Ultrasonics in Endodontics: A Review of the Literature

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Abstract

During the past few decades endodontic treatment has benefited from the development of new techniques and equipment, which have improved outcome and predictability. Important attributes such as the operating microscope and ultrasonics (US) have found indispensable applications in a number of dental procedures in periodontology, to a much lesser extent in restorative dentistry, while being very prominently used in endodontics. US in endodontics has enhanced the quality of treatment and represents an important adjunct in the treatment of difficult cases. Since its introduction, US has become increasingly more useful in applications such as gaining access to canal openings, cleaning and shaping, obturation of root canals, removal of intracanal materials and obstructions, and endodontic surgery. This comprehensive review of the literature aims at presenting the numerous uses of US in clinical endodontics and emphasizes the broad applications in a modern-day endodontic practice. (J Endod 2007;33: 81–95)

Key Words

Endodontics, innovations, ultrasonics

The use of ultrasonics (US) or ultrasonic instrumentation was first introduced to dentistry for cavity preparations (1–3) using an abrasive slurry. Although the technique received favorable reviews (4, 5), it never became popular, because it had to compete with the much more effective and convenient high-speed handpiece (6). However, a different application was introduced in 1955, when Zinner (7) reported on the use of an ultrasonic instrument to remove deposits from the tooth surface. This was improved upon by Johnson and Wilson (8), and the ultrasonic scaler became an established tool in the removal of dental calculus and plaque. The concept of using US in endodontics was first introduced by Richman (9) in 1957. However, it was not until Martin et al. (10–12) demonstrated the ability of ultrasonically activated K-type files to cut dentin that this application found common use in the preparation of root canals before filling and obturation. The term endosonics was coined by Martin and Cunningham (13, 14) and was defined as the ultrasonic and synergistic system of root canal instrumentation and disinfection.

Ultrasound is sound energy with a frequency above the range of human hearing, which is 20 kHz. The range of frequencies employed in the original ultrasonic units was between 25 and 40 kHz (15). Subsequently the so-called low-frequency ultrasonic handpieces operating from 1 to 8 kHz were developed (16–21), which produce lower shear stresses (22), thus causing less alteration to the tooth surface (23).

There are two basic methods of producing ultrasound (24–26). The first is magnetostriction, which converts electromagnetic energy into mechanical energy. A stack of magnetostrictive metal strips in a handpiece is subjected to a standing and alternating magnetic field, as a result of which vibrations are produced. The second method is based on the piezoelectric principle, in which a crystal is used that changes dimension as for cleaning of instruments before sterilization (28), currently its main use is for scaling and root planing of teeth and in root canal therapy (15, 28, 29). The concept of minimally invasive dentistry (30, 31) and the desire for preparations with small dimensions has stimulated new approaches in cavity design and tooth-cutting concepts, including ultrasound for cavity preparation (32).

Applications of US in Endodontics

Although US is used in dentistry for therapeutic and diagnostic applications as well as for cleaning of instruments before sterilization (28), currently its main use is for scaling and root planing of teeth and in root canal therapy (15, 28, 29). The concept of minimally invasive dentistry (30, 31) and the desire for preparations with small dimensions has stimulated new approaches in cavity design and tooth-cutting concepts, including ultrasound for cavity preparation (32).

The following is a list of the most frequent applications of US in endodontics, which will be reviewed in detail:

1. Access refinement, finding calcified canals, and removal of attached pulp stones
Access Refinement, Finding Calcified Canals, and Removal of Attached Pulp Stones

One of the challenges in endodontics is to locate canals, particularly in cases in which the orifice has become occluded by secondary dentin or calcified dentin secondary to the placement of restorative materials or pulpotomies. With every access preparation in a calcified tooth, there is the risk of perforating the root or, when incorrectly performed, of complicating each subsequent procedure. A lack of a straight-line access is arguably the leading cause of separation, perforation, and the inability to negotiate files to the radiographic terminus (33).

The introduction of the microscope, access burs, and US (34) has greatly reduced these risks. Microscopic visualization and ultrasonic instruments are a safe and effective combination to achieve optimal results (35–37).

In difficult-to-treat teeth such as molars, US has proven to be useful for access preparation, not only for finding canals, but also for reducing the time and the predictability of the treatment (33, 34).

In conventional access procedures, ultrasonic tips are useful for access refinement, location of MB2 canals in upper molars and accessory canals in other teeth, location of calcified canals in any tooth, and removal of attached pulp stones (35–37).

