Endodontic Update 2006

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ABSTRACT

The past 10 years have witnessed more significant changes in the art and science of endodontics than the previous 100 years. This observation is no surprise, given that change is our only constant. The rate of change, however, has been anything but constant. The rate has accelerated so fast that all clinicians in the field of dentistry need a reliable source to guide us in what works. What works today in endodontics is the theme of this update.

The discoveries and advancements in endodontic technology, instruments, and materials enable practitioners to achieve treatment outcomes that were previously considered unattainable. For example, in nonsurgical endodontic treatment, nickel titanium technology consistently can produce predictable radicular preparations that can be easily obturated. In nonsurgical re-treatment, the previous endodontic obturation attempt frequently can be removed and successfully re-treated largely because of enhanced vision and coaxial lighting from the operating microscope. Importantly, careful nonsurgical re-treatment usually can be accomplished without disruption to the existing restorations and without risk to ferrule integrity. In endodontic surgery underfilled foramina, and the isthmi between them, predictably can be connected and obturated with state-of-the-art miniature instruments.

CLINICAL SIGNIFICANCE

This article reviews the clinical endodontic breakthroughs encountered during the last decade and focuses on three primary topics: (1) *finding canals*; (2) *following canals*; and (3) *finishing canals*. Every day, dentists are faced with the interdisciplinary treatment planning question of to "save or not to save a tooth?" Dentists must routinely make the decision of whether to remove or restore the tooth based on biology, structure, function, esthetics, and value.[1] Occasionally, the endodontically treated tooth can be the weakest link in the restorative and esthetic sequence. This article examines the current state of endodontic technology, as well as the fundamentals of endodontic mechanics needed to achieve the most predictable endodontic outcome with the highest degree of success.

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Publications
Obturation of the radicular space (with Dr. John Ingle) in Ingle's 1994 and 2002 editions of Endodontics
Cleaning and shaping the root canal system in Cohen and Burns (senior author) in 1994 and 1998 Pathways of the Pulp
Orthodontic–endodontic treatment planning of traumatized teeth (with Dr. Dave Steiner). Semin Orthod 1997;3(1):39–44
A method to determine the location and shape of an intracoronal bleach barrier (with Dr. Dave Steiner) J Endod 1994;20(6);304–6
Bleaching pulpless teeth (with Dr. Dave Steiner) in Goldstein and Garker's 1995 edition of Complete Dental Bleaching.

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Boating/skiing, golfing, and being with family and friends

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FINDING CANALS

The rationale for endodontics states that "any endodontically involved tooth can be saved if the root canal system can be sealed nonsurgically or surgically, if the periodontal condition is healthy or can be made healthy, and the tooth is restorable"[2] (Figure 1). While endodontic treatment may have a 100% "capacity" for healing and success, in reality, the success rate is 100–*X*, where *X* represents the clinician's endodontic knowledge and skill as well as their "willingness" to stay focused on the desired outcome while there may be pressures to do otherwise. But, in order to have success, dentists must first *find* the canals. The microscope, improved access cavities, and ultrasonics have significantly enhanced dentists' ability to find the canals in endodontics.

Microscope

The early 1990s was a time that was highlighted by significant technological advances in endodontics (Figure 2).[3,4] It began with the introduction of the microscope. Not only did the microscope allow dentists to *find* canals that were previously difficult or impossible to *find*, but also, it allowed dentists to *find* these canals more frequently. The microscope allowed clinicians to see better, feel better, and think better. In addition to facilitating *finding* canals, the microscope also has improved endodontic outcomes in diagnosis, predictability, tooth conservation, and location of additional canals.[5] The microscope makes it easier to diagnose hairline vertical fractures especially in Class I and II cracked tooth syndrome cases, micromovement of loose crowns, bridges and restorations, detecting internal access microleakage under restorations and crowns, tracing orifi of sinus tracts, detecting Class V apical fractures, discovering isthmi between two canals in the same root, and finding canal orifi that are difficult to see (Figure 3A–F). Predictability of the outcome improves because of better access, debridement, shaping, and obturation. The literature suggests

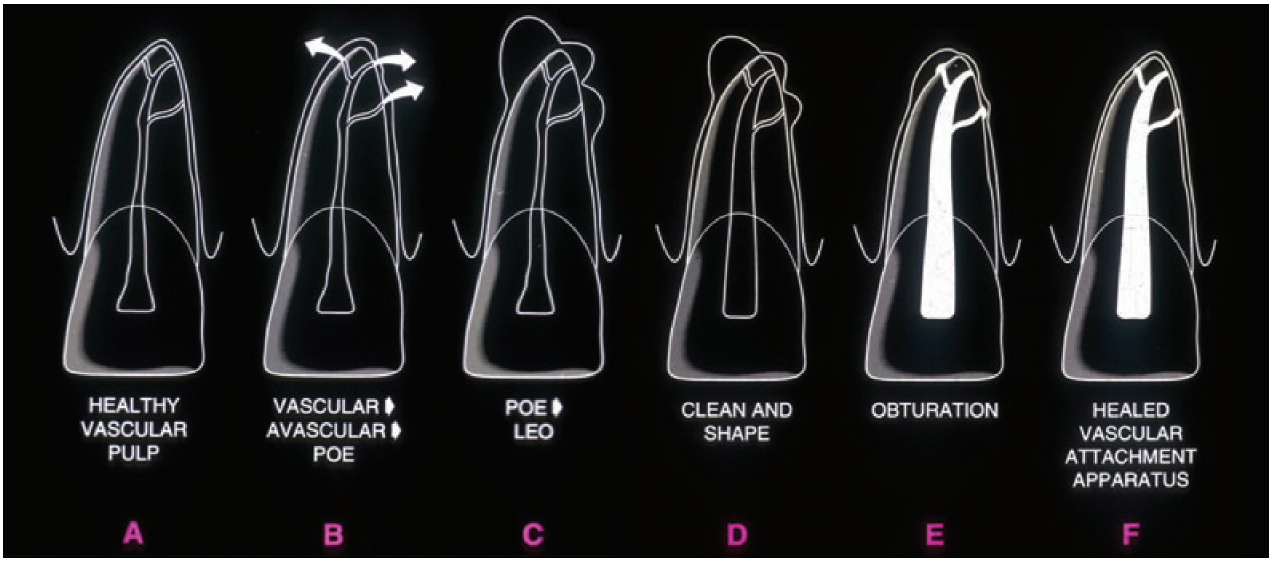

Figure 1. Rationale for endodontics. A, *Teeth exist first with a healthy pulp and healthy attachment apparatus.* B, *When pulps die, they become avascular, and viable and nonviable irritants migrate out of the root canal system portals of exit (POE) or foramina.* C, *Lesions of endodontic origin form adjacent to the POEs.* D, *The root canal system is cleaned and shaped with the same thoroughness as if the tooth were actually extracted.* E, *The cleaned and shaped preparation is obturated.* F, *The lesions of endodontic origin predictably heal.*

Figure 2. Microscope enables both clinician and dental assistant to treat in healthy posture without tethering to the light source and without often-awkward magnifying glasses.

that the use of the microscope in combination with an appropriate case selection and other current technologies and materials may result in improved surgical treatment outcomes.[6–8]

The microscope literally brought endodontics out of the dark and represented a paradigm shift not only in endodontics, but also in periodontics[9–11] and advanced esthetic and restorative dentistry.[12,13] The use of the microscope has been met with both excitement and controversy in the past decade. It is, of course, not a panacea. It is certainly not a religion, as some may have us believe. It will not make a good dentist great. It will, however, make both a good dentist and a great dentist better because they can see better. The benefit is just that simple. The microscope also does not define the standard of care in endodontics, but it can help define the level of precision and therefore potentially the level of excellence. The microscope has clearly advanced from a novelty item and marketing tool to an indispensable instrument.

Beginning in 1997, residents in the field of endodontics in America and Canada have been required to graduate with proficiency in the use of the operating microscope. In addition, industry insiders estimate that 76% of all US endodontists currently own a microscope in their practice. Interestingly, the market growth potential seems to be in the general practitioner arena. The percentage of general dentists currently owning a microscope is estimated at a mere 1%. Recently, the University of Washington School of Dentistry in Seattle, Washington, was the first dental school in the country and the world to provide predoctoral students with the use of microscopes in clinical dentistry.[14] Three years from now, in 2009, these dentists will be among the first generation of graduates in the world where the use of the microscope to enhance their restorative precision will be second nature. They will change dentistry, because they will be able to see better.

Access Cavities

The first step toward successful cleaning and shaping is a straight-line access cavity.[15] This means that files enter the root canal system unimpeded from the restriction of enamel or dentin triangles. These triangles act as file fulcrums, both by deflecting the desired instrument path and decreasing the operator's tactile sense and control.

