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Is a "Flexible" Glass Fiber-Bundle Dowel System as Retentive as a "Rigid" Quartz Fiber Dowel System?

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Abstract

Purpose: This study had two aims: (1) to compare the retention of a flexible directly placed fiber-bundle dowel system with that of a rigid prefabricated fiber-reinforced composite (FRC) dowel system, and (2) to determine the effect of decreasing the volume of luting cement around the flexible fiber-bundle dowels on the axial retention of the restorations.
Materials and Methods: Single-canal premolars ($n = 36$) were decoronated, cleaned, shaped, and prepared for both flexible and rigid dowels to a depth of 10 mm using a size 2 drill. The roots were then randomly allocated into three groups: Ia, Ib, and II ($n = 12$). Flexible fiber-bundle dowels were placed in groups Ia and Ib. These were available in three fiber-bundle diameters: small (0.9 mm), medium (1.2 mm), and large (1.5 mm). These bundles were luted in the root canals with Variolink II. The differences between Ia and Ib were in the ratio of the volume of fiber-bundles to the volume of luting cement and in the mode of application. Medium fiber-bundles were placed to the end of the preparation in groups Ia and Ib; however, in group Ia, a small diameter auxiliary bundle was placed, whereas in group Ib, a large-diameter auxiliary bundle was cut axially into strips of circa 0.2-mm thickness before being sequentially overlapped in placement. Roots in group II were restored with size 2 rigid prefabricated fiber dowels and luted with the light-cured cement provided by the manufacturer. After 24 hours of storage, axial tensile forces were applied to all luted dowels progressively to failure at 0.5 mm/min. Data were analyzed using a one-way analysis of variance (ANOVA) and the Bonferonni test.
Results: The mean axial resistance forces (standard deviation [SD]) for groups Ia, Ib, and II were not statistically different at 166 (49), 157 (36), and 151 (44) N, respectively ($p > 0.05$).
Conclusions: There was no significant difference between the retention of the flexible fiber-bundle dowel system and that of the rigid prefabricated fiber dowel system. Decreasing the volume of luting cement around the flexible dowels did not have a significant effect on the axial retention of the restorations.

It is well documented that the retention of dowels in tooth roots is essential to the success of the definitive restoration.[1-4] Traditionally, dowels have been constructed from metal and have been dependent on mechanical features and designs to enhance their retention.[5,6]

Fiber-reinforced composite (FRC) dowels were introduced as a replacement for metal dowels due to their lower modulus of elasticity, which is closer to that of dentin,[7] as well as their adhesive properties.[8] Although carbon FRC dowels were found to have limited adhesive properties,[9-11] the new esthetic generation of FRC dowels showed more favorable bonding properties.[12-14] Further, they have been reported to be more retentive than the clinically accepted parallel Paraposts (Coltene Whaledent, Wellingford, CT).[15]

The values of the mean axial retentive forces of dowel systems obtained from the literature were in the range of 98 N to 338 N.[15-18] It would appear that a value in the region of 100 N may be acceptable for use in clinical practice.

The adhesive properties of tooth-colored FRC dowels have allowed for the development of more anatomic dowel designs.[19] These dowels are usually prefabricated and require mechanical canal enlargement. An innovative approach has been proposed by the manufacturer of a flexible light-curable directly placed fiber-bundle dowel system (everStick; StickTech, Turku, Finland). In this system, glass fibers are impregnated with a semi-interpenetrating polymer network (IPN). An IPN polymer may be defined as a polymer comprising two or more networks that are not covalently bonded to each other, while a semi-IPN comprises only one network and a linear polymer. In the everStick dowel, the matrix is a multiphase of bisphenol A diglycidylether methacrylate (Bis-GMA) monomer resin partially diffused into a linear phase of polymethyl methacrylate (PMMA). Further, the fiber-bundle is surrounded by a PMMA outer layer to improve the adhesive properties of the dowel. According to the manufacturer, when a light-curing bonding resin is applied for 5 minutes onto the surface of the fiber-bundle preimpregnated with PMMA, the latter will be partially dissolved. Consequently, grooves and undercuts are created on the surface to provide micromechanical bonding in addition to the chemical adhesion "surface reactivation." Upon polymerization, the monomers form a cross-linked semi-IPN polymer together with phases of linear polymer.[14] The flexible dowel system is not based on a matching reamer and dowel approach. Instead, the most appropriate dowel size for the available canal space is advocated by the manufacturer. The word "flexible" as used here in relation to a dowel system refers to the flexibility of the dowel before being light-cured. This allows the pre-cured dowel to conform to the natural morphology of the canal. Subsequently, when the resin components are light-cured, this flexibility will be substantially reduced. One advantage of this dowel system is that it facilitates conservation of root tissue, which is an important contribution to the durability of the dowel and core restoration.[20,21] Another advantage is that it has the potential for use in curved and diverted root canals in which conventional prefabricated dowels may not be applicable.[22] This dowel system is not based on a matching reamer and dowel approach. Instead, the most appropriate dowel size for the available canal space is advocated by the manufacturer. Such a method is clearly dependent on the luting cement to fill any remaining space between the restoration and canal walls. The influence of the volume of the luting cement is an unknown factor with respect to the longevity of the definitive restoration, but it has been reported that lower volumes are preferable.[23,24] With this in mind, a sequential overlap method of flexible dowel placement was developed to increase the ratio of fiber to luting cement volume in the final dowel restoration and improve dowel adaptation to the canal walls.

