Endodontic Topics 2005, 11, 131–151

ENDODONTIC TOPICS 2005
1601-1538

Root-end management: resection, cavity preparation, and material placement

JOHN J. STROPKO, GLEN E. DOYON & JAMES L. GUTMANN

Current protocols for root-end management in apical microsurgery are described. The dramatic increase in light and magnification as the advent of the surgical operating microscope (SOM) for use in endodontic apical surgery has caused a renewed examination of the rationale, indications, techniques, instrumentation, and materials for root-end procedures. Additional research and increased use of the SOM in endodontic surgery have elucidated many shortcomings of previous techniques. Root-end resection, root-end bevel, root-end preparation, and root-end filling are discussed. The steps necessary to achieve a predictable result in performing surgical root-end procedures using the enhanced vision of the SOM are presented.

Root-end resection – rationale

Review of the literature over the last decade supports the following common indications for resection of the apical portion of the root during periradicular surgery (1) (Fig. 1):

- *Removal of pathologic processes* – Some examples include symptomatic fractured root apices, suspected contaminated apices (retained microorganisms and biofilms), root apices with tenaciously attached pathologic tissue, and removal of foreign material in the apical portion of the canal.
- *Removal of anatomic variations* – The anatomic variations most commonly encountered are apical deltas, accessory canals, apical canal bifurcations, severe curves, lateral canals, and calcifications.
- *Removal of operator errors in non-surgical treatment* – These include complications such as ledges, blockages, zips, perforations, and separated instruments.
- *Enhanced removal of the soft tissue lesion* – Root resection is often necessary to gain access to deeply placed soft tissue around the root in order to secure an adequate biopsy.
- *Access to the canal system* – In cases where the major canal systems are blocked with, for example, a post-core restoration, and the apical portion of the canal has not been properly cleaned, shaped, or obturated, root-end resection (RER) may be necessary to manage the untreated portion of the root canal system (Fig. 2).
- *Evaluation of the apical seal* – This can occur in conjunction with the previous indication, when the canal obturation is questionable, yet access to the entire root system with non-surgical retreatment is impractical or impossible.
- *Creation of an apical seal* – This is one of the most common indications for RER. In cases where the root canal treatment has already been performed non-surgically, RER may be necessary to create an environment for access and vision so that an adequate apical seal can be achieved.
- *Reduction of fenestrated root apices* – This situation is most common in maxillary teeth, but can occur anywhere in the dentition. Possible contributing factors include age, anatomical anomalies, orthodontics, and trauma.
- *Evaluation for aberrant canals and root fractures* – In some cases, the root canal obturation is judged to be satisfactory and the etiology of failure is not clinically or radiographically evident. RER will potentially expose these aberrant canal communications, complete, or incomplete vertical fractures, which can be detected on a stained root-end bevel (REB). (See following section on staining.)

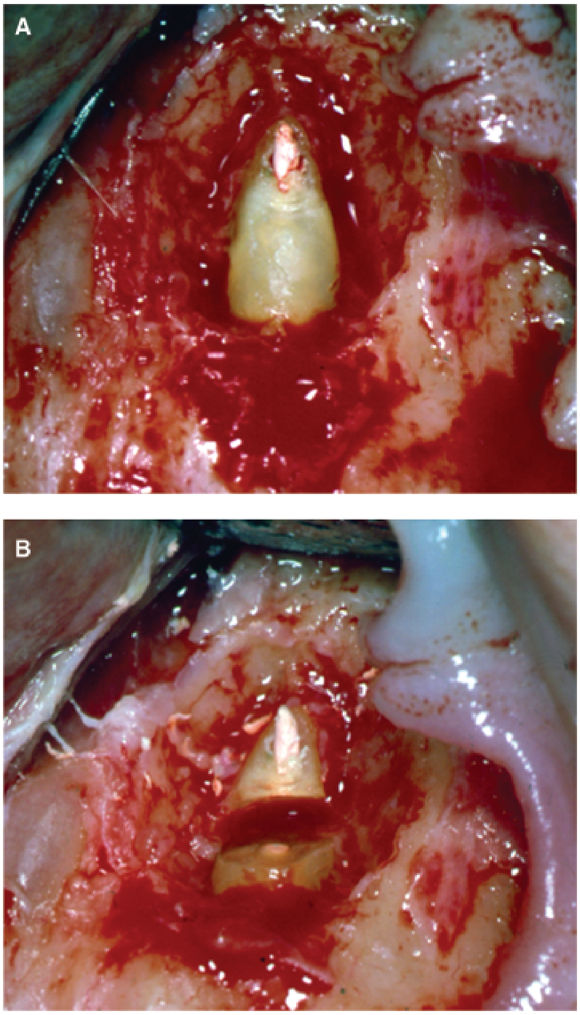

Fig. 1. (A) Surgically exposed root apex with obvious laceration of the root canal at the root end and overextension of the filling material. (B) Root-end resection removing approximately 3 mm of the root apex.

The validity of these indications, and the rationale for their use, resides in each individual case being treated.

RER – the bevel

Long bevel vs. short bevel

When the apical end of a root is removed, the remaining surface of the root is described as having been 'bevelled.' The amount and degree of the resected bevel are of utmost importance. The overall crown/root ratio, presence of posts or other obstacles, root anatomy, remaining crestal bone, and the periodontal status of the tooth must be considered. If the bevel is made in the traditional manner at a 20–45° bucco-

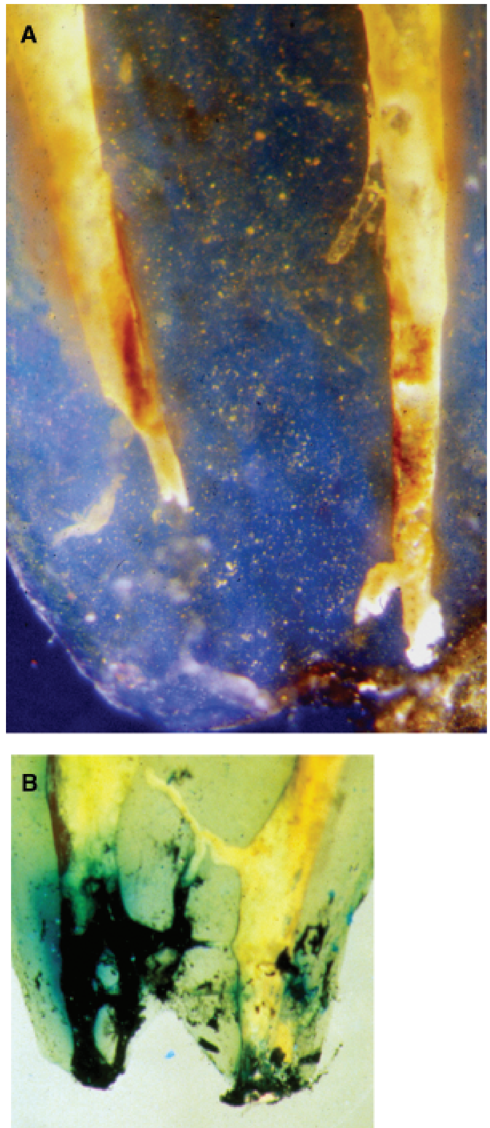

Fig. 2. Double root canal systems in single roots. (A) Root with obturated canals; root had been placed in India ink dye for 5 days and cleared chemically. Note the complexity of the canal systems and the leakage pattern. Root-end resection (RER) would be necessary to remove these irregularities. (B) Cleared extracted root with two canals. Note that both canals are not clean (brownish material), and that one canal is cleaned and shaped significantly short of the desired length. Canal irregularities are present. RER of the apical 3 mm would be necessary to remove these uncleaned areas and enable proper cleaning and sealing.

lingual incline, more of the palatal or lingual aspect of the root will be left untreated (2–5). This situation occurs when the surgeon is trying to be conservative in order to maintain a more favorable crown/root ratio. Because 98% of apical canal anomalies and 93% of lateral canals system ramifications occur in the apical

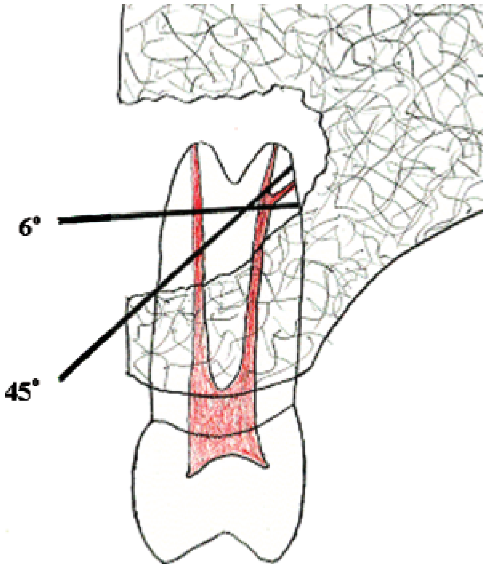

Fig. 3. The 'long' bevel (45°) removes more root structure and increases the probability of overlooking important lingual anatomy. The 'shorter' bevel (6°) conserves root structure, maintains a better crown/root ratio, and increases the ability to visualize important lingual anatomy.

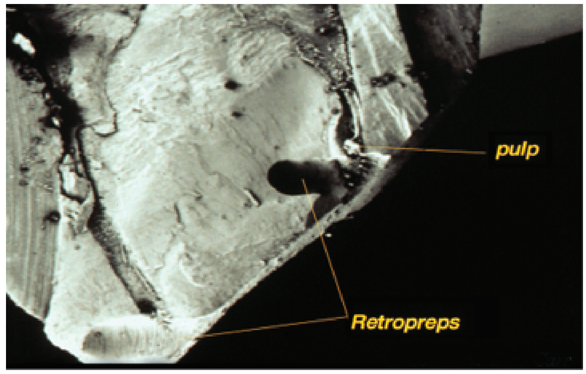

Fig. 4. The 'long' bevel minimizes tooth structure to the lingual and makes it more difficult for the operator to visualize the long axis of the tooth. Courtesy Dr Gary B. Carr, San Diego, CA, USA.

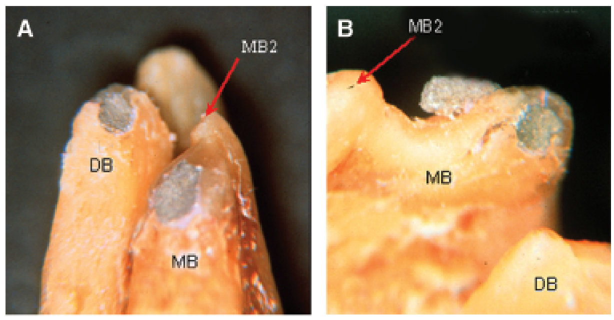

Fig. 5. (A) The 'long,' but conservative bevel of the mesiobuccal (MB) root did not address the more the second mesiobuccal root canal (MB2) of this maxillary first molar. (B) Not only was the MB2 canal completely 'missed', but there was an inadvertent perforation of the MB root – and incomplete bevel of distobuccal (DB) root end.

3 mm, it is essential that at least 3 mm of the root end is removed (6–8). Long bevels require the removal of an excessive amount of root structure to include the lingual, or palatal 3 mm of the root apex. If the bevel is closer to 0°, more root structure can be conserved, improving the crown/root ratio while meeting the objective of removing the vast majority of apical ramifications (Fig. 3).

The long bevel creates a spatial disorientation that is often difficult to overcome regarding the true long axis of the canal system (Fig. 4). As it is difficult to visualize the long axis of the tooth, the subsequent root-end preparation (REP) will usually not be within the long axis of the canal. Failure to comprehend this concept is the primary reason that perforations to the lingual, or palatal, occur (9) (Fig. 5). Another consideration for the 0° bevel is that the cavo-surface marginal dimensions of the preparation will be considerably decreased, therefore allowing an easier and more predictable seal. A good axiom to consider is this: whatever the angle of the bevel, it is almost always greater than it appears to be (7, 9).

Knowledge of root anatomy is especially important when there are more than two canals in one root. This anatomical complexity was identified and delineated over 100 years ago (10), and its implications in surgical endodontics were highlighted 70 years ago (11) (Fig. 6). This occurs most commonly in maxillary premolars and in the mesial roots of nearly all molars; however, multiple canals can occur in any root (12–14).