Anterior teeth typically have an incisal enamel triangle (triangle I) and a lingual dentin triangle (triangle II) that must be removed in order to achieve straight-line

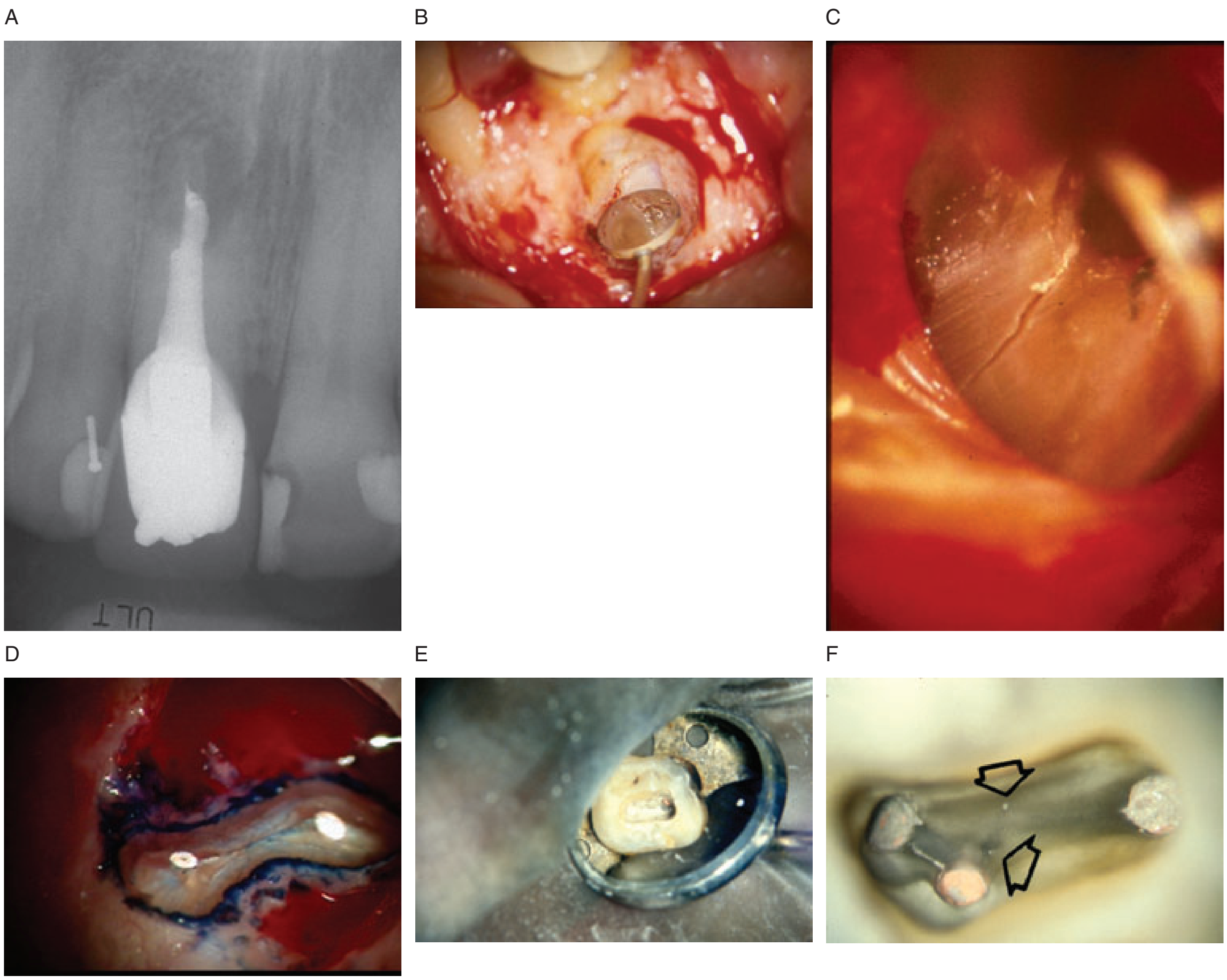

Figure 3. The microscope can bring the dentist closer to reality. A, *Pretreatment radiograph of symptomatic tooth #8.* B, *Surgically beveled root-end with 2.5× magnification.* C, *At 10× apical Class V, fracture becomes obvious.* D, *Root-end preparation of maxillary premolar stained with methylene blue. Note the patent isthmus between the buccal and lingual canal. In order to maximize endodontic success, the isthmus must be prepared with small ultrasonic instruments and sealed.* E, *Access cavity of maxillary first molar endodontic failure, as seen with low eyewear magnification.* F, *15× magnification reveals a second distobuccal and second mesiobuccal canal entrance (arrows).*

access. Triangle I is most easily removed with the same round bur used to attain the initial access by penetrating and alternately flaring incisally until the enamel triangle is removed. A thin tapered diamond is useful for finishing. The dentin triangle II is most easily removed with a #1 and #2 Gates Glidden drill and finished with a thin tapered diamond or a ProTaper SX file (Dentsply Tulsa Dental, Tulsa, OK, USA) in a lingual brushing motion.

In posterior multirooted teeth, orifice dentin triangles frequently prevent straight-line access and must be removed by a small Gates Glidden or an endodontic rotary instrument such as the SX ProTaper shaping file (Figure 4A–D).

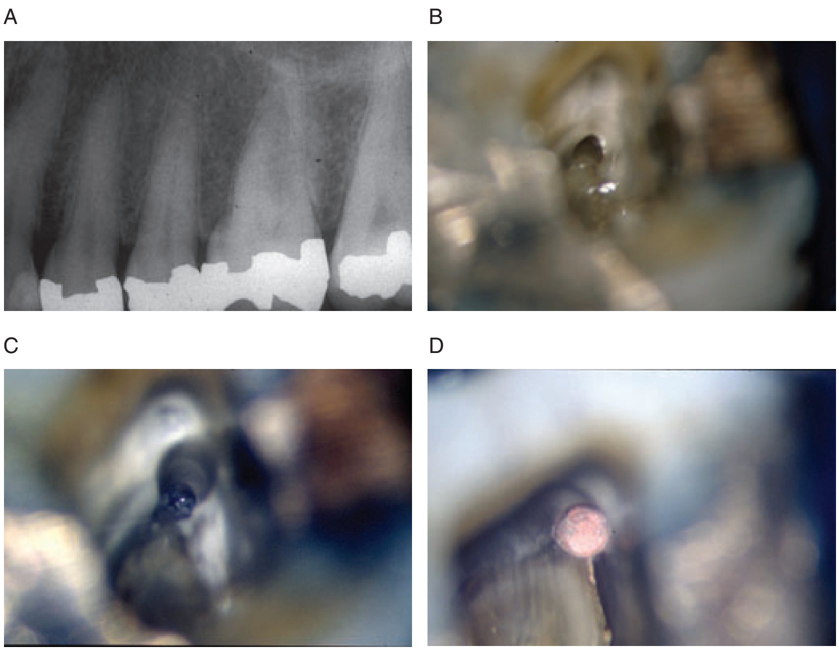

Figure 4. Straight-line access for posterior teeth. A, *Pretreatment radiograph of pulpitic tooth #14.* B, *Dentinal triangle prevents unrestricted access into the MB canal.* C, *Dentinal triangle removed.* D, *Straight-line access is achieved. Cleaned and shaped canal is easily obturated.*

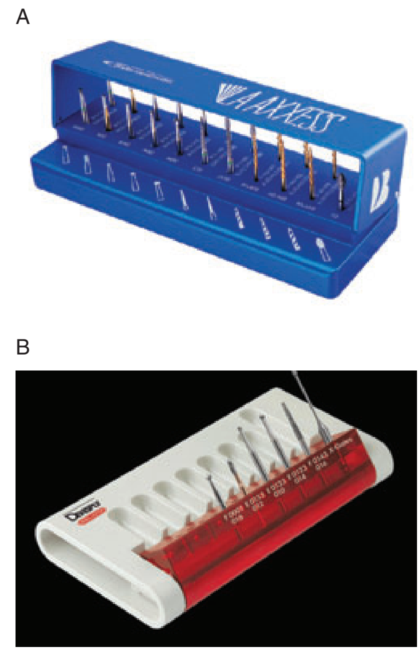

Figure 5. Modern access kits. A, *LA Axxess kit.* B, *ProTaper access kit.*

Many errors are made in the selection of access burs. They are often too large in diameter, resulting in gouging the axial walls and pulpal floor. Smaller burs tend to cut smoother than larger burs and are, therefore, kinder to the tooth and to restorative materials such as porcelain. Additionally, the smoother a bur cuts, the more positive the patient experience. Ideally, only new burs should be used in the endodontic access. In an attempt to simplify access choices, two new systems have been recently introduced. The LA Axxess kit (SybronEndo, Orange, CA, USA) features both high- and low-speed latch-grip burs numbering a total of 11 burs (Figure 5A). Second, the ProTaper access kit (Dentsply Tulsa Dental) consists of just six essential burs, including the new X-Gates Glidden that features a consolidation of all six Gates Glidden drill geometries into one single drill. Space also exists in the kit for the clinician's addition of his or her personal choice of burs (Figure 5B).

