

Computer-aided design finite element modeling of different approaches to rehabilitate endodontically treated teeth

Gabriela Fernandes da Fonseca, Guilherme Schmitt de Andrade, Amanda Maria de Oliveira Dal Piva, João Paulo Mendes Tribst, Alexandre Luiz Souto Borges

Dental Materials and Prosthodontics, São Paulo State University (Unesp), Institute of Science and Technology, São José dos Campos/SP, Brazil

Abstract

Background: Carious lesions and dental fractures cause weakening in the dental structure. In these situations, endodontic treatment and prosthetic rehabilitation using an intraradicular post are indicated. However, the postspace preparation of the root canal further weakens the dental remnant, especially if there is no ferrule present. This study aimed to evaluate the stress distribution in endodontically treated upper premolars treated with different rehabilitation approaches.

Materials and Methods: An endodontically treated first upper premolar was modeled for finite element analysis. Three different approaches were carried out on this model: rehabilitation with fiberglass post (FCP), endocrown (ECW), or buildup. The models were exported in STEP format to the analysis software (ANSYS 17.2, ANSYS Inc., Houston, TX, USA). The solids were considered isotropic, homogeneous, and linearly elastic. A mechanical, structural static analysis was used as the criterion of maximum principal stress to show regions under tensile stress to evaluate the stress distribution in the restoration, cementation line, and root. A load of 400 N (90°) was applied to the lingual triangular ridge. The values of maximum principal stress in MPa were evaluated through colorimetric graphs.

Results: Similar stress concentration was observed for all groups. However, the ECW group presented higher values in the restoration/cement interface and root dentin.

Conclusions: All the treatment modalities had favorable mechanical behavior to support the masticatory loads; nevertheless, the ECW group presented a higher risk of detachment failure.

Keywords: Dental prosthesis, dental restoration, finite element analysis, permanent crowns, post and core technique

Address for correspondence: Dr. Amanda Maria de Oliveira Dal Piva, Av Engenheiro Francisco José Longo, 777, Jardim São Dimas, São José Dos Campos, São Paulo, Brazil.

E-mail: amanda.piva@ict.unesp.br

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INTRODUCTION

The weakening of the dental structure due to tissue loss caused by caries or dental fractures hinders decision-making and the prognosis of the restorative treatment.^[1] Complete

all-ceramic crowns may be an option for prosthetic treatment in such cases.^[2] However, in situations in which endodontic treatment is required, and the tooth does not have adequate ferrule to provide a greater surface area for

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bonding, an intraradicular post can be indicated to retain the restoration.^[3,4]

One of the most important factors in the fracture resistance of endodontically treated teeth restored with full crowns is the amount of coronal dentin remnant after postpreparation.^[5] The presence of a suitable ferrule effect may reduce the stress concentration within the tooth structure, thus decreasing the stress on the post and also reducing the stresses between cement/post/core.^[4] Unfortunately, it is not always possible to obtain a remnant with a minimum height of 2 mm due to the presence of extensive caries or coronary fracture.^[6]

The mechanical properties of the material to be used as post and core have a crucial influence on the biomechanical behavior of the dental remnant and prosthetic restoration, influencing the treatment longevity.^[7] Due to the variety of post and core materials and techniques,^[8] the literature is not yet concise about the most appropriate treatment.^[9] Among the most commonly used methods, cast post-and-core and prefabricated fiberglass posts with composite buildup (BUP) are still available.^[7] Prefabricated fiberglass posts have the advantage of a dentin-like elastic modulus,^[10] allowing a more homogeneous distribution of masticatory loads, reducing the root fracture risk.^[11]

With the advent of bonding procedures, the approaches that depend on macro retentions have been questioned; for example, in the situation of using an intraradicular post that requires additional wear of the healthy dental structure for the postinstallation.^[9,12,13] Thus, the possibility of using monolithic restorations without the presence of a post has emerged as a promising alternative^[14-17] with a success rate of 94%–100%.^[15] Endocrown (ECW) restorations allow for a more conservative approach^[18] than conventional complete crown preparations. In this technique, the operative stages are reduced, enabling a simpler, and less costly treatment for the patient.^[15,19] However, this approach requires the presence of healthy cervical enamel so that adhesive procedures can be more effective.^[19]

The question about the need for an intraradicular post to retain cores is not recent.^[20] In 1984,^[21] a success rate of 87% was observed for restored premolars without post installation. Regarding this, an alternative approach of using a BUP with a dentin-like elastic modulus (for example, composite resin) and complete all-ceramic crowns both bonded to the dental structure has been studied.^[9,12,22] Enamel and dentin play important roles in the biomechanical behavior of natural teeth.^[2,23] Thus, the difference between the elastic moduli of these tissues has

great significance in the maintenance of dental integrity against the functional and parafunctional mechanical stresses.^[24] Within the biomimetic concept, it is important that the restorations which reestablish the compromised function mimic these structures.

