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Microtensile Bond Strength of Nonmetallic Dowels Bonded to Radicular Dentin with Self-Etch Adhesives

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Abstract

Purpose: The bonding potential of nonmetallic dowels to root dentin, particularly with new self-etch adhesives, has not been fully investigated. The aim of this study was to determine microtensile bond strength (μTBS) of nonmetallic dowels, including a novel glass fiber dowel, when bonded to radicular dentin with self-etch adhesives.
Materials and Methods: Crowns of extracted anterior teeth were severed, and endodontic treatment was performed. Teeth were divided into six groups according to dowel/adhesive. Teeth received dowels as follows: group I: Light Post + Clearfil-SE Bond/Panavia-F (SE/PF), group II: Light Post + Xeno III/Panavia-F (XN/PF), group III: ParaPost Fiber White + SE/PF, group IV: ParaPost Fiber White + XN/PF, group V: everStick Post + SE/PF, and group VI: everStick Post + XN/PF. Teeth were sectioned to produce 1 mm specimens from both cervical and middle thirds with the dowel at the center. Specimens were tested in a special machine, and μTBS values were determined.
Results: Mean μTBS values and SDs in MPa for the cervical region were as follows: group I: 10.36 (1.88), group II: 8.51 (1.41), group III: 11.61 (1.06), group IV: 9.37 (1.61), group V: 14.22 (1.16), and group VI: 12.97 (1.69). Group V had the highest mean value—significantly higher than the means of groups I, II, III, and IV ($p < 0.0001$ to $p < 0.02$). For the middle region: group I, 9.72 (1.61); group II, 7.62 (1.42); group III, 10.28 (0.75); group IV, 8.48 (1.51); group V, 13.23 (1.06); group VI, 11.07 (1.49). Group V also had highest mean value—significantly higher than the means of groups I, II, III, and IV ($p < 0.0001$ to $p < 0.004$).
Conclusions: everStick glass fiber dowel, bonded with either adhesive, showed the highest μTBS. Microtensile bond strengths were not significantly different with cervical root dentin than with middle root dentin.

To overcome the excessive rigidity encountered with metal dowels, several types of nonmetallic dowels have been made available. A carbon fiber dowel with a modulus of elasticity value comparable to that of dentin has been reported.[1] Use of this material results in better stress distribution and may help prevent root fracture in the long term.[2] Other types of nonmetallic dowels, such as glass fiber, quartz fiber, and ceramic dowels, were later introduced. Not all of these dowels had modulus of elasticity values similar to that of dentin, however.

If dowels are well bonded to root dentin, a monoblock composed of dowel/cement/dentin is created. The three components of such a monoblock will act as one unit under functional forces with better stress distribution and fracture resistance.

The effectiveness of the dentin bond to resin cement and dowel can be evaluated by means of tests for microleakage,[3] bond strength tests,[4] and scanning electron microscopy (SEM) analysis.[5] A number of factors can affect the bond strength of dowels to dentin. These include type of dentin (normal vs. sclerotic), region of dentin (cervical vs. middle), and type of adhesive (light-polymerized vs. self-polymerized).[6-9] Yoshiyama et al[6] reported significantly lower (from 20 to 45%) microtensile bond strength (μTBS) values when bonding to sclerotic dentin compared to bonding to normal dentin. In another study that evaluated bond strength of light- and self-cured adhesives to different radicular dentin regions (cervical, middle, and apical) using a translucent dowel, significant differences in bond strength values were found among the groups.[10] The cervical region showed significantly higher mean bond strength values than the middle and apical regions.[10] The authors concluded that the optimal choice of an adhesive system that provides a

Table 1 Dowels used

Dowel	Manufacturer	Location	Composition	Lot #
Light Post	RDT	St Egrève, France	Quartz fibers in a polymerized resin	–
Parapost Fiber White	Coltene Whaledent	Langenau, Germany	Glass fibers in a polymerized resin	MT-49162
everStick Post	StickTech	Turku, Finland	Glass fibers in an unpolymerized resin	2030605-PI-005

reliable long-lasting bonding mechanism to root canal dentin remains unclear.[10]

In another study that used the push-out test to compare bond strength of two adhesives, an etch and rinse and a self-etch, used in conjunction with a self-adhesive resin cement to fiber dowels, a higher push-out force was reported for the etch and rinse adhesive.[11] Although bond strength of composite core to nonmetallic fiber dowels is affected by dowel type and surface treatment, the bond is not region dependent when a dual-cured composite core material is used.[12]

A novel glass fiber dowel has recently been introduced (everStick, StickTech, Turku, Finland). This dowel is fabricated of glass fibers embedded in an unpolymerized resin matrix. The dowel is supplied in a soft form and hardens upon light polymerization. Investigation of the bond produced with new self-etch adhesives to radicular dentin using this new dowel is desirable.

