14

Cleaning and Shaping

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CHAPTER OUTLINE

LEARNING OBJECTIVES

After reading this chapter, the student will be able to:

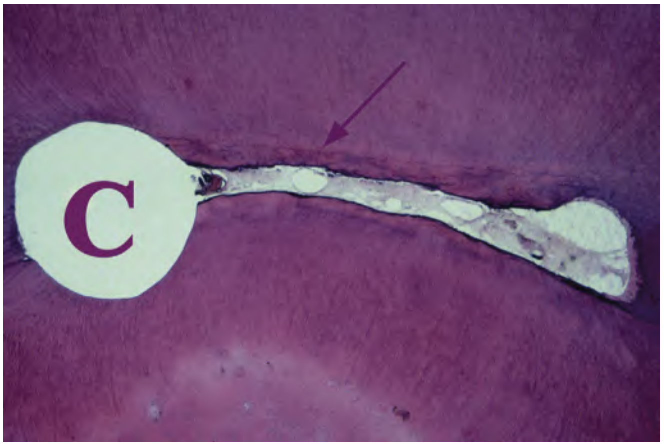
1. State reasons and describe strategies for enlarging the cervical portion of the canal to promote straight-line access.
2. Define how to determine the appropriate size of the master apical file.
3. Describe objectives for biomechanical cleaning and shaping and explain how to determine when these have been achieved.
4. Illustrate shapes of differently created preparations and draw these both in longitudinal and cross-sectional diagrams.
5. Describe techniques for shaping canals that have irregular shapes, such as round, oval, hourglass, bowling pin, kidney bean, or ribbon.
6. Distinguish between apical stop, apical seat, and open apex, and discuss how to manage obturation in each.
7. Describe appropriate techniques for removing the pulp.
8. Characterize the difficulties of preparation in the presence of anatomic aberrations that make complete débridement difficult.
9. Describe techniques for negotiating severely curved, "blocked," "ledged," or constricted canals.
10. Discuss the properties and role of intracanal, interappointment medicaments.

Successful long-term outcomes of root canal treatment are based on establishing an accurate diagnosis and developing an appropriate treatment plan; applying knowledge of tooth anatomy and morphology (shape); and performing débridement, disinfection, and obturation of the entire root canal system while maintaining the strength of the tooth. Historically, emphasis was on obturation and sealing the radicular space. However, no technique or material provides a seal that is completely impervious to moisture from either the apical or coronal aspects. Early studies on prognosis indicated failures were attributable to incomplete obturation.[1] This proved fallacious as obturation merely reflects the adequacy of the cleaning and shaping. Canals that are poorly obturated may be incompletely cleaned and shaped. Adequate cleaning and shaping and establishing a coronal seal are essential elements for successful treatment, with obturation being less important for short-term success.[2] Elimination (or significant reduction) of inflamed or necrotic pulp tissue and microorganisms are the most critical factors. The role of obturation in long-term success has not been established but may be significant in preventing recontamination either from the coronal or apical direction. Sealing the canal space after cleaning and shaping will help to entomb any remaining organisms[3] and, with the coronal seal, prevent or at least delay recontamination of the canal and periradicular tissues. However, some bacterial species have been shown to survive entombment.[4]

These classic concepts define success in endodontics by healing of apical periodontitis if present preoperatively or the prevention of its occurrence in case that began with normal periapical tissues. However, in recent years, it has been demonstrated that vertical fracture or other nonendodontic causes are the major reasons for the eventual loss of root canal–treated teeth.[5] As a result, a more patient-centered outcome as increased susceptibility to fracture should be considered. Functional retention of the endodontically treated tooth may serve as a relevant endpoint in endodontic treatment,[6] which may compliment but should not replace the traditional focus on healing or prevention of apical periodontitis.

Principles of Cleaning and Shaping

Nonsurgical root canal treatment is a predictable method of retaining a tooth that otherwise would require extraction. Success



• **Fig. 14.1** Cross-section through a root showing the main canal (C) and a fin *(arrow)* and associated cul-de-sac after cleaning and shaping using files and sodium hypochlorite. Note the tissue remnants in the fin.

• **Fig. 14.2** The main canal (C) has a lateral canal *(arrow)* extending to the root surface. After cleaning and shaping with sodium hypochlorite irrigation, tissue remains in the lateral canal.

of root canal treatment in a tooth with a vital pulp is higher than that of a tooth diagnosed with necrotic pulp and periradicular pathosis.[7]

The reason for this difference in outcome is the persistent presence of microorganisms and their metabolic byproducts. The most significant factors affecting the clinician's inability to completely remove intracanal microorganisms are tooth anatomy and morphology. Instruments are believed to contact and plane the canal walls to débride the canal (Figs. 14.1 to 14.4), aided by irrigating solutions. Morphologic factors include lateral (see Fig. 14.2) and accessory canals, canal curvatures, canal wall irregularities, fins, cul-de-sacs (see Fig. 14.1), and isthmuses. These aberrations render full wall contact and therefore complete débridement virtually impossible. Consequently, a practical objective of cleaning is to significantly reduce the irritants, not totally eliminate them. Frequent and effective irrigation is necessary to achieve this goal. At the same time, root canals need to be enlarged to allow irrigants to properly clean the canal and to remove contaminated dentin. Irrigants readily remove microorganisms from the coronal third of a root canal, but further shaping is necessary to eliminate bacteria in less accessible canal areas. Meanwhile, the mechanical action of instruments generates debris that is typically pushed into accessory anatomy and may block the access to subsequent irrigation. This debris also needs to be flushed and removed. Therefore it is imperative to use mechanical shaping and irrigation in synergy to maximize antibacterial efficacy of endodontic procedures.

Apart from enhancing cleaning procedures, another purpose of shaping is to provide space for an effective filling of the root canal space. The main mechanistic objective of shaping is to maintain or develop a continuously tapering funnel from the canal orifice to the apex. Conceptually, the degree of enlargement is partly dictated by the method of obturation. For lateral compaction of gutta-percha, the canal should be enlarged sufficiently to permit placement of the spreader to within 1 to 2 mm of the working length (WL).[8] For warm vertical compaction techniques, the coronal enlargement must permit the placement of pluggers to within 3 to 5 mm of the WL.[9]

However, the more dentin is removed from the canal walls, the less resistant to fracture the root becomes.[10] Micronized gutta-percha points for vertical compaction that allows melting at larger distances from the heat source are now available in order to allow proper obturation of more conservative preparations. New materials based on the concept of so-called hydraulic obturation techniques are also marketed for the same purpose. However, as always, clinicians should select an obturation technique judiciously, based on available evidence.

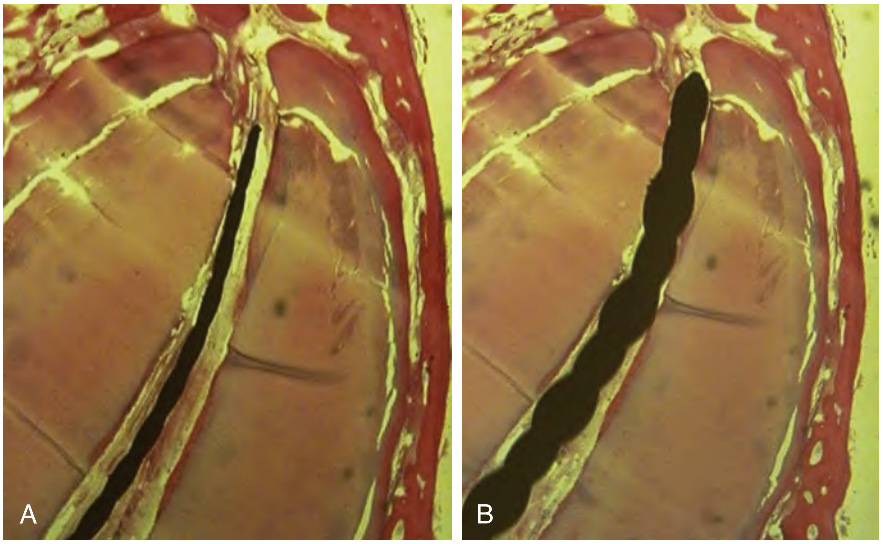
Ideally, the degree of shaping should be tooth dependent and not depend on the obturation technique. As an example, narrow thin roots, such as mandibular incisors, may not permit the same degree of enlargement as more bulky roots, such as the maxillary central incisors.

Apical Canal Preparation

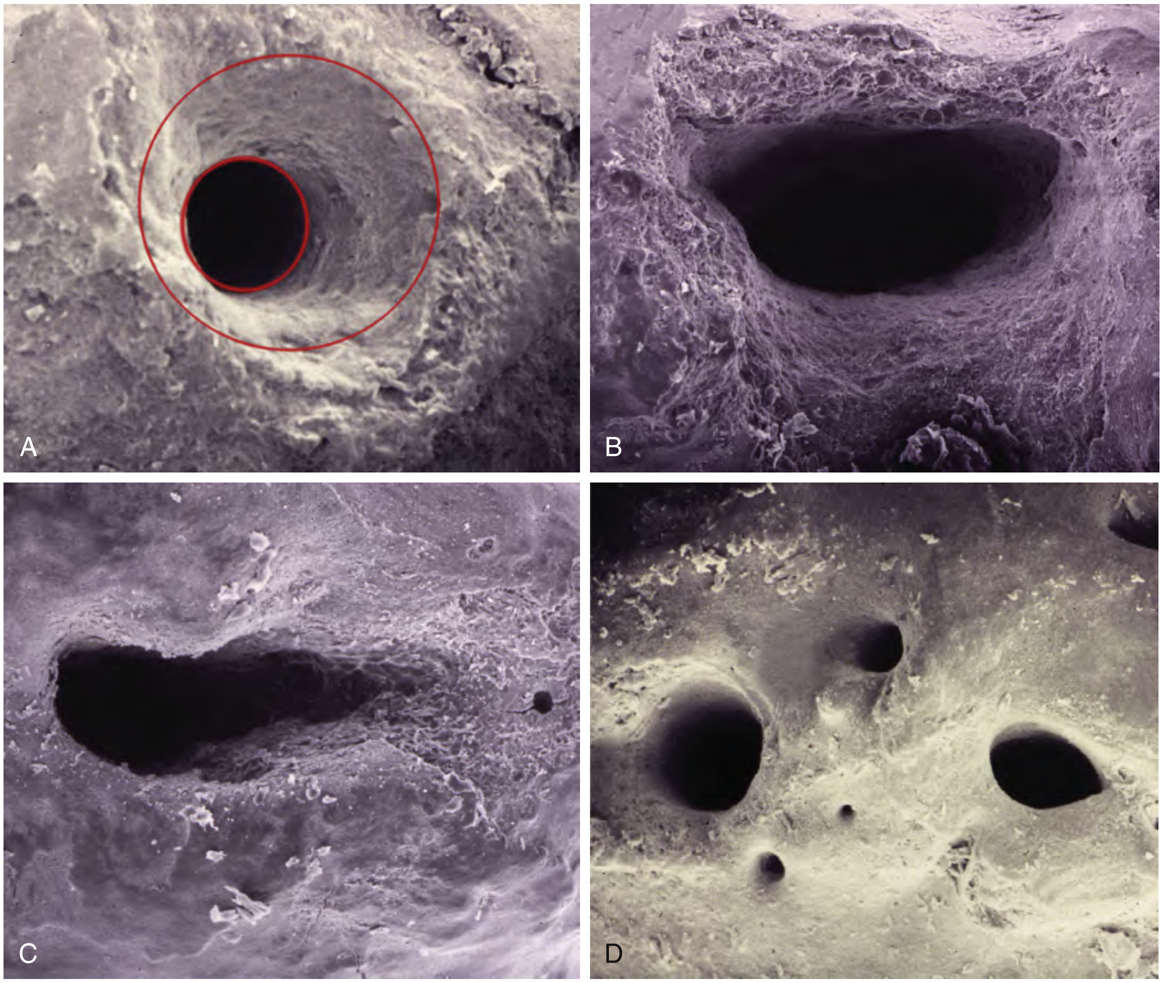
Termination of Cleaning and Shaping

Although the concept of cleaning and shaping the root canal space appears to be straightforward, there are areas where consensus does not exist. The first is the extent of the apical preparation. Early studies identified the dentinocemental junction as the area where the pulp ends and the periodontal ligament begins. Unfortunately, this is a histologic landmark and the position (which is irregular within the canal) cannot be determined clinically.

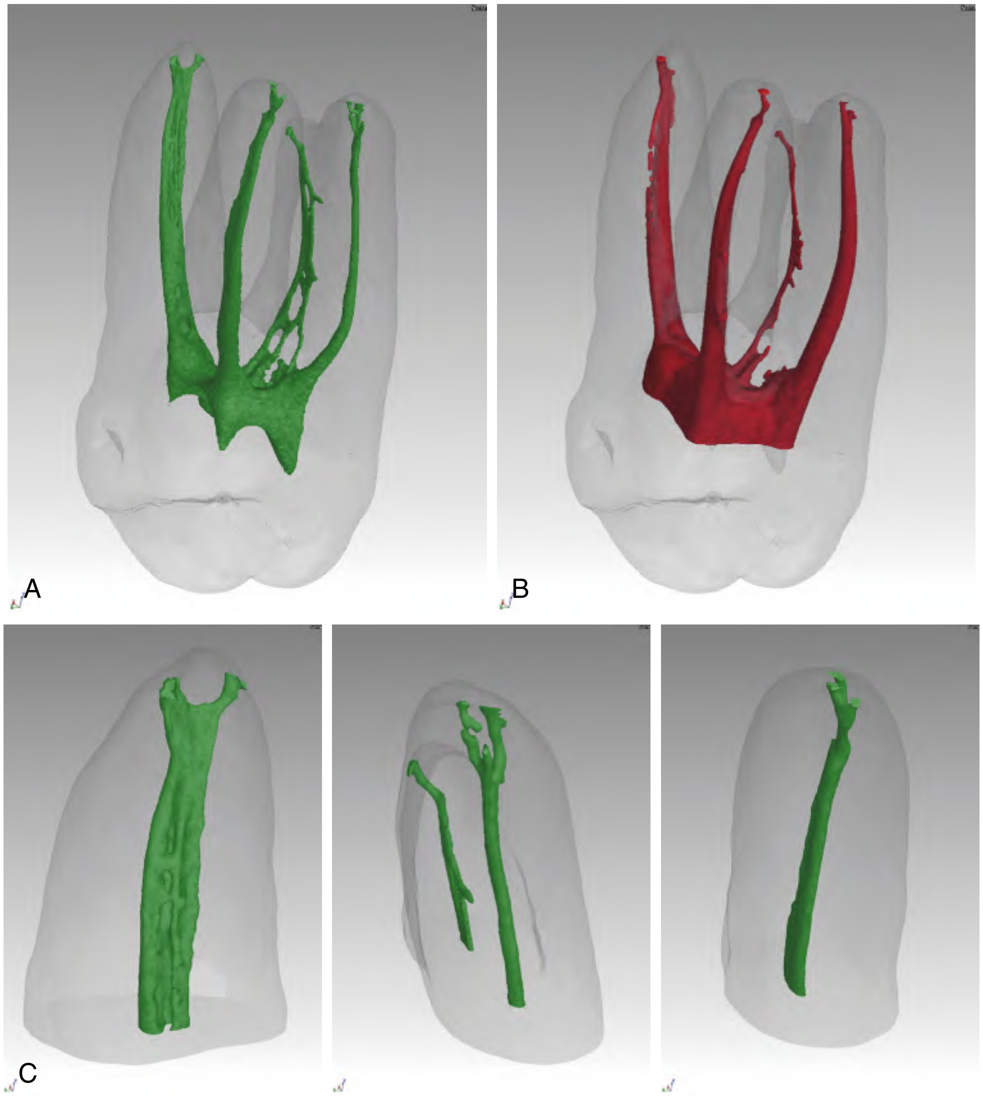
Traditionally, the apical point of termination, also known as *WL*, has been 1 mm from the radiographic apex. A classic study described the apical portion of the canal with the major diameter of the foramen and the minor diameter of the constriction (Fig. 14.4).[11] The apical constriction is defined as the narrowest portion of the canal, and the average distance from the foramen to the constriction was found to be 0.5 mm. Another study found the classic apical constriction to be present in only 46% of the teeth and, when present, varied in shape and in relation to the apical foramen.[12] Variations from the classic appearance consist of the tapering constriction, multiple constrictions, and a parallel apical canal part.[12] To complicate the issue, the foramen is rarely located at the anatomic apex. Convincing micro–computed tomography data provide a more realistic portrait of apical canal morphology (Fig. 14.5).



