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RESEARCH AND EDUCATION

Influence of post material and ferrule thickness on the fracture resistance of endodontically treated premolars: A laboratory study

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ABSTRACT

Statement of problem. The influence of the ferrule thickness and post materials on the fracture resistance of endodontically treated teeth remains unclear.

Purpose. The purpose of this laboratory study was to evaluate the influence of post material and ferrule thickness on the fracture resistance of endodontically treated mandibular premolars.

Material and methods. Sixty-four extracted and endodontically treated mandibular first premolars were used and divided into 4 test groups (n=16) depending on the ferrule thickness: F-0: without a ferrule, F-0.5: with a 0.5-mm ferrule thickness, F-1: with a 1-mm ferrule thickness, and F-1.5: with a 1.5-mm ferrule thickness. In groups with ferrules, the height ranged from 2 mm buccally/lingually to 1 mm proximally. Teeth in subgroups (n=8) were restored with either prefabricated glass fiber (FF) or titanium posts (FT) (ISO size 70 and length of 7.5 mm) and then adhesively restored with composite resin foundation materials. After foundation procedures, each specimen was restored with a cobalt chromium crown which was cemented with glass-ionomer cement. All specimens were subjected to dynamic loading in a masticatory simulator for 1 200 000 loading cycles with a nominal load of 5 Kg at 1.2 Hz and simultaneous thermocycling (5 to 55 °C). Specimens were then quasistatically loaded at 30 degrees in a universal testing machine until fracture. Fracture loads were analyzed by using 2-way ANOVA followed by the Tukey honestly significant difference test (α=.05).

Results. Fracture loads ranged from 610 ±45 N (no ferrule – glass fiber post) to 1216 ±169 N (1.5 mm ferrule thickness – glass fiber post). A statistically significant increase in fracture resistance was observed with increasing ferrule thickness (*P*<.001). However, post materials did not show a statistically significant influence (*P*=.977).

Conclusions. Under the conditions of this laboratory study, increasing the ferrule thickness had a significant effect on the fracture resistance of endodontically treated teeth after thermomechanical fatigue, irrespective of post materials. (J Prosthet Dent xxxx;xxx:xxx-xxx)

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Clinical Implications

Endodontically treated teeth with a ferrule thickness of 1.5 mm can provide better fracture resistance regardless of the post type used for the definitive restoration.

Endodontically treated teeth (ETT) present a greater risk of biomechanical failure than vital teeth,[1–3] and the longevity of a restored tooth thus depends on the amount of tooth structure remaining and on the efficiency of the restorative procedure used to replace lost structural integrity.[3,4] Posts should only be placed to retain a core within the remaining tooth structure and do not strengthen the tooth.[5–7] Prefabricated posts are usually made of materials such as stainless steel, titanium, zirconia ceramic, and fiber reinforced resin materials, of which fiber posts have become popular because of their favorable physical properties.[8–10] Glass fiber posts have a flexural modulus similar to that of human dentin,[11] leading to a uniform stress distribution at the post-cement-dentin interface. They behave as a mechanically homogeneous complex with dentin and represent a new restorative concept for ensuring high resistance to occlusal loading.[7,12] However, Barbizam and White[13] reported that composite fiber post materials are susceptible to fatigue.

Research using the finite element method has demonstrated that the use of posts with a higher modulus of elasticity than dentin results in biomechanical impairments,[14] while the stress profile inside the root canal is unaffected when materials with an elasticity modulus similar to dentin are used. However, the material needs to be strong enough to tolerate severe mechanical loads. Human dentin's modulus of elasticity has been reported to range from 10 to 30 GPa,[15] but enamel has a much higher modulus of elasticity, up to 87.5 GPa.[16] Although the impact of a low modulus of elasticity is controversial, some have argued that stiff posts are necessary,[4,8,9] while others have supported having dentin-like mechanical properties for the posts.[1,17]