The aim of this study was to determine the effect of two self-etch adhesives on μTBS of different regions of radicular dentin of anterior teeth restored with a novel glass fiber dowel and using dual-polymerized resin cement.

Materials and methods

Maxillary anterior teeth extracted because of periodontal disease were assessed for cracks, caries, and fractures. Twenty-four teeth were selected and sterilized with gamma radiation (Gamma cell 220, Atomic Energy Ltd, Missisauga, Canada). Teeth were then divided into six groups of four, each composed of two central incisors and two canines. The anatomic crowns of the teeth were cut horizontal to the long axis, 2 mm above the cervical line.

All teeth were endodontically treated. The K^3 Ni–Ti rotary system (SybronEndo, Orange, CA) was used with periodic rinsing with 2.5% sodium hypochlorite. The canals were obturated with K^3 gutta-percha points (SybronEndo) and AH 26 eugenol-free sealer (De Trey, Konstanz, Germany). Three types of dowels were used: Light Post, 1.2-mm diameter, a quartz-reinforced dowel; ParaPost Fiber White, 1.14-mm diameter, a glass fiber dowel; and everStick Post, 1.2-mm diameter, a glass fiber dowel supplied in a soft unpolymerized form (Table 1).

Using analog drills corresponding to the selected dowels, channel holes for dowel placement were prepared leaving 4 to 5 mm of gutta-percha as apical seal. All dowels were cemented with a dual-polymerized resin cement (Panavia-F) following manufacturers' instructions. Two self-etch adhesives were used along with the cement, a two-step adhesive (Clearfil-SE Bond) and a single-step adhesive (Xeno III) (Table 2).

Experimental groups were as follows:

Group I: Light Post + Clearfil-SE Bond/Panavia-F (SE/PF)
Group II: Light Post + Xeno III/Panavia-F (XN/PF)
Group III: ParaPost Fiber White + SE/PF
Group IV: ParaPost Fiber White + XN/PF
Group V: everStick Post + SE/PF
Group VI: everStick Post + XN/PF.

Following application of monomer/adhesive, mixed cement was lentulated inside the canal. The apical portion of the dowel surface was smeared with cement, and the dowel was seated into place. Excess cement was removed, and light polymerization with an LED light unit with output of 950 mW/cm^2 (UltraLume 5, Ultradent, South Jordan, UT) for 40 seconds followed. The light guide was maintained as close as possible to the dowel so that light would travel vertically along the length of the root canal.

Core buildups were made for all specimens using an incremental technique with TPH^3 hybrid composite (Dentsply DeTrey GmbH). Light polymerization was applied for 40 seconds per increment (UltraLume 5) to ensure complete polymerization.

Specimens were kept in 100% relative humidity for 24 hours before being stored in distilled water for an additional 24 hours in an incubator (Isotemp, Fisher Scientific, Pittsburgh, PA) at 37°C. The teeth were cut perpendicularly into 1-mm-thick sections using a thin diamond saw at low speed under constant water cooling (Isomet, Buehler, Lake Bluff, IL). Sections were obtained from both cervical and middle root thirds. Each section was further cut to produce a rectangular rod 1×1 mm^2 in cross-section (Fig 1). The rods were subjected to tensile loading in a special μTBS machine (Bisco Inc., Schaumburg, IL) at room temperature and were maintained moist throughout. Each rod was fastened at both ends to the testing device

Table 2 Bonding agents and resin cements used

Bonding agent/resin cement	Manufacturer	Location	Category
Clearfil-SE Bond	Kuraray Medical Inc.	Okayama, Japan	Two-bottle self-etching bonding resin
Xeno III	Dentsply DeTrey GmbH	Konstanz, Germany	One-bottle self-etching bonding resin
Panavia-F	Kuraray Medical Inc.	Okayama, Japan	Dual-cured resin cement