• **Fig. 14.3** **(A)** No. 15 file in the apical canal space. Note the size is inadequate for planing the walls. **(B)** No. 40 file more closely approximates the canal morphology. (Courtesy Dr. Randy Madsen.)



• **Fig. 14.4** **(A)** The classic apical anatomy consisting of the major diameter of the foramen and the minor diameter of the constriction. **(B)** An irregular ovoid apical canal shape and external resorption. **(C)** A bowling pin apical morphology and an accessory canal. **(D)** Multiple apical foramina.



• **Fig. 14.5** **(A)** Micro–computed tomography (micro-CT) reconstruction of an unprepared root canal system of a maxillary molar. **(B)** Prepared canal system, enlarged to an apical size 30 in the palatal and 25 in the mesiobuccal and distobuccal canal. **(C)** Magnified view of the initial canal configuration for all three apices.

Apical anatomy has also been shown to be quite variable (see Figs. 14.4, *B*, and 14.5). A study found no typical pattern for foraminal openings and that no foramen coincided with the apex of the root.[13] The same group reported the foramen to apex distance to range from 0.20 to 3.8 mm.

It has also been noted that the foramen to constriction distance increases with age,[11] and root resorption may destroy the classic anatomic constriction.[14] Resorptive processes are common with pulp necrosis and apical bone resorption. Therefore root resorption is an additional factor to consider in length determination.

In a prospective study, significant adverse factors influencing success and failure were the presence of a perforation, preoperative periradicular disease, and incorrect length of the root canal filling.[15,16] The authors speculated that canals filled more than 2.0 mm short harbored necrotic tissue, bacteria, and irritants that when retreated could be cleaned and sealed.[15] A meta-analysis evaluation of success and failure indicated a better success rate when the obturation was confined to the canal space.[17] A review of several studies on endodontic outcomes confirms that extrusion of materials decreases success.[7,18,19] In one study examining cases with pulp necrosis, better success was achieved when the procedures terminated at or within 2 mm of the radiographic apex. Obturation shorter than 2 mm from the apex or past the apex resulted in a decreased success rate. In teeth with vital inflamed pulp tissue, termination between 1 and 3 mm was acceptable.[18] Two larger studies confirmed that overfill was associated with inferior outcomes.[7,19]

At the same time, working short presents higher risks of accumulation and retention of debris, which in turn may result in apical blockage and may contribute to procedural errors in the first place; furthermore, infected debris, bacteria, and their byproducts can remain in the most apical portion of the canal in cases with pulpal necrosis jeopardizing apical healing and contributing to a persistent or recurrent apical periodontitis[20,21] or posttreatment disease.[22,23]

Most publications on outcomes that extrapolate the effect of apical termination are retrospective. On the other hand, a recent prospective study demonstrated that not only the maintenance of apical patency, but also the apical extent of canal cleaning, is a significant prognostic factor for root canal treatment, recommending extending canal cleaning as close as possible to its apical terminus. In that study, the odds of success were reduced by 12% for every 1 mm of the canal short of the terminus remaining "uninstrumented."[7]

Therefore the exact clinical point of apical termination of the preparation and obturation remains a matter of debate. The need to compact the gutta-percha and sealer against the apical dentin matrix (constriction of the canal) is important in creating a seal. The decision of where to terminate the preparation is based on knowledge of apical anatomy, tactile sensation, radiographic interpretation, apex locators, apical bleeding, and the patient's response. To prevent extrusion, the cleaning and shaping procedures should be confined to the radicular space. Canals filled to the radiographic apex are actually slightly overextended.[13]

Degree of Apical Enlargement

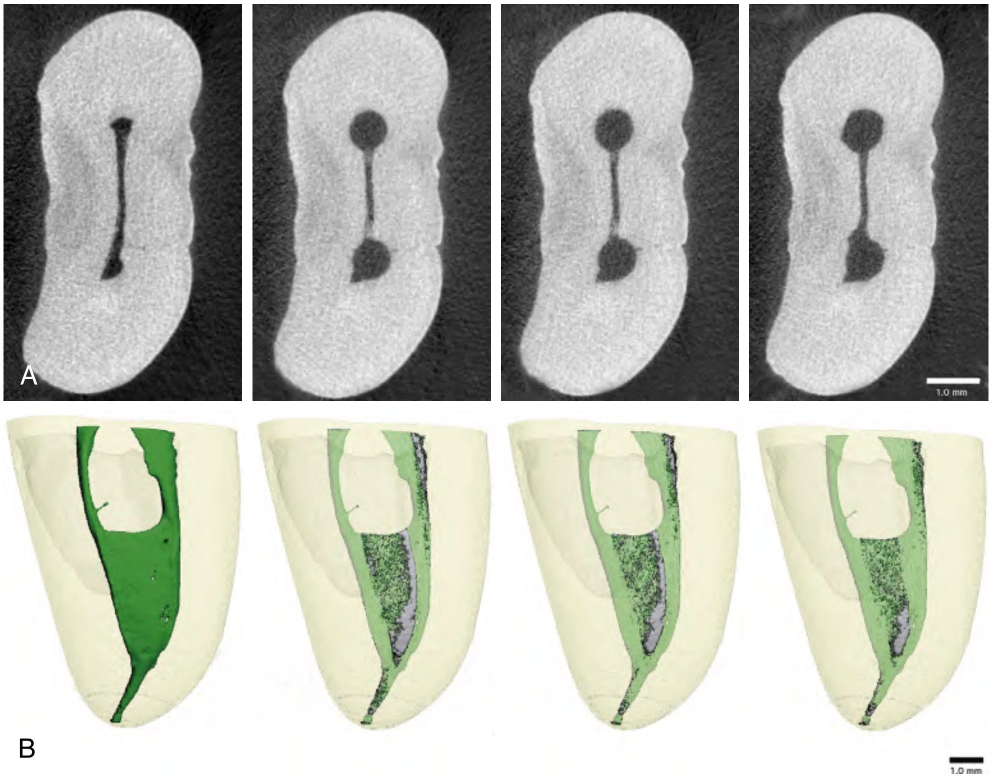
Generalizations can be made regarding tooth anatomy and morphology, although each tooth is unique. Length of canal preparation is often emphasized with little consideration given to important factors such as canal diameter and shape. Because morphology is variable, there is no standardized apical canal size. Traditionally, preparation techniques were determined by the desire to limit procedural errors and by the method of obturation. Small apical preparation reduces the incidence of preparation errors (as is discussed in the following section) but may decrease antimicrobial efficacy of cleaning procedures. It appears that with traditional hand instruments, apical transportation occurs in many curved canals enlarged beyond a No. 20 stainless steel file.[24]

The criteria for cleaning and shaping should be based on the ability to adequately deliver sufficient amounts of irrigant and not on a specific obturation technique. The ability of irrigants to reach the apical portion of the root canal depends on canal's size, taper, and the irrigation device used.[25-27]

Larger preparation sizes have been shown to provide adequate irrigation and debris removal and significantly decrease the number of microorganisms.[28-31] However, any removal of dentin has the potential to weaken radicular structure and therefore the use of an irrigation adjunct designed to promote irrigation efficacy in smaller canals may be advantageous.[32,33]

In principle there may to be a relationship between increasing the size of the apical preparation and canal cleanliness[34] and bacterial reduction.[35,36] Instrumentation techniques that advocate minimal apical preparation may be ineffective at achieving the goal of cleaning and disinfecting the root canal space.[34,36] However, this concept reaches its limits when too large a preparation leads to procedural errors[37,38] and when modifications created in the hard tissue block the very anatomy that was to be cleaned (Fig. 14.6).[39]

A variety of microbial species can penetrate deep into dentinal tubules.[40] These intratubular organisms are sheltered from endodontic instruments, the action of irrigants, and intracanal medicaments. Dentin removal appears to be the primary method for decreasing



• **Fig. 14.6** **(A)** Individual micro–computed tomography scans from the apical root third of a typical specimen before and after root canal preparation and irrigation with sodium hypochlorite (NaOCl), subsequent irrigation with ethylenediaminetetraacetic acid and final passive ultrasonic irrigation using again NaOCl (from left to right). **(B)** The corresponding three-dimensional reconstructions of the whole canal system are depicted below. (Reprinted from Paqué F, Boessler C, Zehnder M: Accumulated hard tissue débris levels in mesial roots of mandibular molars after sequential irrigation steps, *Int Endod J* 44(2):148, 2011 with permission.[39])

their numbers. However, it may not be possible to remove bacteria that are deep in the tubules, regardless of the technique. There is a correlation between the number of organisms present and the depth of tubular penetration[41]; in teeth with apical periodontitis, bacteria may penetrate the tubules to the periphery of the root.[42,43]

Elimination of Etiology

The development of nickel-titanium (NiTi) instruments has dramatically changed the techniques of cleaning and shaping; these instruments have been rapidly adopted by clinicians in many countries.[44-46] The primary advantage to using these flexible instruments is related to shaping, specifically a significant reduction in the incidence of preparation errors.[37]

Neither hand instruments nor rotary files have been shown to completely débride the canal.[29,47,48] Mechanical enlargement of the canal space dramatically decreases the presence of microorganisms present in the canal[49] but cannot render the canal sterile.[29] Therefore antimicrobial irrigants have been recommended in addition to mechanical preparation techniques.[50] There is currently no consensus on the most appropriate irrigant or concentration of solution, although sodium hypochlorite (NaOCl) is the most widely used irrigant.[51]

Unfortunately, solutions such as NaOCl that are designed to kill bacteria[50,52,53] are often toxic for the host cells,[54-57] and therefore extrusion beyond the canal space is to be avoided.[58,59] A major factor related to effectiveness is the volume of irrigant used during the procedure. Increasing the volume produces cleaner preparations.[60]

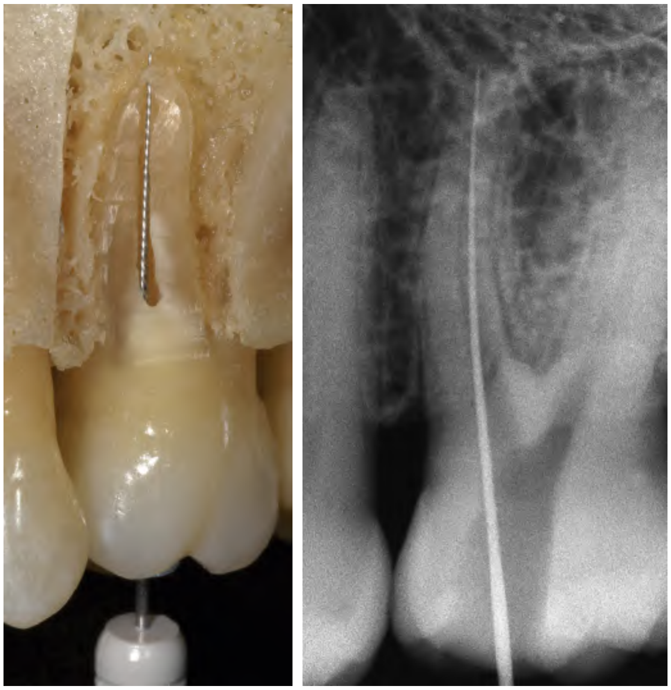
Apical Patency

Apical patency is a technique that advocated the repeated placement of small hand files to or slightly beyond the apical foramen during canal preparation (Fig. 14.7). A benefit of this technique during cleaning and shaping procedures is to ensure that WL is not lost and that the apical portion of the root is not packed with tissue, dentin debris, and bacteria (see Fig. 14.6, *A*). The patency concept has historically been controversial; indeed, concerns regarding possible extrusion of dentinal debris, bacteria, and irrigants have been raised,[61] a condition often considered to result in postoperative pain and possibly delayed healing.[62]

However, a large retrospective study identified the presence of apical patency as a factor possibly associated with higher success rates.[7] Moreover, at least in vitro, microorganisms do not appear to be transported beyond the confines of the canal by patency filing.[63] Small files are not directly effective in débridement (see Fig. 14.3) but achieving patency may be helpful in enhancing irrigation efficacy,[64] determining electronic WL, minimizing the risk of loss of length, reducing shaping mishaps such as canal transportation and ledges,[65] better maintaining the anatomy of the apical constriction,[66] and improving clinicians' tactile sense during apical shaping.[67]

Studies evaluating treatment failure have noted, besides several other factors, presence of bacteria outside the radicular space,[20] and bacteria have in some cases been shown to exist as plaques or biofilms on the external root structure.[68] It has been shown in vitro that maintaining patency may be connected to small amounts of irrigant to reach the periodontium, but this did not appear to increase the chance of irrigation accidents in the clinic.[69]

Moreover, a recently published systematic review concluded that maintaining apical patency was not associated with postoperative pain in teeth with either vital or nonvital pulp.[70] For all these reasons the benefits of maintaining apical patency seem to outweigh possible risks.



• **Fig. 14.7** A small file (No. 10 or 15) is placed beyond the radiographic apex to maintain patency of the foramen. Note the tip extends beyond the apical foramen.

Pretreatment Evaluation

Before treatment, each case should be evaluated for its degree of difficulty. The American Association of Endodontists has developed *The Endodontic Case Difficulty Assessment Form*, a practical tool that helps practitioners to identify the complexities that should not be overlooked before starting a root canal treatment. All three, patient, diagnostic, and treatment aspects, are considered to identify the level of difficulty of a specific case and help in 3 minutes to both anticipate problems the clinician may have during the treatment and determine whether the complexity of the case is suitable for the clinician's level of expertise and comfort.

Normal anatomy and anatomic variations are determined, as well as variations in canal morphology.[71] The mishandling of natural difficulties will lead to procedural mishaps that will be even more difficult to manage. A root canal that seems to be straight in a radiograph may have multiple curvatures in three dimensions that are not captured using a two-dimensional film. Therefore more than one preoperative radiograph might be needed for a proper assessment; a cone beam scan or cone beam computed tomography (CBCT) may also help to determine the best strategy to shape the most difficult canal anatomies.

Specifically, the longer a root, the more difficult it is to treat; apically, a narrow, curved root is susceptible to perforation; in multirooted teeth, a narrow area midroot could result in a stripping perforation toward the root concavity. The degree and location of curvature are determined. Canals are seldom straight, and curvatures in a buccolingual direction are normally not visible on the radiograph. Sharp curvatures or dilacerations are more difficult to manage than a continuous gentle curve. Roots with an S-shape or bayonet configuration are very difficult to treat. Intracanal mineralization will also complicate treatment. Such mineralization generally occurs in a coronal to apical direction, thus a large tapering canal may become more cylindrical with irritation or age.

The presence of resorption also will complicate treatment. With internal resorption, it is difficult to pass instruments through the coronal portion of the canal and the resorptive defect and into the apical portion. Also, files will not remove tissue, necrotic debris, and bacteria from such a resorptive defect. External resorption may perforate the canal space and present problems with hemostasis and isolation. Restorations may obstruct access and visibility, as well as change the orientation of the crown in relation to the root.

Principles of Cleaning and Shaping Techniques

Cleaning and shaping are separate and distinct concepts but are performed concurrently. The criteria of canal preparation include developing a continuously tapered funnel, maintaining the original shape of the canal, maintaining the apical foramen in its original position, keeping the apical opening as small as possible, and developing glassy smooth walls.[9] The cleaning and shaping procedures are designed to maintain an apical matrix for compacting the obturating material regardless of the obturation technique.[9]

Knowledge of a variety of techniques and instruments for treatment of the myriad variations in canal anatomy is required. There is no consensus or clinical evidence on which technique or instrument design or type is clinically superior (Video 14.3).[38,72]

NiTi files have been incorporated into endodontics because of their flexibility and resistance to cyclic fatigue.[73] The resistance to cyclic fatigue permits these instruments to be used in a rotary handpiece, which gives them an advantage over stainless steel files. NiTi files are manufactured in both hand and rotary versions and have been demonstrated to produce superior shaping compared with stainless steel hand instruments (Video 14.1).[37,72,74]

NiTi instruments are available in a variety of designs, many with increased taper compared with .02 mm standardized stainless steel files. The superelasticity of NiTi alloy enabled the manufacturing of more tapered instruments still flexible enough to properly shape canals with different angles and radius of curvature. The increase in the taper provides better and more continuous shapes with the use of fewer instruments and in a shorter period of time. Common tapers are .04 and .06, and the tip diameters may or may not conform to the traditional manufacturing specifications. The file systems can vary the taper while maintaining the same tip diameter or they can employ varied tapers with International Organization for Standardization (ISO) standardized tip diameters; some NiTi instruments have multiple tapers along their cutting portions, with more recent instruments featuring smaller maximum fluted diameters of less than 1 mm at the end of the fluted instrument portion.

