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The effect of ultrasonic removal of various root-end filling materials

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Abstract

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Aim To compare residual root-end filling material in apical root-end cavities following their removal with ultrasonic retrotips.

Methodology Thirty single-rooted teeth were filled with Thermafil and AH Plus sealer. Root-ends were resected at 90°, 3 mm from the apex. Root-end cavities were prepared with diamond burs and ultrasonic retrotips and filled with one of three filling materials: group I: Retro-TC (calcium silicate-based cement), group II: IRM (Dentsply, Germany), group III: Vitrebond (3M ESPE, USA). After 30 days of storage, ultrasonic retrotips were used to remove materials from the root-end cavities. The ultrasonic application time was fixed at 60 s. Polyether impressions and replicas of the root-ends were made. Root apices and replicas were examined by one operator under a scanning electron microscope. Remnants of residual materials were evaluated using a four-level scoring system; fractures, smear layer and exposed dentinal tubules were also examined.

Results Forty per cent of the specimens filled with Retro-TC revealed complete removal of the material with exposure of dentinal tubules, whilst 60% contained residual cement. Twenty per cent of specimens filled with IRM were completely devoid of material, whereas 80% had retained material. Ten per cent of specimens filled with Vitrebond retained a moderate amount of material whilst 90% had substantial retention of the material. Statistically significant differences were found ($P < 0.05$) amongst the three groups of materials.

Conclusions Retro-TC was successfully removed in 40% of cases using ultrasonics retrotips for 60 s, whereas IRM and Vitrebond specimens had evidence of retained material in 80% and 90% of all specimens respectively.

Keywords: endodontic retreatment, Portland cement, root-end filling material, ultrasound retro-tip.

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Introduction

When root canal treatment fails, the optimal approach is to undertake conventional retreatment. However, periapical surgery remains an option for management of cases in which retreatment is not possible (Sundqvist *et al.* 1998). The success rate of endodontic surgery has been reported to be over 80% (Zuolo *et al.* 2000, von Arx *et al.* 2001, Rubinstein & Kim 2002, Kim & Kratchman 2006). However, there is little information available regarding the outcome of surgical procedures performed on teeth that have previously undergone periapical surgery (Gagliani *et al.* 2005). Peterson & Gutmann (2001) reported that the success rate of repeat surgery was reduced to 35.7%, whereas a recent

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study demonstrated that surgical retreatment of teeth previously treated with surgery is a valid alternative to extraction (Gagliani *et al.* 2005).

The recent introduction of new root-end filling materials with improved sealing ability and biocompatibility might partially explain the high healing rates achieved by modern surgical techniques (Tsesis *et al.* 2006). A retrospective report on treatment outcomes after root-end filling claimed successful clinical and radiographic healing in over 90% of the cases (Tsesis *et al.* 2006). Lindeboom *et al.* (2005) found no statistically significant differences in the clinical success rates of MTA and IRM when they were employed for root-end fillings in single-rooted teeth, even though IRM is less biocompatible (Yoshimine *et al.* 2007).

It is widely believed that cases that fail post-surgically should be re-operated, if possible (Gagliani *et al.* 2005). However, the removal of root-end filling materials during a second surgical approach has never been investigated.

The structural characteristics, marginal adaptation and sealing ability of new root-end filling materials, such as calcium silicate and Portland-based cements (i.e. ProRoot MTA and other MTAs), have been demonstrated (Gandolfi *et al.* 2007, Camilleri & Pitt Ford 2008). These materials may be considered as viable alternatives to currently available root-end filling materials (Torabinejad *et al.* 1995, Roberts *et al.* 2008).

The purpose of this study was to compare the quality of root-end cavity preparations following ultrasonic removal of filling materials. These root-end filling materials consisted of IRM (Lindeboom *et al.* 2005, Tobón-Arroyave *et al.* 2007), Vitrebond (Chong *et al.* 1995, 1997, Roux *et al.* 2002) and a modified calcium silicate-based cement (Torabinejad *et al.* 1999; Gandolfi *et al.* 2007, 2008) designated as Retro-TC. The null hypothesis tested was that there are no differences in the retention of the three filling materials following their attempted removal from root-end cavities with ultrasonic retrotips.

Materials and methods

Selection of teeth

Thirty single-rooted incisor and canine teeth, extracted for orthodontic/periodontal reasons, were employed in the study. All teeth were thoroughly cleaned and stored in distilled water at 4 °C for no more than 3 months prior to the root-end filling procedures. None of the teeth had root fractures, root caries, evidence of periradicular resorption, previous restoration or root canal treatment. All specimens were examined under 50× magnification using a stereomicroscope (Carl Zeiss, Oberkochen, Germany) to exclude cracks or fractured apices.