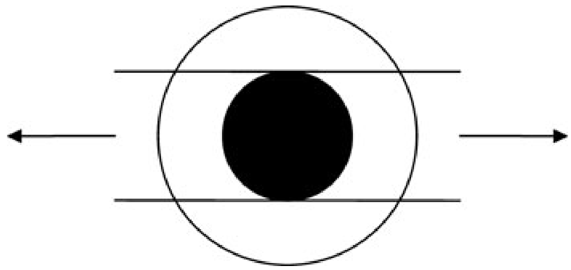

Figure 1 Diagrammatic representation of specimen preparation. Outer circle represents dentin of a root section that is 1 mm thick, while inner circle represents bonded dowel section. Two parallel cuts were made to remove dentin as indicated by the two horizontal lines. Specimens were loaded in the microtensile testing machine and load was applied as indicated by the arrows.

with cyanoacrylate glue (Zapit, DVA, Anaheim, CA). Tensile loading was maintained until failure occurred. The load at failure divided by the bonded surface area was used to calculate the bond strength in MPa as follows:

$$\mu\text{TBS} = \text{F}/{}^1\!/_2\text{C} \times \text{T}$$

where

F is the force at failure,
C is the circumference of the post and is equal to 2πR (π = 3.14 and R = radius of the post), and
T is the thickness of the rod.

Means and standard deviations of μTBS were calculated, and data statistically analyzed with one-way ANOVA and Tukey's tests at the 95% confidence level. Specimens that separated prior to mechanical testing were not included in the statistical analysis.

For the SEM analysis, 2-mm-thick sections from roots of restored teeth were sequentially polished under water irrigation using silicon carbide papers with grits varying from 120 to 4000. Specimens were then prepared for SEM examination through placing on stubs with aid of adhesive double-faced ribbon (Shintron, Shinto Paint Co., Amagasaki, Japan) and coating with a thin film of platinum (6 nm thick). Because the root sections completely encompassed the dowel sections within, no attempt was made to fix the dentin specimens before processing. SEM (Hitachi, Tokyo, Japan) was used at different magnifications, and images were captured at magnification of $\times$500.

Results

Mean μTBS values are shown in Table 3. Group V had the highest mean value in the cervical region—significantly higher than the means of groups I, II, III, and IV ($p < 0.0001$ to $p < 0.02$). Group V also had the highest mean value in the middle region—significantly higher than the means of groups I, II, III, and IV ($p < 0.0001$ to $p < 0.004$).

Table 3 also shows a breakdown of the specimens per group that underwent premature separation during sectioning and could not be subjected to tensile loading. This premature separation occurred more frequently when Xeno III was used than when Clearfil-SE Bond was used.

An ANOVA test revealed significant differences among group means ($p < 0.001$). Further analysis with post hoc Tukey's test revealed significant differences among some groups (Table 3).

Figure 2 shows representative images of the cross-sections of roots of teeth from the six experimental groups.

Discussion

Microtensile testing provides a better understanding of the quality of bonding inside the root canal.[13] For this study, it was the best method that could be used with the fiber dowels for three reasons. First, the dowel sections were bonded to radicular dentin at both ends, and separation between different interfaces could be easily identified. Secondly, because of the number of rod specimens that could be obtained from one tooth at both cervical and middle thirds, more efficient specimen preparation with a smaller number of extracted teeth required was enabled. Finally, this approach enabled testing at different regions of root dentin allowing regional μTBS to be determined.

Every attempt was made to maintain testing conditions that paralleled the actual clinical situation as closely as possible. The extracted teeth were sterilized with gamma radiation, which is known to cause no structural changes to tooth structure according to White et al.[14] To mimic clinical conditions, endodontic treatment was carried out for all teeth with intraradicular surfaces first subjected to irrigation with sodium hypochlorite solution during canal preparation and later smeared with the

Table 3 Means and standard deviations of μTBS values (MPa)

