Fracture strength of endodontically treated teeth restored with different strategies after mechanical cycling

Ricardo Rosa, DDS, MSD ▪ Amal Hwas ▪ Daniela Melo ▪ Luiz Felipe Valandro, DDS, MSD, PhD
Osvaldo Kaizer, DDS, MSD, PhD

The aim of this study was to analyze the fracture strength of endodontically treated teeth with different coronal restoration strategies after mechanical cycling. Thirty bovine teeth were randomly allocated into three groups ($n = 10$): Group 1, cast metal post and core; Group 2, glass fiber post with a composite resin core; Group 3, glass fiber post with a glass prefabricated core. For post cementation, an etch and rinse multistep adhesive system and resin cement were used. The specimens were submitted to mechanical cycling (10^6 cycles, 90 N, 4 Hz, 37±1°C) and immediately loaded in a universal testing machine.

The statistical analysis (one-way ANOVA) did not indicate a significant difference among the tested groups (Group 1 = 593.9 ± 128.7 N; Group 2 = 554.4 ± 213.3 N; Group 3 = 427 ± 104.8 N; $P = 0.06$). With regard to fracture patterns, all Group 1 specimens demonstrated catastrophic failures, while the specimens in Groups 2 and 3 demonstrated core or core/post failure.

Despite the similar fracture strength observed in the tested groups, teeth restored with composite resin or glass prefabricated cores demonstrated favorable failure patterns compared to the cast metal post and core group. This study demonstrates that a glass prefabricated core can be an acceptable alternative for the reconstruction of endodontically treated teeth.

Pulpless teeth are more susceptible than sound teeth to fracture due to decreased moisture content, coronal destruction from dental caries, previous restorations, and endodontic therapy.[1] When extensive coronal destruction or esthetic needs are presented, a full crown should be required.[1,2] A core build-up is a restoration placed in a badly broken-down tooth to restore the coronal portion and withstand a subsequent indirect restoration.[3] Thus, a core build-up should provide resistance to the abutment preparation and the molding procedures as well as provisional and definitive crown support and retention.[4] Finally, the post and core should withstand multidirectional masticatory forces for many years.[5-7]

Several materials have been used as core build-up materials, although they were not developed specifically for this purpose. These materials have been used because of their properties, such as fluoride release, esthetic factors, adhesion to root structure, easy handling, and cure time control. Biomechanical properties that are similar to those of dentin, including fracture strength and elastic modulus, support their use.[3]

For many years, silver amalgam was used for core build-ups. However, despite its satisfactory resistance to masticatory efforts, it presents unfavorable esthetics, a high thermal expansion coefficient when compared to dentin, matrix needs for condensation, no chemical adhesion to tooth structure, and a lengthy setting time.[5,8] These limitations lead to the substitution of silver amalgam for other materials with better biomechanical properties and easier handling.

Cast metal post and cores are used for core build-ups as well. Despite their satisfactory resistance, however, they present high stiffness and rigidity.[9-11] Inappropriate (more rigid than dentin) cast metal post and cores could increase the fracture risk of the remaining tooth structure.[9-11] Some *in vitro* studies have shown a high number of root fractures when cast metal posts are used when compared with fiber posts and composites.[2,12-19] These findings are corroborated by finite element analysis (FEA) studies.[20,21] FEA has demonstrated that post and core materials affect the stress distribution in endodontically treated teeth.[20-23] Stress concentration seems more intense at specific locations, resulting in root fractures. The inverse occurs when materials with properties similar to dentin are used. Glass fiber posts distribute the stress along the tooth more homogeneously, reducing the risk of fracture.[20-25]

The development of enamel and dentin bonding and techniques for

more conservative composite resins have made their use in association with fiber posts more widely accepted.[26,27] Composite resins present better esthetic characteristics than metallic materials while also allowing photocuring, easy handling, complete coronal preparation, and chemical tooth structure adhesion.[26] The biomechanical behavior of composites is similar to that of dentin.[20] Composite resins present an elastic modulus of approximately 16.6 GPa, while the elastic modulus of dentin is 18.6 GPa.[20,28,29]

Recently, a new material was developed based on glass fiber. It consists of a prefabricated core that is cemented over a glass fiber post, providing a monoblock restoration, a single biomechanical complex through adhesion between the tooth structure and the restorative materials (glass fiber post, luting agent, prefabricated glass fiber core, and bonding agent), and utilization of materials with similar mechanical properties as the remaining dentin structure.[30]

The present study evaluated the fracture strength and the failure pattern of endodontically treated teeth restored with different post and core strategies after mechanical cycling. Two null hypotheses were tested: There is no significant difference in the fracture resistance of the three strategies used, and there are no significant differences regarding the failure patterns.

