Restor Dent Endod. 2019 Aug;44(3):e33
https://doi.org/10.5395/rde.2019.44.e33
pISSN 2234-7658·eISSN 2234-7666

Restorative Dentistry & Endodontics

Research Article

Effect of the restorative technique on load-bearing capacity, cusp deflection, and stress distribution of endodontically-treated premolars with MOD restoration

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ABSTRACT

Objectives: To evaluate the influence of the restorative technique on the mechanical response of endodontically-treated upper premolars with mesio-occluso-distal (MOD) cavity.
Materials and Methods: Forty-eight premolars received MOD preparation (4 groups, $n = 12$) with different restorative techniques: glass ionomer cement + composite resin (the GIC group), a metallic post + composite resin (the MP group), a fiberglass post + composite resin (the FGP group), or no endodontic treatment + restoration with composite resin (the CR group). Cusp strain and load-bearing capacity were evaluated. One-way analysis of variance and the Tukey test were used with $\alpha = 5\%$. Finite element analysis (FEA) was used to calculate displacement and tensile stress for the teeth and restorations.
Results: MP showed the highest cusp ($p = 0.027$) deflection (24.28 ± 5.09 μm/μm), followed by FGP (20.61 ± 5.05 μm/μm), CR (17.72 ± 6.32 μm/μm), and GIC (17.62 ± 7.00 μm/μm). For load-bearing, CR (38.89 ± 3.24 N) showed the highest, followed by GIC (37.51 ± 6.69 N), FGP (29.80 ± 10.03 N), and MP (18.41 ± 4.15 N) ($p = 0.001$) value. FEA showed similar behavior in the restorations in all groups, while MP showed the highest stress concentration in the tooth and post.
Conclusions: There is no mechanical advantage in using intraradicular posts for endodontically-treated premolars requiring MOD restoration. Filling the pulp chamber with GIC and restoring the tooth with only CR showed the most promising results for cusp deflection, failure load, and stress distribution.

Keywords: Cusp deflection; Endodontics; Load-bearing; Restorative dentistry; Stress distribution; Finite element analysis

Received: May 7, 2019
Revised: Jul 1, 2019
Accepted: Jul 21, 2019

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INTRODUCTION

Dental fracture can be a consequence of tooth weakening, abrasion, attrition, erosion, abfraction, caries lesions, restorative procedures, and trauma [1-4]. Weakened teeth are characterized by a decrease in their volume and the loss of healthy dentin due to caries lesions and tooth preparation [1,5]. The most common causes of dental fractures are high-impact loads during chewing or premature occlusal contact [5,6]. It has been reported that dental fractures occur more frequently in teeth with large restorations than in teeth with small restorations or sound teeth [5].

Extensive restorations are often associated with endodontic treatment due to pulp vitality impairment. Endodontically-treated teeth are at a higher risk of biomechanical failure than vital teeth [7]. The factors posing the highest risk of fracture include loss of dental tissue [8], preparation of an endodontic access cavity to disinfect the root canal [6], and/or changes in the physical properties of dentin due to dehydration [8]. In cases of extensive tooth destruction, intraradicular retainers are required to provide sufficient retention for the restorative material since the dental remnant is insufficient [9,10]. However, the use of intraradicular posts in order to strengthen dental structure has already been reported to be ineffective [11,12].

For posterior teeth with a mesio-occlusal-distal (MOD) cavity, the most suitable treatment consists of a direct restoration using composite resin due to its high bond strength to the dental substrate [3,13-15]. In cases where dental pulp has been compromised and endodontic treatment has been performed, the best protocol prior to performing the restoration, which may increase the resistance of the dental structure, is still not well-defined [16,17]. It has been generally reported in the literature that glass ionomer cement should be used to support the composite resin restoration [18,19]. Other authors have reported the use of fiberglass posts and filling the pulp chamber with resin cement [11]. Finally, some manufacturers offer pre-framed metal posts with this indication. Therefore, this study evaluated whether there were any advantages in using a prefabricated post in terms of load-bearing capacity, cusp deflection, and stress distribution of endodontically-treated human upper premolars with MOD restoration. The first null hypothesis was that different techniques would not influence the cusp deflection and load-bearing capacity of human upper premolars with MOD restoration, while the second null hypothesis was that the different restorative techniques would not influence the stress concentration in the cervical area of the teeth.

MATERIALS AND METHODS

Samples preparation

The Ethics Committee of the Institute of Science and Technology—São Paulo State University approved this study under the review protocol approval number 071/2009. Forty-eight extracted upper premolars without caries, restorations, or wear on the cusp tip that could modify their anatomy were collected and stored in saline solution for 30 days [20]. After, the teeth were marked 2 mm below the cementoenamel junction, and the root portion apical to the demarcation was inserted in polyurethane resin (Polyurethane F160, Axson, Cercy, France) [20]. All specimens received MOD-type preparations, with one-third of the intercuspal distance being respected as the maximum width. The cavity dimensions consisted of 3.8 mm bucco-lingually, 2.8 mm of height to the pulpal wall, a proximal cavity length of 2.5 mm, and a proximal box thickness of 1.5 mm. For these purposes, graphite markings were made of the

