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Stress Distribution, Tooth Remaining Strain, and Fracture Resistance of Endodontically Treated Molars Restored Without or With One or Two Fiberglass Posts And Direct Composite Resin

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Clinical Relevance

The use of one fiberglass post is necessary and sufficient to achieve better biomechanical behavior of endodontically treated molars with severe tooth structure loss using direct composite resin.

ABSTRACT

Objectives: To evaluate the effects of direct composite resin without a post or with one or two fiberglass posts on the restoration of severely compromised endodontically treated molars.

Methods and Materials: Forty-five molars with 2 mm of "remaining tooth structure" were divided into three groups: Wfgp, restored with Filtek Z350XT without a fiberglass post; 1fgp, restored with Z350XT with one fiberglass post in the distal root canal; and 2fgp, restored with Z350XT with two fiberglass posts, one in the distal root canal and the other in the mesial-buccal root canal. The teeth were load cycled. Tooth remaining strain was measured using strain gauges (n=10) at two moments: TrSt-100 N, during 100 N occlusal loading, and TrSt-Fr, at fracture load. Fracture resistance was calculated, and fracture mode was classified. The elastic modulus and Vickers hardness were

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calculated using dynamic indentation (n=5). Stress distribution was analyzed by three-dimensional finite element analysis.

Results: The use of two fiberglass posts resulted in lower fracture resistance than was noted in the groups with one fiberglass post and without fiberglass posts. The lingual surface of the remaining tooth had higher strain values than the buccal surface, regardless of the restorative technique and moment of evaluation. The absence of a fiberglass post resulted in significantly higher strain values and more irreparable fracture modes than were noted in the other groups. The use of one fiberglass post had a better strain/fracture resistance ratio. Stresses were concentrated in the occlusal portion of the post and in the furcation region. The presence of one fiberglass post resulted in better stress distribution in the entire distal root dentin, reducing stress on the critical areas.

Conclusions: The use of one fiberglass post for restoring molars with direct composite resin resulted in higher fracture resistance than did the use of two fiberglass posts; it also resulted in better tooth remaining strain and stress distribution and more reparable fracture modes than were seen in the group without a fiberglass post.

INTRODUCTION

In emerging countries, dental caries remain one of the most prevalent health problems—mainly in children—that affects quality of life as a result of reduced esthetics and chewing abilities.[1] Dental caries comprise the most common reason for tooth extractions in young patients.[2] A considerable number of children have restricted access to dental services, and parents generally take their children to the dentist only when a problem becomes serious and causes discomfort or pain.[3] When the molar teeth affected by occlusal caries are not extracted, they can require endodontic treatment as a result of deep caries.[4]

Compared to intact teeth,[5] endodontically treated teeth are more susceptible to fracture as a result of extensive tissue loss and the loss of moisture content and flexibility,[6] as well as reduced resistance due to endodontic access preparations.[7] Despite the improvements in restorative materials and techniques, root fractures of endodontically treated teeth are still observed.[8,9] The most efficient way to prevent root fractures in endodontically treated teeth is through tooth structure conservation during restorative and endodontic procedures.[10] Therefore, better restorative methods are needed to effectively restore endodontically treated molar teeth.[10]

Evaluation of the remaining coronal structure is used to identify whether the use of a fiberglass post is necessary to retain the restoration material.[11] Direct composite resin is a treatment option that conserves the remaining tooth structure and results in good patient compliance.[12] Composite resin restorations associated with a fiberglass post have good results in terms of cusp strain and fracture resistance when used as indirect restorations for posterior teeth.[13] Teeth with a major loss of the coronal tooth structure require the placement of a post to ensure satisfactory core retention.[14,15] Of the different post materials, fiberglass posts have advantageous characteristics due to their mechanical properties.[16,17] Fiberglass posts have an elastic modulus similar to that of dentin structure, which has been reported[18] to reduce root fracture and to provide better stress distribution. Similar to the elastic modulus of fiberglass posts, resin cements, composite resin, and dentin are beneficial for improving stress distribution and produce better biomechanical restoration results in endodontically treated teeth.[19,20] The bonding interaction between the composite materials, specifically of the fiberglass post to the dental substrate, may create a structure, known as "monoblock," that dissipates the stresses produced by occlusal loads.[21] Nonetheless, clinicians frequently ask "How many posts are necessary to restore endodontically treated molars with severe tooth loss?" The use of two posts in a molar has, to our knowledge, not been described.

Therefore, the aim of this study was to evaluate the effects of the absence and the presence of one or two fiberglass posts in the restoration of severely damaged endodontically treated molars. The null hypothesis was that the mechanical behavior of endodontically treated molars, expressed as strain, fracture resistance, and stress distribution, is not influenced by the presence or number of fiberglass posts.