Groups	Cervical	Middle	Mean cervical and middle	Number of specimens failed prior to testing
	N = 8	N = 8	N = 16	
Group I: Light Post + SE/PF	10.36 (1.88)^{A}	9.72 (1.61)^{A}	10.03 (1.72)^{ab}	5
Group II: Light Post + XN/PF	8.51 (1.41)^{A}	7.62 (1.42)^{A}	8.09 (1.44)^{c}	13
Group III: Parapost Fiber White + SE/PF	11.61 (1.06)^{A}	10.28 (0.75)^{A}	10.95 (1.12)^{bf}	3
Group IV: Parapost Fiber White + XN/PF	9.37 (1.61)^{A}	8.48 (1.51)^{A}	8.93 (1.57)^{acd}	10
Group V: everstick Post + SE/PF	14.22 (1.16)^{A}	13.23 (1.06)^{A}	13.73 (1.19)^{e}	2
Group VI, everstick Post + XN/PF	12.97 (1.69)^{A}	11.07 (1.49)^{A}	11.05 (1.83)^{f}	7

Capital superscripts show differences between columns for cervical and middle third values ($p < 0.05$).
Lowercase superscripts show differences among overall values within the third column ($p < 0.05$).

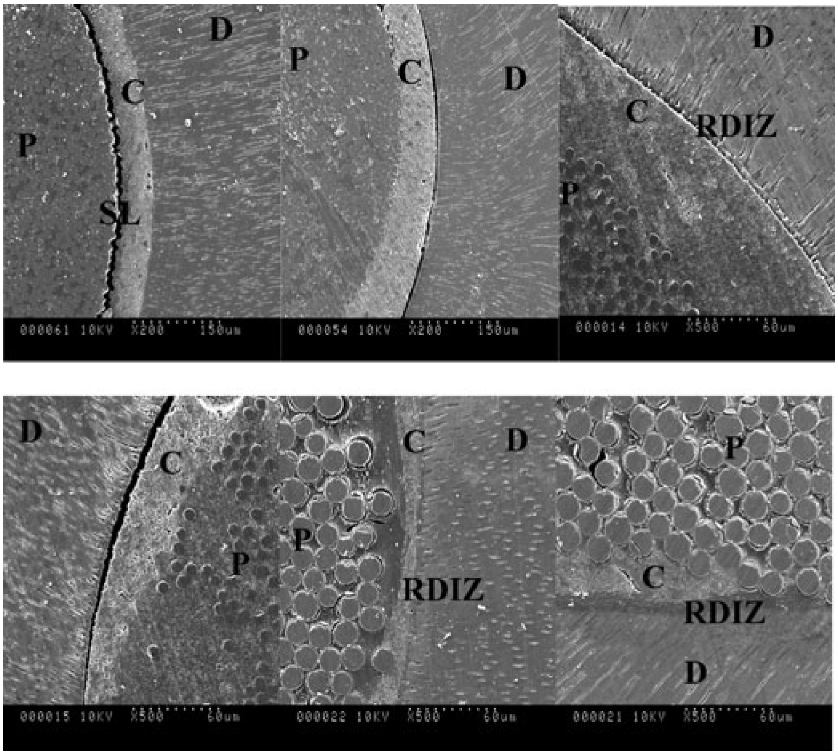

Figure 2 SEM magnification ×500. P: dowel, C: cement, D: dentin, SL: separation line, RDIZ: resin-dentin interdiffusion zone. Top left: Image of specimen from group I (Light Post + Clearfil-SE Bond/Panavia-F). Separation took place along the cement/dowel interface indicating a weak link in the joint. Top center: Image of specimen from group II (Light Post + Xeno III/Panavia-F). Separation also took place along the dentin/cement interface indicating a weak link in the joint. Top right: Image of specimen from group III (Parapost Fiber White + Clearfil-SE Bond/Panavia-F). Good adaptation can be seen along the joint. Bottom left: Image of specimen from group IV (Parapost Fiber White + Xeno III/Panavia-F). Separation took place at the dentin/cement interface indicating a weak link. Bottom center: Image of specimen from group V (everstick Post + Clearfil-SE Bond/Panavia-F). Good adaptation can be seen along the joint. Bottom right: Image of specimen from group VI (everstick Post + Xeno III/Panavia-F). Good adaptation can also be seen along the joint.

endodontic sealer during canal obturation. After completion of endodontic treatment, the composite core buildups were made in order to seal the root and minimize moisture contamination along the multiple intraradicular interfaces during storage. The teeth were continuously maintained in a moist environment throughout the experiment to avoid drying out, which can adversely affect the bond.