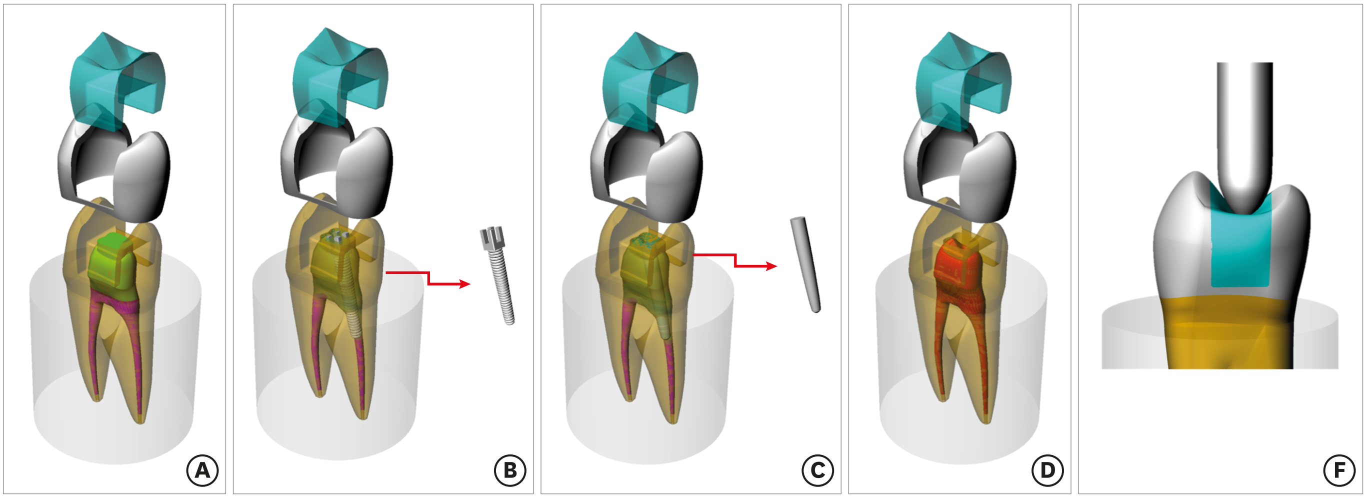

Figure 1. Schematic illustration of the modeled structures used in this study. The groups were distributed according to the restorative modality: (A) GIC group, glass ionomer cement + composite resin; (B) MP group, metallic post + composite resin; (C) FGP group, fiber glass post + composite resin; (D) CR group, composite resin; (E) Load application using a blunt tip of 2 mm in diameter with a load of 50 N.
GIC, glass ionomer cement + composite resin; MP, metallic post + composite resin; FGP, fiber glass post + composite resin; CR, composite resin.

preparation limits, and cylindrical diamond tips (1094, 2095, 2096, KG Sorensen, São Paulo, SP, Brazil) were used with sizes compatible with the cavities to be prepared.

The teeth were randomly distributed into 4 groups ($n = 12$) according to the use of endodontic treatment and restorative techniques: endodontic treatment + glass ionomer cement + composite resin (the GIC group), endodontic treatment + metallic post + composite resin (the MP group), endodontic treatment + fiberglass post + composite resin (the FGP group), and teeth restored with composite resin without endodontic treatment (the CR group) (**Figure 1**).

Endodontic treatment

For the groups with endodontic treatment and an MOD cavity, the specimens underwent pulp chamber access preparation with a spherical diamond tip followed by the use of inactive tip drills for complete removal of the pulp chamber ceiling. All root canals were instrumented to the working length, which was defined as the total length minus 1 mm, up to the size of a #40 K-file (Dentsply Maillefer, Ballaigues, Switzerland) and staggered with Gates-Gliden drills #2 and #3 (Dentsply/Maillefer Instruments SA, Ballaigues, Switzerland). For obturation, the master gutta-percha cones (Dentsply/Maillefer) were selected according to the final diameter obtained in the biomechanical preparation. They were then placed in the canal with an endodontic resin sealer (AH Plus, Dentsply/Maillefer), spreading the cement on all the canal walls. Lateral condensation was performed with accessory gutta-percha cones (Dentsply Maillefer) with the aid of a spreader compatible with a size #30 K-file (Dentsply Maillefer) until lateral filling of the root canals was achieved, as confirmed radiographically in the mesio-distal direction. The gutta-percha cones were cut (4 mm short of the apex) with a heated endodontic condenser (Duflex, SS White, Rio de Janeiro, RJ, Brazil), and then with another cold endodontic plugger, after which the cervical accesses were cleaned with 70% alcohol (Miyako do Brasil Ind., Com., Ltd., São Paulo, SP, Brazil). The teeth were then stored in artificial saliva for 24 hours at 37°C.

Restorative treatment in each group

After endodontic treatment, the following tooth restoration procedures were performed for the teeth in each group.

1. Glass ionomer cement + composite resin (the GIC group)

The pulp chamber was sealed and filled with glass ionomer cement (Vidrion F, SS White, Rio de Janeiro, RJ, Brazil) using a Centrix syringe for restorative material injection. Next, direct composite resin restoration was performed by acid conditioning of the tooth with 37% phosphoric acid (Etch-37, BISCO Inc., Schaumburg, IL, USA) for 30 seconds in enamel and 15 seconds in dentin. Then, the tooth was washed for 20 seconds and dried with air jets. The two-step adhesive system (All Bond 3, BISCO Inc.) was used as recommended by the manufacturer. A direct restoration with microhybrid composite resin (AELITE LS, BISCO Inc.) was carried out using an incremental technique. Each increment had a maximum thickness of 2 mm and was polymerized for 40 seconds.

2. Metallic post + composite resin (the MP group)

The root canal was prepared with the aid of the drills of the metallic post system in order to maintain at least one-third of the gutta-percha obturating the root canal. After preparation, a stainless steel metallic root post (REFORPOST, Angelus Indústria de Produtos Odontológicos S/A, Londrina, PR, Brazil) was cemented with Duo-Link dual-cure resin cement (BISCO Inc.). Direct composite resin restoration was performed as in the GIC group.

