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Review article

Microsurgical instruments for root-end cavity preparation following apicoectomy: a literature review

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Abstract – Root-end cavities have traditionally been prepared by means of small round or inverted cone burs in a micro-handpiece. Since sonically or ultrasonically driven microsurgical retrotips became commercially available in the early 1990s, this new technique of retrograde root canal instrumentation has been established as an essential adjunct in periradicular surgery. At first glance, the most relevant clinical advantages are the enhanced access to root ends in limited working space and the smaller osteotomy required for surgical access because of the various angled designs and small size of the retrotips. However, a number of experimental studies comparing root-end preparations made with microsurgical tips to those made with burs have demonstrated other advantages of this new technique, such as deeper cavities that follow the original path of the root canal more closely. The more centered root-end preparation also lessens the risk of lateral perforation. In addition, the geometry of the retrotip design does not require a beveled root-end resection for surgical access thus decreasing the number of exposed dentinal tubules. A controversial issue of sonic or ultrasonic root-end preparation is the formation of cracks or microfractures, and its implication on healing success. The present paper reviews experimental and clinical studies about the use of microsurgical retrotips in periradicular surgery and discusses many issues raised in previous papers.

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Preservation of natural teeth is one of the ultimate goals of modern dentistry. In the case of periradicular pathosis, potential pathogens are usually eliminated by non-surgical root canal treatment with subsequent obturation and coronal restoration. However, in some cases, the periradicular lesion does not heal or it flares up, indicating the persistence of noxious agents within the physical confines of the canal system. If conventional endodontic retreatment is neither indicated nor feasible, endodontic surgery may become the last resort for salvaging the affected tooth.

One of several treatment options in endodontic surgery is periradicular surgery, which includes three critical steps to eliminate persistent endodontic pathogens: 1) surgical debridement of pathological periradicular tissue, 2) root-end resection (apicoectomy), and 3) retrograde root canal obturation (root-end filling). The goals of root-end resection are listed in Table 1.

The objectives of retrograde obturation are shown in Table 2.

A root-end cavity is conventionally prepared by means of a round or inverted cone bur in a micro-handpiece. However, this technique of apical preparation has a number of limitations (Table 3). Alternative root-end preparation techniques like slot preparation using a fissure bur or reverse instrumentation using modified K-files or Hedström files in special holders or hemostats were advocated in the 1980s (1–3). These methods have circumvented some of the limitations inherent to the conventional technique, but have not become standard procedures in periradicular surgery.

Richman (4) reported the first documented application of ultrasound in periradicular surgery in 1957 using an ultrasonic chisel to cut bone and resect apical tooth tissue. The first root-end preparation by means of modified ultrasonic inserts following apicoectomy is attributed to Bertrand et al. (5). Flath & Hicks (6) also reported the application of ultrasonics and sonics for root-end cavity preparation in two case presentations. They used cut-off and bent or precurved files that were driven by ultrasonic or sonic devices. In an experimental study in extracted human teeth, Sultan & Pitt Ford (7) compared root-end preparation with either hand-held or ultrasonically activated files. At the beginning of the 1990s, commercially produced microsurgical tips became available for endodontic surgery (8–11). Other terms used for these microinstruments are retrotips or retroprep tips. Since the introduction of these retrotips, a number of experimental and clinical studies have investigated different aspects of their application in periradicular surgery. The objectives of the present paper are to review the literature as of July 1999 and to discuss the reported results. The review is divided in two sections: (I) experimental studies and (II) clinical studies. The multitude of experimental studies further warranted subdivision into the following sections:

– Geometry and cleanliness of root-end preparations prepared with retrotips
– Cutting ability of retrotips
– Sealing ability of root-end fillings placed into cavities prepared with retrotips
– Root-face alterations following root-end preparation with retrotips
– Fracture of retrotips.

Experimental studies have also been summarized in tables for quick references.

Table 1. Objectives of root-end resection (apicoectomy)

– Surgical removal of apical delta (root canal ramifications)
– Enhancement of access to apex
– Creation of a working surface for retrograde preparation
– Facilitate debridement of periapical tissue
– Observation of resected root end for presence of vertical fractures

Table 2. Objectives of root-end obturation

– Removing irritants during root-end cavity preparation
– Preventing penetration of microorganisms and their by-products from the root canal into the periapical region
– Optimizing conditions for periapical tissue healing including regeneration of attachment apparatus

Table 3. Limitations inherent to the conventional bur technique for root-end cavity preparation

– Axis of preparation not parallel to root canal
– Risk of perforation of lingual dentin wall
– Insufficient depth of root-end cavity
– Difficult in limited working space
– Requires a root-face bevel of 45° or more
– Enlarged area of patent dentinal tubules due to acute angle of bevel
– Reduced surgical site visibility

Experimental studies

1. Geometry and cleanliness of root-end preparations prepared with retrotips (Table 4)

Wuchenich et al. (12) published the first experimental study on ultrasonic root-end preparation using microsurgical tips. The objective of their study was to evaluate the depth, parallelism and cleanliness of root-end cavities prepared by ultrasonic tips compared to conventional apical preparations made by burs. Twenty teeth from two human cadavers were instrumented and obturated with gutta-percha and sealer. Following flap reflection and osteotomy, the apical third of each root was resected. Subsequently, root-end cavities were prepared either with an ultrasonic retrotip (Excellence in Endodontics, San Diego, CA) or with an inverted cone bur driven by a slow-speed micro-handpiece. Following extraction, the teeth were sectioned longitudinally and sputter-coated with gold for SEM analysis. Ultrasonic root-end preparations were found to be at least 2.5 mm deep and closely followed the root canal space. Cavity walls showed many patent dentinal tubules with little debris. In contrast, preparations made with the bur were offset to the long-axis of the root by 45° to 60° and had only an average depth of 1 mm. In addition, the tubules of the cavity walls were covered with a heavy smear layer.

Gutmann et al. (13) evaluated three different techniques of root-end cavity preparation. Sixty single-rooted extracted human teeth were prepared and obturated with subsequent root-end resection at a 45° angle. Three groups of 20 teeth each were treated as follows: Group 1 had a 2–3-mm deep root-end preparation prepared using a round bur in a slow-

Table 4. Summary of experimental studies evaluating geometry and cleanliness of root-end cavities prepared with retrotips