While fiber posts with a modulus of elasticity approximating that of dentin could reduce stress at the post-dentin interface, they might also increase stresses at the margin of the restoration, as the relatively elastic posts are placed in the neutral axis of stressed ETT[18]; evidence for a final recommendation on the post material is lacking.[19] However, recently published clinical studies[20–22] reporting higher failure rates with glass fiber posts than with zirconia ceramic posts have caused the validity of this concept to be questioned. In addition, 2 systematic reviews of randomized clinical trials reported no significant difference between fiber posts and metal posts regarding fracture resistance, and the failure rates of both were similar for the restoration of ETT.[23,24]

The choice of an appropriate restoration for ETT is guided by strength and esthetics.[25] The restoration of teeth with adhesively bonded restorations offers improved mechanical stability over conventionally cemented restorations.[26] An important consideration when restoring ETT is the ferrule effect.[26–29] Several studies have indicated the importance of a circumferential ferrule design with a height of at least 2 mm.[29–32] Samran et al[29] reported that advantages of the ferrule effect were associated with a minimum height of 1.5 to 2 mm. Fontana et al,[33] Xie et al,[34] and Nascimento et al[35] investigated the effect of the ferrule thickness on the fracture resistance of ETT, but they either used bovine anterior teeth rather than human posterior teeth, or they did not include different post materials in their studies. Moreover, Samran et al[4,8,29,36] assessed the influence of the ferrule location, ferrule height, and different post materials on the fracture resistance of ETT, but the effect of the ferrule thickness was not assessed. Therefore, the aim of the present study was to evaluate the fracture resistance and primary mode of failure in ETT with different ferrule thicknesses and different post materials. The null hypothesis was that the ferrule thickness and the post material would not affect the fracture resistance of crowned human premolar ETT.

MATERIAL AND METHODS

The materials used in the current study are listed in Table 1. After informed consent had been obtained according to the regulations of the local ethical committee, 64 human mandibular first premolars, freshly extracted

Table 1. Materials used

Material	Manufacturer	Composition	Batch No.
ER DentinPosts	Komet Dental	Glass fibers embedded in epoxy resin	00308655
ER Posts	Komet Dental	Pure titanium	00262175
Clearfil Ceramic Primer Plus	Kuraray Noritake	Ethanol >80%, 3-trimethoxysilylpropyl methacrylate <5% and 10-methacryloyloxydecyl dihydrogen phosphate	BR0069
Panavia V5	Kuraray Noritake	Bis-GMA, TEGDMA, silanated barium glass filler, silanated fluoroaluminosilicate glass filler, colloidal silica, surface-treated aluminum oxide filler, hydrophobic aromatic dimethacrylate, hydrophilic aliphatic dimethacrylate, CQ, initiators, accelerators, pigments	1B0022
Clearfil Core New Bond	Kuraray Noritake	1- Catalyst paste: Bisphenol A diglycidylmethacrylate (Bis-GMA), triethyleneglycol dimethacrylate (TEGDMA), silanated glass filler, colloidal silica, catalysts. 2- Universal paste: Bisphenol A diglycidylmethacrylate (Bis-GMA), triethyleneglycol dimethacrylate (TEGDMA), silanated silica filler, colloidal silica, accelerators	140156
Ketac Cem Aplicap	3M	Powder: Glass powder and pigments. Liquid: Polycarboxylic acid, tartaric acid, water conservation agents	8903945

for either orthodontic or periodontal reasons, were stored in 0.1% thymol solution (Caelo) at 5 °C for 2 weeks and then stored in distilled water at 5 °C. The teeth were cleaned with a hand-scaler, and those with similar crown and root sizes and free of caries or cracks were used in this study. The sample size was determined with a software program (G*Power V 3.1.9.7; Heinrich Heine University Düsseldorf). The power of the study was defined as 80% at a level of significance α=.05, which identified the need for 8 teeth per group.