3. Fiberglass post + composite resin (the FGP group)

The root canal was prepared with the D.T. LightPost Illusion drill system (BISCO Inc.), and the fiberglass post from the same system was then cemented using Duo-Link dual-cure resin cement (BISCO Inc.). Direct composite resin restoration was performed as in the GIC and MP groups.

4. Composite resin (the CR group)

The teeth in this group did not receive endodontic treatment. Thus, the sound tooth was restored following the protocol performed in the GIC, MP, and FGP groups.

Cusp deflection

Strain gauges (KFG-1-120-C1-11L1M2R, KYOWA Electronic Instruments Co., Ltd., Tokyo, Japan: resistance, 119.6% ± 0.4%Ω; gauge length, 1 mm; gauge factor, 2.08% ± 1.0%) were attached with cyanoacrylate adhesive (Super Bonder Loctite, São Paulo, SP, Brazil) in each tooth (**Figure 2**). The wires of the strain gauges were welded to a circuit board on which copper wires were also welded, and then attached to a terminal to capture the information generated by the devices (Model 5100B Scanner - System 5000, Inter Technology Inc., Raleigh, NC, USA). A multimeter was used to verify the absence of electric terminal defects

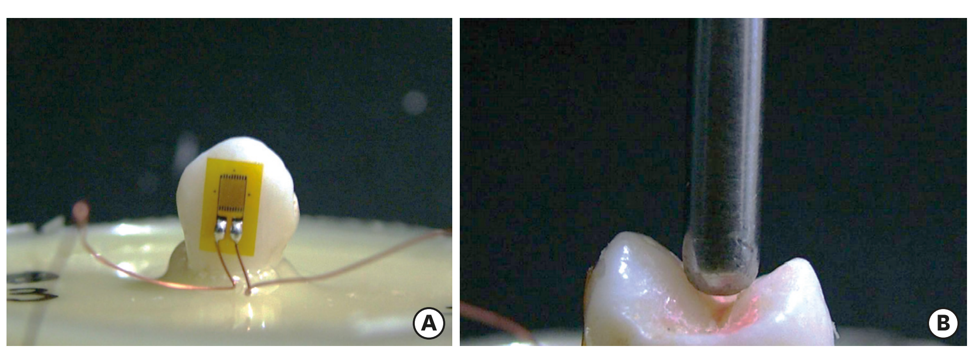

Figure 2. Cusp deflection analysis. (A) Strain gauges were bonded to each tooth to evaluate the cusp deflection; (B) Load application.

https://doi.org/10.5395/rde.2019.44.e33

(Minida ET 2055, Minida, São Paulo, SP, Brazil) [20]. The samples were placed on a steel base perpendicular to the ground, and a blunt tip of 2 mm in diameter was used to apply a load of 50 N for 20 seconds [20], with the tip touching the composite restoration. The generated microstrains were interpreted by specific software (StrainSmart, Inter Technology Inc.).

Load-bearing capacity

After the cusp deflection measurement, the samples underwent the load-bearing capacity test in similar conditions. A compression load was applied to each tooth assembly by a unidirectional vertical platform and loaded with a 0.5 mm/min rate until failure, which was defined as cusp fracture. The maximum load to failure was recorded in newtons [21].

Finite element analysis

The complete structures of the tooth and polyurethane resin [11,22,23] were exported to modeling software (Rhinoceros 4.0 McNeel North America, Seattle, WA, USA). The premolar included 7.5 mm from the buccal cusp to the cementoenamel junction, 6 mm between both cusp, and 9 mm as the buccal-palatal distance. The MOD restoration consisted of a volume of 82 mm^3. All materials were considered isotropic, linear, and homogeneous. The mechanical properties of the materials and structures considered in the analysis are summarized in **Table 1** [24-26]. The contact regions between the structures were considered to be perfectly bonded and the mesh had quadratic tetrahedral elements, being controlled by a sizing method with 0.3 mm, resulting in a total of 624,153 nodes and 462,228 elements. The aspect ratio of the mesh metrics presented an average of 1.77 with a standard deviation of 0.67. The polyurethane base was considered fixed in the three axes, and the load (50 N) was applied with a 2 mm diameter spherical tip (following the *in vitro* test) parallel to the principal axis to keep the analysis in the elastic field. The set displacement (mm) and maximum principal stress (MPa) for the tooth, restoration, and post were obtained. The data were summarized through colorimetric maps, which enabled visualization of the limit between each stress fringe. Tensile stress (MPa) peaks were recorded and summarized in **Table 2** for a quantitative comparison.

Table 1. Mechanical properties of the materials/structures used in the present study

Material/structure	Elastic modulus (GPa)	Poisson ratio	Reference
Glass ionomer cement	8	0.25	17
Glass fiber post	49	0.28	18
Conical-tapered metal post	110	0.35	19
Composite resin	12	0.30	19
Gutta-percha	0.69	0.28	18
Enamel	80	0.30	18
Dentin	18	0.23	18

Table 2. Descriptive statistical analysis and *post hoc* Tukey test for cusp deflection (μm/μm), load to failure (N), and stress peak values (MPa) in the restorations and teeth

Group	Cusp deflection	Load to failure	Stress in the restoration	Stress in the enamel	
				Buccal	Palatal
GIC	17.62 ± 7.00^{B}	37.51 ± 6.69^{A}	2.23	2.98	5.62
MP	24.28 ± 5.09^{A}	18.41 ± 4.15^{C}	2.25	3.23	5.89
FGP	20.61 ± 5.05^{AB}	29.80 ± 10.03^{B}	2.28	3.17	5.77
CR	17.72 ± 6.32^{B}	38.89 ± 3.24^{A}	2.25	2.51	5.45

Different superscripts mean that there is a significant difference between 2 groups.
GIC, glass ionomer cement + composite resin; MP, metallic post + composite resin; FGP, fiber glass post + composite resin; CR, composite resin.

