSpeed, has flat outer edges that cut with a planing action, allowing it to remain more centered in the canal compared to conventional instruments (Figure 10-86). The ProFile tapers also have a built-in safety feature, in which, by patented design, they purportedly unwind and then wind up backward prior to breaking. These Profile Variable Taper instruments are manufactured in standard ISO sizing as well as Series 29 standards (ie, every instrument increases 29% in diameter).

The Orifice Shapers, in 0.06 and 0.07 mm/mm tapers, are designed to replace Gates-Glidden drills for shaping the coronal portion of the canal. Because of their tapered, radial-landed flutes and U-file design, these instruments remain centered in the canal while creating a tapering preparation. In turn, this preflaring allows for more effective cleaning and shaping of the apical half of the canal with the Profile Series 0.04 Tapers.

In contrast to Profile Tapers, however, the total length of the Orifice Openers is 19 mm, with a cutting length of approximately 9 mm. Besides reducing file separation, this shorter length also makes them easier to manipulate in difficult access areas. ISO tip sizes of 30, 40, and 50 are built into these files with tapers of 0.06 and 0.07. These instruments serve the same function as the Quantec Flares.

The ProFile Variable Taper has a 60-degree bullet-nose tip that smoothly joins the flat radial lands.

Figure 10-85  ProFile instrument sequence showing Orifice shapers and 0.04 tapers. (Courtesy of Dentsply/Tulsa Dental.)

Figure 10-86  Comparative cross-sectional shapes between a U-shaped Profile 0.04 taper with a 90-degree rake angle and the conventional triangular reamer with a 60-degree cutting angle. (Courtesy of Dentsply/Tulsa Dental.)
Although these tapers have a 90-degree cutting angle (Figure 10-87), the nonaggressive radial landed flutes gently plane the walls without gouging and self-threading; in addition, they are cut deeper to add flexibility and help create a parallel inner core of metal. Thus, when the Profile Taper is rotated, stresses become more evenly distributed along the entire instrument in contrast to a nonparallel core or tapered shaft of a conventional instrument in which stresses are more concentrated toward the tip of its narrow end. An investigation by Blum, Mactou et al., however, demonstrated that torque can still develop at the apical 3 mm of the ProFiles even when used in a step-down procedure.517

Profile instruments are available in either 0.04 (double taper) or 0.06 (triple taper) over the ISO 0.02 taper. Kavanaugh and Lumley found no significant differences between the 0.04 and 0.06 tapers with respect to canal transportation. On the other hand, the use of 0.06 tapers improved canal shape.515 The 0.04 is more suitable for small canals and apical regions of most canals, including the mesial roots of mandibular molars and buccal roots of maxillary molars. The 0.06 is recommended for the midroot portions of most canals, distal roots of mandibular molars, and palatal roots of maxillary molars. Similar to the graduating taper technique of the Quantec Series, the clinician has the option of using alternating tapers within a single canal (ie, combinations of 0.04, 0.06, and 0.07 taper Profile instruments).

Since the development of the Profile tapers, a number of methods for use have been espoused. As such, there is currently no recommended “stand-alone” technique. In fact, a number of clinicians incorporate the Profile System near the end of the canal preparation to blend the apical preparation with coronal preflare.

Canal Preparation
A basic technique that primarily uses Orifice Shapers and Profile tapers is as follows: Once access, canal patency, and an estimated working length have been determined, the No. 30 0.06 taper Orifice Shaper is taken several millimeters into the canal, thus creating a pathway for the next instruments. The No. 50 0.07 Orifice Shaper is then used to create more coronal flare followed by the No. 40 0.06 taper Orifice Shaper. This last instrument should be advanced about halfway down the canal using minimal pressure. Constant irrigation and recapitulation must be followed throughout the entire sequence.

A working length radiograph is then taken with a stainless steel hand file to determine the precise length. The tip of all subsequent tapers becomes a guide as the instrument cuts higher up the shaft, mostly with the middle blades. In all cases, a Profile taper file should never be used in the canal longer than 4 to 6 seconds. The clinician must now passively advance the 0.04 or 0.06 taper instruments, or combinations thereof, to or near the working length. As the rotary reamers move closer to length, a funnel shape is imparted to the canal walls. In most cases, a No. 30 or an equivalent 29 Series 0.04 taper eventually reaches at or near the working length with minimal resistance. In more constricted cases, however, a No. 25 or 20 0.04 taper may be the first to reach the working length. If the tapers are not taken to full working length, hand files, either stainless steel or nickel-titanium, can be used to complete the apical 1 to 2 mm.

Profile GT Rotary Instrumentation
Profile GT (Greater Taper) Rotary Files (Dentsply/Tulsa Dental; Tulsa, Okla.) are made of nickel-titanium alloy, and their intended purpose is to create a predefined shape in a single canal. Designed by Dr. Steven Buchanan and also available as hand files, these uniquely engineered files are manufactured in 0.06, 0.08, 0.10, and 0.12 tapers, all having a constant ISO noncutting tip diameter of 0.20 mm (ISO size 20) to ensure maintenance of a small apical preparation (Figure 10-88). They have variably pitched, radially-landed, clockwise cut U-blade flutes that provide reamer-like efficiency at the shank with K-file strength at their tips (ie, they have closed flute angles at their tips and more open flute angles at their shank ends). The open flute angles at the shank end also tend to reduce the file’s ability to thread into the canal, a typical problem that occurs with other rotary designs. The maxi-
mum flute diameter is also set at 1.0 mm, safely limiting coronal enlargement.

Because the GT files vary by taper but have the same tip diameters and maximum flute diameters, the flute lengths become shorter as the tapers increase. The 0.06 taper is designed for moderate to severely curved canals in small roots, the 0.08 taper for straight to moderately curved canals in small roots, and the 0.10 taper for straight to moderately curved canals in large roots. A set of three accessory GT files (see Figure 10-88) is available for unusually large root canals having apical diameters greater than 0.3 mm. These instruments have a taper of 0.12 mm per mm, a larger maximum flute diameter of 1.5 mm, and varying tip diameters of 0.35, 0.50, and 0.70 mm. When used in canals with large apical diameters, they are typically able to complete the whole shape with one file. The ProFile GT files are thus designed so that the final taper of the preparation is essentially equivalent to the respective GT file used.

A recent study (unpublished, 2000) conducted at the University of Pacific found that undergraduate dental students, who were trained in the GT rotary technique, completed shapes in 75% less time than with standard K files and Gates-Glidden drills. Shapes were also rounder throughout their lengths, and coronal canal shaping was more conservative.