Materials and methods

Thirty bovine teeth were sectioned at 14 mm from the apex with a diamond double-face disc (KG Sorensen) cooled with water. The root canal diameter at the level of the section was measured with a digital caliper (Starrett 727, L.S. Starrett Company). Specimens with a diameter larger than 2.0 mm were discarded and replaced by other specimens that met this requirement. Only roots with cervical diameters of 5.0–5.5 mm in the mesiodistal direction and 7.0–7.5 mm in the buccal-palatal direction were included.

The root canals were endodontically treated and the teeth were embedded in a PVC cylinder filled with a chemically cured acrylic resin as follows: The preparation bur of the post system was placed inside the prepared root canal; the bur (with the root) was attached to an adapted surveyor, where the long axes of the bur, specimen, and cylinder were parallel to each other and perpendicular to the ground; and the acrylic resin was prepared and poured inside the cylinder up to 3.0 mm of the most coronal portion of the specimen.

The specimens were randomized into three groups (*n* = 10), as follows: Group 1, cast metal post and core (control); Group 2, glass fiber post with the coronal portion filled with composite resin; Group 3, glass fiber post with the coronal portion filled with a prefabricated glass fiber core.

The specimens were prepared as described below. The root canals were prepared to 10 mm deep using the White Post DC No. 3 bur (FGM). All samples were kept in distilled water until testing.

Preparation of specimens
Group 1
Ten cast metal posts (Nihon Shika Kinzoku Co., Ltd.) were fabricated using root canal molding with self-curing acrylic resin (Duralay, Reliance Dental Mfg. Co.). The same resin was employed for filling the plastic matrices that simulated canine preparation for placement of a full crown, allowing for a standardized shape and dimension of the coronal portion of the posts (6.0 mm in height with a 1.0 mm chamfer). Posts were cast in nickel-chrome alloy.

Root canals were cleaned with 17% EDTA for three minutes, rinsed with distilled water for 60 seconds, and dried with paper points. Next, the root canal and remaining tooth structure were etched with 37% phosphoric acid for 30 seconds, rinsed for one minute, and dried with paper points. Scotchbond Multi-Purpose Plus (3M ESPE) was applied following the manufacturer's instructions for dual cure. The dual-cure resin cement RelyX ARC (3M ESPE) was prepared following the manufacturer's instructions and applied in the root canal with a Lentulo spiral. The post was inserted into the root canal and kept under a 2 kg static load for six minutes. The cement was photocured around the post for one minute (XL 2500, 3M ESPE). After 10 minutes, the assembly was removed from the press.[31]

Group 2
Ten White Post DC No. 3 glass fiber posts with 2.0 mm of cervical diameter and 1.25 mm apical diameter, respectively, were used. The post length was reduced until an extra-root height of 5.0 mm was achieved. The specimens were cleaned with ethylic alcohol. A coat of Prosil (FGM) was applied and gently air-dried for 60 seconds. Adhesive treatment of root canals was performed as described for Group 1. RelyX ARC was prepared following the manufacturer's instructions and applied in the root canal with a Lentulo spiral. The posts were inserted into the root canal, the excess cement was removed, and photocuring was performed for one minute.

The posts were submitted to a new silane application, as described above, and the cervical portion of the teeth
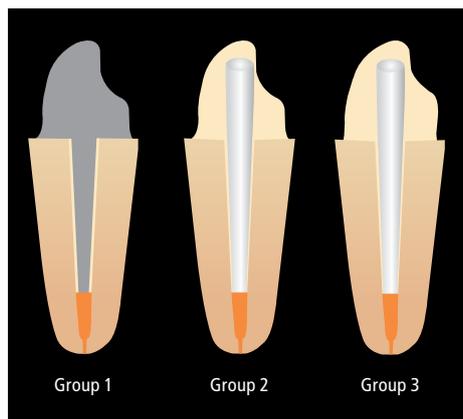
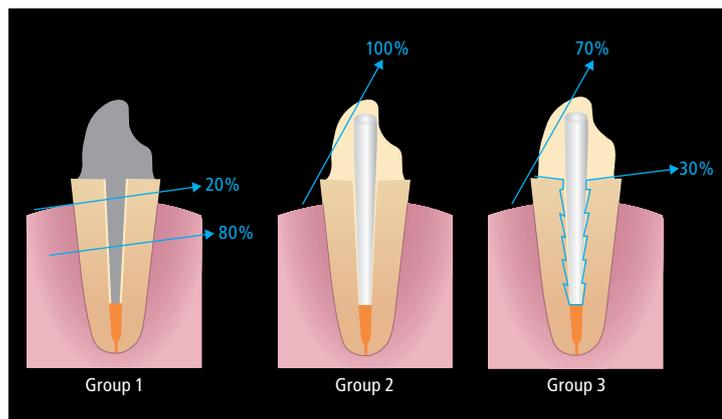Fig. 1. Schematic representation of experimental groups.

