INFLUENCE OF GEOMETRICAL CONFIGURATION OF THE CAVITY IN THE STRESS DISTRIBUTION OF RESTORED PREMOLARS WITH COMPOSITE RESIN

ABSTRACT

The aim of the study was to analyze and quantify the influence of isthmus extension and depth of MOD cavity of upper premolars on stress distribution by means of two-dimensional finite element method. Seven different homogeneous and elastic models were created:Model 1, intact teeth;Model 2, MOD cavity with 2 mm isthmus, 2 mm depth and composite resin restoration;Model 3, MOD cavity with 2 mm isthmus, 3 mm depth and composite resin restoration;Model 4, MOD cavity with 2 mm isthmus, 4 mm depth and composite resin restoration;Model 5, MOD cavity with 4 mm isthmus, 2 mm depth and composite resin restoration;Model 6, MOD cavity with 4 mm isthmus, 3 mm depth and composite resin restoration;Model 7, MOD cavity with 4 mm isthmus, 4 mm depth and composite resin restoration. Each model were submitted to a 100N load and analyzed. The greater the depth extent of MOD cavity, the greater the stress generated in the cavity pulp wall and in the cervical region of the tooth. Increasing the extension of the cavity isthmus intensifies stress in these regions and generates stress concentration on palatal and vestibular faces. Stress generated in the cavity pulp wall was predominantly tensile stress. The loss of marginal ridges influences the stress distribution pattern of upper premolars. It is indicated restorative techniques that allow greater conservation of tooth structure.

KEYWORDS

MOD cavity. Isthmus.Depth. Stress distribution.

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INTRODUCTION

The dental structure reduction is a modulator factor of the tooth's biomechanical behavior. There is a direct relationship between remaining tooth structure and greater longevity for the teeth[1].

Several studies have emphasized the importance of maintaining dental structure to preserve the strength of remaining tooth.

Generally, some clinical situations such as involvement by recurrent caries, excessive replacements of restorations and cavity preparation make the tooth susceptible to failure of the restoration, fracture and possible loss.[2, 3]

Since the early work of Vale[4] numerous authors have documented the effect of cavity preparationsby weakening the tooth. The drastic consequence of dental weakness is cusp fracture, and studies to evaluate the influence of structure loss and type of restorative material on tooth's biomechanical behavior prior to fracture are relevant because it is considered a common occurrence in clinics[5-9].

The incidence of these dental fractures in oral cavity is increased in upper premolars[7-9].

Maxillary premolar teeth have an unfavorable anatomic shape, crown volume and crown/root proportion, thus making them more susceptible to cusp fracture compared to other posterior teeth.[2, 10-12] Some studies have emphasized that cavity designs on premolars with class II mesio-occlusal-distal (MOD)have influence on stress distribution pattern.[13-16] It has been suggested that cusp thinning and deepening of cavity preparation may be the major factor in premolars fracture susceptibility.[2, 8]

The loss of marginal ridge integrity results in a significant decrease in fracture resistance.[4, 17, 18]Theproximal marginal ridges loss generates stress concentration and leads to greater cuspal deflection[10, 16, 19],consequently it can result in fracture of the tooth tissue after the final restoration.[10, 11]

In this aspect, premolars'MOD occlusal isthmus extension and cavity depth plays an important role and have been shown to be critical factors for stress concentration and, consequently, cusp fractures.[14, 20]

To minimizing the effect of tooth loss structure by cavity preparation restorative procedures are necessary to ensure function, aesthetics, ease sensitivity and prevent pulpal pathology. As alternatives to non-adhesive restorations have been proposed materials with mechanical properties that allow better stress distribuiton in both the restorative material and the remainning structure.

Composite resin can play this role due to the ability to adhere to the dental structures and maximum structure conservation during cavity preparations.[10, 21]

Finite Element Analyses (FEA) plays an essential role in investigations of clinical and therapeutical situations in different dental fields[22]. The use of virtual models and simulation can contribute to better performance of an investigation, reducing costs of in vitro and in vivo experiments and improving benefits. Thus, in adhesive and restorative dentistry there has arisen stronginterest in FEM with studies on different loading conditions at the tooth–restoration behavior[23-25], on tooth deformation[26], and on residual shrinkage stresses within dental composite cavities[27].

The aim of the study was to analyze and quantify the influence of isthmus extension and depth of MOD cavity of upper premolars on stress distribution by means of two-dimensional finite element method.