Ideally, the short bevel (0°) is as perpendicular to the long axis of the tooth as possible in order to predictably achieve several important criteria:

- *Conservation of root length* – When a long bevel (20–45°) is made, more tooth structure has to be removed in order to expose the anatomical apex of the tooth (5, 7, 9) (Fig. 7). With a long bevel, an inordinate amount of root structure would have to be removed in order to include the entire apical 3 mm.
- *Less chance of missing lingual anatomy* – The short bevel allows inclusion of lingual anatomy with less

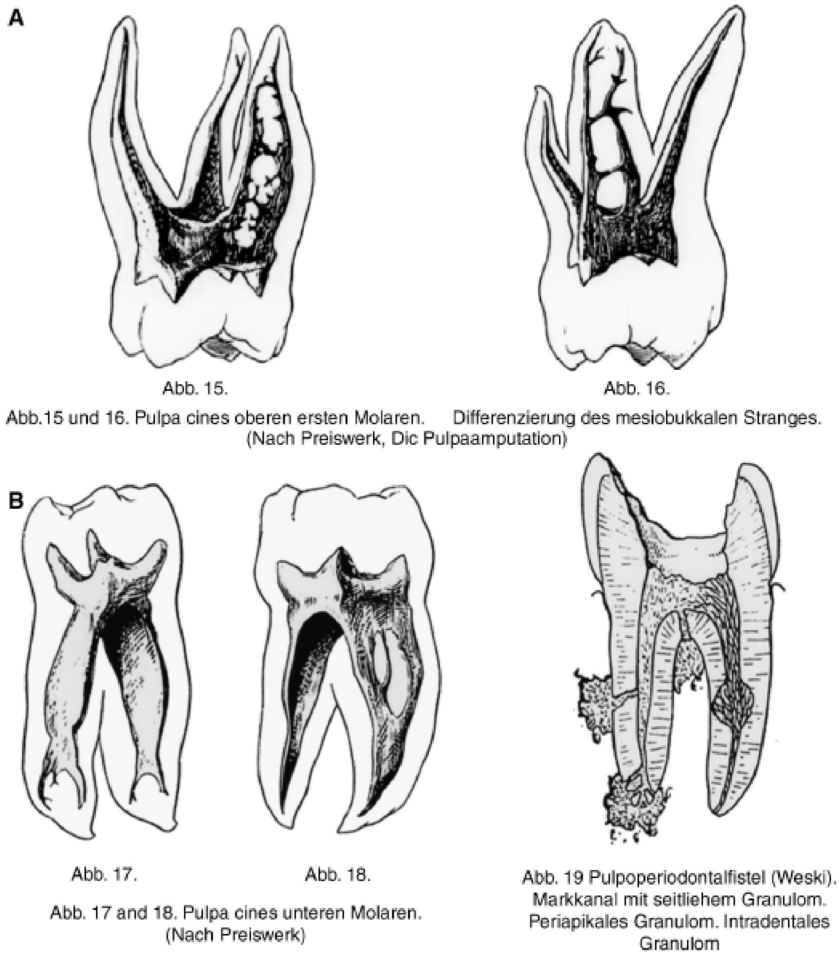

Fig. 6. (A, B) Diagrams taken from Peter (11). These are drawings from the 1901 publication (10) by Gustav Prieswerk that emphasized the complexity of the root canal systems located in roots with multiple canals.

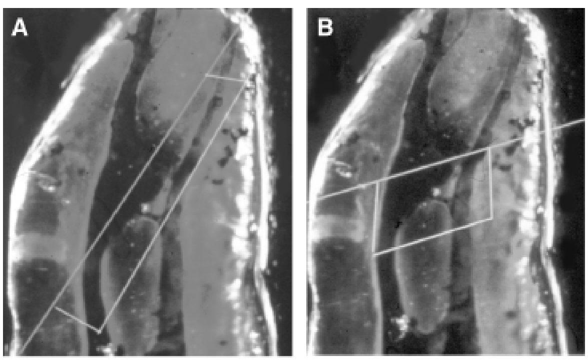

Fig. 7. (A) The *long bevel* has a greater cavo-surface margin length with a greater probability of leakage. (B) The *short bevel* has a shorter cavo-surface margin length to seal and, therefore, decreases the chances of leakage. Courtesy Dr Gary B. Carr, San Diego, CA, USA.

reduction. With the long bevel, there is a decreased probability of encroachment on the lingual root surface (Figs 2, 3 and 8, 9).

- *A shorter cavo-surface margin* – If multiple canals are present, the distance between them will increase as the angle of the bevel increases. As it is recommended that the isthmus also be prepared, a shorter bevel allows for a shorter cavo-surface margin length in the completed REP (7).
- *Less chance of an incomplete resection* – The shorter bevel makes it easier for the operator to resect the root end completely and not leave a 'lingual cusp,' or incomplete resection (7–9, 15).
- *Easier to detect multiple or aberrant canals* – When the short bevel is prepared, more lingual anatomy can be accessed (7–9, 15).
- *Less exposed dentinal tubules* – As the dentinal tubules are more perpendicularly oriented to the long axis of the tooth, the short bevel will expose fewer tubules (Fig. 10A). The long bevel opens more tubules to be exposed to the environment, which can allow more micro-leakage over a period of time.

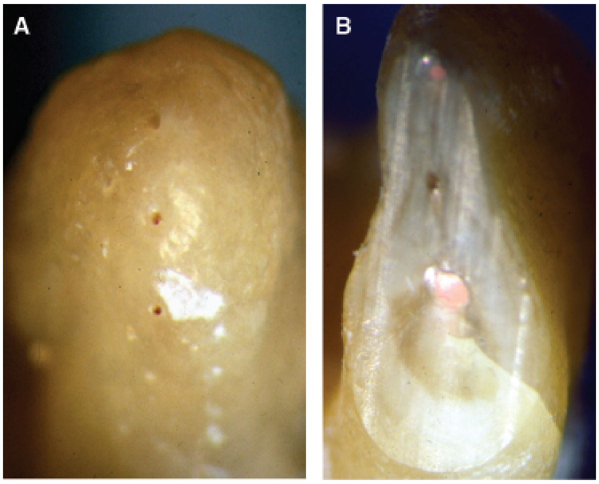

Fig. 8. (A) Multiple apical foramina evident on the palatal surface of the mesiobuccal (MB) root of a maxillary first molar. If this were resected with a long bevel, the canals and exits would be overlooked. (B) Long bevel resection of an MB root of a maxillary first molar shows the main canal with gutta-percha and sealer; an isthmus is above it and a second, uncleaned canal is visible; then an isthmus is above this second canal, and at the very tip of the resected surface an additional canal is present with gutta-percha. Management of this complex anatomy requires a much shorter bevel and a significantly more resected root face around the most palatally placed canal to permit thorough debridement and preparation.

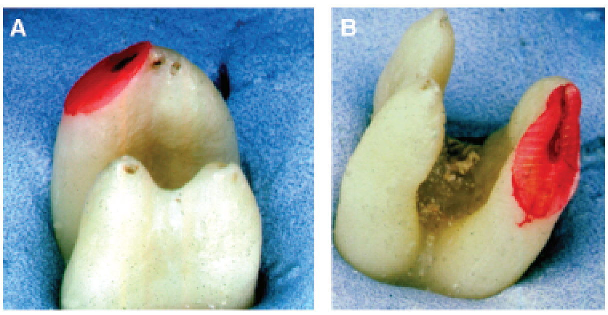

Fig. 9. (A) The long bevel does not address an adequate amount of the lingual portion of the root apex and important apical anatomy is overlooked by the surgeon. (B) The apical portion of the long bevel causes the lingual wall to be very thin and more susceptible to perforation.

- *Easier to maintain REP within the long axis* – Instrumentation of the REP should be kept within the long axis of the tooth to avoid unnecessary or excess removal of radicular dentin. The longer the bevel, the more difficult it is to envision and maintain the REP within the long axis of the tooth (7–9, 15) (Fig. 10B).
- *Easier to include the isthmus in the REP if multiple canals are present in a single root* – The cleaning and preparation of the isthmus that usually exists between the canals whether or not it is visible after the REB is very important. When there are multiple canals in a root, isthmus tissue is present 100% of the time at the 4 mm level (16). The short bevel facilitates the isthmus preparation by allowing a better 'mental picture' of the long axis of the tooth (3, 7–9, 15).

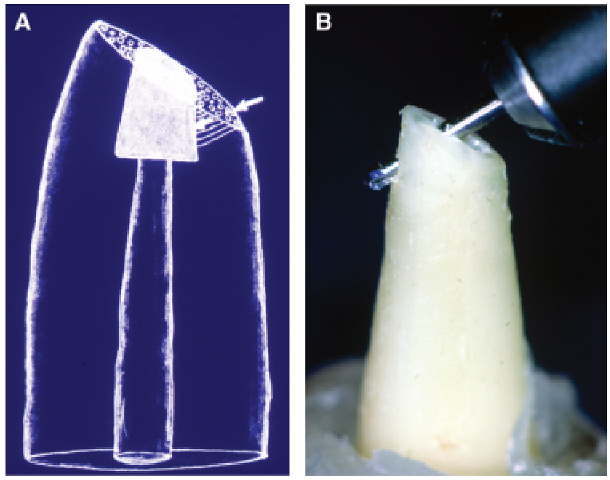

Fig. 10. (A) The long bevel exposes more dentinal tubules at an angle so they are left open to cause possible future contamination, or leakage, to the REF. (B) The long bevel disorients the surgeon, and the tendency for a lingual perforation of the root-end preparation is increased.

Ideally, the root-end bevel (REB) is kept as short, or as perpendicular to the long axis of the root as practical, to facilitate complete resection and to expose the entire apical canal system (3, 8, 9, 15). However, after positive identification of the features on the surface of the bevel has been made, it may be necessary to increase the angle of bevel slightly, to achieve better access for instruments, for improved vision, and/or to enhance ergonomics for the patient and clinician.

Instrumentation and technique

After the cortical bone is removed to unroof the lesion, the soft tissue is curetted from the crypt and the root-end exposed. Adequate hemostasis is established if necessary with appropriate hemostatic agents such as ferric subsulfate (Cut-trol, Ichthys Enterprises, Mobile, AL, USA), Telfa pads (Tyco Healthcare, Mansfield, MA, USA), CollaCote (Sulzer Dental, Carlsbad, CA, USA), calcium sulfate (LifeCore, Chaska, MN, USA), SurgiPlaster (ClassImplant, Rome, Italy), CollaCote

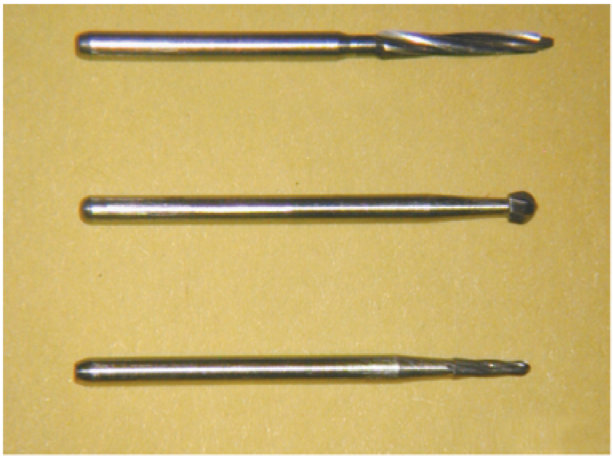

Fig. 11. Three essential surgical length burs will accomplish all that is necessary to achieve an efficient root-end resection and refinement of the root-end bevel. (top) Lindemann bone cutting bur, (middle) #6 or #8 Round bur, (bottom) #1170 or #1171 tapered-fissure surgical length bur.

(Integra™, Plainsboro, NJ, USA), and the root end is resected as quickly and efficiently as possible.

Although many instruments and burs are available to complete the RER and REB, there is no need to complicate a rather straightforward procedure. Essentially, there are only three surgical length burs necessary to accomplish the required tasks regarding the RER and REB. They are: (1) the #6 or #8 round bur (S. S. White, Lakewood, NJ, USA), for osseous access and gross removal of the apex; (2) the Lindemann bone bur (Brasseler USA, Savannah, GA, USA), for rapid hard tissue removal and cutting the initial root bevel; and (3) the #1170 or #1171 bur (S. S. White), for refinement of the bevelled surface (Fig. 11). Note that, removal of a minimum of 3 mm of the root apex is necessary, as most canal aberrations and/or abnormalities that may have contributed to the unfavorable response to non-surgical treatment are within this zone (6, 8, 15, 16).