The aim of this study was to evaluate the stress distribution in endodontically treated maxillary premolars with different rehabilitation approaches: (1) computer-aided design (CAD)/computer-aided manufacturing composite resin BUP without glass fiber reinforced post + all-ceramic crown; (2) a composite resin BUP with glass fiber reinforced post + all-ceramic crown; or (3) an all-ceramic ECW. The null hypothesis was that the stress distribution would be similar in all approaches.

MATERIALS AND METHODS

The three-dimensional (3D) finite element (FE) method was used to evaluate the mechanical behavior and stress distribution in endodontically treated maxillary premolars with three different prosthetic treatment approaches. Initially, a 3D mathematical model of a previously validated biradicular upper premolar^[25] was selected, and the coronary remnant maintained at 1.5-mm height from the cement-enamel junction. This 3D model was then modified to simulate a tooth with endodontic treatment containing a tapered root canal preparation. The tooth was triplicated, and each dental element received a different restoration modality [Figure 1]:

- Fiberglass post (FCP): Model containing fiberglass post, nanoparticulate composite resin BUP and complete crown in lithium disilicate ceramic, maintaining a 1.5 mm high ferrule
- ECW: Model containing a ceramic ECW restoration of lithium disilicate with anchorage in the pulp chamber (2 mm high)
- BUP: Model containing composite resin BUP without post restored with full ceramic crown of lithium disilicate, maintaining a 1.5 mm high ferrule.

For groups, FCP e BUP, a preparation height of 5.5 mm, chamfer finish line at the cemento-enamel junction, 1.5-mm buccal reduction, 1.0-mm interproximal and lingual reductions, and 2-mm incisal reduction was performed. For ECW group, the dental remnant and the floor of the pulp chamber were planned [Figure 1] with defined margins at 1.5 mm supragingivally.^[18] The restorations were designed using rhinoceros CAD software (version 5.0SR8 McNeil, North America, Seattle, WA, USA). A 0.2 mm polyether layer around the root simulated the periodontium, and the full extension of root canal was filled with gutta-percha. For

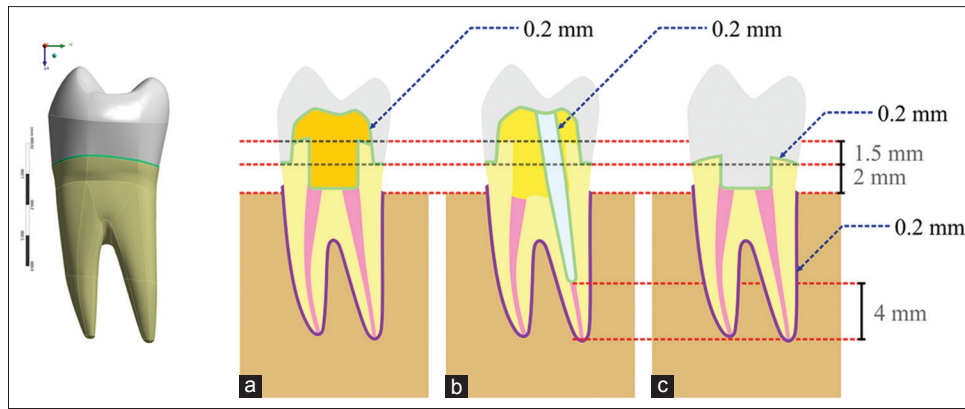


Figure 1: Schematic illustration of different approaches. (a) FCP, (b) endocrown, and (c) build-up groups

the FCP approach, gutta-percha was removed maintaining 4 mm in the apex region of the palatine root following the root canal preparation protocol for this type of restoration. The cementation lines were standardized with a 0.2 mm uniform film of resin cement. The alveolar bone was simulated by a polyurethane cylinder, 2 mm below the margin of the restorations.