A rational concept of root canal preparation using current instruments unfolds in stages. Classically, Stage 1 is a defined preflaring, before bringing any hand file to the apical third of the canal. Depending on the expected canal difficulty, instruments may reach WL during Stage 2; for example, if there is only one curvature. If preoperative assessments have indicated that an S-shape or multiple curvatures are present, it may be useful to introduce a Stage 3 that finally reaches the estimated WL, whereas Stage 2 provides additional enlargement into the secondary curvature.[75]

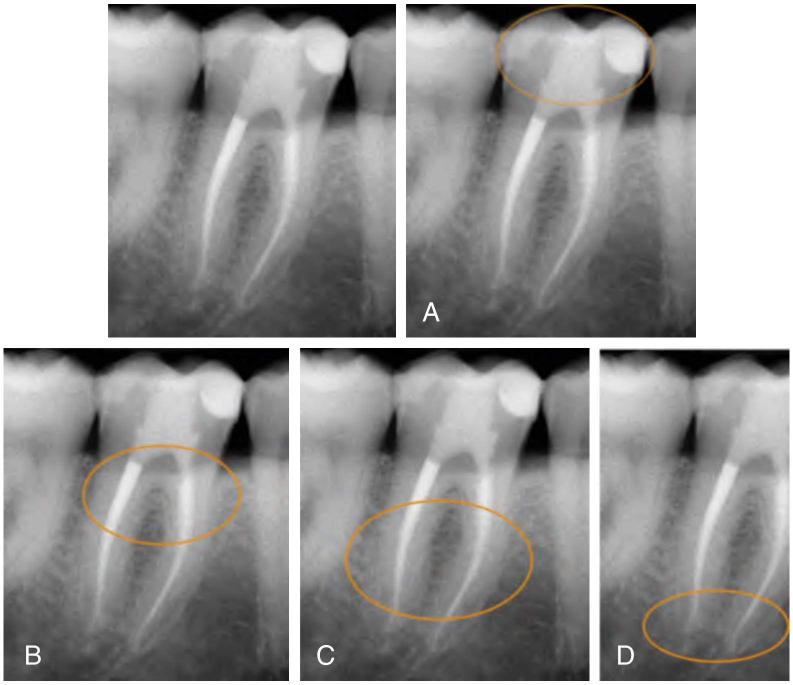
However, the appearance of proprietary thermal treatments of NiTi alloys with different series of heating and cooling treatments has led to the enhancement of the mechanical properties of contemporary rotary instruments by optimizing the microstructural characteristics of the alloy. The higher flexibility and cyclic fatigue resistance of these new instruments provides better clinical behavior and allows dentin preservation in the coronal third of many cases with a minimal orifice modification in Stage 1. Scientific evidence suggests that preserving pericervical dentin (4 mm above and below the crestal bone) is crucial for the distribution of functional stresses and the maintenance of the strength of the tooth and long-term survival.[76] Computational simulations with finite element analysis showed that masticatory stresses are reduced even when small amounts of this pericervical dentin are preserved.[77]

The authors strongly believe in this minimally invasive component of the technique because overflaring is liable to reduce dentinal wall thickness and structural strength and perhaps overall restorability (see Fig. 14.8). On the other hand, when it is performed with an instrument that allows a selective removal of dentin because of a limited maximum fluted diameter (MFD) that provides a conservative coronal preparation, early coronal flaring is also beneficial for the earlier access of disinfecting irrigation solutions, better tactile control of hand instruments during negotiation, and the easier placement of files in the delicate apical third.[78]

In general, the use of NiTi rotary instruments to WL should be preceded by a manual exploration of the canal to the desired preparation length, also known as glide path verification. This step is performed with one or more small K-files that are not precurved. In recent years, NiTi rotary instruments have been specifically designed to simplify the process of glide path preparation after a negotiating file has previously reached WL. If it is possible to predictably reach WL without precurving, rotary instruments may be used to the desired length. However, caution should be exercised in S-shaped canals, canals that join within a single root, and canals with severe dilacerations. Canals in which ledge formation is present, and very large canals where instruments fail to contact the canal walls, do not lend themselves to rotary preparation.

Instrument fracture can occur as a result of torsional loading or cyclic fatigue.[38] Torsional forces develop because of frictional resistance; therefore as the surface area increases along the flutes, the greater the friction and the more potential for fracture. Torsional stress can be reduced by limiting file contact, using a crown-down preparation technique, by verifying a glide path to WL, and with the presence of liquid irrigants such as NaOCl during shaping procedures.

Cyclic fatigue occurs as a file rotates in a curved canal.[79] At the point of curvature the outer surface of the file is under tension while the inner surface of the instrument is compressed. As the instrument rotates, the areas of tension and compression alternate, crack initiation begins, ultimately leading to fracture. There is often no visible evidence that fracture is imminent.



• **Fig. 14.8** An endodontically treated mandibular molar through constricted access and limited shaping, highlighting its guidelines by area: **(A)** coronal, **(B)** pericervical, **(C)** radicular body, and **(D)** apical. (Reprinted from Boveda C, Kishen A: Contracted endodontic cavities: the foundation for less invasive alternatives in the management of apical periodontitis. *Endod Topics* 33:169, 2015 with permission.)

Study Questions

1. Endodontic treatment failures result from all except which of the following?
   a. Inadequate root canal débridement
   b. Use of hand instrumentations
   c. Coronal leakage
   d. Bacteria that are more resistant to treatment protocols
2. Use of antimicrobial irrigants is an optional component of root canal débridement because new technologic advancements in file design allow better adaptation to canal irregularities.
   a. True
   b. False
3. Precise location of the apical constriction may be difficult to identify because of which of the following?
   a. The location of the apical foramen may vary
   b. The apical constriction can be altered by inflammatory changes
   c. The canal terminus is not always located at the root apex
   d. All of the above
3. Iatrogenic root perforation can adversely affect endodontic treatment outcome.
   a. True
   b. False
4. Maintenance of pericervical dentin contributes to the resistance to fractures that may be caused by masticatory forces.
   a. True
   b. False

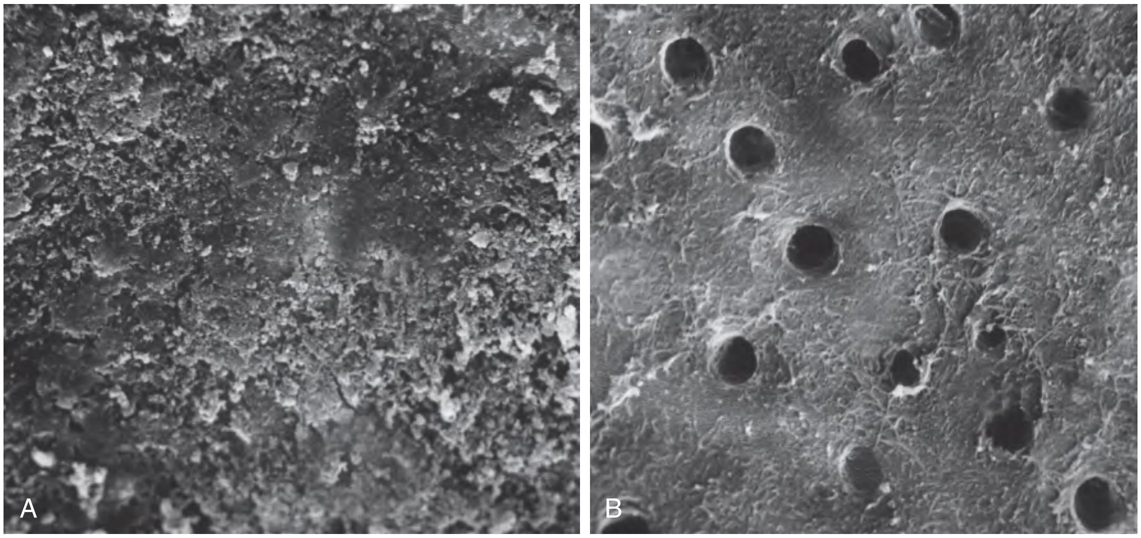
Although new thermomechanical processed alloys have improved lifespan of instruments, it is still advised that the use of NiTi instruments be monitored[80] and limited to a reduced number of cases. For difficult or calcified or severely curved canals, it is recommended the instruments be used only once.[72]

Smear Layer Management

During cleaning and shaping, organic components of pulp tissue and inorganic dentinal debris accumulate that are not only pressed into accessory canals, fins, and isthmuses (Fig. 14.6) but also deposited on the radicular canal wall, producing an amorphous, irregular smear layer (Fig. 14.9).[81] With pulp necrosis, the smear layer may be contaminated with bacteria and their metabolic byproducts. The smear layer is superficial, with a thickness of 1 to 5 µm, and debris can be packed into the dentinal tubules to varying distances.[82]

There is not a consensus on removing the smear layer before obturation.[81,83,84] The advantages and disadvantages of the smear layer removal remain controversial; however, evidence generally supports removing the smear layer before obturation.[81,85] The organic debris present in the smear layer might constitute substrate for bacterial growth, and it has been suggested that the smear layer prohibits sealer contact with the canal wall, which permits leakage. In addition, viable microorganisms in the dentinal tubules may use the smear layer as a substrate for sustained growth. When the smear layer is not removed, it may slowly disintegrate with leaking obturation materials, or it may be removed by acids and enzymes that are produced by viable bacteria left in the tubules or that enter via coronal leakage.[3] The presence of a smear layer may also interfere with the action and effectiveness of root canal irrigants and interappointment disinfectants.[53]

With smear layer removal, filling materials adapt better to the canal wall.[86,87] Removal of the smear layer also enhances the adhesion of sealers to dentin and tubular penetration[83,86-88] and permits the penetration of all sealers to varying depths.[89] Removal of the smear layer reduces both coronal and apical leakage (Video 14.2).[85,90]



• **Fig. 14.9** **(A)** A canal wall with the smear layer present. **(B)** The smear layer removed with 17% ethylene-diaminetetraacetic acid.

• BOX 14.1 Properties of an Ideal Irrigant

Organic tissue solvent
Inorganic tissue solvent
Antimicrobial action
Nontoxic
Low surface tension
Lubricant

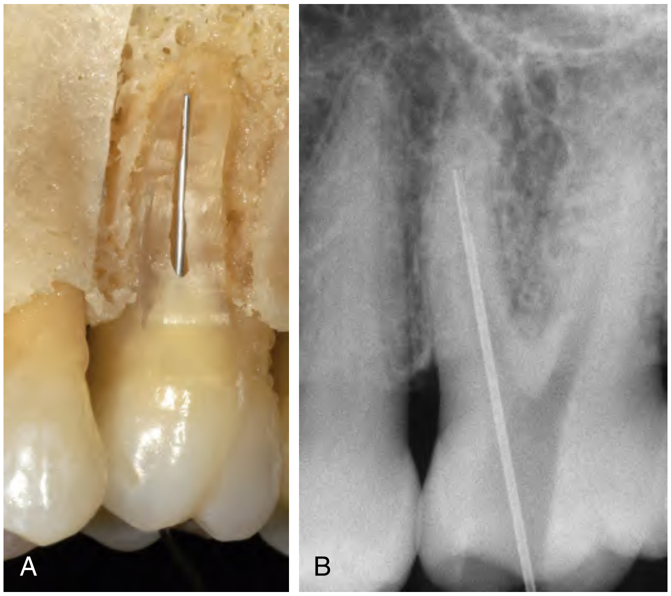
Irrigants

The ideal properties for an endodontic irrigant are listed in Box 14.1.[81] Currently, no solution meets all the requirements outlined. In fact, no techniques appear able to completely clean the root canal space.[39,91-93] Frequent irrigation is necessary to flush and remove the debris generated by the mechanical action of the instruments. At the same time, preparation of radicular wall creates hard tissue debris that is typically pushed into accessory anatomy, blocking access for subsequent irrigation.[39] Therefore it is imperative to use mechanical shaping and irrigation in synergy to maximize antibacterial efficacy of endodontic procedures.

Sodium Hypochlorite

The most common irrigant is NaOCl, which is also known as household bleach. Advantages to NaOCl include the mechanical flushing of debris from the canal, the ability of the solution to dissolve vital[94] and necrotic tissue,[95] the antimicrobial action of the solution,[47] and the lubricating action.[96] In addition, it is inexpensive and readily available.[97]

Free chlorine in NaOCl dissolves necrotic tissue by breaking down proteins into amino acids. There is no proven appropriate concentration of NaOCl, but concentrations ranging from 0.5% to 5.25% have been recommended. A common concentration is 2.5%, which decreases the potential for toxicity yet still maintains some tissue dissolving and antimicrobial activity.[98,99] Because the action of the irrigant is related to the amount of free chlorine, decreasing the concentration can be compensated by increasing the volume. Warming the solution can also increase the



• **Fig. 14.10** **(A and B)** For effective irrigation the needle must be placed in the apical one-third of the root and must not bind.

effectiveness of the solution.[100,101] However, NaOCl has limitations to tissue dissolution in the canal, because of limited contact with tissues in all areas of the canal.

Because of toxicity, extrusion is to be avoided.[55,59,102] The irrigating needle must be placed loosely in the canal (Fig. 14.10), and the use of side-vented needles specifically designed for endodontic irrigation is recommended in order to avoid accidents. Insertion to binding and slight withdrawal minimizes the potential for possible extrusion and an NaOCl accident (Fig. 14.11). Special care should be exercised when irrigating a canal with an open apex. To control the depth of insertion the needle is bent slightly at the appropriate length or a rubber stopper is placed on the needle.

Most likely, any irrigant does not travel apically more than 1 mm beyond the irrigation tip, so deep placement with small-gauge needles enhances irrigation (see Fig. 14.10).[103] During rinsing, the needle is moved up and down constantly to produce agitation and prevent binding or wedging of the needle.

• **Fig. 14.11** **(A and B)** A sodium hypochlorite accident during treatment of the maxillary left central incisor. Extensive edema occurred in the upper lip and was accompanied by severe pain.

Chelating Irrigants: Ethylenediaminetetraacetic Acid, Citric Acid, Hydroxyethylidene Bisphosphonate

As described previously, NaOCl is the most effective irrigant for organic tissue dissolution and elimination of bacteria biofilm; however, it does not remove inorganic tissue. For this reason, it needs to be combined with a chelating agent, such as ethylenediaminetetraacetic acid (EDTA), citric acid, or the more recently suggested hydroxyethylidene bisphosphonate (HEPB), also called etidronate. The chelating activity is directed toward removal of the smear layer because, in fact, these chelators have minimal tissue dissolution capacity.[104]

EDTA [105] is the most frequently used irrigant for this purpose. However, chemical interactions between EDTA and NaOCl have been described, and when combined, tissue dissolution ability of NaOCl may be affected as a result of a reduction in the active chlorine content.[106,107] For this reason, when using EDTA, the irrigation protocol recommended includes an irrigation with 17% EDTA for 1 minute at the end of the shaping procedure followed by a final rinse with NaOCl.[108] Chelators such as EDTA remove the inorganic components and leave the organic tissue elements intact. NaOCl is then necessary for removal of the remaining organic components; however, the additional use of NaOCl after chelating agents may lead to excessive demineralization of radicular wall dentin.[109]

Demineralization results in removal of the smear layer and plugs and enlargement of the tubules.[110,111] The action is most effective in the coronal and middle thirds of the canal whereas the effect is diminished in the apical third.[105,112]

Reduced efficacy may be a reflection of canal size[113] or anatomic variations such as irregular or sclerotic tubules.[114,115] The variable structure of the apical dentin presents a challenge during endodontic obturation with adhesive materials.