**Canal Preparation.** According to the manufacturer, the ProFile GT technique can be broken down into three steps: step-down with ProFile GTs and then step back with ProFile 0.04 taper files and a GT file to create final canal shape. As in all rotary techniques, a step-down approach is used once initial negotiation is completed with hand files and lubricant. Standard GT files (0.12, 0.10, 0.08, and 0.06 tapers) are then used in a step-down manner at 150 to 300 rpm, allowing each to cut to their passive lengths.

**Working length** should be determined once the GT file has reached two-thirds of the estimated length of the canal. In some cases, the 0.06 taper will reach full length. Since the standard GT files all have a 0.20 mm tip diameter, the 0.08 and 0.10 taper files should easily go to length if a 0.08 or 0.10 taper is desired for that particular canal.

Rather than using the GT file to the apical terminus, a variation of the technique involves the creation of an apical taper. ProFile 0.04 taper instruments, usually sizes 25 to 35, can be used in a step-back fashion, starting about 2 mm short of working length. The standard GT files can then be used in a step-down fashion again to create the final canal shape right to working length, or, if preferred, hand instruments may be used to shape the apical 2 mm of the canal. If additional coronal flare is needed, an appropriate GT accessory file can be used.

With the ProFile GT rotary instrumentation technique, as with most other nickel-titanium rotary techniques, basic rules need to be adhered to. **Speeds must**
be kept constant, a light touch must be used, the GT files should not be used in a canal more than 4 to 6 seconds, and irrigation and lubrication must be continually used throughout the procedure.

**ProTaper Rotary System**

According to the developers, ProTaper (Progressively Tapered), nickel-titanium rotary files substantially simplify root canal preparation, particularly in curved and restricted canals. The claim is made that they consistently produce proper canal shaping that enables predictable obturation by any vertical obturation method. This new instrument system, consisting of three “shaping” and three “finishing” files, was co-developed by Drs. Clifford Ruddle, John West, Pierre Mactou, and Ben Johnson and was designed by François Aebey and Gilbert Rota of Dentsply/Maillefer in Switzerland.

The distinguishing feature of the ProTaper System (Dentsply/Tulsa Dental) is the progressively variable tapers of each instrument that develop a “progressive preparation” in both vertical and horizontal directions. Under use, the file blades engage a smaller area of dentin, thus reducing torsional load that leads to instrument fatigue and file separation. During rotation, there is also an increased tactile sense when compared with traditionally shaped rotary instruments. “Taper lock” is reportedly reduced, extending a newly found freedom from concern about breakage. As with any new system, however, the ProTaper beginner is advised to first practice on extracted teeth with restricted curved canals.

**ProTaper Configurations.** As previously stated, the ProTaper System consists of only six instrument sizes: three shaping files and three finishing files.

**Shaping Files.** The Shaping Files are labeled S-X, S-1, and S-2. The S-X Shaper (Figure 10-89, A) is an auxiliary instrument used in canals of teeth with shorter roots or to extend and expand the coronal aspects of the preparation, similar to the use of Gates-Glidden drills or orifice openers. The S-X has a much increased rate of taper from D₀ (tip diameter) to D₉ (9.0 mm point on the blades) than do the other two shapers, S-1 and S-2. At the tip (D₀), the S-X shaper has an ISO diameter of 0.19 mm. This rises to 1.1 mm at D₉ (comparable to the tip size of a size 110 ISO instrument). After D₀, the rate of taper drops off up to D₁₄, which thins and increases the flexibility of the instrument. The S-1 and S-2 files start at tip sizes of 0.17 mm and 0.20 mm, respectively, and each file gains in taper up to 1.2 mm (Figure 10-89, B). But unlike the consistent increase of taper per millimeter in the ISO instruments, the ProTaper Shapers have increasingly larger tapers each millimeter over the 14 mm length of their cutting blades. This is what makes the instruments unique.

**Shaping File S-1** is designed to prepare the coronal one-third of the canal, whereas **Shaping File S-2** enlarges and prepares the middle third in addition to the critical coronal region of the apical third. Eventually, both size instruments may also help enlarge the apical third of the canal as well.

**Finishing Files.** The three finishing files have been designed to plane away the variations in canal diameter in the apical one-third. **Finishing Files F-1, F-2,** and F-3 have tip diameters (D₀) of ISO sizes 20, 25, and 30, respectively. Their tapers differ as well (Figure 10-89, C). Between D₀ nd D₃, they taper at rates of 0.07, 0.08, and 0.09 mm/mm, respectively. From D₄ to D₁₄, each instrument shows a decreased taper that improves its flexibility.

Although primarily designed to finish the apical third of the canal, finishers do progressively expand the middle third as well. Generally, only one instrument is needed to prepare the apical third to working length, and tip sizes (0.20, 0.25, or 0.30) will be selected based on the canal’s curvature and cross-sectional diameter. **Finisher F-3** has been further engineered to increase its flexibility in spite of its size (Figure 10-89, D).

**ProTaper Benefits.**

1. The progressive (multiple) taper design improves flexibility and “carving” efficiency, an important asset in curved and restrictive canals (Figure 10-89, E).
2. The balanced pitch and helical angles of the instrument optimize cutting action while effectively augering debris coronally, as well as preventing the instrument from screwing into the canal.
3. Both the “shapers” and the “finishers” remove the debris and soft tissue from the canal and finish the preparation with a smooth continuous taper.
4. The triangular cross-section of the instruments increases safety, cutting action, and tactile sense while reducing the lateral contact area between the file and the dentin (Figure 10-89, F).
5. The modified guiding instrument tip can easily follow a prepared glide path without gouging side walls.

**Canal Preparation.**

**ProTaper System: Guidelines for Use**

1. Prepare a straight-line access cavity with no restrictions in the entry path into the chamber.
2. Fill the access cavity brimful with sodium hypochlorite and/or ProLube.
Endodontic Cavity Preparation