The models were then imported into computer-aided engineering software (ANSYS 17.2, ANSYS Inc., Houston, TX, USA). A static structural, mechanical analysis was used with the maximum principal stress (in MPa) criteria which show stress regions to evaluate the stress distribution in the restoration, cement line, and root dentin.^[18] Tensile is the main failure criteria of brittle materials.^[26,27] During the analysis, all interfaces were considered perfectly bonded and the materials considered isotropic, homogeneous, and linearly elastic. The mechanical properties (elastic modulus [E] and Poisson ratio [V]) for each evaluated material/structure were determined from the literature [Table 1].^[28-31]

The subdivision of the 3D complex geometry into FEs was made using a mesh with a mean of 73,368 tetrahedral elements and 134,279 nodes obtained after applying the convergence test (10%). The system was fixed in the base of the polyurethane cylinder. A load of 400 N (90°) was applied to the lingual triangular ridge. Maximum principal stress values were evaluated through colorimetric graphs.

RESULTS

The stress distribution in the resin cement line showed higher magnitude in the ECW group, and it was not possible to observe a difference between BUP and FCP [Figure 2a]. In the root dentin [Figure 2b], the stress generated in the ECW group presents a displacement region under the palatal cusp due to larger tensile zones

Table 1: Mechanical properties of the materials and structures used involved in the analyzed system

Material/structure	Elastic modulus (GPa)	Poisson ratio (V)
Dentin ^[25]	18.6	0.32
Polyether ^[26]	0.05	0.45
Polyurethane resin ^[27]	3.6	0.30
CAD/CAM resin composite ^[28]	16.3	0.45
resin composite ^[29]	16.0	0.30
Dual resin cement ^[28,30]	5.1	0.27
Lithium disilicate ^[31]	95.0	0.30
Gutta-percha ^[32]	0.00069	0.28
Fiber post ^[33]	49.0	0.28

CAD/CAM: Computer-aided design/computer-aided manufacturing

than in the BUP and FCP groups. For the restoration itself, the ECW group stands out due to a higher restoration volume which benefits the stress distribution, presenting less stressed areas than BUP and FCP [Figure 2c and d]. To better demonstrate the difference between the groups, 30 stress peaks were selected in the analyzed structures and plotted in linear distribution graphs in ascending order [Figure 3]. In this way, it is possible to observe that there is no difference between FCP and BUP. Although ECW presents less possibility of restoration fracture, it shows greater restoration displacement facility.

DISCUSSION

This study evaluated the stress distribution in endodontically treated maxillary premolars with three different rehabilitation approaches. The hypothesis of this study was rejected since there were differences in the stress distribution according to the evaluated restorative approaches. Considering the stress distribution in dentin, there were differences between the groups in the cervical region. However, the BUP approach did not dramatically increase the stress concentration in dentin, so that the use of a BUP filling the pulp chamber proved to be a good option.^[9,13]

With the development and success of metal-free restorations and adhesive systems, it was observed that the