The recommended time for removal of the smear layer with EDTA is 1 minute.[105,116,117] The small particles of the smear layer are primarily inorganic with a high surface to mass ratio, which facilitates removal by acids and chelators. EDTA exposure over 10 minutes causes excessive removal of both peritubular and intratubular dentin.[117] A 10% solution of citric acid has also been shown to be an effective method for removing the smear layer, although it also reduces available chlorine in NaOCl solutions.[118,119]

A possible alternative to citric acid or EDTA recently suggested is HEBP. HEBP is a weak and biocompatible chelator that prevents bone resorption and is used systemically in patients suffering from osteoporosis or Paget's disease.[98] In contrast with EDTA or citric acid, HEBP appeared to reduce NaOCl active chlorine content after 1 hour and reduction continued over time, but the mixture seemed not to interfere with the dissolving properties of NaOCl. Therefore it may be mixed and used in combination with NaOCl, reducing the formation of smear layer during the mechanical preparation of the root canal. It seems that 7% to 10% HEBP could be mixed chair-side with NaOCl, without fearing any loss of NaOCl activity and administered during the whole course of root canal preparation.[107]

Chlorhexidine

Chlorhexidine possesses a broad spectrum of antimicrobial activity, provides a sustained action,[102,120] and has little toxicity.[121-124] Two percent chlorhexidine has similar antimicrobial action as 5.25% NaOCl[121] and is more effective against *Enterococcus faecalis.*[102] NaOCl and chlorhexidine are synergistic in their ability to eliminate microorganisms.[122] A disadvantage of chlorhexidine is its inability to dissolve necrotic tissue and remove the smear layer. Moreover, clinical studies do not confirm that the use of chlorhexidine is associated with better outcomes.[7]

Moreover, the interaction between chlorhexidine and NaOCl produced a precipitate that may have detrimental consequences for endodontic therapy; among them it may produce discoloration and potential toxic substances for periradicular tissues. At the same time, when chlorhexidine interacted with EDTA a precipitate was also produced.[106,125]

MTAD

An alternative method for disinfecting while at the same time removing the smear layer employs a mixture of a tetracycline isomer, an acid, and a detergent (MTAD) as a final rinse to remove the smear layer.[126] The effectiveness of MTAD to completely remove the smear layer is enhanced when low concentrations of NaOCl are used as an intracanal irrigant before the use of MTAD.[127] A 1.3% concentration is recommended. MTAD may be superior to NaOCl in antimicrobial action.[128,129] MTAD has been shown to be effective in killing *E. faecalis*, an organism commonly found in failing treatments, and may prove beneficial during retreatment. It is biocompatible,[130] does not alter the physical properties of the dentin,[130] and enhances bond strength.[131] Although there are encouraging in vitro data, MTAD has not been shown to be clinically beneficial at this point.[132]

QMix

A chlorhexidine-based mixture, marketed as QMix,[133] employs a similar underlying strategy with the potential to not only remove smear layer but also to provide antibiofilm activity. QMix consists of a proprietary mix of chlorhexidine, EDTA, and a surface-active agent. Nothing is known about its contribution to clinical outcomes, but it appears that smear layer removal is similar to 17% EDTA,[134] and antimicrobial effects are adequate.[135,136] However, tissue dissolution with prior canal shaping and use of NaOCl are still required.[137]

Irrigants for Cryotherapy

A new use of irrigant solution has been recently described in root canal treatment. Posttreatment pain is a very common situation, especially in teeth presenting with preoperative pain, pulp necrosis, and symptomatic apical periodontitis. Postoperative pain has traditionally been controlled with paracetamol, nonsteroidal antiinflammatory medication, opioids, and/or corticosteroids. In other fields of medicine, other alternatives have been suggested in search of a greater efficacy for pain control while avoiding secondary effects, cryotherapy among them. A controlled irrigation with cold saline after cleaning and shaping procedures has been recently suggested to reduce incidence and intensity of postoperative pain in those patients presenting symptomatic apical periodontitis.[138] The authors suggested a final irrigation after cleaning and shaping with cold (2.5°C) sterile saline solution, also using a cold (2.5°C) sterile microcannula attached to the Endovac negative pressure irrigation system for 5 minutes. Recently different cryotherapy applications have also resulted in lower postoperative pain levels (intracanal, intraoral, and extraoral).[139]

Ultrasonics

There are many uses of ultrasonics in root canal treatment; for example, refinement of access cavity preparations for a more conservative approach, orifice location, pulp stone removal, removal of materials from the inside of the root canal (including posts, separated instruments, silver cones), enhancing irrigation, thermoplastic obturation, and root-end preparation during surgery;[140] however, shaping curved root canals with ultrasonic instruments has been shown to create preparation errors and is no longer recommended.[141-143]

In terms of enhancing irrigation, agitation techniques allow an irrigation solution to reach the apical third and irregularities in the root canal system, and hence improve cleaning efficiency. The use of ultrasonics,[144] sonic devices,[145] or apical negative pressure[146] irrigation has been recommended. Many other devices or instruments are continuously being marketed for further disinfection of root canal system; however, cost-effectiveness still needs to be scientifically demonstrated.

The main mechanism of adjunctive cleaning with ultrasonics is acoustic microstreaming,[147] which is described as complex steady-state streaming patterns in vortex-like motions or eddy flows that are formed close to the instrument. Agitation of the irrigant with an ultrasonically activated instrument after completion of cleaning and shaping has the benefit of increasing the effectiveness of the solution.[113,148-150]

Lubricants

Lubricants facilitate manipulation of hand files during cleaning and shaping. They are an aid in initial canal negotiation, especially in small and constricted canals without taper. The use of lubricants during negotiation helps to avoid pulp tissue blockage. Especially in vital teeth, pulp tissue may block the root canal during negotiation. This type of blockage is difficult to bypass but very easy to prevent by filling the pulp chamber with viscous lubricants that will enhance the advancement of the small file without apically pushing the pulp tissue remnants.[151]

Glycerin is a mild alcohol that is inexpensive, nontoxic, aseptic, and somewhat soluble. A small amount can be placed along the shaft of the file or deposited in the canal orifice. Counterclockwise rotation of the file carries the material apically. The file can then be worked to length using a watch winding motion.

Paste lubricants can incorporate chelators. One advantage to paste lubricants is that they can suspend dentinal debris and prevent apical compaction. One proprietary product consists of glycol, urea peroxide, and EDTA in a special water-soluble base. It has been demonstrated to exhibit an antimicrobial action.[152] Another type is composed of 19% EDTA in a water-soluble viscous solution.

A disadvantage to these EDTA compounds appears to be the deactivation of NaOCl by reducing the available chlorine[153] and potential toxicity.[154] The addition of EDTA to the lubricants has not proved to be effective.[155] In general, files remove dentin faster than the chelators can soften the canal walls. Aqueous solutions, such as NaOCl, should always be used instead of paste lubricants when using NiTi rotary techniques to reduce torque.[96]

Preparation Errors

Regardless of the technique used in root canal preparation, procedural errors can occur (see Chapter 18). These include loss of WL, apical transportation, apical perforation, instrument fracture, and stripping perforations.

Loss of WL has several causes, including failure to have an adequate reference point from which the WL is determined, packing tissue and debris in the apical portion of the canal, ledge formation, and inaccurate measurements of files.

The selection of an adequate coronal reference point is very important. Some clinicians advocate for using the same coronal reference for all root canals in the same tooth to ease the procedure; however, the proper determination of a straight and stable reference localized in the original path of the instrument when shaping each canal will avoid procedural mishaps during canal preparation. Moreover, the more visible the reference point, the less stress for the rotary instrument when the clinician checks the proper shaping length.

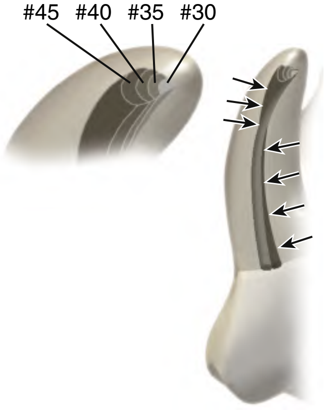
On the other hand, the most predictable method to prevent any kind of blockage in the apical portion of the canal is to regularly use the so-called patency file during cleaning and shaping procedures. Not only does it minimize the risk of loss of length, but it also reduces further mishaps occurring when trying to force an instrument to go back to the initial length.

And lastly, the reconfirmation of the WL electronically with an apex locator after preparation of the coronal third will also help to maintain the correct length during the whole shaping procedure.

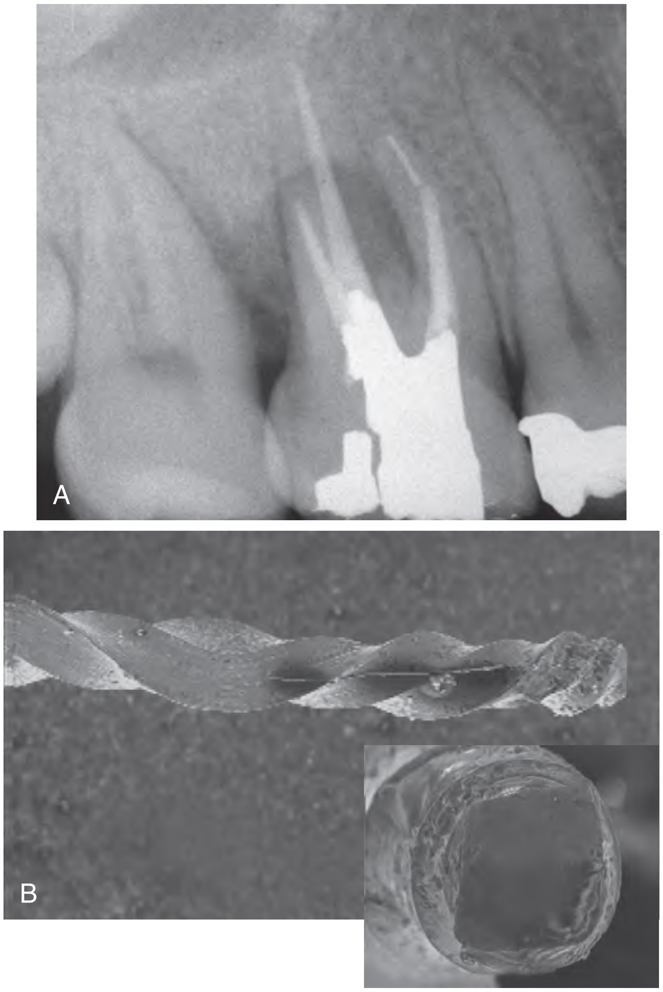
Apical transportation and zipping occur when relatively inflexible files are used to prepare curved canals. The restoring force of the file (the tendency to return to the original straight shape of the file) exceeds the threshold for cutting dentin in a curved canal (Figs. 14.12 and 14.13).[156] When this apical transportation continues with larger and larger files, a "teardrop" shape develops, and apical perforation can occur on the lateral root surface (see Fig. 14.12). Transportation in curved canals already begins with a No. 25 file.[24] Enlargement of curved canals at the WL beyond a No. 25 file can be done only when an adequate coronal flare is developed. Moreover, when shaping a difficult root canal, the most challenge anatomy is often located in the apical third. The potential of avoiding accidents in this delicate portion starts with a proper negotiation after removing the restrictive dentin in the coronal and middle third if the root canal presents great curvatures or S-shaped root canals. Choosing flexible and resistant rotary instruments is very important not to deform the apical third of root canals with complicated anatomy.

As stated before, instrument fracture occurs with torsional and cyclic fatigue. Locking the flutes of a file in the canal wall while continuing to rotate the coronal portion of the instrument is an example of torsional failure (Fig. 14.14). Conversely, cyclic fatigue results when repetitive low-level strain develops in the metal. File fracture occurs more frequently with rotaries but may also involve hand instruments such as K-type and Hedström files.[157]

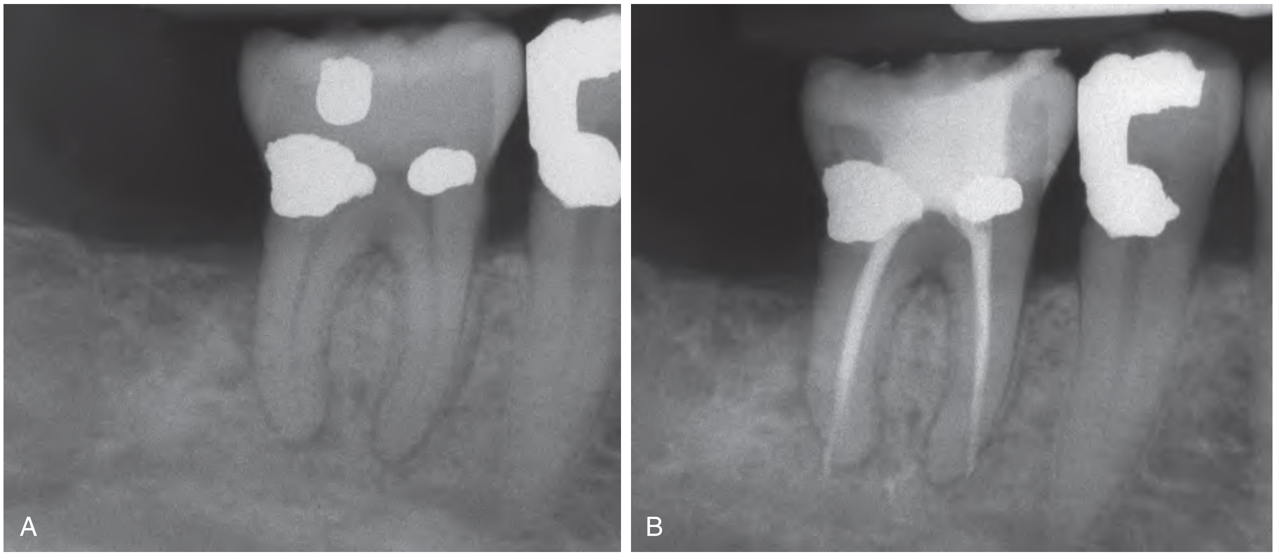
Working under the operating microscope, using specific ultrasonic tips and specifically designed armamentarium will help to retrieve broken instruments from the root canal, but it is a difficult task and in most situations leads to a weakening of the tooth caused by excessive removal of dentin, allowing the instrument to disengage from the dentin and finding a path for the exit. Therefore the best way to deal with instrument fracture is prevention. To avoid NiTi rotary instruments separation some strategies are recommended: optimal case selection; understanding the



• **Fig. 14.12** Procedural errors of canal transportation, zipping, and strip perforation occur during standardized preparation when files remove dentin from the outer canal wall apical to the curve and from the inner wall coronal to the curve. This is related to the restoring force (stiffness) of the files. Note in the apical portion the transportation takes the shape of a tear drop as the larger files are used.



• **Fig. 14.14** **(A)** No. 35 file fractured in the mesiobuccal canal. **(B)** Scanning electron microscope examination reveals torsional failure at the point of fracture. Note the tightening of the flutes near the fracture and the unwinding of the flutes along the shaft.



• **Fig. 14.13** A typical procedural error in shaping of curved root canals is straightening or transportation. A comparison of **(A)** preoperative and **(B)** postoperative radiographs in this case reveals that mesial and distal canals have been transported, and there are apical perforations.

