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Effect of different ferrule designs on the fracture resistance and failure pattern of endodontically treated teeth restored with fiber posts and all-ceramic crowns

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ABSTRACT

Objective: This study investigated the effect of different ferrule heights on endodontically treated premolars. Materials and Methods: Fifty sound mandibular first premolars were endodontically treated and then restored with 7-mm fiber post (FRC Postec Plus #1 Ivoclar-Vivadent) luted with self-polymerized resin cement (Multilink, Ivoclar Vivadent) while the coronal section was restored with hybrid composite core build-up material (Tetric Ceram, Ivoclar-Vivadent), which received all-ceramic crown. Different ferrule heights were investigated: 1-mm circumferential ferrule without post and core (group 1 used as control), a circumferential 1-mm ferrule (group 2), non-uniform ferrule 2-mm buccally and 1-mm lingually (group 3), non-uniform ferrule 3-mm buccally and 2-mm lingually (group 4), and finally no ferrule preparation (group 5). The fracture load and failure pattern of the tested groups were investigated by applying axial load to the ceramic crowns (n=10). Data were analyzed statistically by one-way ANOVA and Tukey's *post-hoc* test was used for pair-wise comparisons (α=0.05). Results: There were no significant differences among the failure load of all tested groups (P<0.780). The control group had the lowest fracture resistance (891.43±202.22 N) and the highest catastrophic failure rate (P<0.05). Compared to the control group, the use of fiber post reduced the percentage of catastrophic failure while increasing the ferrule height did not influence the fracture resistance of the restored specimens. Conclusions: Within the limitations of this study, increasing the ferrule length did not influence the fracture resistance of endodontically treated teeth restored with glass ceramic crowns. Insertion of a fiber post could reduce the percentage of catastrophic failure of these restorations under function.

Key words: Endodontics. Post. Material resistance.

INTRODUCTION

Endodontically treated teeth often loose substantial tooth structure from previous caries, pre-existing restorations, and/or endodontic treatment[18], which reduce tooth bulk and thickness of healthy dentin resulting in increased chances of fracture under function[8]. Controversy exists as to whether endodontic procedures are the primary cause for loss of strength. Panitvisai and Messer[23] (1995) reported that cuspal deflection increased with increasing the extension of cavity preparations and was greatest when endodontic access was incorporated into a preparation. It has been reported that endodontically treated teeth and their contralateral vital pairs exhibited similar biomechanical properties, such as punch shear strength, toughness, and load required for fracture[28].

Although the insertion of a post does not strengthen or reinforce endodontically treated teeth[11,12], it is basically used to provide sufficient retention of the core material which in turn is used to retain a fixed restoration[15]. For the inserted post to perform its function, several variables must be put into consideration such as post length, diameter, geometric design, and surface configuration[15]. Additionally, special attention should be given to the material the post is made of in order to ensure adequate distribution of the absorbed stresses and to prevent root fracture during[29]. Regarding with consideration to the well-known success of metallic posts there are now many concerns regarding the associated inhomogeneous stress distribution, biological side effects due to microleakage and corrosion, and the influence of their dark color under an all-ceramic restorations[5].

The introduction of non-metallic fiber reinforced composite (FRC) posts helped improving stress distribution because their elastic modulus is similar to that of dentin as indicated by several clinical and laboratory studies[10,17,33]. FRC post systems showed more frequent favorable failure modes than did metal post systems[11,14]. Although fiber posts proved effective in withstanding compressive loads in posterior teeth[1], they behave differently in anterior teeth where non-axial biting forces prevail and where their flexural behavior becomes more effective[27]. Recent studies[15-30] suggested that glass-fiber posts contributed to the reinforcement and strengthening of endodontically treated teeth under full coverage crowns.

A ferrule or encircling band of cast metal around the remaining coronal surface can provide protective reinforcement to endodontically treated teeth by encapsulation of the remaining coronal structure and by resisting functional lever forces during mastication. A minimum 1 to 2 mm of ferrule height is necessary to achieve such protective effect[20]. Recent clinical studies reported that the ferrule structure have a direct influence on the clinical success rate of endodontically treated premolars restored with fiber posts and the failure events were due mainly to post debonding[3,9]. An *in vitro* study reported that incomplete crown ferrule was associated with greater variation in load capacity after chewing simulation[19], while other studies found no effect of different ferrule heights in teeth restored with fiber posts and resin cores[6,22,24].

The aim of this study was to evaluate the fracture resistance and failure pattern of endodontically treated mandibular premolars restored with different ferrule heights in combination with fiber posts and all-ceramic crowns. The null hypothesis was that different ferrule heights do not improve the fracture resistance or the failure pattern of the tested restorations.