Paper	Tested issues	Material	Evaluation	Root-end treatment	Results
Wuchenich et al. 1994 (12)	Depth, cleanliness and parallelism of root-end preparations	Teeth of human cadavers	Scanning electron microscopy	Retroprep with ultrasonic retrotips (CT, EIE) (n=10)	Minimum depth 2.5 mm, direction of cavity parallel to canal space, cavity walls with minimal debris
				Retroprep with a #33$^1/_2$ inverted cone bur in a slow-speed microhead handpiece (n=10)	Mean depth 1 mm, direction of cavity deviated 45–60° from long axis of the root, cavity walls with heavy debris layer
Gutmann et al. 1994 (13)	Amount of debris, and smear layer	Extracted human teeth	SEM analysis with gradation scoring 1–4 (1=least, 4=greatest amount)	Retroprep with a round bur (n=20)	Debris score: 2.33 Smear score: 3.98
				Retroprep with a round bur+ acid etching (n=20)	Debris score: 2.16 Smear score: 2.27
				Retroprep with ultrasonic retrotip (n=20)	Debris score: 1.70 Smear score: 2.74
Engel & Steiman 1995 (14)	Size of preparation, canal debridement, time required for preparation, root fractures	Extracted human teeth (only roots with 2 canals selected)	Visual and metric analysis of photomicrographs	Retroprep with #1 round bur with slow-speed (n=10)	Mean postop canal area 2.8 mm^2, prep time 80 s, one root fractured
				Retroprep with #1 round bur with slow-speed+10 s use of ultrasonic retrotip (Neosonic) (n=10)	Mean postop canal area 3.4 mm^2, prep time 95 s, one root fractured
				Retroprep with Neosonic ultrasonic retrotip (n=10)	Mean postop canal area 2.2 mm^2, prep time 85 s, one root fractured
Gorman et al. 1995 (15)	Presence of debris, and smear layer	Extracted human teeth with a single canal	Photomicrographs at ×600 magnification (scores 0–3 recorded for amount of debris and smear layer) (0= least, 3=greatest amount)	Retroprep with #1 round bur with slow-speed and refinement with ultrasonic retrotip (Neosonic) (n=10)	Debris score: 1.2 Smear score: 2.2
				Retroprep with #1 round bur alone (n=10)	Debris score: 1.7 Smear score: 2.7
				Retroprep with ultrasonic retro-tip (Neosonic) (n=10)	Debris score: 1.5 Smear score: 1.5
Mehlhaff et al. 1997 (16)	Preparation depth, deviation of cavity from long axis of root, size of bony crypt and bevel angle of resection needed for access	Bilaterally matched pairs of teeth in human cadavers	Bony crypt measured in cadavers before tooth extraction, all other parameters measured on radiographs projected at ×10 power	Retroprep with ultrasonic tips (CT-5 and CT-1, EIE) (n=38)	Mean depth 2.51 mm, 2.6% of specimens showed prep deviation from long axis, mean bevel 16.0°, mean size of bony crypt 4.3×5.2 mm
				Retroprep with round bur in high-speed handpiece (n=38)	Mean depth 2.05 mm, 100% of specimens showed prep deviation from long axis, mean bevel 35.1°, mean size of bony crypt 4.7×6.3 mm
Lin et al. 1998 (17)	Enlargement of cavity, loss of tooth structure, width of remaining dentin wall	Extracted human teeth	Stereomicroscopic quantitative analysis	Retroprep with ultrasonic retrotip (CT-5, EIE) (n=10)	326% enlargement, 17.6% loss, 0.43 mm wall thickness
				Retroprep with #8 bur in micro-handpiece (n=10)	616% enlargement, 30% loss, 0.17 mm wall thickness

speed handpiece. Group 2 received the same treatment, but a 10% citric acid and 3% ferric chloride solution was subsequently applied for 60 s to flush the apical cavity. In group 3, an ultrasonic retrotip was employed to prepare a 2–3-mm deep apical cavity. All specimens were then split longitudinally and the two halves were analyzed by SEM. The preparations were evaluated in the apical, middle, and coronal portions for the amount of superficial debris at ×100 magnification and the amount of remaining smear layer at ×780 magnification. Each specimen was graded using a scoring system. Group 3 (ultrasonic retrotip) had significantly less superficial debris ($P<0.05$). However, group 2 (bur+acid etching) significantly ($P<0.05$) showed the least amount of smear layer and the greatest amount of clean dentin and patent tubules, especially in the apical one-third of the cavity. No technique effectively removed the smear layer in the coronal one-third of the preparation.

Engel & Steiman (14) compared three different techniques of root-end cavity preparation. Thirty extracted human roots containing two canals were selected to examine isthmus instrumentation. Following conventional root canal preparation and obturation, the apical third of the root end was resected perpendicular to its long axis. Three different root-end preparation techniques were analyzed: In group 1, preparations were made with a round bur in a slow-speed handpiece. In group 2, the teeth were prepared identically to group 1, but an ultrasonic retrotip was additionally applied for 10 s. In group 3, only the ultrasonic instrument was used for root-end preparation. All root ends were stained with methylene blue dye and photographed at ×20 magnification before and after retrograde instrumentation. Ultrasonically prepared cavities were found to be significantly smaller compared to the other two techniques ($P<0.02$ and 0.001). In contrast, the ultrasonic instrumentation resulted in less canal debridement with some residual gutta-percha remaining on the walls. Preparation time did not significantly differ between the conventional and the ultrasonic technique ($P>0.20$).

Gorman et al. (15) performed a similar study with 30 extracted human teeth. Following standard root canal instrumentation, canals were obturated with laterally condensed gutta-percha and sealer. The root ends were then resected at a 45° angle 3–5 mm from the apex. Three different techniques were used to make 3-mm deep root-end preparations. In group 1, a round bur in a straight handpiece was used followed by ultrasonic instrumentation (Neosonic, Amadent, Cherry Hill, NJ) to refine the preparation. In group 2, only the bur was used and teeth in group 3 were prepared by ultrasonic instrumentation alone. The samples were then sputter-coated with gold-palladium prior to SEM analysis. Photomicrographs at ×600 magnification were analyzed for the following parameters: presence of debris, smear layer, smoothness and uniformity of preparation. The amount of debris and smear layer was graded with scores from 0 (none) to 3 (heavy). Mean scores were calculated per parameter and group from the original data and are shown in Table 4. Statistically, the ultrasonic group performed significantly better than both other groups with respect to smear layer removal ($P<0.01$). The combination of bur and ultrasonic showed the least amount of debris. No differences between the techniques were observed for smoothness or uniformity of the preparations.

Mehlhaff et al. (16) compared ultrasonic and bur preparations in three human adult cadavers to simulate *in vivo* conditions. They selected 29 bilaterally matched pairs of teeth for a total of 76 root-end preparations. Full-thickness flaps were reflected and an osteotomy performed. The size of the bony crypt and the root bevel angle were determined by the need for access and visualization to attempt a 3-mm deep root-end preparation. Thirty-eight roots were prepared with ultrasonic tips (CT-1 and CT-5, EIE) and 38 roots were prepared using a round bur in a high-speed handpiece. Preparations were then filled with amalgam enabling subsequent radiographic measurements. After measuring the bony crypt, the remaining buccal cortical bone was removed and the teeth were extracted. Radiographs were then taken in a mesiodistal and bucco-lingual direction. The following parameters were measured radiographically using a digital micrometer: depth of preparation, deviation of preparation from long axis of root, and bevel angle of root resection. None of the 76 specimens showed a root perforation. Only one (2.6%) ultrasonic preparation deviated from the long axis, whereas all bur preparations were at an acute angle to the root canal. Mean measurements of cavity depth were significantly greater for ultrasonic (2.51 mm) compared to bur (2.05) preparations. Also, a statistically significant difference was found for the mean angle of root-end resection (35.1° for bur *vs* 16° for ultrasonic preparations) and for the bony crypt size (all $P<0.0001$).

Lin et al. (17) measured different geometrical parameters of root-end cavities prepared by ultrasonics compared to the conventional technique. Twenty roots from extracted human maxillary molars containing two canals and an isthmus were instrumented and then obturated with gutta-percha and sealer. Subsequently, 3-mm root-end resections were made perpendicularly to the long axis of the root. In group 1, 3-mm deep root-end preparations including the obturated canals and the isthmus were carried out with an ultrasonic retrotip (CT-5, EIE) and in group 2 with a bur in a slow-speed micro-handpiece. The root ends were analyzed prior to and after instrumentation under a stereomicroscope. Images were captured using a CCD camera for quantitative computer-aided evaluation. The mean increase for the cross-sectional area was 616% for cavities made by burs *vs* 326% for cavities prepared by ultrasonics. A mean loss of tooth structure of 30% was calculated for bur preparations compared to only 17.6% following ultrasonic instrumentation. Three out of 10 bur specimens showed root perforations in the isthmus area. All postoperative data were statistically significantly different between the two groups ($P<0.0001$). The main concern with the bur preparations was that root-end preparations were irregularly shaped and poorly centered with little dentin remaining at the isthmus area.

Discussion

Six studies have evaluated the geometry and cleanliness of root-end preparations made with microsurgical instruments (12–17). All studies compared the new microsurgical technique to the conventional bur technique. All but two studies were performed on extracted human teeth. This has certainly simplified the root-end preparation procedure compared to a clinical situation. The studies by Wuchenich et al. (12)

and by Mehlhaff et al. (16) were conducted in human cadaver teeth. Therefore, they are of particular interest, since they tried to simulate the clinical approach. Both studies found that preparations made with ultrasonic retrotips are deeper and more parallel to the root canal than those made by burs. These findings are consistent with the concept that root-end preparations should be 3-mm deep and follow the original path of the root canal (18). These requirements are more easily achieved if straight line access can be gained during the use of the root-end preparation instrument.