There are numerous variations of rotary access burs available; however, one of the more important advantages of ultrasonic tips is that they do not rotate, thus enhancing safety and control, while maintaining a high cutting efficiency. This is especially important when the risk of perforation is high.

The visual access and superior control that ultrasonic cutting tips provide during access procedures make them a most convenient tool, especially when treating difficult molars. When locating the MB2 canals in upper molars, US is an excellent means for the removal of secondary dentin on the mesial wall (Fig. 1). When searching for hidden canals, one should remember that secondary dentin is generally whitish or opaque, whereas the floor of the pulp chamber is darker and gray in appearance. US works well when breaking through the calcification that covers the canal orifice. A troughing tip is a good choice for this task (Fig. 2a,b). For these applications, bigger tips with a limited diamond-coated extension should be used during the initial phase of removing calcification, interferences, materials, and secondary dentin, as they offer maximum cutting efficiency and enhance control while working in the pulp chamber (Fig. 2c,d). The subsequent phase of finding canal orifices should be carried out with thinner and longer tips that facilitate working in deeper areas while maintaining clear vision (33, 34) (Fig. 2e).

The diamond-coated tips used in orthograde endodontic treatment (Fig. 2a–e) have shown significantly greater cutting efficiency than either stainless steel tips or zirconium nitride–coated tips, but they have a tendency to break (38). Moreover, thinner diamond-coated tips seem to be able to transmit the oscillation of the ultrasonic unit more efficiently into dentin; this results in a more aggressive cutting action (39). Ultrasonic cutting seems to be significantly influenced by the power setting (39), as larger fragments of dentin are removed at higher power (40), and by the ultrasonic unit type used (39). Therefore, care should be exercised while searching for canal orifices, as aggressive cutting may cause an undesired modification of the anatomy of the pulp chamber.

Removal of Intracanal Obstructions

Clinicians are frequently challenged by endodontically treated teeth that have obstructions such as hard impenetrable pastes, separated instruments, silver points, or posts in their roots (41). If endodontic treatment has failed, these obstructions need to be removed to perform nonsurgical retreatment. Many instruments and techniques have been reported (42, 43). They include appropriate burs (44); special forceps (45); ultrasonic instruments in direct or indirect contact (46–49); peripheral filing techniques in the presence of solvents, chelators, or irrigants (50); microtube delivery using mechanical adhesion techniques (51); and different kits and extractors (52–54).

Ultrasonic energy has proven effective as an adjunct in the removal of silver points, fractured instruments, and cemented posts (55). It has
have shown only limited success, while often causing considerable damage. Techniques and devices have been suggested (67, 68). These techniques for the safe removal of fractured instruments exist, although various approaches have been recommended (57). When these obstructions can be removed, successful treatment or retreatment generally occurs (61). If an instrument can be removed or bypassed and the canal can be properly cleaned and filled, nonsurgical endodontics is a more desirable and conservative approach (62).

Separation of Instruments

Management of a broken instrument requires an orthograde or a surgical approach. The three orthograde approaches are (a) attempt to remove the instrument; (b) attempt to bypass the instrument; and (c) prepare and obturate to the fractured segment (65).

In most cases, removal of broken instruments from the root canal is difficult and often hopeless (66). To date, no standardized procedure for the safe removal of fractured instruments exists, although various techniques and devices have been suggested (67, 68). These techniques have shown only limited success, while often causing considerable damage to the remaining root (61, 68). Complications as a result of these techniques include excessive loss of root canal dentin, ledging, perforation, and extrusion of the fractured instrument fragment through the apex (69). Therefore, many techniques cannot be used in narrow and curved canals (61).

Over the years, different techniques have been proposed for the removal of separated instruments from root canals (44, 57, 60, 63, 66, 70–72). Recent advances in endodontics have led to the development of techniques and devices designed specifically for the safe removal of fractured instruments from deep within narrow curved root canals (73, 74) (Fig. 3). Ruddle (64, 71) proposed a technique for the removal of broken instruments using Gates Glidden drills (size 3 or 4) to prepare a circumferential “staging platform” at the coronal aspect of the obstruction (Fig. 4). Attention must be paid during preparation of a staging platform, because a size 3 or 4 Gates Glidden may perforate or weaken a root, for instance the mesial (74, 75) and distal root (76) of mandibular molars, the distobuccal and mesiobuccal roots of maxillary molars (77), and central and lateral mandibular incisors (78). Their use seems safe in central and lateral maxillary incisors (77), maxillary and mandibular canines (77), and mandibular premolars (78, 79). The literature is controversial with regard to maxillary premolars because of their particular anatomy (80–82).