Statistical analysis

Mean values and standard deviations were determined for each group. The normality of the data was checked by the Kolmogorov-Smirnov test. One-way analysis of variance (ANOVA) was used, followed by the *post hoc* Tukey test for multiple comparisons ($\alpha = 0.05$) to compare the cusp deflection and load-bearing capacity. The stress data were qualitatively evaluated based on the colorimetric stress map and quantitatively evaluated using the stress peaks.

RESULTS

One-way ANOVA revealed that the different treatments significantly influenced the mean values of cusp deflection ($p = 0.027$) and load-bearing capacity ($p = 0.001$). The restorations using a metal post (MP group) showed the highest cusp deflection and the lowest mean value for load-bearing capacity. The GIC and CR groups showed lower mean values for cusp deflection and higher mean values for load-bearing capacity. The descriptive statistical analysis and results of the Tukey test are shown in **Table 2**. According to the finite element analysis, all modalities presented a similar profile for cusp linear deformation (**Figure 3**). However, more fringes were present in the MP group, followed by the FGP, GIC, and CR groups. In analyzing the tooth surfaces (**Figure 4**), it was noted that the MP group presented more areas with red color on the colorimetric stress map, meaning that it experienced the highest stress concentration. **Figure 5** shows that both metallic and fiber posts concentrated more stress (metal > FGP) in the cervical area, increasing the stress concentration below the

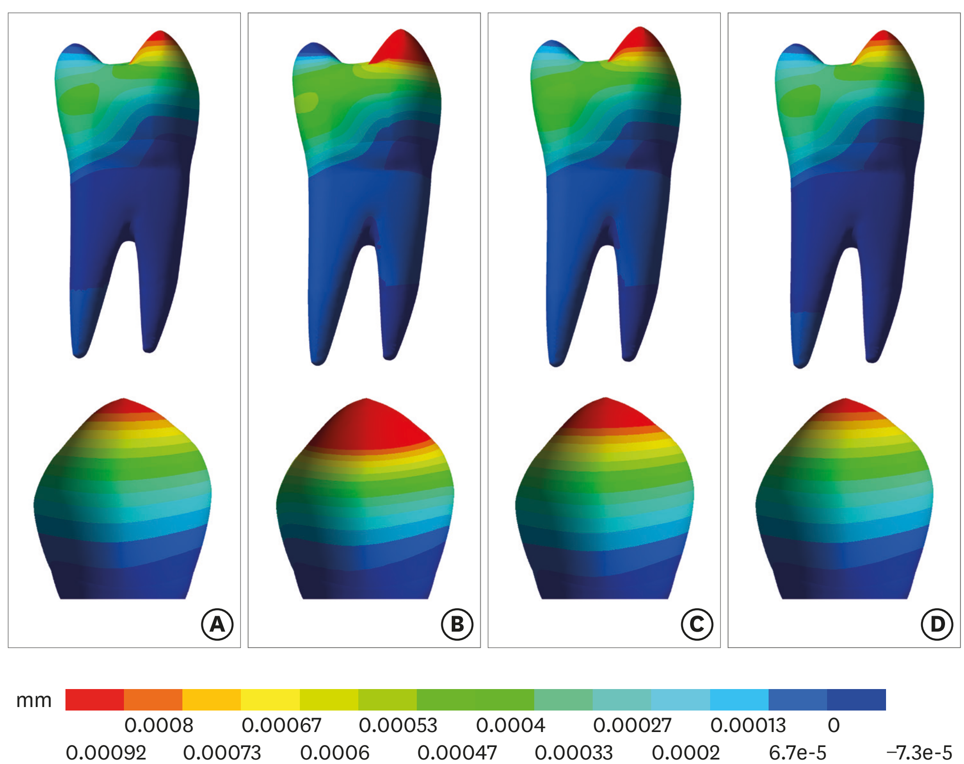

Figure 3. Results of cusp linear deformation (mm) according to the restorative modality: (A) GIC group, glass ionomer cement + composite resin; (B) MP group, metallic post + composite resin; (C) FGP group, fiber glass post + composite resin; (D) CR group, composite resin.
GIC, glass ionomer cement + composite resin; MP, metallic post + composite resin; FGP, fiber glass post + composite resin; CR, composite resin.

