Effect of Obturating Systems, Dowel Materials, and Adhesive Luting Techniques on the Resistance to Fracture of Endodontically Treated Teeth

Jylan El Guindy, BDS, MSc, PhD[1] & Manar Y. Fouda, BDS, MSc, PhD[2]

[1] Assistant Professor, Department of Fixed Prosthodontics, Faculty of Oral and Dental Medicine, Cairo University, Cairo, Egypt
[2] Assistant Professor, Department of Endodontics, Faculty of Oral and Dental Medicine, Cairo University, Cairo, Egypt

Keywords
RealSeal; gutta-percha, ceramic post; ceramic dowel; fiber dowel; adhesive techniques; resistance to fracture.

Correspondence
Jylan El Guindy, Faculty of Oral and Dental Medicine—Fixed Prosthodontics, Cairo University, 45 Mosadak St., Dokki, Giza, Cairo 12311, Egypt.
E-mail: dr_jul@hotmail.com

Accepted September 25, 2009

doi: 10.1111/j.1532-849X.2010.00636.x

Abstract

Purpose: The aim of this study was to assess the role of obturating systems, dowel materials, and adhesive techniques on the resistance to fracture of endodontically treated teeth.
Material and Methods: Eighty maxillary central incisors were selected and randomly divided into two groups according to the obturating system ($n = 40$); group I: gutta-percha and Roeko sealer; group II: RealSeal. Both groups were further subdivided into two subgroups; subgroup A: using ceramic dowels (Cosmopost); subgroup B using fiber dowels (Easy Post). Each subgroup was assigned to two divisions according to the adhesive luting technique; division V (total-etch) Variolink II resin cement; division U (self-adhesive) RelyX Unicem. Composite core build-up was made using a core former. Each specimen was loaded 2 mm from its incisal edge on the palatal side at a 135° angle with the long axis of the tooth using a universal testing machine with a load cell of 5 KN at a crosshead speed of 0.5 mm/min until fracture. Failure loads were recorded in N. Scanning electron microscopic examination at the dentin/resin interface (1000x) was performed. Three-way ANOVA was used to test the effect of obturating system, dowel material, adhesive technique, and their interactions (obturating system * dowel material, obturating system * adhesive, dowel material * adhesive, obturating system * dowel material * adhesive). Duncan's test was used for pairwise comparison. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with SPSS 16.0.
Results: The mean resistance to fracture (617.4 N) was statistically significantly higher in the ceramic dowel with gutta-percha and Variolink (GP/C/V) group than in the other groups. The RealSeal and RelyX fiber dowel group's mean resistance was the lowest and was significantly lower than the other groups.
Conclusions: In this study, three factors played a part in enhancing the resistance to fracture of endodontically treated teeth. High resistance to fracture was achieved when ceramic dowels were luted with total-etch technique in gutta-percha-obturated teeth.

Endodontically treated teeth are structurally different from unrestored vital teeth and necessitate special care during restoration. The combined loss of structural integrity associated with access preparation, dehydration of dentin after chemomechanical preparation, and the excessive pressure during obturation compromises those teeth and makes them more susceptible to fracture.[1] Randow and Glantz[2] reported that teeth have a protective feedback mechanism that is lost when the pulp is removed, which also may contribute to tooth fracture.

Several factors should be considered when selecting a material or a combination of materials to fill a root canal. It would be advantageous if root canal obturation, in addition to providing an adequate seal, could contribute to the reduction in the incidence of root fractures and have a potential to reinforce the root structure. Despite apparently satisfactory performance over many decades, gutta-percha and sealer-filling techniques do not represent the universal ideal. Although few materials have seriously challenged gutta-percha and sealer in most filling situations, research continues to find alternatives that may seal better and mechanically reinforce compromised roots.[3,4]

Dual-curable methacrylate resin-based sealers have attracted considerable attention because of their hydrophilic characteristics, enabling them to wet canal walls and penetrate dentinal tubules, their bondability to radicular dentin via the use of self-etching primers, and their potential bondability to root-filling materials; however, the bonding concept of root-filling material is hampered by lack of a chemical union between the polyisoprene component of gutta-percha and methacrylate-based resin sealers.[5] Recently, a new obturation system was introduced under the name RealSeal (SybronEndo Orange, CA) containing Resilon and a resin-based sealer. Resilon (Pentron Clinical Technologies, Wallingford, CT) is a thermoplastic, synthetic polymer-based root canal filling material. Based on polymers of polyester, Resilon contains bioactive glasses and radiopaque fillers. It performs in a similar way to gutta-percha, has the same handling properties, and for retreatment purposes may be heat softened or dissolved with solvents such as chloroform. The RealSeal sealer (Pentron Clinical Technologies) is a dual-curable dentin resin composite sealer. The Resilon core material is used with the RealSeal dual-cured resin sealer and self-etching primer forming a single entity or monoblock in the root canal system. This material has been shown to be more resistant to leakage than gutta-percha-based obturation systems.[5-7] As the resin core, sealer, and dentinal wall all adhere together, the manufacturer claims this monoblock provides better flexural strength than gutta-percha and strengthens the root by more than 20%, making the root more resistant to fracture. This was confirmed by Teixeira et al[8]

