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Stress Analysis of Direct Restoration Techniques for Endodontically Treated Maxillary Premolars

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BACKGROUND/AIMS

Direct restoration of root-filled premolars with cusp fractures is controversial. The aim of the present study was to compare two different direct restoration techniques with and without cuspal coverage for the restoration of root-filled two-rooted maxillary premolar without palatal cusp using three-dimensional (3D) finite element method (FEM).

MATERIAL and METHODS

Three-dimensional FEM mathematical models were used to evaluate how different restorative options changed stress distribution of the remaining dental tissues. These models were: (1) intact maxillary first premolar (control group), (2) coronal-radicular build-up restoration (CRBR) with buccal cusp coverage (BCC), (3) CRBR without BCC, (4) post-retained direct restoration (PDR) with BCC, and (5) PDR without BCC. A 100 N occlusal load was applied to calculate stress distributions. The Algor Fempro program was used for FEM analysis. von Mises stress distributions and values on the remaining enamel, dentin, and restorative materials were evaluated.

RESULTS

Regarding stresses that occurred in the enamel, models with BCC transferred lower stress than models without BCC. The lowest stress value in the enamel was observed in the control group with 24.86 MPa. The stress values of the control group, PDR, and CRBR in the dentin were 9.93, 9.68, and 9.32 MPa, respectively.

CONCLUSION

The present study found out that direct cuspal coverage with resin composites appeared to be a reliable method in restoring maxillary first premolar with missing palatal cusp. Reinforcing the restoration with either post- or intraradicular extensions was both protective in the case of dentin.

Keywords: Finite element analysis, premolar, composite resins

INTRODUCTION

The quality of post-endodontic restorations is as important as endodontic therapy for the prognosis of endodontically treated teeth (ETT) (1). In modern dentistry, the approaches related with the least invasive and the most tissue-preserving techniques are recommended to be followed for the long-term survival of ETT. In this context, composite resins with improvements on the physical and mechanical properties become suitable materials for the restoration of these teeth with extensive cavities (2). With the development of fiber-reinforced composite (FRC) technology, practitioners found a new perspective to solve problems with unique and modern solutions (1). When the fiber-reinforced post systems developed, they were offered as good esthetic alternatives to metal posts with the elastic modulus close to that of dentin, resulting in lower stress transmission to the root and decreasing the risk of root fracture (1, 3). Then, the short FRC (everX Posterior; GC, Tokyo, Japan) has been developed to mimic the stress-absorbing properties of dentin and dentin-enamel junction and to be used in high stress-bearing areas (2).

Restorative treatment options of ETT that is more brittle than vital teeth should be carefully considered (4). Traditionally, these teeth could be reinforced with pins, cast restorations, and post placement and full-crown coverage. However, these materials and methods weaken the remaining tooth tissue and led to fracture of the root and/or crown (5). Extracoronal

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(4) and intracoronal methods with adhesive technology have been suggested for the reinforcement of weak posterior ETT (5).

Finite element analysis is a method that has its own advantages, such as repeatability, high accuracy, and efficiency. It also allows measurement of stress values and distributions that cannot be measured due to the actual size of the teeth at any desired point and interface. It provides reference data in determining the durability of the restorations planned to be performed (6).

There have been many finite element studies about restoration of ETT with direct methods (1, 2, 7, 8). This three-dimensional (3D) finite element study aimed to compare stress distributions of two different direct restoration designs with support from root canals with and without cuspal coverage for a maxillary first premolar tooth without functional cusp.