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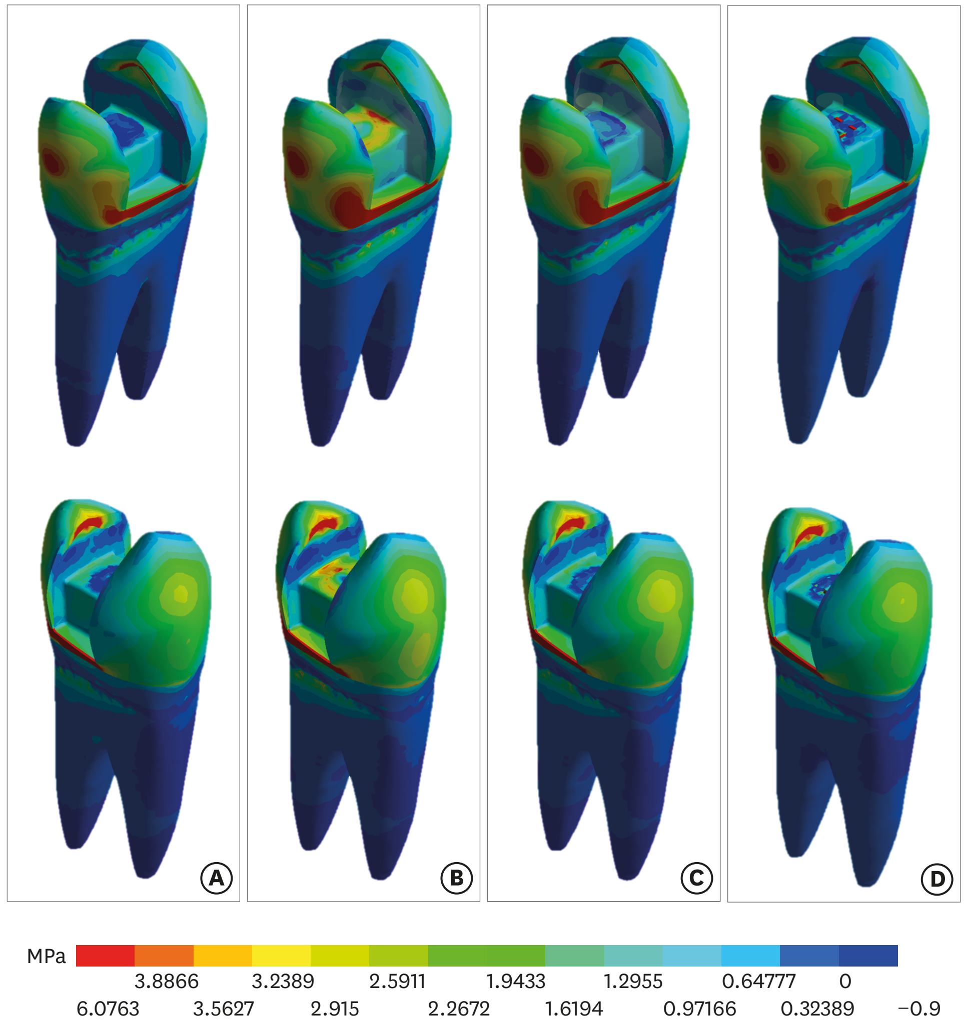

Figure 4. Results of maximum principal stress (MPa) in the tooth according to the restorative modality: (A) GIC group, glass ionomer cement + composite resin; (B) MP group, metallic post + composite resin; (C) FGP group, fiber glass post + composite resin; (D) CR group, composite resin.
GIC, glass ionomer cement + composite resin; MP, metallic post + composite resin; FGP, fiber glass post + composite resin; CR, composite resin.

restoration compared to the GIC and CR groups. There was no significant difference among the groups in the stress distribution in the composite resin restoration (**Figure 6**). All groups showed the highest stress peak on the palatal surface (5.45–5.89 MPa), in comparison with the buccal face (2.51–3.23 MPa). The results are summarized in **Table 2**.

DISCUSSION

This study aimed to evaluate the influence of prefabricated posts on cusp deflection, load-bearing capacity, and stress distribution in endodontically-treated upper human premolars with a MOD restoration. The microstrain results showed statistically significant differences among the experimental groups, leading the first null hypothesis to be rejected. The stress distribution results showed different values among the evaluated treatments, causing the second null hypothesis to be rejected.

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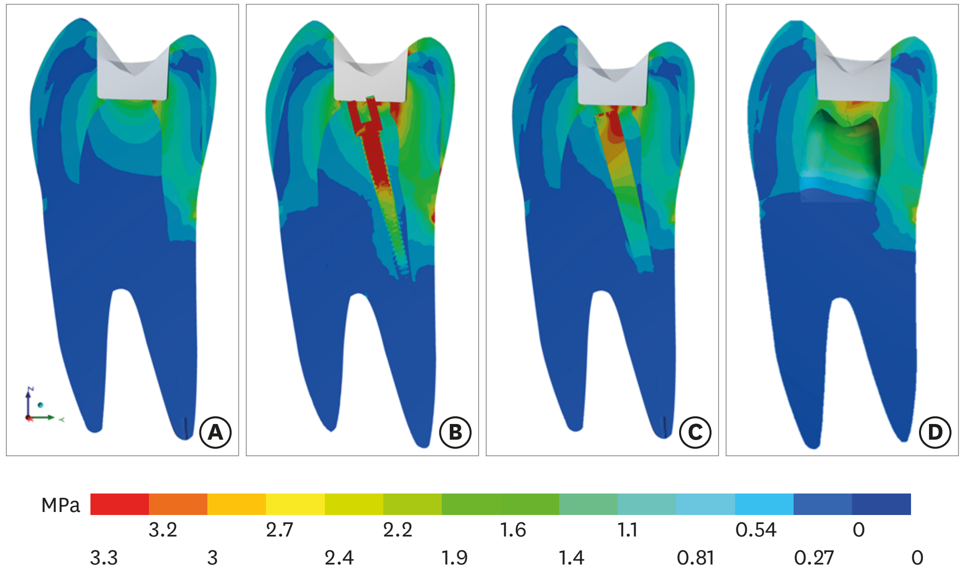

Figure 5. Results of maximum principal stress (MPa) in the root dentin and post according to the restorative modality: (A) GIC group, glass ionomer cement + composite resin; (B) MP group, metallic post + composite resin; (C) FGP group, fiber glass post + composite resin; (D) CR group, composite resin.
GIC, glass ionomer cement + composite resin; MP, metallic post + composite resin; FGP, fiber glass post + composite resin; CR, composite resin.

Restoration of teeth with composite resin without endodontic treatment has already been reported to show promising mechanical behavior [27,28]. These previous studies have suggested that composite resin restoration decreases cusp deflection. This can be explained through the adhesive characteristics of this type of restoration, which partially restore the rigidity of the dental element through adequate bond strength at the tooth/restoration interface [29].