MATERIAL AND METHODS

A intact premolar was sectioned in its long axis in the bucco-lingual direction, with diamond saw blade (4 "x 0.12 x 0.12, Extec, Enfield, CT, USA) in precision cutting machine (Isomet 1000, Buehler, Lake Bluff, IL, USA) to enable viewing of each internal tooth structure and their respective dimensions. Based on an image of the sectioned tooth, the external outline and dimensions of each dental structure were performed by using computer aided design (CAE) software (Autodesk Mechanical Desktop 6; Autodesk Inc, San Rafael, Calif). CAD draw with cavities of different dimensions were createdfrom the intact tooth draw so that geometry and supporting structures of all models remained constant.

Seven different draws were created in this study(Figure 1):

- Model 1, intact teeth;
- Model 2, MOD cavity with 2 mm isthmus, 2 mm depth and composite resin restoration;
- Model 3, MOD cavity with 2 mm isthmus, 3 mm depth and composite resin restoration;
- Model 4, MOD cavity with 2 mm isthmus, 4 mm depth and composite resin restoration;
- Model 5, MOD cavity with 4 mm isthmus, 2 mm depth and composite resin restoration;
- Model 6, MOD cavity with 4 mm isthmus, 3 mm depth and composite resin restoration;
- Model 7, MOD cavity with 4 mm isthmus, 4 mm depth and composite resin restoration;

The data obtained were exported to CAE (Computer-aided engineering) software (ANSYS 12.0; ANSYS Inc, Canonsburg, Pa). In this program the areas corresponding to each structure were plotted, and then meshed with quadratic elements of 8 nodes (Plane 182) in accordance with the mechanical properties (Table 1) of each structure and materials used.

The models were considered homogeneous, the tooth structure and materials used, isotropic and elastic, and it was performed a linear analyze. The areas corresponding to restorations were bonded at the interface of the adjacent areas of the enamel and dentin, to simulate adhesion between the structures.

Table 1. Mechanical properties of isotropic materials and structures[40].

Material	Young Modulus (GPA)	Poisson's Ratio
Polyether	**0.05**	**0.45**
Polystyrene resin	**13.5**	**0.31**
Composite resin	**15.8**	**0.24**
Pulp	**0.003**	**0.45**

Table 2. Mechanical properties of orthotropic structures[41].

	Longitudinal (L)	Transverse (T)
	Elastic Coefficient (GPA)	
Enamel	**73.72**	**63.27**
Dentin	**17.07**	**5.62**
	Shear Coefficient (GPA)	
Enamel	**20.89**	**24.07**
Dentin	**1.70**	**6.0**
	Poisson's Ratio	
Enamel	**0.23**	**0.45**
Dentin	**0.30**	**0.33**

An oblique load of 100N was applied to the occlusal incline of both cusps (45° to the long axis of the tooth) simulating a rounded loading tip, which contacted the restorative material surface away from the restoration margin. This pattern of loading was intended to simulate normal occlusal contacts. Models movements were restricted at the external lateral outline and cylindrical specimen support base.

Stress distribution analysis was performed by means of the quantitative association with the Maximum principal stress and the von Mises criteria.Quantitative analysis was performed based on stress values measured at four specific points in the models:point A:cavosurface angle of vestibular cusp;point B: cavosurface angle of palatal cusp;point C: cementoenamel junction of the buccal cusp and point D: cementoenamel junction of palatal cusp (Figure 2).

Figure 1. CAD draws: A) Model 1; B) Model 2; C) Model 3; D) Model 4; E) Models 5; F) Model 6; G) Model 7.