Radiographic evaluation of the residual dentin thickness during preparation of the platform can be misleading because of the inaccuracy of radiographic interpretation. Overestimation may lead to over-preparation of the canal or root perforation (83). Recently, it has been shown that preparation of staging platforms was best accomplished with the use of modified LightSpeed files (84). The inability to see the instrument with direct vision and the difficulty of creating a staging platform, as well as the use of US in curved roots, has contributed to a lack of success in removing fractured instruments under these circumstances (57, 61, 63, 69, 84).

Root Canal Posts

Nonsurgical endodontic retreatment of teeth restored with intraradicular posts continues to present a challenge because of the inherent...
difficulties of removing posts without weakening, perforating, or fracturing the remaining root structure (85–88). Many techniques and instruments have been described to aid in the removal of posts (52, 85, 88–94).

US has provided clinicians with a useful adjunct to facilitate post removal with minimal loss of tooth structure and root damage (48, 95–97). Many studies have focused on the removal of metallic posts; however, retreatment of fiber-reinforced composite posts cemented with adhesive systems presents a new challenge in cases in which endodontic treatment has failed (98). Different bur kits have been proposed to remove fiber posts (99, 100); however, the preservation of maximum root structure requires the use of specific ultrasonic

![Figure 3](image3.png)

**Figure 3.** NiTi rotary instrument separated in the distobuccal canal of an upper first molar (a). The fragment was removed using ultrasonic tips, and the root canals were successfully negotiated to the apex (b) and cleaned, shaped, and filled (c). The tooth was subsequently restored with two fiber-reinforced posts, one in the palatal and one in the mesiobuccal canal, followed by a dual-cure resin composite core buildup (c).

![Figure 4](image4.png)

**Figure 4.** Gates Glidden bur modified by cutting it at the maximum diameter viewed from an apical (a) and lateral direction (b). This permits the preparation of a platform at the extruded portion of the fragment to be removed.
tips (Fig. 2b) and adequate magnification. The disruption of the composite structure through the action of ultrasonic vibration seems to be the most effective technique in fiber post removal (101). Esthetic white posts are more difficult to remove because of their black color, whereas the black carbon fiber posts clearly contrast to dentin. Removal is done in a dry field using a continuous stream of air with direct vision of the ultrasonic tip and the coronal portion of the post, alternated by air and water spray to clean the remnants of fibers and dentin.

It is important that the entire composite material that was used in luting procedure be removed. If the adhesive procedure was done well, removal of the tenaciously attached adhesive materials will be difficult, and high magnification must be used to guide the ultrasonic tip to selectively remove the attached composite material. If the ultrasonic tip leaves behind gray streaks, it is a clear indication that resin composite or resin composite cement is still present.

The need of consuming fiber posts is based on the fact that the viscoelastic nature of composite resin dampens vibrations and adsorbs energy (102). Conductance of vibration forces within a post is proportional to the square root of the modulus of elasticity of the post material (103). Therefore, a fiber-reinforced composite post with a significantly lower modulus of elasticity than stainless steel or titanium (104, 105) conducts vibration less efficiently (97). Combining the low modulus of elasticity of post materials with composite resin cements causes a change in the effectiveness of US as an aid in post removal (97). Resin cements are not friable and do not tend to produce microfractures due to ultrasonic vibration (106). It was suggested that the absence of a water spray seems to increase the action of US when applied to posts cemented with resin cements, possibly because of the increase in heat (107). This is helpful information, as it has been observed that the capacity of adhesion of a resin cement, and consequently mechanical retention, gradually reduces with the number of thermal cycles (108).

Several studies point to the fact that ultrasonic vibration of posts facilitates their removal while conserving tooth structure and reducing the possibility of fractures or root perforations (55, 86–88, 95, 102, 109). Several studies have demonstrated a reduction in tensile failure loads of intraradicular-cemented posts after ultrasonic vibration (55, 86–88, 95, 102, 107, 109–116). Other studies did not find a difference (97, 117, 118). Bergeron et al. (119) and Garrido et al. (107) suggested that heat generation might have been responsible for the increase in retention after ultrasonic vibration, as no water-cooling was used during the procedure. As to the fiber-reinforced root canal posts, Bergeron et al. (119) and Hauman et al. (97) further hypothesized that the lower modulus of elasticity of the titanium compared with that of the stainless steel may have been responsible for the ineffectiveness of US in reducing post retention.