MATERIAL AND METHODS

Preparation of specimens

Fifty sound mandibular first premolars were extracted for orthodontic reasons. All external debris were removed with an ultrasonic scaler, and examined stereoscopically at 10x magnification to verify the absence of cracks, defects and dental caries. Teeth were stored in a 0.5% chloramine T (Prolabo, Paris, France) in saline solution. Buccolingual and mesiodistal coronal dimensions plus root length of all selected teeth were measured using a digital caliper (Digimatic Calipers, Mitsutoyo, Tokyo, Japan) and only teeth with the following mean dimensions were selected: 14.1 mm root length, 7.3 mm buccolingual width, and 4.9 mm mesiodistal width.

Standardized root canal preparations were made using the following procedure: initial probing using no. 10 K-files (Flexo files, Maillefer, Ballaigues, Switzerland); the root canal length was established through direct observation of the file extruding from the apical foramen. The specimens were then prepared endodontically with a stepback procedure with size 45 (Flex R file; Union Broach, York PA). After intermittent rinsing with 2.5% sodium hypochlorite solution, the endodontic treatment was completed using manual lateral condensation method (AH Plus, Dentsply, De Tray, Konstanz, Germany).

After endodontic treatment, each root was thinly covered with a silicone impression material (Aquasil, Dentsply) to simulate thickness of periodontal ligament[22]. All specimens were embedded in self-polymerized acrylic resin (Orthoresin, Dentsply, Degudent GmbH, Postfach 1364, D-63403 Hanau, Germany) poured into a mold while maintaining 2 mm below the cervical line exposed. The teeth were embedded along their long axis using a surveyor (Ney Surveyor; Dentsply).

Full crown preparation

The teeth were randomly divided into 5 groups of 10 teeth each. Crown margins were prepared under constant water cooling and using 2.5x optical loops. A new diamond point (Lot-NR 1599, DFS Dental and Technical Products, GmbH, Germany) was attached to the milling machine (K9 Milling Apparatus-990, Kavo, Germany) for every group. The MRD gauged diamond had a self-limiting tip, which produced a 1-mm-deep chamfer and the margins and the angle of convergence were standardized.

After preparation of the finish line, the coronal dentinal extension was modified accordingly (Figure 1): Group 1 (control): 1 mm circumferential ferrule from the gingival margin without a fiber post; Group 2: 1 mm circumferential ferrule with fiber post and resin core; Group 3: non-uniform ferrule height (2 mm buccally and 1 mm lingually) with fiber post and resin core; Group 4: a non-uniform ferrule height (3 mm buccally and 2 mm lingually) with fiber and resin core post; Group 5: received no ferrule preparation with fiber post and resin core.

Post-space preparation

In the control group, excess gutta-percha was removed to a depth of 2 mm from the coronal surface of the preparation, using a carbide bur (171L-012, Brasseler, USA). The coronal walls were etched with 36% phosphoric acid (Total Etch, Ivoclar-Vivadent, Schaan, Liechtenstein) for 15 s, washed with water spray and then gently air-dried. One coat of adhesive resin (Excite, Ivoclar-Vivadent) was applied using a microbrush and light polymerized for 20 s (Astralis 10, Ivoclar-Vivadent). A hybrid composite resin (Tetric Ceram, Ivoclar-Vivadent) was applied and light polymerized for 40 s.

For the remaining groups, post space was created using no. 1 Peeso reamer (Union Broach Co., Long Island, NY, USA) and corresponding calibrating drill (FRC Postec Plus, #1, Ivoclar-Vivadent) leaving 4 mm of apical gutta-percha intact. A translucent glass fiber reinforced composite post (FRC Postec Plus #1 Ivoclar-Vivadent, Schaan, Liechtenstein) was used. Each post was cut to a suitable length with a diamond bur so that it was covered with at least 2 mm of resin composite occlusally.

Post cementation was carried out with self-polymerized resin cement (Multilink, Ivoclar Vivadent) following manufacturer's instructions. Silane coupling agent (Monobond-S, Ivoclar-Vivadent) was applied on the post surface for 60 s and then air-dried. After post cementation, the surrounding dentin surface was etched with 36% phosphoric acid (Total Etch, Ivoclar-Vivadent) for 15 s, washed with water spray and gently air-dried. One coat of adhesive resin (Excite, Ivoclar-Vivadent) was applied using a microbrush and light polymerized for 20 s (Astralis 10, Ivoclar-Vivadent). Then core build-up was performed using hybrid composite resin (Tetric Ceram, Ivoclar-Vivadent) in 1-mm-thick increments and light polymerized (Astralis 10; Ivocar-Vivadent) for 40 s until the core was restored to predetermined dimensions. The final layer was placed using a transparent matrix to allow for shape consistency between specimens. The dimensions of the prepared cores were confirmed with a measuring microscope with 30x magnification lens with precision of 5 Um.