Figure 10-89  The ProTaper File Rotary System. A, Shaping File X, an auxiliary instrument used primarily to extend canal orifices and widen access as well as create coronal two-thirds shaping in short teeth. B, Shaping Files 1 and 2, used primarily to open and expand the coronal and middle thirds of the canal. C, Finishing Files 1, 2, and 3, used to expand and finish the apical third of progressively larger canals. D, Finishing File 3 is used to finish the apical third of larger canals. A No. 30 file is used to gauge the apical opening. Recapitulation with a regular No. 30 instrument, followed by liberal irrigation, is most important. E, The flexibility and cutting ability of nickel-titanium ProTaper Rotary Files are assets in preparing curved constricted canals. F, Triangular cross-section presents three sharp blade edges that improve cutting ability and tactile sense. Reproduced with permission from ADVANCED ENDODONTICS video and Drs. John West and Clifford Ruddle. (Color reproduction courtesy of Dentsply Tulsa Dental)
3. Establish a smooth glide path with No. 10 and No. 15 stainless steel hand files.
4. Use maximum magnification to observe the movement of the rotary instrument. “Seeing” rotary apical movement is safer than simply “feeling” such movement.
5. Use a torque- and speed-controlled electric motor, powering the handpiece at 200 to 300 rpm.
6. Be much gentler than with hand instruments. Always treat in a moist canal. Irrigate frequently!
7. **Slow down!** Each instrument should do minimal shaping. Only two, three, or four passes may be required for the file to engage restrictive dentin and carve the shape to the proper depth.
8. Instruments break when flutes become loaded or when instruments are forced. Check the flutes frequently under magnification and clean them. Cyclic fatigue from overuse, or if the glide path is not well established, also leads to breakage.
9. ProTaper instruments are disposable and, like all endodontic files and reamers, are designed for single-patient use. Sometimes instruments are even changed within the same treatment (eg, in the case of a four-canal molar).
10. Irrigate with 17% EDTA or a viscous chelator during the ProTaper shaping.

**ProTaper System: Directions for Use**

1. Establish proper access and a glide path with No. 10 and No. 15 stainless steel files to the working length or the apical constriction exit.
2. Flood the canal and chamber with sodium hypochlorite and begin shaping with the **Shaper S-1** using multiple, passive-pressure passes. Go no deeper than three-quarters of the estimated canal length. Irrigate and recapitulate with a No. 10 hand file, establishing patency to full working length. Now, with S-1, extend the preparation to full working length. Again irrigate and recapitulate.
3. “Brush” with the **Shaper S-X** to improve the straight-line access in short teeth or to relocate canal access away from furcations in posterior teeth.
4. **Shaping file S-2** is now used to full working length. Irrigate, recapitulate, and reirrigate.
5. Confirm and maintain working length with a hand file. (Remember, as curves are straightened, canals are shortened.)
6. With **Finisher F-1**, passively extend the preparation to within 0.5 mm of the working length. **Withdraw after one second! And only one second!** The F-1 has a tip size of 0.20 mm, and if a No. 20 hand instrument is found to be snug, the preparation is finished. With the instrument in place, radiographically verify the exact length before final irrigation.
7. If the F-1 and the No. 20 hand file are loose, continue the preparation with the **Finisher F-2**, which is 0.25 mm diameter at the tip. Confirm with a No. 25 hand instrument and, if snug, confirm the length radiographically, irrigate, and complete.
8. If the F-2 instrument and the No. 25 hand file are loose, continue the preparation to just short of the working length with the **Finisher F-3 file**, which has a 0.30 mm tip diameter, and follow with the confirming No. 30 instrument. If the No. 30 is found to be snug, the preparation is finished (see Figure 10-89, D). If this is loose, there are a number of techniques to enlarge the apical third to larger sizes.
9. Frequent irrigation and file cleansing are imperative—**irrigation and recapitulation!**

Now that the perfectly tapered preparation is complete, smear layer removal with EDTA and sodium hypochlorite is in order, followed by either medication and/or obturation.

**Quantec System and Graduating Taper Technique**

The **Quantec Series** (Sybron Endo/Analytic; Orange, Calif.) consists of a series of 10 graduated nickel-titanium tapers from 0.02 through 0.06 with ISO tip sizing (Figure 10-90). The Quantec **Flare Series**, with increased tapers of 0.08, 0.10, and 0.12, all with tip sizes of ISO 25, are designed to quickly and safely shape the **coronal third** of the canal. In contrast to the basic principles of other rotary instrument techniques, this system incorporates a built-in “**graduated tapers technique**,” whereby a series of **varying tapers** are used to prepare a single canal. The instruments are used at 300 to 350 rpm in a high-torque, gear-reduction, slow-speed handpiece.

Proponents of the **graduating tapers** technique claim that, theoretically, using a series of files of a single taper, whether it is a conventional 0.02 taper or a greater taper, will result in decreased efficiency as larger instruments are used, that is, more of the file comes into contact with the dentinal walls, making it more difficult to remove dentin as forces are generated over a larger area. Ultimately, each instrument will become fully engaged along the canal wall, potentially inhibiting proper cleaning and shaping of the apical canal.

In contrast and in accordance with the graduating tapers technique, by **restricting the surface contact** between instrument and wall, an instrument’s efficiency is increased since the forces used are concentrated on a smaller area. In this technique, for example, once a
0.02 taper has shaped the canal, a 0.03 taper with the same apical diameter would engage the canal more coronally; by altering the taper from 0.02, to 0.03, and up the scale to 0.06, the efficiency of canal preparation is maximized by restricting surface contact.

The Quantec rotary instruments are uniquely engineered with slightly positive rake or blade angles on each of their twin flutes; these are designed to shave rather than scrape dentin (negative rake angle), which most conventional files do. Flute design also includes a 30-degree helical angle with flute space that becomes progressively larger distal to the cutting blade, helping channel the debris coronally. More peripheral mass has been added to these files rather than depending on core strength alone as in other rotary systems.

The Quantec’s wide radial lands are purported to prevent crack formation in the blades and aid in deflecting the instrument around curvatures. By recessing the wide radial lands behind the blade, there is a concomitant reduction in frictional resistance while maintaining canal centering.

With respect to tip geometry, the clinician has a choice of two designs. The SC safe-cutting tip (see Figure 10-28, A) is specifically designed for small, tight canals, narrow curvatures, and calcified canal systems. This faceted 60-degree tip cuts as it moves apically; as the tip approaches a curve, conceptually, a balance takes place between file deflection and cutting. The LX noncutting tip, on the other hand, is a nonfaceted bullet-nosed tip, acting as a pilot in the canal and deflecting around severe curvatures in less constricted canals (see Figure 10-28, B). These LX Quantec instruments are also recommended for enlarging the body and coronal segments and managing delicate apical regions.

**Canal Preparation.** The Graduating Tapers technique involves a modified step-down sequence, starting with a larger tapered file first and progressing with files of lesser taper until working length is achieved. The technique involves canal negotiation, canal shaping, and, finally, apical preparation. As in all instrumentation techniques, straight-line access to the canal orifices must be made first, followed by passive negotiation of the canal using No. 10 and No. 15 0.02 taper hand files. A Quantec No. 25, 0.06 taper, 17 mm in length, is passively used. In most cases, this instrument should approach the apical third of the canal; at this point, the working length must be established.