Using US involves the initial removal of restorative material(s) and luting cement around the post, followed by application of the tip of an ultrasonic instrument to the post (Fig. 5a–g). Ultrasonic energy is transferred through the post and breaks down the cement until the post loosens (107) (Fig. 5b). This method of post removal minimizes loss of tooth structure and decreases the risk of tooth damage (48, 95, 97).

When removing a post, it is critical to break the seal between the post and the tooth structure. It has been recommended to reduce the extraradicular portion of the post to the same diameter as the intraradicular portion (118) to reduce the necessary tension to remove it (114). In some cases this can be accomplished with a surgical-length round bur, a technique not without danger. Once trephining around the post has been done, a basic spreader tip placed in the trough is a good choice (Fig. 2b). This will further break down the integrity of the cement or resin, usually resulting in loosening of the post. Alternatively, the ultrasonic tip can be placed on the post or on a hemostat that is clamped to the post. The tip should not be too thin, because small-diameter ultrasonic instruments are weak and more predisposed to breakage, especially when they are used for a long time on a resistant material (Fig. 2f). On the other hand, the tip should not be too large, because it must be kept in intimate contact with the post when it is moved counterclockwise around the post (98) (Fig. 2a, b). Usually, the ultrasonic unit is set to the maximum power level (97, 107, 111, 114, 119, 120). Because this generates heat, especially over longer periods of application, cooling with a water spray is of the essence. When heat is transferred to a metal post, it can be transferred to the periodontal ligament, causing damage (121), even with the use of a piezoelectric ultrasonic handpiece (122). There is in vitro evidence that application of US to metal posts, even with adequate water-spray cooling (120), can lead to rapid in-

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**Figure 5.** Preoperative image (a) and radiograph (b) of a mandibular first molar with three gold cast posts and cores and full-crown coverage. The patient presented with pain and swelling. The preoperative diagnostic radiograph revealed signs of radiolucency in the furcal area toward the mesial root. The metal-ceramic crown was sectioned (c) and removed (d), and the gold cast posts were separated to facilitate their removal (e, f). The three posts were removed (g) by vibrating with an ultrasonic tip to disrupt the cement seal (h). This clinical image revealed two perforations in the mesial root canal (b). Perforations were repaired using gray MTA compacted with an ultrasonic tip (i). Root canals were filled with gutta-percha and sealer (j), and the coronal portions of the mesial canals were further filled with MTA to enhance the seal of the perforations (m). Postendodontic preprosthetic restoration was performed using a fiber-reinforced post in the distal canal and a dual-cure resin composite buildup material (n).
creases in temperature of the root surface, causing damage to the periodontal ligament (122, 123).

The relative ease of removing prefabricated parallel posts with the use of US is probably related to their design, as they do not adapt well to the coronal third of most root canals. This allows for easy breakdown of the cement in the coronal third and subsequent shifting of the fulcrum point toward the apical end of the post. As the fulcrum point shifts apically, the ultrasonic vibrations start to move the post about this point and within the space created in the coronal third. This movement helps to break down the cement/post interface toward the apical end of the post in conjunction with breakdown within the cement itself.

In cases in which the post has a tight fit with adequate length and diameter, and with limited access to the coronal portion, the effect of US alone may be limited or even ineffective. In these situations the clinician has to consider other treatment options (118).

In a clinical study by Smith (112), the mean time required to dislodge posts with an ultrasonic instrument was approximately one-quarter of that reported for in vitro studies (97). This may be explained in that, in a clinical setting, the reason for removing posts is due to infected root canals frequently caused by coronal leakage, leading to breakdown of the cement, retaining both the coronal restoration and the post. In clinical practice posts should therefore be easier to remove than under laboratory conditions (97). Clinically, after removing all circumferential restorative materials, the majority of posts can be safely and successfully removed within approximately 10 minutes (102, 110). However, certain posts resist removal, even after 10 minutes of ultrasonic activation (98).

**Silver Points and Fractured Metallic Posts**

Several studies have shown that retrieval of silver cones can be performed with traditional techniques using hand instruments and particular devices and extractors (45, 50, 51, 66, 124, 125).

