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The fracture resistance of teeth restored with different adhesive dowels

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Abstract

Objective. Fiber-reinforced composite dowels are suggested to be a better alternative to metal dowels. This *in vitro* study evaluated the fracture resistance and fracture modes of teeth restored with nine different dowel systems. ***Materials and methods.*** Ninety mandibular pre-molar teeth were decoronated and nine homogenous groups were composed. Root canal and dowel canal preparations were made and nine different dowel systems were used to fabricate restorations. Core build-ups were made with a composite resin core material. Specimens were mounted in acrylic resin blocks and continuous compressive force was applied until fracture occurred. Fracture resistance and fracture mode data were collected. One-sample Kolmogorov-Smirnov and one-way ANOVA tests were performed for the fracture resistance data of the groups. ***Results.*** There were no significant differences among the fracture resistances of the groups. All specimens of the pre-fabricated stainless steel dowel group fractured catastrophically. However, even in the worst-case, five specimens of the fiber-reinforced composite groups had favorable fracture modes. ***Conclusions.*** The teeth restored with fiber reinforced composite dowels were as resistant to fracture as teeth restored with stainless steel dowels. Fracture modes of teeth restored with fiber reinforced composite dowels were more advantageous than teeth restored with pre-fabricated stainless steel dowels.

Key Words: *dowel, fiber, fracture mode, fracture strength, post core*

Introduction

Root canal treated teeth are known to present a higher biomechanical failure risk than vital teeth [1,2]. The loss of structural integrity associated with access preparation and caries or trauma leads to a higher occurrence of fractures in endodontically-treated teeth [3,4]. In addition, teeth have a protective proprioceptive feedback mechanism that is partially lost when the pulp is removed, which also may contribute to tooth fracture [5].

After endodontic treatment, if the remaining coronal tooth structure is inadequate to retain and support a core build-up, the use of a dowel becomes essential [6]. In spite of its benefit, the use of a dowel increases the mechanical failure risk of endodontically-treated teeth [7]. For this reason, dowels should be used only when other options are not available to retain a core. In the last decade, with the evolution of adhesive techniques and materials, indications for dowel application have become more restricted, but the use of dowels continues and there is no consensus about the best technique or material [8].

Biomechanical failure risks of dowel restorations are related to the physical and morphologic characteristics of the dowel itself [9,10] and dowel material affects the biomechanical behavior of restorations. Until the early 1990s, all available pre-fabricated dowels were made from metal alloys, which resulted in stresses being concentrated on root structures because of the heterogeneous combination of dentin, metal dowel, cement and core material [11]. In addition, metal dowels present a major disadvantage because of their metallic color, especially with the introduction of metal-free ceramic restorations [11]. The restoration of endodontically-treated teeth with metal-free materials that have physical and esthetic properties similar to those of dentin has become a major objective in dentistry because of these concerns [12]. Fiber-reinforced composite (FRC) dowel systems were introduced to satisfy the increased demands. Some studies support these innovations [13], but there is a need of more information about the differences among various

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commercial FRC dowel systems and their effects on the fracture resistance and fracture type of endodontically-treated teeth.

The aim of this study was to compare fracture resistance and fracture type of endodontically-treated teeth restored with eight different FRC and a stainless steel dowel system. For the purposes of this study, the null hypothesis assumed that there were no significant differences in the fracture resistance and fracture modes of teeth restored with various FRC dowels or a stainless steel dowel.

Materials and methods

The fracture resistance and fracture mode of endodontically-treated teeth restored with a custom-shaped electrical glass fiber (CSG), a ZrO_2 containing tapered glass fiber (TZG), a unidirectional silica zirconium fiber (USZ), a tapered glass fiber with high elastic modulus (HEG), an Al_2O_3 containing tapered glass fiber (TAG), a parallel sided-serrated translucent glass fiber (STG), a double tapered quartz fiber with low elastic modulus (LEQ), a parallel sided-serrated opaque glass fiber (SOG) and a stainless steel (SSP) dowel systems (Table I) were determined through the application of a compressive load on a universal testing machine.

Ninety freshly extracted for periodontal and orthodontic reasons, caries-free mandibular second premolar teeth were selected and stored in distilled water for this study. All debris and soft tissue on the root surface were removed with a manual scaler (Hu-Friedy Mfg. Co. Inc.; Leimen, Germany). Teeth were decoronated to leave a root length of 14.5 mm, which is the average root length of this tooth [14], using a water-cooled diamond disc (Hyperflex 911, Komet Braesseler GmbH; Lemgo, Germany) and assigned to one of nine groups of 10 teeth each. The cervical buccolingual (7.94 ± 0.31 mm) and mesiodistal (5.12 ± 0.19 mm) root dimensions were assessed with one-way analysis of variance (ANOVA) to demonstrate any significant differences among the groups. There were no significant differences among the groups ($p = 1.0$).

