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Fracture Resistance and Stress Distribution in Endodontically Treated Maxillary Premolars Restored with Composite Resin

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Abstract

Purpose: The aim of this study was to evaluate the effect of endodontic and restorative treatment on the fracture resistance of posterior teeth.

Materials and Methods: Fifty intact premolars were selected and randomly placed into five groups (n = 10): G1, intact teeth (control); G2, mesial-occlusal-distal (MOD) preparation; G3, MOD preparation restored with composite resin (Z-250, 3M ESPE); G4, MOD preparation and endodontic treatment; and G5, MOD preparation, endodontic treatment, and composite resin restoration. The specimens were submitted to an axial compression load in a mechanical test machine (EMIC), at a speed of 0.5 mm/min. Fracture patterns were analyzed at four levels. Five 2D numerical models were created by Ansys 10.0 for finite element analysis (FEA).

Results: Mean values of compressive strength for all groups were (Kgf): G1 (83.6 ± 25.4); G2 (52.7 ± 20.2); G3 (82.1 ± 24.9); G4 (40.2 ± 14.2); G5 (64.5 ± 18.1). Statistical analysis (ANOVA and Tukey's test) showed that fracture resistance of G1 was significantly higher than that of G5, G2, and G4. Resistance of G3 was also higher than that of G2 and G4. Results showed that the tooth resistance is completely maintained when MOD preparation is restored with composite resin and partially recovered when MOD preparation associated with an endodontic access is restored in the same way. The endodontic treatment and composite resin restoration influenced stress distribution in the dental structure.

Conclusions: Composite resin restoration plays an important role in recovering tooth strength. With regard to fracture mode, restoration and endodontic treatment increased the incidence of periodontal involvement, which was demonstrated by association with the finite element mechanical test method.

Coronal destruction from dental caries,[1] fractures,[2,3] previous restorations,[4,5] or endodontic techniques[3,5] is a problem present in endodontically treated teeth. It is commonly stated that endodontically treated teeth are more susceptible to fracture as a result of increased brittleness[6] and are weakened because of coronal destruction from dental caries,[5,7–9] access cavity preparation,[7,10] instrumentation of the root canal,[10] previous fracture,[5,6,11] loss of moisture in the dentin,[12] and previous restorations or endodontic techniques.[5,10,11]

Improved physical properties of composite resins and the introduction of adhesive systems offer new potential for the restoration of endodontically treated teeth.[7,13] Mechanical interlocking of resin with peritubular/intertubular dentin and hybrid layer formation is important to the performance of composite resin restorations.[14] Adhesive restorative materials promote enough retention and create an adhesive bridge between the facial and lingual cusps of a significantly weakened tooth.[7,15–17] These materials may have the potential to decrease deflection and fracture of cusps under occlusal load.[18] The fracture resistance of endodontically treated premolars is increased when they receive composite resin restorations.[7]

When analyzing the effect of the application of force on a tooth, various experimental methods are used, each at a specific moment of this process, which starts with the generation of stress and is completed with the failure or rupture of the tooth element. Destructive mechanical tests to analyze the reinforcement and fracture resistance of the tooth/restoration complex are widely used and mentioned in the literature;[5,6,12,19] however, the use of nondestructive tests and biomechanical analyses, such as the finite elements method, have been used more frequently, as they show the behavior and analysis of structure stress, which are not obtained in destructive mechanical tests.[20-23] However, the use of a combination of experimental methods and computational analyses would appear to be more suitable as it facilitates understanding of the real magnitude of anterior tooth resistance to restorative processes, and is able to detail causative factors and the points of greatest influence in which such failures might occur.

A literature review supports the hypothesis that fracture resistance and stress distribution in restored teeth can be influenced by endodontic treatment and composite resin restoration. Therefore, the purpose of the present investigation was to determine the fracture resistance and stress distribution in endodontically treated maxillary premolars restored with composite resin.