MATERIAL and METHODS

The Rhinoceros 4.0 (McNeel North America, Seattle, WA, USA) 3D modeling software, VRMesh Studio (VirtualGrid Inc., Bellevue, WA, USA) meshing software, and Algor Fempro (ALGOR Inc., Pittsburgh, PA, USA) analysis program conducted the 3D finite element study. A plaster model was scanned using SmartOptics (smart optics Sensortechnik GmbH, Bochum, Germany) to obtain a 3D finite element premolar model. The morphology of the two-rooted maxillary first premolar was generated using data from Wheeler's atlas (9). The surrounding structures were modeled as cortical bone (1.5 mm), trabecular bone (rest of the bone model), periodontal ligament (0.2 mm), and lamina dura (0.2 mm). Intact two-rooted maxillary first premolar was modeled as the control group. Four finite element mathematical models were created with mesial-occlusal-distal-palatal (MODP) cavity with a 2 mm intact tooth structure above the cement-enamel junction in two designs with and without a 2 mm buccal cusp reduction. One model was used for each group in the present study. Figure 1 shows the image of intact tooth and MODP cavity design with and without buccal cusp coverage (BCC). Each cavity design was restored by either coronal-radicular build-up restoration (CRBR) or post-retained direct restoration (PDR). The restoration models were as follows: (1) CRBR with BCC, (2) CRBR without BCC, (3) PDR with BCC, and (4) PDR without BCC.

TABLE 1. Elastic moduli, Poisson's ratios, and references of the dental tissues and materials (1, 2, 7, 10-13)

	Young's modulus (MPa)	Poisson's ratio (υ)	References
Enamel	84,100	0.33	(10)
Dentin	18,600	0.32	(7)
Cortical bone	10,700	0.30	(2)
Trabecular bone	1370	0.30	(1)
Periodontal ligament	68.9	0.45	(12)
Pulp	0.98	0.45	(13)
G-aenial Posterior	8200	0.24	(2)
everX Posterior	12,300	0.24	(2)
Post	40,000	0.26	(1)
Gutta-percha	0.69	0.45	(13)

TABLE 2. Number of elements and nodes of models

Models	Elements	Nodes
Intact tooth	281,394	52,732
CRBR with BCC	299,768	55,977
CRBR without BCC	323,881	59,608
PDR with BCC	317,411	60,112
PDR without BCC	315,834	59,625

CRBR: coronal-radicular build-up restoration; BCC: buccal cusp coverage; PDR: post-retained direct restoration.

In CRBR, intraradicular support was provided by 3 mm extensions into both canals, and everX Posterior was used for intraradicular extensions and dentin replacement, whereas G-aenial Posterior (GC Europe, Leuven, Belgium) was used for enamel replacement. In PDR, a glass fiber-reinforced post was inserted in the palatinal canal with a 5 mm apical gutta-percha, and everX Posterior and G-aenial Posterior were used as dentin and enamel replacements, respectively. A 10 μm adhesive thickness was modeled for bonding, whereas a 50 μm cement was modeled for luting procedure (10). All oral structures and materials were assumed to be linearly elastic, homogeneous, and isotropic. The corresponding mechanical properties are determined and shown in Table 1 according to literature data (1, 2, 7, 10-13).

For the generation of the models, bricks and tetrahedral solid elements were prepared whereby 281,394 elements and 52,732 nodes for intact tooth were used in the present study. Table 2 shows the number of elements and nodes of each model.

A 100 N occlusal load was applied to simulate foodstuff. Results were presented by considering maximum von Mises (VM) stress values in megapascals (MPa). The calculated numerical values were transformed into color graphics to better visualize mechanical stresses in the models. The remaining enamel, dentin, and restorative materials were separated from the rest of each model for the analysis of stress distributions. Stress values differing by <5% were considered to be similar.

RESULTS

Intact tooth had minimum VM stress values in the enamel (24.86 MPa). Models of restorations without BCC accumulated maximum VM stresses in the enamel followed by CRBR with BCC. PDR with BCC showed 31.23 MPa VM stress accumulation in the enamel (Figure 2a). Figure 2b shows the stress distribution patterns of the enamel. The cervical region is the most common area for all of the models where intense stress accumulation occurred.

In the case of dentin, intact tooth, models of CRBR, and models of PDR had VM stress values as 9.94 MPa, 9.32 MPa, and 9.68 MPa respectively. There had been no difference between the stress values of models of CRBR and PDR with and without BCC. Stress distribution patterns showed that the most intense VM stress accumulation occurred at the palatal side of the buccal apical root (Figure 3).