Finite element analysis showed that the mechanical behavior was very similar across all groups in an ideal situation in which the adhesive interface is perfectly bonded between the tooth and restoration (**Figure 6**). Thus, the possibility of dental fracture due to stress concentration in the dental structure seems to be more influenced by the restorative treatment after endodontic access than by marginal infiltration along the restoration. **Figure 4** shows that the palatal cusp was the most susceptible to fracture in response to a load being exerted on the restorative material. This finding is in agreement with previous studies that evaluated the biomechanical behavior of healthy [22] and restored teeth [23] using finite element analysis. In addition, it is important to note that intraradicular posts are often indicated for palatal canals [11], which further contributes to this cusp being stressed during masticatory load. This effect is even greater for metal posts than fiberglass posts (**Figures 3** and **4**).

Glass ionomer cement is used as a base material for restorations because its mechanical properties are similar to those of dentin [19,30]. This advantage is reflected in our results, in which the teeth that had their pulp chamber filled with glass ionomer cement and were directly restored with composite resin presented similar cusp deflection values to those restored with composite resin without endodontic treatment (**Table 2**). The good performance of glass ionomer cement as a substitute for lost dentin during access opening for endodontic treatment obtained in this study is in agreement with previous studies [24,31] which indicated that glass ionomer cement is a suitable material to be used under a composite resin restoration.

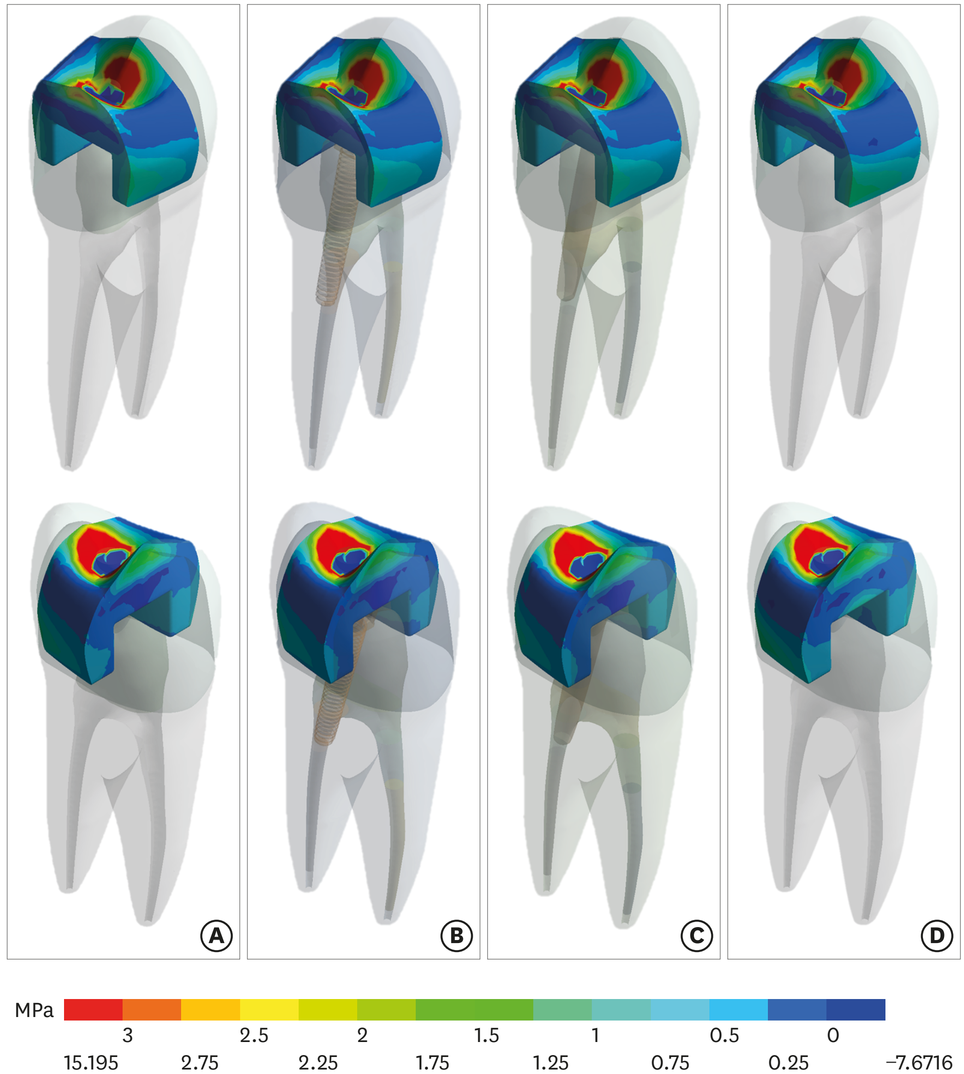

Figure 6. Results of maximum principal stress (MPa) in the restoration according to the restorative modality: (A) GIC group, glass ionomer cement + composite resin; (B) MP group, metallic post + composite resin; (C) FGP group, fiber glass post + composite resin; (D) CR group, composite resin.
GIC, glass ionomer cement + composite resin; MP, metallic post + composite resin; FGP, fiber glass post + composite resin; CR, composite resin.

The use of a metallic post inside the root canal, in addition to removing more dental tissue [11], means that a non-adhesive restorative material is in contact with the composite resin and the remaining structures; this increases the possibility of cusp movement, and thereby elevates the risk of tooth fracture. The results showed a significance difference between the group restored with a metal post and the group restored with a fiberglass post (**Table 2**). In addition, as shown in **Figure 5**, a higher stress concentration was present below the restoration in both groups with an intraradicular post than in the GIC and CR groups, with larger zones of red color for the MP group. This fact corroborates previous reports that fiber posts are preferable to prefabricated metal posts [32]. A correlation between the cusp deflection and fracture resistance values could also be observed, which has also been reported in the literature [33,34].