Methods and materials

Fifty intact extracted human maxillary premolar single-rooted teeth were used in the study. The time from extraction to mechanical test of teeth was less than 3 months. After being measured mesiodistally (MD) and facio-lingually (FL) to determine a medium size range (MD = 8.1 to 9.1 mm; FL = 6.3 to 7.3 mm) the teeth were randomly divided into five groups (n = 10). All teeth were radiographed in a buccal and proximal direction to check for a single root and single canal. Teeth were stored in distilled water and 0.2% thymol solution at 37°C. An acrylic resin cylinder was used to fix each tooth at a distance of 2.0 mm from the cementum enamel junction. Periodontal ligaments were simulated inside the cylinder using a polyether impression material (Impregum F, 3M ESPE, St Paul, MN).[24] A cavity preparation machine[24] was used to prepare standardized mesial-occlusal-distal (MOD) cavities for all teeth, except for the control group, at high-speed and under air–water spray with a #330 bur (KG Sorensen, Barueri, SP, Brazil). Five groups were obtained: G1, intact teeth (control); G2, MOD preparation; G3, MOD preparation and composite resin restoration; G4, MOD preparation and endodontic treatment; and G5, MOD preparation, endodontic treatment, and composite resin restoration.

After MOD preparation for G4 and G5, a conservative endodontic access was done on the pulp chamber wall. Next, all canals were prepared with K files (Malleiffer, Ballaigues, Switzerland) using circumferential filling. Sizes 15 to 50 were taken to the full working length, using a step-back technique in 1.0-mm increments. To obtain a standardized coronal third, a Gates Glidden drill size #5 was used. Sodium hypochlorite (2.5%) solution was used during root canal cleaning and shaping. After instrumentation, all teeth were obturated with gutta-percha (Mailleffer) and endodontic sealer (Sealer 26, Dentsply, New York, NY) by the lateral condensation technique. G3 and G5 were restored with composite resin. After cavity preparation, teeth were etched with 37% phosphoric acid gel for 15 seconds and washed with water for 15 seconds. A one-bottle adhesive system (Single Bond, 3M ESPE) was then applied to the cavities with a microbrush according to the manufacturer's instructions and photopolymerized for 20 seconds. A metal matrix held by a retainer (S.S. White, Philadelphia, PA) was placed around the tooth. The incremental restorative technique was used for microhybrid composite resin restorations (Z 250, 3M ESPE). Each increment was photopolymerized for 40 seconds. After 24 hours of storage in distilled water at 37°C, specimens were finished with fine diamond burs (KG Sorensen) at low speed with a water spray, and polishing was performed with Sof-Lex discs (3M ESPE).

The samples were subjected to a compressive load at a crosshead speed of 0.5 mm/min in a mechanical testing machine (EMIC DL 2000, São José dos Pinhais, Brazil). Compressive loading was applied using a 6.0-mm diameter steel bar placed in the center of the tooth, with contacts only on buccal and lingual cusps. The force required (Kgf) to cause fracture was recorded, and the results were submitted to statistical analysis by one-way ANOVA and Tukey's test ($p < 0.05$). The fractured samples were analyzed by stereomicroscopy to determine the fracture pattern in each sample. The four fracture patterns were: type I, fractures involving small tooth portions (coronal); type II, fractures involving tooth portions (coronal) and cohesive failure of composite resin; type III, fractures involving tooth portions, with periodontal involvement and adhesive failure of composite resin; and type IV, vertical root/coronal fracture (Fig 1).

Five individual finite element models were created in this study: Model 1, sound teeth; Model 2, MOD preparation; Model 3, MOD preparation plus composite resin restoration; Model 4, MOD preparation plus endodontic treatment; and Model 5, MOD preparation plus endodontic treatment plus composite resin restoration. The solid models were constructed with a scanned longitudinal section of a human maxillary premolar. The external contour, cylinder insertion, and periodontal ligament simulation were created using Mechanical AutoCAD V14 software (Autodesk, Inc., San Rafael, CA). The data were exported to Ansys 10.0 (Ansys Inc., Houston, TX). Areas of each structure were created using this software. The models were meshed with eight-node isoparametric plane strain elements (PLANE 183) by mechanical properties, which were obtained by literature review (Table 1). Occlusal loads were applied on buccal and lingual cusps, simulating the load application used in mechanical testing (Fig 2). A 45 N compressive static load was applied at 45° on the inclines of buccal and lingual cusps. The models were restrained on the lateral contour of the cylinder. The finite element analysis (FEA) used the stress distribution of the von Mises criterion (Fig 2).