Root canal treatment

Following access cavity preparation, the canals were shaped using a crown-down technique with nickel–titanium rotary instruments (NRT, Mani, Inc, Tochigi, Japan). The apical stop of each canal was instrumented to size 40 to facilitate the delivery of endodontic irrigants.

Canals were irrigated between instrumentation with 3 mL of 10% EDTA and 5 mL of 5% NaOCl, delivered from a 3 mL syringe with a 27-gauge needle. After cleaning and shaping, each canal was dried with sterile paper points (Mynol, Milwaukee, WI, USA).

All root canals were filled with a core-carrier obturator (Thermafil, Dentsply Maillefer, Ballaigues, Switzerland) and a root canal sealer (AH Plus, Dentsply DeTrey, Konstanz, Germany). Verifiers (Dentsply Maillefer) were used to confirm the appropriate size of the canal. Each root filled tooth was restored with a provisional dressing (Coltosol, Colténe, Altstätten, Switzerland).

Root-end preparation

After 1 month of storage in phosphate-buffered saline at 37 °C, the apical 3 mm of each root was resected at an angle of 90° to the longitudinal axis of the tooth with a water-cooled diamond bur (FG Intensiv n.D2, Lugano-Grancia, Switzerland). A root-end cavity was then prepared with another diamond bur (FG Intensiv n.200S) in a high speed hand piece and with an ultrasonic retrotip (ProUltra Surgical; Dentsply Maillefer) in a Piezosteril 5 endodontic handpiece (Castellini, Castelmaggiore, Italy).

The depth of the root-end cavity preparation was determined by the length of the retrotip (3 mm). After cavity preparation, the resected surface was examined under a stereomicroscope at 50× magnification to exclude any preparation that exhibited cracks. All root-end examinations were performed by the same investigator who also scored all material remnants. Each group comprised samples of similar sizes and cross-sectional diameters to eliminate root-end cavity dimension as a covariate (Zandbiglari *et al.* 2006). To prevent desiccation, the specimens were stored in Dulbecco's phosphate buffered solution (PBS) and were only removed for short periods during canal preparation and filling (Çalişcan 2005).

Root-end filling

The teeth with resected apices were randomly divided into three groups ($n = 10$) with respect to the root-end filling material used:

1. Retro-TC, a white Portland cement (thermally and mechanically treated) mixed with anhydrous calcium sulphate, calcium chloride and phyllosilicate (designed and prepared at the Department of Earth Sciences, University of Bologna);

2. IRM (Dentsply DeTrey, Konstanz, Germany);

3. Vitrebond (3M ESPE, St. Paul, MN, USA) light-cured for 20 s.

The filling materials were mixed according to the manufacturers' recommendations and placed in the root-end cavities using a microspatula and a stainless steel condenser (ASA Dental, Bozzano, Italy). The excess root-end filling material was removed with the microspatula. Specimens were placed immediately, prior to setting, in PBS for 30 days at 37 °C.

Replica technique

After 30 days of storage, a first impression of each root-end filling was obtained to avoid any artefacts induced by polishing procedures. The apices were then gently polished with silicon carbide paper disks under water irrigation. They were subsequently treated for 10 s with 5% NaOCl to remove bacterial contaminants. A low viscosity polyvinyl siloxane (President Jet Light, Coltene, Alstatten, Switzerland) was used to take impressions of the polished fillings, from which polyether replicas (Permadyne Garant, 3 mol L^{-1} ESPE, St. Paul, MN, USA) were prepared from the polyvinyl siloxane negative replicas as a mould for interfacial gap and marginal adaptation evaluation by scanning electron microscopy (SEM).

Root-end filling removal and second replica fabrication

Root-end filling materials were removed using diamond ultrasonic retrotips (ProUltra Surgical Dentsply Maillefer. The application time of the ultrasonic tips was 60 s. A feather-like back-and-forth motion was applied with slight coronal pressure with water cooling (Tobón-Arroyave *et al.* 2007). The procedure was completed under an operating microscope (Carl Zeiss, Oberkochen, Germany) at 25× magnification. After 60 s, a second replica of each cavity was obtained, as described previously.

SEM and image analysis

All tooth specimens were then fixed in 4% glutaraldehyde in 0.2 mol L^{-1} cacodylate buffer for 4 h, rinsed in cacodylate buffer, dehydrated and gold-sputtered. External and internal surface morphology of the root apices was investigated under SEM (JSM-5400, JEOL, Tokyo, Japan). The presence of smear layer, open/closed tubules, dentine fractures and remaining root-end filling material were scored using the micrographs up to 3500× magnification. The amount of residual restorative materials in the root-end cavities was scored by one examiner at 50× magnification.