Other techniques utilize ultrasonic energy in cases of intracanal obstruction and consume the obstruction with particular ultrasonic tips. This predominately applies to silver points inside canals, which cannot be bypassed by conventional methods (62, 126).

The traditional clinical procedure to remove root canal posts or silver points fractured at the orifice consists of exposing the coronal part of the obstacle by cutting an estimated 2.0-mm trough around the oblique point, which can then be removed with a fine Steiglitz forceps or hemostat. At all times, the use of intraoral radiographs is recommended to confirm the position and the remaining length of the obstruction, as well as the thickness of canal walls (47, 64). The time required for removal of a post or silver point is influenced by the nature of the obstruction, its diameter, and location. Semiprecious metals take more time than precious metals. Large-diameter posts are more time-consuming compared with narrow ones (62).

**Increased Action of Irrigating Solutions**

The effectiveness of irrigation relies on both the mechanical flushing action and the chemical ability of irrigants to dissolve tissue (128, 129). Furthermore, the flushing action of irrigants helps to remove organic and dentinal debris and microorganisms from the canal (130). The flushing action from syringe irrigation is relatively weak and dependent not only on the anatomy of the root canal but also on the depth of placement and the diameter of the needle (128, 131, 132). It has been shown that irrigants can only progress 1 mm beyond the tip of the needle (133). An increase in volume does not significantly improve their flushing action and efficacy in removing debris (134, 135). In larger apical canals, the debridement and disinfection of canals is improved (128). However, thorough cleaning of the most apical part of any preparation remains difficult (136). Using thinner needles (30 gauge) may facilitate reaching the apical area directly. Although conclusive evidence is still lacking, the introduction of slim irrigating needles with a safety tip placed to working length or 1 mm short of it is a promising approach to improve irrigant efficacy.

The only effective way to clean webs and fins is through movement of the irrigation solution (137), as they cannot be mechanically cleaned (138). US is a useful adjunct in cleaning these difficult anatomical features. It has been demonstrated that an irrigant in conjunction with ultrasonic vibration, which generates a continuous movement of the irrigant, is directly associated with the effectiveness of the cleaning of the root canal space (22, 137–142).

Acoustic streaming, as described by Ahmad et al. (140), has been shown to produce sufficient shear forces to dislodge debris in instrumented canals. When files were activated with ultrasonic energy in a passive manner, acoustic streaming was sufficient to produce significantly cleaner canals compared with hand filing alone. Similarly, Jensen et al. (143) recommended a vibrating file of small size subjected to a high power setting, as smaller files will be less likely to contact the canal walls.

The flushing action of irrigants may be enhanced by using US (15, 132, 140, 144, 145). This seems to improve the efficacy of irrigation solutions in removing organic and inorganic debris from root canal walls (12, 129, 132, 142, 143, 145–158). A possible explanation for the improved action is that a much higher velocity and volume of irrigant flow is created in the canal during ultrasonic irrigation (129).

The tissue-dissolving capability of solutions with a good wetting ability may be enhanced by US if the pulp tissue remnants and/or smear layer are wetted completely by the solution and become subject to the ultrasonic agitation (145, 159). US creates both cavitation and acoustic streaming. The cavitation is minimal and is restricted to the tip (160). The acoustic streaming effect, however, is significant (161). In fact, the irrigant is activated by the ultrasonic energy imparted from the energized instruments, producing acoustic streaming and eddies (15, 140, 141).

US can also improve disinfection of root canals (148, 149, 162–166), probably because organic tissues entering the streaming field that is generated are disrupted, as proposed by Walmsley (24). Ahmad (167) confirmed that ultrasonically activated files produced streaming patterns close to the file, continuously moving irrigants around, thereby producing shear stress, which can damage biological cells, as stated by Williams (168).

Although the number of surviving colonies was less when ultrasonic activation was used, no technique was able to ensure complete disinfection (130, 145, 161, 169, 170). Cameron (171) postulated that there is a synergistic effect between sodium hypochlorite (NaOCl) and US. The ability of NaOCl to dissolve collagen is enhanced with heat
especially in the apical portion of the post space (197). Cleanliness after post space preparation in endodontically treated teeth, irrigation in vitro was as effective as a K-file in debris removal (196). Surfaces (195) (Fig. 6). The use of a smooth wire during ultrasonic tends to ledge and perforate canal walls because of their sharp cutting contact with the canal walls; therefore, the use of smooth files is recom-

power US with NaOCl was not more effective than NaOCl alone (193, 171, 190–192). It is of interest to note that a combination of low-
solution than one that binds to canal walls (185). Oscillating instrument will cause more ultrasonic effects in the irrigating solution than one that binds to canal walls (185).