A single-phase impression was made using poly-vinylsiloxane impression material (Virtual, Ivoclar-Vivadent) and master dies were fabricated with type 4 die stone (Jad Stone, Whip Mix, Louisville, Kentucky, USA). A press ceramic (e max, A3, Ivoclar-Vivadent) was selected to fabricate all-ceramic crowns of the restored specimens. Crown dimensions were standardized by using a mold for the external shape of each specimen. The fitting surface of the crowns was pretreated with hydrofluoric acid (IPS ceramic etching gel, Ivoclar-Vivadent) for 20 s, rinsed off, air dried, silanized for 60 s and air dried. Dentine primer liquids were mixed and applied on the whole prepared tooth surface for 15 s. Resin cement was dispensed from the automix syringe directly into the inner surface of the crowns which were seated and held in position under fixed load of 20 N; excess resin was removed immediately with a micro brush. Exposed margins were covered with glycerin gel and rinsed off after complete polymerization of the resin cement. The specimens were stored in distilled water at 37°C for 7 days prior to testing.

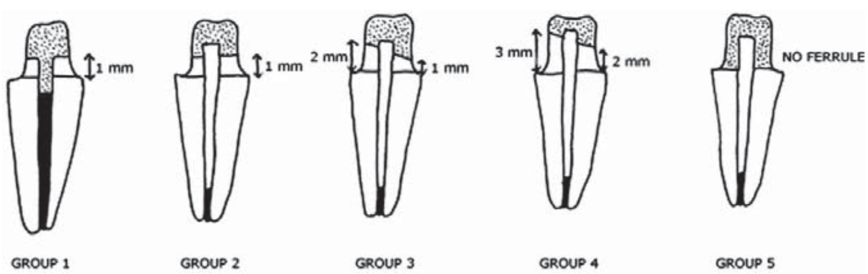

Figure 1- Schematic representation of the different tested groups

Table 1- Failure load (standard deviation) and failure type of tested groups

Group	Failure load (N)	Number of favorable fracture	Number of catastrophic fracture
Group 1 (Control)	891.4 (203)[a]	7 (70%)	3 (30%)
Group 2	1011.5 (289)[a]	10 (100%)	0 (0%)
Group 3	952.8 (246)[a]	10 (100%)	0 (0%)
Group 4	909.2 (226)[a]	9 (100%)	1 (10%)
Group 5	996.7 (279)[a]	9 (90%)	1(10%)

Similar superscript letter indicates no significant difference between different test groups

Fracture resistance

All specimens were subjected to cyclic loading according to the following regime: sinusoidal load between 50 and 200 N at a rate of 2 hertz. All specimens received 15,000 cycles and surface damage was prevented by insertion of a 0.5 mm silicon sheet between the occlusal surface of the ceramic crown and the loading indenter (3 mm diameter) of the pneumatically activated loading machine. After completion of cyclic loading, a universal testing machine (Instron 8500 Plus, Instron, 100 Royal St. Canton, MA, USA) was used to deliver a compressive load to the specimens at a crosshead speed of 1 mm/min at 45 degree angle to the long axis of the teeth (root apex tilted lingually) until failure. Load-time curves were recorded using a universal testing machine's computer software. The load was measured in Newton. The failure load of the specimen was determined when the force-versus-time graph showed an abrupt change in load, indicating a sudden decrease in the specimen's resistance to compressive loading.

After loading, the failure mode recorded for each specimen and classified as either favorable facture above the cement-enamel junction (repairable) or catastrophic fracture of the root below cement-enamel junction (non repairable). These inspections were made using a stereomicroscope (Stereoscopic zoom microscope, SMZ-1000, Nikon, Japan) and during inspection, the teeth were trans-illuminated with a fiber optic cable. Complete or partial debonding of the crown or of the post and core were also considered as favorable failure modes. Data were analyzed statistically by one-way ANOVA and Tukey's *post-hoc* test was used for pair-wise comparisons (α=0.05).