METHODS AND MATERIALS

Forty-five extracted, intact, caries-free human molars were used (Ethics Committee in Human Research approval No. 35506614.2.0000.5152). The selected teeth had an intercuspal width within a maximum deviation of 10% from the determined mean.[22] The intercuspal width varied between 4.81 mm and 5.98 mm. The teeth were cleaned using a rubber cup and fine pumice water slurry. The tooth roots were covered with a 0.3-mm layer of a polyether impression material (Impregum, 3M ESPE, St Paul, MN, USA) to simulate a periodontal ligament and were then embedded in a polystyrene resin (Cristal, Piracicaba, Brazil) up to 2 mm below the cemento-enamel junction to simulate the alveolar bone.[23]

The teeth were randomly divided into three groups (n=15) according to the rehabilitation technique used. All groups had their coronal portions reconstructed directly with composite resin. The "without fiberglass post" (Wfgp) group did not receive a fiberglass post, the "one fiberglass post" (1fgp) group was restored using one fiberglass post in the distal root canal, and the "two fiberglass post" (2fgp) group was restored using two fiberglass posts, one in the distal root canal and the other in the mesial buccal root canal. The teeth (n=10) were submitted to mechanical fatigue cycles. Then the "tooth remaining strain" (TrSt) was measured using the strain gauge method, and the teeth were loaded until fracture. The other five teeth per group were restored and used for Vickers hardness (VH) and elastic modulus (E) measurements using the dynamic indentation method.

Specimen Preparation

A plastic mold of the occlusal surface of each tooth was created using an acetate matrix (Bio-art, São Carlos, SP, Brazil) and a vacuum-forming machine (Plastivac P7; Bio-art, SP, Brazil). The teeth had their coronal portion cut 2 mm above the enamel-cement limit by a precision saw (Isomet 1000, Buehler, Lake Bluff, IL, USA), simulating severe coronal tooth loss. Endodontic access was performed using spherical diamond burs (No. 1016; KG Sorensen, Barueri, SP, Brazil) and tapered carbide burs with noncutting tips (Endo-Z; Dentsply Maillefer, Ballaigues, Switzerland) in a high-speed handpiece with abundant irrigation. The root canals were located and initially explored with a No. 10 K-file (Dentsply Maillefer). The working length was determined by subtracting 1 mm from the length measured when the tip of the file emerged from the apical foramen. The cervical portion was prepared using Gates Glidden drills (Dentsply Maillefer) and was irrigated with 1.0% NaOCl and saline solution. An operator was calibrated to use the rotary nickel-titanium (Ni-Ti) System (Dentsply Maillefer) to perform all of the endodontic treatments and restorative procedures. The root canals were instrumented at the previously determined working length using rotary files (ProTaper Universal; Dentsply Maillefer), following the manufacturer's instructions. Each instrument was passively introduced into the root canals at a 250-rpm rotation rate (X Smart; Dentsply Maillefer). Irrigation was performed using 1% NaOCl after each instrument. The roots were filled with gutta-percha (Dentsply Maillefer) and calcium hydroxide–based endodontic sealer (Sealer 26, Dentsply Maillefer).

Post Space Preparation

Post spaces were prepared maintaining 4 mm of the gutta-percha. Heated instruments (GP heater; Dentsply Maillefer) were used to remove the gutta-percha, and a specific drill system corresponding to the fiberglass conical post (Exacto #2, Angelus, Londrina, PR, Brazil) properly shaped the root to receive the posts. The canal roots were cleaned with ethylenediaminetetraacetic acid for three minutes, rinsed well, and dried with absorbent paper points (Dentsply Maillefer).

Post Cementation and Remaining Tooth Restoration

All posts were cemented with self-adhesive resin cement (RelyX U200; 3M ESPE). The fiberglass posts were cleaned using a single application of 70% alcohol by microbrush (KG Sorensen) for one minute; then posts were dried and immersed in a solution of 24% hydrogen peroxide (H_2O_2; Dinâmica, SP, Brazil) for one minute.[24] Silano (Angelus) was applied to the post surface for one minute. Self-adhesive resin cement (RelyX U200; 3M-ESPE) was prepared according to the manufacturer's instructions and introduced into the canal; the post was seated under digital pressure. Excess cement was removed at one minute and five minutes later,[25] and the resin cement was light-cured at each coronal root surface (buccal, lingual, and occlusal) for 40 seconds using a quartz-tungsten-halogen unit (800 mW/cm^2; Optilux 501, Kerr Mfg Co, Orange, CA, USA).

The coronal reconstruction was incrementally built with nanofilled composite resin (Filtek Supreme, A2 Shade; 3M-ESPE). Each increment was light-cured for 20 seconds. The fiberglass posts were cut off 2 mm below the occlusal surface using a diamond bur. The last increment of the composite resin was applied using the acetate matrix to ensure adequate coronal anatomy reconstruction.

Mechanical Fatigue Cycling

Mechanical fatigue cycling was used to simulate chewing (Biocycle, Biopdi, São Paulo, SP, Brazil).

The samples were immersed in water maintained at approximately 37°C and were cycled 1.2 X 10^6 times at a 0 to 50–N axial compressive load with a 2-Hz frequency and an 8-mm-diameter stainless-steel sphere on the occlusal, simulating five years of aging.[26]

Tooth Remaining Strain During Occlusal Load Simulation (TrSt-100 N) of the Fracture Procedure (TrSt-Fr), Fracture Resistance, and Fracture Mode

To measure the TrSt, two strain gauges (PA-06-038AA-120-L; Excel Sensores, Embú, SP, Brazil) were attached to all specimens. One gauge was placed on the remaining buccal surface parallel to its long axis, and the other was placed on the remaining lingual surface.[27] The strain gauges were bonded using cyanoacrylate adhesive (Super Bonder; Loctite, Itapeví, SP, Brazil) and connected to a data acquisition device (ADS0500IP; Lynx Tecnologia Eletrônica, SP, Brazil).