A “Glide Path” is now established for all subsequent Quantec files by working No. 10 and No. 15 0.02 taper...
hand files along with sodium hypochlorite to the established working length. During the shaping phase, each Quantec file, progressing sequentially from a 0.12 taper down to a 0.03 taper, is passively carried into the canal as far as possible. In all cases, light apical pressure must be applied, using a light pecking motion and never advancing more than 1 mm per second into the canal. Each instrument should be used for no more than 2 to 5 seconds. The sequence is repeated until a 0.06 or 0.05 taper reaches the working length. The apical preparation can then be deemed complete or further enlarged by using the Quantec standard 0.02 taper No. 40 or No. 45 rotary instruments or hand files.

With the Quantec series, the correct amount of apical pressure must be maintained at all times; the continuously rotating instrument should either be inserted or withdrawn from the canal while allowing for its slow apical progression. The instrument, however, should be withdrawn after the desired depth has been reached and not left in the canal for an extended period of time, potentially causing canal transportation, ledge formation, and instrument separation. Thus, to reduce procedural problems, there should always be a continuous apical/coronal movement of the instrument, and, if the rotating file begins to make a clicking sound (file binding), one should withdraw the file and observe for instrument distortion.

LightSpeed Endodontic Instruments

The LightSpeed rotary instrumentation system (LightSpeed Technology; San Antonio, Tex.), so named because of the “light” touch needed as the “speed” of instrumentation is increased, involves the use of specially engineered nickel-titanium “Gates-Glidden-like” reamers (see Figure 10-90) that allow for enhanced tactile control and apical preparations larger than those created via conventional techniques and other nickel-titanium rotary systems. The set of instruments consists of ISO-sized rotary files from size 20 through 100, including nine half-sizes ranging from 22.5 through 65. The half sizes help reduce stress on both the instrument and root during preparation and decrease the amount of cutting that each instrument must accomplish. In most clinical cases, about 8 to 14 instruments are needed. They are used in a continuous, 360-degree clockwise rotation with very light apical pressure in a slow-speed handpiece. The recommended rpm is between 750 and 2,000, with preference toward the 1,300 to 2,000 range.

Owing to the flexible, slender, parallel shaft (Figure 10-91) that makes up the body of the instrument, the clinician can prepare the apical portion of the canal with the “head” of the LightSpeed to a size larger than what could normally be produced using tapered instruments. Since taper adds metal and decreases both flexibility and tactile feel toward the more apical regions of the canal, the LightSpeed instrument head, with its short cutting blades, only binds at its tip, thus increasing the accuracy of the tactile feedback. This results in rounder and centered apical preparations. Success with the LightSpeed, however, is predicated on straight-line access, an adequate coronal preflare, and establishment of working length prior to its introduction into a canal.

The LightSpeed instrument has a short cutting blade with three flat radial lands, which keeps the instrument from screwing into the canal, a noncutting pilot tip (see Figures 10-90 inset, and Figure 10-26), and a small-diameter noncutting flexible shaft, which is smaller than the blade and eliminates contact with the canal wall. Laser-etched length control rings on the shaft eliminate the need for silicone stops (see Figure 10-90). The LightSpeed instrument has a cross-sectional U-blade design in which flat radial lands with neutral rake angles enhance planing of the canal walls and centering of the instrument within the canal. The helical blade angle and narrow shaft diameter facilitate debris removal coronally.

Canal Preparation. Following proper coronal access, preflaring with Gates-Glidden drills or another method is highly recommended. The working length must first be established with at least a No. 15 stainless steel K file. Prior to using the LightSpeed in the handpiece, the clinician should first select and hand-fit a No. 20 LightSpeed instrument that binds short of the working length. Once
fitted, that LightSpeed instrument is now inserted in the gear-reduction, slow-speed handpiece. The LightSpeed must enter and exit the canal at the proper rpm, preferably 1,300 to 2,000 rpm for smoother and faster instrumentation. As with other systems, the rpm must be kept constant to avoid abrupt changes that may result in loss of tactile feedback and instrument breakage.

There are two recommended motions with LightSpeed: (1) if no resistance is felt, the LightSpeed is gently advanced to the desired length and withdrawn, or (2) if resistance is felt, a very light apical pecking motion (advance and withdraw motion) should be used until working length is attained. In either case, the instrument should never stay in one place as this increases transportation and enhances separation. This gentle pecking motion prevents blade locking, removes debris coronally, and aids in keeping the blades clean.

Increasingly larger LightSpeed instruments are used to the working length, never skipping sizes, including the half-sizes. Irrigation should occur at least once after every three instruments. Once the apical stop has been established, the LightSpeed should never be forced beyond this point. If forced, buckling along the shaft may occur, potentially leading to fatigue and instrument separation.

The MAR, or Master Apical Rotary (the smallest LightSpeed size to reach the working length, yet large enough to clean the apical part of the canal), becomes the subsequent instrument that first binds 3 to 4 mm short of the working length. This instrument will require 12 to 16 pecks (ie, 4 pecks per millimeter advancement) to reach the working length. This MAR, typically larger than the size achieved with most other methods, has been shown to clean the sides of the canal while remaining centered and creating a round preparation.

The apical 4 mm of the canal are shaped using sequentially larger instruments in step-back sequence with 1 mm intervals. The remainder of the step-back is done by feel. Finally, the last instrument taken to full working length is used for recapitulation. The taper of a canal prepared with LightSpeed is approximately 0.025 mm/mm to preserve tooth structure. To prevent instrument separation from torsional overload or from buckling along the shaft (cyclic or bending fatigue), LightSpeed instruments must always be used with light apical pressure—never forced. If the blade breaks off, it frequently can be bypassed.

**Rapid Body Shapers, Rotary Reamers, and Pow-R Rotary Files**

**Rapid Body Shaper (RBS)** (Moyco/Union Broach; Bethpage, N.Y.) consists of a series of four nickel-titanium rotary engine reamers (Figure 10-92). These instruments feature the patented nonledging Roane bullet tip and allow the practitioner to rapidly shape the body of the canal without the problems that can occur using Gates-Glidden drills. The RBS instruments develop a parallel-walled canal shape. The RBS series consists of four instruments: No. 1 (0.61 mm at the tip), No. 2 (0.66 mm at the tip), No. 3 (0.76 mm at the tip), and No. 4 (0.86 mm at the tip).

**Canal Preparation.** Prior to using RBS, the apical region of the canal must be prepared with a minimum No. 35 ISO instrument to within 0.5 mm of the apex. The No. 1 RBS is then placed in a gear-reduction, slow-speed handpiece at 275 to 300 rpm and allowed to track down the canal 2 to 3 mm. Constant and copious irrigation is necessary at all times. The RBS is removed to clean the fluting and is reinserted to track another 2 to 3 mm down the canal. This sequence is repeated until the No. 1 RBS is within 4 mm of the apex. The No. 2 RBS is then used like the No. 1, also to within 4 mm or shorter from the apex. The No. 3 RBS, followed by the No. 4 RBS, is used to within 7 mm of the apex, completing the body shaping. The No. 1 RBS will feel very aggressive, whereas the No. 2 through 4 RBS feel almost passive in comparison. Apical refinement is subsequently completed by hand instruments or via Pow-R nickel-titanium rotary instruments.