One experimental study also demonstrated that the bevel of root-end resection needed for surgical access to the root canal is significantly smaller for microsurgical tips than for conventional burs (16). These authors also made a special effort to select bilaterally matched pairs of teeth to exclude variations of tooth position and morphology that might have influenced the outcome.

The amount of debris and smear layer production was addressed in three studies (12, 13, 15). The removal of debris and smear layer is of clinical importance, since they may serve as an avenue for leakage and prevent intimate contact of the root-end filling with the cavity walls. Root-end preparations, irrespective of the technique used, resulted in a significant accumulation of dentin debris and root canal filling materials in the base of the root-end preparation (13). This material might serve as a reservoir of future contamination if coronal leakage occurred. Two studies also reported difficulty in removing gutta-percha with ultrasonic instrumentation (13, 14). However, this might be explained by the fact that the tested ultrasonic retrotips used in these studies had a smooth working tip without abrasive properties. Therefore, a gutta-percha thermoplasticizing rather than a cutting effect was created. Diamond-coated retrotips with better cutting abilities might be advantageous in this respect (19). Abedi et al. (20) suggested removing the gutta-percha with heat-carrying instruments before applying the ultrasonic tip. In terms of smear layer removal, ultrasonic tips performed better than burs. However, a considerable number of specimens showed moderate to heavy smear layers (13, 15). The importance of using a citric acid and ferric chloride combination to remove the smear layer prior to placement of the root-end filling was therefore emphasized. However, this etching agent failed to effectively remove the smear layer in the root-end preparation other than in its apical one-third (13).

The microsurgical technique clearly preserved more tooth structure than the conventional technique (14, 17). Ultrasonic instrumentation was found to produce less enlargement of the canal. Preparations were well centered and thicker dentin walls were maintained in ultrasonically prepared teeth compared to bur preparations. A more conservative root-end preparation is essential to prevent apical perforations or fractures, especially in deeply fluted or invaginated roots with an isthmus.

2. Cutting ability of retrotips (Table 5)

Waplington et al. (21) investigated the cutting ability of three ultrasonically driven retrotips in nine freshly extracted human teeth. The teeth were sectioned longitudinally and polished to produce a flat surface onto which the surgical tips could be applied. The ultrasonic handpiece (Neosonic) had an operating frequency of 29 kHz. Three different tips with two geometrical designs were tested. The activated ultrasonic tips were applied for 1 min using a load of 20 g at six different power settings. The depth of the dentin cut was measured using a two-dimensional surface profilometry technique and ranged from 50 μm to 610 μm. For all tips, the depth of cut increased in a linear manner along with the displacement amplitude which

Table 5. Summary of experimental studies evaluating the cutting ability of retrotips

Paper	Tested issues	Material	Evaluation	Root-end treatment	Results
Waplington et al. 1995 (21)	Displacement amplitude of tips, cutting ability of tips (depth of dentin cut)	Extracted human teeth	Light stereo-microscope, profilometry	Ultrasonic tip CT-1 (isthmus prep tip)	Amplitude range 26.5 to 46.5 μm, depth of cut range 50 to 290 μm
				Ultrasonic tip CT-2 (main prep tip)	Amplitude range 40.5 to 70.0 μm, depth of cut range 130 to 610 μm
				Ultrasonic tip CT-3 (main prep tip)	Amplitude range 31.0 to 53.5 μm, depth of cut range 70 to 470 μm
Devall et al. 1996 (22)	Cutting ability of sonic retrotips with respect to power setting, orientation of tip, loading of tip, length of tip, and tip size (depth of cut)	Bovine bone, 1-mm thick sections	Stereomicroscope with calibrated eyepiece reticle at ×50 magnification	Sonic retrotips powered by sonic handpiece (MM 1500)	Cutting depth: Full>half power; parallel>perpendicular tip orientation; narrow>wide tip; short>long; 50>25 g load.

Table 6. Summary of experimental studies evaluating the sealing ability following root-end cavity preparation with retrotips

Paper	Tested issues	Material	Evaluation	Root-end treatment	Results
Saunders et al. 1994 (23)	Apical seal of EBA root-end fillings following three methods of root-end preparation; analysis after 7 days and 7 months	Extracted human teeth	Stereomicroscopic evaluation of dye penetration (gradation scoring 0–4; 0=no leakage; 4=leakage >2 mm)	Retroprep with a round bur (n=40; 20+20)	Mean leakage score for 7 days: 0.7 Mean leakage score for 7 months: 2.2
				Retroprep with a round bur+acid etching (n=38; 20+18)	Mean leakage score for 7 days: 1.2 Mean leakage score for 7 months: 2.6
				Retroprep with ultrasonic retrotip (n=38; 19+19)	Mean leakage score for 7 days: 1.1 Mean leakage score for 7 months: 3.1
O'Connor et al. 1995 (24)	Apical seal of EBA and amalgam root-end fillings following two methods of root-end preparation	Extracted human teeth	Stereomicroscopic evaluation of dye penetration	Retroprep with ultrasonic, 0° bevel, Super-EBA retrofilling (n=17)	44% of specimens with leakage beyond retrofilling
				Retroprep with ultrasonic, 0° bevel, amalgam + cavity varnish for retrofilling (n=17)	87% of specimens with leakage beyond retrofilling
				Retroprep with #2 bur, 45° bevel, Super-EBA retrofilling (n=17)	56% of specimens with leakage beyond retrofilling
				Retroprep with #2 bur, 45° bevel, amalgam + cavity varnish for retrofilling (n=17)	100% of specimens with leakage beyond retrofilling
Lloyd et al. 1997 (25)	Apical leakage of amalgam or Diaket root-end fillings following two different methods of root-end preparation and two different resection angles	Extracted human teeth	Microscopic metric evaluation of linear dye penetration	Retroprep with #8 round bur (n=4×20)	45°/amalgam=1.08 mm penetration 45°/Diaket=0 mm penetration 0°/amalgam=1.4 mm penetration 0°/Diaket=0.02 mm penetration
				Retroprep with sonic retrotip (MicroMega) (n=4×20)	45°/amalgam=1.2 mm penetration 45°/Diaket=0.13 mm penetration 0°/amalgam=0.37 mm penetration 0°/Diaket=0.26 mm penetration
Chailertvanitkul et al. 1998 (26)	Coronal seal of EBA root-end filling following two different methods of root-end preparation	Extracted human teeth	Time delay for contamination with a polymicrobial marker (gradation score 0–4; 0=no leakage at 60 days; 4=leakage within 1–15 days)	Retroprep with #8 round bur (n=17)	Mean leakage score 2.0
				Retroprep with ultrasonic tip CT3 (EIE) (n=18)	Mean leakage score 0.7

itself correlated with the power setting. The analyzed tips were capable of removing dentin across the full power range; however, a medium to high power setting was suggested to optimize their efficiency.

Devall et al. (22) performed an *in vitro* experiment in which they evaluated the effect of different variables on the cutting ability of retrotips powered by a sonic handpiece (MicroMega, Prodonta SA, Geneva, Switzerland). The following factors were investigated: power setting (half or full power), width (#35 or #55) and length (2 mm or 3 mm) of retrotip, tip orientation (parallel or perpendicular to long axis of handpiece), and tip loading (25 g or 50 g). One-millimeter thick sections of bovine bone were instrumented for 10 s. The depths of the cuts measured with a stereomicroscope at ×50 magnification ranged from 0.2 mm to 0.45 mm. All factors tested had a significant effect on the cutting performance of the sonic retrotips ($P<0.05$). The most significant effect was determined for the power setting ($P<0.001$). The parallel orientation of the tips produced deeper cuts than the perpendicular orientation. The narrow tips cut more than the wide tips, and the short more than the long. The least significant variable upon the cutting ability was load applied to the retrotip.