A control specimen was attached adjacent to the tooth being tested to compensate for temperature variations due to electrical gauge resistance or the local environment.[27] The specimens with strain gauges were subjected to a nondestructive ramp load from 0 to 100 N in a mechanical testing machine (EMIC DL2000; EMIC Ltd, São José dos Pinhais, Paraná, Brazil).[28] The load was applied to the long axis of the tooth with an 8-mm-diameter metal sphere at a crosshead speed of 0.5 mm/min in a universal machine (DL2000, EMIC). The data were recorded on a computer that performed the signal transformation and the data analysis (AqDados 7.02 and AqAnalysis; Lynx, SP, Brazil).

The specimens were loaded until fracture using an axial compressive loading test. The force required (N) to cause fracture was recorded by a 500-kN load cell hardwired to software (TESC; EMIC) that detected any sudden load drop in the load cell during the compression tests. Strains were also recorded at failure load (TrSt-Fr). The fractured specimens were then analyzed in failure mode to determine the fracture types using the following classifications: I) fractures involving less than half of the composite resin restoration without post involvement; II) fractures involving more than half of the composite resin restoration without post involvement; III) fractures involving the restoration and tooth structure without post involvement, which are repairable with periodontal surgery; and IV) severe root and composite/post restoration fractures, which require extraction of the tooth, as shown in Figure 1.

Vickers Hardness and Elastic Modulus

The remaining five specimens from each group were used to analyze the Vickers hardness (VH) and elastic modulus (E) of the enamel and dentin of the remaining tooth structure, in addition to longitudinal and perpendicular analyses of the composite resin and fiberglass post. Each restored tooth was sectioned into two halves using a precision saw (Isomet 1000, Buehler). One section per tooth was randomly selected for the assessment of mechanical properties. The specimens were embedded in polyester resin (Instrumental Instrumentos de Medição Ltda, São Paulo, SP, Brazil). The surfaces were finished using silicon carbide papers (No. 600, 800, 1200, and 2000 grit; Norton, Campinas, Brazil) and polished with metallographic diamond pastes (6-, 3-, 1-, and 1/4-µm; Arotec, São Paulo, Brazil). After polishing, the specimens were cleaned using an ultrasonic cleaner filled with absolute alcohol for 10 minutes. Using a Vickers indenter (CSM Micro-Hardness Tester, CSM Instruments, Peseux, Switzerland), five indentations were made in each area to be analyzed. The indentations were made with controlled force, and the test load was increased or decreased at a constant speed of 0 to 500 mN in 20-second intervals. A maximum force of 500 mN was maintained for 15 seconds. The load and the penetration depth of the indenter were continuously measured during the load-unload hysteresis. The universal hardness was defined as the applied force divided by the apparent area of the indentation at the maximum force. The measurements were expressed in VH units by applying the conversion factor supplied by the manufacturer. The E value was calculated from the slope of the tangent of the indentation depth curve at the maximum force.[29]

Stress Distribution—Three-dimensional Finite Element Analysis (3D FEA)

To calculate stress distribution, a 3D finite element model was generated using a molar tooth with dimensions and geometry representative of the average selected teeth, employing the method based on MicroCT image.[30,31] A molar tooth was scanned by MicroCT (Model 1272, Bruker Skyscan, Kontich, Belgium) (Figure 2A). This MicroCT is an X-ray micro–computer tomographic unit composed of a scanner coupled to a Dell Precision workstation T5600 Intel Xeon (128GB 1600 MHz) and a Dell Precision cluster Intel Core (4 Gb CPU, 2.13 GHz) with NRecon software (Skyscan).

The equipment was adjusted to scan the whole tooth using the following: a beam accelerating

