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Influence of Irrigant, Dowel Type, and Root-Reinforcing Material on Fracture Resistance of Thin-Walled Endodontically Treated Teeth

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Keywords
Reinforcement; thin-walled roots; glass ionomer; composite resin; fracture resistance.

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Presented at the 37th annual meeting of the American Association for Dental Research, Part of the International Association for Dental Research meeting, Dallas, TX, April, 2008.

Grant supplied by King Abdulaziz City for Science and Technology, Riyadh, Saudi Arabia (No. AT-25-93).

Accepted May 18, 2010

doi: 10.1111/j.1532-849X.2011.00687.x

Abstract

Purpose: Unresolved controversy exists concerning the optimum restorative material to reinforce the thin-walled roots of endodontically treated teeth to improve their fracture resistance under occlusal load. This study evaluated the effectiveness of irrigant, dowel type, and root-reinforcing material on the fracture resistance of thin-walled endodontically treated teeth.

Materials and Methods: The root canals of 140 maxillary central incisors were enlarged and equally divided into seven groups according to the canal irrigant: no irrigant (control), 5% hydrogen peroxide, 5% sodium hypochlorite, a combination of 5% hydrogen peroxide and sodium hypochlorite, 15% ethylenediaminotetraacetic acid (EDTA), 10% lactic acid, or 20% lactic acid. Within each group, root canals were lined with composite resin (PermaFlo) or glass ionomer cement (Fuji II LC). A light-transmitting plastic dowel (Luminex) was used to create space for a quartz fiber-reinforced dowel (Aestheti Post) or a titanium alloy dowel (ParaPost XH) and to cure the restorative materials. Following dowel cementation and restoration of the roots with composite core, the teeth were submitted to fracture resistance testing, and data were analyzed with 3-way ANOVA followed by Ryan-Einot-Gabriel-Welsch Multiple Range Test ($\alpha = 0.05$).

Results: Fracture resistance values were significantly different among irrigants, restorative materials, and their interaction ($p < 0.001$); however, the dowel type was not significantly different ($p = 0.51$).

Conclusions: Thin-walled roots that had the smear layer removed with lactic acid and that were then lined with composite resin had a higher fracture resistance.

Endodontically treated teeth with extensive loss of tooth structure have numerous problems due to significant reduction in their capacity to resist functional forces.[1] Moreover, a thin residual root wall can seriously compromise their prognosis for long-term success.

Different approaches exist for restoring thin-walled endodontically treated teeth, but there is no consensus on which technique and materials are best suited for use.[2-5] A cast dowel and core closely reproduces the morphology of the root canal space; however a cast metal dowel and core has biological and mechanical disadvantages, such as longer treatment time, involvement of laboratory procedures, high modulus of elasticity, excessive tooth reduction, lack of retention, and catastrophic root fracture. Additionally, cast metal dowels may present an esthetic challenge in the anterior dentition.[6-8] Prefabricated dowel systems are widely used, and their biomechanics have been widely studied[4,5,9] and have been revisited recently with the advent of newer esthetic dowel materials with mechanical properties closer to dentin[10-12] that may result in reduced stresses in the root walls.[6,13,14] Other techniques incorporate the use of adhesive materials, taking advantage of advances in restorative technologies.[15,16]

Numerous studies have demonstrated coronal reinforcement of tooth structure with bonded restorations.[17,18] Composite resins and glass ionomer cements reinforce remaining tooth structure by bonding to dentin and enamel.[19-22] Similarly, composite resins and glass ionomer cements could enhance resistance to fracture of endodontically treated teeth with thin-walled roots.[15,23–25] Doubts remain about bonding to root dentin,[26] although it has been suggested that using bonding resin prior to the placement of glass ionomer cement increases its bond strength to dentin.[27,28] Laboratory studies evaluating the fracture resistance of endodontically treated teeth have shown that composite resins and glass ionomer cements reinforce remaining tooth structure by bonding to dentin.[16,24,25,29,30] Several factors, such as morphological differences between coronal and apical root canal dentin,[12] morphological variations,[31] and polymerization contraction of the resin cement,[32,33] may have contributed to the discrepancies in bond strength values; however, the efficacy of various agents for cleansing root canals during and after endodontic instrumentation has not been well studied.[34] These solutions include proteolytic enzymes,[35] chlorine-releasing agents,[36] chlorhexidine,[37] citric acid,[38] sodium hypochlorite,[39] sulfuric acid,[40] tannic acid,[41] lactic acid,[42] and ethylenediaminetetraacetic acid (EDTA).[43]

For a restorative material to reinforce the tooth, it must bond to dentin.[18,29,44–46] An essential attribute of a good bond is the ability of the restorative material to wet and infiltrate the dentin.[31,32,47,48] Conditioning the tooth surface with an acid prior to bonding removes the smear layer, alters surface energy, and demineralizes the dentin, exposing a fine network of collagen fibrils.[49–51] Infiltration of this network with resin permits formation of a resin dentin interdiffusion zone with resin tags and adhesive lateral branches, thus creating micromechanical retention of the resin to the demineralized substrate.[52,53] In addition, acid conditioning removes surface contaminants before material placement, possibly permitting greater ion exchange and improved bonding between the adhesive cement and the tooth structure.[42,54]

Mechanical loading and scanning electron microscopic (SEM) investigations have been used to evaluate factors such as bonding mechanism of adhesive cements and dowel systems that may affect dowel retention and root fracture resistance;[6,55–58] however, there is a lack of accepted clinical standards and consensus regarding the optimal way to reinforce thin-walled endodontically treated teeth. Therefore, the purpose of this study was to investigate the effect of irrigant, dowel type, and root-reinforcing material (composite resin and glass ionomer cement) on fracture resistance of endodontically treated teeth with thin-walled roots. The null hypothesis was that there would be no difference in the fracture strengths of thin-walled roots of endodontically treated teeth regardless of the irrigant, dowel type, or the restorative material used for strengthening.

Materials and methods

One hundred and forty similar-sized intact recently extracted human maxillary central incisors were scraped clean of remnants of periodontal ligament and examined stereoscopically at 10× to verify the absence of cracks. The teeth were stored in distilled water with 0.1% thymol disinfectant (Mallinckrodt Baker Inc, Phillipsburg, NJ) at room temperature and equally divided into seven test groups ($n = 20$ per group) according to the irrigant used. The irrigants used were: no irrigant (control), 5% hydrogen peroxide (Pharmaplane; Fresenius, Bad Homberg, Germany), 5% sodium hypochlorite (Sainsbury's bleach; Sainbury, London, UK), a 50–50% combination of 5% sodium hypochlorite and 5% hydrogen peroxide, 15% ethylenediaminetetraacetic acid (EDTA enlargement; Produits Dentaires, Vevey, Switzerland), 10% lactic acid, and 20% lactic acid (Fisher Chemicals, Fair Lawn, NJ).