Measurement of punch-shear strength of materials

To determine the intrinsic cohesive strength of each of the three filling materials, thin disks of the materials were prepared for measurement of punch-shear strength (Xiao *et al.* 2007). The Retro-TC and IRM were mixed with a liquid-to-powder ratio of 1 : 3. Vitrebond was used according to the manufacturer's recommendations, and light-cured for 20 s with an LED curing unit (Elipar FreeLight 2, 3 M ESPE) with an output intensity of 600 mW cm^{-2}. Each cement was placed inside a Teflon mould that was 15 mm in diameter and 0.8 mm thick. The mould was placed over a Mylar strip on top of a glass slab. The surface of the material was then covered with another Mylar strip and a glass slide. The assembly was secured with binder clips so that excess material was expressed laterally from the surface and bottom Mylar strips. The assemblies were transferred to a humidity chamber and stored under 100% relative humidity for 48 h. The surfaces of each material were polished with 800-grit silicon carbide paper under water to remove excess material until the thickness was 0.4 mm. The punch-shear strength of the material was determined by the push-out strength of the material after 1 month of incubation in PBS. To prevent microbial growth, 0.02% sodium azide was also included in the PBS. Prior to testing, the exact thickness of each disk was measured using a pair of digital calipers. A 0.7 mm diameter carbon steel cylindrical plunger was used for the push-out test. The plunger was attached to a 100 N load cell that was connected to a universal testing machine (Vitrodyne V1000; Liveco Inc, Burlington, VT, USA). The punch-shear device consisted of a clear Plexiglas platform with a vertical cylindrical channel, which served as the support for the disk and provided space for the vertical movement of the plunger through the restorative material (Fig. 1). As the plunger forced its way through the material, it created shear stresses between the edges of the plunger and the support hole. Those shear stresses created cracks in the material when the shear stress exceeded the cohesive strength of the material. These cracks propagated through the thickness of the material resulting in the ejection of a core of the material.

The punch-shear strength was computed by dividing the maximum load (N) derived from the load-displacement curve by calculating the surface area of the hole (mm^2) and expressed in megaPascals (MPa). The results were statistically compared using the Kruskal–Wallis test followed by the Dunn's multiple comparison test. Statistical significance was set in advance as $\alpha = 0.05$.

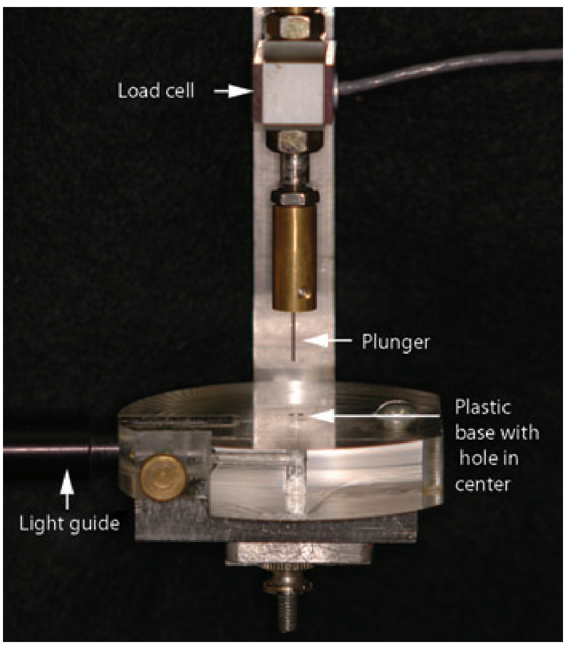

Figure 1 The punch-shear testing apparatus used to estimate the cohesive strength of restorative materials. A 0.7 mm thick disk of material was centred over the hole and a plunger was used to force a plug of material from the disk into the underlying hole.

Scoring system

A four-level scoring system was used to score each specimen (Fig. 2). Each root-end cavity was evaluated in terms of empty or filled area and cleanliness of the cavity floor. Score A (Fig. 2a) was assigned if the root-end cavity was completely empty and the cavity floor was completely free from root-end filling material and had smooth dentine surfaces. Score B (Fig. 2b) was applied if the material was removed from at least one-half of the area of the cavity floor. Score C (Fig. 2c) was assigned if the material was removed from less than one-half of the area; the cavity floor was partially visible and the dentine surface was rough and irregular. Score D (Fig. 2d) was assigned if residual root-end material filled the entire area of the cavity and prevented detection of the cavity floor even though some material had been removed.

In addition, all images were scored by one operator for evidence of the presence of a smear layer and exposed dentinal tubules (both scored as present or absent) within the root-end cavity of each specimen.