Restoration of endodontically treated teeth becomes more complex with the substantial loss of coronal tooth structure from preexisting restorations and dental caries. Loss of about more than 50% of the coronal structure may necessitate the use of a dowel to provide core retention. Dowels vary from a conventional custom-cast dowel and core to one-visit techniques, using commercially available prefabricated dowel systems. Failure of dowel and cores can result from fracture or bending of dowels, loss of retention, core fracture or root fracture and corrosion of metallic dowels;[9,10] however, the risk of root fracture is substantial when endodontically treated teeth are provided with metal dowels. It has been suggested that the difference between the elastic modulus of dentin and dowel material is a source of stress for the root structures. Research into dowels continues in efforts to develop systems that are biocompatible, preserve root dentin, do not stress the root, are strong and retentive to dental cements with corrosion resistance, and biocompatible with restorative materials. To secure improved visual effects, this esthetic concern has led to the development of esthetic dowels made from reinforced resin or ceramics in an effort to eliminate the color deficiency.[11,12]

Fiber dowels have an elastic modulus close to that of dentin. These dowels, bonded in place with resin cement allow for reduction of stress concentration between the dentin/dowel interface, and forces can be more evenly transferred to the root. Consequently, the incidence of root fracture may decrease.[12] EasyPost (Dentsply, Maillefer Instruments, Ballaigues Switzerland) was introduced to the market characterized as having a high proportion of unidirectional silicon fibers. This fiber dowel is made of an epoxy resin matrix reinforced with silicon fibers enriched with zircon. As reported by the manufacturer, the EasyPost is cylindrical and slightly tapered with different diameters. It is passive and designed to be used with any bonding technique. It has a modulus of elasticity ($\sim$18 GPa) close to that of dentin (18.6 GPa), thus minimizing the risk of root fracture.[13]

Ceramic dowels have been developed with the idea of improving esthetic appearance, fracture resistance, and biocompatibility. Cosmopost (Ivoclar, Vivadent AG, Schaan, Liechtenstein) is a Yttrium-stabilized zirconium oxide ceramic dowel with a modulus of elasticity of 210 GPa. It is passively cemented, smooth sided, parallel in the coronal two thirds, and tapered in the apical one third.[14]

The significant improvements in the adhesion of composite resin to dentin lead to significant leakage reduction with effective bonding of the adhesive-resin-based systems. In addition to the flexibility and shock-absorbing effect of the cement layer, adhesive resin cements might contribute to uniform stress distribution between the dowel and the dentinal walls, and absorb micromovements of the artificial crown resulting from occlusal forces more effectively than conventional brittle cements. Thus, loss of cement seal of the artificial crown and damage of dowel, core, and root dentin might be prevented.[12,13]

The behavior of cement and bonding systems is complex and partly depends on the properties and quality of the component parts of each system. An ideal dental adhesive should be able to wet, infiltrate dentin, and provide a durable bond between the unhomogenicity of enamel and dentin and the restoration.[15] The permeability of dentin to adhesive agents depends on the resin infiltration of both dentinal tubules and intertubular dentin; however, resin infiltration into intertubular dentin can occur only if the mineral phase of dentin is removed by acid conditioners. Knobloch et al[16] reported modification through the bonding agent. Total-etch technique, including dry and wet techniques, relies on etching the dentin and removal of the smear layer. This technique involves a separate etch-and-rinse step followed by priming and application of the bonding resin. It is said to be a time-consuming technique. An example of the total-etch system is Variolink II, which is a luting cement preceded by the application of bonding agent Excite DSC (Ivoclar, Vivadent). Excite contains an alcohol-based liquid (acetone free) with high-flow properties, producing hybridization between and within the dentinal tubules. The self-etching technique relies on etching dentin using nonrinse acidic monomers that simultaneously condition and prime in one step, incorporating the smear layer within the hybrid layer so it becomes one single layer. Recently developed one-bottle self-etching systems are more hydrophilic, due to a higher concentration of acidic monomers to properly etch the dentin surface. RelyX Unicem, a self-adhesive, universal resin cement without surface pretreatment has been introduced (3M ESPE, Seefeld, Germany). It is based on a novel initiation technology using new monomer and filler. The organic matrix consists of newly developed multifunctional phosphoric acid methacrylate, which can react with the basic fillers in the luting cement and the hydroxyapatite of the hard tooth tissue. This cement quickly neutralizes during the curing process, to switch from a hydrophilic to a hydrophobic state. This unique switch allows the material to adapt to the tooth structure while in the hydrophilic state, yet provide for ongoing dimensional stability with the restoration after converting to the hydrophobic matrix.[17,18] The aim of this study was to evaluate the effect of obturating system, dowel material, and adhesive luting system on the fracture resistance of endodontically treated teeth.

Materials and methods

Eighty recently extracted maxillary central incisors were selected for the present study. The teeth had to show an intact noncarious crown with comparable lengths and diameter. Teeth were immersed in 5% sodium hypochlorite for 15 minutes to remove organic materials from root surfaces. Any remaining tissue was carefully cleaned using a curette and then stored in distilled water until use. Fiber-optic transillumination was used to inspect the roots for cracks.

The crown was removed by horizontal sectioning perpendicular to the long axis at a line 2-mm incisal to the most coronal point of the approximal cementoenamel junction (CEJ) using diamond discs mounted on a lathe-cut machine under continuous water coolant. The cut surfaces were smoothed using fine sandpaper disc. The roots were prepared to have 2-mm ferruled collar with 5-mm diameter, 6° convergences, and a 1-mm shoulder finish line.

Root canal preparation

After access cavity preparation, the working length was established 1 mm short of the apex. A size 15 K-Flex (Dentsply Maillefer) was passed through the apical foramen of the canal before and after instrumentation to ensure patency. The canals were instrumented to working length with a size 40 K-Flex file. A step-back flaring technique was performed at 1-mm increments with Gates Glidden burs number 2–6 (Dentsply Maillefer) with a low-speed hand piece. The root canals were irrigated with 15 mL of 1.25% NaOCl after every change of file. Five mililitre of 17% EDTA rinses were used to remove the smear layer, followed by a final flush of 3 mL distilled water. The root canals were dried with sterile paper points before filling.