Ultrasonics

Ultrasonic technology, such as ProUltra ultrasonic tips (Dentsply Tulsa Dental), has become an indispensable part of the endodontic armamentarium[16] (Figure 6A). Ultrasonic instrument use includes removing pulp stones, denticles, posts, separated instruments, silver cones, gutta-percha, Resilon, and carrier-based obturators. Locating MB2 canals, which exist in over 93% of maxillary molars and, of which, over 50% are entirely separate canals, is challenging, because the head of the high-speed handpiece often blocks the precision placement of the bur even if using extra-long surgical length burs.[17] The ultrasonic unit has no handpiece head and, therefore, no line-of-sight barrier. The clinician can safely control where the ultrasonic tip cuts (Figure 6B–H). Because canals calcify in a coronal to apical direction, ultrasonics are extremely valuable

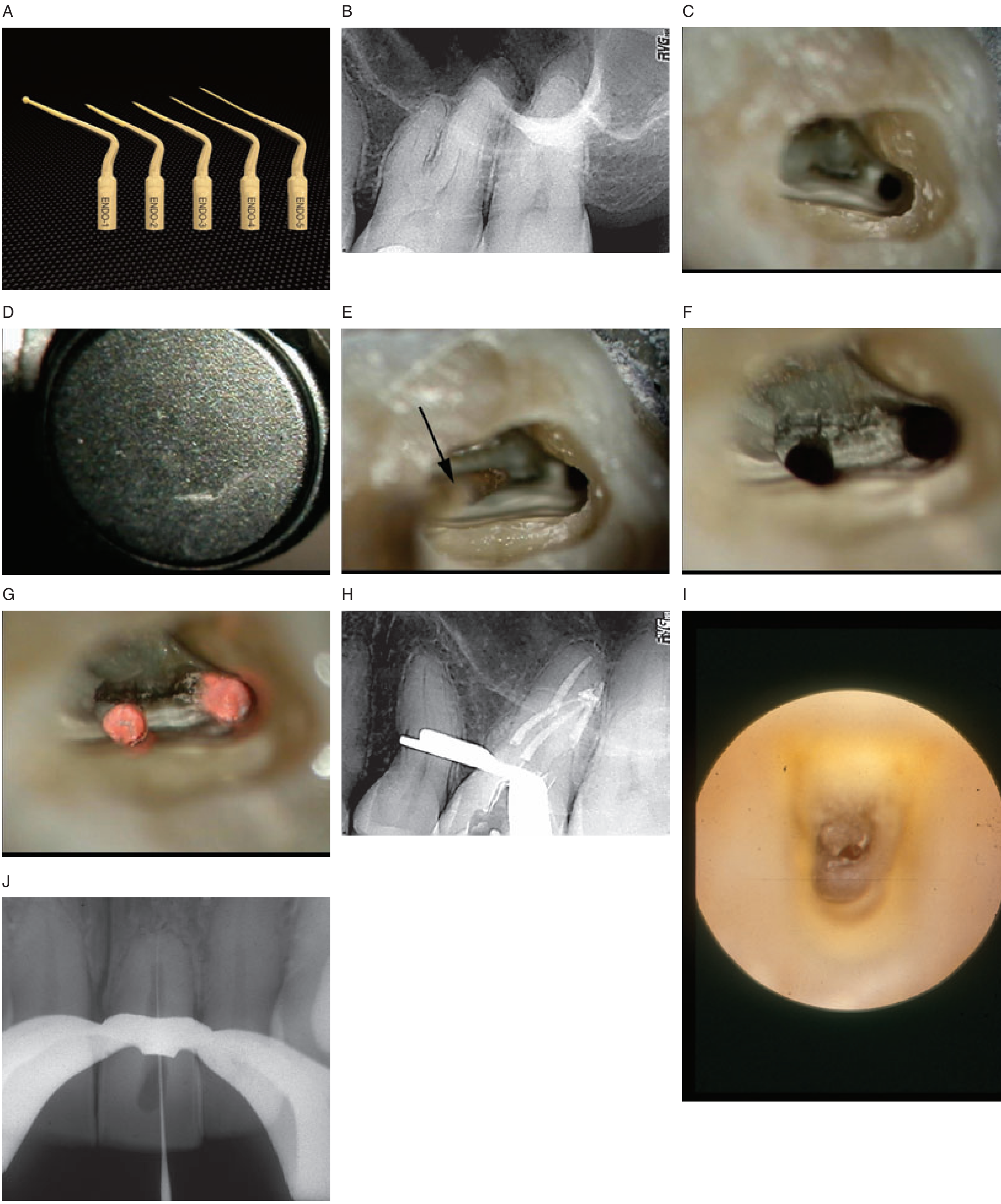

Figure 6. The ultrasonic advantage. A, *ProUltra ultrasonic tips are one brand of several that enable unprecedented visual accuracy during their use.* B, *Pretreatment radiograph of tooth #14 with necrotic pulp and chamber calcific metamorphosis.* C, *Mesiopalatal canal is palatal to mesiobuccal, but is not patent due to chamber calcification.* D, *Head of handpiece with long-shank #2 round bur blocks the view of the bur's cutting tip.* E, *Ultrasonic tip allows operator to observe active tip for pinpoint accuracy.* F, *Mesiopalatal canal conservatively located and cleaned and shaped.* G, *Both mesiobuccal canals obturated.* H, *Radiograph shows two distinct canals with separate orifi and separate apical portals or exit.* I, *Orifice of calcified canal is discovered less than 3 mm from the apex! Note that calcified dentin is darker than the surrounding dentin. Patent canal entrance is darker yet and in the middle of the ultrasonic penetration.* J, *Radiograph demonstrates the extraordinary yet safe depth before the canal could be negotiated.*

in following "darker-than-dentin color maps" until the calcified canal becomes patent and can be *followed* with an endodontic file (Figure 6I,J).

Ultrasonic tips should be used in a light brushing motion. When used to vibrate posts in order to remove them, use water coolant spray to prevent overheating the post, tooth, and periodontal ligament.[18] If the tooth is anesthetized, there is no heat warning to the patient whatsoever. Ultrasonics also can refine and marry the access cavity to the canal's entrance and subsequent radicular "glide path."

Finally, *finding* canals is more successful today because of endodontic explorers that are less than half the diameter of traditional endodontic explorers (CK Dental, Orange, CA, USA). They enable the clinician to access the canal entrance with finesse and without instantly blocking it with "dentin mud" that would typically be entrapped in the canal orifice using the wider standard endodontic explorer.

FOLLOWING CANALS

There is perhaps no part of endodontic treatment that requires greater delicacy and greater restraint than *following* the canal from the orifice entrance to the radiographic terminus (RT) (Figure 7). The RT is the only reproducible

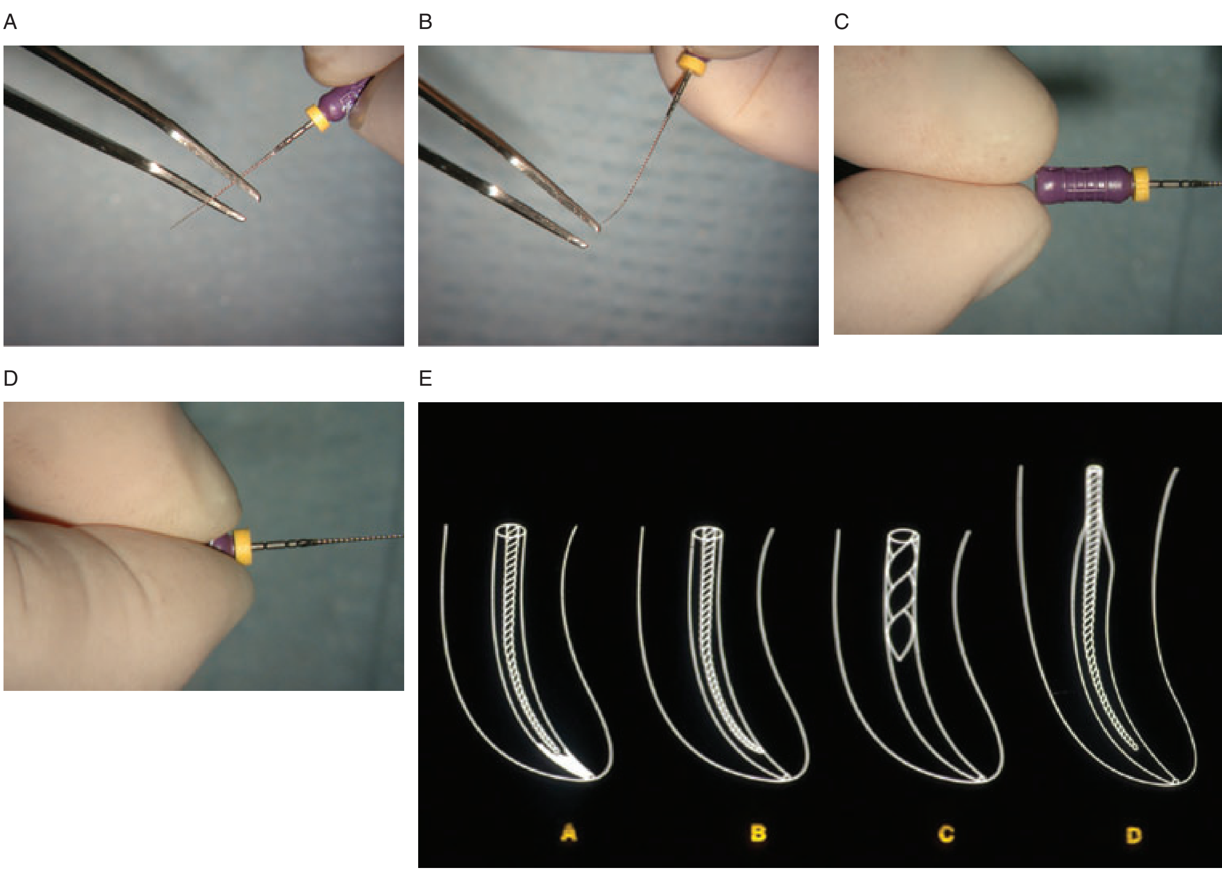

Figure 7. Important keys to successful endodontic mechanics. A, *#10 file before curving the tip.* B, *Using cotton pliers with beaks parallel to the shaft of the file, gently sweep to the file tip while intentionally curving the file. Now the instrument has the capacity to slide around denticles, dense collogen, or necrotic debris.* C, *Maximum tactile sense is achieved by using minimal "skin contact."* D, *Maximum "skin contact" results in minimal tactile sense.* E, *Diagram of the four possible reasons a file does not go to length during the early stages of cleaning and shaping.*

landmark that allows patency throughout cleaning and shaping and is, by definition, slightly past the foraminal constriction. The skill required in *following* canals is at the heart of the art of predictably successful endodontics and represents one of the four intentional motions that are key in developing a "glide path."[19] Whenever a dentist passes a file past the canal orifice, he or she must ask, "What is my intention with this file? What is the outcome I want from its use?" Most endodontic students learned to "file for awhile and hope that something good would happen." Often, it did not! Other motions were "watch/wind" and "push/pull." None of these motions accurately described how to progressively begin the cleaning and shaping mechanics.