Restorative materials were evaluated into two parts. In the case of materials used as enamel replacement, there had been no

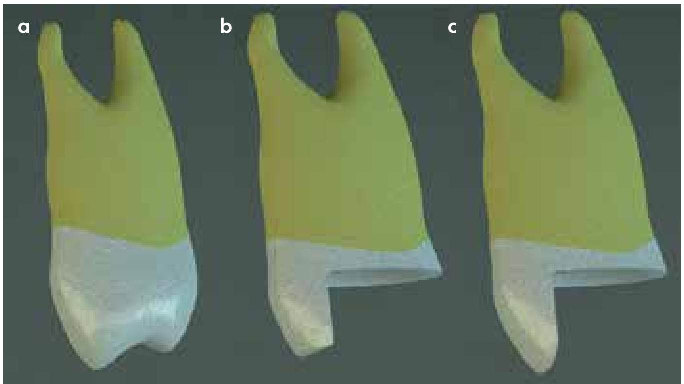

FIGURE 1. a, b. Images of intact tooth (a) and MODP cavity design (b) with and without buccal cusp reduction (c)
MODP: mesial-occlusal-distal-palatal.

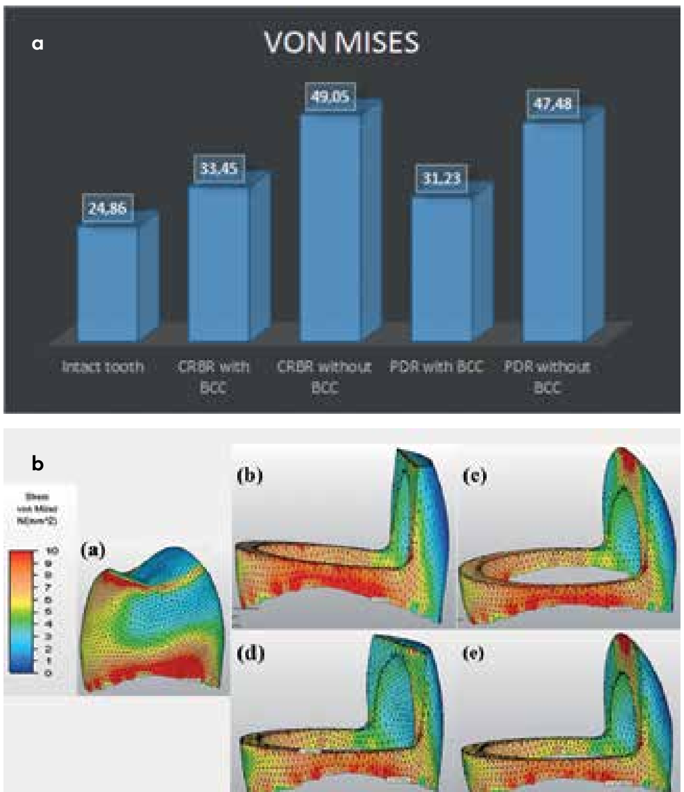

FIGURE 2. a, b. Stress values of models that occurred in the enamel (a). CRBR: coronal-radicular build-up restoration; BCC: buccal cusp coverage; PDR: post-retained direct restoration. Stress distribution patterns of the enamel (b). Intact tooth (a), CRBR with BCC (b), CRBR without BCC (c), PDR with BCC (d), and PDR without BCC (e).

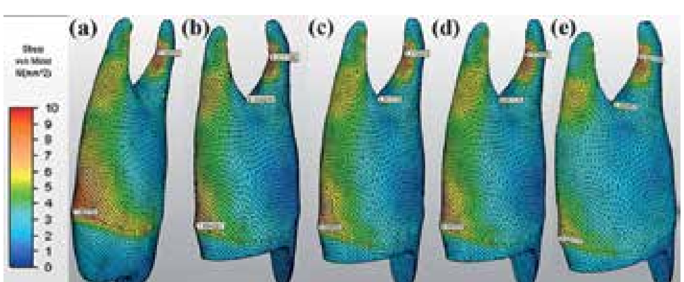

FIGURE 3. a-e. Stress distribution patterns that occurred in the dentin. Intact tooth (a), CRBR with BCC (b), CRBR without BCC (c), PDR with BCC (d), and PDR without BCC (e).