A high-speed handpiece that has no air exiting from the working end, such as a Palisades Dental Impact Air 45 handpiece (Star Dental, Lancaster, PA, USA) (Fig. 12), should be used to eliminate the possibility of air emphysema or an air embolism beneath the flap in the soft tissues (9, 17). For these reasons, a standard high-speed handpiece should never be used.

As the anesthetized bone in the endodontic surgical site has a temporary decrease in blood supply, it is more sensitive to heat. Therefore, small changes in the technical aspects of osseous removal may significantly

Fig. 12. The Impact Air 45 hand piece, with fiber optics, enhances efficiency, safety, and vision.

affect bone physiology and viability (1). Bonfield & Li (18) reported that at temperatures from +50°C to 90°C, there was an irreversible bone deformation because of both a reorientation of the structure of collagen and a weakening of the bonds between the collagen and hydroxyapatite. These findings are consistent with protein denaturation subsequent to a burn injury. Eriksson and co-workers (19–23) noted that above 40°C, a hyperemia occurred as the blood flow increased. At a thermal stimulus of 50–53°C for 1 min, there was blood flow stasis with ultimate death of the vascular network within 2 days. Heating of bone to 60°C, or more, resulted in permanent cessation of blood flow and tissue necrosis.

Most studies using rotary instruments to generate heat are confounded by such variables as speed of drilling, pressure, air conduction, amount of coolant, accumulation of chips and debris, and friction (1). In any event, during the removal of osseous tissue, adequate coolant must be applied and the cutting must be performed with a light, brushing stroke. All burs used in apical surgery must have shapes that cut sharply and flutes that are far enough apart to shed debris and avoid ‘clogging.’ Clogging can result in decreased efficiency and unintentional over heating of tissue (24). The use of diamond burs to remove osseous tissue is not recommended because of their inefficiency and tendency to overheat the osseous tissues. The excessive heat causes necrosis, and can result in an extremely slow healing rate (24, 25) Using newer burs with sharp cutting edges will also improve efficiency and accuracy while decreasing the chances of over heating the osseous tissues.

During RER, REB, or the refinement of the bevel, some new bleeding may occur. Hemostasis must be re-established before continuing with further root-end procedures as it is imperative that the operator maintains complete control of the surgical environment. Note that it is of utmost importance to complete one step fully before proceeding to another!

Methylene blue staining

After complete hemostasis is achieved, the bevelled surface is ready for close inspection to be certain that the REB has been properly completed. The resected root end is rinsed and dried with an irrigator (Stropko Irrigator, Vista Dental, Racine, WI, USA). The dried surface is then stained with 1% methylene blue (MBS) (8, 15, 26), which is allowed to remain undisturbed on the resected surface for 10–15 s before once again gently flushing with a sterile solution and drying with an irrigator (Fig. 13A). As the MBS only discolors organic material, it readily defines the anatomy within, or around, the resected root end with a deep blue color. If there are any fractures, tissue remnants in the isthmus, or accessory canals present, the staining process will greatly enhance the operator's ability to see them. When used properly, the MBS will delineate the periodontal ligament and the operator can be sure the apex has been completely resected (7) (Figs 13B and C).

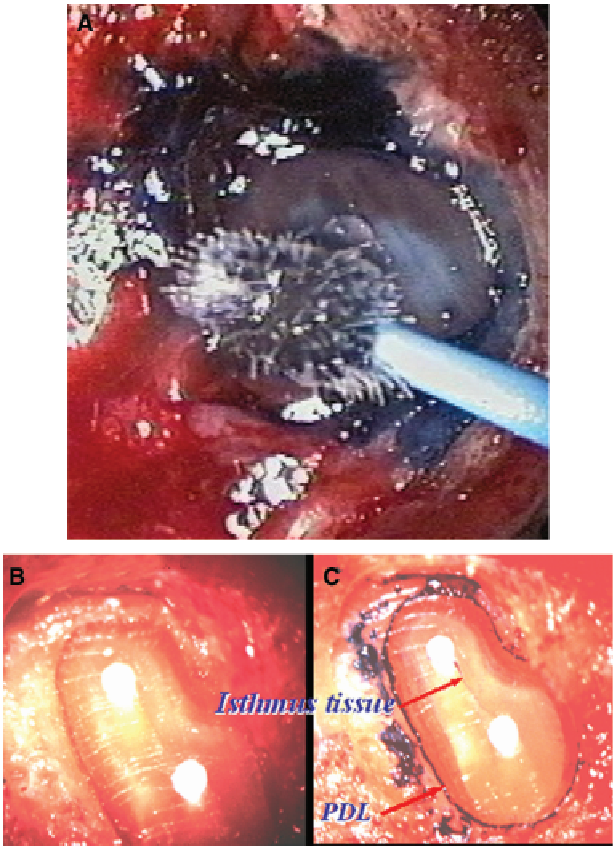

Fig. 13. (A) MBS is applied to the root-end bevel with a micro-applicator and allowed to remain on the surface for a short period of time. (B, C) Methylene Blue staining enhances vision and defines possible fractures, accessories, lateral canals, isthmus tissue, contaminated root surface, periodontal ligaments, etc. Courtesy Dr Gary B. Carr, San Diego, CA, USA.

To obtain the maximum benefits of MBS, and to inspect the bevelled surface thoroughly:

- the surface must be clean and dry before applying the MBS;
- the MBS must be applied for 10–15 s to saturate the surface and periodontal ligament;
- the surface must then be rinsed and dried thoroughly; and
- the REB should be examined using varying powers of the SOM to see whether the RER is complete and to insure that no abnormalities are present.

If after MBS there is an accessory canal present, the easiest way to manage this anatomical entity is to bevel past it and re-stain the surface to be sure that the defect is completely eliminated. Alternately, the accessory canal can be simply 'troughed out,' leaving the bevel as it is. If a white background such as Telfa pads, CollaCote, or calcium sulfate has been used to aid in hemostasis, or vision enhancement, it should be replaced after staining so that more light is reflected and vision renewed.

REP

Ultrasonic REP

Prior to ultrasonic instrumentation, various types of rotary handpieces and 'mini-burs' were used. Because of the necessity of using a 'straight-in approach,' it was not possible to maintain the REP within the confines of the long axis of the tooth and perforation of the lingual surface could easily occur (see Fig. 10B). With the advent of ultrasonic instrumentation, and the array of angled tips currently available to the operator, it is now possible to prepare a REP that will adequately and predictably accept several different root-end filling (REF) materials. The requirements for an REP include (3, 7–9, 15):

- the apical 3 mm of the canal system is thoroughly cleaned and shaped;
- the preparation is parallel to, and centered within, the anatomic outline of the pulpal space;
- there is adequate retention form for the ref material used,
- all isthmus tissue is removed; and

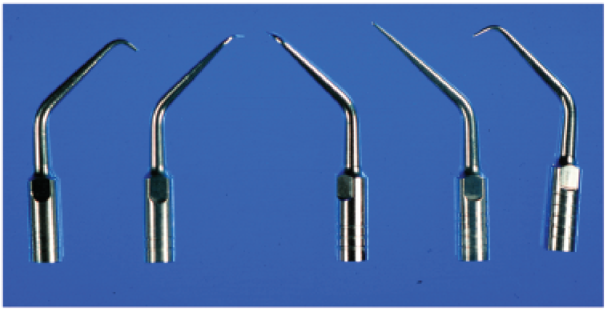

Fig. 14. The first ultrasonic tips available – CT tips (www.eie2.com).

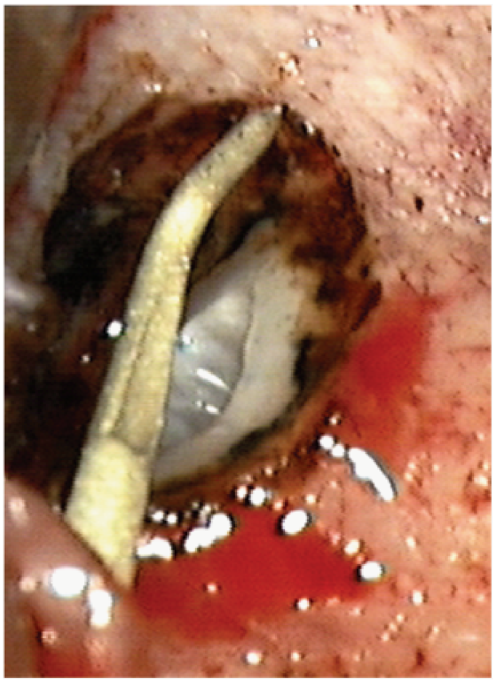

Fig. 15. The diamond-coated KiS ultrasonic tips are very effective and utilize newer vent technology. The water spray is directed into the root-end preparation , efficiently eliminating debris and helping to prevent overheating of the root end.

- the remaining dentinal walls are not weakened.

The use of any one of a number of ultrasonic units will allow the operator to complete the REP. The Satelec P-5 (Mount Laurel, NJ, USA), EMS MiniEndo (SybronEndo, Orange, CA, USA), NSK (Brasseler, Savannah, GA, USA), and Spartan (Obtura-Spartan, Fenton, MO, USA) units are currently the most common and all have a good reputation for performance, reliability, and versatility (27). Some older EMS units only accept tips made for its European thread, but the newer models accept all of the common tips manufactured in the United States.

There are a multitude of ultrasonic tips to choose from and they come in all shapes and sizes. The first tips made for endodontic apical microsurgery were the CT series tips (PERF online at www.eie2.com or SybronEndo). They are made of stainless steel, very popular, and are still in widespread use today (Fig. 14).

Some tips have special surface coatings to increase their cutting efficiency. Diamond-coated tips are very efficient and especially useful for removing gutta-percha from the REP. Because of their efficiency, the surgeon must avoid the tendency to overprepare the REP. In addition, care must be exercised when using diamond-coated tips because they can leave a heavily abraded surface. The debris generated by these tips can collect in these abrasions surface and if not removed can affect the apical seal of the REF (28). The KiS ultrasonic tips (Obtura-Spartan, Fenton, MO, USA) use port technology and deliver a constant stream of water aimed directly at the working end of the tip (8, 15) (Fig. 15). Ticonium-coated tips (ProUltra, DENTSPLY Tulsa Dental, Tulsa, OK, USA) are also very efficient. Like all tips, they provide excellent vision for the operator during the REP. These are just two of the hundreds of tip designs available today in the worldwide market.

The most important consideration in the use of ultrasonics is not the brand of the unit, or type of tip, but how the instrument is used. The tendency for the new operator is to use the ultrasonic in the same manner (pressure-wise) as the hand piece. The secret is an extremely light touch! In general, the lighter the touch, the more efficient the cutting efficiency will be. The correct amount of water is also important. If too much spray is used, visibility and cutting efficiency are both decreased. If too little water is used, the necessary amount of cooling and rinsing of the debris will not occur. This can cause overheating of the REP. Micro-cracks and decreased vision may be the undesired result (3, 7–9, 15). Numerous studies have shown that when ultrasonic instrumentation is used properly, micro-cracks are uncommon and should be of no concern to the clinician (29–31). In addition, use of ultrasonic instrumentation for REP, in place of the traditional, or miniature, hand piece results in cleaner preps and fewer perforations (30, 32). With the advent of ultrasonic techniques for the preparation of the root end, the use of a rotary hand piece is not advocated for root-end cavity preparation in apical surgery.