For the endodontic treatment, the pulp chambers were accessed using a round diamond rotary instrument (Komet Dental), and the root canals were instrumented to an International Organization for Standardization (ISO) size 50 (K-files; Dentsply Sirona). After rinsing with 3% sodium hypochlorite solution and drying with paper points (Roeko; Coltène), the root canals were sealed with a thin layer of sealer (AH Plus; Dentsply Sirona) and obturated with laterally condensed gutta percha points (Roeko; Coltène). The access cavities were sealed with interim filling material (Cavit; 3M), and all specimens were placed in distilled water. To create an artificial periodontal ligament, the roots were embedded in a rubber material diluted with its thinner liquid (Plasti Dip; Plasti Dip International) to produce a thin and homogenous layer of rubber; this was left for 6 hours to completely polymerize. The specimens were embedded in Ø15×25-mm brass tubes using an autopolymerizing resin (Technovit 4000; Kulzer) up to 2 mm apical to the cemento-enamel junction (CEJ), with the longitudinal axes oriented perpendicular to the horizontal plane.

The specimens were assigned to 4 groups (n=16) according to the type of post: F-0: specimens without a ferrule; F-0.5: specimens with 0.5-mm ferrule thickness; F-1: specimens with a 1-mm ferrule thickness; and F-1.5: specimens with a 1.5-mm ferrule thickness (Fig. 1). The coronal portion of each tooth was sectioned at a distance of 2 mm (in the presence of a 2-mm-high ferrule with varying thickness) from the CEJ or at the level of the CEJ (in the absence of a 2-mm-high ferrule), resulting in a standard height. Then, the specimens received 0.6-mm rounded shoulder finish lines placed 1 mm more coronally on the mesial and distal surfaces than on the facial and lingual surfaces, and which were cervical to the CEJ (with a 3-degree taper to achieve a 6-degree convergence angle).

The teeth were prepared with diamond rotary cutting instruments (845KR.314.018; Komet Dental) in a high-speed handpiece under copious air-water cooling. Teeth in the subgroups were restored either with titanium posts (ER Post; Komet Dental) or glass fiber posts (ER DentinPost; Komet Dental) (n=8). For all teeth, the post space was prepared with a tapered drill (ER-post set; Komet Dental) of ISO size 70 to achieve an intraradicular post length of 7.5 mm. To increase post retention, all posts were airborne-particle abraded for 5 seconds at a 30-mm distance and with 50-µm alumina