The group that presented the highest cusp deflection means herein also showed the lowest load-bearing capacity. Despite the results of the present study, it is worth noting that it has limitations because it is a laboratory study. The effects of cyclic fatigue, oblique load in the restoration [35], thermal aging [36], different composite materials [37] and sliding occlusal loads can modify the mechanical behavior of restored teeth, thereby weakening the adhesive strength and altering the final results. Moreover, pH variation and defects in the restorative material, such as bubbles within the restoration, were not reproduced in the numerical simulation, as ideal conditions of a homogeneous (without bubbles or defects in the cement or composite) and isotropic material were assumed. Another important limitation of this study is that the finite element simulation was performed with general materials, using mechanical properties reported in the literature [19,24,25]. However, the values used in this study cannot represent the mechanical properties of the current *in vitro* materials during the strain gauge analysis. This simplification was present for all groups; for that reason, the mechanical behavior may not present precisely the same values for each method, but the same profile is likely to be observed. Finally, even though the results are valid, they should be extrapolated with care and explored in future longitudinal clinical studies to define the best clinical approach.

CONCLUSIONS

There is no mechanical advantage in using intraradicular posts when an endodontically-treated premolar requires MOD restoration. Filling the pulp chamber with glass ionomer cement and restoring the tooth with only composite resin showed the most promising results in terms of cusp deflection, failure load, and stress distribution.

ACKNOWLEDGEMENTS

The first author acknowledges the Coordination for the Improvement of Higher Education Personnel (CAPES) for financial support in the form of a scholarship.

REFERENCES

1. Popescu SM, Diaconu OA, Scrieciu M, Marinescu IR, Drăghici EC, Truşcă AG, Bănică AC, Vătu M, MercuŢ V. Root fractures: epidemiological, clinical and radiographic aspects. Rom J Morphol Embryol 2017;58:501-506.
PUBMED
2. Bastone EB, Freer TJ, McNamara JR. Epidemiology of dental trauma: a review of the literature. Aust Dent J 2000;45:2-9.
PUBMED | CROSSREF
3. Rho YJ, Namgung C, Jin BH, Lim BS, Cho BH. Longevity of direct restorations in stress-bearing posterior cavities: a retrospective study. Oper Dent 2013;38:572-582.
PUBMED | CROSSREF
4. Tribst JP, Dal Piva AM, Borges AL, Bottino MA. Simulation of mouthguard use in preventing dental injuries caused by different impacts in sports activities. Sport Sci Health 2019;15:85-90.
CROSSREF
5. Teixeira ES, Rizzante FA, Ishikiriama SK, Mondelli J, Furuse AY, Mondelli RF, Bombonatti JF. Fracture strength of the remaining dental structure after different cavity preparation designs. Gen Dent 2016;64:33-36.
PUBMED
6. Laske M, Opdam NJ, Bronkhorst EM, Braspenning JC, Huysmans MC. Risk factors for dental restoration survival: a practice-based study. J Dent Res 2019;98:414-422.
PUBMED | CROSSREF

7. Mergulhão VA, de Mendonça LS, de Albuquerque MS, Braz R. Fracture resistance of endodontically treated maxillary premolars restored with different methods. Oper Dent 2019;44:E1-E11.
PUBMED | CROSSREF

8. Tang W, Wu Y, Smales RJ. Identifying and reducing risks for potential fractures in endodontically treated teeth. J Endod 2010;36:609-617.
PUBMED | CROSSREF

9. de Andrade GS, Tribst JP, Dal Piva AO, Bottino MA, Borges AL, Valandro LF, Özcan M. A study on stress distribution to cement layer and root dentin for post and cores made of CAD/CAM materials with different elasticity modulus in the absence of ferrule. J Clin Exp Dent 2019;11:e1-e8.
PUBMED

10. Dal Piva AM, Tribst JP, Borges AL, Bottino MA, Souza RO. Do mechanical advantages exist in relining fiber posts with composite prior to its cementation? J Adhes Dent 2018;20:511-518.
PUBMED

11. da Fonseca GF, de Andrade GS, Dal Piva AM, Tribst JP, Borges AL. Computer-aided design finite element modeling of different approaches to rehabilitate endodontically treated teeth. J Indian Prosthodont Soc 2018;18:329-335.
PUBMED | CROSSREF

12. Barcellos RR, Correia DP, Farina AP, Mesquita MF, Ferraz CC, Cecchin D. Fracture resistance of endodontically treated teeth restored with intra-radicular post: the effects of post system and dentine thickness. J Biomech 2013;46:2572-2577.
PUBMED | CROSSREF

13. Ausiello P, Apicella A, Davidson CL, Rengo S. 3D-finite element analyses of cusp movements in a human upper premolar, restored with adhesive resin-based composites. J Biomech 2001;34:1269-1277.
PUBMED | CROSSREF

14. Srivastava B, Devi NN, Gupta N, Singh R. Comparative evaluation of various temperature changes on stress distribution in class II mesial-occlusal-distal preparation restored with different restorative materials: a finite element analysis. Int J Clin Pediatr Dent 2018;11:167-170.
PUBMED | CROSSREF

15. Lee MR, Cho BH, Son HH, Um CM, Lee IB. Influence of cavity dimension and restoration methods on the cusp deflection of premolars in composite restoration. Dent Mater 2007;23:288-295.
PUBMED | CROSSREF

16. Nothdurft FP, Seidel E, Gebhart F, Naumann M, Motter PJ, Pospiech PR. The fracture behavior of premolar teeth with class II cavities restored by both direct composite restorations and endodontic post systems. J Dent 2008;36:444-449.
PUBMED | CROSSREF