Results

Data showed normal and homogeneous distribution, and significant differences among the groups were indicated by one-way ANOVA. Fracture strength values are summarized in Table 2, and fracture patterns are presented in Table 3. Tukey's test ($p < 0.05$) showed that G1 (control) was significantly stronger than G2, G4, and G5; G3 was significantly stronger than G2 and G4.

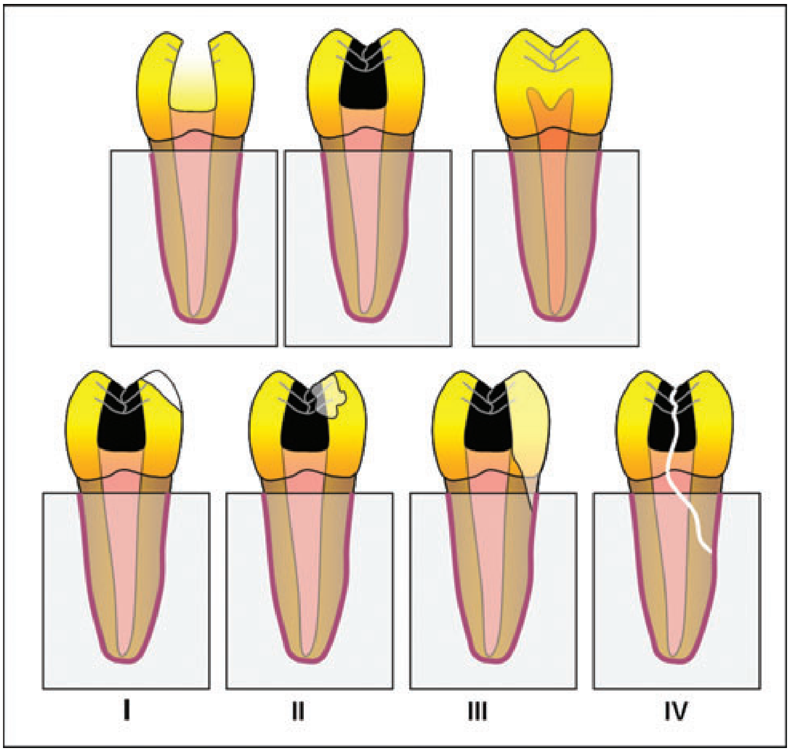

Figure 1 Fracture patterns.

The samples of G3, G4, and G5, which had composite resin restorations or had been endodontically treated, demonstrated a high incidence of fracture patterns with tooth structure and periodontal involvement.

All the analyses performed were static linear analyses. The von Mises equivalent stress was evaluated for the five models under oblique loads (Fig 3). The nonrestored models showed high stress concentration in the following dental structures: pulp chamber and internal angles in Model #2 and root canal walls in Model #4. On the other hand, the tooth restored with composite resin model (Models #3 and #5) showed stress distribution similar to the sound model (Model #1), which is presented in Figure 3.

Both hypotheses were accepted.