Crowns of the selected teeth were sectioned perpendicular to the long axis, 2 ± 1 mm coronal to the cementoenamel junction (CEJ) with a 0.15 diamond wafering blade (Buehler, Lake Bluff, IL) in an Isomet 1000 slow-speed saw (Buehler), to provide root lengths of 13 ± 1 mm. To prevent weak dentin remaining after preparation, the labial and palatal dentine of the tooth was modified to the same height as that in lateral sides, 2 mm incisal to the CEJ. Access to the root canals was gained with diamond rotary cutting instruments (Brasseler USA, Savannah, GA). Canals were endodontically instrumented. All teeth were held by hand during instrumentation, and the plane of greatest curvature was aligned parallel to the plane of file oscillation. Each canal was widened manually by a single operator until an ISO size 15 file (K-flex; Kerr, Romulus, MI) could be inserted to the working length with little or no resistance. Root canals were manually instrumented to a working length of 13 mm (1 mm above the apical foramen) with K-files (Kerr).[16,23,25]

The canals were enlarged to an ISO size 50 file (K-flex; Kerr). Each canal was irrigated with 3 ml of the assigned irrigating solution when there was a file size change and after filing was complete. This was accomplished using a syringe fitted with a 27-gauge needle placed passively in the coronal canal opening. The maximum depth of placement of the needle tip was 1 to 2 mm incisal to the apical foramen.[15,16,24] During irrigations, roots were held vertically, apices down, to ensure apical penetration of irrigant solutions. After the last irrigation, canals were completely dried with paper points. Ketac-Endo Aplicap (3M ESPE, St. Paul, MN) root canal sealer was mixed according to manufacturer's direction, and the canals were filled using a Lentulo spiral (Henry J. Schein, Port Washington, NY). The apical third of a size 50 master gutta percha cone (Hygienic Corp, Akron, OH) was coated with the sealer, and then fully seated to the working length. Root canals were obturated using a lateral condensation technique and accessory gutta percha points. Extracoronal excess of gutta percha was removed using heated condenser (Paiva; Duflex SS White, Rio de Janeiro, Brazil). Vertical condensation was performed with the same instruments.[16,23–25] The gutta percha was then removed from each canal to a point 5 mm from the apex using a Gates-Glidden drill (Lexicon, Dentsply Maillefer, Tulsa, OK) with a plastic stop. To simulate extensive clinical structure damage, the entire surface of each root canal space was further enlarged to reduce dentin wall thicknesses using the profile nickel titanium files to a size #40.06 taper (ProFile, Dentsply Maillefer) leaving specimens with 8.0 mm dowel space length and a residual dentin wall thickness of 0.5 to 0.75 mm at the CEJ. The buccal aspect of each residual root at points 2.5 and 5.0 mm apical to the coronal sectioned surface was measured for uniformity in thickness (0.50 to 0.75 mm) among the specimens. A 0.5 mm thickness of dentin was chosen to represent the worst-case clinical situation.[15,24,25] The profile was attached to a surveyor (Bioart, Sao Carlos, Brazil) to ensure that the surface was kept parallel to the horizontal plane and to obtain standard preparations with dentinal walls parallel to the long axis of each specimen. Again, each dowel space was rinsed with 10 ml of the corresponding irrigant for 30 seconds to remove any remaining sealer. Irrigating solutions were removed from the canal with sufficient paper points to completely dry the canal surface.

To standardize the bond so that it would be solely through micromechanical interaction when dentin was etched prior to the application of composite resin or glass ionomer cement,[27,28,59,60] the root canal spaces were prepared by etching the surface with 32% phosphoric acid for 15 seconds applied with a plastic needle-nose application tip, until excess was seen extruding from the canal space. This was followed by rinsing with water for 30 seconds and air drying. Two thin consecutive coats of single-bond adhesive system (OptiBond Solo Plus, Kerr) were applied, gently air dried for 5 seconds, excess carefully removed with paper points, and then light cured for 10 seconds. OptiBond Solo Plus bonding system uses a hydrophilic primer and light-curable hydrophilic adhesive resin based on bis-GMA, HEMA, and GDM. The adhesive resin is filled to 48% with colloidal silica.

Specimens were randomly assigned into two groups. Within each group, half of the enlarged root canal spaces ($n = 10$ per group) were lined with composite resin (PermaFlo; Kerr Corp, Orange, CA); the other half were lined with glass ionomer cement (Fuji II LC; GC America, Alsip, IL). A light-transmitting 1.4 mm diameter plastic dowel (Luminex; Dentatus USA Ltd, New York, NY) was used to create space for the dowels and to allow the use of light-polymerizing restorative materials. Flowable light-polymerizing composite resin (PermaFlo) or light-cured reinforced glass ionomer cement (Fuji II LC) was injected into the canal spaces using a 21 mm needle tip (Navi-Tip; Ultradent Products, Inc, South Jordan, UT). Then, smooth light transilluminating dowels (Dentatus) were inserted and centered manually in the root spaces, and the restorative material was compacted around the dowels. The curing light (UltraLume LED 5; Ultradent Products) was placed at the end of the smooth light transilluminating dowel to polymerize the restorative material by transmitting light down the length of the dowel for 1 minute.[16,61] Light intensity output was monitored with a curing radiometer (Demetron/Kerr, Danbury, CT) to be at least 750 mW/cm^2. Next, the smooth light transilluminating dowel was removed, and light was applied for another 20 seconds.

An additional tooth preparation for each irrigant and restorative material combination was used to identify the microscopic appearance of the composite resin/glass ionomer cement-to-dentin interface with a scanning electron microscope (Philips Electron Optics BV, Achseweg Noords, The Netherlands). The prepared specimens were fixed in 2.5% glutaraldehyde solution for 24 hours, and then fixed in 0.1 mol/L phosphate buffered in 2.5% glutaraledehyde (pH 7.4) for an additional 24 hours. Then specimens were processed through critical point drying, a preservation technique that maintains the fibrous integrity of the outer mineral-depleted zone.[54] This process is essential to the accurate examination of dentin morphology without water loss or dimensional changes during preparation for SEM.[42] The moist state of the dentin was maintained with the use of liquid carbon dioxide as a transitional fluid under pressure (CPD-2, TED Pella Inc, Redding, CA). The specimen was then freeze fractured, mounted on aluminum stubs, sputter-coated with gold-palladium alloy (Denton Vacuum Inc, desk II, Cherry Hill, NJ), and observed with a scanning electron microscope. Raster scans were performed at 500× magnification with an accelerating voltage of 15 KV.