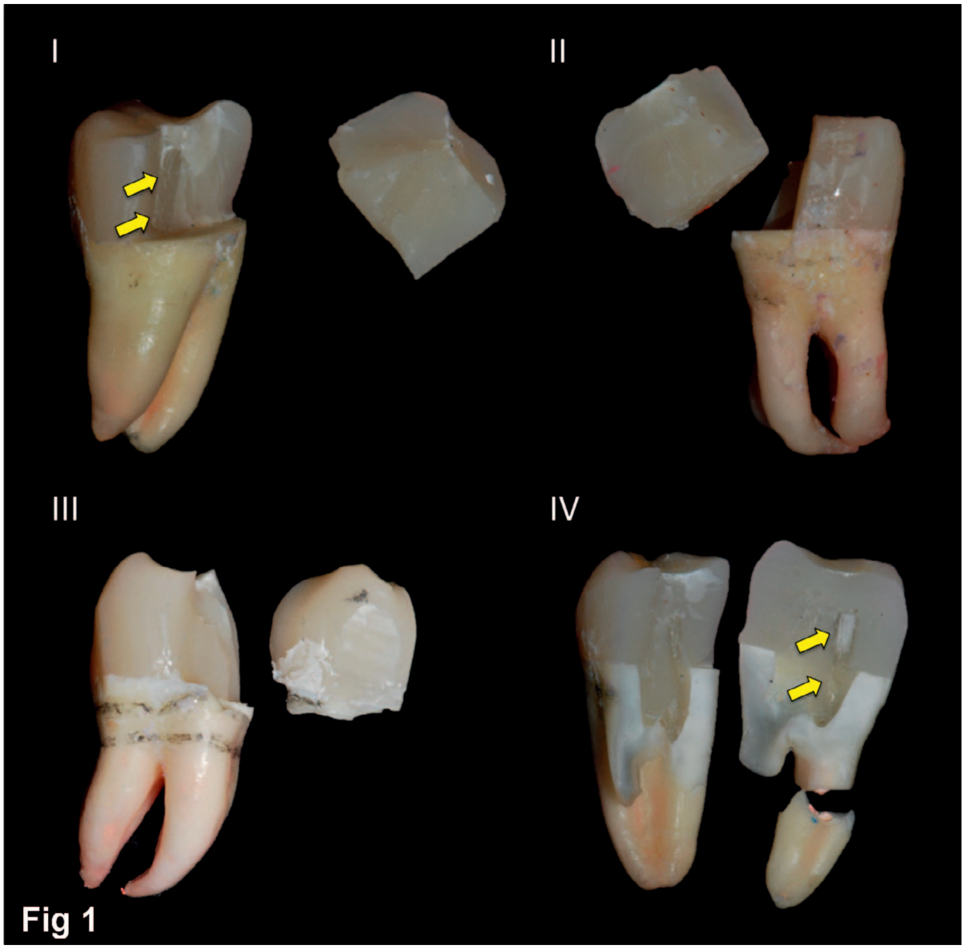

Figure 1. *Representative images of fracture modes: I, fracture involving less than half of the composite resin restoration without post involvement; II, fracture involving more than half of the composite resin restoration without post involvement; III, fracture involving the restoration and tooth structure without post involvement, which can be repaired by periodontal surgery; and IV, severe root and composite/post restoration fracture, which requires tooth extraction. Yellow arrow indicates the fiberglass post presence.*

voltage of 100 kV, an X-ray beam current of 100 μA, a copper (Cu) filter of 0.11 mm, an image pixel size of 13 μm, a resolution of 1632 × 1092, and a rotation step of 0.6°. Three frames per 1850 milliseconds with 20 random movements were obtained, which resulted in 1692 slices. Using NRecon software, 847 slices of tooth structure were selected, and the artefact correction parameters of smoothing 4 and ring 9 were applied to obtain an image with different shades of gray due to the different densities of the structure. The *.bpm files obtained from the MicroCT were viewed using an interactive medical image control system (MIMICS 16.0, Materialise, Leuven, Belgium). The segmentation of dental structures was accomplished based on image density thresholding. The masks of the cylinder, which simulate the bone, periodontal ligament, enamel, dentin, resin cement, gutta-percha, fiberglass post, and composite resin, were converted into a 3D file (via *.STL, bilinear, and interplane interpolation algorithms) using the Mimics *.STL shown in Figure 2B. The aspect ratio and connectivity of the triangles in the *.STLs resulted in an inappropriate model for FEA use. Therefore, the remesh component present in Mimics software was used to reduce the number of triangles and to simultaneously improve the quality of the triangles while maintaining the geometry. In addition, an advanced *.STL file design and meshing software (3-Matic 8.0; Materialise) were used to simulate the forms of treatment used in the specimens. The treatment of each *.STL was performed separately, followed by merging all the parts into a single *.STL file called the "assembly." The final assembly was then remeshed using the 3-matic remesh component and Boolean operations shown in Figure 2C. Self-intersecting curves were maintained, and the tolerance variation from the original data was specified (the quality of triangles does not mean tolerance variation from the original data). The Mimics remesh using the high-quality triangle height/base ratio can be imported to the FEA software package without producing errors.

As a specific approach for better model generation, the *.STL models were imported to MSC.Patran 2010r2 (MSC.Software, Santa Ana, CA, USA) and