17. Nothdurft FP, Seidel E, Gebhart F, Naumann M, Motter PJ, Pospiech PR. Influence of endodontic posts on the fracture behavior of crowned premolars with Class II cavities. J Dent 2008;36:287-293.
PUBMED | CROSSREF

18. Hofmann N, Just N, Haller B, Hugo B, Klaiber B. The effect of glass ionomer cement or composite resin bases on restoration of cuspal stiffness of endodontically treated premolars in vitro. Clin Oral Investig 1998;2:77-83.
PUBMED | CROSSREF

19. Ausiello PP, Ciaramella S, Lanzotti A, Ventre M, Borges AL, Tribst JP, Dal Piva A, Garcia-Godoy F. Mechanical behavior of Class I cavities restored by different material combinations under loading and polymerization shrinkage stress. A 3D-FEA study. Am J Dent 2019;32:55-60.
PUBMED

20. Costa VL, Tribst JP, Uemura ES, de Morais DC, Borges AL. Influence of thickness and incisal extension of indirect veneers on the biomechanical behavior of maxillary canine teeth. Restor Dent Endod 2018;43:e48.
PUBMED | CROSSREF

21. Sousa MP, Tribst JP, de Oliveira Dal Piva AM, Borges AL, de Oliveira S, da Cruz PC. Capacity to maintain placement torque at removal, single load-to-failure, and stress concentration of straight and angled abutments. Int J Periodontics Restorative Dent 2019;39:213-218.
PUBMED | CROSSREF

22. Costa VL, Tribst JP, Borges AL. Influence of the occlusal contacts in formation of Abfraction Lesions in the upper premolar. Braz Dent Sci 2017;20:115-123.
CROSSREF

23. Tribst JP, Dal Piva AM, Borges AL. Biomechanical behavior of indirect composite materials: a 3D-FEA study. Braz Dent Sci 2017;20:52-57.
CROSSREF

24. Ausiello P, Ciaramella S, Martorelli M, Lanzotti A, Gloria A, Watts DC. CAD-FE modeling and analysis of class II restorations incorporating resin-composite, glass ionomer and glass ceramic materials. Dent Mater 2017;33:1456-1465.
PUBMED | CROSSREF

25. Monteiro JB, Dal Piva AM, Tribst JP, Borges AL, Tango RN. The effect of resection angle on stress distribution after root-end surgery. Iran Endod J 2018;13:188-194.
PUBMED

26. Gloria A, Maietta S, Richetta M, Ausiello P, Martorelli M. Metal posts and the effect of material–shape combination on the mechanical behavior of endodontically treated anterior teeth. Metals (Basel) 2019;9:125.
CROSSREF

27. Menezes-Silva R, Velasco SR, Bastos RS, Molina G, Honório HM, Frencken JE, Navarro MF. Randomized clinical trial of class II restoration in permanent teeth comparing ART with composite resin after 12 months. Clin Oral Investig 2019 Jan 6. doi: 10.1007/s00784-018-2787-1. [Epub ahead of print].
PUBMED | CROSSREF

28. Kim ME, Park SH. Comparison of premolar cuspal deflection in bulk or in incremental composite restoration methods. Oper Dent 2011;36:326-334.
PUBMED | CROSSREF

29. Braga S, Oliveira L, Rodrigues RB, Bicalho AA, Novais VR, Armstrong S, Soares CJ. The effects of cavity preparation and composite resin on bond strength and stress distribution using the microtensile bond test. Oper Dent 2018;43:81-89.
PUBMED | CROSSREF

30. Santos SS, Delbem AC, Moraes JC, Souza JA, Oliveira LQ, Pedrini D. Resin-modified glass ionomer containing calcium glycerophosphate: physico-mechanical properties and enamel demineralization. J Appl Oral Sci 2019;27:e20180188.
PUBMED | CROSSREF

31. Jones G, Taylor G. Glass ionomer or composite resin for primary molars. Evid Based Dent 2018;19:86-87.
PUBMED | CROSSREF

32. Wang X, Shu X, Zhang Y, Yang B, Jian Y, Zhao K. Evaluation of fiber posts vs metal posts for restoring severely damaged endodontically treated teeth: a systematic review and meta-analysis. Quintessence Int 2019;50:8-20.
PUBMED

33. Elsharkasi MM, Platt JA, Cook NB, Yassen GH, Matis BA. Cuspal deflection in premolar teeth restored with bulk-fill resin-based composite materials. Oper Dent 2018;43:E1-E9.
PUBMED | CROSSREF

34. Yarmohamadi E, Jahromi PR, Akbarzadeh M. Comparison of cuspal deflection and microleakage of premolar teeth restored with three restorative materials. J Contemp Dent Pract 2018;19:684-689.
PUBMED | CROSSREF

35. Tribst JP, Kohn BM, de Oliveira Dal Piva AM, Spinola MS, Borges AL, Andreatta Filho OD. Influence of restoration thickness on the stress distribution of ultrathin ceramic onlay rehabilitating canine guidance: a 3D-finite element analysis. Minerva Stomatol 2019;68:126-131.
PUBMED | CROSSREF

36. Heikkinen TT, Matinlinna JP, Vallittu PK, Lassila LV. Long term water storage deteriorates bonding of composite resin to alumina and zirconia short communication. Open Dent J 2013;7:123-125.
PUBMED | CROSSREF

37. Ausiello P, Ciaramella S, Fabianelli A, Gloria A, Martorelli M, Lanzotti A, Watts DC. Mechanical behavior of bulk direct composite versus block composite and lithium disilicate indirect Class II restorations by CAD-FEM modeling. Dent Mater 2017;33:690-701.
PUBMED | CROSSREF