**Pow-R Nickel-Titanium Rotary Files** (Moyco/Union Broach; Bethpage, N.Y.), also with a nonledging Roane bullet tip, are available in both 0.02 and 0.04 tapers and, owing to their taper design, allow the practitioner to clean and shape the middle and apical regions of the canal in a conservative manner. These instruments come in standard ISO instrument sizes as well as in half sizes 17.5, 22.5, 27.5, 32.5, and 37.5 for more precise apical refinement. They follow standard ISO color codes as well.
Canal Preparation. Once Gates-Glidden drills are used to prepare and shape the coronal region of the canal in a step-down manner, and the canal has been at least partially negotiated with hand files, Pow-R files can be used. The clinician should select a file that binds at its tip in the middle third and begin to gradually move and push that file as it is rotating, slightly withdrawing it every 0.25 mm penetration until no more than 2 mm of depth are achieved or until resistance is felt. Like any other nickel-titanium file, these instruments must be used passively and with a light touch or pecking motion. The working length should now be determined using a hand file. Constant recapitulation with hand files is the rule along with constant irrigation. The next smaller Pow-R file is used to continue shaping an additional 1 to 2 mm deeper. Rotary instrumentation continues, decreasing sizes in sequence until the shaping is about 1.5 mm short of the apical foramen. The remaining portion of the canal can be finished with hand instruments or with Pow-R files. If more flare is needed, particularly if an obturation technique requires deep condenser penetration is considered, a rotary incremental step-back can be used to generate additional space in the apical and middle portions of the canal.

Both the RBS files and Pow-R instruments are used in high-torque, gear-reduction handpieces with rpm ranging from 300 to 400.

Principles of Nickel-Titanium Rotary Instrumentation
Irrespective of the nickel-titanium system used, nickel-titanium instruments are not designed for pathfinding, negotiating small calcified or curved canals, or bypassing ledges. Placing undue pressure on these extremely flexible instruments may lead to file breakage. This is attributable to the fact that nickel-titanium has less longitudinal strength and may deflect at a point where pressure is off the file. As mentioned throughout this section, stainless steel instruments should be used initially for pathfinding owing to their enhanced stiffness. Once the canal has been negotiated with at least a stainless steel No. 15 K-type file or a ledge has been bypassed and removed, then rotary nickel-titanium instruments can be used. Stainless steel instruments are also more radiopaque than nickel-titanium and “show up” better in tooth length measurements.

When using a gear-reduction, slow-speed, nickel-titanium rotary handpiece, the clinician must always keep the handpiece head aligned with the long axis of each canal as good straight-line access decreases excessive bending on the instrument. Nickel-titanium rotary instruments must be used with light apical pressure and never be forced and must always be used in a lubricated canal system to reduce frictional resistance, preferably with RC-Prep or Glyde or another acceptable lubricant.

Abrupt curvatures, S-shaped canal systems, and canals that join must be avoided with any nickel-titanium rotary file; use of rotary files in these cases may also lead to breakage. When a nickel-titanium file rotates inside any canal system, it becomes stressed and may subsequently “wobble” in the handpiece once the instrument is removed; the file should be disposed of. As the nickel-titanium file experiences any undue stress, including cyclic fatigue, the metal undergoes a crystalline (microscopic) phase transformation and can become structurally weaker. In many cases, there is usually no visible or macroscopic indication that the metal has fatigued. With repeated sterilization, Rapisarda et al. demonstrated decreased cutting efficiency and alteration of the superficial structure of Nickel-titanium Profiles, thus indicating a weakened structure, possibly prone to fracture. Essentially, a nickel-titanium file may disarticulate without any warning, especially if not properly used. Thus, it behooves the astute clinician to develop a systematic method for recognizing potential problems (grabbing or frictional locking of files into the canal, unwinding, twisting, cyclic fatigue, etc) and disposing of these nickel-titanium instruments. No one knows the maximum or ideal number of times that a nickel-titanium file can be used.

There is no doubt that the evolution of mechanized or rotary instrumentation using specially designed nickel-titanium files in gear-reduction, high-torque handpieces has revolutionized endodontics owing to their speed and efficacy in canal shaping and maintaining canal curvature. There is also no doubt that the development of the shape-memory alloy, nickel titanium, for use in endodontics has elevated the practice of endodontics to a higher level. With the evolution of torque-control electric motors and the continual engineering of more sophisticated instrument designs, cleaning and shaping with rotary instruments, made with shape-memory alloys, may eventually become the standard of care.

LASER-ASSISTED CANAL PREPARATION
After the development of the ruby laser by Maiman in 1960, Stern and Sognnaes (1964) were the first investigators to look at the effects of ruby laser irradiation on hard dental tissues. Early studies of the effects of lasers on hard dental tissues were based simply on the
empirical use of available lasers and an examination of the tissue modified by various techniques.

Laser stands for Light Amplification by Stimulated Emission of Radiation, and it is characterized by being monochromatic (one color/one wavelength), coherent, and unidirectional. These are specific qualities that differentiate the laser light from, say, an incandescent light bulb.

For any procedures using lasers, the optical interactions between the laser and the tissue must be thoroughly understood to ensure safe and effective treatment. The laser-light interaction is controlled by the irradiation parameters, that is, the wavelength, the repetition rate, the pulse energy of the laser, as well as the optical properties of the tissue. Typically, optical properties are characterized by the refraction index, scattering (μs), and absorption coefficients (μa). However, the ultimate effects of laser irradiation on dental tissue depend on the distribution of energy deposited inside the tooth. Laser energy must be absorbed by tissue to produce an effect. The temperature rise is the fundamental effect determining the extent of changes in the morphology and chemical structure of the irradiated tissue.\(^\text{524}\)

Lasers emitting in the ultraviolet, visible (ie, argon laser—488 and 514 nm), and near infrared (ie, neodymium:yttrium-aluminum-garnet [Nd:YAG] laser—1.064 µm) are weakly absorbed by dental hard tissue, such as enamel and dentin, and light scattering plays a very important role in determining the energy distribution in the tissue. Nd:YAG laser energy, on the other hand, interacts well with dark tissues and is transmitted by water. Argon lasers are more effective on pigmented or highly vascular tissues.