Statistical analysis

The material removal scores A–D for the ten specimens in each group were analysed using the Kruskal–Wallis test, which assumes that in this ordinal data, A > B > C > D. Multiple comparison were performed using Dunn's test at $\alpha = 0.05$. To score the presence (+) or absence (−) of smear layers and open tubules on the dentine exposed by removal of the three filling materials, the Fisher-Freeman-Halton test with mid-*P* correction was used at a significance level of 0.05.

To analyse the punch-shear strength of the three materials, a one-way ANOVA was used seeking to identify significant differences amongst the three materials. Tukey's multiple comparison test was used to isolate those materials that were significantly stronger from the others at $\alpha = 0.05$.

Results

Material removal scores (A–D) obtained for each material are summarized in Table 1. The Kruskal–Wallis test revealed that there was a significant difference ($P = 0.002$) amongst the materials. Multiple comparisons (Dunn's test) identified that there were significant differences ($P < 0.05$) in the degree of removal of Retro-TC compared with Vitrebond, and

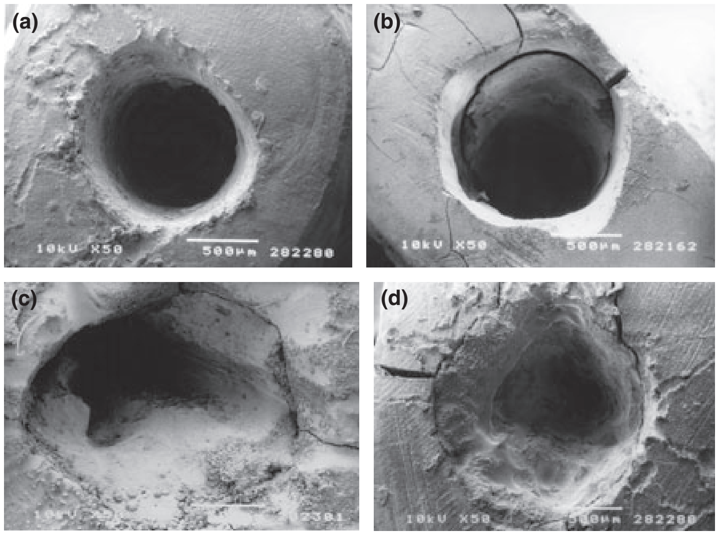

Figure 2 (a, b, c, d) Score A: (a) no root-end filling material detected, cavity floor completely free from root-end filling material and smooth dentine surfaces of the cavity. Score B: (b) root-end filling material removed from at least one-half of the area and cavity floor completely free from root-end filling debris. Score C: (c) material removed from less than one-half of the area, cavity floor partially visible and rough and irregular dentine surface. Score D: (d) residual root-end material present in the entire cavity and cavity floor not visible.

Table 1 Removal score of root-end filling materials

	No. teeth with removal scores of A–D				
	A	B	C	D	Statistical significance
Retro-TC	4	4	2	0	a
IRM	2	3	5	0	a
Vitrebond	0	1	7	3	b

Score A, no retained filling material; Score B, <25% of residual filling material remained; Score C, >50% of cavity remained filled with residual material; Score D, >75% residual filling material retained around the circumference of the cavity. Groups identified by different lowercase alphabets are significantly different ($P < 0.05$).

between IRM and Vitrebond ($P < 0.05$) but that there were no differences between Retro-TC and IRM ($P > 0.05$).

Group I: Forty per cent (i.e. 4 out of 10 specimens) of the retreated specimens had no remaining Retro-TC left in the cavities and many dentinal tubules were exposed. Forty per cent of specimens had some cement remaining and 20% had more than half of the cavity covered with residual cement (Table 1). In the dentine that was exposed by removal of Retro-TC material, 70% of the cavities had smear layer covering the exposed dentine, whilst 80% had open tubules (Table 2). That is, some of the exposed dentine was covered with smear layer, whilst adjacent areas exhibited open tubules (Table 2). Only one specimen had visible cracks after root-end filling removal. Figure 3a shows the complete removal of Retro-TC from the root-end cavity, whilst Fig. 3b shows the axial wall of the same specimen. There was no trace of filling material or smear layer on

Table 2 Appearance of dentine surface following ultrasonic removal of root-end filling material

	1	2	3	4	5	6	7	8	9	10
	Teeth showing presence of smear layer on exposed dentine (+, presence of smear layer; –, absence of smear layer)									
Retro-TC	+	–	+	+	+	–	+	+	–	+
IRM	+	+	–	+	+	+	+	–	+	+
Vitrebond	–	–	+	–	–	–	+	–	–	–
	Teeth showing presence of open tubules in exposed dentine (+, presence of open tubules; –, absence of open tubules)									
Retro-TC	+	+	–	+	+	+	+	+	–	+
IRM	+	–	+	+	+	+	+	–	+	+
Vitrebond	–	–	+	–	–	+	–	–	–	–

Percentage is referred to the fraction of specimens revealing the presence of smear layers or open tubules, not the surface area exhibiting smear layer or exposed tubules. That is, 70% of specimens filled with Retro-TC exhibited evidence of smear layers on exposed dentine and 80% of them also exhibited open dentinal tubules. These percentages were lower in specimens filled with Vitrebond because very little dentine was exposed because the material was difficult to remove.