A dowel space was prepared in each reinforced tooth to a standardized length of 8 mm. The length of the dowel space was verified with a periodontal probe fitted with an endodontic reference stop and a radiograph. Again, each subgroup was divided according to the type of dowel used ($n = 5$ per group). The similar-size dowels used were: Ti alloy dowel (ParaPost XH; Coltene/Whaledent, Inc, Mahwah, NJ) (control), and quartz fiber-reinforced dowel (Aestheti-Post; Bisco Dental Products, Schaumburg, IL). Then, the corresponding drill #2 to each dowel kit was used to prepare the dowel space to the desired depth. Each dowel was marked at a distance of 11 mm from its apical end. A line was drawn around the dowel at this point, and all dowels were cut to an 11-mm length with a water-cooled diamond-fissure rotary instrument (Komet-Brasseler GMbH, Lemgo, Germany), leaving 3 mm of the dowel head extended above the preparation. This procedure standardized the dowel lengths and established diameter similarity between dowels with tapered designs.[15,16,23]

All dowels were cemented into the newly created canal space with resin luting cement (Panavia 21; Kuraray Co., Ltd, Tustin, CA) following the manufacturer's instructions. Cement was mixed for 60 seconds with the base dispensed in proportion to the catalyst at room temperature and placed in the dowel spaces using a Lentulo spiral (Henry J Schein). Each dowel was uniformly coated with cement and seated into the dowel space by finger pressure. An air-inhibiting coating material (Oxyguard; Kuraray Co) was applied to exclude air during polymerization and cleaned with the use of a continuous air-water spray following polymerization of the cement.[62] Excess cement was removed with an explorer.

Composite cores (CoreRestore 2, Kerr) extending 6 mm incisal to the sectioned tooth surfaces were fabricated with polyester central incisor-shaped matrices (CoreForm, Kerr) seated over the dowels' crown portion. First, coronal tooth surfaces were etched for 15 seconds with 32% phosphoric acid, rinsed, and air dried. Two layers of OptiBond Solo Plus bonding agent (Kerr) were applied to the cervical dentin and the coronal portion of the dowel and were polymerized for 20 seconds. For each specimen, equal measures of core base and catalyst were thoroughly mixed with a plastic spatula, loaded into a syringe (Centrix CR EZ Syringe; Centrix, Shelton, CT) and carefully applied to the tooth surface to avoid air entrapment. Then, the clear plastic core matrix was filled with core material and polymerized (UltraLume LED 5; Ultradent Products) for 40 seconds on each of the five surfaces. The preformed polyester matrix was then removed with a surgical blade.

Each tooth was mounted on a surveyor and prepared for a complete cast crown with 0.5 mm chamfer finish line using a high-speed diamond rotary cutting instrument (6856 L-016; Brasseler) and water spray. The preparations ended on the level of the composite build-up (no ferrule effect) to enable the load force to be transferred from the restoration to the root structure.[16,24,25] A single-mix technique was used to make impressions of the prepared teeth with poly(vinyl siloxane) (Examix, GC America Inc., Chicago, IL), and cast with type IV die-stone (Jade stone, Whip Mix Corp., Louisville, KY). Two coats of die spacer (Tru Fit; George Taub Products and Fusion, Jersey City, NJ) were applied to the axial surfaces of each die 1 mm short of the finish lines. Wax copings (Gator Wax, Whip Mix Corp) were fabricated for each die using cellulose acetate crown formers for the standardized wax patterns. A marking line was scraped 2 mm below the incisal edge of each wax pattern on the palatal surface. A palatal step design 0.3-mm deep and 1-mm wide was formed on each specimen to standardize the position of the loading device during testing. The patterns were invested with phosphate-bonded investment (Cera-Fina, Whip Mix Corp.) and cast with ADA base metal alloy (Rexillium III, Pentron, Wallingford, CT). Castings were recovered from investment, bench-cooled to room temperature, cleaned in pickling solution (Jet-Pac; JF Jelenko Co, Armonk, NY), and air-abraded with 50 μm aluminum oxide for 10 seconds with contra-angle microetcher (model erc-er; Danville Engineering, Danville, CA) at 60 psi. To minimize the effect of variations in the casting procedure, the same clinician completed all castings. The internal surface of each casting was inspected with a 20× stereomicroscope. After necessary adjustment, crowns were cemented to their respective preparations with Panavia 21 cement (Kuraray Co) according to the manufacturer's instructions. The specimens were then placed in 100% humidity for 24 hours at 37°C.

To simulate the periodontal ligament, each root was coated to within 1 mm of the CEJ with a thin layer (approximately 0.1 to 0.2 mm) of wax (Gator Wax), and was embedded in a plastic ring (60-mm diameter, 20-mm high) with epoxy resin (Epoxide Resin; Leco Corp., St. Joseph, MI). The set was immersed in water at 75°C for 1 minute to remove the wax layer, leaving a space between the root and the epoxy resin. An addition-cured silicone rubber (Speedex; Coltene/Whaledent Inc, Cuyahoga Falls, OH) was manipulated and coated on the surface of the roots, which were repositioned into the epoxy resin blocks. After polymerization, the excess impression material was removed with a surgical blade. Roots with periodontal membrane simulation were mounted and secured in epoxy resin blocks with plastic rings. With a special mounting jig, each specimen was positioned in the mounting device and aligned at a 45° angle with respect to the long axis of the tooth. A unidirectional static load was then applied with a 1-mm diameter steel bar, beveled 45° at the terminus using a universal load-testing machine (Instron 4204; Instron Corp, Canton, MA) in the compression mode with a crosshead speed of 0.5 mm/min to the locating groove in the palatal concavity of the crown and at an angle of 135° from the long axis of the root (Fig 1). This angle approximated the present palatal angle between the long axis of the maxillary and mandibular central incisors.[63] The load was applied until fracture.

Means and standard deviations were calculated for each group, and results were compared by a three-way ANOVA and Ryan-Einot-Gabriel-Welsch (REGWQ) multiple range test at 5% level of significance. REGWQ was used because it appears to be the most powerful, yet valid, step-down multiple-stage test in the current literature.[64]

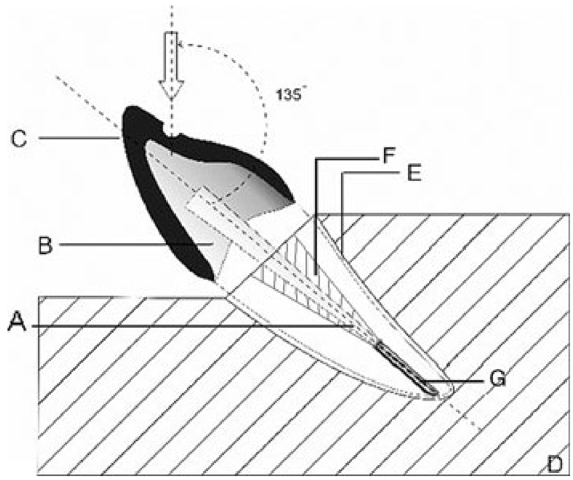

Figure 1 Schematic drawing of the fracture resistance assembly. (A) Fiber dowel surrounded by restorative material; (B) Composite resin core; (C) Cemented metal crown; (D) Epoxy resin block; (E) Silicone-simulated periodontal ligament. Arrow indicates 135° angle load applied to prepared notch on the palatal surface; (F) Restorative material (composite resin or glass ionomer cement); (G) Gutta percha.