Specimen division

Random allocation of teeth was done as follows: Each tooth was given a number (from 1 to 80). Using SPSS software, the teeth were randomly allocated into eight subgroups. Then the 80 teeth were divided according to obturating material into two groups ($n = 40$): group I: gutta-percha and eugenol-free sealer; group II: RealSeal obturation system. Each group was subdivided according to dowel type into two subgroups ($n = 20$): subgroup A using ceramic dowels (Cosmopost); subgroup B using fiber dowels (EasyPost). The teeth from each subgroup were assigned to two divisions according to the adhesive luting technique ($n = 10$): division V: total-etch adhesive technique; division U: self-adhesive technique.

Root canal obturation

Group I: Gutta-percha/Eugenol-free sealer: Root canals were obturated using lateral condensation technique with gutta-percha, eugenol-free sealer (Roeka, Coltene/Whaledent, Konstanz, Germany), and 0.02 taper gutta-percha (Diadent, Chongju, Korea). A size 40 gutta-percha master cone coated with Roeko sealer was inserted into the canal. Light pumping motions were used to fill the canal with sealer and bring the cone to full working length. The canals were then obturated by lateral compaction

Group II: RealSeal Obturation System: Root canals were obturated using lateral condensation technique using RealSeal points and RealSeal (resin-based sealer). After drying the canals, RealSeal primer was applied using a microbrush in the canal, and excess was removed using paper points. The apical one-third of the master cone was coated with the sealer and placed into the canal, and then a size 20 finger spreader was inserted, rotated, and withdrawn. An accessory cone, coated with a thin layer of sealer, was placed into the space created by the spreader, and the process repeated until the canal was completely obturated. Excess RealSeal points were removed and condensed with a hot plugger, and the sealer was light cured for 40 seconds and left to self-cure in 30 minutes.

Periapical radiographs were made to asses the quality of the root canal filling in the buccolingual and mesiodistal directions. After filling, the specimens were stored at 37°C in 100% relative humidity for 7 days to allow for complete setting of the sealer.

Mounting teeth in acrylic blocks

Specimens were individually mounted vertically in self-cure acrylic resin (Meliodent, Bayer Dental, Newbury, UK) in root block former to a depth of 2-mm apical from the CEJ, representing the natural biological width. For periodontal ligament simulation, root surfaces were dipped into a molten wax to a depth of 2 mm below CEJ to provide a 0.2 to 0.3-mm spacer before their embedding in the acrylic resin poured into the root block former. After the first signs of polymerization, teeth were removed from the resin blocks; wax spacer was eliminated and replaced by silicon impression material (Impregum, 3M ESPE) injected into the acrylic resin alveolus. The teeth were reinserted into the resin cylinders. During the course of polymerization, the acrylic resin block was cooled in water to avoid dehydration of the dentin and also to prevent the deformation of the resin.

Adjustment of dowel length

Since Cosmopost and EasyPost are supplied in one length (20 mm), the adjustment of dowel length was found necessary for the specimens tested. Each dowel was held with tweezers from its head side; a mark was made with a lead pencil to the required length (14 mm). Then, the cutting procedures were done using a diamond disc to remove the excess length from the dowel head.

Dowel-hole preparation

A dowel hole of 11-mm length was prepared under water coolant in each root using 1.4 mm diameter Cosmopost drill (C0 601–3) corresponding to the Cosmoposts. EasyPost drills, size 1.4-mm diameter (A0009), were used for corresponding EasyPosts. Before drilling, excess coronal gutta-percha was removed by Gates Glidden drills (Les Fils d'Auguste, Maillfer, Switzerland). A rubber stopper was placed on its shaft and adjusted to the desired dowel length to keep a depth of 11 mm. The canals were cleaned using air/water spray, and then dried

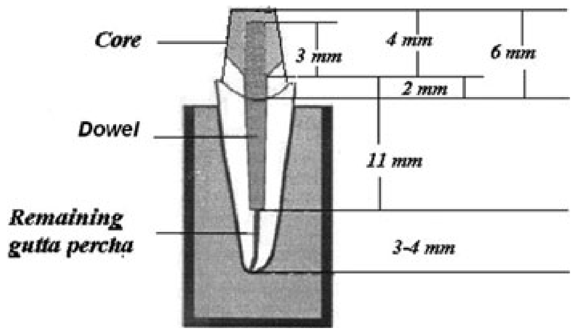

Figure 1 Specimen tested.

using paper points. The dowels were trial seated in their dowel holes.

Dowel cementation

Division (V): Total-etch adhesive technique was employed. The dentin walls of the dowel space were etched with 37% phosphoric acid for 15 seconds, rinsed, gently air dried, and followed by Excite DSC (Ivoclar Vivadent) bonding agent application. Variolink II (Ivoclar Vivadent) resin cement was mixed according to the manufacturer's instructions. The dowel was coated with cement and positioned in place under firm finger pressure; excess cement was removed, then light cured from the buccal, lingual, mesial, and distal surfaces for 30 seconds each.

Division (U): The self-adhesive technique was employed using RelyX Unicem resin cement (3M ESPE) according to the manufacturer's instruction for luting the esthetic dowels. For cementation, each dowel was coated with the cement. A lentulo spiral filler (Dentsply, Maillefer) was used to introduce the cement along the canal walls. Each dowel was inserted in the canal with a gentle pumping action to prevent air from being trapped. Any excess cement in the coronal area was removed with a brush. Continued slight pressure was applied to position the dowel in place under firm finger pressure. The entire complex was then light cured multidirectionally for 2 minutes.