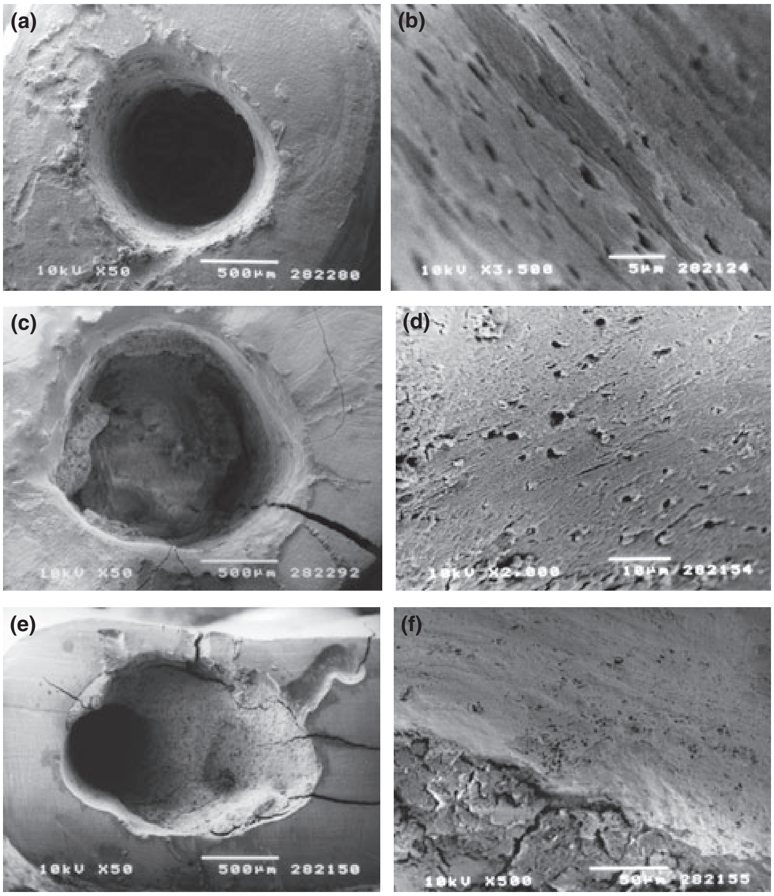

Figure 3 (a,c,e) SEM micrographs at 50× magnification showing different samples filled with Retro-TC prior to retreatment with ultrasonic retrotips. The top figure was scored as A; the middle figure as B and the bottom figure as C. (b,d,f) High magnification SEM revealed dentinal walls following ultrasonic removal of root-end-filling materials. The top figure shows many open tubules free of smear layer. The middle figure shows some open tubules and many tubule orifices covered with smear layer. The bottom figure shows dentine covered with Retro-TC cement.

the dentine and most of the tubule orifices were open. Figure 3a was scored as category 'A'. Figure 3c,e show two more specimens that had been filled with Retro-TC. Some residual Retro-TC material was seen adhering to the cavity in both specimens. Figure 3c was scored as 'B' and Fig. 3e as 'C'. Figure 3d shows the axial wall of most of the cavity was free of retained filling material. The dentine had many open tubules but there was evidence of a smear layer obscuring some tubule orifices. Figure 3f shows the axial surface of the cavity was covered with a thick smear layer.

Group II: Twenty per cent of retreated specimens had complete absence of residual IRM, whilst 80% of specimens had moderate amounts of retained IRM (Table 1). In those specimens where the restorative material was lost and dentine was exposed, 80% of them had smear layer covering the dentine, whilst 60% had exposed dentinal tubules (Table 2). Two specimens had cracks on the cavity margins. Figure 4a,c,e show three specimens that had been filled with IRM. All three specimens exhibited various degree of IRM retention. Figure 4a was scored as 'B', Fig. 4c as 'C' and Fig. 4e as 'D'. When the axial wall of the cavities was examined, Fig. 4b shows clean dentine with open tubule orifices. Figure 4d shows most of the dentine was covered by IRM. Figure 4f reveals dentine was covered by a smear layer. No tubule orifices were observed in that specimen.