Quartz fiber dowels (DT Light dowel; RTD, St. Egrève, France) are rigid prefabricated dowels and were selected for comparison with flexible dowels because they are tooth-colored and have a favorable anatomical shape due to their double-tapered design.[19] They were also reported to have favorable physical properties.[25-28]

This study compared the axial retention of two FRC dowel systems and evaluated the effect of decreasing the volume of the luting cement around the flexible fiber-bundle dowels on the axial retention of the definitive restoration.

Materials and methods

The products used in this study and their manufacturers are listed in Table 1. Thirty-six recently extracted caries-free human single-canal premolars were used. All teeth were disinfected in a solution of 0.05% sodium hypochlorite and then stored in normal saline solution at 37°C until testing. The crown of each tooth was removed at the cemento–enamel junction using a model 650 low-speed diamond wheel blade rotating at constant speeds under water cooling (South Bay Technology, San Clemente, CA). Each canal was negotiated with a size 25 endodontic K-file, irrigated with a 2% solution of sodium hypochlorite, and shaped coronally with sizes 2 and 3 Gates-Glidden burs (Maillefer Ballaigues, Switzerland). Dowel-space preparation was carried out using a size 2 bur (corresponding to a size 2 DT Light dowel) and with normal saline irrigation. All dowel spaces were prepared to a depth of 10 mm, and all roots with canals larger than the size 2 bur were discarded. The outer periphery of the prepared roots was notched to enhance retention before being embedded in individual acrylic blocks. The blocks were then randomly allocated into three groups of 12 (Table 1). For roots in group Ia, a flexible fiber-bundle dowel of 1.2-mm diameter was inserted to a 10-mm depth. Sharp scissors were used to modify the apical end to ensure that the dowel reached the depth of the dowel space. The dowel was light-cured in this position in the canal for 20 seconds. A further light curing for 40 seconds took place outside the canal. An additional fiber-bundle of 0.9-mm diameter was fitted in the

Table 1 Materials and dowel allocations into groups

Group	Dowel system	Composition*	Method of dowel application	Cement
Ia	everStick dowel (StickTech, Turku, Finland)	Unidirectional glass fiber (60% volume) preimpregnated in a highly porous linear PMMA and Bis-GMA matrix	1.2 + 0.9 mm (Manufacturer's method)	Variolink II (Ivoclar Vivadent, Liechtenstein) Lot no. E43259
Ib	everStick dowel	As above	(Sequential overlap method)	Variolink II
II	DT Light (RTD, St. Egrève, France)	Unidirectional pretensed quartz fiber (60% volume) in epoxy resin matrix	Prefabricated dowel of size "2" (1 mm in diameter apically and 1.8 mm coronally)	Sealbond Ultima Cement system (RTD) Lot no. 0310 A

*As indicated in the manufacturers' instructions.

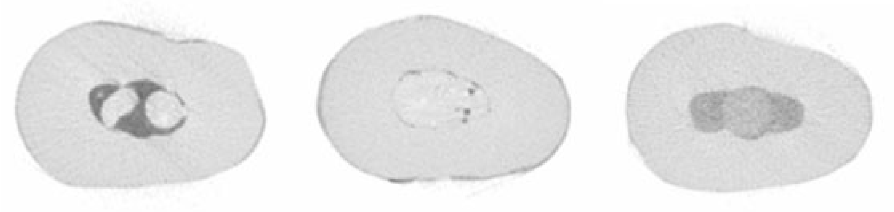

Figure 1 Representative coronal views from an X-ray microtomography are shown for groups Ia, Ib, and II.

coronal aspect of the oval canal, with the main dowel in place, and light-cured for 20 seconds in situ and for a further 40 seconds outside the canal. A layer of adhesive resin (Stick resin; StickTech) was applied to the surface of the two fiber-bundle dowels and allowed to be absorbed under a light shield to prevent polymerization while the canal was prepared for dowel cementation.