Motions

Masterful cleaning and shaping begins with understanding the role of thoughtful and efficient manual file motions that are used to pave the way for successful rotary finishing. Essentially, there are four critically distinct motions that take advantage of the geometries of today's hand files. The motions are *follow*, *smooth*, *balance*, and *envelope*.

Follow

A good analogy to describe the *follow* motion is a child sliding down a curved playground slide. If the child simply does not fight the tendency to "go with the flow," he or she will safely arrive at the bottom of the slide time after time without fail. Successful endodontic *following* requires a precurved instrument, copious irrigation with sodium hypochlorite, and minimal tactile contact with the endodontic file (Figure 7A,B). The index finger and thumb should literally be positioned behind the instrument rather than to the side (Figure 7C,D). This positioning reduces the temptation to direct the instrument, and increases the desired motion of simply "going along for the ride." The minimal finger contact also increases tactile sense.

Anytime an instrument cannot be followed to the radiographic and/or electronic terminus, there are four possible causes or combination of causes (Figure 7E).

1. The apical area is clogged with "dentin mud." The solution is to irrigate and gently "disrupt" the coronal fraction of the apical block by placing an abrupt apical curve on the file and *following* with the instrument until it touches the coronal portion of the block. By repeating the sequence, the file will often disrupt the dense dentin mud that is packed at the coronal end of the dense plug. Next, *follow* the more loosely packed dentin mud to the terminus.
2. The curve of the file does not match the curve of the canal. The solution is to re-curve the file with cotton pliers and systematically mimic the possible curvatures until the file finds the path to follow to the terminus.
3. The tip diameter of the file is too wide for the width of the canal. The solution is to select a tip size one or two sizes narrower. In dealing with a calcified canal, the choice should be a #6 or #8 file.
4. The shaft of the file is wider than the coronal portion of the canal. This problem is because of the restrictive dentin formation and a natural expression of canals calcifying from the crown down. The solution is to widen the coronal dentin using the remaining three motions.

Smooth

Once the dentist has reached the radiographic terminus with a #10 and then a #15 file, for example, the very next step is to reproduce this path and begin the "glide path," which represents a *smooth*, though perhaps narrow, tunnel from the orifice to the electronic portal of exit or the radiographic terminus. Then, and only then, are rotary files predictably safe to use. The *smoothing* motion is an "in and out" vertical movement using small amplitudes of 1 mm until the amplitude is naturally and easily increased because of the wearing away of the dentinal walls. This approach is dissimilar to "circumferential filing" in that the file is not leaned against one wall and then another wall. Circumferential filing only creates the illusion that all the walls are actually filed. In reality, the orifice acts as a fulcrum and the canal is indiscriminately widened. In addition, because curved stainless steel files have memory, circumferential filing risks apical transportation. The desired motion is directly in and out until the file can enter from the orifice and *follow* the *smooth* canal walls uninterrupted to the terminus.

Balance

Introduced by Roane[20] and further popularized by Buchanan,[21] this motion is especially effective in removing coronal dentin. The motion is simple: first turn the handle clockwise one-half to one full rotation. The dentin is "loaded" in the file's blades. With slight, and yet enough, apical pressure that prevents the file from unscrewing out of the canal, counter-rotate the file one-half to two or three full rotations. The dentin is "cut" and resting in the flutes of the file's blades. Always use delicate motions and do not screw the file into the canal. The file is removed using the initial clockwise motion while, at the same time, withdrawing it. Inspection of the blades under magnification usually reveals small amounts of dentin. Remember, endodontics is not a big job, it is a small job. It is, however, a smart job. After irrigation, the same or previous-size file that did not easily *follow* to the desired depth previously will almost always now *follow* deeper. Switch to the *follow* motion or continue with *balance* motion until a wide enough, smooth, and reproducible glide path is made. Usually, this means a #10 or #15 file *follows* easily to length.

Envelope

The envelope of motion is extremely efficient for removing restrictive dentin, and it is a motion that requires more restraint than the *balance* motion. It is the only motion that does not engage dentin with the "in" stroke. *Envelope* actually carves dentin on the "out" stroke. Specifically, a precurved file is *followed* short of maximum resistance, then removed while rotating it in a clockwise direction. With each pass the file will easily and predictably advance deeper into the canal as the restrictive dentin is passively and yet intentionally removed. The shape produced in the canal is actually determined by the envelope of motion created by the path of the precurved file as it is withdrawn in the clockwise direction. The resulting preparation shape is a function of the shape of the original instrument modified by its curvature within the canal.

Blocks, Ledges, and Transportations

During the manual phase of canal preparations, there are three main problems that can be encountered: blocks, ledges, and apical transportations (Figure 8).[22] Although it is better to prevent these temporary setbacks, techniques exist to correct them.

Blocks

The steps for removing a block are:

1. Remember the path is still there. It is temporarily clogged with the densest dentin coronally (dentin mud). While it may appear that the clinician is 2 to 3 mm short, in fact, he or she is more likely only a fraction of a millimeter away from the more lightly packed dentin, which can be negotiated easily once the file has delicately disrupted the dense coronal dentin mud.
2. Shake your fingers loose.
3. Relax.
4. Irrigate thoroughly.
5. Picture in your mind what it will look like, feel like, and what you will be thinking after you successfully ferrite your way through the block.
6. Forget the clock. Act like you have all the time in the world.
7. Be gentle, gentle, gentle.
8. *Follow* the canal in a randomized fashion. Do not search for the canal direction. Let the canal do the directing.

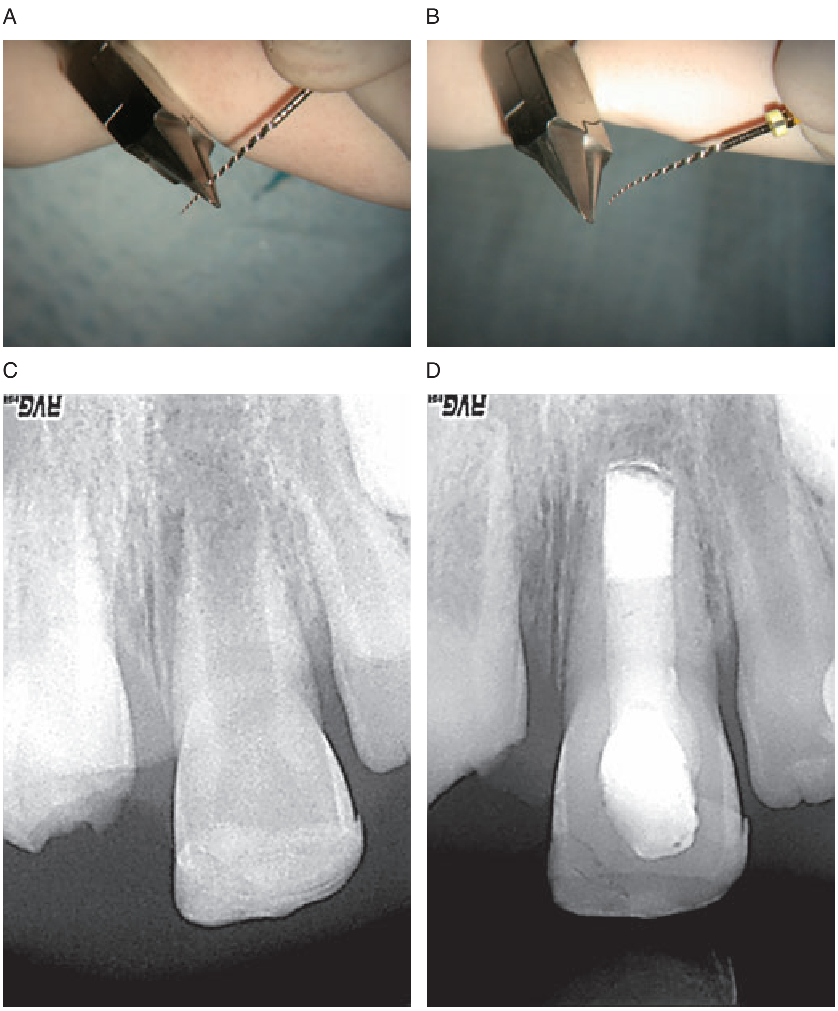

Figure 8. Ledges and transportations. A, *Straight ProTaper F1 usually cannot predictably bypass a ledge.* B, *Orthodontic birdbeak pliers can easily curve the ProTaper file, which retains the curve even though made of nickel titanium metal. The file can then manually slide past ledge, rotated, and remove ledge while simultaneously carving a proper apical shape.* C, *Maxillary central incisor with necrotic pulp and underformed root.* D, *Apical barrier is placed, MTA compacted into canal and restored. Treatment is without the need for gutta-percha and can be a single-visit procedure.*

9. Know that with each pass the file *will* advance deeper, although you may not perceive it at first because the distance is so small. Be patient.