Results

The ANOVA results (Table 1) demonstrated a statistically significant difference for irrigant, restorative material, and their interaction ($p < 0.001$); however, the dowel type was not significantly different ($p = 0.51$). The interaction effect between the dowel/irrigant ($p = 0.99$) and dowel/restorative material ($p = 0.97$) combinations were not significantly different. Also, the interaction effects between irrigant/restorative material/dowel combinations were not significantly different ($p = 0.98$).

Mean values and standard deviations for each treated group are listed in Table 2. The highest mean fracture resistance (SD) was obtained from the group treated with 20% lactic acid solution and reinforced with composite resin [800.4 (14.3) N]. This is about 100.7% more than the weakest mean fracture resistance, obtained from the 5% sodium hypochlorite-treated group and reinforced with glass ionomer cement [398.8 (13.5) N], regardless of the dowel type.

Fracture resistance of root canal dentin irrigated with 20% lactic acid improved by 59.7% with composite resin (800.4 N)

Table 1 Three-way repeated measure ANOVA

Source	*df*	MS	F value	*p*
Irrigant	6	344730.11	793.94	<0.001
Restorative material	1	583080.18	1342.87	<0.001
Irrigant ∗ restorative	6	127452.18	293.53	<0.001
Dowel	1	189.78	0.44	0.51
Irrigant ∗ dowel	6	36.68	0.08	0.99
Restorative ∗ dowel	1	0.87	0.00	0.97
Irrigant ∗ restorative ∗ dowel	6	83.89	0.19	0.98

Df = degree of freedom; MS = mean square.

Table 2 Fracture resistance (N) for root canal irrigant and restorative material (means ± SD, n = 10)

Irrigant	Restorative material	Mean ± SD
20% lactic acid	Composite resin	800.4 ± 14.3[a]
10% lactic acid	Composite resin	798.9 ± 22.5[a]
15% EDTA	Composite resin	795.0 ± 14.8[a]
20% lactic acid	Glass ionomer	501.3 ± 13.5[b]
10% lactic acid	Glass ionomer	497.9 ± 10.1[b]
15% EDTA	Glass ionomer	495.9 ± 9.6[b]
Control	Composite resin	414.3 ± 25.5[c]
Control	Glass ionomer	409.3 ± 38.5[c]
5% Hydrogen peroxide	Composite resin	401.0 ± 17.8[c]
5% Hydrogen peroxide	Glass ionomer	400.9 ± 22.4[c]
5% Sodium hypochlorite	Composite resin	399.7 (13.7)[c]
Combination	Composite resin	399.1 (20.6)[c]
Combination	Glass ionomer	399.0 (21.2)[c]
5% sodium hypochlorite	Glass ionomer	398.8 (13.5)[c]

Means with the same letters are not significantly different at $p < 0.05$.

compared with glass ionomer cement (501.3 N). A similar comparison for 10% lactic acid, fracture resistance of root canal dentin was improved by 60.5% with composite resin (798.9 N) compared with glass ionomer cement (497.9 N). In addition, the fracture resistance of root canal dentin irrigated with 15% EDTA was improved by 60.3% when composite resin was used (795 N) compared to glass ionomer cement (495.9 N).

Regardless of the irrigant used, fracture resistance of root canal dentin restored with quartz fiber-reinforced dowels was improved with composite resin compared with titanium alloy dowels; however, the differences were not significantly different. For quartz fiber-reinforced dowel subgroups, the highest mean fracture resistance (SD) was obtained from the group treated with 20% lactic acid solution and strengthened with composite resin [804 (20.5) N]. The lowest mean fracture resistance (SD) was obtained from the 50–50% combination of 5% sodium hypochlorite and 5% hydrogen peroxide treated group and strengthened with glass ionomer cement [399.2 (23.8) N]. Similarly for Ti alloy dowels, the highest mean fracture resistance (SD) was obtained from the group treated with 20% lactic acid solution and strengthened with composite resin [798 (16.6) N]. The lowest mean fracture resistance (SD) was obtained from a 50–50% combination of 5% sodium hypochlorite and 5% hydrogen peroxide-treated group and strengthened with composite resin [396.2 (20.9) N].

The REGW multiple-range test revealed no significant difference in the fracture resistance of endodontically treated teeth irrigated with 10% lactic acid, 20% lactic acid, and 15% EDTA and reinforced with composite resin. There was no significance in fracture resistance between teeth irrigated with 10% or 20% lactic acid or EDTA and reinforced with glass ionomer cement. Similarly for other irrigant groups, no irrigant (control), 5% hydrogen peroxide, 5% sodium hypochlorite, or a 50–50% combination of 5% sodium hypochlorite and 5% hydrogen peroxide produced no difference in fracture resistance (Fig 2).

Mean values and standard deviations for each dowel type are listed in Table 3. The highest mean fracture resistance (SD) was obtained from the group treated with quartz fiber-reinforced dowel [509.1 (158.4) N]. This is about 0.5% more than the

Table 3 Fracture resistance (N) for prefabricated dowel type (means ± SD, n = 70)

Dowel	Mean ± SD
Quartz fiber-reinforced	509.1 ± 158.4[a]
Titanium alloy	506.8 ± 158.6[a]

Means with the same letters are not significantly different at $p < 0.05$.

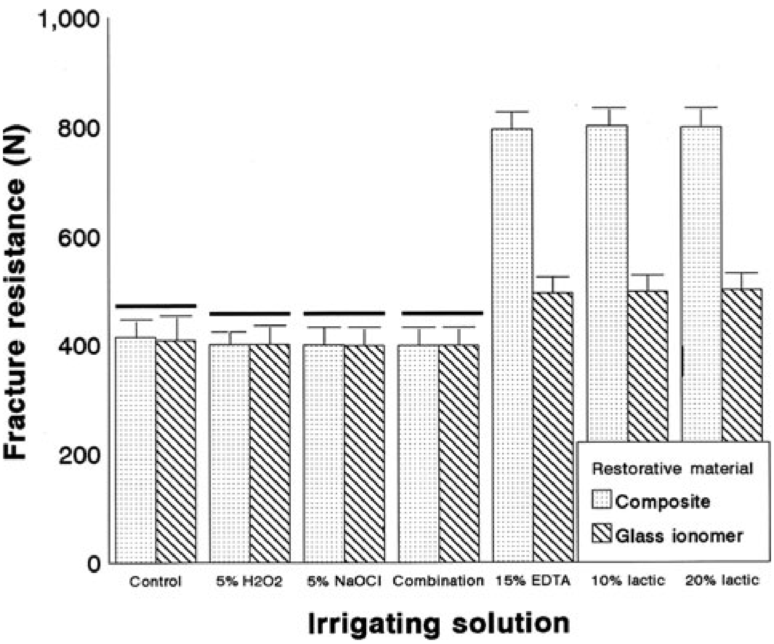

Figure 2 Mean fracture resistance measurements for irrigant-restorative material combination. Horizontal line connects values that are not significantly different at $p < 0.05$.