Core construction

To standardize the shape and dimensions of the core in all specimens, a specially designed Teflon mold core former was fabricated. It consisted of two identical Teflon halves with a central hole of 5-mm diameter, 6° convergence, and 6-mm height, to form 4-mm core height. The two halves were assembled by a plastic ring of 2-cm internal diameter.

The dentin of the root face was etched with 37% phosphoric acid (total-etch) for 15 seconds, then was rinsed with water spray applied for 15 seconds. The root face was conditioned with a bonding agent (Excite, Ivoclar Vivadent), then light cured for 10 seconds and left for another 10 seconds for complete polymerization. The core former was placed over the prepared root face, and MultiCore HB (Ivoclar Vivadent) was mixed according to the manufacturer's instruction. The mix was inserted into the core former and light cured for 40 seconds multidirectionally. After complete core build-up (Fig 1), the specimens were stored in distilled water for 48 hours before being tested for resistance to fracture.

Resistance-to-fracture testing

The specimens were secured by tightening screws into a specially designed 45° angle jig which in turn was mounted onto the lower fixed compartment of the universal testing machine (Model LRX-plus; Lloyd instruments Ltd., Fareham, UK) with a load cell capacity of 5 KN, at a crosshead speed of 0.5 mm/min and a resolution of 0.5%. The load was applied by a metal rod with a flat end of a 3.8-mm diameter positioned in such a way to make 135° angles with the long axis of the tooth. The load was applied on the palatal side 2 mm from the incisal edge of the core. Failure loads were recorded in N, and data were recorded using Nexygen-MT: Lloyd Instruments computer software. Specimens were considered to have failed either with root fracture, core fracture, core/tooth interfacial failure, or dowel/core/tooth complex fracture. The fracture load was recorded, and the failure modes of the specimens were also determined by visual inspection. The pattern of failure was described as favorable or unfavorable depending on the ability to retreat the teeth.

Scanning electron microscopic (SEM) examination

Four extra teeth were collected, decoronated, and endodontically treated. Drilling of the dowel space was performed similar to the previous teeth. The teeth were selected as representative specimens for each group (2 teeth for each group) with each group's prementioned protocol of adhesive application into the canal space but without the esthetic dowels. Longitudinal sectioning of teeth was performed at the dentin/resin interface using a low-speed rotary cutting machine under copious water coolant. After the surfaces were polished with Soflex polishing discs, they were immersed in 6 mol/liter hydrochloric acid (HCl) for 30 seconds to demineralize any minerals not protected by resin infiltration within the hybrid layer. This was followed by rinsing the specimens with water for 1 minute. The specimens were then immersed in 1% NaOCl for 10 minutes to dissolve all exposed collagen beneath the hybrid layer. Thorough rinsing with water was then performed for 5 minutes.[19] Specimens were dehydrated in ascending concentration of alcohol, subjected to critical point drying, and then all specimens were gold sputtered. The hybrid layer and the resin tags at resin/dentin interfaces of these specimens were observed with SEM (Jeol, XL, Philips, Eindhoven, The Netherlands) at magnification 1000x.

Statistical analysis

Resistance-to-fracture data were presented as means and 95% Confidence Interval (CI) values. Data were explored for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests, which showed that data were normally distributed. Levene test for homogeneity of variance indicated homogeneity of variance between groups. Three-way ANOVA was used to test the effect of obturating system, dowel material, adhesive technique, and their interactions on the resistance to fracture (obturating

Table 1 ANOVA table representing the relationship between the studied variables

Factor	DF	SS (sum of squares)	MS (mean square)	*p*-value
Obturating system	1	5248.800	5248.800	<0.001*
Dowel material	1	967,736.018	967,736.018	<0.001*
Adhesive technique	1	12,063.872	12,063.872	<0.001*
Obturating system * dowel material	1	18.818	18.818	0.691
Obturating system * adhesive technique	1	6.728	6.728	0.812
Dowel material * adhesive technique	1	598.418	598.418	0.027*
Obturating * dowel * adhesive	4	1629.582	407.396	0.045*

*Significant at $p \leq 0.05$.

system * dowel material, obturating system * adhesive, dowel material * adhesive, obturating system * dowel material * adhesive). Duncan's test was used for pairwise comparison. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with SPSS 16.0 (SPSS, Inc., Chicago, IL).

Results

Three-way ANOVA indicated there was a statistically significant interaction among the obturating system, dowel material, and adhesive on the mean resistance to fracture (Table 1). None of the explanatory factors can be simply interpreted without considering the differing effects when used in combination.

The mean resistance to fracture (617.4 N) was statistically significantly higher in the ceramic dowel with gutta-percha and Variolink (GP/C/V) group than in the other groups (Table 2). Ceramic dowel with gutta-percha and RelyX and ceramic dowel with RealSeal and Variolink groups had statistically lower mean resistance values than the ceramic/gutta-percha/Variolink group but were significantly higher than the other groups. The RealSeal and RelyX fiber dowel group's mean resistance was the lowest (357.2 N) and was significantly lower than the other groups.

Visual inspection for the pattern of failure revealed that teeth restored with fiber dowels displayed favorable fractures. This favorable type of fracture was in the form of core/tooth interfacial separation, or core fracture, which can be repairable; however, teeth restored with zirconia ceramic dowels demonstrated catastrophic fractures (nonrestorable) with oblique root fractures propagating apically, including the core/dowel/tooth interface (Fig 2).

SEM examination (1000×) at the dentin/resin interface using total-etch approach (V) (Fig 3) revealed the presence of a hybrid layer with numerous long, tubular resin tags forming a bundled appearance. They are connected with resin-infiltrated dentin surface in a rough pattern. A gap-free attachment at the interface was evident. SEM micrograph of the dentin/resin interface of self-etch adhesive approach (U) (Fig 4) revealed fewer resin tags formed in some areas. Typical well-formed resin tags were not prominent. A gap-free attachment at the interface was evident.

