

EFFECT OF LOADING DIRECTION, CROWN COVERAGE, AND ADJACENT TEETH ON STRESSES IN POST-RESTORED PREMOLARS

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The aims of this finite elemental stress analysis (FEA) study were to evaluate the effects of loading direction, crown coverage, and adjacent teeth on stress distribution in premolar tooth models restored using fiber-post restoration. Three 3D premolar tooth FEA models were created as follows: Model 1: sound tooth; Model 2: tooth-model including root filling, fiber-post and composite resin restoration; Model 3: tooth-model including root filling, fiber-post, composite resin core and ceramic crown. Three more models were created using Models 1, 2, and 3 with adjacent teeth (Models 4, 5, and 6). The Cosmoworks structural-analysis program was used for the stress analysis, which was based on the von Mises criterion. High stress concentrations were observed at the mesial side of the sound tooth models while the stresses were localized at both sides in the others. Loading with a nonzero inclination angle caused higher stress concentrations within the tooth structure than is other models with the normal/vertical loading. The presence of adjacent teeth strongly influenced stress distributions and concentrations in Models 4, 5, and 6, reducing the stress level. Meanwhile, crown restoration did not change the stress patterns.

Keywords: finite element analysis, proximal contacts, stress distributions, dental arch.

Introduction. There are several in-vitro studies concerning the structure and placement design of post materials. Due to differences in experimental designs, however, these studies cannot be equated, the results often conflict, and the extent, to which they can be generalized, is controversial [1]. Placement of a dowel core to increase retention in the final restoration is important when a large amount of the tooth's coronal structure has been lost or when only the root remains. The core provides a form of retention and resistance for restoration, and it provides retention between the post and the crown [2]. However, the increase in frequency of vertical root fracture which has not occurred in the vital tooth is strongly correlated with post placement [2]. The functional force applied to the restoration from the post material through the core creates significant tension in the supporting root structure [3]. In the past, the cast-post-and-core was a widely-used technique to save teeth that were seriously damaged. Later, several different post materials were used. In more recent years, the use of glass fiber posts has been widely accepted. The elastic modulus of fiber posts is similar to dentin, and studies have reported that this property allows better distribution of the chewing loads to the tooth and the root [4, 5]. Furthermore, glass fiber posts have several advantages such as better aesthetics and corrosion resistance [6]. Concerns about the preservation of weakened teeth in the dental arch, protection function, and aesthetics have led to the development of alternative fiber materials and the use of glass fiber posts in the root canal. This allows coronal restoration to be applied [7, 8].

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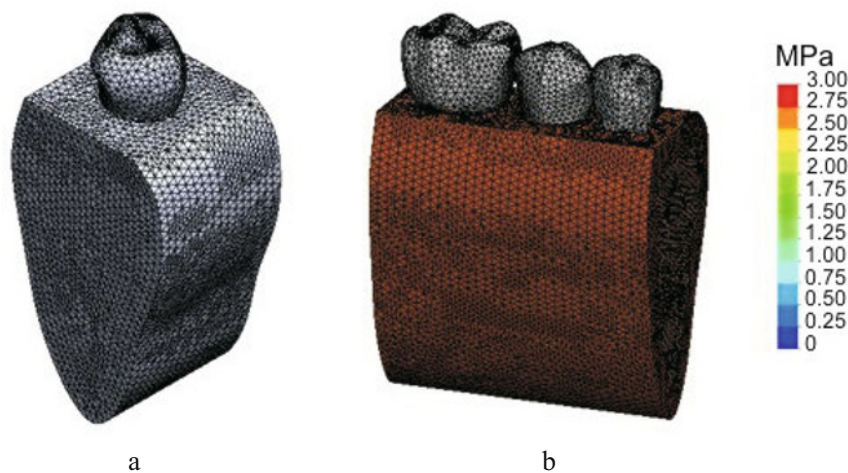


Fig. 1. Sound tooth model prepared for the study (a) and the second study model including adjacent teeth (b).

The belief that post materials placed on root canals increase the survival rate of teeth has lost its validity today [9, 10]. Many studies have shown that endodontic post materials cause a weakening of root structures and increase root fractures [11, 12]. A randomized controlled trial of post-endodontic restorations investigated the effects of endodontically-treated MOD cavity premolars on the survival rate of full crown or direct composite restorations [13]. The crown was restored with a carbon-fiber post and composite core. The failure rate was reported as 13% after a three-year follow-up. According to the results of this study, restorations using fiber-reinforced posts delivered a high survival rate [13].