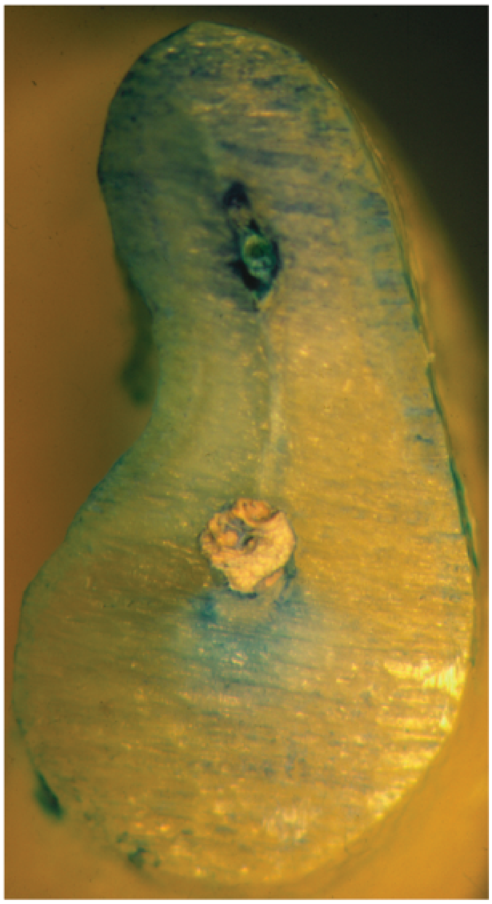

Fig. 16. After root-end resection and visualization of the resected surface, two canals with a uniting isthmus are usually visible and need to be addressed.

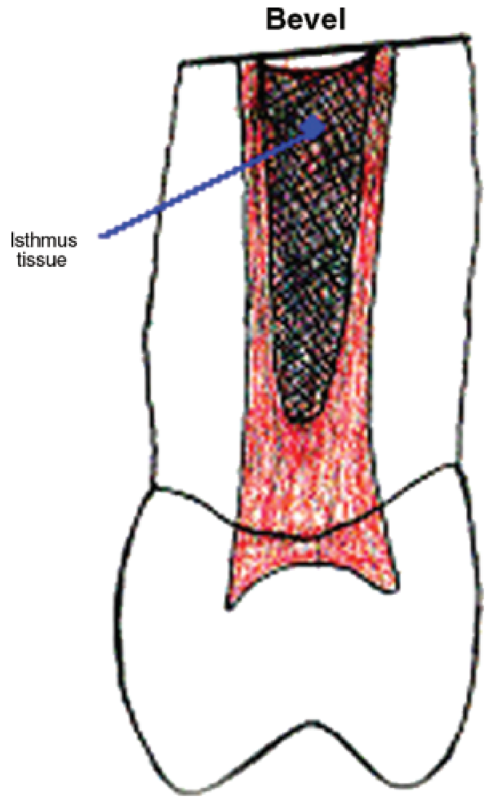

Fig. 17. When the isthmus is just coronal to the bevelled surface, the isthmus must be prepared or the contaminated pulp tissue just beneath the surface will not be eliminated. Postsurgical remodelling of the bevelled root surface could possibly result in the entire canal system becoming susceptible to bacterial invasion.

If the canal is large and/or filled with gutta-percha, a diamond-coated anterior KiS tip can be used most effectively. The various left- and right-angled tips are necessary on occasion, but in most cases, the anterior-type tips will suffice. The keys to successful preparation are to apply the cutting tips slowly, using a gentle, light, brushing motion.

The use of ultrasonic instrumentation is especially useful in the preparation of an isthmus between two canals present in one root. This is a commonly required procedure during apical microsurgery. For example, two canals can be present as much as 93% of the time in the mesiobuccal root of the maxillary first molars, and 59% in maxillary second molars (12, 15, 34). Following RER and visualization of the resected surface, two canals with a uniting isthmus are usually visible (Fig. 16). For this reason, it is important to routinely prepare the isthmus, whether it is defined by staining, or not, because if the isthmus is just coronal to the bevelled surface, post-surgical remodelling of the bevelled root surface may expose the entire canal system to the periradicular tissues. If the non-surgical root canal treatment fails to clean the canal system thoroughly or coronal leakage is present, failure may ensue (Fig. 17). A good rule to follow is to always prepare an isthmus when there are two canals in one root.

For the preparation of an isthmus, a CT-X explorer (SybronEndo), or a sharp restorative chisel (1) may be used to 'scratch' a 'tracking groove' between the canals. With the water spray turned off, a CT-1 tip (SybronEndo), or any sharp, pointed ultrasonic tip can be used, at low power, to deepen the tracking groove. Not using a water spray allows excellent vision for the creation of the 'tracking groove,' but the groove should only be deepened enough without the water spray to make it more definitive and easy to follow. The water spray should be resumed as soon as possible to allow for appropriate cooling and cleaning of the REP.

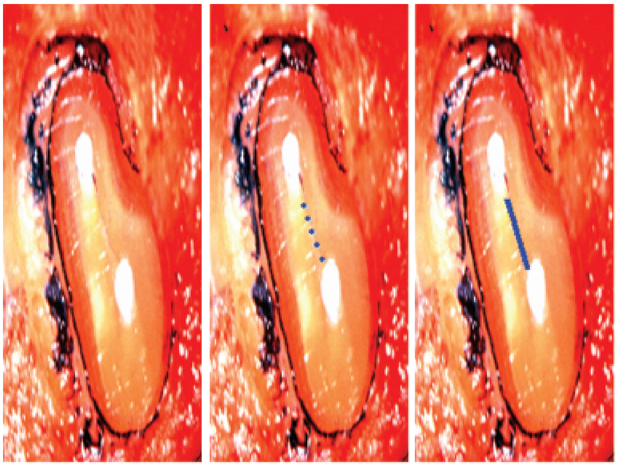

Fig. 18. Left to right: 'tapping' the rheostat until a series of 'dots' are created on the isthmus as a guide. It is then a simple matter of connecting the dots to create the initial 'tracking groove' to prevent inadvertent 'slipping-off' from the desired isthmus track.

If difficulty is experienced when trying to establish a tracking groove, the 'dot technique' may be used. With the CT-1 tip inactivated and no water spray, place the pointed tip exactly where desired and just lightly 'tap' the rheostat for an instant. The process is repeated again, and again, as many times as necessary, until there are a series of 'dots' created on the isthmus. It is then a simple matter of connecting the dots to create the initial 'tracking groove' as described in the preceding paragraph (Fig. 18). The accuracy of cutting is then maintained and the probability of 'slipping off' a small, or thin, bevelled surface is eliminated.

After the groove is deep enough to guide the tip, the water spray is turned back on and the preparation is deepened to 3 mm while using a similar small, pointed tip. Then, a larger and more efficient coated tip is used to finish the walls and flatten out the floor of the REP to the desired finish.

Of particular interest in the development of the apical preparation is the buccal aspect of the internal wall of the prep. Often, this area is not cleaned adequately because of the angulations of the ultrasonic tip within the canal system (Fig. 19). If there is some gutta-percha 'streaming up' the side of the wall, it is usually very time consuming, or futile, to remove this gutta-percha with an ultrasonic tip. The most effective way to finish the REP is to use a small plugger and fold the gutta-percha coronally, so the wall is clean once more.

A clean and dry apical root-end cavity preparation is essential for good visibility when using the SOM.

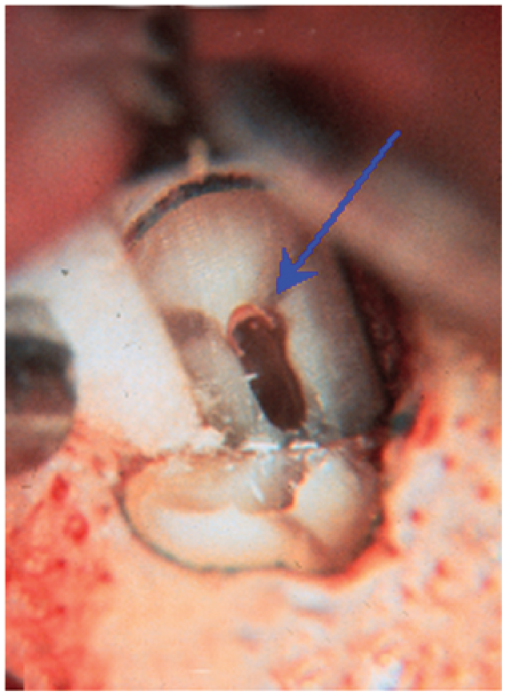

Fig. 19. Close attention must be given to the buccal wall of the root-end preparation. There is a tendency for debris (in this case, gutta-percha) to collect there while preparing the REP and can be easily overlooked. Courtesy Dr Gary B. Carr, San Diego, CA, USA.

Throughout the process, and after completion of the REP, the cavity should be rinsed and dried with a small irrigator/aspiration tip if possible. If a 25- or 27-gauge-irrigating needle has been 'pre-bent' to a similar shape as the ultrasonic tip used for the REP, the ergonomics of using the irrigator will be more efficient (Fig. 20). Subsequently, the cavity is inspected using various levels of magnification and sizes of micro-mirrors (Fig. 21) to confirm that the preparation is within the long axis of the canal system and all debris has been removed (Fig. 22). As an alternative, some surgeons choose to use small segments of paper points to dry the cavity; however, this may leave particles of paper in the preparation or may fail to provide a thorough drying in all dimensions.

The smear layer consists of organic and inorganic substances, including fragments of odontoblastic processes, microorganisms, and necrotic materials (35). The presence of a smear layer prevents penetration of intracanal medication into the irregularities of the root canal system and the dentinal tubules and also prevents complete adaptation of obturation materials to the prepared root canal surface (36). If the surgeon is satisfied that all other requirements for the REP have

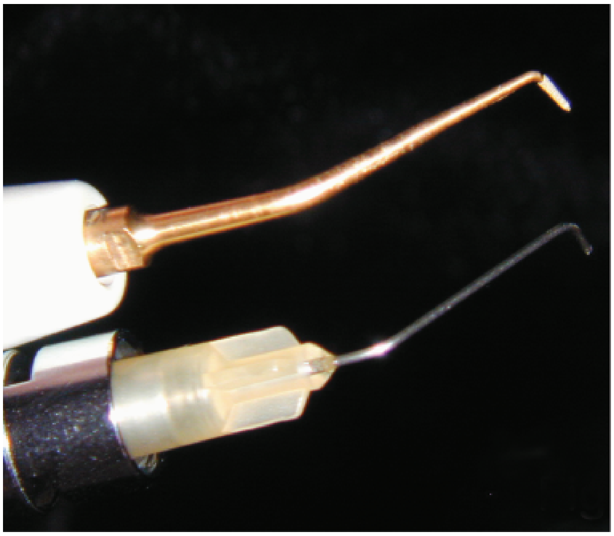

Fig. 20. 'Pre-bending' of a 25- or 27- gauge irrigating needle to a shape similar to the ultrasonic tip used for the root-end preparation; the ergonomics of using the irrigator will be more efficient.

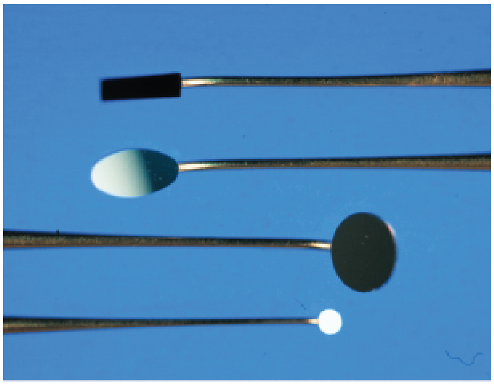

Fig. 21. Various sizes and shapes of micro-mirrors are used to monitor the progress of the entire root-end procedure.

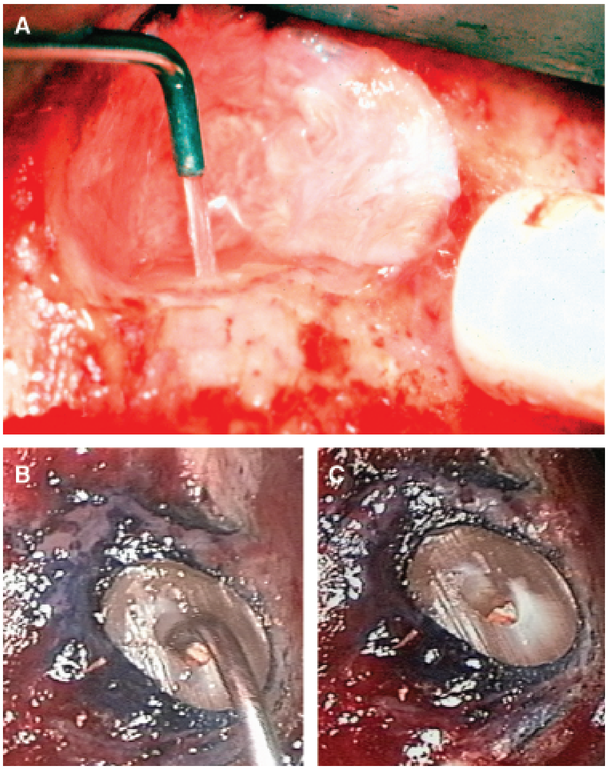

Fig. 22. The Stropko irrigator can direct a precise stream of water or air into the root-end preparation (REP), enhancing the inspection process. (A) Water is used to flush out debris; then, (B) air is used to dry the REP for better vision, and (C) the clean and dry REP is ready for inspection.