Table 2 Mean resistance-to-fracture values (N) and 95%CI as comparison between the different interactions

Variables interaction	Mean	95% CI	*p*-value
GP/Ceramic dowel/Variolink	617.4[a]	614.9–619.8	0.045*
RealSeal/Ceramic dowel/Variolink	601.3[b]	596.1–606.5	
GP/Ceramic dowel/RelyX	588.5[b]	585.3–591.6	
RealSeal /Ceramic dowel/RelyX	570.2[c]	566–574.3	
GP/Fiber dowel/Variolink	391.5[d]	371.5–411.5	
RealSeal/Fiber dowel/Variolink	376.3[e]	373.8–378.9	
GP/Fiber dowel/RelyX	372.5[e]	370.6 – 374.4	
RealSeal /Fiber dowel/RelyX	357.2[f]	353.8–360.6	

*: Significant at $p \leq 0.05$; different letters indicate statistically significant differences according to Duncan's test. The superscripted alphabets signify that same alphabets show no significant difference, while different alphabets show significant difference, according to Duncan Test.

Discussion

The effect and interactions of obturating materials, dowel type, and adhesive luting techniques on the resistance to fracture of endodontically treated teeth were evaluated in this study. The introduction of the RealSeal system replaced gutta-percha with a filled polycaprolactone polymer. In theory, the methacrylate resin-based sealer of this system is able to adhere to the Resilon core material.[20]

In this study, the mean resistance to fracture of the specimens filled with RealSeal was significantly lower than those filled

Figure 2 Representative specimens demonstrating the fracture patterns for fiber dowel (F) and ceramic dowel (C).

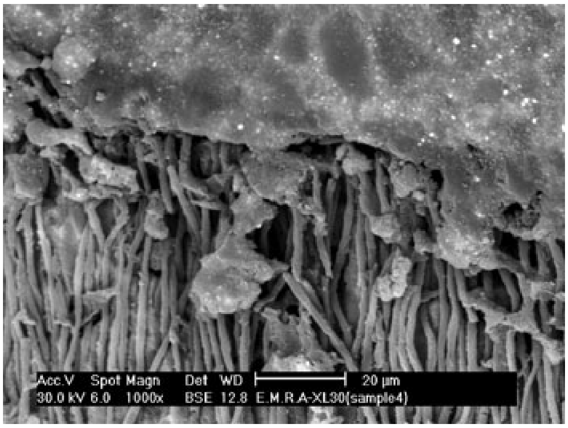

Figure 3 SEM of dentin/resin interface with total-etch technique (Variolink II) (1000×).

with gutta-percha/eugenol-free sealer. Previous results reported by Texiera et al[8] showed that RealSeal significantly increased the resistance to fracture of instrumented roots, and increased the resistance of root canal-filled teeth to vertical root fracture.[21] Others reported bonding of the methacrylate resin-based sealer to Resilon to be weaker than theoretically expected.[22] Both microshear bond and push-out tests[4,22] have shown that the bonding of RealSeal plus a urethane dimethacrylate-based sealer to root dentin is not superior to other sealer systems. To achieve a monoblock, as advertised by the manufacturer, high bond strengths are necessary between the dentin and sealer, as well as between the sealer and obturating material. Bond strengths less than 2 MPa were reported between Epiphany and Resilon.[8,23] This is not surprising, because unpolymerized resin must be available in both materials to achieve copolymerization.[24] There is no unpolymerized resin in Resilon.

In this study, the obturating materials were only limited to the apical part of the root canal to create a room for the dowel placement. Although RealSeal-obturated roots were light cured for 40 seconds, it is probable that light, as a source of activation for polymerizing, did not reach the apical third of the filling.

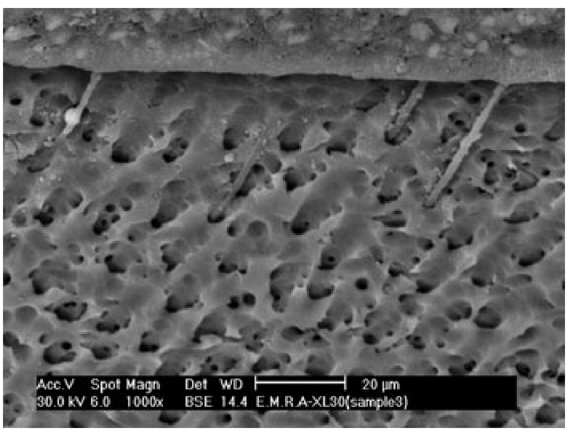

Figure 4 SEM of dentin/resin interface with self-etch adhesive technique (RelyX Unicem) (1000×).

Hence, it was expected to be chemically activated; however, the limitation of depth of light curing in the apical area may result in incomplete polymerization of Epiphany and may compromise the mechanical properties of the material and lead to a higher percentage of type 1 adhesive failures in the most apical sections.[25]

In addition, the C factor, which is defined as the ratio of bonded to unbonded surface areas of cavities, is highly unfavorable in a root canal and contributes to maximizing the polymerization stress of resin-based materials along the root canal walls.[26] With light-curing materials, the curing stress generated in the adverse geometrical configuration of the root canal may be so intense that the resin composites may detach from the dentin walls, creating interfacial gaps.[26]

Moreover, the lowest mean resistance-to-fracture values reported with RealSeal in this study may be related to the large plate-like structure of RealSeal filler particles which, according to a previous study,[22] appeared to align in layers parallel to each other and the dentin surface, possibly creating cleavage planes that readily fail in shear mode. Not to neglect the fact that when the filler particle size is larger than the dentinal tubule diameter, only the unfilled resin component is able to penetrate the tubules.[4] A recommendation of incorporating nano-fillers into future sealers may help enhance the bonding between the sealer and dentin.