Discussion

Two studies have been published which determined the cutting characteristics of microsurgical instruments, one evaluating ultrasonically (21) and the other sonically powered retrotips (22). The depth of the cuts was strongly correlated with the power setting for all tested microsurgical retrotips. The study on ultrasonic retrotips also clearly showed a linear increase of the displacement amplitude with increasing power settings. But the amount of oscillation is not solely determined by the power setting, but also by the tip design, especially by the angulation and position of bends. This correlation was also demonstrated in the study evaluating the cutting ability of sonic retrotips where a tip orientation parallel to the driver head resulted in more cutting, probably because of the vertical rather than horizontal oscillation of the powered tip with respect to the driving handpiece. However, in a clinical situation, access to root ends requires bent instruments with a horizontal oscillation plane relative to the cutting end of the working tips. The recorded cutting depths were minimal, ranging from 0.05 mm to 0.61 mm for ultrasonic retrotips and from 0.2 mm to 0.45 mm for sonic retrotips. However, this is not a shortcoming since a conservative cavity preparation reduces the risk of perforation or microfracture of the root end. No studies have been published on the cutting characteristics of retrotips with roughened or coated working ends. It would be clinically relevant to know whether such instruments enhance canal debridement compared to retrotips with a smooth working end, and how such instruments alter the root-end morphology.

3. Sealing ability of root-end fillings placed into cavities prepared with retrotips (Table 6)

Saunders et al. (23) evaluated the apical seal of root-end fillings following three different techniques of root-end preparation. The root canals of 116 extracted human teeth were instrumented and obturated with gutta-percha and sealer. Subsequently, root ends were resected at a 45° angle. In group 1, a 2–3-mm deep root-end preparation was made using a round bur in a slow-speed handpiece. Teeth in group 2 received the same treatment, but the apical cavity was subsequently flushed with a 10% citric acid and 3% ferric chloride solution for 60 s. In group 3, an ultrasonic retrotip was employed to prepare a 2–3-mm deep apical cavity. All cavities were then obturated with EBA cement. Apical dye leakage of india ink was analyzed after 7 days (in 59 teeth) and after 7 months (in 57 teeth) using a stereomicroscope at ×6 magnification. A gradation score of 0–4 was applied for each specimen depending on the depth of dye penetration. No statistically significantly different leakage was found between the three preparation techniques at either time point. However, 7-month specimens showed significantly more leakage than 7-day specimens irrespective of the preparation technique ($P<0.01$). In addition, the ultrasonic technique produced significantly more cracks at the root end than the conventional bur technique ($P<0.001$).

O'Connor et al. (24) investigated the apical leakage of amalgam and EBA root-end fillings with two methods of root-end preparation. Seventy-six extracted human teeth were instrumented and obturated with laterally condensed gutta-percha. However, no sealer was used to simulate a poorly obturated root canal. Four groups each containing 17 teeth were treated as follows: in groups 1 and 2, perpendicular root-end resections were made 3 mm from the apex with subsequent ultrasonic (Neosonic) preparation of a 3-mm deep cavity. In groups 3 and 4, specimens were resected at a 45° bevel 3 mm from the apex and root-end preparations were made with a round bur in a micro-handpiece. For root-end filling, Super-EBA cement was used in groups 1 and 3, and amalgam with cavity varnish in groups 2 and 4. After 4 months, root-end filled teeth were coated with nail polish except for the cut root face and suspended in an aqueous solution of 1% methylene blue dye for 2 weeks. After longitudinal separation, dye penetration was graded under a stereomicroscope at ×6 magnification as either acceptable (no leakage beyond root-end filling) or unacceptable (leakage beyond root-end filling). Irrespective of root-end bevel and cavity preparation technique, Super-EBA root-end fillings demonstrated significantly less dye penetration than amalgam and varnish. Although the ultrasonic preparations tended to show less leakage than bur preparations, no statistically significant difference was found between the two techniques ($P>0.05$).

Lloyd et al. (25) analyzed the apical seal of two root-end filling materials following two root-end preparation techniques. The crowns of 172 recently extracted human teeth were removed and the canals were instrumented and obturated using gutta-percha and sealer. The teeth were then randomly assigned to eight treatment groups (each with 20 teeth) combining three variables such as bevel of root-end resection (0° or 45° bevel), cavity preparation (round bur or sonic retrotip (MicroMega), and root-end filling (amalgam or Diaket). Specimens were then coated with sticky wax and nail varnish and placed into india ink for 2 weeks. Following demineralization of the teeth, the maximum linear dye penetration was examined at ×10 magnification. No significant difference in leakage was observed between the two cavity preparation techniques or between the two resection angles. Amalgam fillings exhibited significantly more linear leakage than Diaket irrespective of the two other variables. In addition, root-end preparations made with sonic retrotips resulted in significantly more root canal enlargement compared to cavities prepared by burs ($P<0.05$).

Chailertvanitkul et al. (26) evaluated the coronal leakage of EBA root-end fillings following two root-end preparation techniques in extracted human teeth. Root canal treatment included instrumentation and obturation with gutta-percha and sealer. After a storage period of 6 months in artificial saliva containing Gentamycin, the root-ends were resected 3–4 mm perpendicularly to the long axis and crowns were removed. In group 1, at least 3-mm deep root-end preparations were made using a round bur, while in group 2, an ultrasonic tip (CT-3, EIE) was employed for root-end preparation. Super-EBA cement was placed into the root-end cavity. Instead of assessing dye penetration from the apical aspect, specimens were attached to a coronal chamber containing microbial markers of anaerobic streptococci and *Fusobacterium nucleatum*. The cut root surface was placed in "Brain Heart Infusion Broth" (BHIB) in an apical chamber. The time taken for the broth to become turbid following bacterial penetration and contamination was recorded as an indicator of leakage. Scoring (0–4) was based on the number of days for leakage to occur. After 90 days, the ultrasonic group showed significantly fewer specimens with complete leakage than the bur group ($P<0.05$).

Discussion

Four studies (23–26) have evaluated the sealing ability of root-end fillings placed into ultrasonically or sonically and conventionally prepared root ends. It is difficult to compare the studies because of the variations of treatment parameters such as different leakage methods (apical or coronal leakage, dye or polymicrobial penetration, leakage distance or time required for leakage), various root-end filling materials (amalgam, amalgam + varnish, EBA, Diaket), and different bevels of root-end resection (0° or 45°). In addition, the period after placing the root-end filling until dye or microbial exposure and the duration of exposure showed considerable variability (Table 7).

The study by Chailertvanitkul et al. (26) should be regarded as the most clinically relevant with respect to methodology of leakage assessment and time intervals selected. It is the only study to analyze coronal leakage using a polymicrobial marker. The purpose of placing a root-end filling material is to prevent penetration of microorganisms and irritants from the root canal system into periradicular tissues (27). Therefore, the assessment of the coronal seal of root-end filling materials is clinically more relevant than the determination of the apical seal (28). In addition, a short setting time for the root-end filling prior to an immediate, but extended period of exposure is a more demanding model and better simulates the clinical situation. The study by Chailertvanitkul et al. (26) was the only one to demonstrate significantly less (coronal) leakage of root-end fillings following ultrasonic root-end preparation compared to bur preparation. All other leakage studies (23–25) found no statistically significant differences between root-end preparation techniques within the limits of apical dye penetration studies.