Excimer lasers (193, 248, and 308 nm) and the erbium laser (~3.0 µm) are strongly absorbed by dental hard tissues. Neev et al. have shown that the excimer at 308 nm is efficiently absorbed by dentin since it overlaps protein absorption bands.\(^\text{525,526}\) The erbium laser emits in the mid-infrared, which coincides with one of the peaks of absorption of water and the OH- of hydroxyapatite. Because of that, this laser is strongly absorbed by water, the absorbed energy induces a rapid rise in temperature and pressure, and the heated material is explosively removed.

The carbon-dioxide lasers emitting in the far infrared (10.6 µm) were among the first used experimentally for the ablation of dental hard tissues. The carbon-dioxide laser is the most effective on tissues with high water content and is also well absorbed by hydroxyapatite.

Studies have been conducted evaluating the effects of laser irradiation inside root canals. The authors have discussed laser-endodontic therapy, some as supplementary and others as a purely laser-assisted method.\(^\text{527}\) Although the erbium:YAG (May 1997) and erbium:YSGG (October 1998) lasers were approved for dental hard tissues, lasers still need to be approved by the US Food and Drug Administration (FDA) Committee on Devices for intracanal irradiation. The FDA’s clearance for these devices includes caries removal and cavity preparation, as well as roughening enamel. Other countries, such as Germany, Japan, and Brazil, have been conducting basic research and laser clinical trials, and some of the devices have been used there for treatment.

**Laser Endodontics**

In 1971, at the University of Southern California, Weichman and Johnson were probably the first researchers to suggest the use of lasers in endodontics.\(^\text{528}\) A preliminary study was undertaken to attempt to retroseal the apical orifice of the root canal using an Nd:YAG and a carbon-dioxide laser. Although the goal was not achieved, relevant data were obtained. In 1972, Weichman et al. suggested the occurrence of chemical and physical changes of irradiated dentin.\(^\text{529}\) The same laser wavelengths were then used, with different materials, in an attempt to seal internally the apical constriction.

Applications of lasers in endodontic therapy have been aggressively investigated over the last two decades. According to Stabholz of Israel, there are three main areas in endodontics for the use of lasers: (1) the periradicular, (2) the root canal system, and (3) hard tissue, mainly the dentin.\(^\text{530}\) One of the major concerns of endodontic therapy is to extensively clean the root canal to achieve necrotic tissue débridement and disinfection. In this sense, lasers are being used as a coadjuvant tool in endodontic therapy, for bacterial reduction, and to modify the root canal surface. The action of different types of laser irradiation on dental root canals—the carbon-dioxide laser,\(^\text{531}\) the Nd:YAG laser,\(^\text{532}\) the argon laser,\(^\text{533}\) the excimer laser,\(^\text{534}\) the holmium:YAG laser,\(^\text{535}\) the diode laser,\(^\text{536}\) and, more recently, the erbium:YAG laser—\(^\text{537}\)—has been investigated.

Unlike the carbon-dioxide laser, the Nd:YAG (Figure 10-93, A), argon, excimer, holmium, and erbium laser beams can be delivered through an optical fiber (Figure 10-93, B) that allows for better accessibility to different areas and structures in the oral cavity,\(^\text{530}\) including root canals. The technique requires widening the root canal by conventional methods before the laser probe can be placed in the canal. The fiber’s diameter, used inside the canal space, ranges from 200 to 400 µm, equivalent to a No. 20-40 file (Figure 10-93, C).
Dederich et al., in 1984, used an Nd:YAG laser to irradiate the root canal walls and showed melted, recrystallized, and glazed surfaces. Bahcall et al., in 1992, investigated the use of the pulsed Nd:YAG laser to cleanse root canals. Their results showed that the Nd:YAG laser may cause harm to the bone and periodontal tissues—a good example that laser parameters should constitute one of the factors for safety and efficacy of laser treatment.

According to Levy and Goodis et al., the Nd:YAG, in combination with hand filing, is able to produce a cleaner root canal with a general absence of smear layer. The sealing depth of 4 µm produced by the Nd:YAG laser was reported by Liu et al.

One concern for laser safety is the heat produced at the irradiated root surface that may cause damage to surrounding supporting tissue. Studies evaluating changes at the apical constriction and histopathologic analysis of the periapical tissues were presented by Koba and associates. They maintained the fiber optic at a stationary point, 1 mm from the apical foramen, for 2 to 3 seconds. Infiltration of inflammatory cells was observed in all groups in 2 weeks, including the control group. Indeed, the degree of inflammation reported in the laser-irradiated group at 2 weeks, 30 Hz (0.67 mJ/p) for 2 seconds, was significantly less than in the control group at 4 and 8 weeks. However, the same authors have shown that carbonization was observed in irradiated root canals depending on the parameter used. A technique considered optimal by Gutknecht et al. would be the irradiation from apical to coronal surface in a continuous, circling fashion.

Different laser “initiators” (dyes to increase absorption) with the Nd:YAG laser were tested by Zhang et al. Black ink was an effective initiator for this laser, but the root canal was inconsistently changed. It might be a consequence of the lack of uniformity in the distribution of the ink or laser irradiation inside the canals.

Under the scanning electron microscope (SEM), lased dentin showed different levels of canal débride-
ment, including smear layer removal and morphologic changes, related to the energy level and repetition rate used.545 There was no indication of cracking in all of the SEM samples at these laser parameters. The erbium:YAG laser, at 80 mJ, 10 Hz, was more effective for debris removal (Figure 10-94, A), producing a cleaner surface with a higher number of open tubules when compared with the other laser treatment and the control—without laser treatment (Figure 10-94, B). A decreased level was observed when the energy was reduced from 80 to 40 mJ. Nd:YAG laser-irradiated samples presented melted and recrystalized dentin and smear layer removal (Figure 10-94, C).

The root canal walls irradiated by the erbium:YAG laser were free of debris, the smear layer was removed, and the dentinal tubules were opened, as recently reported by Takeda et al.546,547 and Harashima et al.,548 although areas covered by residual debris could be found where the laser light did not enter into contact with the root canal surface.548 Scanning electron microscopic evaluation showed different patterns as a result of the different mechanisms of laser-tissue interaction by these two wavelengths.546–548

According to Hibst et al., the use of a highly absorbed laser light, like the erbium laser, tends to localize heating to a thin layer at the sample surface, thus minimizing the absorption depth.549 There follows a decrease in the risk of subsurface thermal damage since less energy is necessary to heat the surface.

The efficacy of argon laser irradiation in removing debris from the root canal system was evaluated by Moshonov et al.533 After cleaning and shaping, a 300 µm fiber optic was introduced into the root canals of single-rooted teeth to their working length. During irradiation, the fiber was then retrieved, from the apex to the orifice. Scanning electron microscopic analysis revealed that significantly more debris was removed from the lased group than from the control (Figure 10-95).