It is believed that the use of a rigid material to embed extracted teeth may lead to distorted load values and possibly affect the mode of failure of the specimens. Therefore, an attempt was made to simulate periodontal ligament and surrounding anatomical structures by coating the roots with poly(vinyl siloxane) and embedding the roots in acrylic resin. The acrylic resin embedment would simulate the alveoli, as it has the compressive index of bone.[27]

Various in vivo and in vitro studies claim that the presence of a crown caused the differences between various dowel systems to disappear,[28,29] yet widespread studies report significant differences in magnitude and failure pattern with different dowel systems even when the teeth were crowned.[30,31] Crowns hinder assessing the direct effects on the mechanical properties of dowel materials. In addition, cracks propagating from the loading point can be more clearly seen without crowns. As in a similar previous study, the compressive load was directly applied to the inclined surfaces of the cores. In this manner, the variation in parameters such as material structure, shape, length, and thickness by crown restorations was avoided. By eliminating such parameters, the structural integrity and resistance to fracture of a dowel and core foundation could be tested more precisely.[32] This is contrary to Heydecke et al[33] and Dikbas et al,[34] who advocated that testing dowel-and-core preparations without placement of a crown do not reflect common clinical practice.

An ideal dowel should have an optimal combination of resilience, stiffness, flexibility, and strength. Stiffness would make the dowel not distort or bend under masticatory forces. Rigid dowel systems traditionally were designed to protect tooth structure from fracture by dissipating functional force along the length of the root and periodontal membrane. Forces from a stiff dowel are transmitted to the root apex of the dowel. Thus, attempts to add a stiff dowel in a weak root can weaken the root further due to force concentration by a stiff rod in a more flexible material, resulting in root fracture.[35]

The findings of this study were contrary to Nothdurft et al,[11] who reported higher mean fracture loads for teeth restored with quartz fiber dowels than with more rigid zirconium dioxide dowels. Cormier et al[10] identified fiber dowels as having the lowest resistance to fracture when compared to metal or ceramic dowels without crown application, whereas Akkayan and Gulmez[13] found comparable resistance-to-fracture loads between ceramic and fiber dowels. Love and Purton[36] believed that a high modulus dowel would have high resistance to elastic deformation and provide more even distribution of stresses. It was suggested that a dowel with high elastic modulus could improve the bending resistance of dowel-retained teeth. Isidor et al[37] recorded higher failure loads for teeth restored with high modulus metal dowels than teeth restored with carbon fiber dowels with an elastic modulus similar to dentin.

Low modulus dowels absorb more forces and transmit less force to the root than high modulus dowels, but fail at lower levels. Their excessive flexing and micro-movement are a risk in teeth with minimal remaining tooth structure. They are more beneficial in teeth with 3 to 4 mm of remaining axial dentin, which provides cervical stiffness in the tooth/dowel/core complex.[30,38]

The elastic characteristics of fiber-reinforced dowels may be considered a disadvantage. Occlusal loads may cause the dowel to flex with eventual micro-movement of the core, and the cement seal at the margin of the crown may fracture in a short time with resultant leakage and caries.[30,38] The results of the failure mode in this study indicated that the failure of fiber dowel groups (EasyPost) were mostly of the favorable (restorable) mode, in contrast to the unfavorable (unrestorable) mode of failure observed for the ceramic dowel groups (Fig 2). Such mode of failure was also reported in other studies.[10,13] Our results were in accordance with a previous study by Maccari et al,[39] who showed that fiber dowels produce more favorable fracture patterns by having a predominance of restorable instead of nonrestorable fracture patterns. Asmussen et al[40] indicated that higher elastic moduli of the dowels resulted in lower stresses throughout the remaining dentin of the tooth structure. Uddanwadiker et al[41] showed that the dowel material with a higher modulus of elasticity induces more stresses on the dowel and less stress on the root. They showed that stresses developing in the dowel system are maximum for the rigid titanium dowel group; alternatively, stresses on the remaining tooth structure of the root were minimum for the titanium dowel restoration. On the other hand, stresses on the dowel system were minimum for the glass fiber dowel and maximum for the remaining tooth structure of the root in case of glass fiber dowels. The high resistance to fracture obtained with the zirconia Cosmoposts may be attributable to the fact that Cosmoposts have higher modulus of elasticity (210 GPa) than the fiber dowel used (18 GPa). Higher modulus of elasticity resulted in less bending of the dowel/core unit under load as reported by a previous investigator.[31]