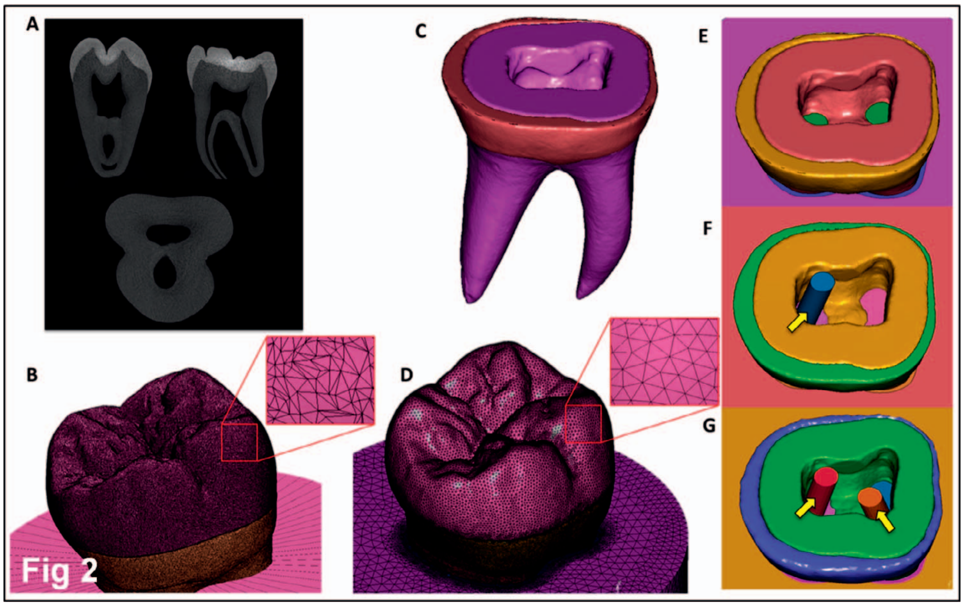

Figure 2. *3D finite element model generation; (A) MicroCT scanning of the molar; (B) the mesh process on Mimics software; (C) Boolean operation for cavity preparation; (D) the remeshing process on Patran software; (E) a model without a post; (F) a model with one fiberglass post; and (G) a model with two fiberglass posts. Yellow arrow indicates the fiberglass post presence.*

meshed (Figure 2D); four nodes of the tetrahedral elements were used to ensure the smooth contact of all interfaces of the models. The volumetric meshes of the model components were created based on the optimized surfaces standard triangulated language *.STL descriptions.[32] Afterwards, the meshes were imported to the FEA software package (MSC.Marc/MSC.Mentat, MSC.Software) for the attribution of material properties to the other model components (ie, cylinder, periodontal ligament, enamel, dentin, resin cement, gutta-percha, fiberglass post, and composite resin). The elastic modulus of the fiberglass post composite resin, enamel, and dentin were experimentally determined in this study and are shown in Table 1. The other material properties used were as follows: enamel with a Poisson ratio of 0.30 and dentin with a Poisson ratio of 0.23;[33] composite resin with a Poisson ratio of 0.24;[34] periodontal ligament elastic modulus of 50 MPa and a Poisson ratio of 0.45; gutta-percha elastic modulus of 0.69 MPa and a Poisson ratio of 0.45; and polyester resin elastic modulus of 13.7 GPa and a Poisson ratio of 0.30.[21] To simulate the interface among the model components, precisely bonded contacts were maintained. The nodes on the base of the bone model structure were rigidly fixed in the x, y, and z directions to simulate the experimental test. The loading conditions were simulated with nodal point load using individual force as experimentally determined (100 N on the occlusal surface of the restored model structure). The load application was in the coronal-apical direction in relation to the tooth longitudinal axis. The evaluation and postprocessing for each model were performed using the modified von Mises analysis with MSC.MARC/Mentat 2010r3 software (MSC.Software). The modified von Mises parameter takes into account the difference between the compressive and tensile strengths of the enamel, dentin, and composite resin.

Statistical Analysis

The TrSt and fracture resistance data were tested for normal distribution (Shapiro-Wilk) and equality of variances (Levene test), followed by parametric statistical tests. One-way analysis of variance (ANOVA) was performed to analyze the TrSt and fracture resistance. One-way ANOVA was also performed to analyze the effect of the depth of the cavities on the VH and E values for composite resin. One-way ANOVA was performed to analyze fracture resistance values. Multiple comparisons were made using the Tukey test. The failure mode data were

Table 1: *Means and (standard deviation) of ElasticModulus (GPa) and Vickers Hardness (N/mm^2) of Restorative Materials and Tooth Structures*

Materials/Tooth Structures	Elastic Modulus, GPa	Vickers Hardness, N/mm^2
Z350XT	14.9 (0.4)	153.4 (4.7)
Enamel	50.2 (0.9)	399.3 (8.6)
Dentin	18.3 (1.1)	180.5 (5.8)
Exacto Fiberglass post		
Parallel	29.8 (1.7)	201.9 (12.1)
Transversally	10.6 (0.8)	108.0 (7.6)

Table 2: *Means and (standard deviation) of Tooth Remaining Strain (μS) Measured by Strain Gauges (n=10)*[a]

Groups	Tooth Remaining Strain at 100-N Loading, μS			Tooth Remaining Strain at Fracture Load, μS		
	Buccal	Lingual	Mean	Buccal	Lingual	Mean
Without post	572.6 (142.5)	785.0 (173.9)	687.8 (189.3) B	3806.8 (341.8)	3419.8 (341.1)	3613.3 (387.1) B
One fiberglass post	563.6 (175.8)	631.8 (173.0)	583.1 (170.9) A	3612.0 (340.9)	3173.2 (449.4)	3392.6 (475.0) A
Two fiberglass posts	551.6 (194.4)	581.8 (194.4)	566.7 (185.2) A	3326.2 (497.0)	2807.2 (422.9)	3066.7 (522.1) A

[a] *Different letters indicate a significant difference between the restorative techniques (p<0.05).*

subjected to a chi-square test. Analysis of variance (two-way ANOVA) was performed to analyze the TrSt (B and L) and rehabilitation techniques. All tests were performed using a significance level of $\alpha = 0.05$, and all analyses were performed using the Sigma Plot version 13.1 statistical package (Systat Software Inc, San Jose, CA, USA). The stress distribution using the finite element method was analyzed descriptively.