Microtensile bond strength values reported in the present study are comparable to those found by Mallman et al.[10] Those authors reported mean μTBS values of 10.8 and 8.1 MPa for self-polymerized and light-polymerized adhesives, respectively, when the cervical third of root dentin was used along with a resin cement.[10] Their work also indicated a drop of about 20% in μTBS values when middle rather than cervical root dentin was used. In spite of the fact that the Mallman et al study used different adhesives than were used in the present study, similar trends were reported in both studies for cervical and middle dentin. In the present study, however, the differences were not significant. Yoshiyama et al, examining the regional bond strength of self-etching/self-priming adhesives, reported μTBS values for middle root dentin that were slightly lower than for the cervical, although not statistically significantly different.[8] This is in agreement with findings of the present study. This is in spite of the fact that Yoshiyama et al used different adhesives in their work.[8]

It is debatable whether specimens that failed prematurely during preparation should be included in analysis of the results. A total of 40 specimens failed during sectioning (Table 3). If these specimens had been included in analysis of the results, they would have been assigned values of zero. Since the majority of these specimens belonged to the groups in which Xeno III had been used as adhesive, it is likely that greater statistically significant differences would have been detected between these groups and the groups that used Clearfil-SE Bond as adhesive. Causes of premature separation include lack of bond, manipulation error, or inadvertent critical stresses during handling; however, because it is difficult to ascertain the reason(s) for their premature failure, these specimens were not included in data analysis.

Generally, for all test groups, μTBS values recorded for the cervical region were approximately 10% higher than those recorded for the middle region; however, statistical analysis confirmed that these differences, in spite of being consistent, were not significant. If these differences had been significant, one might attribute the difference to attenuation of the polymerizing light, as light power density tends to decrease as light travels through the length of the root from cervical third to middle. Also, another explanation could be variability in tubule density between the cervical and middle thirds, with more intertubular dentin available for bonding in the cervical region and greater potential for increased resin tag density.[15]

One adhesive, Clearfil-SE Bond, resulted in significantly higher μTBS values than the other, Xeno III. This observation was consistent independent of the type of dowel used. Clearfil-SE Bond is a two-step self-etch adhesive while Xeno III is a one-step self-etch adhesive. Also, considering the fact that more specimens exhibited premature separation during sectioning when the one-step self-etch adhesive was used, one may conclude that the two-step adhesive was significantly superior in terms of bonding potential to radicular dentin.

Some SEM images showed evidence of separation along the dowel/dentin joint. With the two-step adhesive, this separation occurred along the dowel/cement interface while with the one-step adhesive the separation took place along the dentin/cement interface (Fig 2). While it is difficult to determine the reasons for this separation, one may speculate that it must have occurred during preparation of specimens for SEM viewing. These preparations included polishing with varying grits of sandpaper and critical point drying before sputtering with a thin layer of platinum. It is unlikely that polymerization shrinkage would have caused this separation, since the majority of sectioned specimens prepared for μTBS testing did not separate. Nevertheless, this mode of separation indicates a weak link along the dentin/adhesive/cement interfaces in the case of the one-step adhesive and along the dowel/cement interface in the case of the two-step adhesive. The bond between the dowel and cement can be increased through surface treatment (microetching with aluminum oxide powder, application of a bonding agent, etc); however, currently there is no known procedure for enhancing the bond along dentin/adhesive/cement interfaces.

Among the three nonmetallic dowels used, everStick Post resulted in μTBS values consistently higher than the values obtained with the other two dowels. This could be due to the fact that this dowel was supplied with unpolymerized resin monomer that reacted well with monomers in the resin cement used. On the other hand, the two other dowels were supplied hard (with prepolymerized monomer), which may have reduced their potential for bonding to the resin cement and, hence, account for the relatively lower μTBS values associated with their use.

Based on findings of this study and in comparison with the work of Mallman et al,[10] who used etch and bond adhesive, one may conclude that some self-etch adhesives have good potential for bonding nonmetallic fiber dowels in root canals of endodontically treated teeth.

Conclusions

Within the limitations of this study the following can be concluded:

1. Among a group of three nonmetallic dowels, everStick glass fiber dowel, when bonded with self-etch adhesives and resin cement, resulted in the highest mean μTBS ($p <$ 0.0001).
2. Bonding to cervical root dentin resulted in mean μTBS values that were not significantly higher than those associated with dowels located in middle root dentin ($p = 0.258$ to 0.999).

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