Table 1 Mechanical properties of dental structures and restorative materials

Structure/ material	Modulus of elasticity (MPa)	Poisson's ratio	References
Enamel	46.8×10^3	0.30	Wright & Yettram[33]
Dentin	18.0×10^3	0.31	Joshi et al[34]
Pulp	0.69	0.45	Farah et al[35]
Polyether	50	0.45	Manufacturer's information
Polystyrene resin	13.5×10^3	0.31	Manufacturer's information
Gutta-percha	0.93	0.40	Joshi et al[34]
Composite resin	16.6×10^3	0.24	Joshi et al[34]

Discussion

Studies have indicated the need for special considerations for restoring endodontically treated teeth, which are considered highly susceptible to fracture.[3,5,11] Fracture resistance of a restored, endodontically treated tooth decreases as the amount of dentin removed increases.[25]

In this study, restoration of endodontically treated teeth (G5) partially recovered the resistance of the teeth, when compared with the control group (G1) and the MOD restored group (G3). This can be explained by loss of tooth structure, with consequent reduction in the ability of the tooth to resist intraoral forces. The thickness of the dentinal wall at the root circumference is critical, and there is a direct correlation between the root diameter and the ability of the tooth to resist lateral forces and avoid fracture.[9] There are approximately 10% fewer organic substances (collagen and water) in the endodontically treated teeth when compared with vital teeth;[12] however, there were no significant changes in the hardness, elasticity modulus, or fracture resistance of endodontically treated teeth.[26] The main factor for increased brittleness appears to be the amount of removed structure, presence of cracks, previous fractures, or dental caries.[26] The ability of the tooth to resist occlusal forces is directly related to the amount of remaining coronal tooth structure.[1,2] This may explain why G3 (MOD restored) presented similar strength to the control group after being restored.

Posterior teeth, particularly maxillary premolars, have an anatomic shape that makes them more susceptible to cusp fractures when under occlusal load.[8] Premolars are more brittle when subjected to lateral forces during mastication and present

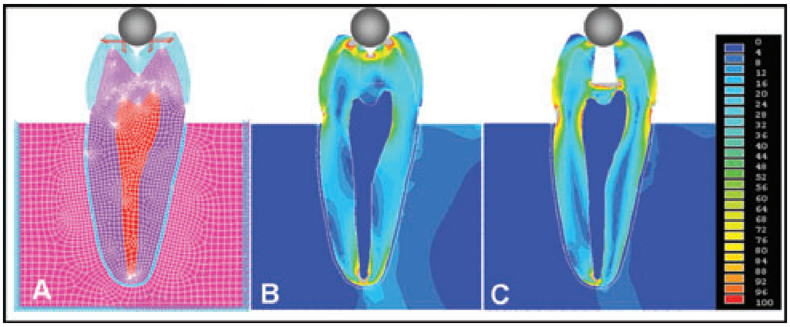

Figure 2 2D finite elements models. (A) Mesh of each area and load application; stress distribution and load application on sound (B) and prepared teeth (C).

delicate root morphology.[5] Endodontic access only to teeth with intact marginal ridges has a minimal effect on the strength of the dental structure. Conversely, the deflection of premolar cusps under occlusal loading is greater in endodontically treated premolars with MOD preparation.[3] Access preparations increase the possibility of cusp fracture because of increased cuspal deflection during function.[2,27]

The type and quality of the remaining structure also has an influence on fracture resistance when the tooth is submitted to load application. Thus, the lingual/buccal cusps and the mesial and distal marginal ridges form a circle of enamel that is important to fracture resistance.[2] Previous studies have demonstrated low values of fracture resistance for MOD preparation[1,8,9,25] and high deflection values.[2] The cylinder–tooth contact acts as a wedge between the buccal and lingual cusps in nonrestored teeth, therefore decreasing the mean fracture resistance values and promoting more catastrophic types of fractures.

Numerous studies have been conducted to determine the ideal way to restore endodontically treated teeth. Tooth fracture resistance increased significantly when MOD cavities were restored with composite resin.[7] Adhesive restorations are better able to transmit and distribute functional stresses through the restorative material–tooth interface, with the potential to reinforce the weakened tooth structure.[5,15-18] In this study, the majority of the specimens restored with composite resin showed catastrophic fractures (type IV). Transmission of strain energy[18] for crack propagation within dentin is dependent on the shape, composition, and biomechanical properties of the restorative material adjacent to the crack.[28,29] The higher the elastic modulus of the restorative material when the joint restorative material/dental structure is stressed, the lower the deformation of dental structures.[18] The low elastic modulus of composite resin may be a primary factor in explaining how this material can transmit the energy produced by the compressive test to adjacent dental structures. The concentration of stresses in the inner dentin can lead to catastrophic structure fracture.[18,29] As dentin is weakened as the channel diameter increases,[6] conservation of the remaining healthy dentin is considered important, and restorations that support this concept are preferable.[5,16-18,30]