RESULTS

VH and E Values

The means and standard deviations of VH and E for all tested materials are shown in Table 1. One-way ANOVA analysis showed no significant differences among the depth of the cavities for both mechanical properties of the composite resin restorations (p=0.435).

TrSt Values

The values of TrSt during the simulation at 100-N occlusal loading and maximum fracture loading are shown in Table 2. Factorial ANOVA showed significant differences in the TrSt values for the moment of measurement factor (p=0.008) and the restorative technique (p<0.001); however, no significant difference was found for the interaction between both factors (p=0.212). The lingual surface had higher TrSt values than the buccal surface, regardless of the restorative technique (p=0.008). For TrSt measured during the 100-N occlusal loading and until fracture, the restorative technique without posts had significantly higher TrSt values than did the other groups (p<0.001). No significant difference was found between the groups with one or two posts (p=0.783).

Fracture Resistance and Failure Mode

The means and 95% confidence intervals of fracture resistance and for the three restorative techniques are shown in Table 3. One-way ANOVA showed significant differences among the groups (p<0.001). The group with two fiberglass posts had significantly lower fracture resistance than the group with one fiberglass post (p<0.001) and the group without a fiberglass post (p=0.002). No difference was found between the group with one fiberglass post and the group without a fiberglass post (p=0.798).

The group without a fiberglass post had significantly more irreparable fracture modes than the groups with one or two fiberglass posts (p=0.031) (Table 3). The ratio between the maximum resistance and strain at the fracture moment is shown in Table 3. The group with one fiberglass post had a better ratio value than the group with two fiberglass posts (p=0.001), followed by the group without a fiberglass post, and the worst ratio was for the one fiberglass post group.

FEA Values

Stress distribution (MPa) during occlusal loading with 100 N was evaluated by modified von Mises criterion. The stress concentration values are visualized according to a linear scale of colors: blue indicates low stress values and gray and yellow indicate high stress values. The FEA indicated that

Table 3: *Means (Confidence Interval–95% Confidence Interval) of Fracture Resistance (N), Mode of Fracture, and the Ratio Between Maximum Cusp Deformation/Fracture Resistance Measured by the Axial Compression Test (n=10)*[a]

Groups	Fracture Resistance, N	Fracture Mode				Ratio Between Strain/ Fracture Resistance
		I	II	III	IV	
Without post	2939.4 (2617.3 – 3261.5) A	0	2	1	7	1.23 B
One fiberglass post	3096.1 (2758.6 – 3433.6) A	6	0	0	4	1.10 A
Two fiberglass posts	2023.7 (1670.1 – 2377.4) B	5	0	1	4	1.52 C

[a] *Different letters indicate a significant difference between the restorative techniques (p<0.05).*

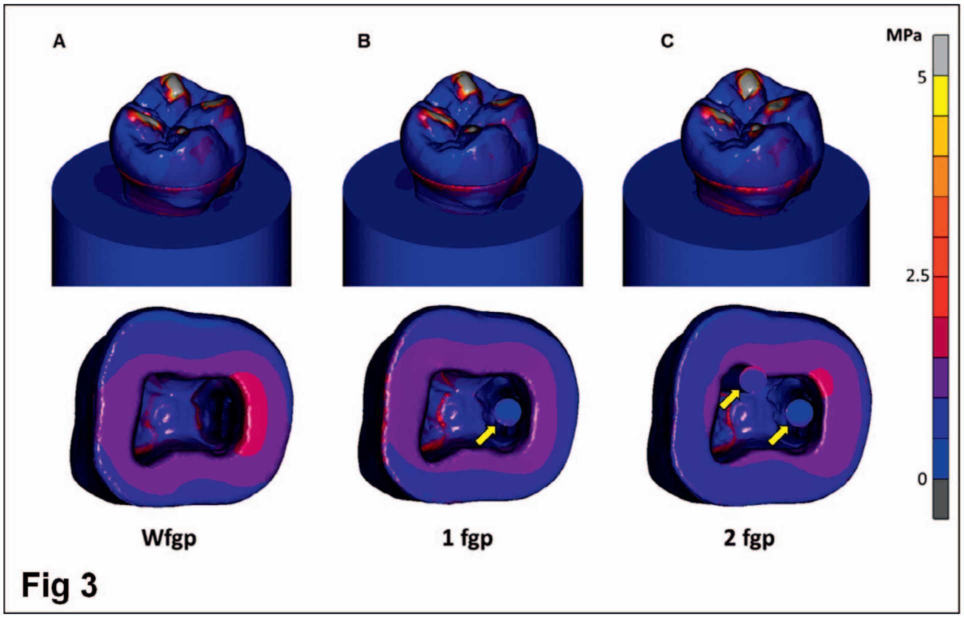

Figure 3. *Stress distribution (modified von Mises stress–MPa); (A) stress on the load application points on the occlusal surface of the composite resin restoration and (B) the pulp chamber and inner root canal surface. Yellow arrow indicates the fiberglass post presence.*

the group without a fiberglass post had higher stress levels in the external occlusal surface and higher stress levels in the cervical region than did other groups (Figure 3). We also observed higher stress levels in the mesial root and in the furcation region (Figure 4A) of the model without a post. The presence of one fiberglass post distributed stress to the entire distal root dentin, thereby reducing the stress on the critical areas (Figure 4B). Two fiberglass posts did not result in significant stress reduction when compared to one fiberglass post (Figure 4C).