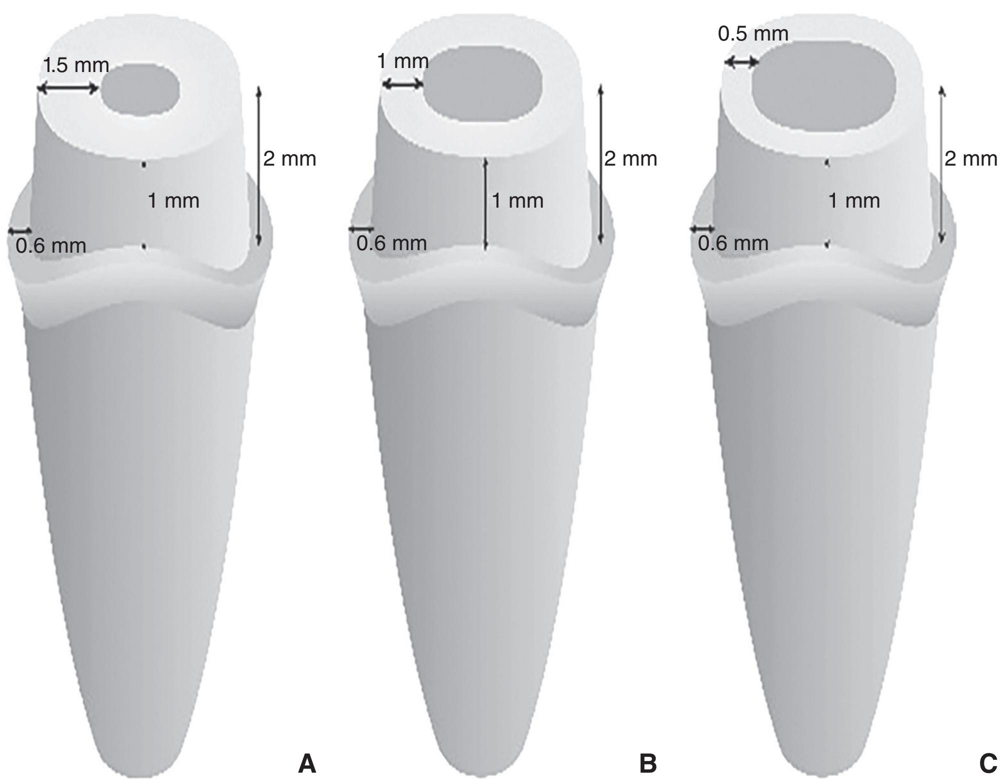

Figure 1. Ferrule thickness in different groups. A, With 0.5-mm ferrule thickness, B, With 1-mm ferrule thickness. C, With 1.5-mm ferrule thickness.

particles at 0.1 MPa.[37,38] To achieve a uniformly abraded surface, the glass fiber posts were abraded for 8 seconds, and the titanium posts were abraded for 15 seconds and then cleaned ultrasonically in 99% isopropanol for 3 minutes.[38] After irrigation with 3% sodium hypochlorite solution and ethylenediaminetetraacetic acid (EDTA), the canal and cavity were cleaned for 20 seconds with water spray and then dried with paper points. Using a microbrush, the airborne-particle abraded surfaces of the posts received a thin coat of bonding agent (Clearfil Ceramic Primer Plus; Kuraray Noritake). The dentinal walls were conditioned with a self-etching dentin primer (Panavia V5 Tooth Primer; Kuraray Noritake) for 20 seconds, and the posts were luted with a dual-polymerizing resin cement (Panavia V5 Paste; Kuraray Noritake). The cement was light polymerized for 10 seconds from all directions (buccal, lingual, mesial, distal, and occlusal).

For the foundation, an autopolymerizing composite resin (Clearfil Core New Bond; Kuraray Noritake) was applied on the coronal tooth structure and allowed to polymerize for 5 minutes before being prepared to the required dimensions. Digital scans of the prepared specimens were made with an oral scanner (TRIOS 3; 3Shape A/S). To obtain identical crown dimensions for all specimens, a virtual waxing of the mandibular premolar was designed using a software program (DentalCAD 3.0 Galway software; Exocad GmbH). Subsequently, the virtual 3D design of the mandibular premolar was replicated to obtain standardized dimensions for all crowns. The exported designs were milled in CAD wax (Ceramill wax; Amann Girrbach AG). All wax patterns were invested and cast in a cobalt chromium alloy (Wironit; Bego). The intaglio surfaces of the crowns were airborne-particle abraded with 50-µm alumina at 0.25 MPa and then ultrasonically cleaned in 96% isopropanol. The tooth preparations were cleaned with a rotary brush and pumice (Sterilbimspaste; Ernst Hinrichs Dental GmbH). Then, the crowns were cemented using glass-ionomer cement (Ketac Cem Alica; 3M). During the cementing procedures, each crown was held in place for 7 minutes under a load of 49 N using a custom-made positioning device (Fig. 2).

After storing the specimens for 3 days in distilled water at 37 °C, they were subjected to mastication simulation in a dual-axis mastication simulator (Willytec; Feldkirchen-Westerham,) with a nominal load of 49 N for 1 200 000 cycles and simultaneous thermocycling (5 to 55 °C).[39] All specimens that survived the dynamic loading were quasistatically loaded in a universal testing machine (Zwick Z010/TN2A; Zwick) with a crosshead speed of 1 mm/minute at an angle of 30 degrees to the longitudinal axis of the tooth until fracture. After that, the fractured specimens were examined under a stereomicroscope at ×25 magnification (Wild M420; Wild Heerbrugg).