Root canals were prepared with tapered rotary instruments to a size of 0.46 mm (ProFile Ni-Ti, Dentsply Maillefer; Ballaigues, Switzerland). Irrigation was carried out using 1 ml of 5.2% NaOCl solution between each file and 2 ml of saline solution after preparation. Root canal fillings were omitted to avoid the probable undesired effects of root canal filling and removal processes on the experimental method. For all groups, dowel spaces were prepared to a depth of 10 mm [15–17] with the drills of dowel systems supplied by the manufacturer or with universal peeso reamers, if recommended by the manufacturer. Dowels were cut to a length of 14.5 mm with a water-cooled diamond disc in order to support and retain the core build up by the dowel extension of 4.5 mm.

Before dowel cementation, to remove the smear layer and dentinal debris and to simulate an endodontically-treated root dentin surface, 2 ml of 17% EDTA solution and 2 ml of 5.2% NaOCl solution followed by 5 ml of water were used before the cementation procedure [18]. Various and specific surface conditioning procedures for each dowel system were performed according to the manufacturer's instructions (Table I).

All dowels were cemented with a self-cure adhesive resin cement (Multilink Automix, Ivoclar-Vivadent; Schaan, Liechtenstein). Initially, primer A and primer B, which are presented in the Multilink system, were mixed in 1/1 portions and applied into the prepared root canals with a brushing technique using an endodontic applicator for 15 s. The mixture remained on the root surface for another 15 s and then the excess mixture was removed with paper points. The resin cement was mixed with an auto-mixing tip and loaded directly on to the dowels. The dowels were placed into the prepared canals with a slightly rotating action and finger pressure. Excess cement was removed and canal entrances were sealed with glycerin gel (Liquid Strip, Ivoclar-Vivadent) to inhibit oxygen contact. Glycerin gel was kept during the ultimate chemical curing time (300 s at room temperature) of the resin cement and then rinsed-off with water and air spray.

Core build-ups were made with a self-cure resin core material that also has a light-curing option (MultiCore HB, Ivoclar-Vivadent) [18]. A self-etching bonding agent (AdheSE, Ivoclar-Vivadent) was used, which was supplied with the core material kit. The primer was applied to the coronal section surface of the root and to the dowel surface for 30 s and dried. Later, bonding agent was applied to the surface, slightly refined with air compression and light-cured for 10 s. The roots were embraced with a straight matrix band (Roeko GmbH., Langenau, Germany), 7 mm high. The base and the catalyst of the resin core material were mixed in 1/1 portions and condensed inside the band. The matrix band remained for 5 min to allow chemical polymerization. Later, a halogen curing light (Hilux Optimax, 800 mW/cm^2, Benlioglu Dental, Ankara; Turkey) was applied to the cores from each direction for 40 s to complete the polymerization. Finally, all the cores were prepared under water cooling with an 8° taper and at a height of 6 mm using a milling device (Bego Paraflex, Bremer Goldschlägerei Wilh. Herbst GmbH. & Co., KG, Bremen, Germany), to receive crown restoration. Ferrule preparation and crown restorations were not made.

A thin layer of silicon light-body impression material (Oranwash, Zhermack S.p.a., Badia Polesine, Italy) was used to simulate the periodontal ligament as described by Toksavul et al. [19]. Dipping wax (Rewax, Renfert GmbH, Hilzingen, Germany) was

Table I. Features and application procedures of nine different dowel systems tested.