Ledges

A ledge is one of the most difficult preparation errors to overcome. Once created, files and subsequent obturation materials do not easily bypass the ledge. Correction attempts were previously made by first *following* a precurved #20 hedstrom file past the ledge and then circumferentially filing the ledge until the edge of the ledge was partly worn away. The ledge could rarely be removed completely. In addition, unnecessary and indiscriminate dentin was removed. With the advent of nickel-titanian (NiTi), the ledge can be more easily corrected while, at the same time, cutting the proper apical taper. For example, a manual ProTaper F1 can be precurved using orthodontic birdbeak pliers and used to easily remove the ledge (Figure 8A,B). The curved F1 is guided around the ledge and then manually rotated clockwise. As the file is rotated in an apical direction, the ledge is usually removed and the F1 shape is made (apical size 20 and 7-degree apical taper). The cone-fit and subsequent obturation is uneventful.

Transportation. If a terminal foramen is externally torn (inadvertently enlarged) and if enough tooth structure remains to properly shape the canal using the new "superforamen," then proceed. If bleeding persists, intracanal calcium hydroxide dressings may be useful. If, however, there is not enough tooth structure to shape, or the canal cannot be dried, a barrier of calcium sulfate or CollaPlug (Sultzer Medica, Plainsboro, NJ, USA) must be placed to act as a backstop for vertical obturation of gutta-percha or mineral trioxide aggregate (MTA) (Figure 8C,D).

Electronic Apex Locators

The length of a root canal has always been one of the milestones of root canal preparation. Research and clinical experience support the claim that apex locators can assist in accurately determining canal length in the majority of cases.[23–26] In the past, manual shaping could require up to an hour per canal. Lengths of curved canals (the shortest distance between two points is a straight line) would shorten slowly over that hour. Rotary shaping has significantly changed the rate and time of canal shortening. For example, a single pass with a rotary instrument may shorten a long and curved canal by 2 mm or more. Instead of change that previously took an hour will now take only a few minutes! What this means to the operator is that canal length is dynamic. To say that a canal is 24-mm long, write it down, and be married to that length is a big mistake. This situation is where the electronic apex locator (Figure 9A) has tremendous value, because at any time, the apex locator can be attached to a manually placed rotary file and the length can be adjusted accordingly.

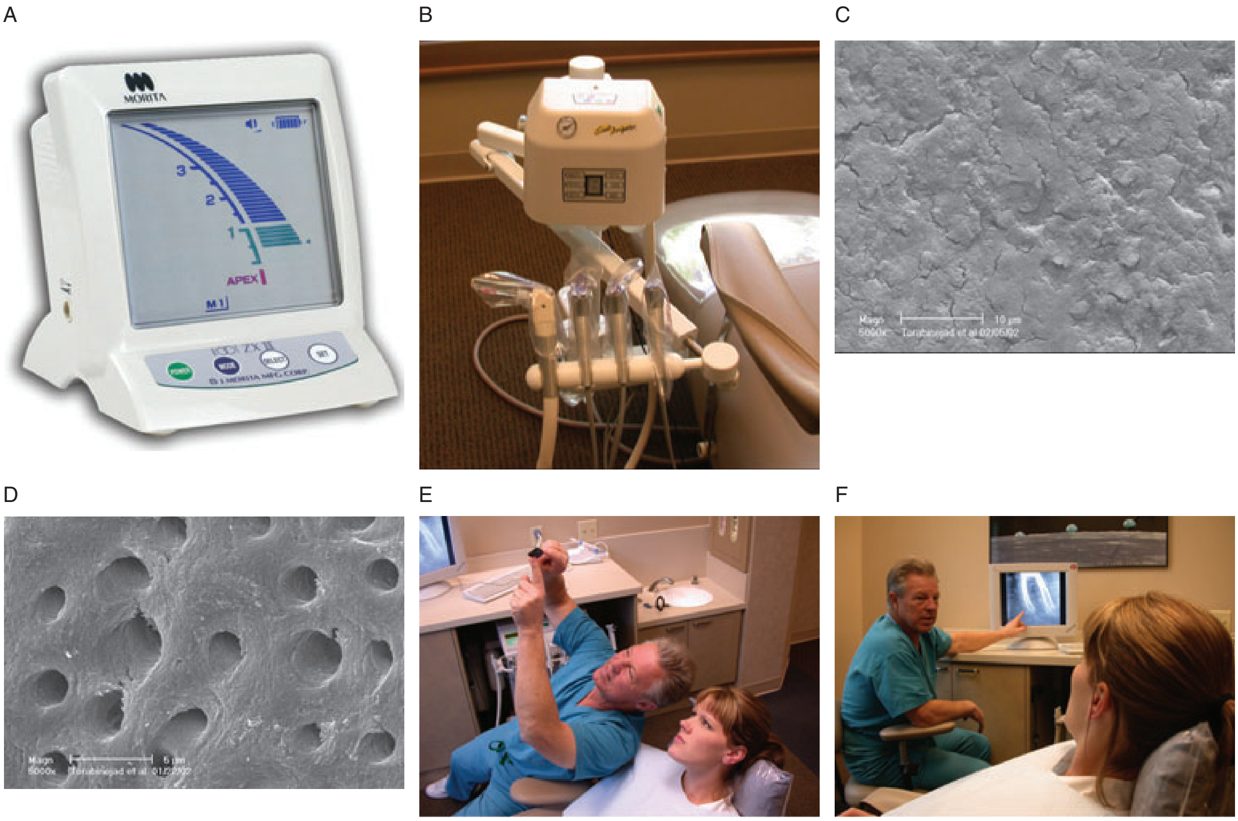

Figure 9. Adjuncts for "following" and cleaning root canal systems. A, *New Root ZX II.* B, *EndoIrrigator for precise and convenient delivery of up to six different irrigants.* C, *Radicular preparation before removal of smear layer. Note dentinal tubules are covered.* D, *Smear layer removed using combination of sodium hypochlorite followed by MTAD. (Scanning electron microscope [SEM] images compliments of Dr. Mahmoud Torabinejad, Loma Linda University).* E, *Before digital radiographs, doctor and patient had to squint at a film less than an inch in size and attempt to educate about a tooth's condition.* F, *Digital images are easily seen by doctor, staff, and patient. In addition, they can be viewed instantly and are significantly safer for the patient due to the reduction in radiation.*

In addition, apex locators can identify perforations resulting from instrument errors or resorptions, root fractures, and lateral portals of exit. Finally, the use of apex locators is contraindicated in patients who have cardiac pacemakers.[27]

Irrigation

Irrigation is a key part of both *following* and *finishing*. New and innovative devices such as the EndoIrrigator (Vista Dental Products, Racine, WI, USA) facilitate irrigation efficiency (Figure 9B). Of all endodontic irrigants, sodium hypochlorite is perhaps the most widely used endodontic irrigating solution. It effectively digests detached and necrotic pulpal tissue and possesses excellent antimicrobial efficacy. Baumgartner and Cuenin, in an in vitro study, found that sodium hypochlorite completely removed pulpal remnants and predentin, even in uninstrumented surfaces of single canal premolars.[28] Ethylenediaminetetraacetic acid (EDTA) removes the smear layer, which may block the cleaning and obturation of potentially significant lateral canals.[29–30] Both sodium hypochlorite and EDTA should be alternated for maximum effect. Hydrogen peroxide is useful in combination with sodium hypochlorite when cleaning and shaping mandibular teeth. The resulting effervescence elevates "dentin mud" coronally and therefore reduces the chance of blocking the canal apically.

More recently, a mixture of tetracycline acid, and a detergent (MTAD) (Dentsply Tulsa Dental) has been introduced as a 5-minute rinse prior to obturation.[31] The MTAD is designed to remove possible remaining smear layer and bacteria (Figure 9C,D).

Regardless of the personal irrigation preference, several guidelines will increase their effectiveness:

1. increase volume
2. increase temperature
3. agitate
4. use combinations
5. change solution frequently
6. increase contact time
7. place irrigating needle closer to canal terminus

Digital Radiography

Like the microscope, the digital image allows the dentist, patient, and assistant to see instantly and clearly.[32–35] The image on a standard radiograph will typically become more difficult to read with age (Figure 9E). Making the image the size of a computer screen is a great advantage beyond the educational value to the patient, assistant, and dentist (Figure 9F). If the patient cannot see or understand the problem, they will often not accept the solution. Another advantage is that instead of waiting for a conventional radiograph for 2 minutes or more, the treatment image appears seconds after taking the digital radiograph. Instant modifications can be made if film placement correction is needed and the dentist keeps flowing with the treatment instead of having to keep stopping and starting. Digital radiography has made dental radiography better, safer, and more efficient.