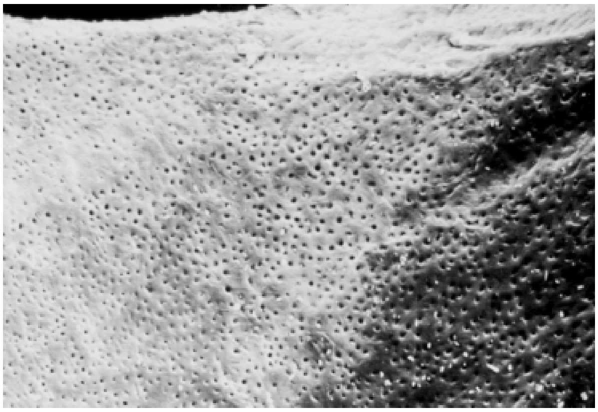

Fig. 23. SEM of an apical root cavity that has been subjected to acid etching using 10% citric acid combined with 3% Fe_2Cl_3) ($\times$ 420). Note the patent dentinal tubules and clean walls. Photo previously unpublished used to support data found in (38).

been met, the smear layer can be effectively removed by etching with either 10% citric acid gel (Ultradent, Salt Lake City, UT, USA), 17% EDTA (Pulpdent, Watertown, MA, USA), BioPure™ (DENTSPLY Tulsa Dental), or 35% phosphoric acid gel (Ultra-Etch, Ultradent) (36–38). After etching, the REP is again thoroughly rinsed, dried, and re-examined under varying powers of magnification (Fig. 23).

The underlying reason for endodontic failures is almost invariably because of persistent infection of the root canal space (39). In the majority of cases requiring non-surgical retreatment, *Enterococcus faecalis* is the main and persistent microbial species (40–44). If the vast majority of teeth requiring endodontic surgery do not responding favorably to previous non-surgical endodontic treatment, it is imperative that treatment be directed at eradicating bacterial infection including *E. faecalis* from within the REP. Two percent chlorhexidine (CHX) gluconate is an effective antimicrobial irrigating agent for this purpose, and is available as a liquid or gel (Ultradent) (45–50). Once the REP has been cleaned, dried, thoroughly inspected, and the smear layeres removed, it should be irrigated with 2% CHX liquid for 15 s or 2% CHX gel for 1 min (47), then once again, thoroughly rinsed and dried. The use of the CHX in a gel, rather than the liquid, may take slightly more time but, the surgeon has better control over its placement. The REP is now complete and ready to be filled (Fig. 22C).

REF

Filling materials

At this point in the microsurgical procedure, the tissues have been retracted, bleeding in the surgical crypt is well managed, and the REP is ready to fill. The ideal material for use as an REF should meet the following requirements (8, 9, 15):

1. Provide for easy manipulation and placement with adequate working time.
2. Maintain dimensional stability after being inserted.
3. Seal the REP completely.
4. Conform and adapt easily to the various shapes and contours of the REP.
5. Be biocompatible and promote cementogenesis.
6. Be non-porous and impervious to all periapical tissues and fluids.
7. Be insoluble in tissue fluids, not corrode or oxidize.
8. Be non-resorbable.
9. Be unaffected by moisture.
10. Be bacteriostatic, or not encourage bacterial growth.
11. Be radiopaque, or easily discernable on radiographs.
12. Not discolor tooth structure of the surrounding tissues.
13. Be sterile, or easily and quickly sterilizable immediately before insertion.
14. Be easily removed if necessary.
15. Be non-carcinogenic, and non-irritating to the periapical tissues.

There are several materials currently available for the REF, each having been used with varying degrees of success (51–58). They include, among many others, amalgam, IRM (DENTSPLY Caulk, Milford, DE, USA), Super-EBA (S-EBA, Bosworth, Skokie, IL, USA), Optibond (Kerr, Orange, CA, USA), Geristore (DenMat, Santa Maria, CA, USA), and, most recently, mineral trioxide aggregate (Pro Root™ MTA, DENTSPLY Tulsa Dental).

Amalgam

For many years, amalgam was the only commonly available REF material. Its radiopacity is the better than any other REF materials (Fig. 24). Retrospective studies demonstrate both long-term success and long-term failure. Research indicates that amalgam exhibits the greatest amount of leakage when compared with newer materials such as S-EBA and MTA (1, 44, 51, 59, 60), oftentimes ending in amalgam corrosion and significant tissue argyria (Fig. 25). Furthermore, there is no evidence to demonstrate its ability to support tissue regeneration (1). Moreover, in many parts of the world, there is a general controversy over the presence of mercury in amalgam, and therefore, there appears to be no valid reason to continue its use as REF material (61).

Zinc oxide-eugenol cements

Historically, zinc oxide-eugenol cements have been used extensively as REF materials. The two most widely accepted are IRM (DENTSPLY Caulk) and Super EBA

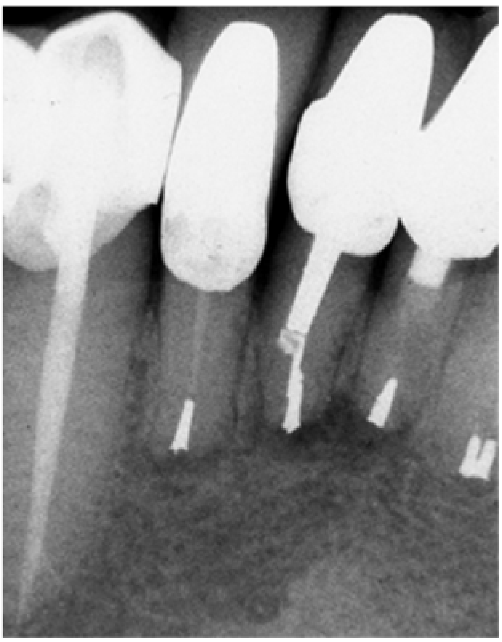

Fig. 24. Radiopacity of amalgam is better than any currently used root-end filling materials.

Fig. 25. Corrosion and breakdown of apically placed amalgams often lead to extensive tissue argyria.

(S-EBS, Bosworth, Skokie, IL, USA). Dorn & Gartner (57) reviewed REFs in 194 cases and evaluated the success rates of S-EBA, IRM, and non-zinc high copper amalgam. The success rates over a 10-year period were reported to be 95% for EBA, 91% for IRM, and 75% for amalgam. Tissue responses demonstrated repair as opposed to regeneration, a response no different from that observed with gutta-percha (58, 62). Both IRM and S-EBA exhibit similar and favorable properties and are clinically and histopathologically better than amalgam (9): some of these desirable properties include:

- ease of manipulation,
- adequate working time,
- dimensional stability,
- placement and ease of adaptation in the REPs,
- biocompatibility,
- imperviousness to tissue fluids,
- lack of corrosion or oxidation,
- unaffected by moisture,
- bacteriostatic,
- radiopaque,
- will not discolor tooth or surrounding tissues,
- easily removable,
- non-carcinogenic, and
- predictable over time.

When solubility was measured in a buffered phosphate solution, both IRM and S-EBA exhibited no significant signs of disintegration after a 6-month period (62). The addition of ortho-ethoxybenzoic acid to the formulation of S-EBA decreased the amount of the tissue-irritating eugenol in the liquid portion of the formula to 37.5% vs. 99% eugenol in the IRM liquid (63).

The ability to create a conservative, anatomically correct REP with ultrasonic armamentarium demanded an alternative to amalgam as an REF material and led to the popularity of S-EBA for this purpose. While leakage patterns with the use of S-EBA as a filling material following ultrasonic REPs were disturbing (64), Rubinstein & Kim (65) reported the short-term success of endodontic surgery using microsurgical techniques and S-EBA as an REF. All 94 cases included in the study were treated by a single clinician. Postoperative radiographs were taken every 3 months for a 12-month period until the lamina dura was completely restored, or the case had clinically failed. Successful healing, evaluated radiographically, was 96.8%. In a follow-up study (66), clinical examinations were made and radiographs were evaluated 5–7 years after the cases had first been considered healed. The same criteria for evaluating successful healing were applied. Of the 59 cases examined, 54 (91.5%) remained healed, whereas five (8.5%) showed evidence of apical deterioration.

The setting time of S-EBA can be unpredictable, sometimes setting too quickly, and at other times, taking too long. Ambient temperature and humidity have a profound effect on the setting time. An increase in temperature and/or humidity will shorten the setting time (67–69). If the setting time needs to be increased, the glass slab used to mix the S-EBA can be cooled (70). The powder/water ratio of SEBA has to be correct to ensure a thick, dough-like consistency, permitting the assistant to roll it into a thin tapered point. The 'dough-like' tapered end of the thin S-EBA 'roll' is segmented and passed to the doctor on the end of either a small Hollenback, or spoon, and subsequently inserted into the REP, and gently compacted coronally with the appropriate plugger. Two to five of these small segments are usually necessary to overfill the REP slightly.

After the REF is complete, an instrument and/or a multi-fluted finishing bur are used to smooth the surface, producing the final finish. It has been demonstrated that the use of a 30-fluted tungsten carbide finishing bur creates a better marginal adaptation to the set S-EBA REF (71). An etchant may be used, once again, to remove the 'smear layer' that was created during the final finishing process. The removal of the 'smear layer' and the demineralization of the resected

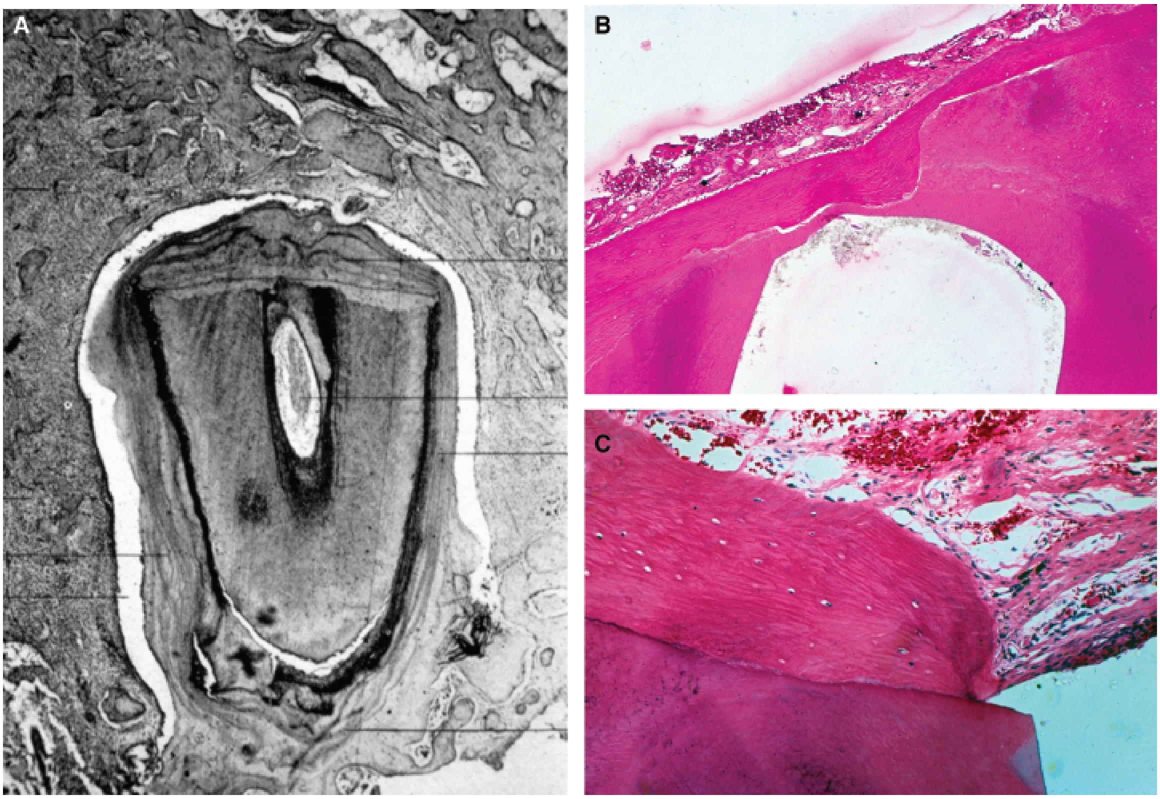

Fig. 26. Evidence for the formation of cementum on exposed human dentine without the use of an acid etchant. (A) Photomicrograph of a retained fractured root tip from Boulger EP. Histologic studies of a specimen of fractured roots. J Am Dent Assoc 1928: 15: 1787–1779. The coronal portion of the root segment shows significant cement formation. (B, C) Histological demonstration of significant cementum formation on a resected root surface; tooth had a coronal fracture and was extracted. No etchant was used subsequently to remove the smear layer from the resected root end. Note how the cementum ceased to form adjacent to the root-end filling in (C), which was a zinc oxide-eugenol-based product.

root end are thought to enhance cementogenesis, the key to dentoalveolar healing, by exposing the collagen fibrils of the dentin and cementum (72). However, these data have only been supported in an animal model, while the use of this approach has been shown to be unfavorable for cementum deposition when MTA was used as an REF material (73). For decades, the presence of cemental deposition has been observed to occur on exposed dentinal surfaces, which supports the fact that acid etching of the surface may not be essential to obtain full tissue regeneration. Further research to provide clinical directives in this matter is warranted (Fig. 26).