Group	Commercial name	Manufacturer	Chemical composition	Surface treatments	Diameter (mm)	Elastic modulus (GPa)
CSG	Everstick	Stick Tech Ltd. Oy, Turku, Finland	BIS-GMA, PMMA, E-Glass Fiber	60 s initial light curing, system component stick-resin conditioner for 5 min, 10 s final light curing	1.5	27
TZG	ER Dentin Post	Komet Braesseler GmbH, Lemgo, Germany	Epoxy Resin, ZrO_2, Glass Fiber	Cleaning with alcohol, silanization (Monobond-S; Ivoclar-Vivadent) for 60 s	1.5	30
USZ	Snowpost	Carbotech, Ganges, France	Epoxy Resin, Silica Zirconium Fiber	None (pre-silanated by the manufacturer)	1.4	45
HEG	FRC Postec Plus	Ivoclar-Vivadent, Schaan, Liechtenstein	Dimetacryclate Resins, Yttrium Fluoride, Glass Fiber	60 s 37% phosphoric acid etching (Total Etch; Ivoclar-Vivadent), silanization (Monobond-S; Ivoclar-Vivadent) for 60 s	2.0	48 ± 2
TAG	Fibrekleer	Pentron Clinical Technologies LLC, Wallingford, USA	BIS-GMA, UDMA, HDDMA, Al_2O_3, Glass Fiber	Cleaning with alcohol, silanization (Monobond-S; Ivoclar-Vivadent) for 60 s	1.5	23 ± 1
STG	Parapost Fiber-Lux	Coltene/Whaledent Inc., Cuyahoga Falls, USA	Epoxy Resin, Glass Fiber	Cleaning with alcohol, silanization (Monobond-S; Ivoclar-Vivadent) for 60 s	1.5	45
LEQ	DT Light Post	Bisco Inc., Schaumburg, USA	Epoxy Resin, Quartz Fiber	Cleaning with alcohol, adhesive bonding agent (AdheSE; Ivoclar-Vivadent) and light curing for 10 s	1.5	20
SOG	Reforpost	Angelus Indústria de Produtos Odontológicos Ltd., Londrina, Brazil	BIS-GMA, Glass Fiber	Cleaning with alcohol, silanization (Monobond-S; Ivoclar-Vivadent) for 60 s	1.5	32
SSP	Parapost	Coltene/Whaledent Inc., Cuyahoga Falls, USA	Stainless Steel	Cleaning with alcohol, metal primer (Metal/Zirconia primer; Ivoclar-Vivadent) for 3 min	1.5	117

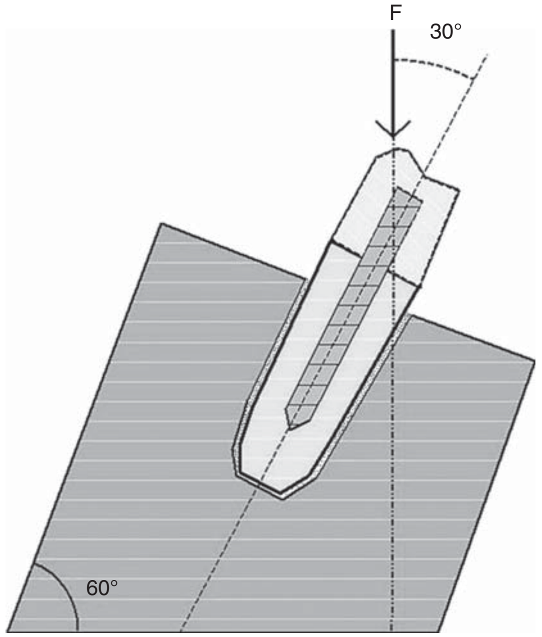

Figure 1. The schematic drawing of compressive load application to the specimen.

melted in a wax dipping pot (Bego Ceradip, Bremer Goldschlägerei Wilh. Herbst GmbH. & Co., KG) at 92°C and the roots were immersed into the wax to a depth of 2 mm below the root–core junction to cover the root surface with a 0.2–0.3 mm wax spacer. Previously fabricated, rectangular, prism-shaped silicon molds were filled with autopolymerizing acrylic resin (Paladent 20, Heraeus Kulzer GmbH, Hanau, Germany) and the roots were embedded vertically into the acrylic resin up to the wax spacer borderline. Each tooth was removed from the resin block when the first signs of polymerization were observed. The wax spacer was removed from the root surface and the alveolus of the acrylic resin block by scraping with hand instruments. Silicone light-body impression material was injected into the root spaces inside the blocks. The teeth were then re-inserted into the resin blocks with finger pressure and, in this way, the root surfaces were covered with a thin layer of silicone material with a 0.2–0.3 mm average thickness as the periodontal ligament simulation. The impression material was allowed to set and excess silicone was removed with a sharp blade to provide a flat surface. Finally, the bases of the resin blocks were beveled to achieve 60° angles to the horizontal plane.

Specimens were mounted in a universal testing machine (TSTM 02500; Elista Ltd. Sti., Turkey) and continuous compressive force was applied by using a cylindrical-shaped and flat-ended stainless steel rod (10 mm in diameter) at a crosshead speed of 1 mm/min to the buccal cusp region of each specimen at an angle of 30° to the long axis of the tooth until failure occurred [20–22]. The bevel of the acrylic block base ensured the placement of the specimens in the right position to apply the force with the proper angulation (Figure 1). Failure loads were recorded in Newtons (N). Failure modes were classified as failures at core level, cervical third, middle third or apical third of the root. Fractures at the core level and cervical third of the root were considered as favorable fracture modes. Failure load data were evaluated with the one-sample Kolmogorov-Smirnov test and the one-way ANOVA (SPSS 15.0.1, IBM Corp., Armonk, NY).