For roots in group Ib, a flexible fiber-bundle dowel of 1.2 mm was fitted in the previously described manner. Outside the canal, a flexible fiber-bundle dowel of 1.5 mm was cut using sharp scissors into eight longitudinal fiber-bundles of approximately 0.2-mm diameter. These were used as supplementary fiber-bundles to overlap the master 1.2-mm dowel and were protected under a light shield until the time of use. Outside the canal, a supplementary fiber-bundle was placed alongside the master dowel. The combined dowel unit was placed in the canal to its terminal position. Readjustment of the supplementary fiber-bundle was carried out, if required. The combined dowel was light-cured in position in the canal for 20 seconds, and for a further 40 seconds outside the canal. This fixed the shape of the combined dowel in harmony with the canal morphology. Further, supplementary fiber-bundles were placed sequentially to overlap the master dowel in a lateral condensation approach to successively shorter lengths until a spreader of size 20 could no longer be placed in the canal. The final dowel was coated with a thin layer of the adhesive resin and protected from light until cementation.

For roots in group II, a size 2 quartz fiber dowel was bonded according to the manufacturer's instructions. The representative coronal views using an X-ray micro-tomography (SkyScan-1072; SkyScan, Kontich, Belgium) for all groups are shown in Figure 1.

For cementation, the manufacturers' instructions were closely followed. Phosphoric acid was left in the canal for 15 seconds and washed with water using a 5-ml syringe. Paper points were used to remove excess water. A single adhesive technique was used with both bond systems. Excite DSC (Ivoclar Vivadent, Schaan, Liechtenstein) was used with Variolink II, while Sealbond Ultima (RTD) was used with Sealbond Cement Dual II. Two coats of the bonding agent were applied into the root canals with a small bristle brush (Composibrush; RTD). Any pooled bonding agent remaining in the dowel space was removed using paper points before the light curing process commenced. The dowel space for all groups of roots was filled with the resin cement using a lentulo spiral paste filler. A constant finger pressure was maintained on the dowel while light curing took place for 40 seconds. After completion of dowel placement, all specimens were stored in normal saline solution at 37°C for 24 hours before mechanical testing using a tensile force-measuring machine (RDP, Southam, Warwks, UK). The tensile force was applied along the long axis of the dowel and the root at a crosshead speed of 0.5 mm/min. The force required to dislodge each dowel was recorded in Newtons. A statistical analysis was carried out using a one-way analysis of variance (ANOVA) and Bonferonni dowel hoc test, and the statistical significance was set at $\alpha = 0.05$.

All roots were longitudinally sectioned and were examined under magnifications of 6.5×, 10×, and 16× using an M3Z light microscope (Wild Heerbrugg Ltd., Heerbrugg, Switzerland). The mode of failure was determined in one of the three categories: adhesive failure at cement–dentin interface, adhesive failure at cement–dowel interface, or cohesive failure (cement remaining on dowel and in dowel preparation).

Results

The means and standard deviations of the tensile force to bond failure are listed in Table 2. The statistical analysis revealed no significant difference among the three groups ($p > 0.05$). This indicated that:

1. There was no significant difference between the axial retention of the flexible fiber-bundle dowel system and that of the rigid FRC dowel system.
2. Decreasing the cement volume had no significant effect on the axial retention of the flexible fiber-bundle dowel restorations.

The failures of the bonded dowels in all groups were adhesive and always occurred at the cement–dentine interface (Fig 2). This indicated that the bond of luting cement to dowel was greater than its bond to dentin for all groups. Figure 3 illustrates a comparison between the luting cement remaining on three representative dislodged dowels. In group Ia, a substantial

Table 2 Loads to failure (N)

Group	Dowel system	Mean (SD)
Ia	everStick dowel (manufacturer's method)	166 (49)
Ib	everStick dowel (sequential overlap method)	157 (36)
II	DT Light dowel	151 (44)