Fig. 2. Schematic representation of failure patterns.

received a new dentin treatment, as described above. Filtek Z350 composite resin was adapted over the entire post and photocured for 60 seconds around the post. Next, Filtek Z350 was inserted in the matrices prepared for Group 1, which were positioned on the post to achieve a standardized shape and dimension of the coronal portion of the posts. Photocuring was performed for 40 seconds for each aspect.

Group 3
Ten White Post DC No. 3 glass fiber posts were cemented into the root canal as described for Group 2, and the coronal portion was restored with a prefabricated glass fiber core (Reforcore, Angelus Dental Industry Products S/A). This glass fiber core has a central opening that the post passes through. After post cementation, prefabricated cores were cleaned with ethyl alcohol, and a silane coat was applied on the coronal portion of the posts. The Reforcore was positioned, and the spaces between it and the post were filled with composite resin, which was photocured for 60 seconds from the occlusal surface, as recommended by the manufacturer (Fig. 1).

Mechanical cycling test
Specimens were positioned in a cycling machine (ERIOS) 24 hours after fabrication (after being kept in distilled water at 37°C). The load was applied on the palatal aspect of the specimens at 135 to the long axis of the tooth. In a wet environment, 1,000,000 cyclic loads (90 N, 4 Hz, 37±1°C) were induced.[32,33] After mechanical cycling, a stereomicroscope with 4X magnification was used to analyze the specimens, which were scored as presence of root fracture or absence of root fracture. The specimens with an absence of root fracture were submitted to compressive strength testing in a universal testing machine.

Compressive strength test
Immediately after the mechanical cycling test, teeth were submitted to a compressive load in an universal testing machine (EMIC Ltd.) at a crosshead speed of 0.5 mm/min, applied on the palatal aspect of the specimens at 135 degrees to the long axis of the tooth. Root fractures below the simulated bone level (the edge of the acrylic resin block) were regarded as unfavorable.[2,15,31,34] Fractures at or above the simulated bone

level, as well as failures in the coronal portion of the post and displacement of the core and/or post, were considered favorable failures.[2,15,31,34]

The fracture strength values were submitted to one-way ANOVA, with a significance level of 5%.

Results
After the mechanical cycling test, all of the specimens presented no root damage, such as root fracture or partial cracks. The coronal portion of the specimens also indicated integrity.

The compressive strength values and standard deviations observed after mechanical cycling and compressive strength testing are presented in Table 1. One-way ANOVA revealed no statistically significant effect of the different strategies on the fracture strength results, indicating no difference between the three groups (P = 0.06).

Tables 2 and 3 and Figure 2 present the failure patterns for each group. Group 1 presented oblique fractures in the middle third of the root (80%) and the cervical third of the root (20%), which are unfavorable fractures. Groups 2 and 3 presented 100% favorable

Table 1. Mean fracture strength (in Newtons) and standard deviations.		
Group	Mean	Standard deviation
1	593.9	128.7
2	554.4	213.3
3	427.0	104.8

Table 2. Failure patterns observed for each group.			
Failure patterns	Group 1 (*n* = 10)	Group 2 (*n* = 10)	Group 3 (*n* = 10)
Core or post dislodgement	–	–	3 (30%)
Core fracture	–	10 (100%)	7 (70%)
Oblique fracture extending to the cervical root third	2 (20%)	–	–
Oblique fracture extending to the middle root third	8 (80%)	–	–

Table 3. Number of specimens with favorable and unfavorable fracture modes for each group.			
Fracture mode	Group 1 (*n* = 10)	Group 2 (*n* = 10)	Group 3 (*n* = 10)
Favorable	–	10	10
Unfavorable	10	–	–

failures. No root fractures were observed in Groups 2 and 3. In Group 2, all composite resin cores fractured during load application. Group 3 presented prefabricated core fracture (70%) and core/post dislodgement (30%).

Discussion

The restoration of endodontically treated teeth has undergone changes recently. Traditional stiff materials, like cast metal posts (amalgam, gold, or nickel-chrome alloys), have been replaced by materials with mechanical properties similar to those of tooth structure, such as fiber posts and composite resins. These new materials present great adhesion to dentin and promote reduction of the stress distribution along the dental structure, due to the load absorption.[16,22,25,35,36]

Some studies have indicated that the static fracture strength of an endodontically treated intact anterior tooth is not affected by (or even decreases with) post placement while failures have been related to fatigue more than maximal loading.[37,38] According to other studies that used a similar methodology to the current study for the mechanical cycling test, specimens restored with fiber posts were not affected by fatigue loads because of their similar elastic modulus when compared to dentin.[20-25,35,36,39,40]

Previous clinical studies have replaced human teeth with bovine teeth due to their micromorphological similarities.[41-47] Specimens restored with cast metal post and cores (Group 1) presented the highest fracture strengths (593.9 ± 128.7 N), followed by specimens restored with fiber posts and composite resin (Group 2) (554.4 ± 213.3 N) and specimens with prefabricated glass fiber cores associated with fiber posts (Group 3) (427.0 ± 104.8); however, one-way ANOVA showed no statistical significance (*P* = 0.006).