FINISHING CANALS

Cleaning and Shaping

Fundamental Mechanics

Many new endodontic technologies are described in this article to make endodontic success easier and to have a more predictable outcome. All these advancements are founded, however, on timeless endodontic biologic and mechanical principles (Figure 10A–C). Just as there are certain mechanical requirements that are prerequisite for the resistance and retention form of a restorative full crown preparation, certain mechanical requirements are also prerequisite for optimal endodontic radicular preparations. In 1974, Schilder suggested that "cleaning and shaping mechanics may be viewed as an extension of the principles of coronal cavity preparations to the full length of the root canal system."[36] Schilder was the first dentist to describe the desired mechanical design objectives for cleaning and shaping:

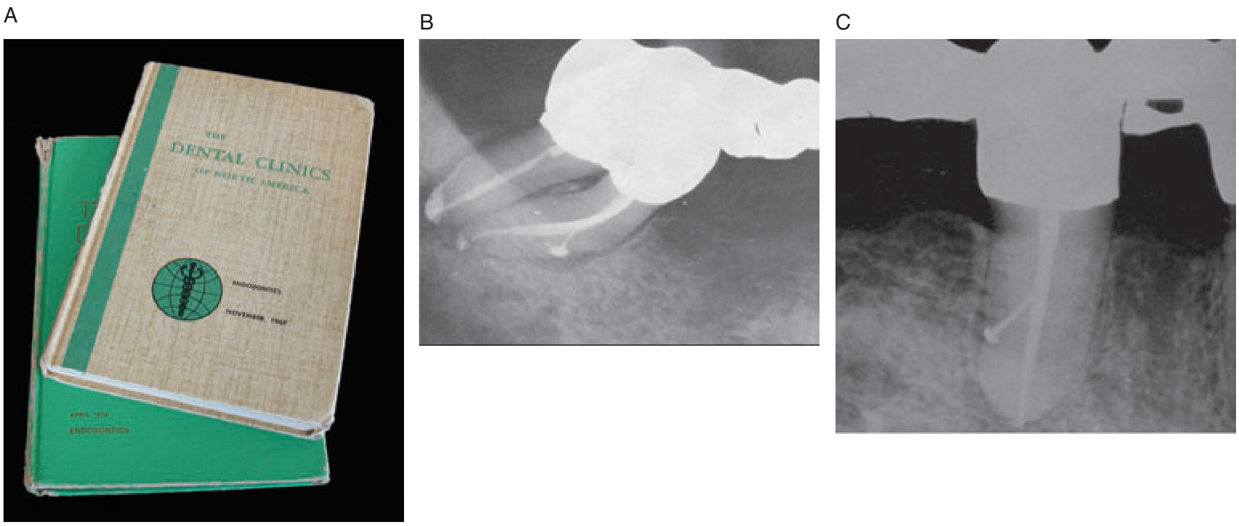

Figure 10. Classic and timeless principles. A, *The two most frequently cited references in endodontics are Schilder's November, 1967* Filling Root Canals in Three Dimensions *and his April, 1974* Cleaning and Shaping the Root Canal *(Dental Clinics of North America).* B and C, *Outstanding examples of endodontic obturation from over 30 years ago! The molar and premolar are abutment teeth for the same fixed prosthesis and appeared on page 223 in Dr. John Ingle's first book titled* Endodontics *in 1965. The treatment was accomplished decades before the microscope and rotary endodontics (courtesy of Dr. Herbert Schilder).*

1. The root canal preparation should develop a continuously tapering funnel from the root apex to the coronal access cavity (Figure 11A,B).
2. In compliance with the above principle, the cross-sectional diameter of the preparation should be narrower at every point apically, and wider at each point as the access cavity is approached (Figure 11C).
3. Unlike funnels of simple geometric design, this root canal preparation should occupy not only three planes, but as many planes as are presented by the root and root canal under treatment; that is, the root canal preparation should have *flow* with the shape of the original canal (Figure 11D–G).
4. The apical foramen should remain in its original spatial relationship both to the bone and to the root surface. The movement or transportation of the apical opening is a common error in root canal preparation, which leads all too frequently to chronic root canal discomfort or outright failure in treatment (Figure 11H–K).
5. The apical opening should be kept as small as is practical in all cases (Figure 11L–O).

When all five mechanical objectives are met, the result truly has "the look" of excellent finishing (Figure 11P).

Glide Path

As previously described, the glide path in endodontics is represented by a smooth pathway from the orifice to the foramen. This path may be narrow and it may be curved. It may be curved gently or abruptly, particularly in the apical 2 to 3 mm. The key word is smooth. Then, and only then, can nickel titanium files predictably *follow*.

A glide path must be created manually with hand files. The problem, however, with hand files is their rapid and inappropriate increase in tip size at D1 (1 mm from the tip of the instrument). For example, a size #15 has a 50% larger D1 than a #10 file! It is no surprise that when a #10 file *follows* easily to the RT, a #15 does not easily reach length as well. In fact, there is substantial risk that a blockage or a ledge will be present after its use. After much

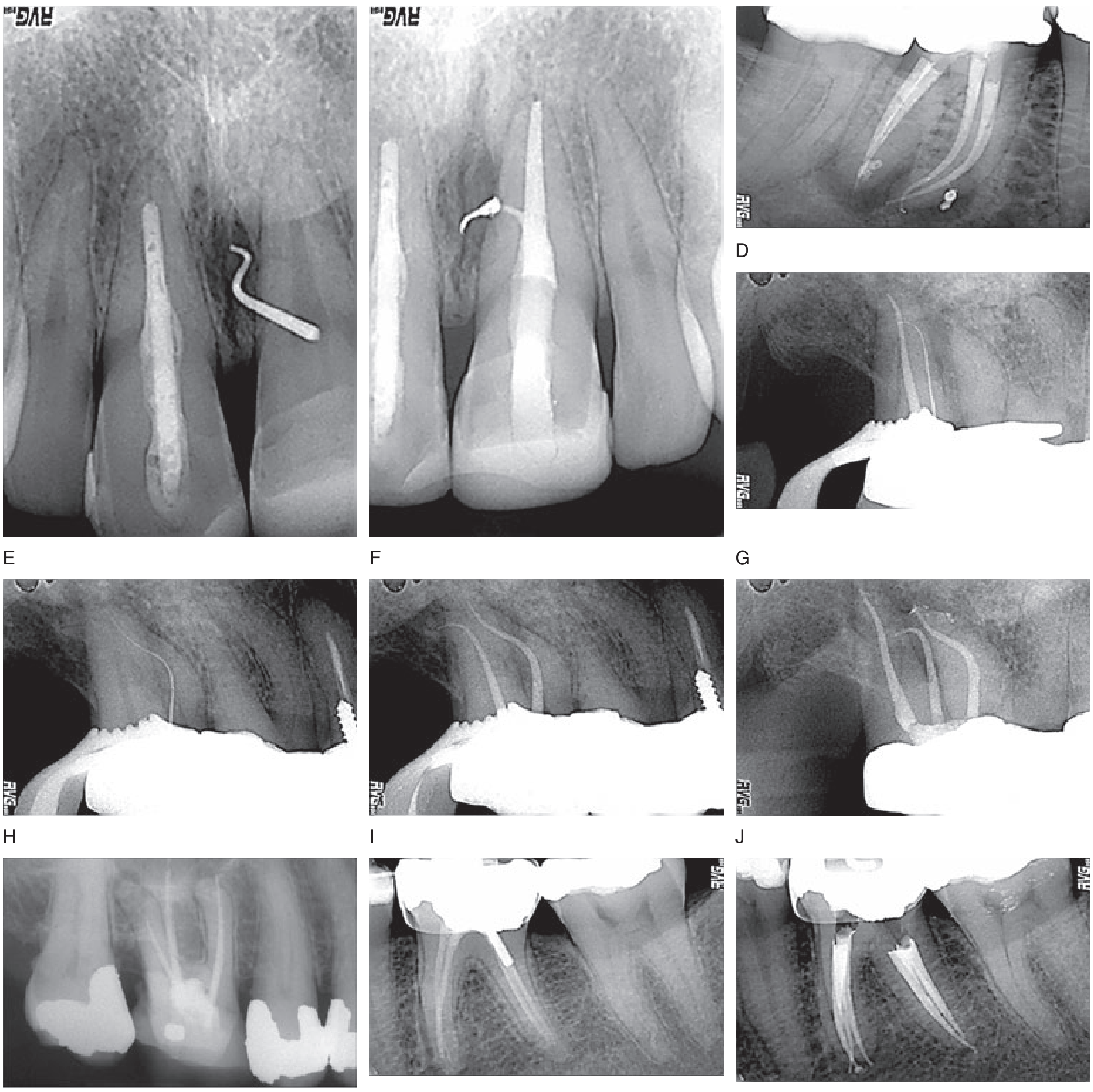

Figure 11. Five mechanical objectives. A, *Pretreatment radiograph of a gutta-percha cone tracing the sinus tract to the mesial of tooth #9.* B, *Objective number 1: continuously tapering cone shape allows successful obturation of one canal and a total of two portals of exit (foramina.)* C, *Mechanical objective number 2: mandibular molar demonstrates objective that states each cross-sectional diameter should become narrower as the preparation moves apically (courtesy of Dr. Jason West). Mechanical objective number 2 facilitates the achievement of objective number 1 and together the two objectives create the hydraulics needed for predictable obturation.* D, *Mechanical objective number 3: the root canal preparation should demonstrate the same flow as the original canal.* D through G *illustrate that the instruments flow with the ouginal buccal canals to the radiographic termini followed by the cone-fit and the eventual obturation that successfully replicates the original natural flow of the root canal system.* H, *Mechanical objective number 4 states "do not transport the foramen either internally (block) or externally (tear)." This maxillary right first molar demonstrates both errors. The distobuccal is blocked and the mesiobuccal is torn apically.* I, *Apical anatomy of mandibular molar is blocked and the tooth is symptomatic.* J and K, *Oblique radiographs show retreatment result. Six canals were discovered and the tooth promptly became asymptomatic (courtesy of Dr. Jason West).*