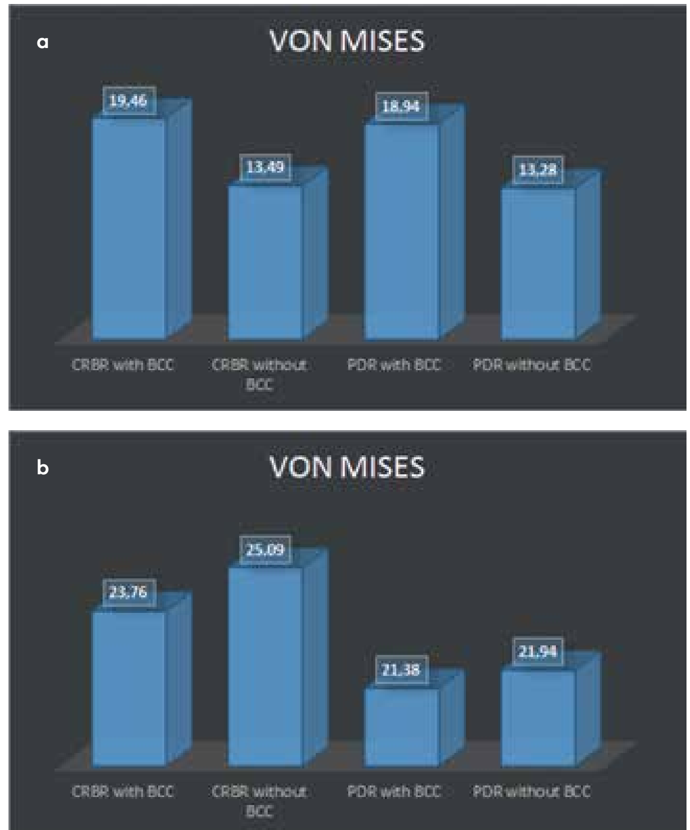

FIGURE 4. a, b. Stress values of restorative materials used as enamel replacement (a). Stress values of restorative materials used as core and substructure (b)
CRBR: coronal-radicular build-up restoration; BCC: buccal cusp coverage; PDR: post-retained direct restoration.

significant difference between models with BCC and without BCC (Figure 4a). The most intense stresses were accumulated on the occlusal surfaces where loading occurs. everX Posterior, used as a substructure material, showed more stress acumulation than G-aenial Posterior. CRBR without BCC accumulated more stress than CRBR with BCC; however, similar stress values were observed between the models of PDR (Figure 4b).

DISCUSSION

The unfavorable morphology and portions of maxillary premolars cause them to be named as the most susceptible posterior teeth to be fractured (7, 14, 15). The cusps of premolars are subjected to a set of forces that is formed by axial and shear loads that could be harmful, whereas the buccal and palatal cusps tend to seperate due to occlusal forces (5, 14, 16). In clinical practice, palatal cusp fractures are observed more than buccal cusp fractures (17). In the present study, the maxillary premolar tooth with MODP cavity design was modeled to simulate the worst case scenario for direct restoration methods.

The materials used for restorations of ETT have been amalgams, composite resins, and indirect materials. The materials should be able to replace loss of tooth tissues to ensure mechanical and functional properties, esthetics, and coronal seal (16). Since maxillary premolars are close to the anterior esthetic region, tooth-colored materials are preferable (14). Composite resins and ceramics are the most frequently used materials due to their esthetical requirements. Ceramic materials exhibit superior esthetic appearance, wear resistance, biocompatibility, stability in the oral cavity, high compression resistance, and a coefficient of thermal expansion similar to that of dental structure in comparison with those of composite resins. However, both materials favor reinforcement of the weakened tooth when combined with adhesive technology (15). Today, composite resins that are more affordable for patients are preferred for the restoration of large cavities including cusp replacement (2). The results of this finite element study showed that intraradicularly supported restoration of endodontically treated maxillary first premolar with composite resins was a safe option for dentin, while it may not be the best choice for enamel.