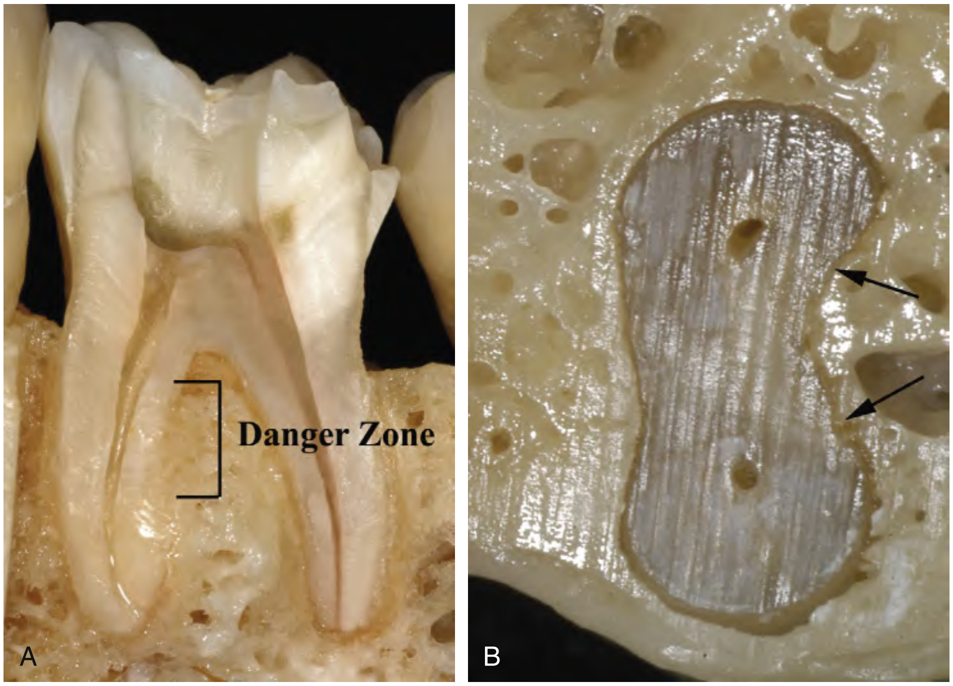
characteristics and limitations of the selected instrument; limiting the use of instruments; prematurely eliminating coronal interference before taking rotary instruments to the full root canal length; ensuring a correct glide path; using the instruments following the recommended directions for use in terms of rotational speed, torque, and motion; not forcing instruments in an apical direction to avoid taper-lock; recapitulating if the instrument is not able to advance in the root canal; and not inserting the instrument in the root canal if the active cutting surface of the instrument is blocked with debris (use gauzes to clean the flutes).[78]

Stripping perforations occur toward the furcal region of curved roots and frequently in the mesial roots of maxillary and mandibular molars (Figs. 14.15 and 14.16). The canal in this area of the root is not always centered in cross-sections; before preparation, the average distance to the furcal wall (danger zone) is less than the distance to the bulky outer wall (safety zone). An additional complicating factor is the furcal concavity of the root.[158]

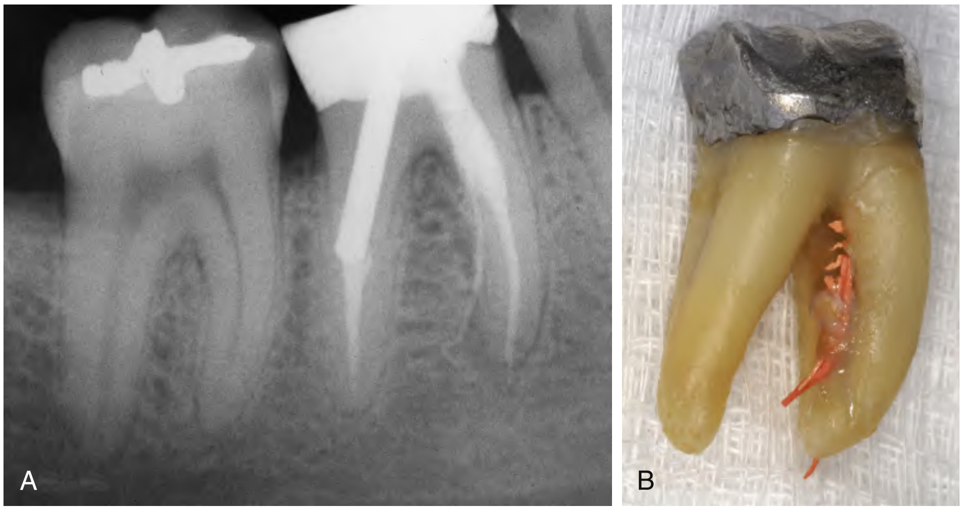
Preparation Techniques

Working Length Determination

A major step in clinical endodontics, regardless of the instruments used, is the determination of the apical termination of cleaning and shaping, as well as obturation procedures. Using diagnostic radiographs, an estimate of the WL can be obtained. With a staged



• **Fig. 14.15** **(A)** The furcal region of molars at the level of the curvature (danger zone) is a common site for stripping perforation. **(B)** Note the concavity *(arrows)* in the furcation area of this mandibular molar.



• **Fig. 14.16** Straight-line access can result in stripping perforations in the furcal areas of molars. **(A)** The use of large Gates-Glidden drills and overpreparation has resulted in the stripping perforation. **(B)** Note that the perforation is in the concavity of the furcation.

preparation sequence as detailed before, initial files will not be placed into the root canal as to reach WL, as their use is restricted to the coronal and middle thirds of the canal. However, during all shaping stages care should be taken not to inadvertently overextend the instruments. As soon as a small file appears to reach the estimated termination point, the use of an electronic apex locator is recommended. These units typically provide an accurate assessment of the location of the narrowest canal diameter and can detect the position of the test file relative to the periodontal ligament. Exposing a radiograph with the test file in place then verifies the measurement.

Based on this information clinicians may note the WL for this canal as the distance between a coronal reference point and the apical termination point. Based on clinical evidence[7,19] as well as classic studies[159] WL should terminate just short of the electronically measured canal length. During canal preparation, WLs tend to shorten as a result of the fact that the enlarged canal provides a straighter path to the apical termination point; however, this effect is minimized with coronal flaring. Nevertheless, it is recommended to periodically check the WL and correct it if needed.

Hand Instrumentation

Watch Winding

Watch winding is reciprocating back and forth (clockwise/counterclockwise) rotation of the instrument in an arch and is used to negotiate canals and to work files to place. The first file that reaches tentative WL and slightly binds is called initial apical file (IAF). Light apical pressure is applied to move the file deeper into the canal.

Reaming

Reaming is defined as the clockwise cutting rotation of the file. Generally, the instruments are placed into the canal until binding is encountered. The instrument is then rotated clockwise 180 to 360 degrees to plane the walls and enlarge the canal space.

Filing

Filing is defined as placing the file into the canal and pressing it laterally while withdrawing it along the path of insertion to scrape (plane) the wall. A modification is the quarter-turn-pull technique. This involves placing the file to the point of binding, rotating the instrument 90 degrees, and pulling the instrument along the canal wall. Any filing technique has a tendency to straighten curved canals.

Circumferential Filing

Circumferential filing is used for canals that are larger and/or not round. The file is placed into the canal and withdrawn in a directional manner sequentially against the mesial, distal, buccal, and lingual walls. Circumferential filing is not very effective beyond the coronal third of a root canal.[160,161]

• BOX 14.2 Descriptors for Files During Root Canal Preparation

Working length (WL)
Initial apical file (IAF)
Master apical file (MAF)
Final file (FF)
Final apical file (FAF)

Standardized Preparation

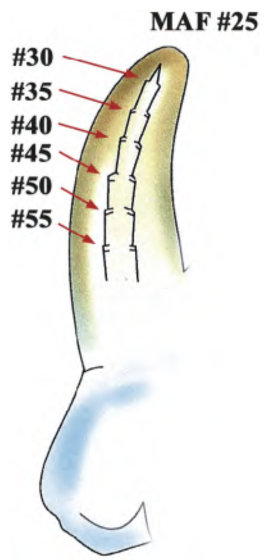
After 1961 instruments were manufactured with a standard formula. Clinicians utilized a preparation technique of sequentially enlarging the canal space with smaller to larger instruments at the WL.[162] In theory, this created a standardized preparation of uniform taper. Unfortunately, in cylindrical and small curved canals, procedural errors were identified with the technique (Box 14.2).[163]

Step-Back Technique

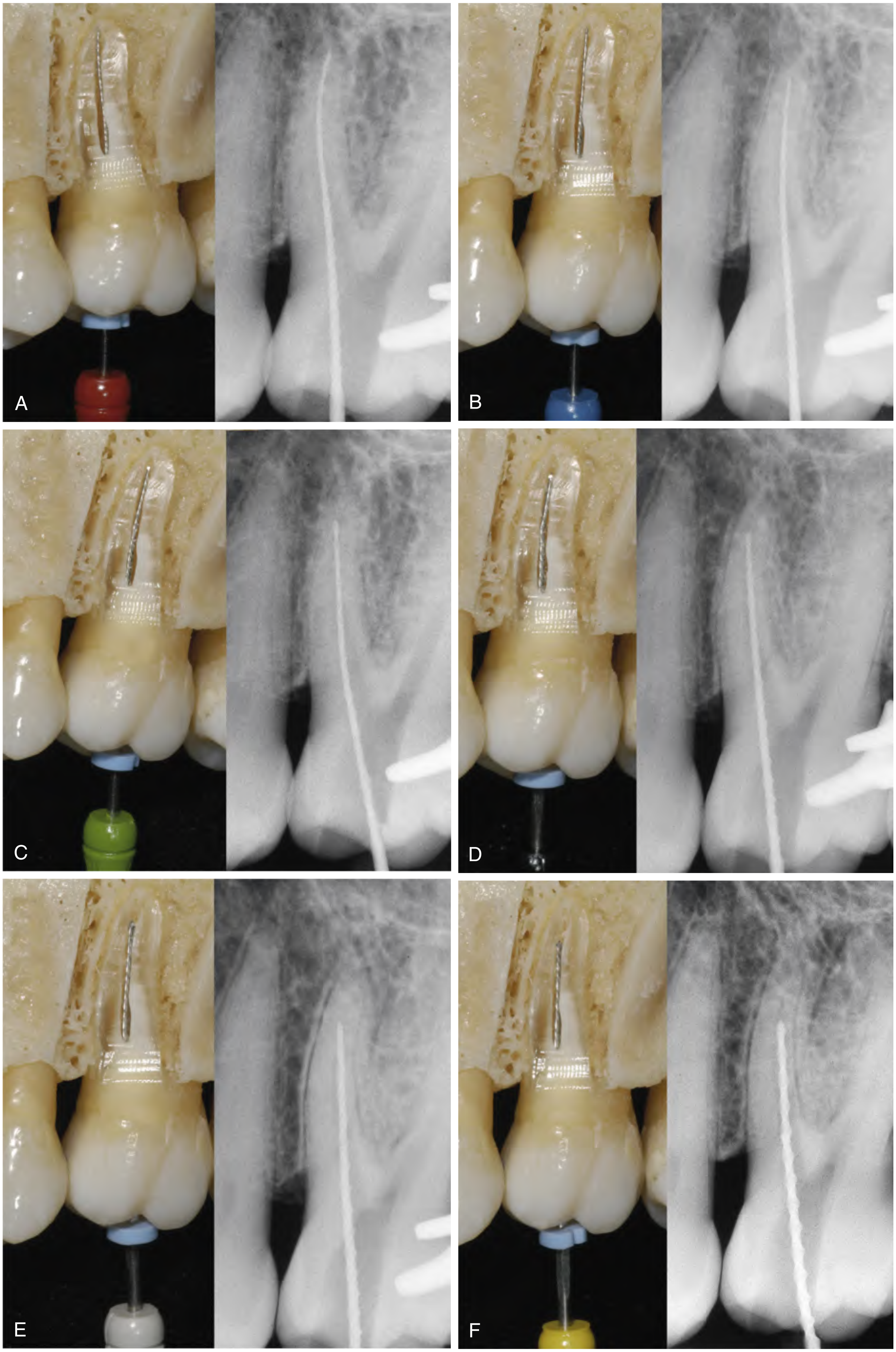
The step-back technique reduces procedural errors and improves débridement.[163,164] It involves that, after coronal flaring, the apical canal diameter is determined with the IAF (the first file that binds at WL). Subsequent preparation to WL up to the master apical file (MAF) creates the apical preparation size, for example, size No. 35; the succeeding larger files are shortened by 0.5- or 1-mm increments from the previous file length (Figs. 14.17 and 14.18) up to the final file (FF), for example, size No. 60. This step-back process creates a flared, tapering preparation while reducing procedural errors. The last file used in the step-back sequence becomes the FF. This type of preparation is superior to standardized serial filing and reaming techniques in débridement and maintaining the canal shape.[164]

Step-Down Technique

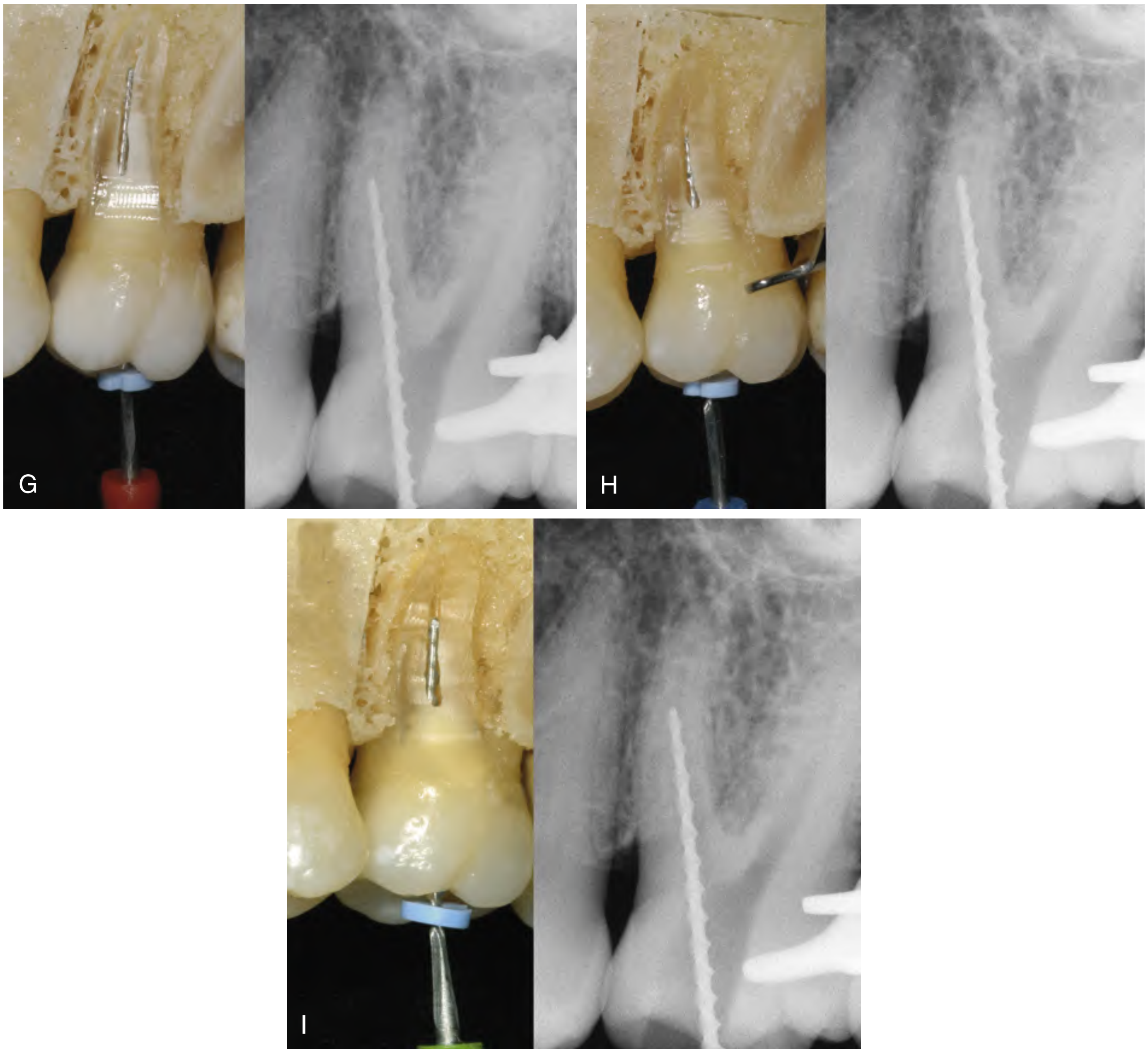
The step-down technique is advocated for cleaning and shaping procedures as it removes coronal interferences and provides coronal taper. Originally advocated for hand-file preparation,[165] the step-down technique has been incorporated into those techniques employing NiTi files. With the pulp chamber filled with irrigant or lubricant, the canal is explored with a small instrument to assess morphology (curvature). The WL can be established at this time. The coronal one third of the canal is then flared with Gates-Glidden drills or NiTi orifice shapers. A large file (such as No. 60) is then placed in the canal, and a watch-winding motion is used until resistance is encountered.[165] The process is repeated with sequentially smaller files until the apical portion of the canal is



• Fig. 14.17 The step-back preparation is designed to provide a tapering preparation. The process begins with one file size larger than the master apical file with incremental shortening of either 0.5 or 1 mm.



• **Fig. 14.18** An example of step-back preparation in a moderately curved canal. **(A)** The No. 25 master apical file at the corrected working length of 21 mm. **(B)** The step-back process begins with the No. 30 file at 20.5 mm. **(C)** No. 35 file at 20 mm. **(D)** No. 40 file at 19.5 mm. **(E)** No. 45 file at 19 mm. **(F)** No. 50 file at 18.5 mm.