The fracture load data were analyzed for their distribution with the Shapiro-Wilk test, and their homogeneity was

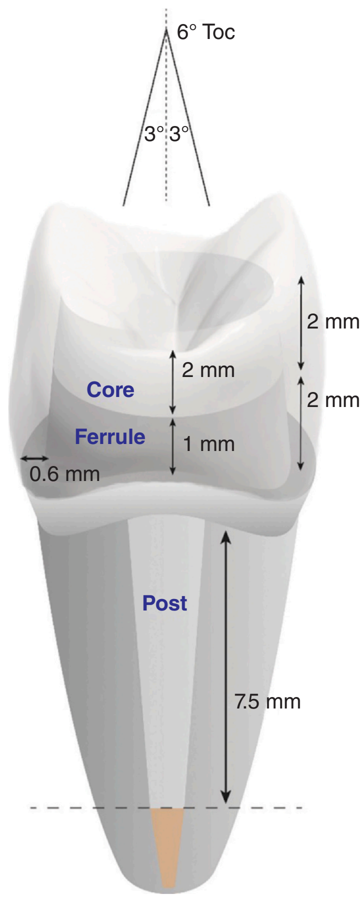

Figure 2. Diagram of post length, restorative core height, and preparation angle in test groups.

analyzed with the Levene test. They were found to have a homogeneous and normal distribution (P>.05). The fracture load data were analyzed using 2-way ANOVA and Tukey HSD tests (α=.05). In addition, the chi-squared test was used to analyze the association between the failure mode and the different ferrule thickness or post materials used.

RESULTS

The mean ±standard deviation fracture loads ranged from 610 ±45 N (no ferrule thickness – glass fiber post) to 1216 ±169 N (1.5 mm ferrule thickness – glass fiber post). A statistically significant increase in fracture resistance was observed with increasing the ferrule thickness ($P\leq$.05). However, post materials did not show a statistically significant influence (P=.977) (Table 2). The post hoc Tukey HD test showed a significant difference (P<.001) between the following groups: F-0 and F-0.5, F-0 and F-1, F-0 and F-1.5, F-0.5 and F-1.5, and F-1 and F-1.5. However, groups F-0.5 and F-1 were statistically similar (P=.999) (Table 3). The investigation of the fractured specimens showed 2 types of fractured modes; specimens with cervical third fractures were classified as favorable (above the acrylic resin border simulating the

Table 2. Two-way ANOVA of main factors (post material and ferrule thickness) and their interaction

Source	Sum of Squares	df	Mean Square	F	*P*
Ferrule thickness	2151157.297	3	717052.432	31.473	.001
Post	19.141	1	19.141	.001	.977
Ferrule×Post	161010.172	3	53670.057	2.356	.082
Error	1275837.875	56	22782.819		
Total	57318757.000	64			
Corrected Total	3588024.484	63			

a. R Squared =.644 (Adjusted R Squared =.600).

Table 3. Mean ± standard deviation fracture loads (N=8).

Group	Glass Fiber Posts	Titanium Posts
No Ferrule	610 ± 45^{A}	715 ± 48^{A}
Ferrule of 0.5 mm	868 ± 153^{B}	962 ± 173^{B}
Ferrule of 1 mm	970 ± 132^{B}	846 ± 234^{B}
Ferrule of 1.5 mm	1216 ± 169^{C}	1145 ± 156^{C}

Statistically different means ($P \leq .05$) within column indicated by different superscript uppercase letters.

bone), while specimens with middle and apical third fractures were classified as unfavorable (below the embedding resin margin). Most groups showed a higher percentage of unfavorable (80%) than favorable (20%) fracture modes (Fig. 3). A chi-squared test comparing the fracture modes in groups with different types of posts showed no significant difference between them (P=.351). However, a significant difference was found when comparing the fracture modes in groups with different ferrule thicknesses (P<.001).