Table 7. Summary of experimental studies evaluating delayed exposure to leakage tracers

Study	Time period between root-end obturation and exposure to tracer	Length of exposure to tracer
Saunders et al. 1994 (23)	7 days or 7 months	90 hours
O'Connor et al. 1995 (24)	4 months	2 weeks
Lloyd et al. 1997 (25)	N/A	2 weeks
Chailertvanitkul et al. 1998 (26)	1 day	Up to 90 days

Saunders et al. (23) reported that root ends that had been acid-etched showed leakage from the cut root face into the dentinal tubules, indicating that the smear layer produced during resection had been removed. Since all teeth in that study had a resection angle of 45°, this was indirect proof that many tubules became patent following a beveled root-end resection. This is of clinical concern, because microorganisms residing in the tubules might move through patent openings into the periapical area. In addition, patent tubules may serve as a pathway of communication between the root canal and the periradicular tissue unless the root-end filling extends beyond the most coronal point of the resection bevel (29, 30). These findings were recently corroborated by a study evaluating the influence of resection angle on the apical seal (31). Standardized resections either perpendicular to the long axis of the root or at an angle of 45° were made followed by ultrasonic root-end preparation and placement of Super-EBA cement. Apical dye penetration from the cut root surface into the dentinal tubules and along the interface of the cavity walls and the root-end filling was investigated. Results showed less infiltration both in dentin and along the root-end filling with the perpendicular resection plane. In summary, all these observations emphasize the need to perform a perpendicular rather than a beveled resection.

The studies comparing different root-end filling materials showed more leakage with amalgam compared to cements (Diaket or EBA). However, it is beyond the scope of this review to discuss root-end filling materials.

4. Root-face alterations following root-end preparation with retrotips

Abedi et al. (20) determined the effects of bur and ultrasonic preparation on the root apex following root-end resection. Forty-seven extracted human teeth with standardized root-end diameters were instrumented and obturated using gutta-percha and sealer. Following root-end resection, epoxy resin replicas were made from polyvinylsiloxane impressions. Each root was also photographed at ×30 magnification. The root ends of one group were prepared by means of a fissure bur, whereas the other group received root-end preparations with an ultrasonic tip (CT-2, EIE) driven by either an Enac (Osada Electric Co., Tokyo, Japan) ultrasonic unit or a Neosonic ultrasonic unit. Photographs and root replicas were made of all specimens and pre- and postoperative replicas and original specimens were sputter-coated with gold for SEM analysis. The following parameters were assessed: cracks present before and/or after root-end preparation, percentage increase of cavity size following preparation, correlation between presence of cracks and width of thinnest dentin wall after cavity preparation. A significantly lower incidence of crack formation was found after bur preparation compared to ultrasonic preparation ($P<0.05$). No difference was observed for the two ultrasonic units. Cavities prepared by burs showed a larger mean increase compared to ultrasonically prepared cavities, but without correlation to crack formation. However, cracking correlated with the remaining width of dentin walls, with 95% of cracks found in the thinnest part of the cavity wall. When the remaining dentin wall was thinner than 1 mm 75% of ultrasonically prepared root-ends developed cracks, whereas this phenomenon was never observed in bur preparations.

Layton et al. (32) evaluated root ends after apicoectomy and after ultrasonic instrumentation at low and high power settings. Thirty unobturated and bilaterally matched extracted human teeth were resected perpendicularly 3 mm from the root tip. Subsequently, 3-mm deep root-end cavities were prepared using ultrasonic tips (CT-1 and 5, EIE). The preparations in group 1 were made at the lowest power setting, whereas in group 2, the highest power setting was applied. Before and after cavity preparation, the roots were immersed in methylene blue dye. Thereafter, the root surfaces were analyzed under a stereomicroscope at ×20 and ×63 magnification. Differences in the numbers and types of cracks following root-end preparation compared to those seen after root-end resection were recorded. In the low-power-setting group 40% of teeth and in the high-power-setting group 47% of teeth developed cracks after ultrasonic root-end preparation compared to 20% and 17%, respectively, observed after root-end resection only. While there was a significant difference ($P<0.05$) for the overall greater percentages of teeth with cracks seen after ultrasonic preparation compared to resection only, no statistically significant difference was found between the two power settings. However, significantly more cracks per tooth were observed in the high-power-setting group, when cracking did occur. Cracks radiating from the canal space were far more often seen than intradentin cracks.

Frank et al. (33) examined the effects of five different root-end preparation techniques on root apices. Sixty extracted human roots were resected 2–3 mm from the apex. Using a microscope at ×16 magnification, no existing fracture lines were detected after staining the resected root ends with methylene blue. The following apical preparation techniques were applied: group 1 no preparation (controls), group 2 a round bur in a high-speed handpiece, group 3 a round bur in a slow-speed handpiece, group 4 a sonic retrotip (MicroMega), group 5 an ultrasonic retrotip (EIE) with a medium power setting, and group 6 an ultrasonic retrotip (EIE) with a high power setting. After root-end preparation, the root tips were again stained and examined at ×10 magnification for the presence of infractions. The frequency of infractions is listed in detail in Table 8. The highest number of infractions was observed in ultrasonically prepared root-ends with a high power setting. In addition, biconcave roots were more susceptible to infractions than oblong or round root-ends. Also root tips with a diameter of less than 3 mm developed more infractions than those with a diameter of 3 mm or greater. However, no statistically significant difference was found for the occurrence of infractions based on root-tip morphology.

Lloyd et al. (34) analyzed chipping and cracking following root-end cavity preparation using a sonic retroprep tip or a bur. Eighty extracted human teeth were instrumented and obturated using thermoplasticized gutta-percha and sealer and divided into four groups of 20 teeth each. In group 1, a perpendicular resection 3–4 mm from the apex was made with subsequent root-end preparation using a sonic retrotip (MicroMega). In group 2, the same instrument was used for cavity preparation, but the root ends were resected at a 45° bevel. Teeth in groups 3 and 4 were resected like those in groups 1 and 2 respectively, but cavities were prepared with a round bur and an inverted cone bur in a handpiece. The cut root faces and the prepared root-end preparations were then replicated in resin and were sputter-coated with gold for SEM analysis. Each specimen was photomicrographed at ×20 magnification to evaluate cracking and at ×80 magnification to evaluate chipping of the cavity margins. No significant difference between the four groups was observed for the incidence of cracking, (range 0% to 15%). Four out of a total of five cracks in 80 specimens were seen after sonic instrumentation. However, the authors were not sure if these lateral canals had been exposed during the resection process. Unfortunately, no root replicas were obtained following resection alone. Bur preparations had significantly less chipping of the cavity margins than sonic preparations ($P<0.001$). Regardless of the cavity preparation technique, teeth with a perpendicular resection showed significantly fewer alterations than those with a beveled resection ($P<0.005$).

Waplington et al. (35) evaluated the incidence of root face alterations following ultrasonic cavity preparation over a full range of power settings in comparison to conventional bur preparation. Fifty-five extracted human teeth were instrumented and obturated with gutta-percha and sealer. Root ends were resected perpendicularly to the long axis of the root

Table 8. Summary of experimental studies evaluating root-face alterations following root-end cavity preparation with retrotips