Although it appears that argon laser irradiation of the root canal system efficiently removes intracanal debris, its use as a treatment modality in endodontics requires further investigation. This is partially true because this laser is emitted in a continuous mode—like the carbon-dioxide laser—in the range of milliseconds. This means that a longer period of interaction with the intracanal surface is required and, consequently, a great increase in temperature.

One of the limitations of the laser treatment was demonstrated by Harashima et al.550 Where the (argon) laser optic fiber had not touched or reached the canal walls, areas with clean root canal surfaces were interspersed with areas covered by residual debris. Access into severely curved roots and the cost of the equipment are other limitations.

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Figure 10-94 Intracanal dentin surfaces (apical third) under SEM—1500X—laser parameters: A, Dentin surface lased with erbium:YAG 100 mJ and 15 Hz. Effective debris removal. B, Control; unlased dentin surface. C, Nd:YAG reduced to 80 mJ and 10 Hz. Note melted and recrystalized dentin surface. Reproduced with permission from Cecchini SCM et al.545
The Future

Wavelengths emitted at the ultraviolet portion of the electromagnetic spectrum appear to be promising in endodontics. ArF excimer laser at 193 nm is well suited to slow selective removal of necrotic debris from the root canal, leaving behind smooth, crack-free and fissure-free, melted dentin walls (P Wilder-Smith, personal communication, July 26, 1993). The XeCl (308 nm) excimer laser was capable of melting and closing dentinal tubules in a study performed by Stabholz and colleagues.551 Very short pulses (15 ns) will avoid significant heat accumulation in the irradiated tooth. When higher-energy densities were used (4 J/cm²), however, rupture of the molten materials and exposure of the tubules were noted. No clinical results are presently available. The second harmonic alexandrite laser (377 nm/ultraviolet), in development by Hennig and colleagues in Germany, has been shown to selectively remove dental calculus and caries and appears to be very promising for bacterial reduction, as well as for future application in periodontics and endodontics.552

Indeed, the ability of certain lasers to ablate necrotic organic materials and tissue remnants and reduce microorganisms seems highly promising in endodontics. A significant reason for using laser intracanal irradiation is the microbial reduction, usually achieved by temperature rise. Several studies have evaluated the effectiveness of lasers in sterilizing root canals and have reported significant in vitro decreases in number of bacteria.537,553–557 However, the performance of this equipment, concerning safe and effective wavelength and energy levels related to temperature rise, morphologic changes, and microbial reduction, should be well documented before it becomes a current method of treatment.

It is important to realize that different types of lasers have different effects on the same tissue, and the same laser will interact differently depending on the types of tissue. Safety precautions used during laser irradiation include safety glasses specific for each wavelength (compatible optical density to filtrate that wavelength), warning signs, and high-volume evacuation close to the treated area (used in soft tissue procedures, cavity preparation, etc).

Noninstrumentation Root Canal Cleansing

Based on the premise that “[O]ptimal cleansing of the root canal system is a prime prerequisite for long term success in endodontics,” Lussi and his associates at the University of Bern, Switzerland, introduced devices to cleanse the root canal “without the need of endodontic instrumentation.”558 The first device, reported in 1993, consisted of a “pump” that inserted an irrigant into the canal, creating “bubbles” and cavitation that loosened the debris. This pressure action was followed by a negative pressure (suction) that removed the debris: “The irrigant fluid was injected through the outer tube while the reflux occurred through the inner tube.” More recently, they have improved the device and reported that the “smaller new machine produced equivalent or better cleanliness results in the root canal system using significantly less irrigant (NaOCl).”559 This cleanses the canal but, of course, does nothing to shape the canal (Figure 10-96).

PULPECTOMY

Rather than break into the flow of detailing the methods of cleaning and shaping the root canal, we have reserved until now the often necessary task of removing a vital pulp, diseased though it may be. This is termed pulp extirpation or pulpectomy. Total pulpectomy, extirpation of the pulp to or near the apical foramen, is indicated when the root apex is fully formed and the foramen sufficiently closed to permit obturation with conventional filling materials. If the pulp must be removed from a tooth with an incompletely formed root and an open apex, partial pulpectomy is preferred. This technique leaves the apical portion of pulp intact with the hope that the remaining stump will encourage completion of the apex (Figure 10-97). The necrotic or “mummified” tissue remaining in the pulp cavity of a pulpless tooth has lost its identity as an organ; hence, its removal is called pulp cavity débridement.
Indications

Pulp “mummification” with arsenic trioxide, formaldehyde, or other destructive compounds was at one time preferable to extirpation. With the advent of effective local anesthetics, pulpectomy has become a relatively painless process and superseded “mummification,” with its attendant hazards of bone necrosis and prolonged postoperative pain.

Pulpectomy is indicated in all cases of irreversible pulp disease. With pulpectomy, dramatic relief is obtained in cases of acute pulpitis resulting from infection, injury, or operative trauma. Pulpectomy is usually the treatment of choice when carious or mechanical exposure has occurred. In a number of instances, restorative and fixed prosthetic procedures require intentional extirpation.

Technique

The following are the steps in the performance of a well-executed pulpectomy:

1. Obtain regional anesthesia.
2. Prepare a minimal coronal opening and, with a sharp explorer, test the pulp for depth of anesthesia.
3. If necessary, inject anesthetic intrapulpally.
4. Complete the access cavity.
5. Excavate the coronal pulp.
6. Extirpate the radicular pulp.
7. Control bleeding and débride and shape the canal.
8. Place medication or the final filling.

Each of these steps must be completed carefully before the next is begun, and each requires some explanation.

Profound Anesthesia
Methods for obtaining profound infiltration and conduction anesthesia have been considered earlier (chapter 9). One aspect of the subject deserves repetition: its unusual importance in endodontics! From the era when pulps were extirpated by driving wooden pegs, red-hot wires, or crude broaches into the living tissues without benefit of anesthesia, there has persisted a profound and widespread dread of “having a ‘nerve’ taken out of a tooth.” The popular misconception that endodontic treatment invariably involves suffering will not be completely dispelled until all practitioners employ effective anesthesia techniques while completing procedures as potentially painful as pulpectomy.

Minimal Coronal Opening and Intrapulpal Anesthesia
It is wise to anticipate that, in spite of apparently profound anesthesia, an intraligamentary or intrapulpal injection may be required to obtain total anesthesia, particularly with an inflamed pulp. If the patient experiences pain during the initial stage of access preparation, there is no question that manipulation of the pulp will be a painful process. The success of the intrapulpal injection will be ensured if the initial penetration of the pulp chamber is made with a sharp explorer close to the size of the injection needle. Since the needle fits the small opening tightly, the anesthetic can be forced into the pulp under pressure. Total anesthesia follows immediately (for greater detail, see chapter 9).