Resin may be bonded to fiber-reinforced composite dowels, so theoretically, the dentin/resin/dowel can be joined via resin adhesion into one unit, creating the monoblock effect with the fiber dowel.[42] It was predicted that cements would improve internal adaptation of the dowels within the roots. This closer adaptation would redistribute the stresses uniformly throughout the entire internal circumference of the root without undue stress at a specific site. From the results, it was noticed that the type of adhesive system played a major role in the resistance to fracture of different dowel/core assemblies, either cemented with total-etch or self-adhesive approach. Failure of the luting cement may lead to dowel failure including loosening of the dowel or root fracture. It has been postulated that when the luting cement fails, the fulcrum point moves in an apical direction. This can increase the lever arm and magnify stresses, leading to further degradation of the cement and an increase in apical stresses, which may cause root fracture. In this study, Variolink II with Excite adhesive bonding system provided better resistance to fracture than RelyX Unicem (Table 2). Variolink II is a total-etch system contributing to complete removal of the smear layer with dentin. Moreover, etch-and-rinse adhesive system is applied directly on the demineralized dentin collagen. The maintenance of the structural integrity of these structures during and after etching should greatly improve the final stability of the hybrid layer, as the collagen in the dentin matrix is preserved.[43] Excite is composed of HEMA in ethanol solution. Therefore, one may speculate that the behavior of this adhesive (Excite used in total-etch) can be attributed to the unique interaction of ethanol and water. The addition of ethanol to water may have caused a decrease in the surface tension of the mixture and an increase of the vapor pressure. The drop in the surface tension allowed the resin to "chase" the water and adapt to the surface, and the increase in the vapor pressure might have caused an increase in the rate of evaporation with subsequent high bond strength, manifested in the high fracture resistance values (Table 2). This was evident in the SEM (Fig 3) where a gap-free attachment at the interface was evident with the presence of hybrid layer and numerous long, tubular resin tags forming a bundled appearance; however, the results of our investigation did not coincide with other studies that reported that HEMA creates a hydrogel within the hybrid layer and adhesive resin in some cases. The hydrogel may provide a channel for water permeation with the potential to affect the durability of bonds.[43,44] Surprisingly, the new self-adhesive universal resin cement (RelyX Unicem) recorded significantly low resistance-to-fracture loads compared to total-etch (V). RelyX Unicem is a self-etch adhesive maintaining the smear layer on the dentin, preventing adhesion between dentin and adhesive (Fig 4). Since the self-etch approach uses acidic adhesive comonomers, which dissolve the inorganic phase of dentin, and simultaneously primes and infiltrates the dentin matrix without removing the smear layer, it leads to fewer exposed collagen fibrils. Adhesive stability is related to the effective coupling of the comonomers with the infiltrated substrate.[45] The pH of the acid used in any adhesive system is related to its success in bonding with dentin. RelyX Unicem contains phosphoric acid ester with higher pH than the phosphoric acid acrylate used for the total-etch technique of the Variolink II and Excite systems, as reported by the manufacturer, and therefore it has a lower bonding capacity. Similarly, the SEM (Fig 4) of this study documented that fewer resin tags were formed.

The limitations of this study include its in vitro nature, which did not replicate oral conditions. Also, a single load test was used to investigate the resistance to fracture of endodontically treated teeth. For more meaningful results, future studies should incorporate thermocycling of specimens and fatigue loading; however, it is important to remember the mean values of forces responsible for failures in the present study and other studies were considerably higher than the maximum physiologic forces acting on teeth. Fatigue stresses may be responsible for fracture with lower forces in the oral cavity. Fracture strength values from other studies are not comparable to the results of the present study because of the differences in research design. Moreover, it is true that a crown creates a ferrule and different load distribution when placed over a core buildup if the margins encircle a sound collar. Therefore, we recommend further investigation of the effect of the studied variables on resistance to fracture in the presence of full-coverage crowns made of different materials, with failure pattern identification under these conditions.

Individual preference of the dentist is the prime decisive factor of whether to use a dowel with a low elastic modulus and an early but hopefully reparable technical failure, or a dowel with high elastic modulus that lasts longer but is more irreparable. Within the limitation of this study, gutta-percha and total-etch adhesives remain the gold standard for obturating and luting esthetic dowels in endodontically treated teeth. Ceramic dowels resulted in higher resistance-to-fracture values than fiber dowels, but with irreparable technical failure.

Conclusions

In this study, three factors played a part in enhancing the resistance to fracture of endodontically treated teeth. High resistance to fracture was achieved when ceramic dowels were luted with total-etch technique in gutta-percha-obturated teeth.