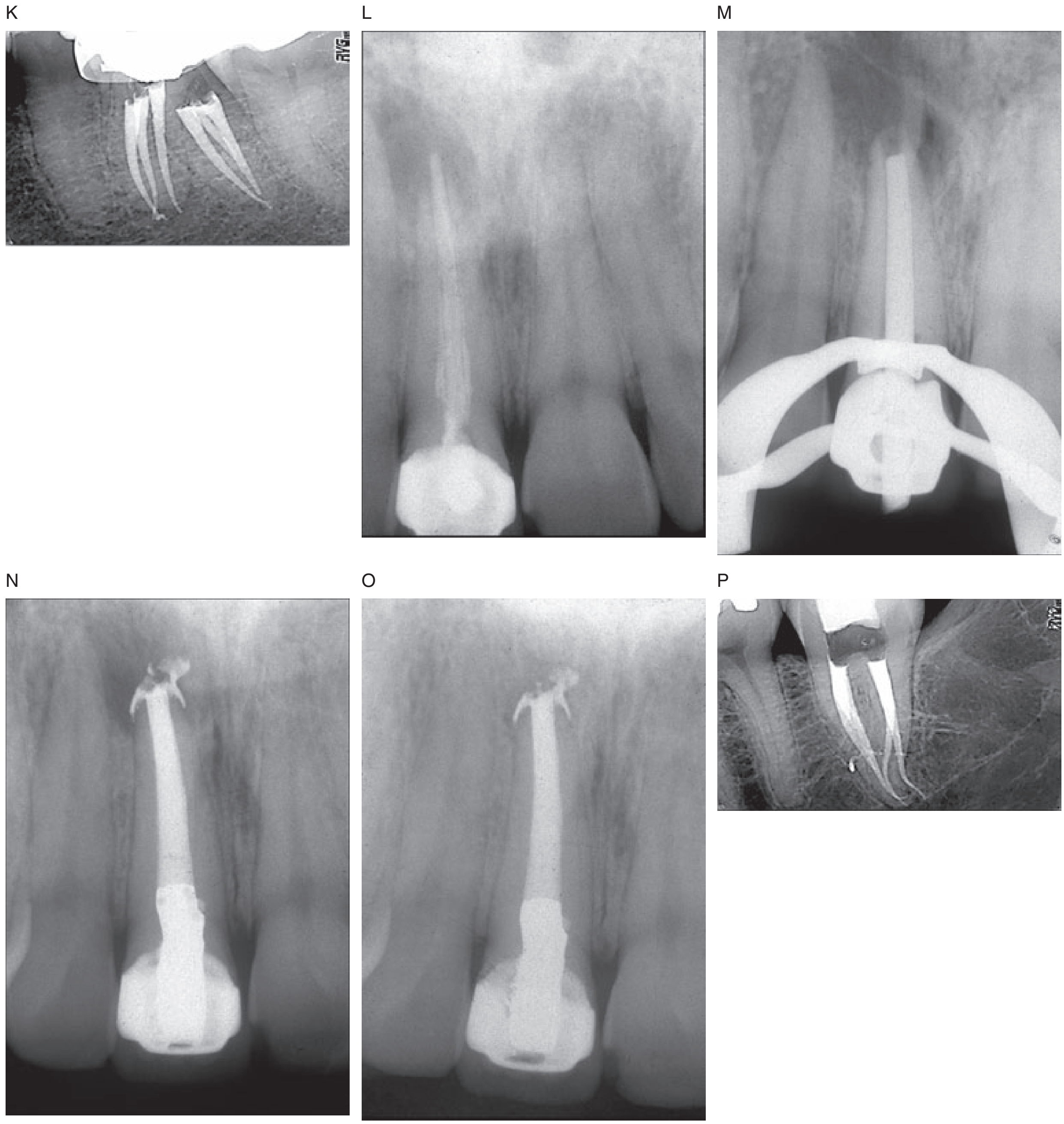

Figure 11. cont'd L, *Mechanical objective number 5 states to keep the foramen as small as is practical. Pretreatment film shows presence of a periradicular radioluceny.* M, *If there is enough tooth structure to make a continuously tapering shape, an appropriate cone-fit is possible.* N, *Posttreatment.* O, *9-month healing.* P, *Radiographic evidence of achieving all five mechanical objectives (courtesy of Dr. Jason West).*

effort, the block or ledge may be removed, only to have the problem amplified further with a #20 file, which is incontinently 33.3% wider at D1 than a #15 file. It is as if the system was sabotaged from the beginning. In order to solve this problem, Dentsply Tulsa Dental, with the late Dr. Herbert Schilder's guidance, introduced the Series 29. The first three files (#1, #2, and #3) are particularly helpful for developing a smooth glide path in a calcified canal. Each tip size has a D1 that is 29% larger than the previous instrument in the series. Clinically, this translates that if a #1 file *follows* easily to the terminus then a #2 and then a #3 file will easily *follow* to the terminus. At this point, rotary files can confidently and safely be introduced.

Recently, a new glide file has been introduced, known as the Sinseus ProFinder glide path file (Maieffer, Ballaigues, Switzerland) (Figure 12A). The ProFinder increases in D1 diameter in a logical progression similar to the 29 series, with the added advantage of reverse progressive geometries similar to ProTaper finishers. The resulting glide path preparations reflect the classical and time-tested Schilder cleaning and shaping principles of progressive shaping (serial reaming and filing), recapitulation (the sequential re-entry of all previous files), and cleaning and shaping to the RT (patency). The ProFinder handles are made of silicone, which increases tactile sensitivity.

Connecting the Dots

With the aid of an endodontic microscope, coaxial light, and knowledge of the root canal system anatomy, most clinicians can find most canal orifi. With small precurved instruments, irrigation, and the added ingredient of restraint, most canals can be successfully *followed* to their terminus. In actuality, dentists can "rough out" the basic radicular shape. However, the chances of making consistently smooth and continuously tapering canal walls from access to the root canal system terminus were slim. It was not until viewing the final radiographs that the clinician even truly knew the outline form. It was then that the outline form was literally "discovered." In a multirooted tooth, the chances of making all the walls smooth was even less. Essentially, only one dimension out of a potential 360 degrees of dimension can be measured in a two-dimensional radiograph.

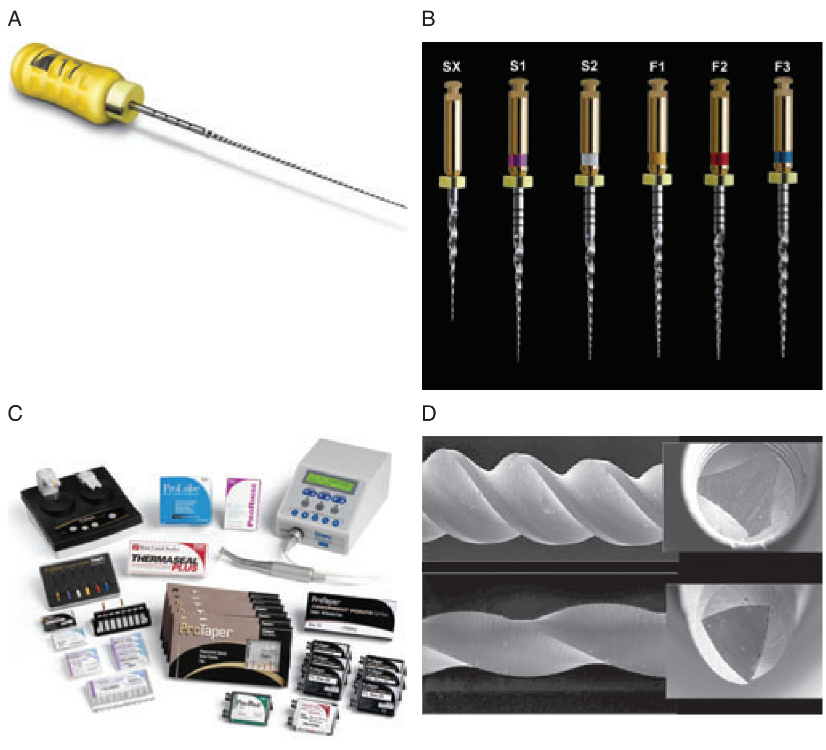

Figure 12. New technologies for cleaning and shaping. A, Senseus glide file with silicone handle. B, Six-pack ProTaper rotary files consisting of three shaping files and three finishing files. C, System-based ProTaper kit including electric motor, rotary and manual files, and matching gutta-percha cones and obturators. D, SEM demonstrating critical distinction of efficient cutting blades (below) and laborious planing blades (above).

Endodontics needed a way to "connect the dots" of the "roughed out" canal so that the walls would be smooth and enable good obturation hydraulics throughout the preparation length and width. Because clinicians cannot crawl into the root canals, something was needed to do it for them. If necessity is the mother of invention, it is no surprise that NiTi solved what seemed to be an insurmountable need in shaping mechanics. This remarkably strong and flexible exotic metal has produced positive results that are impossible with stainless steel.