Results

Mean failure loads were determined for all groups (Table II). The highest fracture resistance was recorded for the CSG group at 1061 ± 147 N. The lowest fracture resistance was recorded for TZG at 820 ± 223 N. There were no significant differences among the fracture resistances of the groups ($p = 0.19$).

The highest catastrophic failure records for the FRC groups were five specimens for two groups (USZ, STG). However, all specimens in the SSP group fractured catastrophically (Table II).

Discussion

This study compared the fracture strengths and fracture modes of teeth restored with nine different and

Table II. Fracture strength and modes of the teeth restored with different dowel systems (n = 10).

Groups	Fracture strength ± SD (N)	Core level	Cervical third of the root	Middle third of the root	Apical third of the root
CSG (Everstick)	1061 ± 147	7	2	—	1
TZG (ER Dentin Post)	820 ± 223	4	3	2	1
USZ (Snowpost)	955 ± 202	5	—	3	2
HEG (FRC Postec Plus)	842 ± 152	5	3	1	1
TAG (Fibrekleer)	953 ± 141	5	2	2	1
STG (Parapost Fiber Lux)	945 ± 240	5	—	4	1
LEQ (DT Light Post)	942 ± 213	6	—	3	1
SOG (Reforpost)	950 ± 221	6	—	2	2
SSP (Parapost)	984 ± 116	—	—	1	9

frequently-used commercial dowel systems. The first part of the hypothesis that there would be no significant differences among the fracture resistances of dowel systems is accepted; however, the second part that there would be no significant differences among the fracture modes of teeth restored with various dowels is rejected.

The results of this study have shown that endodontically-treated teeth restored with FRC dowel systems have fracture resistance comparable with the teeth restored with a stainless steel dowel system. The literature provides some reports with similar conclusions in spite of different experimental groups and designs [19,23,24]. It is well known that the fracture strength of metal dowels is higher than the fracture strength of FRC dowels, if the dowels are compared to each other individually. However, this study indicated that the fracture resistance of teeth restored with dowel-core systems is not dependent only on the fracture resistance of the dowel itself, but rather on all of the components of the restoration complex together.

In addition, no explanatory relationship exists between the dowel design and fracture resistance. Three parallel-sided dowels had the highest mean fracture resistance values, no significant differences were evident and the study indicated that fracture resistance was not dependent only on dowel design.

One of the most common reasons for the failure of dowel-core restorations is root fracture and, usually, this failure mode causes catastrophic problems [25]. In this study, nine of the 10 specimens restored with CSG dowels failed in a way that would allow repair of the tooth. Regarding fracture modes, HEG (8), TZG and TAG (7) groups followed the CSG group as most advantageous. All specimens in the metal SSP group failed catastrophically. According to the results of the current study, fracture modes of teeth restored with FRC dowels are more repairable. Some reports in the literature support the results of the current study [24–26], but there are some contradictory conclusions in the literature as well. Some authors suggest that more elasticity causes more bending under compression and that this behavior causes higher stress levels on the root [19].

The evaluation of the results of this study indicated no relationship between fracture resistance and fracture modes. The CSG group, which had the highest fracture resistance values, was also the most advantageous group with regard to fracture modes. The HEG and TZG groups followed CSG as advantageous groups, although they had the lowest fracture resistance means. In addition, fracture types were not related only to dowel design. The most advantageous CSG group consisted of parallel-sided dowels, while the following advantageous HEG, TZG, TAG and LEQ groups consisted of tapered dowels.

The elastic modulus of SPP dowels was 117 GPa and all specimens of this group failed catastrophically. However, the elastic modulus of the FRC dowels ranged between 26–48 GPa and fracture modes of the teeth restored with these dowels were more repairable. According to the results of the current study, the elastic modulus of the dowel was determined as the primary factor that affects the fracture type. However, when the FRC dowels were compared with each other, it could be seen that the relation between the elastic modulus and the fracture type was not proportional; the elastic modulus was not the only determinant of fracture mode. Other factors, such as dowel design, dowel dimensions and cementation procedure could affect the fracture type in addition to the elastic modulus. The effects of all of these factors must be considered together and further studies are needed about the subject.

This study did not perform ferrule and chamfer preparations or crown restoration to avoid the undesired effects of these factors. Continuous compressive force was preferred over fatigue tests and there was no thermocycling process. When evaluating the results of this study, these limitations should be considered.

Conclusions

In conclusion, the current study revealed that teeth restored with FRC dowels are as resistant to fracture as teeth restored with a pre-fabricated stainless steel dowel. Fracture modes of teeth restored with FRC dowels were more advantageous than fracture modes of teeth restored with the pre-fabricated stainless steel dowel. FRC dowel restorations are, therefore, preferred for clinical use. Fracture resistance and fracture mode test results of the CSG dowel system suggest that this system should be the preferable option for clinical applications.

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