• **Fig. 14.18, cont'd** **(G)** No. 55 file at 18 mm. **(H)** No. 60 file at 17.5 mm. **(I)** No. 70 file at 17 mm.

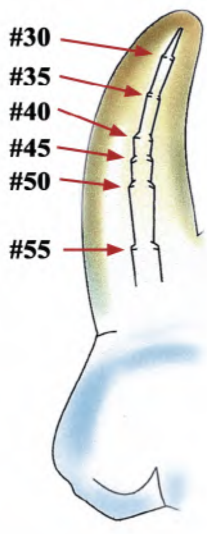
reached. The WL and the IAF (the first file that binds at WL) can be determined whether this was not accomplished initially. The apical portion of the canal can now be prepared by enlarging the canal to the MAF at the WL. Apical taper is accomplished using a step-back technique.

Passive Step-Back Technique

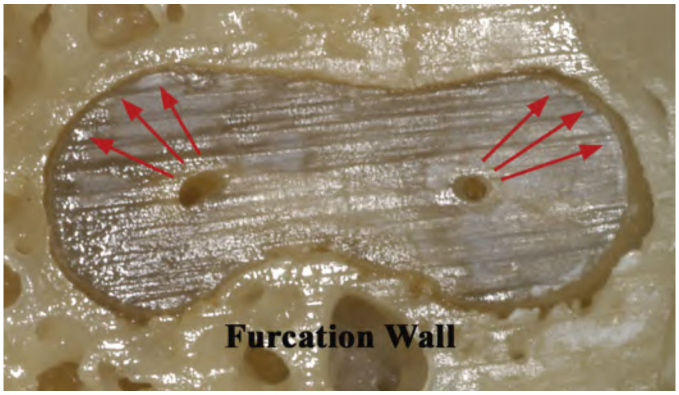
The passive step-back technique is a modification of the incremental step-back technique.[9,166] After the apical diameter of the canal has been determined, the next higher instrument is inserted until it first makes contact (binding point). It is then rotated one-half turn and removed (Fig. 14.19). The process is repeated with larger and larger instruments being placed to their binding point. This entire instrument sequence is then repeated. With each sequence, the instruments drop deeper into the canal, creating a tapered preparation. Advantages to the technique include knowledge of canal morphology, removal of debris and minor canal obstructions, and a gradual passive, slight enlargement of the canal in an apical to coronal direction.

Anticurvature Filing

Anticurvature filing is advocated during coronal flaring procedures to preserve the furcal wall in the treatment of molars (Fig. 14.20). As stated before, canals are often not centered in mesial roots of maxillary and mandibular molars; instead, they are located closer to the furcation. Stripping perforations occur primarily during use of the Gates-Glidden drills but also with overzealous use of hand instruments. To prevent this procedural error, the Gates-Glidden drills should be confined to the canal space coronal to the root curvature and used in a step-back or step-down manner (Figs. 14.21 and 14.22). Gates-Glidden drills and laterally cutting NiTi orifice shapers can also be used directionally in an anticurvature fashion to selectively remove dentin from the bulky wall (safety zone) toward the line angle,



• **Fig. 14.19** Passive step-back. Smaller to larger files are inserted to their initial point of binding and then rotated 180 to 360 degrees and withdrawn. This process creates slight taper and coronal space and permits larger instruments to reach the apical one third.



• **Fig. 14.20** The anticurvature filing technique. Instruments are directed away from the furcal danger zone toward the line angles (safety zone) where the bulk of dentin is greater.

protecting the inner or furcal wall (danger zone) coronal to the curve (see Fig. 14.20).

Balanced Force Technique

The balanced force technique recognizes the fact that instruments are guided by the canal walls when rotated.[167] Because files with a symmetric cross-section will cut in both a clockwise and counterclockwise rotation, the balanced force concept of instrumentation consists of placing the file to length and then a clockwise rotation (less than 180 degrees) engages dentin. This is followed by a counterclockwise rotation (at least 120 degrees) with apical pressure to cut and enlarge the canal. The degree of apical pressure varies from light pressure with small instruments to heavy pressure with large instruments. The clockwise rotation pulls the instrument into the canal in an apical direction. The counterclockwise cutting rotation forces the file in a coronal direction while cutting circumferentially. After the cutting rotation, the file is repositioned, and the process is repeated until the WL is reached. At this point, a final clockwise rotation is employed to evacuate the debris. The balanced force concept is considered the most effective hand instrumentation technique.[74,91]

Recapitulation

Recapitulation is important regardless of the technique selected (Fig. 14.23) and is accomplished by taking a small file to the WL to loosen accumulated debris and then flushing it with 1 to 2 mL of irrigant. Recapitulation is performed between each successive enlarging instrument regardless of the cleaning and shaping technique.

Shaping Modifications

The apical configuration in a given case may be recognized as an apical stop, apical seat, or open apex. In addition to the assessment of a diagnostic radiograph these configurations are detected by placing the MAF to the corrected WL after shaping is completed. If the MAF easily extends past WL, the apical configuration is open. If the MAF stops at WL, a file one or two sizes smaller is placed to the same depth. If this file stops as well, the apical configuration is called an apical stop. When the smaller file goes past the corrected WL, the apical configuration is a seat.

In a small curved canal, enlargement should be restricted to three sizes larger than the IAF to decrease the potential for transportation. In a straight canal, it may be larger without producing a procedural error. Because a properly prepared canal exhibits taper, the small files at the corrected WL can be used to enlarge the canal without transportation. Additional apical enlargement is performed with an irrigant in the canal and employs a reaming action at the corrected WL. The last file used becomes the so-called final apical file (FAF). Because this file is only contacting the apical portion of the canal, the technique may result in a less irregular apical preparation. The canal is then irrigated, the smear layer is removed with a decalcifying agent, and the canal dried with paper points.

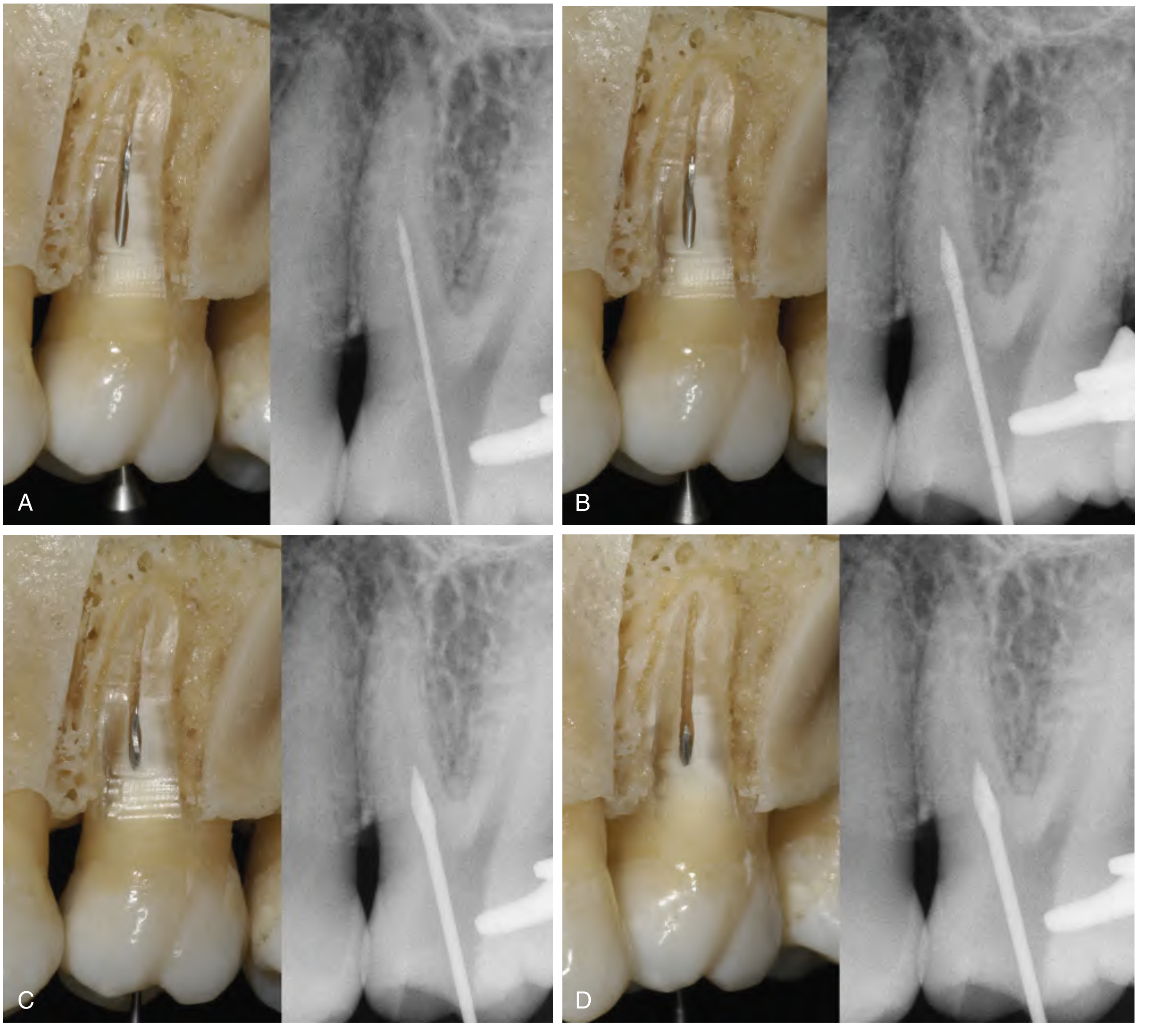
Engine-Driven Instruments

Gates-Glidden Drills

Gates-Glidden drills have been historically used to enlarge canal orifices, preferably in pairs such as size Nos. 3 and 2 (diameters 0.7 and 0.9 mm, respectively) (see Figs. 14.21 and 14.22). If the canal orifice cannot accommodate a No. 50 file, careful hand instrumentation should be performed to provide adequate initial coronal space. To prevent stripping perforations, Gates-Glidden drills should not be placed apical to canal curvatures. Moreover, with the advancement of NiTi rotary instruments and the concept of minimally invasive endodontics, the use of Gates-Glidden drills should be reconsidered. The amount of dentin removed in the coronal third makes Gates-Glidden drills an unsuitable instrument for modern endodontics.

NiTi Rotary Instruments

As stated previously, NiTi rotary preparation is typically performed in a staged approach using coronal flaring; however, the specific technique is based on the instrument system selected. One instrument sequence uses NiTi files in a crown down approach, with a constant taper and variable ISO tip sizes (Fig. 14.24). With this technique, a 0.06 taper is selected. Initially a size .06/45 file is used until resistance, followed by the .06/40, .06/35, .06/30, .06/25, and .06/20. In a second technique, NiTi files with a constant tip diameter are used also in a crown down sequence. The initial file is a .10/20 instrument, the second a .08/20, the third



• **Fig. 14.21** Straight-line access in a maxillary left first molar with Gates-Glidden drills used in a slow-speed handpiece using a step-back technique. **(A)** The No. 1 Gates is used until resistance. **(B)** This is followed by the No. 2, which should not go past the first curvature. **(C)** The No. 3 Gates is used 3 to 4 mm into the canal **(D)** Followed by the No. 4 instrument.

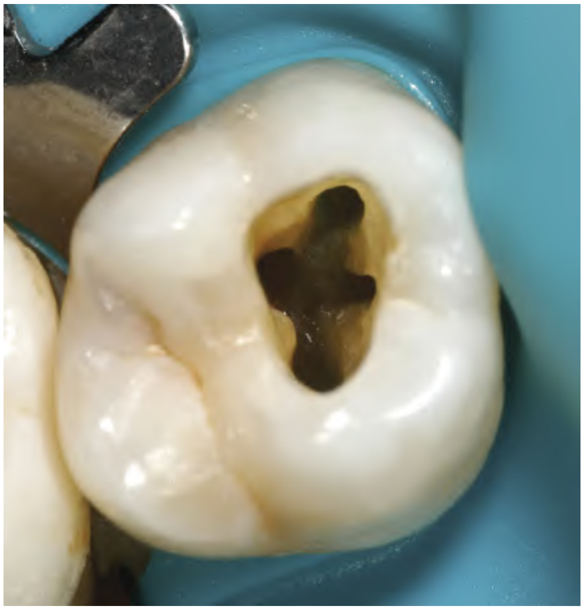
a .06/20, and the fourth a .04/20 (see Fig. 14.24). Many variations of these basic approaches have been recommended for different file designs. More recently introduced systems try to limit the number of file sizes, up to the point of using only one size for the majority of canals. Obviously, one size will not fit all canal shapes, and modifications will frequently need to be made when such a system is used (Video 14.4).

Critical for all rotaries is the handling of these files. Besides manufacturer guidelines for individual files there are several general principles that should be followed.[72,168] For example, instrument insertions should follow an in-and-out pattern; each instrumentation step should consist of three to five movements and should not exceed 10 to 15 seconds. Apically directed force should typically not exceed the force required to bend the rotary when placed on a tabletop. Most NiTi files are made of austenitic alloy and work best with lower rather than higher rotational speed (e.g., 250 rpm). However, martensitic rotaries work better with higher speeds, for example, 500 rpm.[169]

Currently marketed electric motors have the torque setting already programmed. These settings are a reasonable protection against instrument breakage caused by torsional loading but are less effective with greater tapers, such as .06 and .08.[38] All rotaries work best in canals flooded with irrigation solution and not in the presence of a gel-type lubricant such as RC Prep.[96]

NiTi rotaries should not be placed into an unexplored canal but rather follow hand instruments. These hand instruments establish a glide path that then can be followed by rotaries.[170] It is important to note that hand files for glide path preparation should not be precurved; only then can rotaries predictably follow.

Frequently NiTi rotaries are combined with hand files or other rotary instruments. One such combination technique



• **Fig. 14.22** A maxillary first molar following straight-line access with the Gates-Glidden drills.

• **Fig. 14.23** Recapitulation is accomplished between each instrument by reaming with the master apical file or a smaller instrument, minimizing packing of debris and loss of length.

utilizes the following steps: coronal flaring, NiTi rotary preparation to WL, and additional apical enlargement (Box 14.3). After access, the irrigated canal is explored with a No. 10 or 15 K-file into the midroot area. Sometimes a canal is already naturally flared and wide, for example a maxillary central incisor or canine in a younger patient. Then a size No. 10 file may immediately be placed to the estimated WL and a WL radiograph can be obtained (see Fig. 14.25). For more constricted canals, NiTi orifice modifiers can be used to accomplish early coronal enlargement. This step facilitates irrigation and removes coronal interferences, which in turn permits easier access to the apical portion of the root canal and more accurate determination of apical constriction location[171] as well as size.[172]