DISCUSSION

The major advantage of laboratory studies over clinical trials is the possibility of achieving a high degree of standardization with well-defined parameters, such as the biomechanical status of specimens. Based on the clinically commonly used post materials,[40] titanium posts and glass fiber posts were selected. Since artificial teeth do not simulate natural dentin and the bonding process is unrealistic, natural human teeth were used in this laboratory study. The importance of a ferrule height of 1.5 to 2 mm has recently been demonstrated in laboratory studies using the same combination of materials as in the present study.[29,36] Therefore, all the specimens (except groups without ferrule) were prepared to have a 2-mm ferrule height. In addition, a post diameter of ISO size 70 was used, as thicker posts would be too large for use in mandibular premolars, potentially weakening the roots.[41] Composite resin build-up material was used in this study

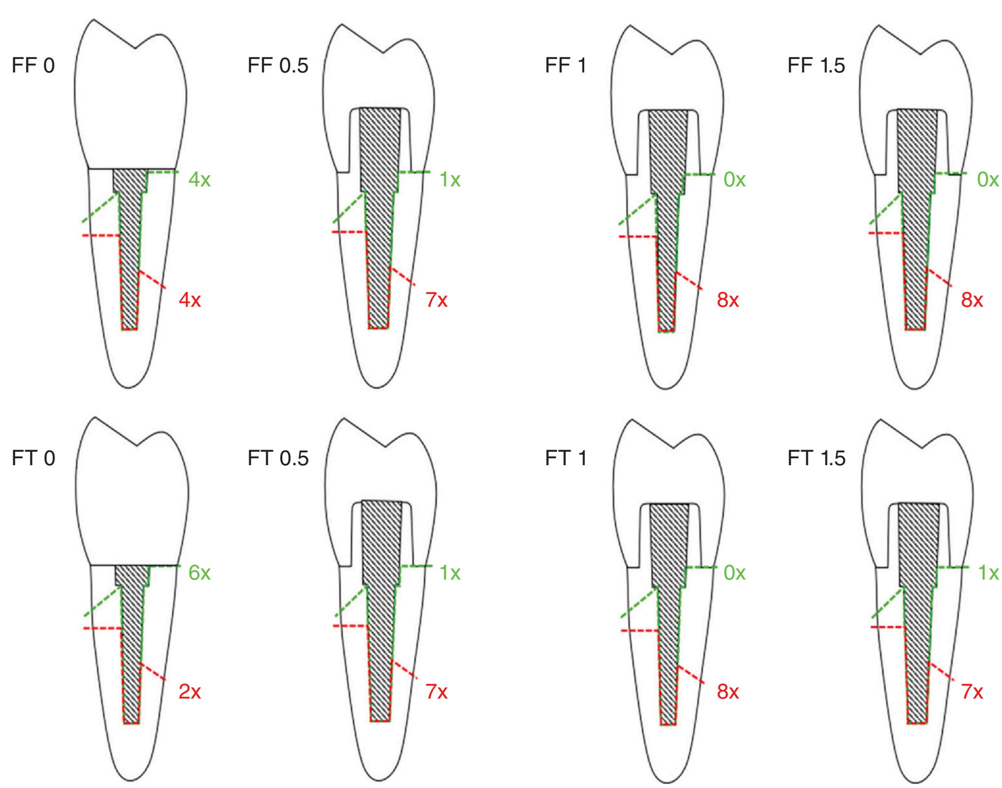

Figure 3. Fracture mode and frequency in test groups. FF, glass fiber post groups; FT, titanium post groups.

because of its good bond strength, good esthetics, and adequate compressive strength.[42]

A standardized artificial periodontal ligament was simulated using a rubber material to mimic the clinical situation. In addition, an artificial environment was used to simulate the clinical environment as closely as possible in regard to load, cycle frequency, loading angle, and temperature changes. Specimens were tilted at a 30-degree angle from the horizontal, reported to be the most comparable angle of loading in premolars area.[29,36] A total of 1 200 000 simulated mastication cycles were used in this study, simulating 5 years of clinical service.[43,44] In addition, the average masticatory force for a young adult is about 50 N, so a load of 50 N was applied for the fatigue load process.[39,45]