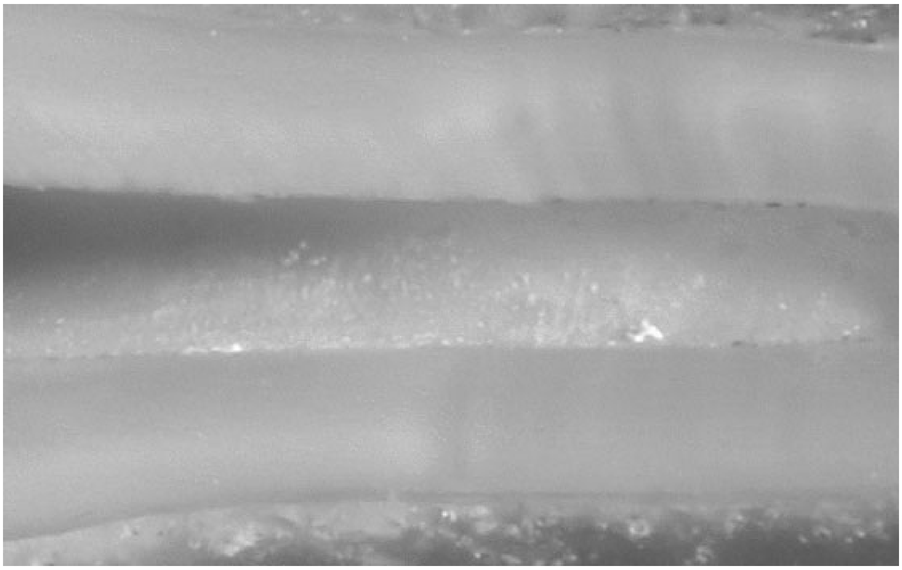

Figure 2 Canal after dislodgment of an ever Stick dowel fabricated using the manufacturer's method (group Ia)—magnification 6.5×.

amount of luting cement was found adhering to the dowels after dislodgment (Fig 3A). In group Ib, remarkably less luting cement was found adhering to the dislodged dowels (Fig 3B). In group II, a substantial amount of luting cement was found adhering to the dislodged quartz fiber dowels coronally (Fig 3C).

Discussion

In this study, when each of the dowels was axially pulled from the root canal, the dowel dislodged together with the adherent resin cement, leaving no cement adhering to the dentin canal walls. It follows that the resultant bond strength data relate to the stability of each dowel system, rather than to the dowels considered in isolation. This overall similarity of behavior is a consequence of developments in adhesive bonding to the new esthetic generation of FRC dowel systems, which have resulted in high bond strengths at the cement–dowel interface.[14,29]

Since failure of the bonded dowels in this study occurred exclusively at the cement–dentin interface in all groups, one can conclude that the resin cement did not effectively bond to the dentin of the root canal even with dentin-bonding pretreatment. Studies have shown that the confined configuration of the root canal preparation can affect the bond strength between resin cement and root canal dentin. It was reported that the C-factor (the ratio of the bonded to the unbonded areas of the preparation), which ranges from 1 to 5 for intracoronal restorations, can reach 200 for dowel restorations.[30] This is attributable to the significant polymerization shrinkage stress of the resin cement, which may reach over 20 MPa when placed in confined preparations.[31] Dual-cured resin composites were found to produce greater polymerization shrinkage stress than self-curing resin composites.[32] Other considerations are the restricted vision and the limited access into the root canal that can make it difficult to accurately control the multistage process of the adhesive bonding systems.[33]

An additional factor that may have contributed to the cement failure at the cement–dentin interface was that root canals were prepared to a tapered shape without undercuts to enhance physical retention of the luting cement in the root canal.

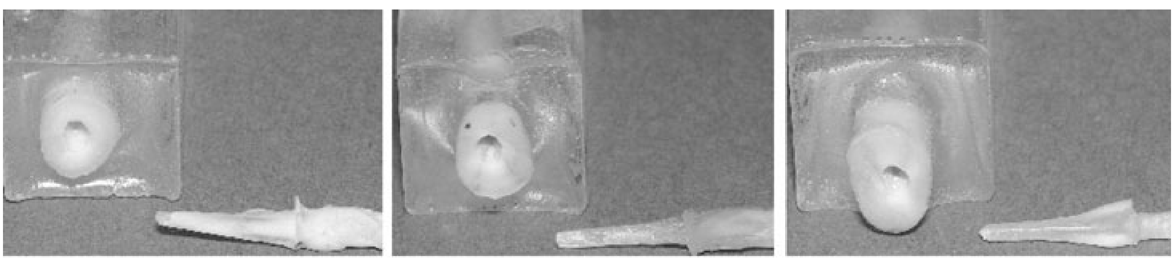

Figure 3 A comparison between the cement remaining on dislodged dowels representing the three groups. (A, left) An everStick dowel fabricated using the manufacturer's method. Note it is fully covered with luting cement after dislodgment. (B, center) An everStick dowel fabricated by the sequential overlap method, showing minimal remnants of luting cement. (C, right) DT Light dowel covered with substantial adhering luting cement in the coronal aspect.