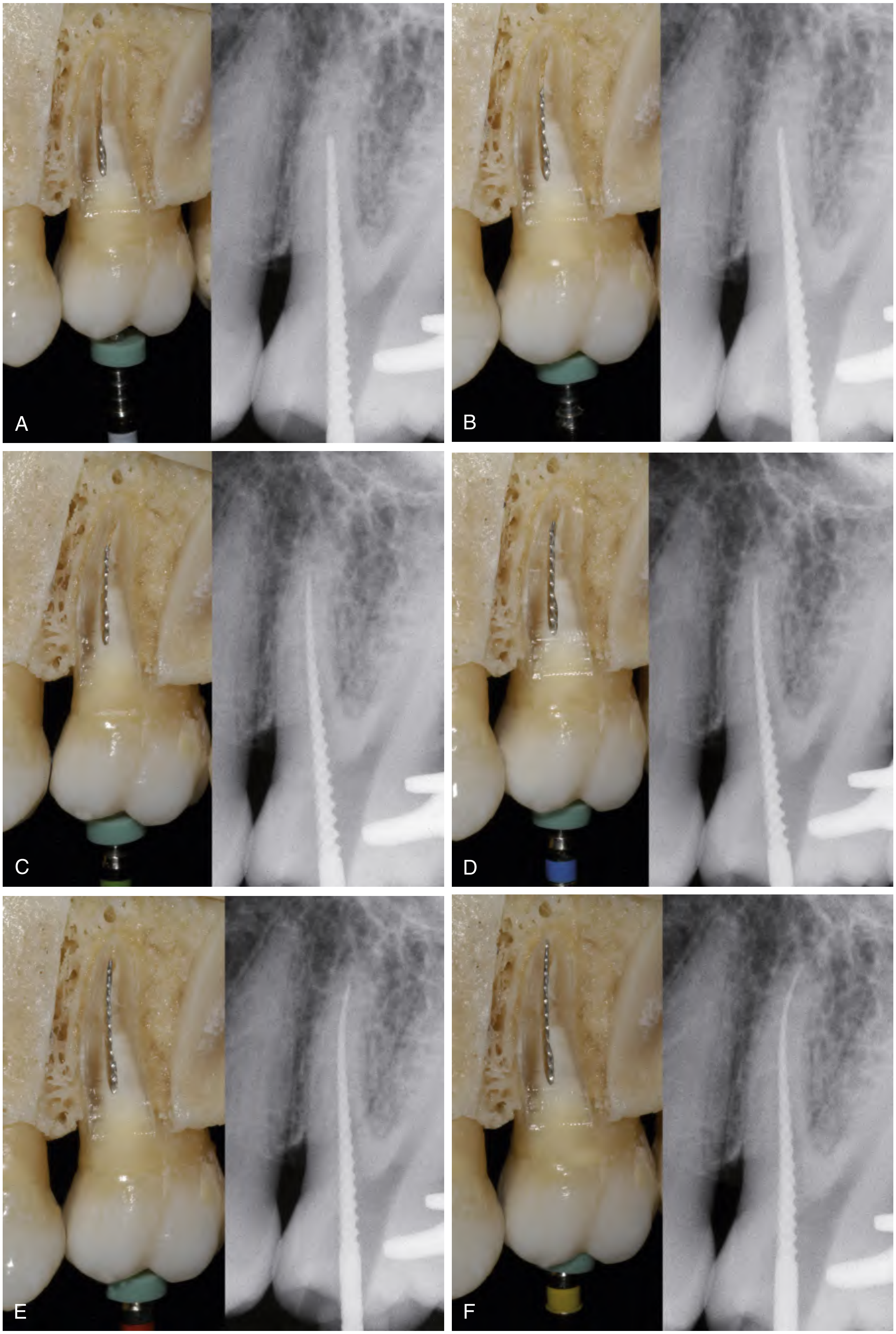
In the presence of irrigant or gel-based lubricant, the canal is negotiated to full length with a hand file used in watch-winding motion. If an impediment is felt, the negotiation files need to be precurved. However, in order to secure a glide path for subsequent rotary use, it must be confirmed that a straight small K-file (e.g., size No. 10 or 15) reaches the corrected WL. The tightness of fit of the negotiation file at WL gives an estimate of the canal size; however, coronal interferences do not permit a more accurate assessment at this point.

Then, the middle and apical portions of the canal are prepared using NiTi rotary instruments (see Figs. 14.24 and 14.25). Rotary files are used with a crown-down approach to reach the corrected WL. Using this approach with continuously tapered rotaries creates coronal taper and reduces the contact area of the file so torsional forces are reduced.[173] Differently designed NiTi rotaries may follow a single-length principle, according to the manufacturers' recommendations.

Emphasis has traditionally been placed on determining the canal length with comparatively little consideration of the canal diameter in the apical portion of the root. Because every canal is unique in its morphology, apical canal diameters must be assessed. After initial preparation to length the size of the apical portion of the canal is determined by placing successively larger instruments to the corrected WL until slight binding is encountered (Fig. 14.26). Often, the next larger instrument will not go to the corrected WL. If it does go to length, a subjective estimation of the apical diameter must be made depending on the degree of binding. This file will be the IAF (initial file to bind). It is defined as the largest file to bind slightly at the corrected WL after straight-line access. This file size provides an estimate of the canal diameter before cleaning and shaping. A shaping target is set, the MAF, which is the point where the step-back preparation begins. It should be considered that this approach may underestimate actual constriction diameters,[174] and therefore additional apical enlargement may be reconsidered.

When the body of the canal has been shaped, the apical portion may be additionally prepared using hand or rotary files (Fig. 14.27). The first instrument selected for this portion of the shaping process is one size larger than the MAF (estimated canal diameter at WL). Recently, clinical evidence suggests that such an enlargement may be beneficial for outcome.[175]

Regardless, NiTi instruments continue to evolve and shaping with modern instruments that are more flexible allows better preparations and respect to natural anatomies. First, manufacturers focused on enhancing design characteristics such as different cross-sections, tip designs, and progressive tapers over the length of the cutting blades to improve the properties of rotary instruments. Second, they suggested reciprocation motions that seemed to enhance cyclic fatigue resistance. Third, proprietary thermal treatments optimized the mechanical properties of NiTi by improving its microstructure through different series of heating and cooling treatments (M-wire, CM-Wire, Blue and Gold alloys are some examples of improved alloys). At the same time, manufacturers have also developed different manufacturing methods to the traditional



• **Fig. 14.24** The mesiobuccal canal is prepared using nickel-titanium rotary files using a crown-down technique. In this sequence, each instrument exhibits the same .06 taper with varied International Organization for Standardization standardized tip diameters. Instruments were used to resistance. **(A)** The process begins with a .06/45 file to resistance at 16.0 mm. **(B)** Followed by a .06/40 instrument at 17.0 mm. **(C)** The .06/35 file is used to 18.0 mm. **(D)** The .06/30 at 19.0 mm. **(E)** The .06/25 at 20.0 mm. **(F)** The .06/20 file is to the corrected working length of 21.0 mm.

grinding method (twisting, shape-setting, and electric discharge machining are some examples). Taking advantage of all these developments together, the last generation of rotary instruments, the so-called 3D conforming instruments (as a result of a characteristic nonflat morphology), better address nonround cross sections[176] and also better respect coronal dentin compared with traditional rotaries.[177]

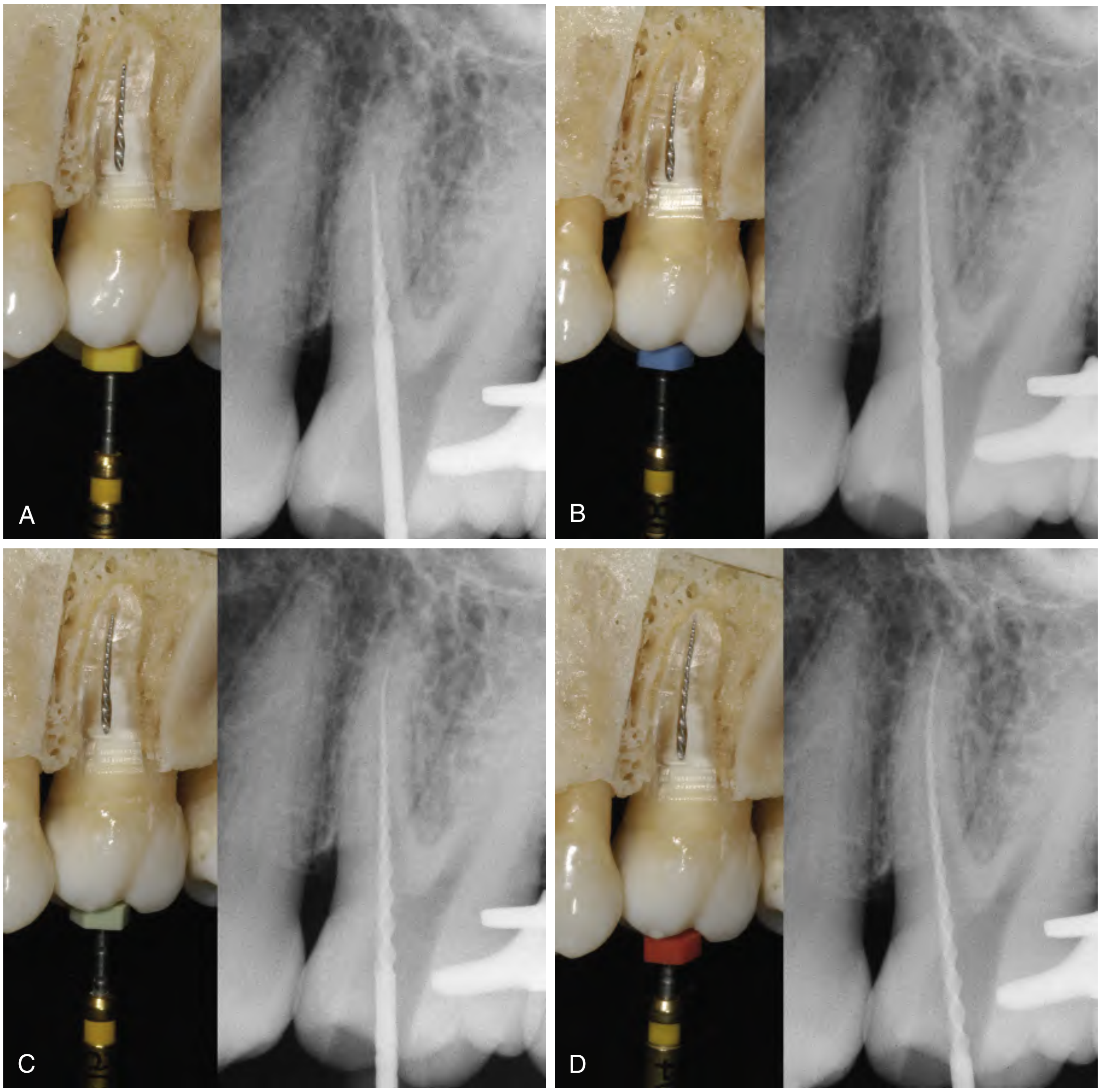
• BOX 14.3 Combination Technique Steps

Canal exploration
Coronal flaring
Canal negotiation
Working length determination
Initial rotary preparation to WL
Master apical file determination
Additional apical enlargement

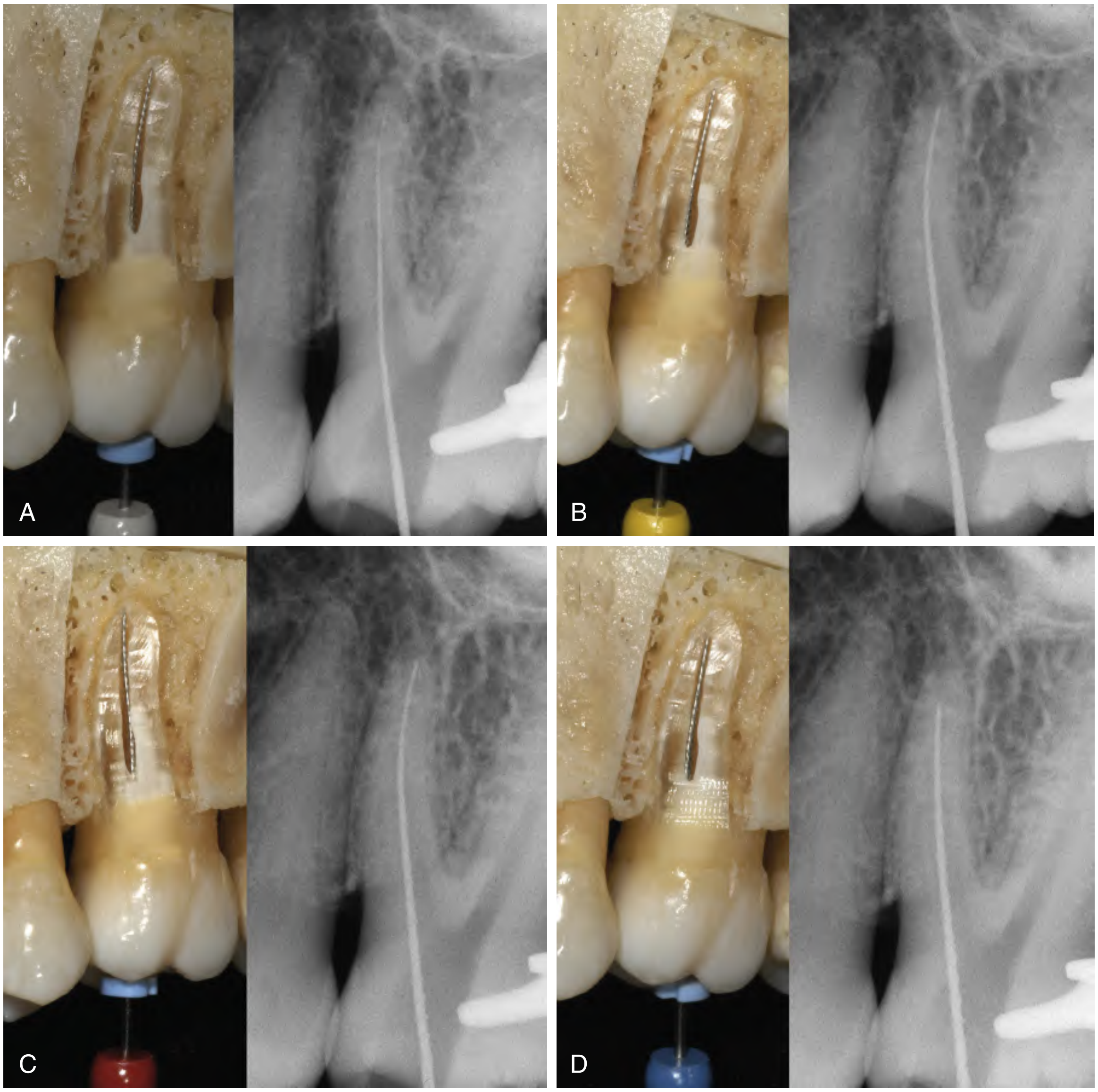
Criteria for Evaluating Cleaning and Shaping

After cleaning and shaping procedures, the canal should exhibit "glassy smooth" walls, and there should be no evidence of dentin filings, debris, or irrigant in the canal. This can be directly determined in the coronal root canal portion when an operating microscope is used to visualize endodontic procedures; it can only be indirectly determined in the more apical portion of the root canal by tactile feedback during instrumentation.

Shaping is evaluated by assessing the canal taper and identifying the apical configuration in size and shape. For obturation with lateral compaction, a small finger spreader should go ideally to



• Fig. 14.25 Nickel-titanium rotary files with a standardized International Organization for Standardization tip diameter and variable tapered files can be used in canal preparation. In this sequence, the instruments have a standardized tip diameter of .20 mm. **(A)** Initially a 1.0/.20 file is used. **(B)** This is followed by .08/.20. **(C)** The third instrument is a .06/.20. **(D)** The final instrument is a .04/.20 file to the corrected working length of 21 mm.