US as an adjunct with various irrigating solutions contributes to the removal of the smear layer (12, 145, 155, 176, 181, 186), however, it seems to be less effective in enhancing the activity of EDTA (154, 163, 187–189).

Thirty seconds to 1 minute of ultrasonic activation seems to be sufficient to produce clean canals (157), whereas others recommend 2 minutes (142). Shorter passive irrigation time makes it easier to maintain the file in the center of the canal, thus preventing it from touching the canal walls (157). Syringe delivery of NaOCl every minute was as effective as a continuous flow of NaOCl during 3 minutes of passive ultrasonic irrigation in the removal of dentin debris (135).

For ultrasonic irrigation, the use of medium power was suggested (171, 190–192). It is of interest to note that a combination of low-power US with NaOCl was not more effective than NaOCl alone (193, 194).

Ultrasonic vibration can also be effective when touching the shank of a hand file inserted in the canal. The hand file will transmit vibrations to the irrigant inside the canal, but a greater risk for touching dentinal walls exists. To prevent a dampening effect, sonic or ultrasonic files should not contact the canal walls; therefore, the use of smooth files is recommended (157). In contrast, ultrasonically activated stainless steel files tend to ledge and perforate canal walls because of their sharp cutting surfaces (195) (Fig. 6). The use of a smooth wire during ultrasonic irrigation in vitro was as effective as a K-file in debris removal (196).

Furthermore, US as an adjunct with EDTA enhanced the canal wall cleanliness after post space preparation in endodontically treated teeth, especially in the apical portion of the post space (197).

Ultrasonic Condensation of Gutta-Percha

Ultrasonically activated spreaders have been used to thermoplasticize gutta-percha in a warm lateral condensation technique. In some in vitro experiments, this was demonstrated to be superior to conventional lateral condensation with respect to sealing properties and density of gutta-percha (198–201). Ultrasonic spreaders that vibrate linearly and produce heat, thus thermoplasticizing the gutta-percha, achieved a more homogeneous mass with a decrease in number and size of voids and produced a more complete three-dimensional obtura-

Ultrasonic condensation of gutta-percha: (a) ultrasonic softening of the master cone followed by cold lateral condensation (198); (b) one or two times of ultrasonic activation after completion of cold lateral conden-

Figure 6. SEM image of the instrumentation grooves on the root canal walls created by an ultrasonic file (×1,150).

Warm lateral condensation combines the advantage of having control over the length of the root fill, similar to cold lateral condensation, with the superior ability of a thermoplasticized material to replicate the three-dimensional shape of the root canal (201). From a practical point of view, ultrasonic condensation of gutta-percha is quickly mastered and has several advantages over other warm lateral condensation tech-

placement of sealers with hand instruments (207, 208).

The obturation technique recommended when using the ultrasonic techniques (204, 205) consists of initial placement of a gutta-

placement of MTA. The inherent irregularities and divergent nature of

Placement of Mineral Trioxide Aggregate (MTA)

Witherspoon and Ham (209) described the use of US to aid in the placement of MTA. The inherent irregularities and divergent nature of
some open apices may predispose the material to marginal gaps at the dentin interface. It was demonstrated that, with the adjunct of US, a significantly better seal with MTA was achieved (210). Placement of MTA with ultrasonic vibration and an endodontic condenser improved the flow, settling, and compaction of MTA. Furthermore, the ultrasonically condensed MTA appeared denser radiographically, with fewer voids (210). These results contradicted those of Aminoshariae et al. (211), who concluded from an in vitro study that hand condensation was superior.

The recommended placement method consists of selecting a condenser tip, then picking up and placing the MTA with the ultrasonic tip, followed by activating the tip and slowly moving the MTA material down using a 1- to 2-mm vertical packing motion. Direct ultrasonic energy will vibrate and generate a wavelike motion, which facilitates moving and adapting the cement to the canal walls (Fig. 5i–l). In a case of repairing a defect apical to the canal curvature, Ruddle (41) recommends incrementally placing MTA deep into a canal, then shepherding it around the curvature with a flexible trimmed gutta-percha cone utilized as a plugger. A precured 15 or 20 stainless steel file is then inserted into the material and placed to within 1 or 2 mm of the working length. This is followed by indirect ultrasound, which involves placing the working end of an ultrasonic instrument on the shaft of the file. This vibratory energy encourages MTA to move and conform to the configurations of the canal laterally as well as controlling its movement.