One of the earlier disadvantages of S-EBA was that it was not as radiopaque as amalgam (Fig. 27). When initially used in apical microsurgical procedures, dentists sometimes had difficulty determining that an REF had, indeed, been placed. This is no longer an issue because the profession is more familiar with the radiographic appearance of the various currently accepted REF materials. Most newly advocated REF materials have a radiographic appearance similar to S-EBA and gutta-percha (74).

Composites

The use of dentin-bonding techniques requires uncompromised control of the surgical crypt. Even a small amount of contamination can cause a failure of the bond to the dentin surface, resulting in micro-leakage (75). The ability to have total control of moisture in the apical surgical environment has led to the use of bondable composite resins as REF materials. Theoretically, any composite can be used as an REF material, whether it is auto, dual, or light cured. Two advantages of dual cure materials are the increase in working time and lowered requirement for direct light necessary to initiate and complete the set.

Optibond (Kerr) is an example of a flowable, dual cure hybrid composite that is easily placed into the REP.

Fig. 27. **Super EBA has a radiopacity similar to that of gutta-percha.**

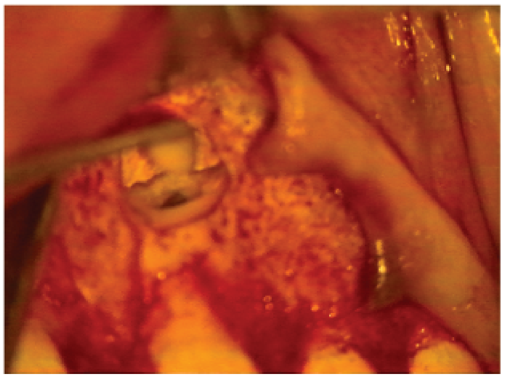

Fig. 28. Flowable composite is easily placed with a small CX-1 Explorer. An orange filter is available that easily and inexpensively replaces the 'blood filter' on the surgical operating microscope light source.

Etching, conditioning of the dentin, insertion of the selected material, and curing by chemical or light are accomplished in the usual manner when bonding into the REP. *Because the light source for the SOM is so intense, premature setting of the light cured material is possible*. For most microscopes, an orange filter is available that easily and inexpensively replaces the 'blood filter' and eliminates this concern (Fig. 28).

Studies have shown very favorable healing when bonded composites are utilized as an REF (74–79). However, there is controversy as to whether the resected surface of the root should also be coated, or 'domed' with the bonding material. A 'cap' or 'dome' of bonded composite can be placed with the intention of sealing the exposed tubules of the entire resected surface (76). The exposed tubules may, or may not be, a factor in the healing process, as their exposure has been controversial for decades (80).

Compomers (polyacrylic-modified composite resins)

Because of their ease of use and other favorable characteristics, resin-reinforced glass ionomers, such as Geristore (DenMat), and Dyract (DENTSPLY Caulk), are popular. They exhibit good flowability, dentinal self-adhesiveness, and demonstrate excellent biocompatibility (81). Dyract and Geristore have been shown to be equal or superior to IRM and equivalent to S-EBA in their ability to reduce apical leakage when used as an REF (54). Geristore is a dual-cure material, whereas Dyract is light cured. After the compomer is completely cured, the REF is finished with a high-speed finishing bur or an ultrafine diamond, and the resected root end is etched to remove the smear layer and to demineralize the surface for enhanced healing (72). When the entire root surface was covered, the failure rate was 50% for the compomer, vs. 10% for the bonded composite (76–79).

MTA

MTA has become very popular and is widely used as an REF material. There are numerous publications extolling the virtues of this material regarding its sealing capabilities and its favorable biocompatibility (59, 82, 83). MTA has been shown to have superior sealing qualities when compared with S-EBA and amalgam (60). The cellular response to MTA has also been shown to be better than IRM and it stimulates interleukin production, indicating biocompatibility with adjacent cells. One of the most important advantages of MTA is that histological responses show evidence of tissue regeneration (reformation of bone periodontal ligament and cementum as a functional unit) as opposed to tissue repair (fibrous connective tissue) (84–87) (Fig. 29).

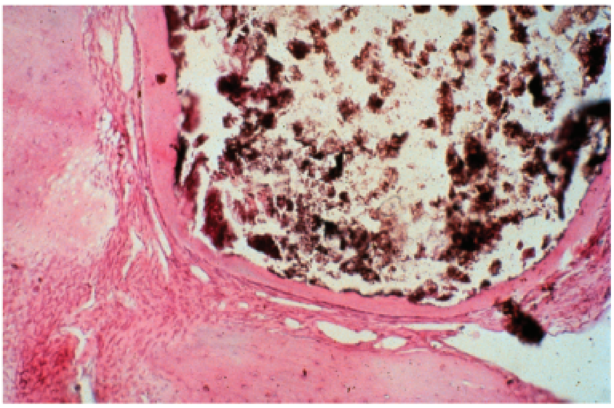

Fig. 29. Histological responses have evidenced tissue regeneration as opposed to tissue repair. A cementoid-like substance has been demonstrated to cover the mineral trioxide aggregate root-end material.

Many clinicians complain of the unforgiving handling characteristics of MTA. The correct powder/water ratio is three parts powder to one part sterile aqueous solution. After mixing for about 30 s, the material should exhibit a putty-like consistency (88). If the mixture is too wet, it acts like wet sand and 'slumps,' but when too dry, it has a 'crumbly' and unmanageable texture, similar to that of dried mud. In either case, when not mixed properly, MTA can be very difficult, if not impossible, to handle.

The central problem with MTA is that this material can be difficult to deliver to a small REP. Most clinicians use a syringe or carrier-type device to deliver MTA. These devices have several limitations (89):

1. The diameter of the syringe or carrier may be too large for small root preps.
2. The syringe and carrier devices may not reach difficult areas of the mouth.
3. The syringe and carrier devices deliver large amounts of MTA, resulting in excessive amounts of material being deposited into the field.
4. The syringe devices can clog and become useless if not properly cleaned immediately after every procedure.

Some of the available carriers used to place MTA into the REP include the Retrofill Amalgam Carrier (Miltex, York, PA, USA), the Messing Root Canal Gun (Miltex), Dovgan MTA Carriers (Quality Aspirators, Duncanville, TX, USA) (Fig. 30A), the MAP System (PD, Vevey, Switzerland) (Fig. 30B), and the Lee MTA Pellet Forming Block (G. Hartzell & Son, Concord, CA, USA) (Fig. 31).

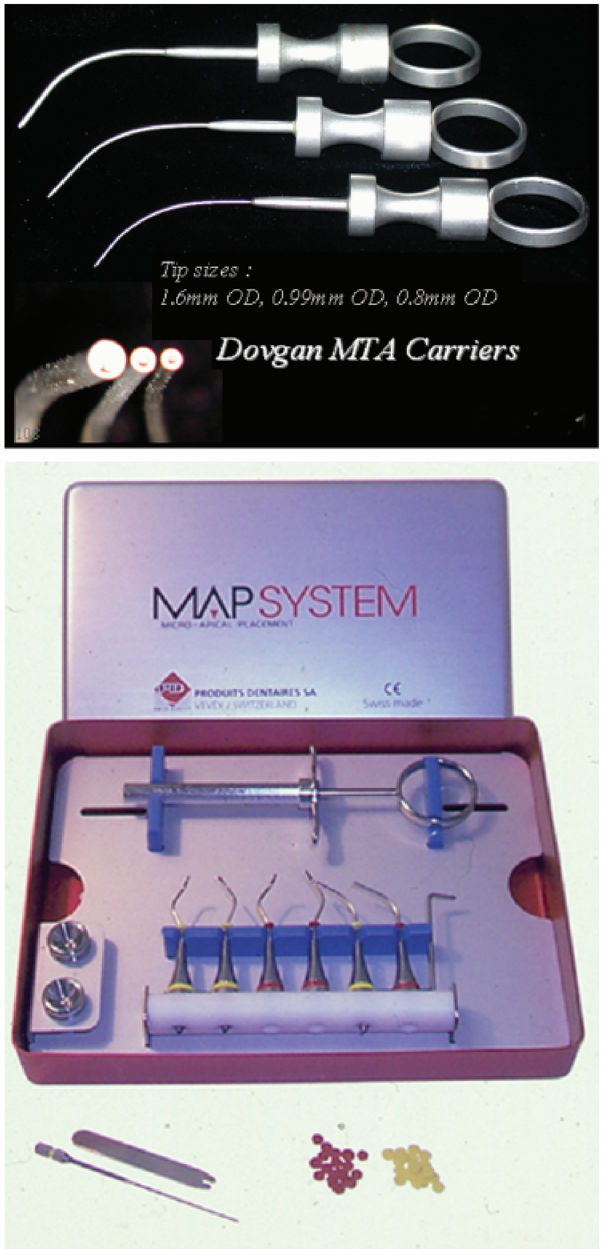

Fig. 30. (A) Dovgan carriers come in three sizes and can deliver mineral trioxide aggregate to the root-end preparation in most situations. (B) Map system is also a versatile system for placing root-end filling materials.

The Lee MTA Pellet Forming Block is a very simple and efficient device for preparing MTA to be carried to the REP (88, 89). Properly mixed MTA is simply wiped onto a specially grooved block and the Lee Instrument is used to slide the desired length of MTA out of one of the appropriately sized grooves (Fig. 31). The MTA adheres to the tip of the instrument, allowing for easy placement into the REP. With this method of delivery,

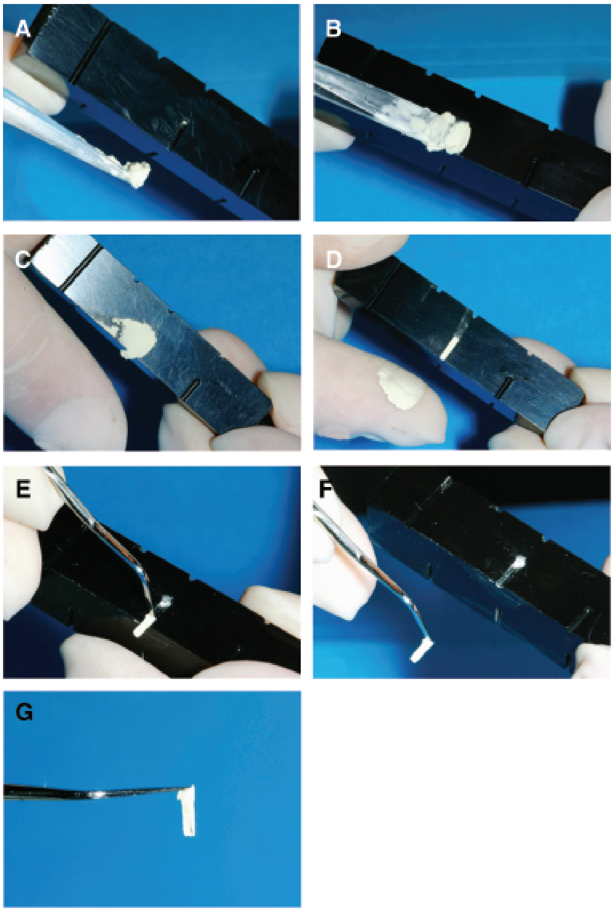

Fig. 31. The Lee mineral trioxide aggregate (MTA) pellet forming block greatly simplifies the process of delivering MTA to the root-end preparation (REP). (A) The MTA mixed to a 'putty-like' consistency on a spatula is (B) placed onto the appropriate size groove in the Lee MTA block, (C) pressed into the groove with a finger, (D) the surface around the groove is wiped clean with a finger, (E) the desired length of the MTA is selected, (F) to be removed by instrument, and (G) carried to the REP in an efficient manner. Slides courtesy Dr Arnaldo Castellucci, Florence, Italy.