Hard tissue loss due to caries lesions, previous restorations, or endodontic access cavities generally determines the load capacity of restorations [14, 15]. Furthermore, some retrospective clinical trials have shown a relationship between the prognosis of post-endodontic restorations and various factors, such as the number of proximal contacts [16], occlusal contacts [17, 18], tooth position in the dental arch [19, 20], crown placement [13, 21], or type of abutment [19, 22].

Teeth with endodontic treatments and extensive restorations combined with high occlusal loads and irregular contacts become more susceptible to fractures [23, 24]. Composite-resin restoration increases the fracture resistance of the premolars with endodontically-treated teeth [25]. The posterior teeth, especially the maxillary premolars, are more susceptible to fracture under occlusal load due to their anatomical structure [26]. Premolars become more sensitive to fracture when exposed to lateral forces during chewing and when their root structure is weak [27]. This sensitivity is further increased with occlusal loading in endodontically-treated premolars [28]. The use of different restorative techniques and materials could strengthen remaining dental structures.

A relationship between the prognosis of post-endodontic restorations and a variety of factors, such as the number of proximal contacts, occlusal contacts, tooth position in the dental arch, crown placement, and post placement, has been reported. The goal of this finite element analysis (FEA) study is to evaluate the effects of loading direction, crown coverage, and adjacent teeth on stress distribution in premolar tooth models restored using either fiber-post in combination with composite resin or a full ceramic crown.

1. Experimental. This study was carried out on a personal computer with a structural analysis program. The resulting outputs were transferred to a program to demonstrate stress values. First, a pseudo-three-dimensional mathematical model of a mandibular premolar tooth was generated using 265,502 nodes and 176,952 elements based on the anatomical model as described by Wheeler [29] (Model 1), as shown in Fig. 1a. This model was then modified to simulate the following study models:

Model 2: tooth-model including root filling, fiber-post, and composite-resin restoration (266,119 nodes and 177,156 elements).

Model 3: tooth-model including root filling, fiber-post, composite-resin core, and ceramic crown (266,119 nodes and 177,156 elements).

TABLE 1. Elastic Properties of the Structures [30, 31]

Material/structure	Elastic modulus E , MPa	Poisson's ratio ν
Enamel	41,000	0.31
Dentin	18,600	0.31
Pulp	3	0.45
Periodontal ligament	0.07	0.45
Composite resin	16,400	0.28
Gutta-percha	140	0.45
Cortical bone	13,700	0.30
Trabecular bone	1370	0.30
IPS e-max crown	95,000	0.24

TABLE 2. Elastic Properties of the Glass Fiber Post [32]

E_x , GPa	E_y , GPa	E_z , GPa	ν_{xy}	ν_{xz}	ν_{yz}	G_{xy} , GPa	G_{xz} , GPa	G_{yz} , GPa
37	9.5	9.5	0.27	0.34	0.27	3.1	3.5	3.1

TABLE 3. Maximum von Mises Stress Values (MPa) Recorded within the Dentin Structures

Adjacent teeth		With crown	Without crown
Natural tooth	Loading with an angle	3.6271	2.2485
	Vertical loading	1.8295	2.4009
Tooth with crown restoration	Loading with an angle	2.5986	2.8756
	Vertical loading	0.6373	1.5519
Tooth with composite restoration	Loading with an angle	1.6162	3.0827
	Vertical loading	0.8047	1.5494

Three more models were then prepared (Models 4, 5, and 6) using the initial models, and adjacent teeth were added to the above models (477,290–568,070 nodes and 321,815–378,663 elements, respectively), as shown in Fig. 1b.

In this study, the materials and structures used were assumed to be homogenous and isotropic, except for the fiber post. The elastic properties of the structures were obtained from the literature and manufacturers (Tables 1 and 2).

Every model was loaded from the functional cusp either vertically or with a 135° inclination angle by a 300 N load. The stress distributions or concentrations within the models were evaluated either with or without the presence of adjacent teeth under two different loading directions (vertical and with an inclination angle). The Cosmoworks structural analysis program produced by SolidWorks Corporation (Waltham, MA, USA) was used for analysis, and the results were presented using the von Mises criterion. The numerical results obtained were converted into color graphics to achieve a better visualization of the mechanical phenomena in the models. A standard view of a mid-sagittal section from each model was provided, and the stress distribution scale range was limited to 0–3+ MPa.

2. Results. The results were presented, according to the von Mises criterion [33, 34]. The numerical data obtained were represented as color graphics to better visualize the mechanical stresses in the models. Model-view sections were provided for each type of restoration, and all stress values were given in MPa.

Table 3 displays the maximum von Mises stress values recorded in the dentin structures with or without crowns, with or without adjacent teeth, under vertical or inclined loading (MPa).