DISCUSSION

The mechanical behavior, expressed by the TrSt, fracture resistance, fracture mode, and stress distribution of endodontically treated human molars, was affected by the presence and number of fiberglass posts; therefore, the null hypothesis was rejected.

The mechanical characterization of the restorative materials is very important for understanding the functional biomechanical behavior of rehabilitated endodontically treated teeth. When loads are applied to tooth structures, stress and strain are generated. Stress and strain are not bad; they are important for maintaining the synergism of the structures and biological components. If such stress becomes excessive and exceeds the elastic limit, structural failure may result.[35] The tooth structure is better able to support compressive stress than tensile stress.[36] When a rehabilitated tooth is subjected to occlusal loading, the stress and strain generated can be dissipated depending on the characteristics of each material and its adhesive integrity.[23]

In this study, mechanical fatigue was induced to simulate chewing cycles, as the oral environment experiences functional load that can lead to the degradation and subsequent fatigue failure of weakened regions. Supposing 240,000 to 250,000 occlusal contacts occur per year, 1.2 million cycles is equivalent to five years of masticatory simulation.[37] In this investigation, a force of 100 N was chosen to simulate the effect of chewing on TrSt and for the stress analysis because physiological biting forces during eating were found to be between 20 and 160 N.[37,38] The periodontal ligament simulation using elastomeric material and embedding of the root inside the polystyrene resin cylinder, which has a similar elastic modulus to bone tissue, offered more similarities to the oral environment than to the *in vitro* experiment.[37,38] The combination of using destructive and nondestructive methods on the same specimen, such as the strain gauge method, the fracture resistance, and fracture mode analysis, permits the sequential understanding of failure.[28,39]

Measuring strain before fracture may contribute to a better understanding of the entire fracture process, from initiation to ultimate rupture.[40] However, stress cannot be determined experimentally because it is necessary to use a FEA with simulation parameters in more realistic conditions.[41] During mastication, maximum stresses are applied to the cervical tooth area.[42] As the maximum stress concentration tends to coincide with higher tooth

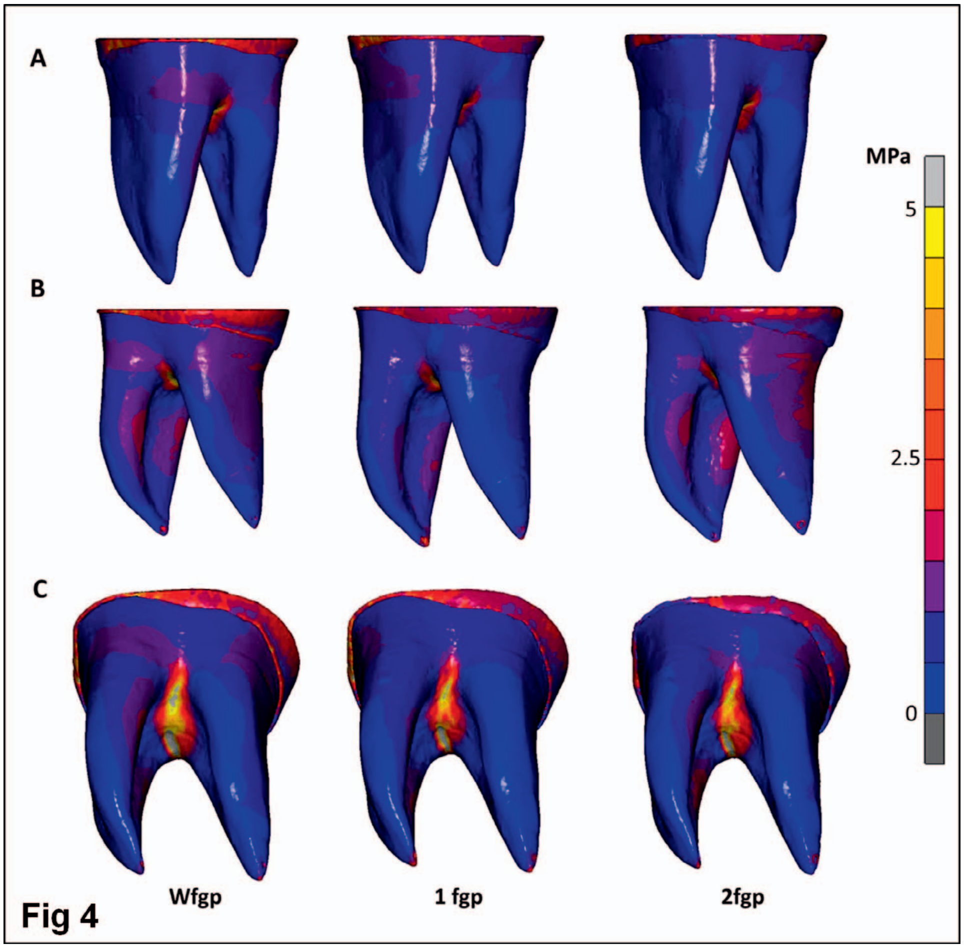

Figure 4. *Stress distribution (modified von Mises stress–MPa); (A) mesial root surface; (B) internal mesial root surface and distal root; and (C) furcation region.*