Studies that predated the introduction of resin-based luting cement indicated that the smaller the mismatch between the dowel and the prepared canal, the greater the retention.[34,35] More recently, some studies have reported the relationship between the volume of the resin-based luting cement and Parapost retention. The axial retention of Paraposts was found to increase when the volume of the luting cement increased[36,37]; however, increase in the volume of the luting cement could have only been achieved by enlarging the volume of the dowel preparation since dowels of fixed diameter were used. Hence, the enhanced retention may be attributed to the increase in contact surface area between luting cement and the dentin.

By contrast, the present study addressed the effect of varying the volume of the resin cement on the retention of flexible fiber-bundle dowels placed in size-standardized root canal preparations. The difference in the resin cement volume was the result of varying the volume of fiber-bundles between groups Ia and Ib. This was clearly noted in the difference in the amount of the luting cement remaining on the dislodged dowels in both groups.

A previous study tested five tooth-colored FRC dowels and compared them to parallel Paraposts when luted with the same resin cement. The results showed that parallel quartz fiber dowels (304 N) were significantly more retentive than parallel Paraposts (127 N); however, no significant difference was found between the mean retentive force of parallel Paraposts and those of other tapered tooth-colored FRC dowels (98 N to 206 N).[15] This indicated the clinical acceptability of the new generation of FRC dowel systems. The mean retentive force of the tapered quartz fiber dowel system reported in this study (117 N) was slightly lower than the value obtained in the present study (151 N); however, another study reported a higher mean retentive value (202 N) for the same tapered quartz fiber dowels.[17] This could be attributed to the differences between teeth, dowel diameters, dowel depths, and the resin cements used among these studies. A previous study reported a wide range of mean retentive forces for the same tapered quartz fiber dowels when luted in bovine teeth with a range of different resin cements (131 N to 338 N). The authors of this study reported a mixed adhesive-cohesive failure.[16] This, however, was not the case in the present study where all specimens restored with tapered quartz fiber dowels had adhesive failure at the cement–dentin interface when luted in human single-canal premolars.

The bonding strength of flexible fiber-bundle dowels was compared with prefabricated carbon-fiber dowels and titanium Paraposts using the push-out test on different dentin disk thicknesses. Although no significant differences were found among the three groups, no adhesive failure was observed at the cement–post interface in the flexible fiber-bundle dowel group, suggesting better interfacial adhesion of the cement to these types of dowels.[13] This can be attributed to the effective penetration of the bonding resin into the dowels with a semi-IPN matrix.[14] The present study supports this finding since no adhesive failure at the cement–dentin interface was observed; however, in the present test, a similar result was found for the tapered quartz fiber dowels with a cross-linked matrix.

It is evident that the previous push-out study failed to test the bonding strength between the resin cement and flexible dowels, as the failure recorded in this study was cohesive in the dowel, adhesive at the cement–dowel interface, or mixed between the two modes. In the present study, no cohesive failure in the dowel was observed when two flexible fiber-bundles (1.2 and 0.9 mm) were placed in the canal; however, it is worth noting that the authors of the present study found that the cohesive failure in the dowel dominated a pilot study in which only a single 1.5-mm fiber-bundle was placed in the root canal to a depth of 8 mm. It would appear that both of the pull-out and push-out tests were limited to the assessment of the bond strength between the resin cement and dentin. Hence, it would be of interest to develop a test method that can evaluate the bonding strength between cements and the new generations of fiber dowels. The finding of the present study suggested that the new generation of FRC dowels have favorable bonding at the cement–dowel interface to the limit that makes it difficult to evaluate their bonding strength; however, it would be of interest to consider further enhancing of the bonding at the cement–dentin interface to avoid premature failures.

Conclusions

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

1. The adhesion at the dentin–cement interface was the weakest link in both dowel systems used. This has limited the findings to an assessment of the failure of the dowel systems at the dentin–cement interface.
2. There was no significant difference between the axial retentions of the flexible, directly placed fiber-bundle dowel system, and the rigid, prefabricated quartz fiber FRC dowel system ($p > 0.05$).
3. Decreasing the volume of luting cement related to flexible dowels did not offer better retention against the tensile forces ($p > 0.05$).

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