Figures 2 and 3 display the stress distributions within the FEA models under different loading conditions. High-stress concentrations were observed at the mesial side of the sound tooth models, while the stresses were localized at both sides in the others (Fig. 2). Loading with an inclination angle caused higher stress concentrations

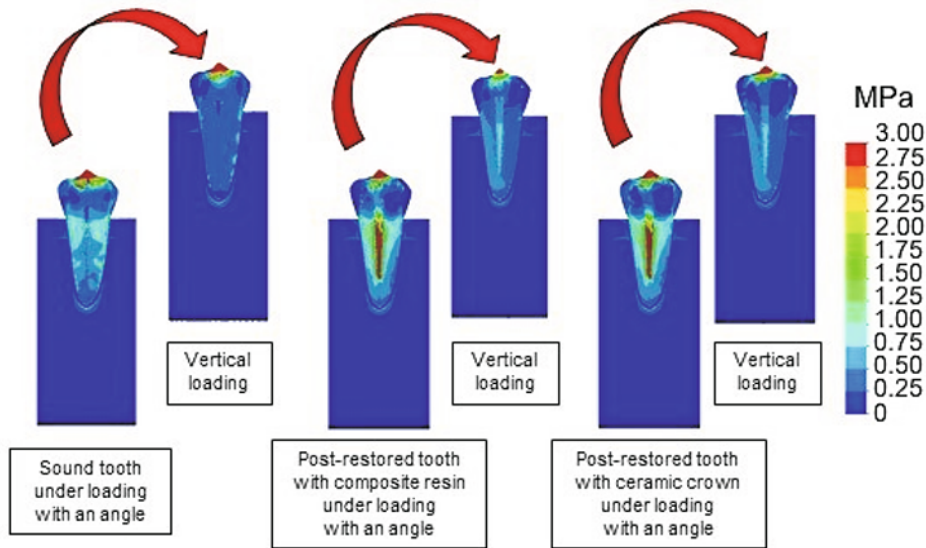


Fig. 2. Distribution of von Mises stresses (MPa) in individual tooth models.

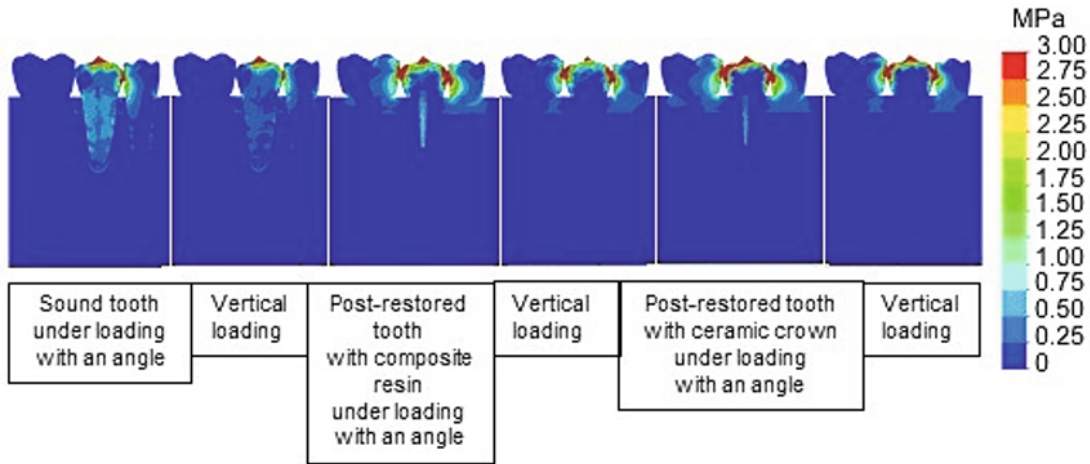


Fig. 3. Distribution of von Mises stresses (MPa) in the FEA models of adjacent teeth under various loading conditions, restorative materials, and teeth models.

within the tooth structure than that in other models, which were loaded vertically (Fig. 3). The presence of adjacent teeth affected the stress distributions and concentrations in sound, composite-resin, or crown-restored tooth models. Lower stresses were observed within the models in the presence of adjacent teeth. The presence of a crown restoration did not change the stress patterns.