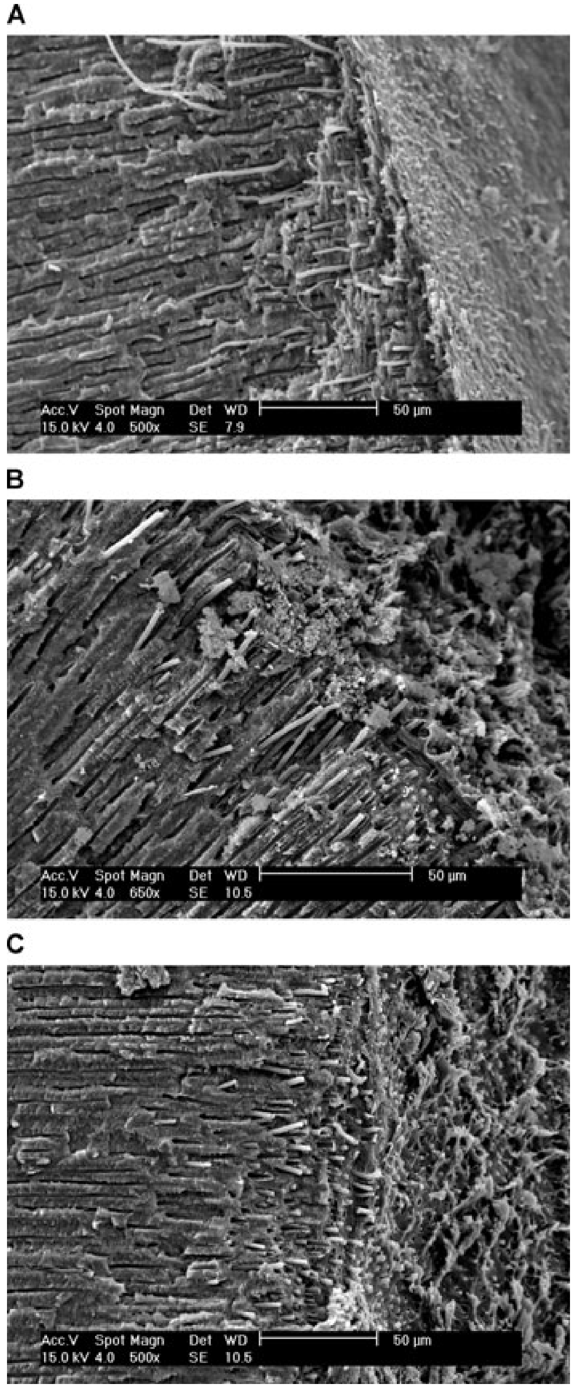

Figure 3 SEM photomicrograph of specimen reinforced with composite resin and irrigated with (A) 15% EDTA. (B) 10% lactic acid. (C) 20% lactic acid. Note complete penetration of composite resin along the widely opened dentinal tubules. Original magnification 500×.

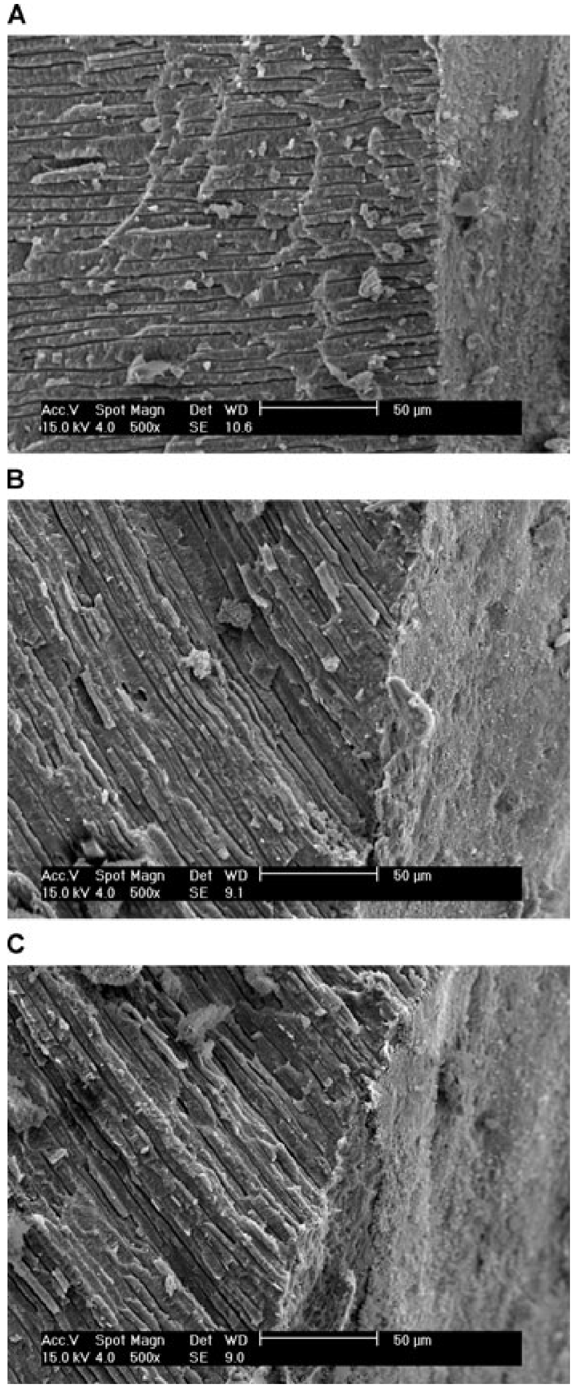

Figure 4 SEM photomicrograph of specimen reinforced with glass ionomer cement and irrigated with (A) 15% EDTA. (B) 10% lactic acid. (C) 20% lactic acid. No evidence of dentinal tubules penetration. Original magnification 500×.

fracture resistance obtained from a Ti alloy dowel [506.8 (158.6) N] treated group.