Paper	Tested issues	Material	Evaluation	Root-end treatment	Results
Abedi et al. 1995 (20)	Crack formation following root-end cavity preparation, increase of cavity size	Extracted human teeth	Light and scanning electron microscopy using the resin replica technique	Retroprep with fissure bur (n=24)	Cracks formed or deteriorated in 33%; cavity increase 480%
				Retroprep with ultrasonic CT-2 tip in Enac unit (n=11) or in Neosonic unit (n=12)	Cracks formed or deteriorated in 70%; cavity increase 200% (Enac) and 333% (Neosonic)
Layton et al. 1996 (32)	Evaluation of frequency and types of cracks following ultrasonic root-end preparation	Extracted human teeth (bilaterally matched)	Immersion of prepared roots in methylene blue solution; stereomicroscopic analysis at ×20 and ×63 magnification	Retroprep with ultrasonic tip (EIE) at lowest power setting (n=30)	40% of teeth showed a total of 16 cracks
				Retroprep with ultrasonic tip (EIE) at highest power setting (n=30)	47% of teeth showed a total of 26 cracks
Frank et al. 1996 (33)	Infractions of dentin following five different methods of root-end cavity preparation	Extracted human teeth	Root-tips stained with methylene blue before and after retroprep, visual analysis of photographs at ×10 magnification	No retroprep (control group) (n=15)	0% with infractions
				Retroprep with #1 bur and high-speed handpiece (n=9)	33.3% with infractions
				Retroprep with #1 bur and slow-speed handpiece (n=9)	11.1% with infractions
				Retroprep with sonic retrotip (n=9)	22.2% with infractions
				Retroprep with ultrasonic tip at medium power (n=9)	11.1% with infractions
				Retroprep with ultrasonic tip at high power (n=9)	55.6% with infractions
Lloyd et al. 1996 (34)	Degree of chipping and cracking following four methods of root-end preparation	Extracted human teeth	SEM analysis with photomicrographs at ×20 and ×80 magnifications. Chipping-scoring 1 (best) – 3 (worst), cracking yes or no	Retroprep with sonic tip, no bevel (n=20)	Mean chipping score: 1.65 Cracking 15%
				Retroprep with sonic tip, 45° bevel (n=20)	Mean chipping score: 2.2 Cracking 5%
				Retroprep with round and inverted cone burs, no bevel (n=20)	Mean chipping score: 1.1 Cracking 0%
				Retroprep with round and inverted cone burs, 45° bevel (n=20)	Mean chipping score: 1.55 Cracking 5%
Waplington et al. 1997 (35)	Cracks and chipping of cavity margins	Extracted human teeth	SEM analysis of resin replicas of preparations (at ×50 magnification) Score 1–3 for chipping	Retroprep with CT-1 or CT-2 ultrasonic tips at five different power settings (10 groups, n=5)	No cracks; marginal chipping score for CT-1=1.24 and for CT-2=1.57
				Retroprep with #1 rotary bur in contra-angle handpiece (n=5)	No cracks; marginal chipping score= 1.0
Beling et al. 1997 (36)	Cracks following root-end preparation in unfilled and filled teeth	Extracted human teeth	Immersion in methylene blue, analysis with stereomicroscope at ×20-×63 magnification	Retroprep of uninstrumented and unfilled teeth with CT-5 and CT-1 (EIE) ultrasonic tips (n=20)	After resection: 5 cracks in 4 teeth, after retroprep: 6 cracks in 4 teeth=1 new crack (5% of teeth developed cracks)
				Retroprep of instrumented and obturated teeth with CT-5 and CT-1 (EIE) ultrasonic tips (n=20)	After resection: 5 cracks in 2 teeth, after retroprep: 7 cracks in 4 teeth=2 new cracks (10% of teeth developed cracks)
Min et al. 1997 (37)	Number, width and length of cracks following different root-end preparation techniques	Extracted human molar teeth	Confocal microscopy and histologic examination of 6-μm thick serial sections of the root-ends	No retroprep (control group) (n=10)	50% with cracks; max width 23 μm; max length 254 μm; max depth 653 μm
				Retroprep with #33$^{1}/_{3}$ inverted cone bur in microhead handpiece (n=10)	60% with cracks; max width 84 μm; max length 494 μm; max depth 906 μm
				Retroprep with ultrasonics (EIE) at lowest power (n=10)	100% with cracks; max width 52 μm; max length 620 μm; max depth 1432 μm
				Retroprep with ultrasonics (EIE) at intensity 5 (n=10)	100% with cracks; max width 66 μm; max length 615 μm; max depth 1740 μm
Calzonetti et al. 1998 (38)	Microfractures following root-end cavity preparation	Human cadaver teeth	Examination of pre- and postop impressions with a stereomicroscope and SEM	Retroprep with ultrasonic tip AP4–90 and Enac unit (n=26)	No microfractures observed
				Retroprep with ultrasonic tip CT-1 and Mini-endo unit (EMS) (n=26)	No microfractures observed

Table 9. Comparison of ultrasonic/sonic and bur application with respect to different parameters of root-end cavity preparation (REP)

Parameter	Comparison	Studies
Depth of cavity	Ultrasonic>Bur	Wuchenich et al. (12), *Mehlhaff et al. (16)
Parallelism of cavity to canal space or long axis of root	Ultrasonic>Bur	Wuchenich et al. (12), Mehlhaff et al. (16)
Amount of smear layer	Ultrasonic>Bur	Wuchenich et al. (12), *Gutmann et al. (13), *Gorman et al. (15)
Amount of superficial debris	Ultrasonic>Bur	Wuchenich et al. (12), *Gutmann et al. (13)
	Ultrasonic≃Bur	*Gorman et al. (15)
Canal debridement	Bur>Ultrasonic	*Gutmann et al. (13), *Engel & Steiman (14)
Root perforation	Ultrasonic>Bur	*Lin et al. (17)
Remaining thickness of dentinal wall	Ultrasonic>Bur	*Lin et al. (17)
Loss of tooth structure	Ultrasonic>Bur	*Engel & Steiman (14), *Lin et al. (17), Abedi et al. (20)
	Bur>Sonic	*Lloyd et al. (25)
Root-face alterations (cracks, microfractures)	Ultrasonic≃Bur	Waplington et al. (35)
	Bur>Ultrasonic	*Abedi et al. (20), *Saunders et al. (23), *Min et al. (37)
Chipping of cavity margins	Bur>Ultrasonic	*Waplington et al. (35)
	Bur>Sonic	*Lloyd et al. (34)
Time needed for preparation	Ultrasonic≃Bur	*Engel & Steiman (14)
	Bur>Ultrasonic	Gutmann et al. (13)
Bevel angle needed for REP	Ultrasonic>Bur	*Mehlhaff et al. (16)
Size of bony crypt needed for REP	Ultrasonic>Bur	*Mehlhaff et al. (16)
Apical leakage of retrofilling	Ultrasonic≃Bur	*Saunders et al. (23), *O'Connor et al. (24)
	Sonic≃Bur	*Lloyd et al. (25)
Coronal leakage of retrofilling	Ultrasonic>Bur	*Chailertvanitkul et al. (26)

Comparison: >performed better than, ≃performed similar to.
Studies: *preceding author's name=statistics were performed.

3 mm from the apex. Root-end preparations were created at five different power settings and with two different tip designs (CT-1 and 2, EIE). This resulted in 10 experimental groups with five teeth each. The remaining five teeth received a conventional root-end preparation with a rotary bur in a contra-angle handpiece. Tips and burs were marked at 3 mm to obtain standardized cavity depths. Replica models were then made using a silicone impression material and epoxy resin to reproduce root-end preparation details. Photomicrographs were taken at ×50 magnification under an SEM. Cracking was assessed as present or absent, whereas chipping of the cavity margin was scored from 1–3 (1=none, 2=modest, 3=severe). No cracks were evident in any of the specimens. However, all ultrasonically prepared cavities showed chipping of the margins. The CT-2 tip produced significantly more chipping than the CT-1, and both tips produced significantly more chipping with increased power settings. No marginal chipping was observed in any of the bur preparations.

Beling et al. (36) investigated cracks in ultrasonically prepared root ends of teeth with or without instrumentation and obturation. Forty extracted human teeth were divided into two groups. In group 1, the teeth were left uninstrumented. In group 2, root canals were instrumented and obturated with gutta-percha, lateral condensation and sealer. Subsequently, all teeth were perpendicularly resected at 3 mm from the apex. Root-end preparations were then made in all teeth using ultrasonic retrotips (CT-1 and 5, EIE) at the lowest power setting. Roots were inspected for cracks at the cut root surface with a stereomicroscope at ×20 to ×63 magnification after resection alone and after root-end preparation. To aid in detection of cracks, teeth were placed in a methylene blue dye solution for 48 h. After root-end resection, five cracks were observed in four unobturated teeth and five cracks were present in two obturated teeth. Only three more cracks developed after ultrasonic root-end preparation: one crack in an unfilled tooth, and two new cracks associated with two filled teeth. All cracks forming after ultrasonic instrumentation were incomplete canal cracks. No statistically significant differences were found between any of the groups.