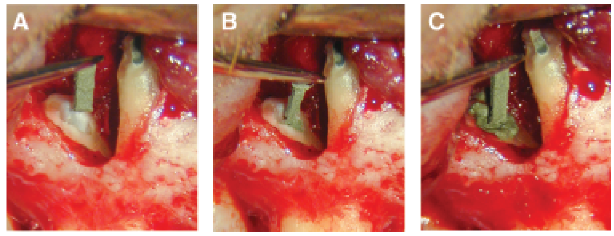

Fig. 32. (A) Pre-measured aliquot of mineral trioxide aggregate (MTA) is easily delivered into the root-end preparation. (B) A sufficient quantity of MTA can be carried on the instrument to minimize the number of 'passes' needed to be made to the surgeon. (C) Because of the efficiency of the system, in many cases, two to three aliquots will suffice to overfill the REP with MTA slightly.

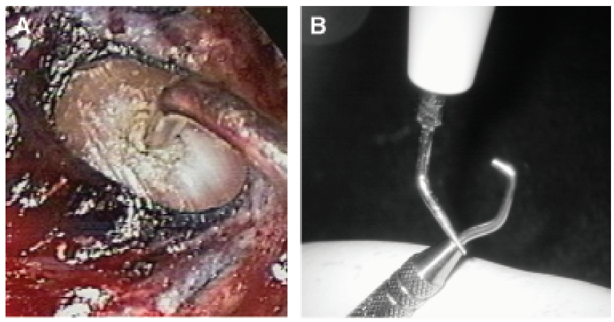

Fig. 33. (A) A plugger, or explorer tip, is placed just in contact with the mineral trioxide aggregate (MTA) and (B) while the doctor activates the ultrasonic hand piece with a rheostat, the assistant gently touches the non-working end of the instrument with an activated ultrasonic tip to 'ultrasonically densify' the MTA.

fewer 'passes' are required to fill the REP adequately (Fig. 32). As with any other MTA carrier, use of the Lee Pellet Forming Block requires the correct powder/water ratio of MTA for ease of use. The mix must be wet enough not to crumble, but dry enough to prevent 'slumping.' Adding or removing water from the mixture leads obtains the desired 'working consistency.' Either a cotton pellet, used dry or moistened with sterile water, or an irrigator, delivering air or water, may be used for this purpose.

After the MTA is delivered into the REP, it is 'patted' or 'persuaded' to place with an appropriate plugger-type instrument. Compaction, as we normally perceive it in dentistry, should be avoided while placing this material. If a plugger or small explorer is placed in contact with the MTA, and the assistant gently touches the 'non-working end' of the instrument with an activated ultrasonic tip, the material 'flows,' entrapped air is released, and the density of the fill is increased (90) (Fig. 33). The radiographic appearance may also improve with 'ultrasonic densification' (74) (Fig. 34). Currently, however, there are no studies evaluating which techniques are most efficacious for the placement of MTA.

MTA has a 2–3 h working time (68), which is more than adequate for apical microsurgery and takes the 'time pressure' out of the procedure. The surface of the MTA is finished by carving away excess material to the level of the resected root end. This is done in a dry

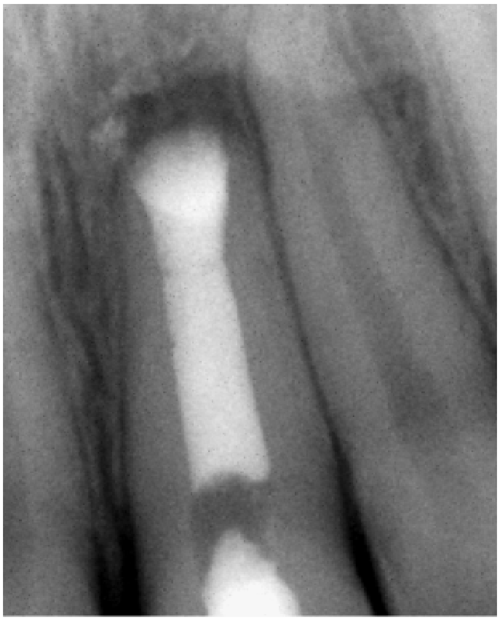

Fig. 34. The radiopacity is similar, if not slightly better than gutta-percha.

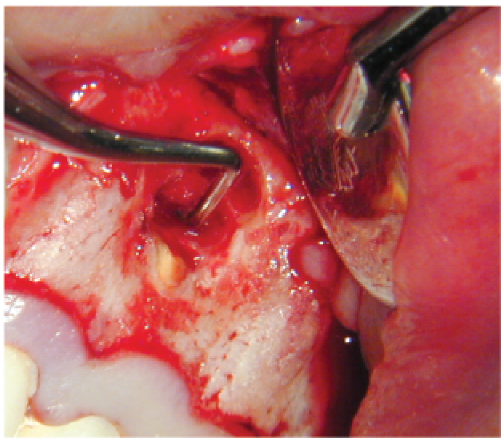

Fig. 35. Gentle curettement of the surgical crypt can initiate fresh bleeding, if necessary, to have assurance the hydrophilic mineral trioxide aggregate is covered with fluid and the surgical crypt fills with blood.

field, as the moisture necessary for the final set is derived from blood that fills the surgical crypt once the tissue is repositioned and sutured. MTA is very hydrophilic and requires moisture for the final set. It is imperative that enough bleeding be re-established to ensure that the crypt is filled with blood. If necessary, gentle curettement of the surgical crypt will initiate the required hemorrhage (1, 90). This is the final step in 'crypt management,' or hemostasis, especially when MTA is used as the REF material (Fig. 35).

Pre-surgical restorations

Whenever apical microsurgery is treatment planned in areas with difficult access such as the palatal root of maxillary molars or either root of some lower molars, the placement of a 'pre-surgical restoration' should be considered (86). Placement of the REF prior to apical surgery may radically simplify the procedure without compromising hard tissue healing (87). In such cases, the canal(s) should be slightly 'over prepared' non-surgically to approximately 1 mm short of the apical terminus so that it can be more easily and completely filled with MTA. Because ultrasonic REP results in a larger than normal canal size at the apex, and the apex will be resected at the 3 mm level anyway, fears of excessive 'overenlargement' during conventional canal preparation techniques are of no concern. The MTA should be placed, 'ultrasonically densified,' and allowed to set for 24–48 h. When the set of the MTA is confirmed, the rest of the coronal seal, or foundation restoration, should be completed under sterile conditions before apical microsurgery is performed. By placing the foundation restoration at this time, coronal micro-leakage is minimized and the predictability of a favorable postsurgical result is enhanced. The subsequent apical surgical procedure is now less complicated as the set MTA is unaffected by the root resection procedure and placement of an REF is no longer required (86). A similar technique may be used when entire roots are to be resected or teeth hemisected (1).

As stated previously, the underlying reason for apical surgery is almost invariably because of persistent infection and residual necrotic tissue left in the root canal space (38–40). Therefore, treatment must be directed at reducing or eradicating these contaminants from within the REP. The use of either 17% EDTA, 10% citric acid, 35% phosphoric acid, or MTAD, followed by irrigating with 2% CHX (41–43), will decrease bacterial load and increase the predictability of success. Before placement of the MTA, temporarily filling the prepared canal space with calcium hydroxide (Pulpdent or UltraCal XS, Ultradent) for a minimum of 7 days, has been demonstrated to reduce contamination of the dentinal tubules in the canal walls and will also increase predictability of complete healing (91–93).

Conclusion

As the SOM became popularized for use in endodontic apical surgery, the expected outcome of the surgical procedure has become more predictable. The 'technological explosion' since 1990 has led to unprecedented advancements and improvements in all areas of surgical treatment, including root-end procedures. Newer techniques, instruments, and materials can be used to effectively overcome the factors that prevented favorable responses to previous surgical endodontic treatment. There is much to consider when performing the root-end procedures, but if the above steps are followed properly in an orderly fashion, healing should be successful and uneventful.

References

1. Gutmann JL, Harrison JW. *Surgical Endodontics*. Boston: Blackwell Scientific Publications, 1991.
2. Carr GB. Common errors in periradicular surgery. *Endod Rep* 1993: **8**: 12–18.
3. Carr GB. Ultrasonic root-end preparation. *Dent Clin North Am* 1997: **41**: 541–554.
4. Stropko JJ. Microchirurgia apicale. *L'informatore Endodontico* 2000: **3**: 40–47.
5. Stropko JJ. Apical surgery: parts III and IV: access and crypt management and the bevel and retropreparation. *Endod Ther* 2002: **2**: 23–28.
6. Vertucci F. Root canal anatomy of human permanent teeth. *Oral Surg* 1984: **58**: 589.
7. Cohen S, Burns RC. *Pathways of the Pulp*, 6th edn. St Louis: CV Mosby, 1994.
8. Cohen S, Burns RC. *Pathways of the Pulp*, 8th edn. St Louis: CV Mosby, 2002.
9. Cohen S, Burns RC. *Pathways of the Pulp*, 7th edn. St Louis: CV Mosby, 1998.
10. Prieswerk G. *Die Pulpa-Amputation eine Klinische, Pathohistologische und Bakeriologishe Studie*. Österr.-Ungar: Vjschr. Zahnjeilk, 1901.
11. Peter K. *Die Wurzelspitzenresektion der Molaren*. Leipzig: Hermann Meusser, 1936.
12. Stropko JJ. Canal morphology of maxillary molars: clinical observation of canal configurations. *J Endod* 1999: **25**: 446–450.
13. Hess W, Zucker E. *The Anatomy of the Root Canals of the Permanent Dentition*. New York: William Wood & Co., 1925.
14. Green D. Double canals in single roots. *Oral Surg* 1973: **35**: 689–696.
15. Kim S, Pecora G, Rubinstein R. *Color Atlas of Microsurgery in Endodontics*. Philadelphia: WB Saunders, 2001.
16. Weller RN, Niemczyk SP, Kim S. Incidence and position of the canal isthmus. Part 1. Mesiobuccal root of the maxillary first molar. *J Endod* 1995: **21**: 380–383.
17. Battrum DE, Gutmann JL. Implications, prevention and management of subcutaneous emphysema during endodontic treatment. *Endod Dent Traumatol* 1995: **11**: 109–114.
18. Bonfield W, Li CH. The temperature dependence of the deformation of bone. *J Biomech* 1968: **1**: 323–329.
19. Eriksson AR, Albrektsson T. Heat induced bone tissue injury. *Swed Dent J* 1982: **6**: 262.
20. Eriksson AR, Albrektsson T, Grane B, McQueen D. Thermal injury to bone. A vital-microscope description of heat effects. *Int J Oral Surg* 1982: **11**: 115–121.
21. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: a vital-microscope study in the rabbit. *J Prosthet Dent* 1983: **50**: 101–107.
22. Eriksson AR, Albrektsson T, Magnusson B. Assessment of bone viability after heat trauma. A histologic, histochemical and vital microscope study in the rabbit. *Scand J Plast Reconstr Surg* 1984: **18**: 261–268.
23. Eriksson AR, Albrektsson T. The effect of heat on bone regeneration: an experimental study in the rabbit using the bone growth chamber. *J Oral Maxillofac Surg* 1984: **42**: 705–711.
24. Calderwood RG, Hera SS, Davis JR, Waite DE. A comparison of the healing rate of bone after production of defects by various rotary instruments. *J Dent Res* 1964: **43**: 207–216.
25. Lobene RR, Glickman I. The response of alveolar bone to grinding with rotary diamond stones. *J Periodontol* 1963: **34**: 105–119.
26. Cambruzzi J, Marshall F. Molar endodontic surgery. *J Can Dent Assoc* 1983: **49**: 61–65.
27. Paz E, Satovsky J, Maldauer I. Comparison of the cutting efficiency of two ultrasonic units utilizing two different tips at two different power settings. *J Endod* 2005: **31**: 824–826.
28. Brent PD, Morgan LA, Marshall JG, Baumgartner JC. Evaluation of diamond-coated ultrasonic instruments for root-end preparations. *J Endod* 1999: **25**: 672–675.
29. Morgan LA, Marshall JG. A scanning electron microscopic study of in vivo ultrasonic root-end preparations. *J Endod* 1999: **25**: 567–570.
30. Lin CP, Chou HG, Chen RS, Lan WH, Hsieh CC. Root deformation during root-end preparation. *J Endod* 1999: **25**: 668–671.
31. Beling KL, Marshall JG, Morgan LA, Baumgardner JC. Evaluation for cracks associated with ultrasonic root-end preparation of gutta-percha filled canals. *J Endod* 1997: **23**: 323–326.
32. Lin CP, Chou HG, Kuo JC, Lan WH. The quality of ultrasonic root-end preparation: a quantitative study. *J Endod* 1998: **24**: 666–670.
33. Scott AE, Apicella MJ. Canal configuration in the mesiobuccal root of the maxillary first molar: a descriptive study. *Gen Dent* 2004: **52**: 34–35.
34. Kulild JC, Peters DD. Incidence and configuration of canal systems in the mesiobuccal root of maxillary first and second molars. *J Endod* 1990: **16**: 311.
35. Torabinejad M, Handysides R, Khademi AA, Bakland LK. Clinical implications of the smear layer in endodontics: a review. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2002: **94**: 658–666.