SEM photomicrographs of root canal dentin irrigated with 15% EDTA (Fig 3A) and 10% or 20% lactic acid (Fig 3B,C) revealed complete tag formation for composite resin along the widely opened dentinal tubules; however, no evidence of tag formation was observed for glass ionomer for root canal dentin irrigated with 15% EDTA (Fig 4A). Appearance was similar for dentin surfaces treated with 10% or 20% lactic acid (Fig 4B,C). Control specimens (Fig 5A) revealed no tag formation for composite resin or glass ionomer cement. The dentin surfaces of specimens irrigated with 5% hydrogen

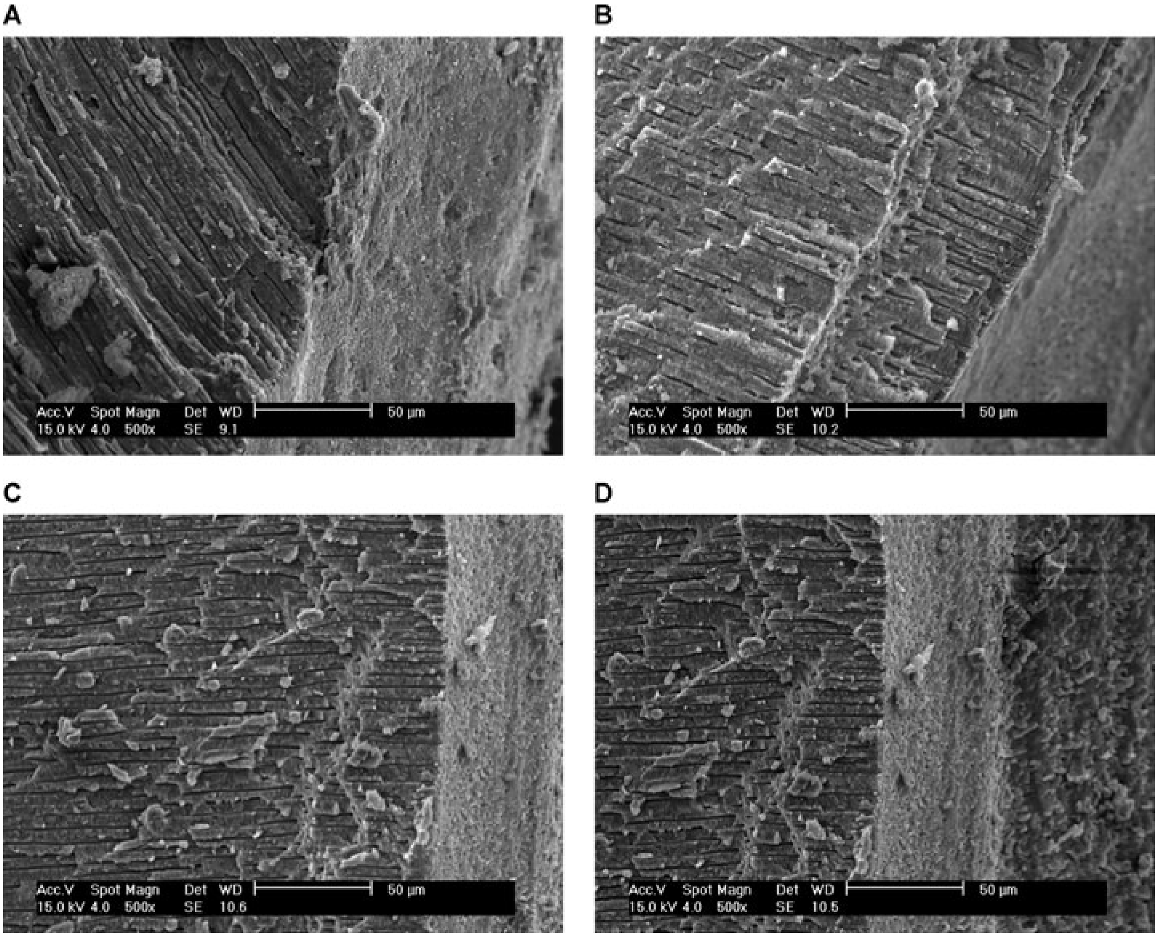

Figure 5 SEM photomicrograph of specimen reinforced with composite resin. (A) control (no irrigant). (B) 5% hydrogen peroxide. (C) 5% sodium hypochlorite. (D) 50–50% combination of 5% sodium hypochlorite and 5% hydrogen peroxide. No evidence of dentinal tubules penetration. This appearance was similar to dentin surfaces strengthened with glass ionomer cement. Original magnification 500×.

peroxide solution (Fig 5B) did not reveal any evidence of tag formation with any root-reinforcing material (Fig 5C). This appearance was similar to dentin surfaces treated with 5% sodium hypochlorite (Fig 5D) or a 50–50% combination of 5% sodium hypochlorite and 5% hydrogen peroxide.

Discussion

The data support rejection of the null hypothesis of the study, that there would be no difference in the fracture strengths of thin-walled roots of endodontically treated teeth regardless of the irrigant, dowel type, or root reinforcement materials used for strengthening. The increased demand for clinically convenient treatment to restore a severely weakened endodontically treated tooth with thin-walled endodontically treated teeth has provided clinicians with a number of simplified dowel-and-core-based restorative options;[1] however, abundant choices can present an understandably difficult situation for clinicians trying to select the best materials and techniques for optimal results. Researchers agree that acid treatment of dentin removes the smear layer and hydroxyapatite from the treated dentin, demineralizing the dentin, and leaving behind a collagen-rich network for interaction with adhesive resins.[31,32] This process results in the formation of a hybrid, or resin-dentin interdiffusion zone.[52,54] The results of this study showed that an intermediate layer of composite resin sandwiched between the root dentin and the dowel significantly increased the fracture resistance of the thin-walled roots. This finding of the strengthening effect of composite resin is supported by another study[15,16,18,23–25] and can be explained by the complete tag formation for composite resin along the widely opened dentinal tubules. Moreover, the loose collagen fiber network represents the demineralized dentinal matrix. The infiltration of this network with resin permits the formation of a resin dentin interdiffusion zone with resin tags, thus creating micromechanical retention of the resin to the demineralized substrate. This study is supported by other studies.[15,23,24] Lactic acid irrigation resulted in higher bond strengths because of complete removal of the smear layer and was equivalent to EDTA.[65] Although sodium hypochlorite irrigation alone is capable of removing the organic portion of the smear layer, it is not effective at removing the entire smear layer.[65] Moreover, it may require a reversal agent because of its ability to affect the polymerization of the resin sealer.[66] This may explain the lower fracture resistance results. The same explanation may extend to control specimens where no irrigant was used, and acid etchant alone was not capable of producing retention and adhesiveness. Although providing some increased reinforcement, the mechanical properties of the glass ionomer cement of this study were inadequate to prevent crushing of the cement during testing where there was no evidence of resin tag formation. Moreover, the differences in the restorative materials: handling characteristics, compositions (i.e., matrix, filler type, load), and properties (i.e., polymerization ability, flexural strength, hardness) may affect their adhesion to the tooth substrate.[19] Another explanation is the placement of dentin adhesive prior to the application of glass ionomer cements that result in the loss of direct contact between the glass ionomer cement and the cavity wall. This barrier may affect the ion exchange that normally occurs between a glass ionomer cement and tooth structure when setting.