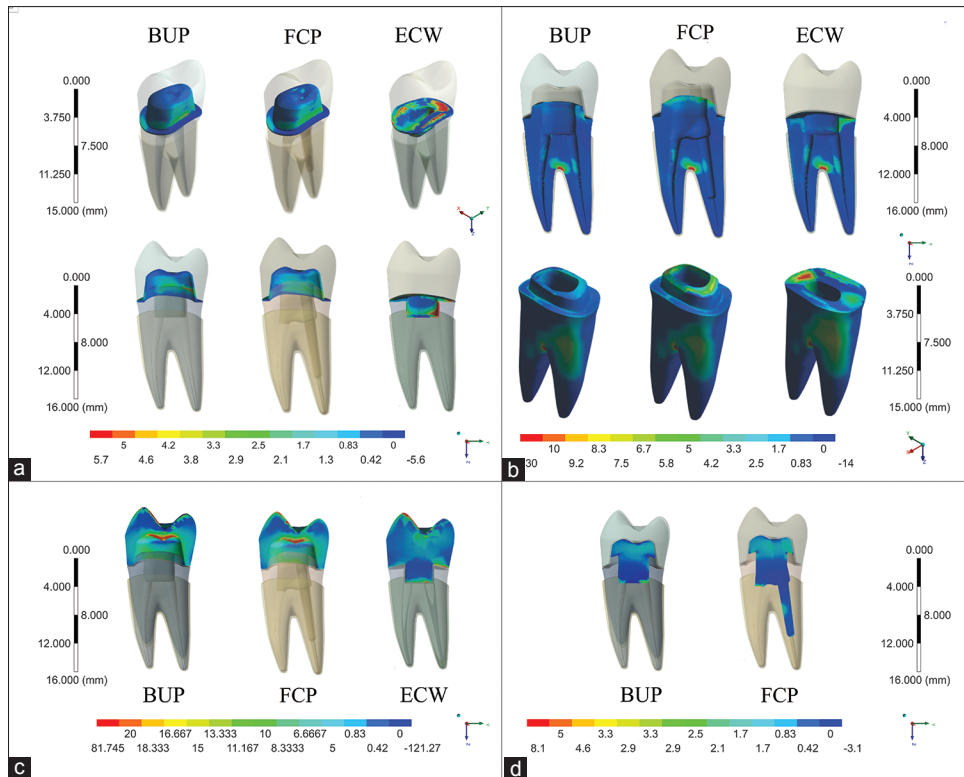


Figure 2: Maximum principal stress values in the models. (a) Cementing line of the restoration, (b) dentin, (c) full-ceramic crown according to three groups BUP, FCP and ECW, (d) core according to the groups BUP and FCP

use of a post in the root canal is not essential for retaining a core.^[9,32] New studies have been carried out with the aim of reassessing the guidelines for using root canal posts not only for the type and material but also the need for their installation. Zicari *et al.*^[33] found that the presence of 2 mm of ferrule does not require the use of posts. The authors also observed that their installation reduced the teeth fracture resistance. In this study, the ferrule height used was 1.5 mm; however, there was no significant difference in the stress distribution in dentin in comparing the groups that were restored with monolithic crowns.

In a similar study,^[34] the use of posts did not increase the fracture resistance of teeth. However, the failure mode proved to be catastrophic when a retainer was not used. ECWs are a good option for the treatment of endodontically treated teeth with little remnant coronary structure,^[18] with the occurrence of secondary caries being the most frequent associated type of failure.^[15] Although stress concentration in dentin was higher for the ECW group, the magnitude of the calculated tensile stress was relatively low, so that under axial load in a patient with physiological occlusion, this value would not approximate the minimum flexural strength of the dentin (171 MPa).^[35] Thus, ECWs appear to be a good treatment option.

At the cement-dentin interface, Maximum Principal Stress values were low in relation to the stress generated in the restoration for all groups, with the highest value being found in the ECW group. However, this stress peak is not close to the bond strength between resin cement and dentin.^[36] In the literature, the indication for ECWs for premolars is still not as established as for molars.^[15,18] This is due to the smaller bonding area provided by the premolar pulp chamber. The proportion of crown height in relation to tooth width increases the lever effect that is pronounced by the oblique force component, which is less present in molars.^[37]

The lithium disilicate is a versatile reinforced glass-ceramic, it can be indicated for monolithic crowns^[2] and also for ECW restorations.^[18] Thus, it was possible to simulate for all group, a coronary rehabilitation with the same material. The stress at the cement/restoration interface was higher for the ECW group, about one-third of the bond strength found in the literature between lithium disilicate ceramics and resin cement (17.1 MPa).^[36] Even when the bond strength is not exceeded, materials in the oral environment are subject to the presence of moisture and cyclic loading, thus aging/wear may lead to a decrease in the materials resistance.^[8] Most materials when subjected to stress for a certain period will fail due to the fatigue process. In brittle