3. Discussion. In this study, the effect of the load direction or adjacent teeth on stress distribution was evaluated via the FEA technique in premolar tooth models, in which different restorative techniques were applied. FEA techniques in dentistry, especially when using experimental methods, cannot provide sufficient information. However, they shed some light on real-world examples, in which images, observations, and calculations are impossible under different environments and conditions [35]. The FEA can accurately analyze and extract the required information from the computer, thereby reducing the number of test subjects required for real-world experiments and saving time and money. FEA has become a very important method for biomedical studies with advances in technology, computer systems, and software [36]. However, this technique requires several assumptions [37]. Since this technique is fundamentally an approximation, many details are idealized, simplified, or ignored [38]. The properties of materials, the model loading, and all the limiting conditions are assumed to be approximate

[37–39]. FEA results can be obtained by creating 2D or 3D realistic models. For FEA analysis, the 3D tooth geometry is created with several simply-shaped small elements. Stress strain is then evaluated for the single elements. Finally, it is calculated for the whole structure [37, 39, 40]. This is one of the limitations of FEA studies [41]. The results of this FEA study showed that loading with an angle caused higher stresses than vertical loading. In addition, this study showed that sound teeth implied lower stresses to the adjacent teeth, as compared to the post-restored teeth, either with composite cores or with ceramic crowns (Fig. 2). The results of this study are similar to those reported by Eskitaşcioğlu et al. [30] which compared the two different restorative techniques and stresses accumulated throughout the post-core system. Loney et al. [42] reported that different load angles can cause different fracture resistances ($110^\circ = 372.4 \text{ N} \pm 140.8 \text{ [SD]}$; $130^\circ = 597.6 \text{ N} \pm 138.5 \text{ [SD]}$; $150^\circ = 1274.3 \text{ N} \pm 429.9 \text{ [SD]}$). The applied force vector was observed to increase the fracture resistance as the teeth approached parallel to the long axes. In an FEA study, Benazzi et al. [43] showed that high-stress areas were formed on both the mesio-buccal side and the disto-buccal side of the lower second premolar teeth, but it did not affect the direction of the lingual region. Their results supported the idea that abfraction might be an important factor of tensile stresses in the buccal cervical region of the lower second premolar [43]. The forces in the posterior region are perpendicular, but are more angular in the premolar region. The restorations in this region should be done considering the destructive effect of the forces. Clinically, in the palatal and buccal areas of the restored maxillary premolar, high-strain areas may be associated with stress concentration as a result of occlusal load application [44]. Broderson et al. [44] described the disadvantages of ceramic restorations in the functional cusps and junction areas which can cause many stress points and fracture. The presence of palatal and buccal cusps with strong mesial and distal marginal edges protects the tooth structure and strengthens the integrity of the tooth [44]. In this study, composite restoration without cusp coverage and ceramic restoration (covering the cusps) were modeled and evaluated. The results showed that fewer stresses were forwarded toward the adjacent teeth in sound tooth models regardless of the angle of the load application, demonstrating the importance of saving the sound tooth structure. On the other hand, according to the results of the present study, if a fiber-post restoration is necessary, restoring the teeth with a ceramic restoration seems advantageous to save the adjacent teeth either with or without adjacent teeth (Fig. 3). Jagadish and Yogesh [45] suggested that the posterior resin composite is an important reinforcement material in the restoration of cusps, which is a substance loss. Sorrentino et al. [46] used feldspathic ceramics to create prosthetic crowns and stated that the mechanical properties of the more elastic composite materials did not significantly affect the stress and strain concentrations in the cores of maxillary central incisors. Belli et al. [47] reported that stress formation in the ceramic inlay model decreases from 1.03 to 0.82 MPa in the cavity base and cavity corners according to von Mises stress values. In the present study, ceramic crowns withstood the stresses within their bodies and forwarded less stresses to the core structure and post material under loading with an angle. Meanwhile, similar stresses were observed within the adjacent teeth when the roots were loaded vertically (Fig. 2). Stress accumulation through the post structure was denser in the composite restorations model under vertical loading (regardless of the presence of adjacent teeth) because of the materials' lower elastic modulus. In cases where the loss of dental structure is high and a fiber post is required, ceramic inlays appear to be a more-suitable form of restoration to support the tooth structure [48]. The loading conditions used in this study did not simulate real clinical conditions. The results might differ if real clinical loading conditions are simulated. Furthermore, other operating conditions, such as thermal change, humidity, patient habits, long-time moisture, temperature, pH variation via the intake of different foods, and exposure to many bacteria and enzymes, should be taken into account. Published reports have provided limited information about the loading conditions and adjacent teeth/sound teeth. Therefore, the results of this FEA study should be supported by further clinical studies.

Conclusions. Within the limitations of this FEA study the following results can be drawn:

1. Stress distributions change under different loading conditions. Oblique forces cause greater stress concentrations than vertical forces in the root structures.
2. The presence of adjacent teeth reduced stresses and stress concentrations, according to sound tooth models, as well as those restored with composite resin or crowns. Sound teeth implied lower stresses in the adjacent teeth when loaded axially.

3. Ceramic crown forwarded less stresses towards the root in the presence of adjacent teeth when fiber post was used.

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