It is estimated that there are at least 18 different rotary file brands in the endodontic marketplace. They vary in tapers, number and types of blades, tip design, and number of files in a series. It is paramount to follow the direction for use of each series because they are markedly different. Most breakage of rotary files, regardless of the manufacturer, is because the dentist failed to follow the directions for that particular file. It has been said that every dentist is capable of breaking every rotary file. The greatest variable, therefore, is not the file; it is, as always, the clinician. To increase safety, most endodontic teachers and educators emphasize sufficient supervised training by endodontists that have mastered any particular system. These skills should be developed using extracted teeth, not live patients! The following are strict guidelines to maximize NiTi rotary file safety:

1. Always have a "glide path" before rotary instruments are used.
2. Never force a rotary file at any time.
3. Start each patient treatment with new files.
4. Bathe the root canal system in EDTA during rotary radicular cavity preparation.
5. Frequently inspect file flutes under magnification.
6. Clean flutes each time the file is removed from the canal.
7. Use an electric torque control motor at 220 to 300 rpm and at 90% torque.

One rotary concept, the ProTaper Endodontic System, like the GT (greater taper) System (both from Dentsply Tulsa Dental), is a comprehensive solution built around the exceptional efficiency of the ProTaper nickel titanium rotary and manual files (Figure 12B–D). Each element of the system works together to intuitively generate a seamless flow from cleaning and shaping to three-dimensional obturation. Like the GT system, each ProTaper obturator and ProTaper gutta-percha cone matches the shape created by its corresponding Pro Taper finishing file. Each ProTaper absorbent point matches the corresponding finisher.

NiTi rotary files coupled with the endodontic microscope are the two biggest and best things to happen to endodontics in the last 100 years. Neither is magic by itself. Skills must be developed and thoroughly rehearsed before use. The reward is consistency and a renewed feeling of confidence and competence.

Electronic Endodontic Motors

The introduction of endodontic electric torque control motors has increased rotary safety and predictability. The DTC electric motor (Dentsply Tulsa Dental), for example, has a lightweight handpiece and is durable.

Obturation

In a survey conducted for the 2002 American Association of Endodontists national annual meeting, the scientific advisory board for the *Journal of Endodontics*, the directors of the graduate schools in the United States and Canada, and "valued and respected" endodontic clinicians all agreed that the quality of obturation was the hallmark determinant of endodontic clinical excellence.[37] Currently, the most effective and well-documented, time-tested obturation systems are the vertical compaction of warm gutta-percha techniques (multiwave or classic Schilder vertical condensation, single-wave or continuous-wave, and carrier-based obturation). These methods have the capacity to successfully distort symmetrical gutta-percha into asymmetrical foraminal constrictions while at the same time reducing the gutta-percha/dentin interface so that it is as narrow as possible (Figure 13A,B). New technologies in thermoplastic obturation have made these procedures safer, easier, and better (Figure 13A). Vertical compaction techniques use heat sources for both their downpack and backpack oburation (Figure 13B,C). Gutta-percha techniques exhibit an extremely high success rate when large patient populations are carefully evaluated. For example, initial nonsurgical endodontics are reported to have a 97% success rate over a period of 8 years.[38] Gutta-percha also requires a coronal seal to be successful.[39–44] The simple solution to overcome any coronal to radicular leakage concern is to place a coronal seal at the time of obturation. This seal can easily be achieved by first stopping the backpacked gutta-percha 1 mm below the chamber floor of the canal orifice. The gutta-percha and chamber floor then can be restored with glass ionomers, flowable composites, IRM, zinc phosphate, amalgam, ZOE, etc.

Recently, dentin bonding technology has become a possibility for endodontic obturation.[45] As with many new materials or techniques, early literature citations and scientific presentations are reporting conflicting results. The inventors claim to use a biocompatible resin as a sealer and an obturator of resin fiber creating an intimate bond of Resilon (Pentron Clinical Technologies, Wallingford, CT, USA), sealant, and dentin. Resilon is a high-performance industrial polyurethane. The new obturation product consists of a resin cone material (Resilon), which is

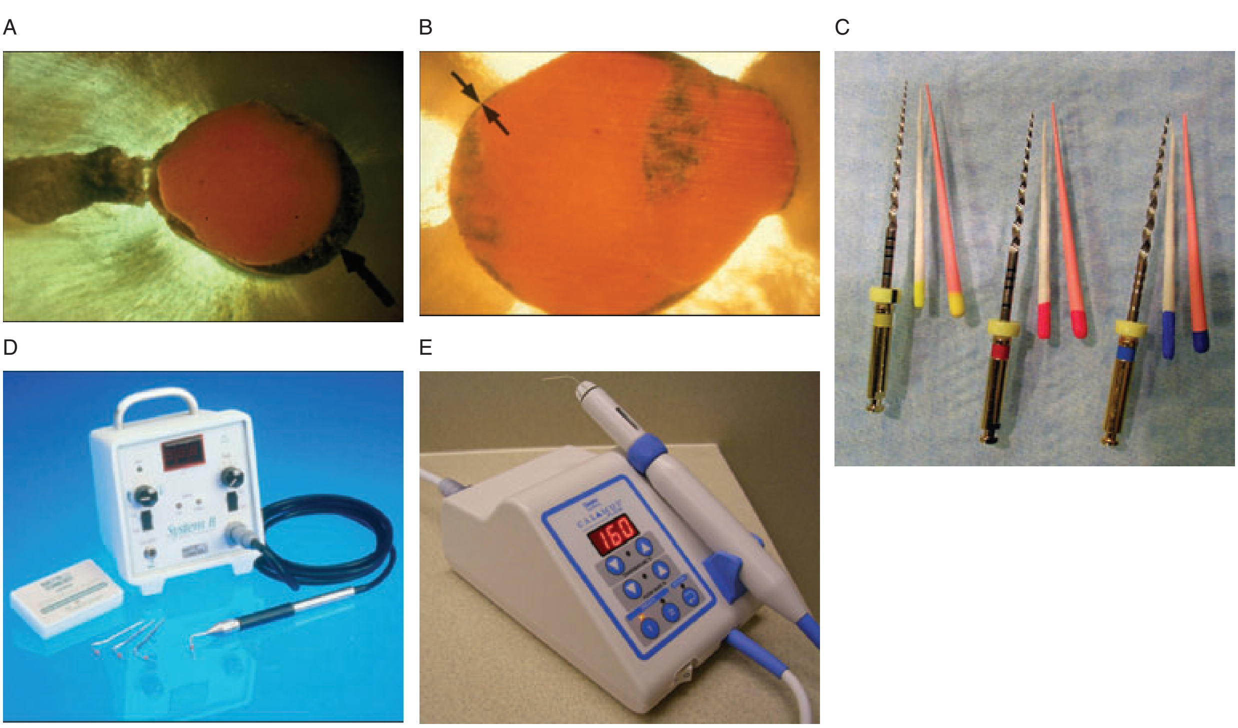

Figure 13. New technologies for obturation. A, *Arrows point to gap between gutta percha and dentin in horizontal root section of an endodontic obturation.* B, *In a different horizontal section, arrows indicate extremely tight gutta percha-dentin interface, which minimizes reliance on endodontic sealer.* C, *Matching finishing files, paper points, and gutta cones.* D, *System B heat source (SybronEndo) for the continuous wave obturation technique.* E, *Calamus flow unit (Dentsply Tulsa Dental) for thermoplastic obturation techniques and for backpacking during the vertical compaction of the warm gutta-percha technique.*

composed of polyester, difunctional methacylate resin, bioactive glass, and radiopaque fillers and a resin sealer. Resilon is reported to be nontoxic, nonmutagenic, and biocompatible. Resilon is similar to gutta-percha, which is 35% rubber and 65% fillers. Resilon is 35% polyester resin and 65% fillers. One of the pioneers of a possible gutta-percha substitute idea is Dr. Martin Trope, who rightfully is also concerned about the same bacterial penetration that a good restorative coronal seal is designed to solve. Dr. Trope writes,

Although sealers can form close adhesion to the root canal wall, none is able to bond to the gutta-percha core material. Upon setting, the sealer pulls away from the gutta-percha core, leaving a gap through which bacteria may pass. This article describes a new thermoplastic, synthetic root canal filling material, whose design is based on polyester chemistry, that looks and handles like gutta-percha. It is used in the same manner as most bonding systems. After the usual preparation of the root canal, a self-etch primer is used to condition the canal walls and prepare them for bonding to the resin. The resin sealant is introduced in the root canal. It bonds to the primer and to the resin core material; thus, a "monoblock" is formed without the gaps typical in gutta-percha fillings.[46]

This author is currently recalling over 100 cases of record where Resilon was the obturation material. Therefore, due to multirooted teeth, approximately 300 canals will be evaluated over 2 years after obturation. No further cases have been obturated with Resilon until the study is complete. As with any new material, they must be tested and the results measured in clinical practice. This retrospective study will be submitted for publication after completion. While the system resembles gutta-percha and can be placed using single cone, lateral condensation, thermoplastic injection, or warm vertical compaction, using Resilon in the "vertical compaction of warm Resilon" multi- and single-wave approach did require modification of technique. Resilon heat wave is shorter in length and duration.

SUMMARY

Instruments, materials, and technology are in constant change. Many come and go with time. Principles are more timeless. In this regard, endodontics is no different from other dental disciplines. The ethical and responsible dentist must learn if these changes help attain and execute the fundamental successful principles better, easier, and/or safer. This article has discussed the key points of a changing field that need to be understood when treating patients who have endodontic disease.

DISCLOSURE AND ACKNOWLEDGMENTS

As a co-inventor, the author has a financial interest in the ProTaper Endodontic System (Dentsply Tulsa Dental).

This article is dedicated to the late Dr. Herbert Schilder—mentor and friend. Most of the state-of-the-art technologies reviewed in this 2006 Endodontic Update were inspired by Schilder's discovery of timeless biologic principles and his vision for masterful endodontics.

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