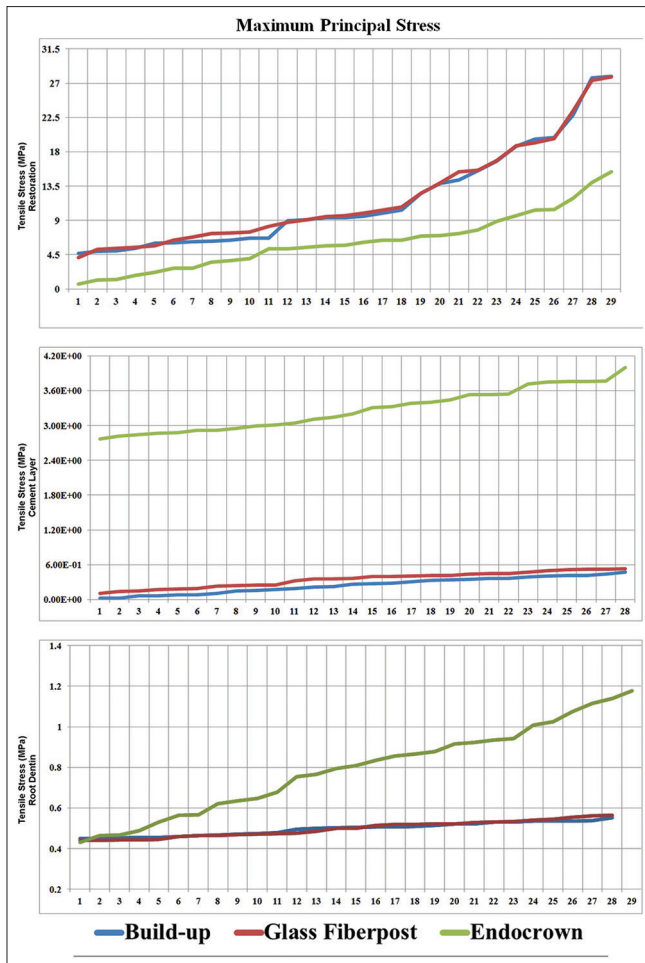


Figure 3: Line graphs of the highest 30 tensile stress peaks in maximum principal stress (MPa) results in the restoration, cement layer, and root dentin

materials, such as ceramics and resin composites, the process of crack enucleation occurs. In addition, crack propagation and the coalescence of defects cause material to fracture.^[38] The propagation of a critical defect in the adhesive interface could detach the restoration. Under fatigue, the restorations will fail with strength values lower than the maximum fracture strength values found in the literature. For the BUP group, even if the tensile stress was more than twice that found in the FCP group, this modality would suffer less risk of failure than the ECW group because it would not approximate to the bond strength value of the composite with resin cement (on average 30.7 MPa).^[39]

Considering the restoration and different from the other results, the ECW group showed the lowest tensile stresses values. This fact can be explained by the greater thickness of ceramic in this restoration. The greater the thickness of the restoration, the lower the material bending and consequently the greater the fracture resistance.^[15,40] For the groups with full crown, the highest stress concentration

occurred in the FCP group. This can be justified by the larger elastic modulus of the BUP of the BUP group and corroborating with previous studies,^[41,42] which assert that the greater elastic modulus of the substrate the larger the fracture resistance of all-ceramic restorations.

In a 2-year follow-up clinical study,^[43] the success rate for pulp premolars restored with full-crowns without posts was 70% compared to 82.5% with posts. In restored teeth without intraradicular post, the prevalent failure was crown detachment. In the present study, the difference in stress concentration between teeth restored with full-crowns using or not using a post was low, with better results when its installation was performed. Moreover, the success in treatment of endodontically treated teeth is related to the amount of dental remnant to support the crown (ferrule).^[44] The height of the evaluated remnant was the minimum recommended;^[45] however, little difference was found between the FCP and BUP groups, probably due to the axial load used.

Despite the success, treatment with intraradicular posts is more sensitive to the operative technique, so that the cases of root perforation^[46,47] are observed during post preparation. In addition, the fiber post insertion technique takes longer clinical time, uses more expensive materials and cannot be performed on curved roots.^[48] In this way, mechanical retention may be restricted to the pulp chamber either by filling it with BUP or by the restoration itself, as in cases of ECWs. Due to the results observed in the present study, non post BUPs are more beneficial for treatment longevity due to less possibility of adhesive failures and fractures. Nevertheless, in a situation where the interocclusal space is low enough to hinder the tooth preparation with retention characteristics, an ECW restoration could easily be used.

Fatigue failures in extensively compromised teeth occur by concentration of tensile forces rather than compression.^[46] Under axial loads, all models showed good behavior against the distribution of tensile stresses. Another factor to be observed is the difference of the elastic modulus between dentin, cement, and the restorative system, which may influence the stress distribution. With the advances in adhesive dentistry, questions about the use of intraradicular posts seem valid since the procedure for its installation increases the risk of root perforation in addition to weakening the dental element. The ECW restoration is a conservative alternative to restore endodontically treated teeth.^[18] Considering the promising results found herein, future clinical trials should be developed to prove it is suitable in the long-term.

CONCLUSION

All treatment modalities for endodontically treated premolars presented mechanical behavior adequate to withstand the masticatory loads. However, the ECW group concentrated more tensile stress at the cementation line and in dentine, which increases the risk of failure by detachment; thus, this modality should only be indicated in the impossibility of performing another approach. The BUP group behaved similarly to the FCP group, which suggests this modality as promising due to greater practicality and fewer operative risks.

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Conflicts of interest

There are no conflicts of interest.

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