36. Torabinejad M, Khademi AA, Babagoli J, Cho Y, Johnson WB, Bozhilov K, Kim J, Shabahang S. A new solution for the removal of the smear layer. *J Endod* 2003: **29**: 170–175.
37. Gogos C, Stavianos C, Kolokouris I, Papadoyannis I, Economides N. Shear bond strength of AH-26 root canal sealer to dentine using three dentine bonding agents. *J Dent* 2003: **31**: 321–326.
38. Gutmann JL, Saunders WP, Nguyen L, Guo IY, Saunders EM. Ultrasonic root-end preparation. Part 1. SEM analysis. *Int Endod J* 1994: **27**: 318–324.
39. Cheung GS. Endodontic failures – changing the approach. *Int Dent J* 1996: **46**: 131–138.
40. Hancock HH III, Sigurdsson A, Trope M, Moiseiwitsch J. Bacteria isolated after unsuccessful endodontic treatment in a North American population. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2001: **91**: 579–586.
41. Pinheiro ET, Gomes BP, Ferraz CC, Teixeira FB, Zaia AA, Souza-Filho FJ. Evaluation of root canal microorganisms isolated from teeth with endodontic failure and their antimicrobial susceptibility. *Oral Microbiol Immunol* 2003: **18**: 100–103.
42. Portenier I, Waltimo TMT, Haapasalo M. *Enterococcus faecalis*- the root canal survivor and 'star' in post-treatment disease. *Endodontic Topics* 2003: **6**: 135–159.
43. Engström B. The significance of enterococci in root canal treatment. *Odontol Revy* 1964: **15**: 87–106.
44. Molander A, Reit C, Dahlén G, Kvist T. Microbiological status of root-filled teeth with apical periodontitis. *Int Endod J* 1998: **31**: 1–7.
45. Leonardo MR, Filho MT, Silva LAB, Filho PN, Bonifácio KC, Ito IY. In vivo antimicrobial activity of 2% chlorhexidine used as a root canal irrigating solution. *J Endod* 1999: **25**: 167–171.
46. Martin MV, Nind D. Use of chlorhexidine gluconate for pre-operative disinfection of apicectomy sites. *Br Dent J* 1987: **162**: 459–461.
47. Vianna ME, Gomes BP, Berber VB, Zaia AA, Ferraz CC, de Souza-Filho FJ. In vitro evaluation of the antimicrobial activity of chlorhexidine and sodium hypochlorite. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2004: **97**: 79–84.
48. Gomes BP, Ferraz CC, Vianna ME, Berber VB, Teixeira FB, Souza-Filho FJ. In vitro antimicrobial activity of several concentrations of sodium hypochlorite and chlorhexidine gluconate in the elimination of Enterococcus faecalis. *Int Endod J* 2001: **34**: 424–428.
49. Bondar VM, Rago C, Cottone FJ, Wilkerson DK, Riggs J. Chlorhexidine lavage in the treatment of experimental intra-abdominal infection. *Arch Surg* 2000: **135**: 309–314.
50. Basrani B, Lemonie C. Chlorhexidine gluconate. *Aus Endod J* 2005: **31**: 48–52.
51. Fogel HM, Peikoff MD. Microleakage of root-end materials. *J Endod* 2001: **27**: 456–458.
52. Holt GM, Dumsha TC. Leakage of amalgam, composite, Super-EBA, compared with a new retrofill material: bone cement. *J Endod* 2000: **26**: 29–31.
53. Scheerer SQ, Steiman HR, Cohen J. A comparative evaluation of three root-end filling materials: an in vitro leakage study using *Prevotella nigrescens*. *J Endod* 2001: **27**: 40–42.
54. Greer BD, West LA, Liewehr FR, Pashley DH. Sealing ability of Dyract, Geristore, IRM and super-EBA as root-end filling materials. *J Endod* 2001: **27**: 441–443.
55. Lindeboom JA, Frenken JW, Kroon FH, van den Akker HP. A comparative prospective randomized clinical study of MTA and IRM as root-end filling materials in single-rooted teeth in endodontic surgery. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2005: **100**: 495–500.
56. Fisher EJ, Arens DE, Miller CH. Bacterial leakage of mineral trioxide aggregate as compared with zinc-free amalgam, intermediate restorative material, and Super-EBA as a root-end filling material. *J Endod* 1998: **24**: 176–179.
57. Dorn SO, Gartner AH. Retrograde filling materials: a retrospective success-failure study of amalgam, EBA, and IRM. *J Endod* 1990: **16**: 391–393.
58. Harrison JW, Johnson SA. Excisional wound healing following the use of IRM as a root-end filling material. *J Endod* 1997: **23**: 19–27.
59. Aqrabawi J. Sealing ability of amalgam, super EBA cement, and MTA when used as retrograde filling materials. *Br Dent J* 2000: **188**: 266–268.
60. Wu MK, Kontakiotis EG, Wesselink PR. Long-term seal provided by some root-end filling materials. *J Endod* 1998: **24**: 557–560.
61. Zhu Q, Safavi KE, Spangberg LS. Cytotoxic evaluation of root-end filling materials in cultures of human osteoblast-like cells and periodontal ligament cells. *J Endod* 1999: **25**: 410–412.
62. Oynick J, Oynick T. A study of a new material for retrograde fillings. *J Endod* 1978: **4**: 203–206.
63. Bondra DL, Hartwell GR, MacPhearson MG, Portell FR. Leakage in vitro with IRM, high copper, and EBA cement as retrofilling materials. *J Endod* 1989: **15**: 157–160.
64. Saunders WP, Saunders EM, Gutmann JL. Ultrasonic root-end preparation: Part II. Microleakage of EBA root-end fillings. *Int Endod J* 1994: **27**: 325–329.
65. Rubinstein RA, Kim S. Short-term observation of the results of endodontic surgery with the use of a surgical operation microscope and super-EBA as root-end filling material. *J Endod* 1999: **25**: 43–48.
66. Rubinstein RA, Kim S. Long-term follow-up of cases considered healed one year after apical microsurgery. *J Endod* 2001: **28**: 378–383.
67. Ferracane JL. *Materials in Dentistry.* Philadelphia: JB Lippincott, 1995.
68. Anusavice KJ. *Philips' Science of Dental Materials*, 11th edn. St Louis: WB Saunders, 2003.
69. Coleman JM, Kirk EEJ. An assessment of a modified zinc oxide eugenol cement. *Br Dent J* 1965: **118**: 482–487.
70. Henry J. Super EBA Instructions for Use. Bosworth, 2005.
71. Gondim E, Zaia AA, Gomes BP, Ferraz CC, Teixeira FB, Souza-Filho FJ. Investigation of the marginal adaptation of root-end filling materials in root-end cavities

prepared with ultrasonic tips. *Int Endod J* 2003: **36**: 491–499.
72. Craig KR, Harrison JW. Wound healing following demineralization of resected root ends in periradicular surgery. *J Endod* 1993: **19**: 339–347.
73. Abedi HR, Torabinejad M, McMillan P. The effect of demineralization of resected root ends on cementogenesis. *J Endod* 1997: **23**: 258.
74. Jou Y, Pertl C. Is there a best retrograde filling material? *Dent Clin North Am* 1997: **3**: 555–561.
75. Miles DA, Anderson RW, Pashley DH. Evaluation of the bond strength of dentin bonding agents used to seal resected root apices. *J Endod* 1994: **20**: 538–541.
76. Jensen SS, Nattestad A, Egdo P, Sewerin I, Munksgaard EC, Schou S. A prospective, randomized, comparative clinical study of resin composite and glass ionomer cement for retrograde root filling. *Clin Oral Invest* 2002: **6**: 236–243.
77. Rud J, Rud V, Munksgaard EC. Long-term evaluation of retrograde root filling with dentin-bonded resin composite. *J Endod* 1996: **22**: 90–93.
78. Rud J, Munksgaard EC, Andreasen JO, Rud V, Asmussen E. Retrograde root filling with composite and a dentin-bonding agent. 1. *Endod Dent Traumatol* 1991: **7**: 118–125.
79. Rud J, Munksgaard EC, Andreasen JO, Rud V. Retrograde root filling with composite and a dentin-bonding agent. 2. *Endod Dent Traumatol* 1991: **7**: 126–131.
80. Gutmann JL, Pitt Ford TR. Management of the resected root end: a clinical review. *Int Endod J* 1993: **26**: 273–283.
81. Sherer W, Dragoo MR. New subgingival restorative procedures with Gerestore resin ionomer. *Pract Proced Aesthet Dent* 1995: **7**: 1–4.
82. Michell PJ, Pitt Ford TR, Torabinejad M, McDonald F. Osteoblast biocompatibility of mineral trioxide aggregate. *Biomaterials* 1999: **20**: 167–173.
83. Torabinejad M, Chivian N. Clinical applications of mineral trioxide aggregate. *J Endod* 1999: **25**: 197–203.
84. Koh ET, McDonald F, Pitt Ford TR, Torabinejad M. Cellular response to mineral trioxide aggregate. *J Endod* 1998: **24**: 543–547.
85. Osorio RM, Hefti A, Vertucci FJ, Shawley AL. Cytotoxicity of endodontic materials. *J Endod* 1998: **24**: 91–96.
86. Andelin WE, Browning DF, Hsu GR, Roland DD, Torabinejad T. Microleakage of resected MTA. *J Endod* 2002: **28**: 573–574.
87. Apaydin ES, Shabahang S, Torabinejad M. Hard-tissue healing after application of fresh or set MTA as root-end filling material. *J Endod* 2004: **30**: 21–24.
88. Lee ES. A new mineral trioxide aggregate root-end filling technique. *J Endod* 2000: **26**: 764–766.
89. Lee ES. Think outside the syringe. *Endod Pract* 2004: **3**: 26–28.
90. Stropko JJ. Apical surgery: Parts V and VI: Retrofill materials, techniques, sutures and suturing techniques. *Endod Ther* 2003: **3**: 10–15.
91. Bystrom A, Claesson R, Sundqvist G. The antibacterial effect of camphorated paramonochlorophenol, camphorated phenol and calcium hydroxide in the treatment of infected root canals. *Endod Dent Traumatol* 1985: **1**: 170–175.
92. Sjogren U, Figdor D, Spangberg L, Sundqvist G. The antimicrobial effect of calcium hydroxide as a short-term intracanal dressing. *Int Endod J* 1991: **24**: 119–125.
93. Law A, Messer H. An evidence-based analysis of the antibacterial effectiveness of intracanal medicaments. *J Endod* 2004: **30**: 689–694.