The fracture strength values of the materials used in the present study are in accordance with previous studies in teeth restored with cast metal posts and cores along with fiber posts and composite resin, because no study has yet evaluated the properties of prefabricated glass fiber cores.[17,48] According to the manufacturers, the fracture resistance of glass fiber cores is attributed to the components (glass fiber 10 µm diameter and 80% ratio fiber/matrix). Moreover, the fibers are longitudinally positioned to enhance the material's resistance. In 2007, glass and quartz fiber posts from different manufacturers were studied by Seefeld *et al,* who found a positive relation between the fiber/matrix ratio and flexural strength values.[49] Fiber disposition and the high fiber/matrix ratio presented by prefabricated glass fiber cores could be responsible for the similar behavior between this material and the fiber posts used in the present study.[49]

Teeth restored with glass fiber posts (Groups 2 and 3) presented 100% favorable failures, independent of the material used for core restoration. All teeth from Group 2 indicated core fracture (Fig. 2). When the specimens were loaded, the composite resin core fractured before any damage to the root

structure occurred. Seven of the 10 teeth in Group 3 had core fractures, which occurred longitudinally to the core, causing dislodgement of the post/core. Three cases of post bending were noted. With the loading over the specimen, the system (prefabricated glass fiber core and fiber post) suffered progressive bending, and separation of the glass fibers and matrix at the prefabricated core were observed.

Endodontically treated teeth restored with fiber posts associated with composite resin cores have shown great results in fracture strength tests, presenting more favorable failure patterns when compared with stiff materials, like metallic posts, cast metal post and cores, and zirconium posts, indicating that stiffer core materials increase the cervical stresses and diminish apical stress as the core material prevents the intrusion of the loaded posts.[2,12-16,50] Moreover, the modulus of elasticity for core materials affects the distribution of stress along the tooth.[51] Fracture strength is only one of the biomechanical properties that should be considered when selecting a core material; properties such as modulus of elasticity, flexural strength, biomechanical and fatigue behavior, biocompatibility, and stiffness should be analyzed as well.

When fiber posts are used, core and/or post fracture occurs before root fracture, indicating the possibility of maintaining teeth after replacing the restoration.[52] Cast metal post and cores concentrate the stress in specific root segments, like the medium and apical thirds, causing vertical root fractures.[53] These findings are in accordance with the failure pattern results in the current study.

Other studies have shown similar longitudinal results when failure modes were evaluated. When the failure patterns and success index of 420 teeth restored with cast metal post and cores or fiber posts after three years were examined, the cast post and core presented 10 cases of root fracture, while fiber posts presented only one failure, which came after debonding.[54-58]

When fiber posts are luted with resin cements, tooth protection occurs via formation of a monoblock restoration (dentin/post/cement/core) with biomechanical properties similar to those of dentin. Monoblock restorations distribute chewing efforts homogeneously along the root and the dentin/cement and post/cement interfaces.[15,59] Systems with several components that are different from a biomechanical point of view have interfaces that represent the critical area of the system. Therefore, the stiffer component transfers the force to the less-stiff materials.[60] The same effect occurs with cast metal post and cores, which distribute stress in a more concentrated way, according to some finite element analysis studies.[20,24] This factor enhances the possibility of radicular fracture.

Conclusion

More studies are needed regarding the biomechanical properties of prefabricated glass fiber cores. The three materials tested in the current study showed statistically similar fracture strengths. Teeth restored with cast metal post and core (Group 1) demonstrated 100% root fracture. However, when composite resin (Group 2) or a prefabricated glass fiber core (Group 3) were used in association with fiber posts, only core fractures or post debonding were observed. Prefabricated glass fiber cores could be an appropriate alternative strategy for restoring endodontically treated teeth.

Author information

Dr. Rosa is a postgraduate (doctorate) student in endodontics, School of Dentistry, Federal University of Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil. Mrs. Hwas and Ms. Melo are undergraduate dental students, Faculty of Odontology, Federal University of Santa Maria, Santa Maria, Rio Grande do Sul, where Drs. Valandro and Kaizer are associate professors, Division of Prosthodontics, Department of Restorative Dentistry.

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Manufacturers

Angelus Dental Industry Products S/A,
Londrina, PR, Brazil
55.43.2101.3200, www.angelus.ind.br

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