strain, strain gauges were fixed on the buccal and lingual cervical area; however, we observed higher FEA stress concentrations in the furcation region. For these reasons, future studies should use strain gauges in places with higher stress concentrations, as previously defined by FEA. In this study, the simulation of a 3D representative molar better qualified and quantified stress and strain in the inner dental structure and in the restorative materials.[43] Other very important and usually neglected aspects of FEA studies are the mechanical properties used to input the data from the restorative materials and dental structures.[41] In this study, we calculated the E and compressive strength of the restorative materials and dental structures isolated for the FEA. In this study we used a light cure composite material, Filtek Z350XT, which has an E value similar to that of the dentin. The use of light cure composite resin may be questionable for the direct core of endodontic treatment because of the reduced light intensity that reaches deep areas in the pulp chamber. In this study, we measured the VH in different depths of the restorations, and it was verified that the values are similar, demonstrating that polymerization of the light-curing composite resin was effective in deep areas of the cavities (Table 1).

TrSt values during the 100-N occlusal loading simulation and at the maximum fracture loading were influenced by study factors, tooth location, and the rehabilitation technique. The lingual surface had a greater degree of tooth remaining deformation during the 100-N occlusal loading and at the failure moment compared to the buccal surface, regardless of the rehabilitation technique used. The volume of dentin in the cervical area may explain the higher deformation at this location.[27] During the 100-N occlusal loading and at the failure moment, the tooth remaining of the Wfgp group had significantly higher TrSt values than did the other groups. The absence of a post resulted in higher strain to the composite resin coronal reconstruction. Because the bond integration was adequately created using a self-etching adhesive system and nanofilled composite resin, the stress is transferred to the root dentin, explaining the higher strain values.

Fiberglass posts have an E value similar to that of dentin, although the orientation of the fibers determines the orthotropic characteristics, resulting in more axial stiffness.[44] The loading application, located close to the occlusal limit of the fiberglass post in the composite resin reconstruction, restricts the composite resin strain and increases the stress and strain concentration factors in this area. This aspect may explain the lower TrSt observed in the groups with one or two posts. We also observed that stress is distributed to the root canal and is dissipated throughout the entire root dentin in the FEA. The number of fiberglass posts did not significantly affect the TrSt.

Destructive mechanical tests, such as compressive occlusal loading, are used to define fracture resistance in situations of concentrated high-intensity load application. Generally, this test produces failure loads that exceed the average masticatory forces.[45,46] This test predicts the failure of restored teeth in complex conditions. The established integration of similar restorative materials, such as composite resin, adhesive system, silane, and self-adhesive resin cement, is essential for improving the fracture strength of endodontically treated teeth.[47,48]

Fracture resistance and the failure mode were influenced by the presence and number of fiberglass posts, which means that the posts had a significant effect on fracture strength. The two fiberglass post group had significantly lower fracture resistance than the other groups. The main purpose of a post is to retain the core material or restoration and not to reinforce the root dentin.[21] The presence of the pulp chamber and the retention capacity of one post are sufficient to retain the composite resin restoration.[27] However, in the presence of two fiberglass posts and when the stress concentration is located close to the loading area, the high stress level is concentrated close to the loading area, and the fracture resistance is reduced as a result of the Saint-Venant principle, as it is present at a stress concentration factor very close to the load application.[48] The presence of two posts determined more coronal fractures, confirming the stress concentration on the composite resin close to the load application area. The absence of a post resulted in lower fracture resistance and more irreparable fractures when compared to one and two fiberglass posts. The higher strain and stress concentrations at the remaining root dentin may explain the more catastrophic failure modes and the lower fracture resistance. The FEA 3D model of an endodontically treated molar is not common. The observation of higher stress concentrations at the furcation region should be taken into account during root canal preparation and during post space preparation. The preservation of dentin in this region is required for improving endodontically treated molar survival.

This study expands our understanding of the nature and development of stress and strain distributions in endodontically treated molars with or without fiberglass posts. The static load used in this study limits direct extrapolation of our findings to clinical conditions. More studies are necessary, especially clinical trials, in order to better maintain severely damaged molar teeth in young patients with debilities. In the present study, we showed that direct composite resin with one fiberglass post is a promising restorative procedure for endodontically treated molars with severely damaged structures, especially in communities in which people cannot afford ceramic restorations.

CONCLUSIONS

The use of one fiberglass post for restoring molars with direct composite resin showed higher fracture resistance than did the use of two fiberglass posts; it also resulted in better TrSt and stress distribution as well as more repairable fracture modes than were observed in the group without fiberglass post. Therefore, clinicians may choose to restore endodontically treated molars with severe tooth structure loss using direct composite resin and the one fiberglass post that is necessary and sufficient to determine better biomechanical behavior.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Ethics Committee in Human Research, Federal University of Uberlândia, Minas Gerais, Brazil. The approval code for this study is 35506614.2.0000.5152.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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