Group III: Ten per cent of retreated specimens had a small amount of retained Vitrebond cement, whilst 70% of the cavities exhibited large amounts of residual Vitrebond. Thirty per cent of the Vitrebond-filled specimens had scores of D (Table 1) meaning that the material covered the entire floor of the cavity. Figure 5 shows three specimens filled with Vitrebond. Attempts to remove the resin-modified GIC ultrasonically within 60 s left retained material in all three specimens (Figs 5a,c,e). Figure 5a was scored as 'B' and Fig. 5c,e as 'D's. Examination of the axial wall revealed residual Vitrebond on all surfaces (Fig. 5b,d,f). As so little dentine was exposed, only 20% of specimens revealed the presence of smear layer or exposed dentinal tubules (Table 2).

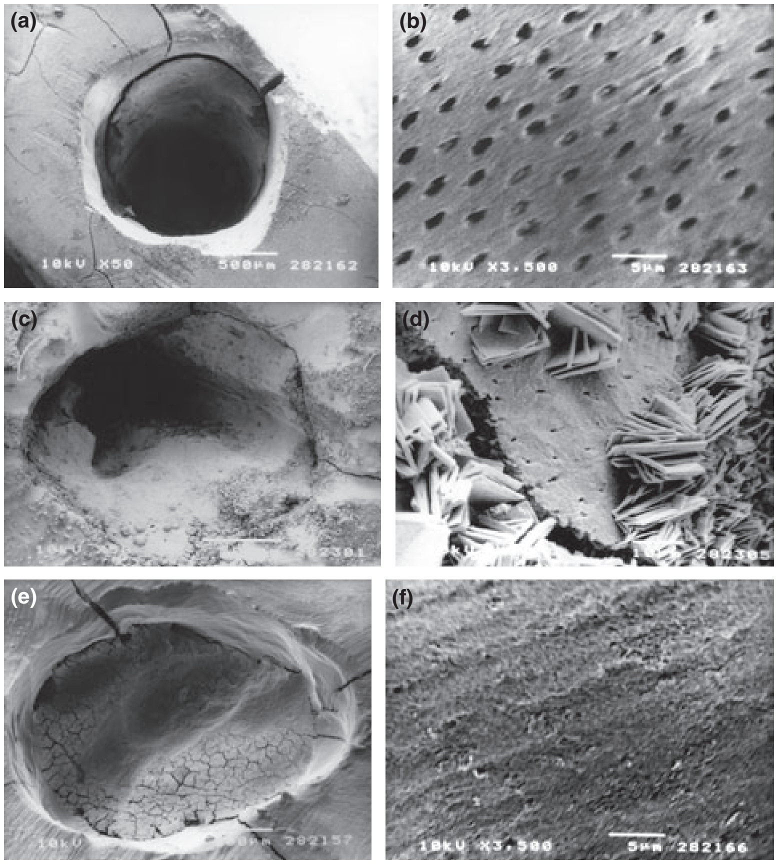

Figure 4 (a,c,e) SEM micrographs at 50× magnification illustrating samples filled with IRM prior to removal of root-end filling material with ultrasonic retrotips. The top figure revealed small-medium amounts of IRM, and was scored as B; the middle left specimen was scored as C, the bottom left as D. (b,d,f) High magnification SEM revealed the surface of root-end cavity following ultrasonic removal of root-end-filling materials. The top right figure shows very clean dentine with no smear layer or smear plugs, and with all tubule orifices open. The middle right SEM shows the dentinal tubules orifices covered with IRM. The bottom right image shows the cavity walls covered with a thick smear layer.

When the presence (+) or absence (–) of smear layer and open tubules were compared on the dentin exposed by removal of the three filling materials, a statistically significant difference was found amongst the three materials in terms of the presence or absence of smear layer ($P = 0.019$), with Vitrebond demonstrating a significantly lower percentage of teeth with a smear layer than IRM (20% vs. 80%). Retro-TC did not differ significantly from either Vitrebond or IRM in terms of percentage of teeth with a smear layer. A statistically significant difference was also found amongst the three materials in terms of the presence or absence of open tubules ($P = 0.035$), with Vitrebond demonstrating a significantly ($P < 0.05$) lower percentage of teeth with open tubules than Retro-TC (20% vs. 80%). IRM did not differ significantly from either Vitrebond or Retro-TC in terms of percentage of teeth with open tubules ($P > 0.05$).

When the punch-shear strength of the three filling materials were compared (Table 3), the lowest strength was obtained with Retro-TC (14.1 ± 0.7 MPa), an intermediate strength was obtained with IRM (21.3 ± 2.9 MPa) and the highest strength was seen in Vitrebond (37.9 ± 4.7 MPa). All of these materials were statistically different from each other (Table 3).