RESULTS

All specimens survived the cyclic loading program without any sign of external failure. Statistical analysis revealed no significant differences between the failure load of the tested groups and the control group restored without fiber post (P<0.780). Although fracture resistance of the control group was comparable to that of the other groups that received fiber post, there was a higher catastrophic failure rate (70%) in the control specimens in the form of vertical root fracture. The groups restored with fiber post, on the other hand, had almost complete favorable fracture in the form of cervical fracture above the cervical line, previous data are summarized in Table 1.

In all specimens, the cemented ceramic crown was fractured without evidence of debonding of either the crown or the cemented post. The internal surface of the fractured ceramic fragments demonstrated evidence of resin cement and part of the core material indicating cohesive fracture of the resin core.

DISCUSSION

Considering the results obtained in this study, different ferrule heights did not improve the fracture resistance or the failure pattern of the tested specimens. On the other hand, the use of fiber posts with a modulus of elasticity close to that of dentin changed the catastrophic failure type of the control group to almost complete favorable fracture for the other four groups. The proposed hypothesis was thus accepted. The dynamic cyclic loading program was intended to quickly screen any possible weakness in the cemented restorations. Providing occlusal protection prevented generation of cone cracks in the brittle ceramic crowns which was the reason why all specimens survived without failure. Longer periods of cyclic loading are required to shed light on the long-term performance of these restorations, but investigating this issue was not within the scope of this study[7].

The results of the fracture resistance test showed that the amount of residual coronal structure (ferrule height) did not increase significantly the fracture resistance of endodontically treated teeth. These results are in agreement with those of previous studies[2,6,22]; while contrary results were reported by other authors[25,34]. This could be explained by the fact that fiber posts transmitted the forces and distributed the loading stresses over a bigger surface area of the tooth structure similarly for all tested groups[7,16]. These results may also be interpreted as the resin bonded fiber posts with resin composite core exerted a reinforcing effect by supporting the remaining tooth structure regardless of the ferrule design[6,27]. These non-metallic post systems have gained widespread popularity in recent years because of other advantages such as their superior esthetics, ease of retrievability, and simple application technique, which allow the clinician to complete the procedure in a single short appointment[6].

According to the results of the present study, specimens in the control group (no fiber post) revealed higher catastrophic failure rate compared to the other groups, which indicates that insertion of a fiber post may enhance the clinical performance of endodontically treated teeth even if the failure load remains relatively not effected[27,30]. The presence of a uniform 1-mm-thick coronal structure (group 2) resulted in the highest fracture resistance value, especially when compared to the control group, which is in agreement with the results of previous studies[31,32].

A point of clinical relevance is that the fracture resistance of specimens with non-uniform coronal structure (group 3 and 4) was lower than the specimens without a ferrule (group 5), with consideration to maintaining as much as possible of sound tooth structure. It could be advised to adjust the coronal structure evenly to provide a flat seat for the core build up material, which could improve the fracture resistance of endodontically, treated teeth. Further research is needed to fully cover this issue[21,26].

Lithia disilicate-based all-ceramic crowns were used in this study because of its high flexural strength (400 MPa), easily etched using hydrofluoric acid, readily silanized and bonded with any suitable resin cement. It has also been reported that the mean chewing force of adults ranges between 7 to 15 kg, and the maximum biting force could reach up to 90 kg[34]. As the fracture loads in all groups in the present study were found to be greater than the ordinary chewing force, and even greater than the maximum biting force, their mechanical strength could be considered satisfactory from a clinical point of view[10].

In terms of the failure modes, the obtained results are in accordance with those of previous studies[15,27], showing that the application of fiber posts resulted in more favorable fracture patterns[4] while the specimens restored without posts showed a higher incidence of catastrophic failure. It could be postulated that specimens restored with fiber-reinforced post systems offered more homogenous stress distribution due to their modulus of elasticity close to that of dentin resulting in a better stress distribution that occurs at the post-dentin interface[24,34] . This could explain why all favorable fractures were limited to the cervical portion of the root including the core-dentin interface, since the stresses were concentrated in the cervical area and the outer root surface. Supporting this opinion is the cohesive fracture of the resin core material, which remained attached to the fractured segments of ceramic crowns, thus indicating good bond strength between the core build up material and the cemented ceramic crown. The limited number of specimens and the difficulty related to reproducing the complexity of functional loads in the oral environment may be some of the shortcomings of the present study. Further investigations including finite element analysis and long-term cyclic loading studies are recommended to complement the present study.

CONCLUSION

Within the limitations of this study, it may be concluded that increasing the ferrule length did not improve the fracture resistance of endodontically treated teeth restored with glass ceramic crowns. Insertion of a fiber post could reduce the percentage of catastrophic failure of these restorations under functional loads.

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