Restoration of ETT has been a challenging procedure for many years (13). Modern clinical approaches are based on the principles of minimally invasive dentistry that aims to protect sound tooth tissue (13, 16). In spite of using "aggresive macroretentive techniques", the new approaches accomplish adhesive technology. In the case of premolars, a post placement is recommended in order to protect the remaining dental structures (16). Furuya et al. (18) reported that restoring endodontically treated multiple root premolars with very little remaining tooth tissue with fiber posts is the most suitable option. However, the unsatisfying adhesion of fiber posts to luting cements or core materials led to criticism (3). Another method for restoring multiple root teeth is based on the technique by Nayyar et al. (19) with an amalgam dowel core. In this technique, gutta-percha is removed from root canals to a depth of 2-4 mm, and root canals are restored with amalgam (19). In our study, a 3 mm depth gutta-percha was removed from root canals, and a short FRC was used to fill the root canals and to form the core structure. According to the results of the comparison of the restoration models, it appeared that stress values on the enamel were similar except for the restorations having BCC, and stress values on the dentin were similar for all models. These findings are consistent with the study by Forster et al. (20) that fracture resistance of glass fiber-reinforced group and short FRC applied as substructure with a 2 mm depth in the root canal group were found to be similar. This result allows us to hypothesize that the selection of restoration type had an importance on the enamel when BCC was performed.

Cuspal coverage that conduces to less cuspal deflection and better protection of the remaining tooth tissue is recommended for the reinforcement of the tooth (15). An early finite element study reported that a minimum of 1.5 mm reduction is recommended for the significant decrease of stress values (17). A 2 mm reduction for cuspal coverage was found as a safe option for the restoration of ETT (21). The results of the present study pointed out that restoration models with BCC transferred less stress to the enamel than models without BCC, and a 2 mm cuspal coverage option significantly reinforced the remaining enamel tissue, whereas it has no effect on the remaining dentin.

EverX Posterior has been used for onlays, core build-up with posts, only core build-up, and direct layered posts (5, 21). In the present study, it was used as core material in PDR models and as substructure material in CRBR models. Garoushi et al. (22) reported that there is a linear direct relationship between the load-bearing capacity of the combination and the thickness of FRC when short random FRC is used under particulate filler composite as substructure. Thus, in the present study, the minimum thickness of G-aenial Posterior was modeled around FRC in order to allow the maximum amount of FRC placement.

Since the functional and parafunctional forces occurring within the mouth result in extremely complex structural responses by the oral tissues, rehabilitation of the oral environment is difficult. Finite element analysis is an appropriate theoretical tool for the evaluation of the resulting stresses (12). On the other hand, finite element analysis is dependent on theoretical assumptions and simplifications, such as material properties, geometry, and boundary conditions (23). Thus, finite element analysis ranks as a powerful tool if all assumptions and material properties coincide with the real situation (23).

In the present study, a 100 N occlusal load was used in order to stimulate foodstuff. Since the models were assumed to be linear, stress values for higher loads can be predictable. On the other hand, Erarslan et al. (1) emphasized that when standardization is ensured between the conditions, it is not precisely necessary to match the reality exactly.

In the literature, there were some studies (24, 25) that accepted luting cement thickness as a part of the dental tissues, and stresses were not evaluated for cement because it was too thin to adequately model in finite element simulation. Furthermore, in a study, no statistical differences in stresses were found between cement thickness varying from 50 to 150 μm on the remaining enamel and dentin for ceramic systems (26). For this reason, in the present study, the thin luting cement and adhesive layer thickness were neglected.

In order to eliminate the disadvantages of assumptions and ignorants and differences in values of parameters and obtain a better insight into the biomechanical aspects and estimation risk of the endodontically treated maxillary two-rooted first premolar, the behavior of different direct restoration designs and materials in the treatment of cuspal fracture of maxillary first premolars should be evaluated with laboratory experiments and long-term clinical trials.

Within the limitations of the present study, it can be concluded that direct cuspal coverage with resin composites transfers less stress to the enamel than restorations without cuspal reduction and appears to be a reliable extracoronal reinforcement method in restoring maxillary first premolar with missing palatal cusp. Reinforcing the restoration with either post or intraradicular extensions was both protective in the case of dentin. Intraradicularly supported direct restoration of endodontically treated maxillary first premolar with resin composites appears to be a safe option for dentin, while it may not be the best choice for enamel.

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Conflict of Interest: The authors have no conflicts of interest to declare.

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