Replica analysis demonstrated an absence of root cracks on the cavity margins after initial root-end cavity preparation. After root-end filling removal, four roots exhibited cracks: one specimen in group I, two specimens in group II and one specimen in group III.

Discussion

The overall objective of this study was to compare the amount of residual root-end filling material remaining in root-end cavities following attempted removal by ultrasonic retrotips. The general findings were that none of the cements were removed predictably, but that the Retro-TC material was completely removed in significantly ($P < 0.05$) more specimens than the other materials. None of the specimens restored with Vitrebond was completely cleared of remnant material and in 70% of those restorations, half of the material adhered to the cavity walls after 60 s of ultrasonica-

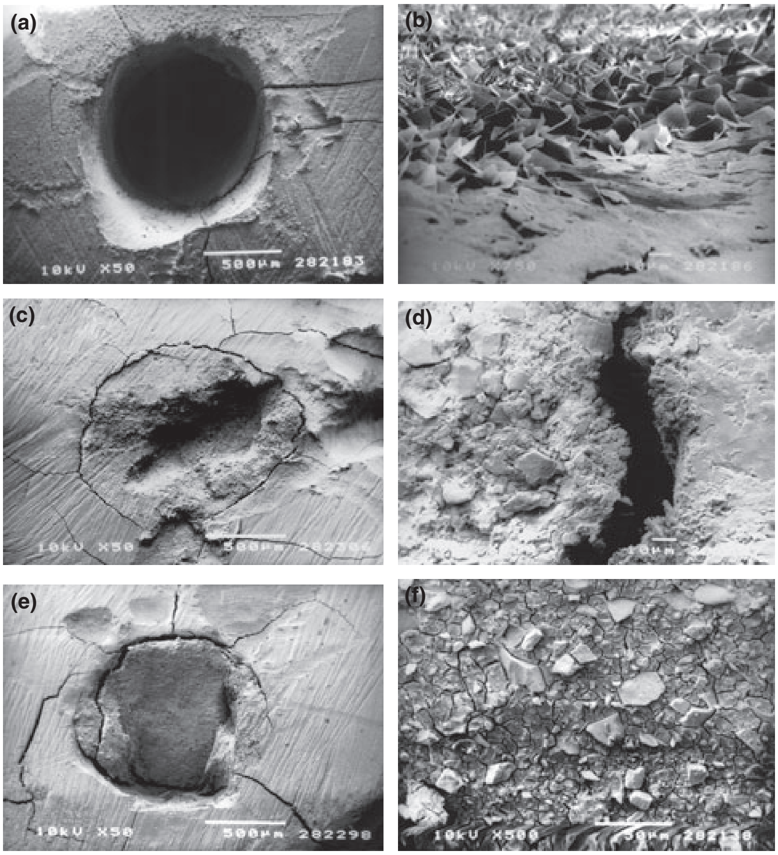

Figure 5 (a,c,e) SEM micrographs at 50× magnification showing samples filled with Vitrebond prior to retreatment with ultrasonic retrotips. The top left specimen was scored as B. The middle and bottom left revealed the entire circumference of the cavity contained residual Vitrebond material and was scored as D. (b,d,f) High magnification SEM revealed the root-end surface following ultrasonic removal of root-end filling materials. The top right figure shows the walls of the cavity were covered by crystalline Vitrebond. The middle and the bottom right also shows dentinal walls covered with Vitrebond.

Table 3 Punch-shear strength of root-end filling materials

Root-end filling material	Punch-shear strength (MPa)*
Retro-TC	14.1 ± 0.7[a]
IRM	21.3 ± 2.9[b]
Vitrebond	37.9 ± 4.7[c]

*Values are mean ± standard deviations. Values identified by different alphabets are significantly different ($P < 0.05$).

tion. These results require rejection of the null hypothesis that there are no differences in the retention of the three filling materials following their attempted removal from root end cavities with ultrasonic retrotips.

The results clearly demonstrate that the resin-modified glass-ionomer, Vitrebond, was extremely difficult to remove, followed by IRM, with Retro-TC being the easiest to remove. It may be assumed that the mechanism of removal of restorative materials using an ultrasonic tip is because of the delivery of vibratory energy from the tip directly to the material. If that vibrational energy exceeds the cohesive energy holding the molecules of these complex restorative materials together, then the materials with the lowest cohesive strength will fail (i.e. crack) and begin to disintegrate. Although water cooling was employed with the application of the ultrasonic tip, it is possible that the heat generated exceeded the glass transitional temperature of the polymerized resin components in Vitrebond. This could have resulted in the viscous, partially melted material adhering tenaciously to the cavity walls. On the contrary, an inorganic material such as Retro-TC that does not bond to the cavity may exhibit brittle fracture following absorption of the ultrasonic energy, causing it to separate easily and cleanly from the cavity walls. Apparently, Retro-TC (i.e. calcium silicate-based restorative) has a lower cohesive strength than IRM or Vitrebond (Table 3).