This technique was recommended initially for placing MTA in open and diverging apices, but it can also be used to put the material in root-end cavities, in perforations, and especially in perforations of the floor of the pulp chamber (Fig. 5i–n).

**Surgical Endodontics: Root-End Cavity Preparation and Refinement and Placement of Root-End Obturation Material**

Recent developments of new instruments and techniques have significantly enhanced the treatment outcome in apicoectomy with retrofilling (212). As the prognosis of endodontic surgery is highly dependent on good obturation and sealing of the root canal, an optimal cavity preparation is an essential prerequisite for an adequate root-end filling after apicoectomy (20, 213, 214).

Root-end cavities have traditionally been prepared by means of small round or inverted cone burs in a microhandpiece. In the mid-1980s, standardized instruments and aluminum oxide ceramic pins were introduced for retrograde filling (215), but that system could not be used in cases with limited working space or in teeth with large oval canals. Since sonically or ultrasonically driven microsurgical retrotips became commercially available in the early 1990s (216–219), this new technique of retrograde root canal instrumentation has been established as an essential adjunct in periradicular surgery (217, 220, 221). However, the cutting properties of the retrotips at that time were limited and seemed to be dependent on loading, power setting, and orientation of the tip to the long axis of the handpiece (222, 223). In some retrotips, cooling of the working tip was insufficient, and dentin and bone were at risk of being overheated (20).

The first root-end preparation using modified ultrasonic inserts following an apicoectomy is attributed to Bertrand et al. (224). Others followed, but it was not until 1987 that Flath and Hicks (225) further reported on the use of ultrasouics and sonic for root-end cavity preparation.

Conventional root-end cavity preparation using rotary burs in a microhandpiece is faced with several problems (21, 226, 227), such as a cavity preparation not being parallel to the canal, difficult access to the root end, and risk of lingual perforation of the root. Furthermore, the inability to prepare to a sufficient depth, thus compromising retention of the root-end filling material, means that the root-end resection procedure requires a longer cutting bevel, thus exposing more dentinal tubules and isthmus tissue, of which the latter is difficult to remove. The development of ultrasonic and sonic retrotips has revolutionized root-end therapy, improving the surgical procedure with better access to the root end, resulting in better canal preparation (226–229). Ultrasonic retrotips come in a variety of shapes and angles, thus improving some steps during the surgical procedures (213, 230, 231) (Figs. 7 and 8).

At first glance, the most relevant clinical advantages are the enhanced access to root ends in a limited working space. This leads to a smaller osteotomy for surgical access because of the advantage of using various angulations and the small size of the retrotips (232). However, a number of studies compared root-end preparations made with microsurgical tips to those made with burs. They demonstrated additional advantages of this technique, such as deeper and more conservative cavities that follow the original path of the root canal more closely (221, 233–237). A better-centered root-end preparation also lessens the risk of lateral perforation (236–238). Furthermore, the geometry of the retrotip design does not require a beveled root-end resection for...
surgical access (232), thus decreasing the number of exposed dentinal tubules (20, 239–241) and minimizing apical leakage (242–245). They also enable the removal of ishissus tissue present between two canals within the same root (234, 236, 246–248). It is considered a timesaving technique (234) that seems to have a lower failure rate (20).

The cleaning effect and the cutting ability of ultrasonic retrotips have been described as satisfactory by many authors (222, 223, 235, 249, 250). Furthermore, US produced less smear layer in a retro-end cavity compared to a slow-speed handpiece (214, 221, 233–235, 251).

The refinement of cavity margins that were obtained with the ultrasonic tips may positively affect the delivery of materials into the cavities and enhance their seal (214, 249, 252–254), even if cavities prepared with erbium:YAG lasers have been shown to produce significantly lower microleakage than ultrasonic preparations (255).