FEA showed that the MOD preparation and endodontic treatment accentuated the concentration of stress inside the dental structure, mainly due to the greater removal of dental structure. The most catastrophic fracture pattern in the samples of the nonrestored and endodontically treated groups after the destructive test showed a direct relation to the level of stress concentration demonstrated by the finite elements test. The nonrestored samples presented high vertical root fracture indices, due to the absence of reinforcement caused by the presence of the MOD preparation and endodontic treatment.[31] This behavior coincides with the distribution of stress demonstrated in Models #2 and #4, which presented high levels of stress concentrations inside the coronary dentin, pulp wall, and root canal (Fig 3).

The models restored with composite resin (#3 and #5) presented a more homogenous stress distribution; however, the mechanical properties of this material associated with the removal of structure[18,32] promoted dissipation of stress to the adjacent dental structures (Fig 3) coinciding with the catastrophic fractures found in G3 and G5. In the destructive mechanical test, the samples in G5 presented a greater loss of reinforcement than the samples in G3, probably due to the greater loss of structure caused during endodontic treatment; however, the comparative analysis of Models #3 and #5 did not show significant differences in the stress distribution patterns and presented a biomechanical behavior more similar to that of Model #1, a result also shown by Arola et al.[20]

The association of the destructive mechanical test (fracture resistance) and finite element methods (stress distribution) proved to be an efficient tool in complex structure analysis.

Table 2 Fracture resistance values (Kgf)

Group (n = 10)	Mean	SD	Statistical*
1 (Control)	83.6	25.4	A
3 (MOD + restored)	82.1	24.9	A B
5 (MOD + Endo + restored)	64.5	18.1	B
2 (MOD preparation)	52.7	20.2	C
4 (MOD + Endo)	40.2	14.2	C

*Different letters represent significant statistical difference shown by the Tukey Test ($p < 0.05$).

Table 3 Fracture patterns

Group (n = 10)	I	II	III	IV
1	10	–	–	0
2	4	–	–	6
3	1	1	2	6
4	1	–	–	9
5	0	1	1	8

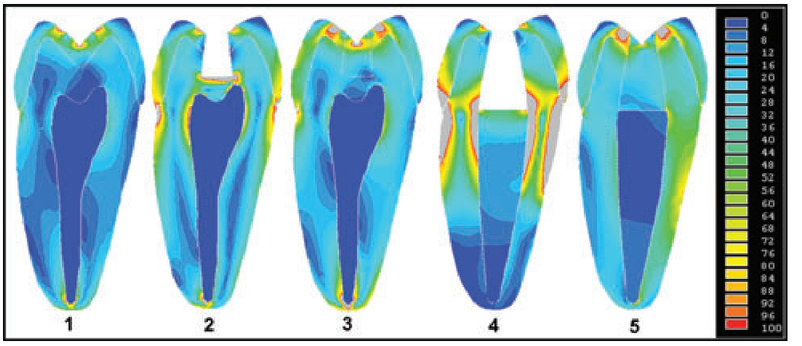

Figure 3 Von Mises stress distribution of the five models.

Furthermore, FEA using 3D models is recommended, as it allows anatomic alterations and device–sample contact to be shown with greater fidelity; in the mechanical test, static load was replaced by cyclic loads.

Conclusion

This study suggested that the conservation of dental structure is crucial to offering fracture resistance. The removal of inner dentin in endodontically treated teeth reduced fracture resistance values and promoted alteration in stress distribution. The use of adhesive restorations is recommended for reinforcing remaining dental structure.

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