Completion of the Access Preparation
Coronal access must be adequate and complete to allow thorough excavation of the tissue from the pulp chamber. Because intrapulpal injection with 2% lidocaine with 1:50,000 epinephrine promotes excellent hemostasis, it can be used during the completion of the access cavity to prevent interference from hemorrhaging tissue.

Excavation of the Coronal Pulp
All of the tissue in the pulp chamber should be removed before extirpation of the radicular pulp is begun. All pulp tissue that has not been removed by the round bur should be eliminated with a sharp spoon excavator. The tissue is carefully curetted from the pulp horns and other ramifications of the chamber. Failure to remove all tissue fragments from the pulp chamber may result in later discoloration of the tooth. At this point, the chamber should be irrigated well to remove blood and debris.

Extrirpation of Radicular Pulp
The instrument used for this procedure is determined by the size of the canal and/or the level at which the pulp is to be excised.

Large Canal, Total Pulpectomy
If the canal is large enough to admit a barbed broach (Figure 10-98, A) and a total pulpectomy is desired, the approach is as follows:

1. A pathway for the broach to follow is created by sliding a reamer, file, or pathfinder along the wall of the canal to the apical third. If the pulp is sensitive or bleeding, the anesthetic syringe needle may be used as the “pathfinder.” A drop of anesthetic deposited...
near the apical foramen will stop the flow of blood and all pain sensations. At the same time, the needle displaces the pulp tissue and creates the desired pathway for a broach.

2. A broach, small enough not to bind in the canal, is passed to a point just short of the apex. The instrument is rotated slowly, to engage the fibrous tissue in the barbs of the broach, and then slowly withdrawn. Hopefully, the entire pulp will be removed with the broach (Figure 10-98, B). If not, the process is repeated. If the canal is large, it may be necessary to insert two or three broaches simultaneously to entwine the pulp on a sufficient number of barbs to ensure its intact removal.

3. If the pulp is not removed intact, small broaches are used to “scrub” the canal walls from the apex outward to remove adherent fragments. A word of caution: The barbed broach is a friable instrument and must never be locked into the canal. Handle with care!

**Small Canal, Total Pulpectomy**

If the canal is slender, and a total pulpectomy is indicated, extirpation becomes part of canal preparation. A broach need not be used. Small files are preferred for the initial instrumentation because they cut more quickly than reamers. In such a canal, Phase I instrumentation to a No. 25 file is usually minimal to remove the apical pulp tissue (Figure 10-99). New rotary increased-tapered instruments open up the coronal third of the canal, allowing for more efficient removal of the pulp.

**Partial Pulpectomy**

When a partial pulpectomy is planned, a technique described by Nygaard-Østby (personal communication, 1963) is employed. From a good radiograph, the width of the canal at the desired level of extirpation is determined. A Hedstroem file of correct size is blunted so that the flattened tip will bind in the canal at the predetermined point of severance. The Hedstroem file has deep fluting and makes a cleaner incision than other intracanal instruments. Enlargement of the canal coronal portion is then carried out with a series of larger instruments trimmed to the same length.

Neither Stromberg nor Pitt Ford was particularly enthusiastic about healing following pulpectomy, either total or partial. Working with dogs, both were troubled by postoperative periradicular infections possibly induced by coronal microleakage. Pitt Ford considered anachoresis the route of bacterial contamination. Others have found, however, that intracanal infections by anachoresis do not occur unless the periradicular tissues were traumatized with a file and bleeding was induced into the canal.

**Control of Bleeding and Débridement of Canal**

Incomplete pulpectomy will leave in the canal fragments of tissue that may remain vital if their blood

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*Figure 10-99*  A, Space between canal walls and No. 10 file demonstrates need to instrument the canal to at least file size No. 25 for total pulpectomy. B, No. 25 instrument engaging walls and removing pulp. (Courtesy of Dr. Thomas P. Mullaney.)
supply is maintained through accessory foramina or along deep fissures in the canal walls (Figure 10-100). These remnants of the pulp may be a source of severe pain to the patient, who will return seeking relief as soon as the anesthesia wears off. This is a desperately painful condition and requires immediate reanesthetization and extirpation of all tissue shreds. Any overlooked tissue will also interfere with proper obturation during immediate filling procedures.

Persistent bleeding following extirpation is usually a sign that “tags” of pulp tissue remain. If the flow of blood is not stopped by scrubbing the canal walls with a broach, as described above, it may originate in the periradicular area. In these cases, it is best to dry the canal as much as possible after irrigating with anesthetic. A dry cotton pellet is then sealed in until a subsequent appointment.

Emergency Pulpotomy

Although complete pulpectomy is the ideal treatment for an irreversibly inflamed vital pulp requiring endodontic therapy, a temporary pulpotomy can be performed in a relatively short period of time. In a busy practice, where it may not be practical to complete instrumentation at the emergency visit, a pulpotomy can be done. First, anesthetic solution is used to irrigate the pulp chamber. The coronal pulp is then amputated with a sharp excavator. A well-blotted Formocresol pellet may be sealed in with a suitable temporary. Some advocate sealing in cotton alone, with no medication. The temporary pulpotomy will normally provide the patient with relief until complete instrumentation can be carried out at a subsequent appointment. Swedish dentists used this technique in 73 teeth with irreversible pulpitis and arrested toothache 96% of the time. Three patients, however, had to return for total pulpectomy for pain relief.566

Placement of Medication or Root Canal Filling

If pulpectomy was necessitated by pulpitis resulting from operative or accidental trauma, or planned extirpation of a normal pulp for restorative purposes was done, cleaning and shaping and obturation of the canal can be completed immediately. If a delay is necessary, a drug of choice or dry cotton should be sealed in the chamber. The final canal filling should never be placed, however, unless all pulpal shreds are removed and hemorrhage has stopped. Immediate filling is contraindicated if the possibility of pulpal infection exists.

INTRACANAL MEDICATION

Antibacterial agents such as calcium hydroxide are recommended for use in the root canal between appointments. While recognizing the fact that most irrigating agents destroy significant numbers of bacteria during canal débridement, it is still thought good form to further attempt canal sterilization between appointments. The drugs recommended and technique used are thoroughly explored in chapter 3.

IATRAL ERRORS IN ENDODONTIC CAVITY PREPARATION

For a description of the prevention and correction of mishaps in endodontic cavity preparations, see chapter 15.

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