In a study by Walmsley et al. (256) the breakage of ultrasonic root-end preparation tips was investigated and attributed to the design of the tip. Increased angulation of retrotips increases the transverse oscillation and decreases the longitudinal oscillation, putting the greatest strain at the bend of the instrument. The authors suggested reducing the angulation and increasing the dimensions of the tip to resist breakage. This may be true, but a straighter design will restrict access and a thicker instrument prevents instrumentation of isthmuses. A controversial issue with sonic or ultrasonic root-end preparation is the formation of cracks or microfractures and its implications for healing success (257, 258). Some studies indicated that this was a possible drawback (23, 238, 253, 259–263). Other studies, however, disputed these findings and did not report a higher prevalence of microfractures (19, 237, 264–272). Khabbaz et al. (237) found that cracks did not correlate directly with the surface area of the root-end surfaces but rather with the type of retrotip used. Preparation with smooth stainless steel ultrasonic tips produced fewer intradentin cracks than diamond-coated stainless steel ultrasonic tips and sonic diamond-coated tips.

The influence of root-end microfractures on the periradicular healing process and apical leakage should be clarified (226). Apical resorption after healing (273) may eliminate the surface defects and contribute to the overall success of treatment. Also, such defects can be removed by finishing resected and retrofilled root-end surfaces (274).

Several in vivo studies reported excellent success rates when the root-end preparation was performed using ultrasonic retrotips (21, 212, 275–283), thus demonstrating that modern surgical endodontic treatment using an operating microscope and ultrasonic tips significantly improves the outcome compared to the traditional techniques (284).

It is recommended that the ultrasonic unit be set at medium power (267) and the cavities be prepared to a depth of 2.5–3 mm (285). This depth allows for a minimum thickness of material that can still provide an effective apical seal (286). The cavity walls should be parallel and follow the anatomical outline of the pulp space (230, 287). It has also been suggested that root-end cavities should be initiated with a diamond-coated retrotip, using its better cutting ability to provide the main cavity. This aids in the removal of root canal obturation materials and should be followed by a smooth retrotip to smooth and clean cavity walls (248).

A condenser tip ultrasonically activated can be utilized for placement of retrograde filling materials, as the ultrasonic vibration is meant to improve the flow, settling and compaction of these materials to root-end dentinal walls. This should improve the delivery of materials into the cavity thus enhancing their seal (210).

Ultrasonic tips can also be used to polish root end material and apical surfaces. Utilizing specific ultrasonic tips for refinement of the external radicular surface may be beneficial in the elimination of extraradicular bacteria, which may be responsible for infection (288, 289).

### Root Canal Preparation

Ultrasonic devices were introduced for use in root canal preparation in 1957 by Richman (9). In 1980, Martin et al. (11, 12) demonstrated the ability of ultrasonically activated K-type files to cut dentin. A commercial ultrasonic unit, designed by Cunningham and Martin (147), was introduced in 1982. Barnett et al. (290, 291) and Tronstad et al. (292) were the first to report on its use in endodontics.

Several studies have shown that ultrasonically or sonically prepared teeth have significantly cleaner canals than teeth prepared by hand instruments (14, 147–149, 293–296). Numerous studies have analyzed the different characteristics of ultrasonically activated files, such as cutting efficiency (11, 12, 297–302), effect on bacteria (168, 303, 304), characteristics of root canal preparation (153, 305–313), mechanical and technical features of files and handpieces (314–318), and clinical implications (319–323).

The results of the above studies can be summarized as being contradictory. They failed to demonstrate the superiority of US or sonicas a primary instrumentation technique, as no improved debridement was accomplished compared with hand instrumentation (22, 140, 152, 160, 176, 194, 291, 324–342). The relative inefficiency of ultrasonic debridement has been attributed to file constraint within the unflared root canal space (343). A modification of the technique in which ultrasonic is activated for a few minutes after hand preparation has instead resulted in greater canal and isthmus cleanliness compared with hand preparation alone (151, 177, 344–346).

Despite the multitude of studies conducted on ultrasonic root canal preparation with ultrasonically activated files, the current consensus is that this is not a viable clinical technique.

### Conclusions

It can be concluded from this review of the literature that US offers many applications and advantages in clinical endodontics. Improved visualization combined with a more conservative approach when selectively removing tooth structure, particularly in difficult situations in which a specific angulation or tip design permits access to restricted work areas, offers opportunities that are not possible with conventional treatment. As a result, access refinement, location of calcified canals, and removal of separated instruments or posts have generated more predictable results. In addition, better action of irrigation solutions and condensation of gutta-percha have benefited from the use of US. Root-end cavity preparation followed by placement of materials in an area that is more often than not constrained has especially improved the quality of treatment and long-term success. Finally, integration of new technologies such as US, leading to improved techniques and use of materials, has changed the way endodontics is being practiced today.

### References


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