The current study revealed that ferrule thickness affected the fracture resistance of ETT restored using fiber or titanium posts. Thus, the first null hypothesis that ferrule thickness would not influence the fracture resistance of ETT was rejected, since increasing the ferrule thickness was accompanied by the increased fracture resistance of ETT ($P<.001$). This finding indicated that increased ferrule thickness required a higher compressive load to fracture. The lowest fracture resistance values were found for the subgroups without a ferrule. These results may be explained by the fact that greater remaining tooth structure results in a stronger tooth. The greater amount of dentin can redistribute and dissipate a larger force. The group with 1.5-mm ferrule thickness and fiber posts had the highest fracture resistance, followed by the group with 1.5-mm ferrule thickness and titanium posts. The least fracture resistance values were found in the group with no ferrule thickness and fiber posts, followed by the group with no ferrule thickness and titanium posts. In addition, a significant difference ($P<.001$) was observed between the following groups: F-0 and F-0.5, F-0 and F-1, F-0 and F-1.5, F-0.5 and F-1.5, and F-1 and F-1.5. The difference can be explained by the fact that a greater amount of dentin allowed for the dissipation of larger forces. Furthermore, the additional dentin may have provided a more stable foundation for the post-and-core, improving resistance to rotation. The relationship between ferrule height, remaining coronal walls, and ferrule thickness on the fracture resistance of ETT was similar, suggesting a positive correlation between fracture strength and the amount of remaining coronal dentin, consistent with previous studies.[6,33–36] Moreover, these results might explain how preserving ferrule thickness can improve the fracture resistance of ETT.

Although there was no significant difference when comparing the fracture resistance between groups with a 0.5-mm and 1-mm ferrule thickness, both groups with a thin ferrule were significantly stronger than groups without a ferrule, likely because of greater preservation of dentin in both groups. Unnecessary removal of sound dentin should always be avoided, as it will weaken the teeth.[4,8,29,36,46,47]

The second null hypothesis that post material would not influence the fracture resistance of ETT was not rejected, as the post material had no significant influence on fracture strength ($P=.977$). These findings were consistent with those of previous studies reporting no major effect on the fracture resistance of ETT when using different post materials.[48–53] In addition, the insertion of a post was found not to increase the fracture resistance enough to compensate for the absence of ferrule. This result was similar to the result of previous laboratory studies which reported that the different post materials performed similarly when combined with different composite resin foundation restorations and were not able to compensate for the absence of a ferrule.[50,54,55] The failure modes of the test groups with different post types were statistically similar ($P=.351$). The similarity can be explained by the fact that the presence of a ferrule masked the post effect, especially for the groups with a ferrule where the fracture mode was unfavorable for the majority of the specimens. However, a statistical difference was found in the fracture mode between groups with regard to the ferrule thickness ($P<.001$), explained by the presence of the ferrule effect. All groups (except FF0 and FT0) showed a higher percentage of unfavorable root fracture modes than of favorable root fracture modes (Fig. 3). Specimens without a ferrule could flex more than those with a ferrule. In addition, the post led to stresses concentrated at the cervical level,[56] increasing stresses in the dentin in this region. However, when a ferrule is present, the post is less prone to flexure, and the fracture load is directed to the root area, resulting in a less favorable fracture mode than for the groups with ferrule. The chi-squared test comparing the fracture modes in groups with different types of posts showed no significant difference between them ($P=.351$). However, there was a significant difference when comparing the fracture modes in groups with different ferrule thicknesses ($P<.001$). These results indicated no relation between the post type and the fracture mode, but there was a relationship between the ferrule thickness and the fracture mode where increased thickness led to a less favorable fracture mode. Presumably, the presence of an increased ferrule thickness will increase the fracture load until fracture occurs at a high load with an unfavorable mode.

Limitations of this study included the in vitro design that cannot be directly extrapolated to clinical situations. In addition, only mandibular first premolars restored with prefabricated posts and with direct cores rather than cast post-and-cores were evaluated. Further investigation should include a comparison between the static and fatigue load.

CONCLUSIONS

Based on the findings of this laboratory study, the following conclusions were drawn:

1. The amount of remaining tooth structure, as indicated by ferrule thickness, affected fracture resistance and the fracture mode.
2. Fracture resistance and mode were unaffected by the choice of post material.

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Informed patient consent has been obtained.

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