References

1. Sedglely CM, Messer HH: Are endodontically treated teeth more brittle?. J Endod 1992;18:332-335
2. Randow K, Glantz P: On cantilever loading of vital and nonvital teeth. Acta Odontol Scand 1986;44:271-277
3. Stuart CH, Schwartz SA, Beeson TJ: Reinforcement of immature roots with a new resin filling material. J Endod 2006;32:350-353
4. Sly MM, Moore BK, Platt JA, et al: Push-out bond strength of a new endodontic obturation system (Resilon/Epiphany). J Endod 2007;33:160-162
5. Hammad M, Qualtrough A, Silikas N: Three-dimensional evaluation of effectiveness of hand and rotary instrumentation for retreatment of canals filled with different materials. J Endod 2008;34:1370-1373
6. Shipper G, Teixeira FB, Arnold RR, et al: Periapical inflammation after coronal microbial inclusion of dog root filled with gutta-percha or Resilon. J Endod 2005;31:91-96
7. Teixeira FB, Teixeira EC, Thompson J, et al: Dentinal bonding reaches the root canal system. J Esthet Restor Dent 2004;16:348-354
8. Teixeira FB, Teixeira EC, Thompson J, et al: Fracture resistance of roots endodontically treated with a new resin filling material. J Am Dent Assoc 2004;135:646-652
9. Robbins JW: Guidelines for the restoration of endodontically treated teeth. J Am Dent Assoc 1990;120:558-566
10. Cormier CJ, Burns DR, Moon P: In vitro comparison of the fracture resistance and failure mode of fiber, ceramic and conventional post systems at various stages of restoration. J Prosthodont 2001;10:26-36
11. Nothdurft FP, Seidel E, Gebhart F, et al: Influence of endodontic posts on the fracture behavior of crowned premolars with class II cavities. J Dent 2008;36:287-293
12. Magni E, Mazzitelli C, Papacchini F, et al: Adhesion between fiber posts and resin luting agents: a microtensile bond strength test and an SEM investigation following different treatments of the post surface. J Adhes Dent 2007;9:195-202
13. Akkayan B, Gulmez T: Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent 2002;87:431-437
14. Ivoclar V: Scientific Document AG FL-9494. Schaan, Liechtenstein, 2005
15. Diaz-Arnold AM, Vargas MA, Haselton DR: Current status of luting agents for fixed prosthodontics. J Prosthet Dent 1999;81:135-141
16. Knobloch LA, Gailey D, Azer SH, et al: Bond strengths of one- and two-step self-etch adhesive systems. J Prosthet Dent 2007;97:216-222
17. Kanca J: A method for bonding to tooth structure using phosphoric acid as a dentin-enamel conditioner. Quintessence Int 1991;22:285-290
18. Scientific Update RelyX™ Unicem Self-Adhesive Universal Resin Cement. 3M ESPE Dental Product Brochure. Minneapolis, 3M ESPE.
19. Nakabayashi N, Watanabe A, Gendusa NJ: Dentin adhesion of modified 4-META/MMA-TBB resin: function of HEMA. Dent Mater 1992;8:259-264
20. Schäfer E, Zandbiglari T, Schäfer J: Influence of resin-based adhesive root canal fillings on the resistance to fracture of endodontically treated roots: an in vitro preliminary study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:274-279
21. Ribeiroa F, Souza-Gabriela AE, Marchesana MA, et al: Influence of different endodontic filling materials on root fracture susceptibility. J Dent 2008;36:69-73
22. Hiraishi N, Papacchini F, Loushine RJ: Shear bond strength of Resilon to a methacrylate-based root canal sealer. Int Endod J 2005;38:753-763
23. Tay FR, Hiraishi N, Pashley DH: Bondability of Resilon to a methacrylate-based root canal sealer. J Endod 2006;32:133-137
24. Hiraishi N, Loushine RJ, Vano M, et al: Is an oxygen inhibited layer required for bonding of resin-coated gutta-percha to a methacrylate-based root canal sealer? J Endod 2006;32:429-433
25. Shirai K, De Munck J, Yoshida Y, et al: Effect of cavity configuration and aging on the bonding effectiveness of six adhesives to dentin. Dent Mater 2005;21:110-124
26. Schwartz RS: Adhesive dentistry and endodontics. Part 2: bonding in the root canal system-the promise and the problems: a review. J Endodon 2006;32:1125-1134
27. Moosavi H, Maleknejad F, Kimyai S: Fracture resistance of endodontically treated teeth restored using three root-reinforcement methods. J Contemp Dent Pract 2008;1:30-37
28. Sirimari S, Rüs DN, Morgano SM: An in vitro study of the fracture resistance and the incidence of vertical root fracture of pulpless teeth restored with six post and core systems. J Prosthet Dent 1999;81:262-269
29. Assif D, Bitenski A, Pilo R, et al: Effect of post design on the resistance to fracture of endodontically treated teeth with complete crowns. J Prosthet Dent 1993;69:36-40
30. Akkayan B: An in vitro study evaluating the effect of ferrule length on fracture resistance of endodontically treated teeth restored with fiber-reinforced and zirconia dowel systems. J Prosthet Dent 2004;92:155-162

31. Butz F, Lenon AM, Heydecke G, et al: Survival rate and fracture strength of endodontically treated maxillary incisors with moderate defects restored with different post and core systems. Int J Prosthodont 2001;14:58-64
32. Greenfeld RS, Roydhouse R, Marshall FJ, et al: A comparison of two post systems under applied compressive shear loads. J Prosthet Dent 1989;61:17-24
33. Heydecke G, Butz F, Hussein A, et al: Fracture strength after dynamic loading of endodontically treated teeth restored with different post-and-core systems. J Prosthet Dent 2002;87: 438-445
34. Dikbas I, Tanalp J, Ozel E, et al: Evaluation of the effect of different ferrule designs on the fracture resistance of endodontically treated maxillary central incisors incorporating fiber posts, composite cores and crown restorations. J Contemp Dent Pract 2007;8:62-69
35. Cohen S, Hargreaveaves KM: Pathways of the Pulp (ed 9). St Louis, MO, Mosby, Inc., 2006, pp. 795-799, 807
36. Love RM, Purton DG: The effect of serrations on carbon fiber post- retention within the root canal, core retention and post rigidity. Int J Prosthodont 1996;9:484-488
37. Isidor F, Odman P, Brondum K: Intermittent loading of teeth restored using prefabricated carbon fiber posts. Int J Prosthodont 1996;9:131-136
38. Morgano SM, Brackett SE: Foundation restorations in fixed prosthodontics: current knowledge and future needs. J Prosthet Dent 1999;82:643-657
39. Maccari PC, Conceicao EN, Nunes MF: Fracture resistance of endodontically treated teeth restored with three different prefabricated esthetic posts. J Esthet Restor Dent 2003;15:25-30
40. Asmussen E, Peutzfeldt A, Sahafi A: Finite element analysis of stresses in endodontically treated, dowel-restored teeth. J Prosthet Dent 2005;94:321-329
41. Uddanwadiker RV, Padole PM, Arya H: Effect of variation of root post in different layers of tooth: linear vs nonlinear finite element stress analysis. J Biosci Bioeng 2007;104:363-370
42. 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
43. Breschi L, Mazzoni A, Ruggeri A, et al: Dental adhesion review. Aging and stability of the bonded interface. Dent Mater 2008;24:90-101
44. Yiu CKY, Pashley EL, Hirashi N, et al: Solvent and water retention in dental adhesive blends after evaporation. J Biomater 2005;26:6863-6872
45. Spencer P, Wang Y, Katz JL: Identification of collagen encapsulation at the dentin/adhesive interface. J Adhes Dent 2004;6:91-95