The thickness of dentin remaining after tooth preparation is the most relevant factor in determining tooth strength.[16,24,25,56,57,67] Compared to an undamaged tooth with a vital pulp, the structural integrity of an endodontically treated tooth is compromised. It is necessary to retain as much tooth tissue as possible during restorative procedures, as roots with little remaining dentin for structural support are less able to withstand functional and impact stresses.[57,67] Dowels placed in thin-walled roots also create an increased risk for root fracture.[2,4,15,16,67] Increasing the thickness of the root walls with composite resin was shown in this study to reduce this risk.[23-25,46]

In this study, specimen teeth with similar root morphology and mesiodistal and buccolingual dimensions were selected. The small variations in root measurements minimized variations in the thickness of the intermediate layer. There were some limitations in this study. The ferrule effect was not included in this study to enable the load force to be transferred from the restoration to the root structure. Though the test method used in this study attempted to simulate the clinical situation, the unidirectional static loading force applied did not replicate the complex dynamic forces present in the oral environment during mastication and with parafunctional habits; however, a unidirectional static loading force was selected in this study and in many other studies of root fractures to minimize the experimental variables.[6,55,56] Clinically, root fractures in maxillary anterior teeth restored with dowel-cores and artificial crowns are more likely to occur from cyclic fatigue than single severe impacts. Further laboratory testing should more closely simulate these two factors. The angulation between the long axes of the anterior teeth also can significantly affect the in vitro loading forces required for the fracture of dowel-core restored roots.[57]

Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. Thin-walled roots could be reinforced significantly by the placement of an intermediate layer of composite, but not by glass ionomer cement.
2. 10% and 20% lactic acid and 15% EDTA irrigation significantly increased fracture resistance, and there was no significant difference between them.
3. The type of prefabricated dowels tested did not influence the fracture resistance of thin-walled roots.
4. The clinical significance of these findings remains to be determined.

Acknowledgments

The authors thank Dr. William Johnston for his statistical assistance.

References

1. Yalçin E, Çehreli M, Canay Ş: Fracture resistances of cast metal and ceramic dowel and core restorations: a pilot study. J Prosthodont 2005;14:84-90
2. Fernandes AS, Sharat Shetty S, Coutinho I: Factors determining post selection: a literature review. J Prosthet Dent 2003;90:556-562
3. Torbjorner A, Fransson B: A literature review on the prosthetic treatment of structurally compromised teeth. Int J Prosthodont 2004;17:369-376
4. Smith CT, Schuman NJ: Restoration of endodontically treated teeth: a guide for the restorative dentistry. Quintessence Int 1997;28:457-462
5. Dietschi D, Duc O, Krejci I, et al: Biomechanical considerations for the restoration of endodontically treated teeth: a systemic review of the literature-Part 1. Composition and micro- and macrostructure alterations. Quintessence Int 2007;38:733-743
6. Newman MP, Yaman P, Dennison J, et al: Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent 2003;89:360-367
7. Albuquerque Rde C, Polleto LT, Fontana RH, et al: Stress analysis of an upper central incisor restored with different posts. J Oral Rehabil 2003;30:936-943
8. Isidor F, Brondum K, Ravnholt G: The influence of post length and crown ferrule length on the resistance to cyclic loading of bovine teeth with prefabricated titanium posts. Int J Prosthodont 1999;12:78-82
9. Assif D, Gorfil C: Biomechanical considerations in restoring endodontically treated teeth. J Endod 1994;71:565-567
10. Morgano SM, Rodrigues AH, Sabrosa CE: Restoration of endodontically treated teeth. Dent Clin N Am 2004;48:397-416
11. Akkayan B, Gulmez T: Resistance to fracture of Endodontically treated teeth restored with different post systems. J Prosthet Dent 2002;87:431-437
12. Ferrari M, Vichi A, Garcia-Godoy F: Clinical evaluation of fiber-reinforced epoxy resin posts and cast post and cores. Am J Dent 2000;13:15-18
13. Kalkan M, Usumez A, Ozturk AN, et al: Bond strength between dentin and three glass-fiber post system. J Prosthet Dent 2006;96:41-46
14. Pest LB, Cavalli G, Bertani P, et al: Adhesive post-endodontic restorations with fiber posts: push –out tests and SEM observations. Dent Mater 2002;18:596-602
15. Saupe WA, Gluskin AH, Radke Jr RA: A comparative study of fracture resistance between morphologic dowel and cores and a resin-reinforced dowel system in the intraradicular restoration of