Min et al. (37) examined serial histologic sections of root ends prepared either with ultrasonics or conventionally to detect structural alterations. Forty roots of extracted human molar teeth were divided in four groups of 10 each. The apical 3 mm of each root was resected at a 90° angle. Group 1 included the control teeth without root-end preparation. In group 2, a 2-mm deep root-end preparation was made with an inverted cone bur in a microhead handpiece. Group 3 received 2-mm deep root-end preparations with ultrasonic tips (CT-3 and 5, EIE) at the lowest power setting. The same ultrasonic instruments were used in group 4 at an intensity level midway between the lowest and highest power settings. All roots were then etched with 37% phosphoric acid to remove the smear layer before they were placed in a fluorescent dye (Eosin Y) solution for 30 min. The specimens were analyzed for structural alterations using a confocal microscope. Thereafter, serial histological sections of 6-μm thickness obtained from the most apical 2 mm and at the 3-mm and 4-mm levels were stained with hematoxylin and eosin. The sections were examined for the number, width, length, and depth of fractures under light microscopy at ×40 and ×100 magnification. The data of the histologic analysis up to the 2-mm levels are listed in Table 8. The control group and the group with the bur preparations had significantly fewer fractures than both ultrasonic groups. Also, the fracture width was significantly smaller in the control group compared to the findings in both ultrasonic groups. However, no differences were found for crack length or depth between the four groups. At the 3- and 4-mm levels, only the presence or absence of fractures was recorded, and no significant differences were found between the four groups.

Calzonetti et al. (38) investigated the incidence of microfractures following root-end preparations in cadaver teeth. *In situ* impressions were used for SEM analysis of root-face alterations. The canals of 52 roots of bilaterally matched teeth were prepared and obturated with gutta-percha and sealer. After 7 days, flaps were reflected and roots were exposed following osteotomy. Root ends were then resected 3 mm from the apex and flushed with 35% phosphoric acid. Using customized minitrays, polyvinylsiloxane impressions were made of the cut root faces before root-end cavity preparation. Cavities were prepared using two different ultrasonic instruments (AP4–90, Enac; and CT-1, EIE). The tips were activated with water coolant for 2 min. Thereafter, impressions were taken as described above. Pre- and postoperative impressions were sputter-coated with platinum subsequently examined under a stereomicroscope (×20) and with a scanning electron microscope (×25, ×50, ×100). Root faces showed some irregularities and grooves due to the ultrasonic tip "skidding". However, no microfractures were seen in any of the specimens. The authors concluded that under the conditions of the study, ultrasonic root-end cavity preparation did not cause root dentin microfractures in endodontically treated teeth.

Discussion

Since the introduction of microsurgical retrotips, the majority of experimental studies on these instruments have evaluated root-end alterations possibly induced by apical instrumentation. All eight studies addressing this subject were *in vitro* studies (20, 32–38). One study was performed in human cadavers (38), while the other seven were conducted in extracted human teeth. It is difficult to transfer the results obtained from extracted teeth to the completely different environment of the clinical situation. The periodontal ligament may act as a dampening and absorbing factor preventing the propagation of cracks following vibratory root-end preparation with sonics or ultrasonics. It has also been claimed that tooth desiccation and brittleness following extraction and SEM preparation may produce artifactual microfractures (38).

Calzonetti et al. (38) found no cracking formation in ultrasonically prepared root ends in cadaver teeth including smaller roots of molar teeth. However, it must also be mentioned that the retrotips were activated at low power settings and no data were given for the depth of the preparations. In fact, the CT-1 tip used in one group has been shown to have a low oscillation amplitude with a low cutting ability (21). Under the limitations mentioned above for *in vitro* studies using extracted human teeth, the results of Calzonetti et al. (38) were corroborated by the study of Waplington et al. (35) in which efforts were made to obtain standardized 3-mm deep cavities. Again, no microfractures were observed with ultrasonic retrotips (CT-1 and 2, EIE) tested over a full power range. However, significantly more chipping of the cavity margins were observed in ultrasonic than in bur preparations. This finding was corroborated by Lloyd et al. (34), who also found little evidence of chipping in bur preparations, while sonic preparation produced significant chipping of the cavo-margins. However, it is questionable whether this surface alteration alters the success rate of clinical treatment since the chipping is shallow and does not extend into the cavity. In addition, removing more tissue in the plane of resection can easily refine a chipped cavity margin.

The depth of possible microfractures was evaluated histologically by Min et al. (37). The observed cracks (maximum depth 1.74 mm) never reached the depth of the cavity (2 mm) following ultrasonic root-end preparation. It is important that cracks present in 50% of the resected teeth without apical preparation had a depth of 0.65 mm. It cannot be excluded with certainty that these preexisting cracks propagated the development of deeper cracks following ultrasonic instrumentation. The role of preoperative cracks on the success of periradicular surgery warrants further investigation. The use of extracted teeth limits the interpretation of the results because of the absence of periodontal support. A better approach would be to do an experimental *in vivo* study in a suitable animal model.

5. Fracture of microinstruments

Walmsley et al. (39) investigated whether the breakage of ultrasonic root-end preparation tips is related to the tip design. Ten different tips were tested in an ultrasonic unit (Enac) at the highest power setting. Tips were evaluated by SEM before and after completion of the experiment. Extracted human teeth were instrumented, but left unobturated. The roots were then resected 2–3 mm from the apex. To ensure that a constant load was applied while the tip was activated, each tooth was attached on a pan balance. Root ends were prepared for three 5-min periods with an initial load of 100 g that was increased by 100 g for each preparation period. Two retrotips and an amalgam condenser tip broke while two other instruments demonstrated bending of the working tip. All broken instruments had a working tip angle greater than 45°. Breakage always occurred approximately 2–3 mm from the end at a bend in the retrotip.

Discussion
A single study (39) addressed the problem of instrument fracture when ultrasonically driven microsurgical instruments were used for root-end cavity preparation. Angulation of retrotips increases the transverse oscillation and decreases the longitudinal oscillation, putting the greatest strain on the bend of the instrument. It is therefore recommended not to put excessive load on the activated retrotips. Walmsley et al. (39) also suggested reducing the angulated design and producing thicker instruments to resist breakage. However, a straighter design will restrict access to difficult to reach areas, and thicker instruments prevent instrumentation of fine root canals and isthmuses.

Clinical studies

The first clinical study evaluating ultrasonic root-end preparation was published in 1996 by Sumi et al. (40). They examined clinically and radiographically the outcome of periradicular surgery of 157 teeth in 86 patients. Root-end resection was performed almost perpendicular to the long axis of the root and 3- to 3.5-mm deep apical cavities were prepared with an ultrasonic tip (type not specified). The preparations were filled with gutta-percha and Super-EBA cement. The bony crypt was irrigated with saline containing antibiotics prior to wound closure. A postoperative radiograph was taken 2 or 3 days later. Follow-up examinations including radiographs were performed every 6 months. The follow-up period ranged from 6 months to 3 years. Success was defined as the absence of clinical symptoms and disappearance or regression of the periapical radiolucency compared to the postoperative radiograph. In all, 92.4% of the teeth were classified as successful.

A year later, the same authors published a preliminary report on the use of a specialized ultrasonic tip for root-end preparation with a congruous titanium-inlay for root-end obturation (41). One hundred and eight teeth were treated in 48 patients with follow-up periods ranging from 1 month to 12 months. Again, an almost perpendicular apical resection was performed with subsequent ultrasonic root-end preparation. The cavity was obturated with a titanium inlay and sealed with Super-EBA cement. Further treatment, examinations, and success criteria were identical to the study mentioned before. For 56 teeth, the follow-up period exceeded 6 months and no failures were recorded.