Vitrebond, with a relatively high cohesive strength, seemed to resist removal using ultrasonic energy. It has a high cohesive strength because its matrix is based upon polyacrylic acid that contains pendant methacrylate groups that can copolymerize with each other and other constituents, including hydroxyethylmethacrylate. The presence of photosensitizers and free-radical accelerants produces covalent chemical bonds between the matrix components when light-cured. Zinc oxide-eugenol cements form a weaker matrix based on chelation of zinc by eugenol (Craig & Powers 2002).

In IRM, the cement is reinforced with 20 wt% polymethylmethacrylate. Both Vitrebond and IRM can form short tags of material in open dentinal tubules that can provide some retention. Calcium silicate-based cements undergo complex hydration reactions that result in formation of a poorly crystalline gel phase. That is, when mixed with water, they rapidly form hydrates of calcium silicate and a $Ca(OH)_2$ phases. The low-cohesive strength of Portland cements is due primarily to its intrinsic porosity and lack of strong chemical bonds between its constituent parts (Coleman *et al.* 2008). The material has poor adhesive strength because it does not penetrate into open tubules.

The experimental ultrasonic application period of 60 s used in this study requires further evaluation. In this preliminary study, the total ultrasonication time was limited to 60 s to minimize the potential of iatrogenic crack induction in dentine around the root-end cavity preparations. By comparing the SEMs of replicas made before and after ultrasonication, only 4 of the 30 restorations (13.3%) exhibited new cracks that could be attributed to ultrasonic attempts to remove the restorative materials. It is likely that by increasing the ultrasonic application time, more filling material could be removed. Nevertheless, increasing the ultrasonic application time required to completely remove root-end material may contribute to the creation of more apical cracks. Perhaps more vertical force would more effectively transfer vibrational energy from the probe to the material. To test these variables in future experiments, preparing flat disks of coronal dentine are suggested. Multiple cylindrical cavities 1.9×3 mm deep could be prepared and restored with test filling materials. By placing the dentine disk on a top loading analytical balance, one can apply known vertical forces on the materials using different ultrasonic energy levels. This will provide a simpler model that should permit the identification of the optimal conditions for ultrasonic removal of restorative materials.

When the dentine surfaces showed absence of smear layers after removal of the adjacent restorative material, it was speculated that the last fragments of restorative material that were removed by the energy of the ultrasonic tip also debonded part of smear layer leaving some exposed dentinal tubules. Because the cohesive strength of these materials exceeded their adhesive bond strength, removal of the material often debonded it from dentine, leaving a clean dentine surface. If SEM examination revealed the dentine surface to be covered by a smear layer that observation may indicate that the ultrasonic tip actually touched the dentine wall and created sufficient local abrasion to create new smear layer. Otherwise previous smear layer could be not removed by procedures.

The smoothest dentine surfaces after root-end filling removal were obtained in groups I and II (Retro-TC and IRM), whilst the roughest surface finish was observed in group III (Vitrebond), because the material was the most difficult to remove. Glass ionomer cements (GIC) have been reported to adhere chemically to dentine (Prati *et al.* 1992, Fritz *et al.* 1996). The resin-phase of modified GIC such as Vitrebond may interfere with chemical adhesion but give high bond strengths by flowing into open tubules (Friedl *et al.* 1995, Carvalho *et al.* 1995, Abdalla 2000).

Retro-TC cement did not flow into the dentinal tubules because the particle size is approximately between 1.5 and 3.5 microns (Gandolfi *et al.* 2008), generally larger than the dentinal tubule diameter of the apical root area (Love & Jenkinson 2002).

Portland cement-containing filling materials such as mineral trioxide aggregate (MTA) were assumed to be equal or superior to the other materials when used as root-end fillings with respect to leakage, cytotoxicity and marginal adaptation (Gondim *et al.* 2003, Gandolfi *et al.* 2007). Calcium-silicate cements are also superior regarding their ease of removal from apical cavities requiring retreatment. Thus, MTA should be considered as a root-end filling material during the first surgical approach both for its better apical sealing capacities and biocompatibility (Bidar *et al.* 2007) and for easier removal during a subsequent second surgical retreatment.

Conclusions

This laboratory study demonstrated the relative ease of partial or total removal of root-end filling materials in 60 s using ultrasonics. The calcium silicate-based cement was removed by ultrasonic tip application more successfully than IRM or Vitrebond. Further investigations are necessary to determine the most effective application time and draw up clinical guidelines for the management of surgical retreatment.

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