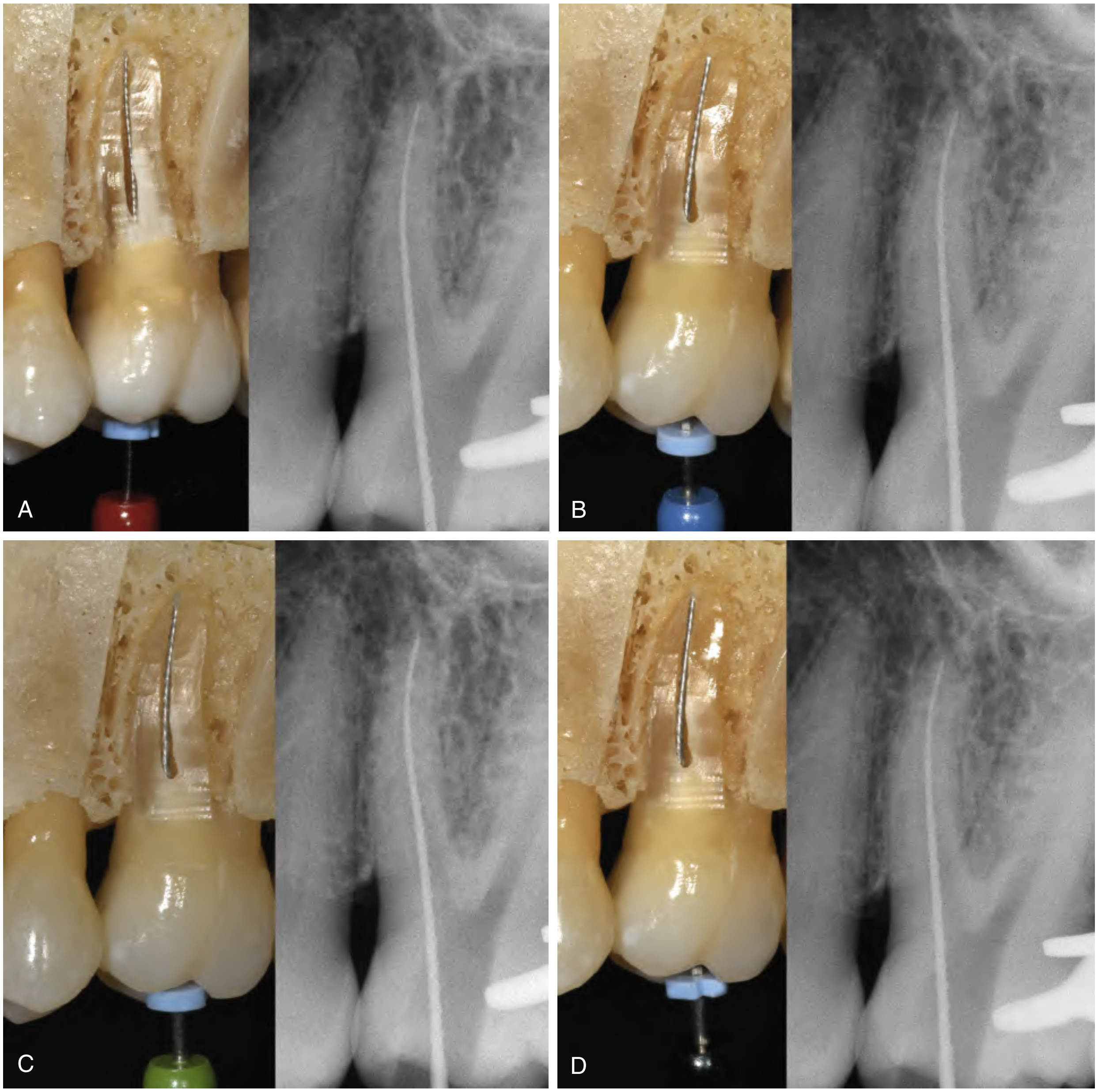


• **Fig. 14.26** After straight-line access in this maxillary molar, the actual constriction size is determined by successively placing small to larger files to the corrected working length. **(A)** No. 15 stainless steel file is placed to 21.0 mm without resistance. **(B)** No. 20 is placed to 21.0 mm without resistance. **(C)** The No. 25 file reaches 21 mm with slight binding. **(D)** No. 30 file is then placed and does not go the corrected working length, indicating the initial canal size in the apical portion of the canal is No. 25.

within 1 mm of the corrected WL without binding. For warm vertical compaction, the plugger should reach to within 5 mm of the corrected WL (Fig. 14.28).

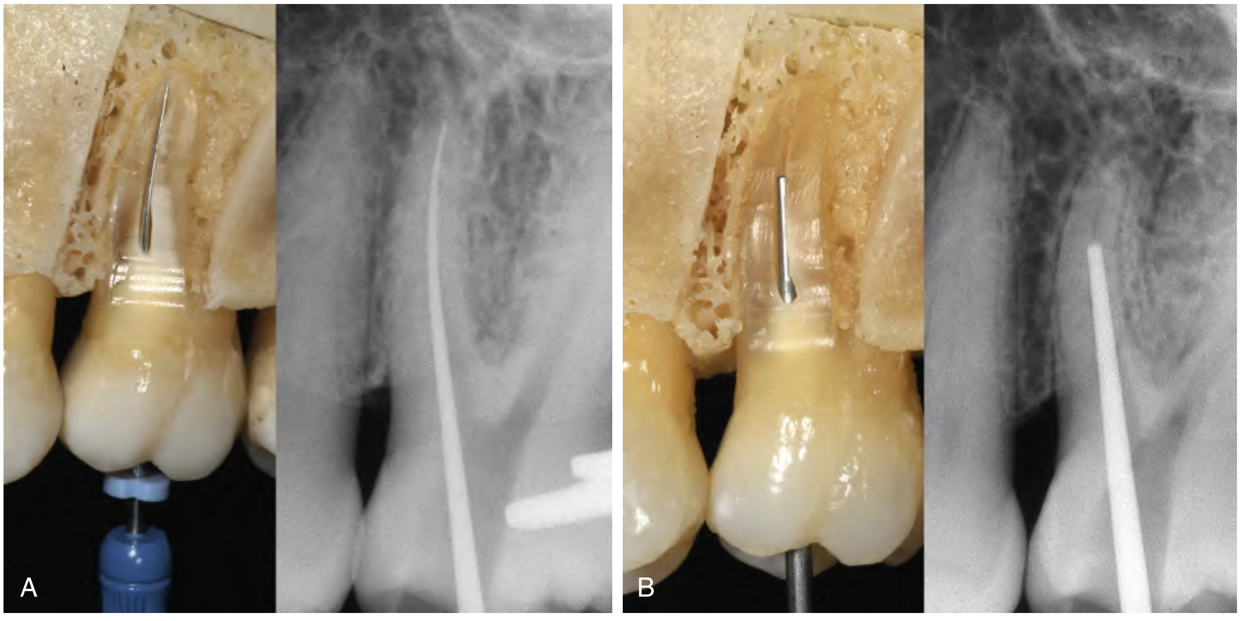
The following principles and concepts should be applied regardless of the instruments or technique selected:

1. Initial canal exploration is always performed with smaller hand files to gauge canal size, shape, and configuration.
2. Copious irrigation must be provided between instruments in the canal.
3. Coronal preflaring will facilitate placing larger files to WL (either hand or rotary) and will reduce procedural errors such as loss of WL and canal transportation.
4. Apical canal enlargement is gradual, using sequentially larger files, regardless of flaring technique.
5. Debris is loosened and dentin is removed from all walls on the outstroke or with a rotating action at or close to WL.
6. Instrument binding or dentin removal on insertion should be avoided. Files are teased to length using a watch-winding action. This is a back-and-forth rotating motion of the files between the thumb and forefinger, continually working the file apically. Careful file manipulation in an irrigant-filled canal will help to avoid apical packing of debris and minimize extrusion of debris into the periradicular tissues.
7. Circumferential filing is used for canals that exhibit cross-sectional shapes that are not round. The file is placed into the canal and withdrawn in a directional manner against the mesial, distal, buccal, and lingual walls.



• **Fig. 14.27** Final apical enlargement. **(A)** The master apical file No. 25 at the corrected working length of 21.0 mm. **(B)** Enlargement with a No. 30 file to the corrected working length of 21.0 mm. **(C)** Further enlargement with a No. 35 file. **(D)** Final enlargement to a No. 40 file. The final instrument used becomes the final apical file (FAF).

8. After each insertion the file is removed and the flutes are cleaned of debris; the file can then be reinserted into the canal to plane the next wall. Debris is removed from the file by wiping it with an alcohol-soaked gauze or a cotton roll.[178]
9. Recapitulation is done to loosen debris by placing a small-size file to the corrected WL followed by irrigation to mechanically remove the material. During recapitulation, the canal walls are not planed, and the canal is not enlarged.
10. Small, long, and curved canals are the most difficult and tedious to enlarge. They require extra caution during preparation because they are the most prone to loss of length and transportation.
11. Overenlargement of curved canals by files attempting to straighten themselves will to lead to procedural errors (see Fig. 14.12).
12. Overpreparation of canal walls toward the furcation may result in a stripping perforation in the danger zone where root dentin is thinner (see Fig. 14.13).
13. Instruments, irrigants, debris, and obturating materials should be contained within the canal. These are all known physical or chemical irritants that will induce periradicular inflammation and may delay or compromise healing.
14. Creation of an apical stop may be impossible if the apical foramen is already very large. An apical taper (seat) is attempted but with care. Overusing large files aggravates the



• **Fig. 14.28** The coronal taper is assessed using the spreader or plugger depth of penetration. **(A)** With lateral compaction, a finger spreader should fit loosely 1.0 mm from the corrected working length with space adjacent to the spreader. **(B)** For warm vertical compaction, the plugger should go to within 5.0 mm of the corrected working length.

problem by creating an even larger apical opening. A resistance form along the root canal should allow proper warm vertical obturation with no need of an apical stop.

15. Forcing or locking (binding) files into dentin produces unwanted torsional force. This tends to untwist or "wrap up" and will weaken and break the instrument.

Intracanal Medicaments

Intracanal medicaments have a long history of use as interim appointment dressings. They have been employed for the following three purposes: (1) to reduce interappointment pain, (2) to decrease the bacterial count and prevent regrowth, and (3) to render the canal contents inert. Some common agents are listed in Box 14.4.

Clinical evidence of the effectiveness of these agents is mixed; this has led to increased interest in the efficacy of so-called single visit endodontic therapy. There are only few prospective studies directly comparing these two treatment modalities, with a meta-analysis favoring single-visit treatment.[179] Two well-done clinical studies[180,181] showed remaining microorganisms in accessory anatomy and isthmi, but also in the main canal, remaining after single visit treatment as well as in the majority of the cases with calcium hydroxide placement.

• BOX 14.4 Groupings of Commonly Used Intracanal Medicaments

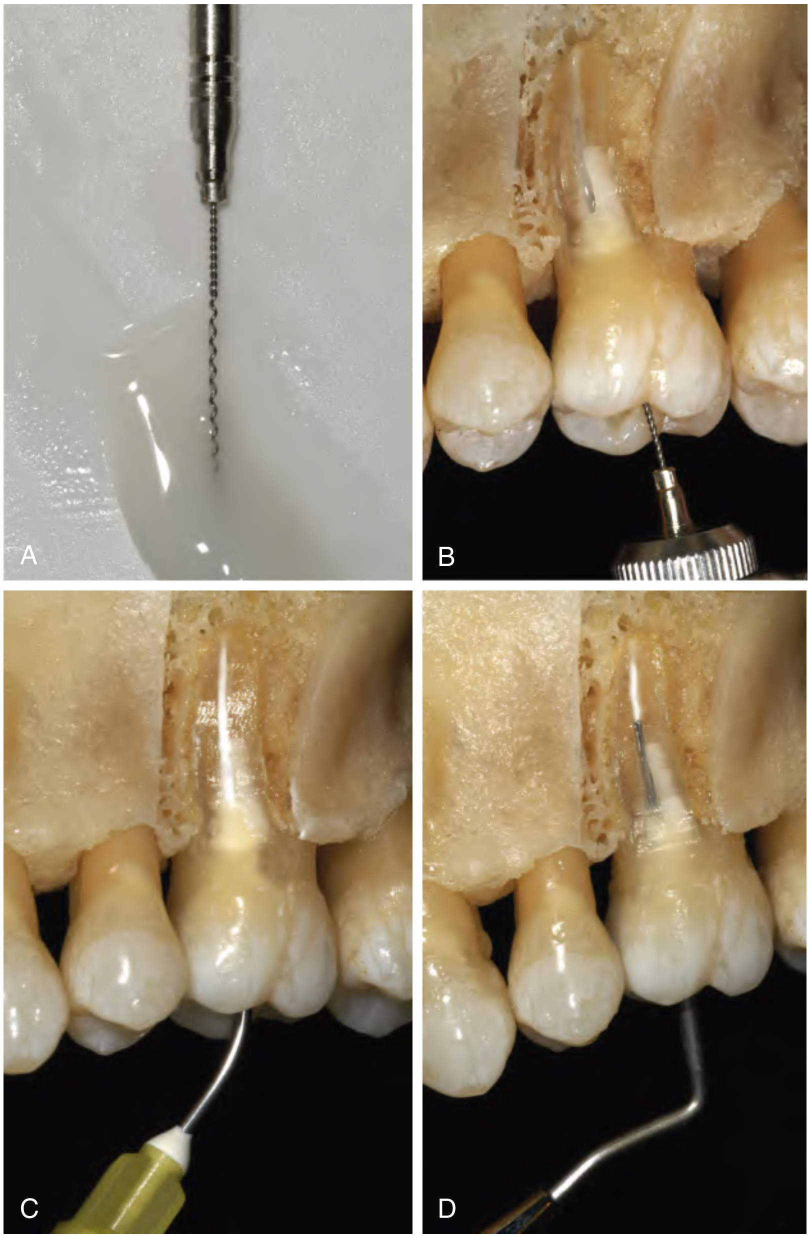
Calcium hydroxide
Phenolics
Aldehydes
Halides
Steroids
Antibiotics
Combinations

Calcium Hydroxide

One intracanal agent that is effective in inhibiting microbial growth in canals is calcium hydroxide.[182] Calcium hydroxide has antimicrobial activity that is a result of the alkaline pH, and it may aid in dissolving necrotic tissue remnants and bacteria and their byproducts.[183-185] Interappointment calcium hydroxide in the canal demonstrates no pain-reduction effects.[186] Calcium hydroxide has been recommended for use in teeth with necrotic pulp tissue and bacterial contamination. It probably has little benefit in teeth with vital pulps. Calcium hydroxide should be placed as a powder mixed with a liquid such as local anesthetic solution, saline, or sterile water, to form a slurry; or as a proprietary paste supplied in a syringe (see Fig. 14.29). A lentulo spiral is effective and efficient for placement.[187-189] Spinning the paste into the canal by rotating a file counterclockwise and using an injection technique is not as effective. It is important to place the material deeply and densely for maximum effectiveness. To accomplish this, straight-line access should be performed, and the apical portion of the canal prepared to a No. 25 file or greater. Removal after placement is difficult,[190] and this is especially true in the apical portion of the root.

Phenols and Aldehydes

The majority of these medicaments exhibit nonspecific action and can destroy host tissues, as well as microbes.[191-193] Historically, it was thought that these agents were effective, although their use was based on opinion and empiricism. The phenols and aldehydes are toxic, and the aldehydes are fixative agents.[194,195] When placed in the radicular space, they have access to the periradicular tissues and the systemic circulation.[196,197] Research has demonstrated that their clinical use is not justified.[198-202] Clinical studies assessing the ability of these agents to prevent or control interappointment pain indicate that they are not effective.[203-206]



• **Fig. 14.29** Calcium hydroxide placement. **(A)** Calcium hydroxide mixed with glycerin to form a thick paste. **(B)** Placement with a lentulo spiral. **(C)** Injection of a proprietary paste. **(D)** Compaction of calcium hydroxide powder with a plugger.

Corticosteroids

Corticosteroids are antiinflammatory agents that have been advocated for decreasing postoperative pain by suppressing inflammation. The use of corticosteroids as intracanal medicaments may decrease lower-level postoperative pain in certain situations;[207] however, evidence also suggests that they may be ineffective, particularly with greater pain levels.[206] Cases of irreversible pulpitis and cases in which the patient is experiencing acute apical periodontitis are examples where steroid use might be beneficial.[207-209]

Chlorhexidine

Chlorhexidine has recently been advocated as an intracanal medicament.[210,211] A 2% gel is recommended, which can be used alone in gel form or mixed with calcium hydroxide. When used with calcium hydroxide, the antimicrobial activity is greater than when calcium hydroxide is mixed with saline,[212] and periradicular healing in animal models appears to be enhanced.[213] However, a recent randomized clinical trial did not show that the combination of calcium hydroxide and 2% chlorhexidine was advantageous compared with single appointment treatment in cases with periapical lesions, after 1 year of observation.[187]

Study Questions

6. Although removal of the smear layer is not universally advocated before root canal obturation, those advocating its removal cite the following rationale.
   a. Smear layer provides an improved seal of the canal during obturation
   b. The organic component of smear layer is antimicrobial
   c. Maintenance of the smear layer strengthens root structure
   d. Smear layer may contain bacterial contaminants
7. NaOCl is effective in removing the smear layer.
   a. True
   b. False
8. Which of the following irrigants may reduce postoperative pain?
   a. NaOCl
   b. EDTA
   c. Cold saline
   d. Chlorhexidine
9. Select the method that is most effective in maintaining canal patency.
   a. Radiographic root length determination
   b. Electronic root length determination
   c. Use of patency file
   d. Selection of correct reference point
10. Select the most commonly used intracanal medication placed when endodontic treatment is not completed.
    a. NaOCl
    b. Calcium hydroxide
    c. Phenolic products
    d. Chlorhexidine

ANSWERS

Answer Box 14

1 b. Use of hand instrumentations
2 b. False
3 d. All of the above
4 a. True
5 a. True
6 d. Smear layer may contain bacterial contaminants
7 b. False
8 c. Cold saline
9 c. Use of patency file
10 b. Calcium hydroxide

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Video 14.1: Removal of Smear Layer
Video 14.2: Cleaning and Shaping NiTi
Video 14.3: Cleaning and Shaping Combined
Video 14.4: Temporalization