Bader & Lejeune (42) published the first clinical study comparing ultrasonic and conventional root-end preparations. The study comprised 320 teeth assigned to four groups of 80 teeth each. Four different techniques of periradicular surgery were evaluated. Perioperative medication was identical for each group and included amoxicillin for 8 days and a steroid for 3 days. Postoperatively, patients received an analgesic and chlorhexidine mouthwash. The following treatment options were investigated. In groups 1 and 2, a microbur was used for root-end preparation following root-end resection. In groups 3 and 4, root-end preparations were made with ultrasonic tips (EMS). In addition, the exposed radicular dentin in groups 2 and 4 were irradiated with a CO_2 laser for 5 s. All root-end preparations were then filled with IRM. After 12 months, all cases were reevaluated clinically and radiographically. Teeth without clinical signs and showing radiographic healing were classified as successful. Success rates for ultrasonically treated teeth (95% in group 3 and 90% in group 4) were significantly better than those treated with microburs (65% in group 1 and 68% in group 2). The laser treatment had no apparent effect on the success rate.

Rubinstein & Kim (43) investigated the outcome of ultrasonically prepared root ends in a prospective study over a period of 14 months. Ninety-four teeth (32 anterior teeth, 31 premolars, and 31 molars) were subjected to periradicular surgery under a surgical operating microscope. All root ends were resected perpendicular to the long axis and were subsequently prepared with appropriate ultrasonic tips (EIE) to a depth of at least 3 mm. For root-end filling, Super-EBA cement was used in all cases. All patients received antibiotics for 7 days starting 2 days preoperatively. Recall radiographs were taken at 3-month intervals. Criteria for success were clinical function, absence of symptoms, and the presence of a restored lamina dura on the radiograph. A very high success rate of 96.8% was reported at the completion of the study after 14 months. A positive correlation was also observed between the healing time and the smaller osteotomy sizes.

The first longitudinal results with an ultrasonic technique for root-end preparation were reported by Testori et al. (44). In 95 root ends, preparations were made with an ultrasonic tip (EIE) and filled with Super-EBA cement. Previously, 207 apices had been prepared with the standard technique using a small round bur. Root-end preparations in these teeth were filled with amalgam. Therefore, the healing obtained for a certain root-end preparation technique could not be separated from the effect of the root-end filling material. Recall radiographs after a mean follow-up period of 4.6 years (range 1–6 years) were assigned to four healing groups: complete, incomplete, and uncertain healing, and failure. The long-term success rates were 85% for the ultrasonic group and 68% for the conventional group.

von Arx & Kurt (45) published the first clinical study reporting the use of a sonic device for root-end cavity preparation. In a prospective study of 50 teeth, apical preparations were made with sonic and diamond-surfaced retrotips (KaVo SONICretro, KaVo GmbH, Biberach, Germany) following a 0° bevel resection 3 mm from the root tip. The apical preparations were at least 2 mm deep. All root-end preparations were filled with Super-EBA cement. Antibiotics were not routinely administered. Patients were followed for 1 year and standardized radiographs were taken preoperatively, postoperatively and at the completion of the study. Periapical healing assessment was based on anamnestic, clinical, and radiographic criteria and was categorized either as successful, improved, or failing. A mean percentage of 93% was calculated for the osseous regeneration seen on radiographs after 1 year. 82% of all cases were classified as successful, 14% as improved, and 4% as failures.

Discussion

A literature search produced five clinical studies on ultrasonic (40–44) and one study (45) on sonic root-end cavity preparation. Although the number of published clinical articles is not overwhelming, the outcome reported in these studies was extremely good with success rates ranging from 82% to 96.8%. Two studies compared the ultrasonic technique with the conventional bur technique (42, 44). However, neither study is a true comparative investigation, since the surgeons switched to the new technique when it became available, and analyzed the data of bur preparations retrospectively. In addition, Testori et al. (44) used two different root-end filling materials for the two different preparation techniques: amalgam in bur prepared teeth and Super EBA-cement in ultrasonically prepared teeth. In the other "comparative" study, all teeth received IRM root-end fillings (42). Significantly higher success rates of 95% and 90% were reported for the ultrasonic groups, with or without laser treatment, compared to 65% and 67.5%, respectively, for the conventional group.

In general, it is difficult to attribute the high success rates of the reviewed clinical studies solely to the new root-end preparation technique. Parallel to the use of microsurgical instruments for apical preparation, the more frequent use of Super-EBA cement as a root-end filling material and new surgical visibility aids such as the surgical operating microscope may have positively affected the outcome. In fact, all but one study used Super-EBA cement for root-end cavity obturation. It has been demonstrated experimentally and clinically that this cement has properties leading to successful healing when used as a root-end filling material (46–48).

The high success rates reported in the reviewed clinical articles also indicate that possible root-face alterations like cracks or microfractures following sonic or ultrasonic instrumentation do not necessarily compromise healing. The fractures, if present at all, probably do not reach the coronal level of the root-end filling which still provides a hermetic seal to potentially noxious agents within the root canal. Most of these clinical studies also emphasized the advantage of a root-end resection perpendicular to the long axis of the root. The avoidance of an angled root surface decreases the number of dentinal tubules that form patent pathways from the canal following steep beveled resections (49). This seems to be a major factor in successful healing. In this respect, it has been shown that a perpendicular resection requires a shallower root-end filling to prevent leakage (30).

The study by Rubinstein & Kim (43) is of particular interest, because of the high success rate of 96.8% in a study population comprising 66% posterior teeth (33% molars and 33% premolars). The authors noted that 80% of the molars presented with isthmuses. The mesial roots of mandibular first molars presented the highest frequency of isthmuses (90%). The identification of isthmuses by surgical operating microscope and the removal of isthmus tissue using a microsurgical retrotip appear to have been key factors in the high success rate.

The ability to remove isthmus tissue without compromising the thickness of the remaining dentin walls is one of the most essential improvements of using the new microsurgical technique for root-end preparation.

Only one of the reviewed clinical studies evaluated a sonic device for apical preparation (45). Utilizing very strict healing criteria, 82% of the cases were classified as successful. Including the 14% of cases with radiographic improvement, the success rate approximated studies which defined success as disappearance or regression of the periapical radiolucency in the absence of clinical manifestations.

The lack of experimental and clinical studies comparing sonic and ultrasonic root-end instrumentation does not allow us to draw conclusive judgments on which type of device is superior.

Concerns have been raised regarding the production of aerosol and splatter when using ultrasonic or sonic scalers and inserts in periodontal procedures (50–53). No study has so far addressed this topic in periradicular surgery using sonically or ultrasonically powered instruments. A microsurgical retrotip driven by such devices will certainly produce an aerosol containing blood and bacteria, considering the open working field with a reflected flap during periradicular surgery. Studies would seem indicated to determine whether a health hazard exists for patients and office staff during ultrasonic or sonic instrumentation of root-ends in periradicular surgery although the use of universal standard surgical precautions such as gloves, eye protection, masks, and gowns should protect office personnel.

Conclusions

- Experimental *in vitro* studies performed in extracted human teeth and in human cadaver teeth have demonstrated several advantages of ultrasonic or sonic root-end preparation compared to conventional bur preparation. These advantages include a deeper root-end preparation, alignment in the original path of the root canal, and a reduced risk of lingual perforation.
- With respect to the cleanliness of the root-end cavity, ultrasonic preparations demonstrated smaller amounts of smear layer compared to bur preparations. However, the latter showed less superficial debris and better canal debridement of gutta-percha.
- The development of cracks and microfractures following sonic or ultrasonic root-end instrumentation is still controversial. It is unknown whether cracks affect the healing success. However, undisputedly more chipping of cavity margins occurs following sonic or ultrasonic compared to bur preparation.
- Apical leakage studies using a dye tracer showed no statistically significant differences between the two root-end preparation techniques. However, a coronal leakage study with a polymicrobial marker demonstrated a significantly better seal of ultrasonically prepared cavities compared to those made with a bur.
- Only a limited number of clinical studies have been published on periradicular surgery using microsurgical retrotips. All these studies reported high success rates for periradicular healing with follow-up periods ranging from 6 to 14 months.
- No controlled clinical prospective studies or experimental *in vivo* studies have been published comparing the new microsurgical technique to the conventional technique.

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