structurally compromised roots. Quintessence Int 1996;27:483-491
16. Goncalves L, Vansan L, Panlino S, et al: Fracture resistance of weakened roots restored with a transilluminating post and adhesive restorative materials. J Prosthet Dent 2006;96:339-344
17. Boyer D, Roth L: Fracture resistance of teeth with bonded amalgams. Am J Dent 1994;7:91-94
18. Eakle W: Increasing the resistance of tooth fracture: bonded composite versus glass ionomer cement. Dent Mater 1985;1:1228-1230
19. Hasegawa T, Itoh K, Koiket T, et al: Effect of mechanical properties of resin composites on the efficiency of the dentin bonding system. Oper Dent 1999;24:323-330
20. Uyehara MY, Davis RD, Overton JD: Cuspal reinforcement in endodontically treated molars. Oper Dent 1999;24:364-370
21. Latino C, Troendle K, Summitt JB: Support of undermined occlusal enamel provided by restorative materials. Quintessence Int 2001;32:287-291
22. Sorensen JA, Martinoff JT: Intracoronal reinforcement and coronal coverage: a study of endodontically treated teeth. J Prosthet Dent 1984;51:780-784
23. Lui J: Composite resin reinforcement of flared canals using light-transmitting plastic posts. Quintessence Int 1994;25:313-319
24. Wu X, Chan AT, Chen YM, et al: Effectiveness and dentin bond strengths of two materials for reinforcing thin-walled roots. Dent Mater 2007;23:479-485
25. Marchi GM, Paulillo LA, Pimenta LA, et al: Effect of different filling materials in combination with intraradicular posts on the resistance to fracture of weakened roots. J Oral Rehabil 2003;30:623-629
26. Vichi A, Grandini S, Davidson CL, et al: An SEM evaluation of several adhesive systems used for bonding fiber posts under clinical conditions. Dent Mater 2002;18:495-502
27. Friedle KH, Power JM, Hiller KA: Influence of different factors on bond strength of hybrid ionomers. Oper Dent 1995;20:74-79
28. Pereira PN, Yamada T, Inohoshi S, et al: Adhesion of resin-modified glass ionomer cements bonding systems. J Dent 1998;26:479-485
29. Cormier C, Burns D, Moon P: In vitro comparison of the fracture resistance and failure mode of fiber, ceramic, and conventional post system at various stages of restoration. J Prosthodont 2001;10:26-36
30. Katebzadeh N, Dalton BC, Trope M: Strengthening immature teeth during and after apexification. J Endodont 1998;24:256-259
31. Gaston BA, West LA, Liewehr FR, et al: Evaluation of regional bond strength of resin cement to endodontic surfaces. J Endod 2001;27:321-324
32. Bouillaguet S, Troesch S, Wataha JC, et al: Microtensile bond strength between adhesive cements and root canal dentin. Dent Mater 2003;19:199-205
33. Sano H, Takatsu T, Ciucchi B, et al: Nanoleakage: leakage within the hybrid layer. Oper Dent 1995;20:18-25
34. Ayad MF, Rosenstiel SF, Farag AM: A pilot study of lactic acid as a dentin conditioner for dentin-bonding agent development. J Prosthet Dent 1996;76:254-259
35. Tay FR, Pashley DH, Loushine RJ, et al: Ultrastructure of smear layer-covered Intraradicular dentin following irrigation with BioPure MTAD. J Endod 2006;32:218-221
36. Kuruvilla JR, Kamath MP: Antimicrobial activity of 2.5% sodium hypochlorite and 0.2% chlorhexidine gluconate separately and combined, as endodontic irrigants. J Endod 1998;24:472-476
37. White RR, Hays GL, Janer LR: Residual antimicrobial activity after canal irrigation with chlorhexidine. J Endod 1997;23:229-231
38. Yamaguchi M, Yoshida K, Suzuki R, et al: Root canal irrigation with citric acid solution. J Endod 1996;22:27-29
39. Torabinejad M, Cho Y, Khademi AA, et al: The effect of various concentrations of sodium hypochlorite on the ability of MTAD to remove the smear layer. J Endod 2003;9:233-239
40. Eakle Von der Fehr FR, Nygaard ØB: Effect of EDTAC and sulfuric acid on root canal dentin. Oral Surg 1963;16:199-205
41. Bitter NC: A 25% tannic acid solution as a root canal irrigant cleanser: a scanning Electron microscope study. Oral Surg Oral Med Oral Pathol 1989;67:333-337
42. Ayad MF: Lactic acid root canal irrigation for dowel and core treatment. A pilot study. J Prosthet Dent 2004;92:540-545
43. Kuah HG, Lui JN, Tseng PS, et al: The effect of EDTA with and without ultrasonics on removal of the smear layer. J Endod 2009;35:393-396
44. McCullock A, Smith B: In vitro studies of cusp reinforcement with adhesive restorative materials. Br Dent J 1986;161:450-452
45. Weiger R, Heuchert T, Hahn R, et al: Adhesion of a glass ionomer cement to human radicular dentin. Endod Dent Traumatol 1995;11:214-219
46. Johnson ME, Stewart GP, Nielsen CJ, et al: Evaluation of root reinforcement of endodontically treated teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Edod 2000;90:360-364
47. Tagger M, Tagger E, Tjan AH, et al: Measurement of adhesion of endodontic sealers to dentin. J Endod 2002;28:351-354
48. Saleh IM, Ruyter IE, Haapasalo MP, et al: The effects of dentine pre-treatment on the adhesion of root canal sealers. Int Endod J 2002;35:859-866
49. Pashley DH: Smear layer: physiological considerations. Oper Dent 1984;3:13-29
50. Kouvas V, Liolios E, Vassiliadis L, et al: Influence of smear layer on depth of penetration of three endodontic sealers: an SEM study. Endod Dent Traumatol 1998;14:191-195
51. Drummond JL, Toepke RS, King TJ: Thermal and cycling loading of endodontic posts. Eur J Oral Sci 1999;107:220-224
52. Pashley DH, Ciucchi B, Sano H, et al: Permeability of dentin to adhesive agents. Quintessence Int 1993;24:618-631
53. Chappel RP, Cobb CM, Spencer P: Dentinal tubule anastomosis: a potential factor in adhesive bonding? J Prosthet Dent 1984;72:183-188
54. Cravalho RM, Yoshiyama M, Brewer PD, et al: Dimensional changes of demineralized human dentin during preparation for scanning electron microscopy. Arch Oral Biol 1996;41:379-386
55. Mitsui FH, Marchi GM, Pimenta LA, et al: In vitro of fracture resistance of bovine roots using different intraradicular post systems. Quintessence Int 2004;35:612-616
56. Tjan AHL, Whang SD: Resistance to root fracture of dowel channels with various thickness of buccal dentin walls. J Prosthet Dent 1985;53:496-500
57. Loney RW, Moulding MB, Ritsco RG: The effect of load angulation on fracture resistance of teeth restored with cast post and cores and crowns. Int J Prosthodont 1995;8:247-251
58. Boschian PL, Cavalli G, Bertani P, et al: Adhesive post-endodontic restorations with fiber posts: push-out tests and SEM observations. Dent Mater 2002;18:596-602
59. De Dunck J, van Meerbeek B, Yoshida Y, et al: Four-years water degradation of a resin-modified glass ionomer adhesive bonded to dentin. Eur J Oral Sci 2004;112:73-83

60. Coutinho E, Van Lamduyt K, De Dunck J, et al: Development of a self-etch adhesive for resin-modified glass ionomers. J Dent Res 2006;85:349-353
61. Yoldas O, Alaçam T: Microhardness of composites in simulated root canals cured with light transmitting post and glass-fiber reinforced composite posts. J Endod 2005;31:104-106
62. Ayad MF: Effects of tooth preparation burs and luting cement types on the marginal fit of extracoronal restorations. J Prosthodont 2009;18:145-151
63. Salzmann JA: Orthodontics in Daily Practice (ed 1). Philadelphia, Lippencott, 1994, pp. 202-205
64. Ramsey PH: Power differences between pairwise multiple comparisons. J Am Statist Assoc 1978;73:363-368
65. Eldeniz AU, Erdemir A, Belli S: Shear bond strength of three resin based sealers to dentin with and without the smear layer. J Endod 2005;31:293-296
66. Lai SC, Mak YF, Cheung GS, et al: Reversal of compromised bonding to oxidized etched dentin. J Dent Res 2001;80:1919-1924
67. Marchi GM, Mitsui FH, Cavalcanti AN: Effect of remaining dentine structure and thermal-mechanical aging on the fracture resistance of bovine roots with different post and core systems. Int Endod J 2008;41:969-976