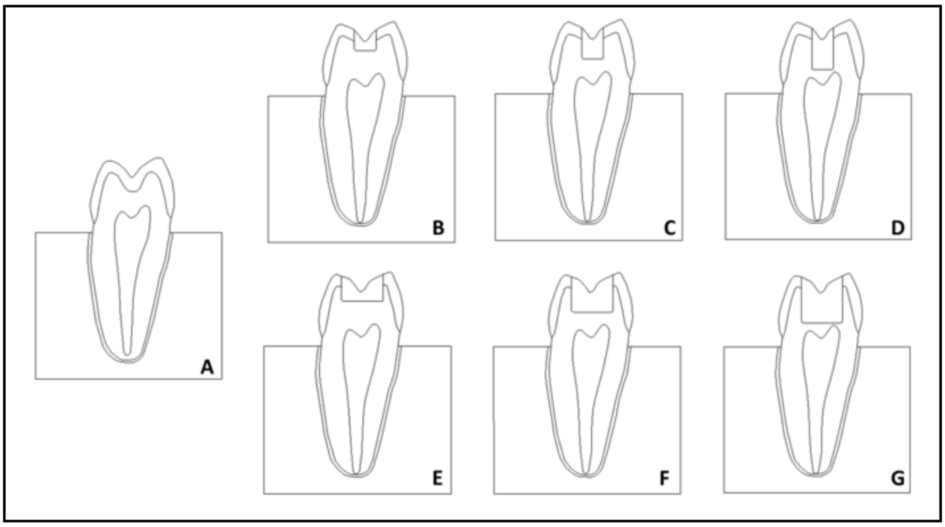


Figure 2. Points of quantitative analyses: A) cavosurface angle of vestibular cusp, B) cavosurface angle of palatal cusp, C) cementoenamel junction of the buccal cusp and D) cementoenamel junction of palatal cusp.

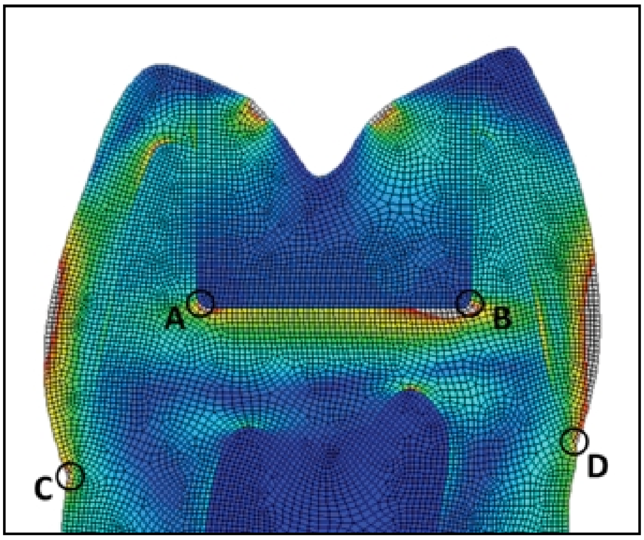


Figure 3. Von Mises criteria analyzis: A) Model 1; B) Model 2; C) Model 3; D) Model 4; E) Models 5; F) Model 6; G) Model 7.

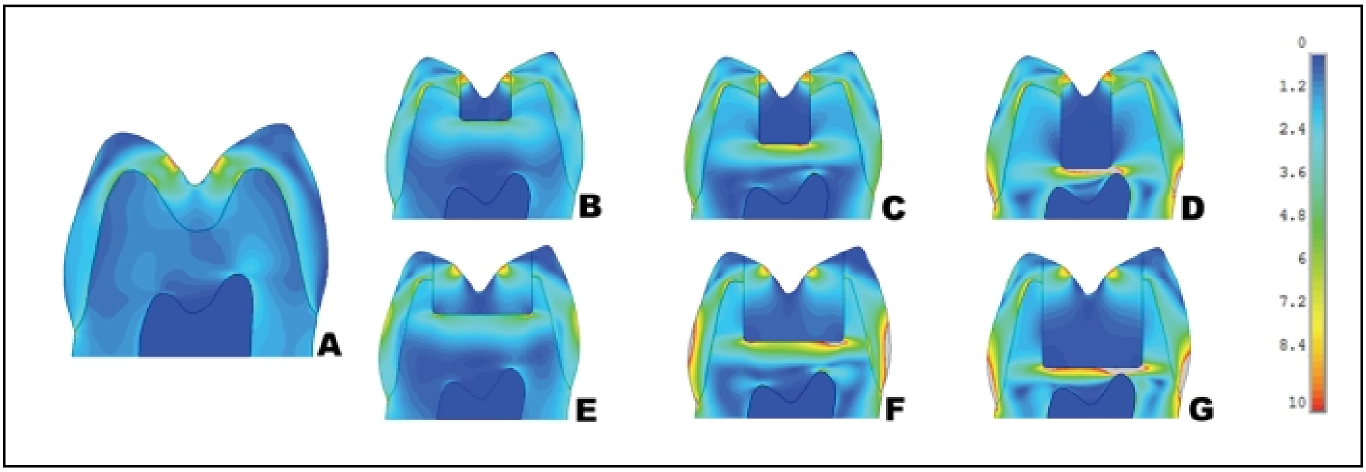


Figure 4. Maximum principal stress: A) Model 1; B) Model 2; C) Model 3; D) Model 4; E) Models 5; F) Model 6; G) Model 7.

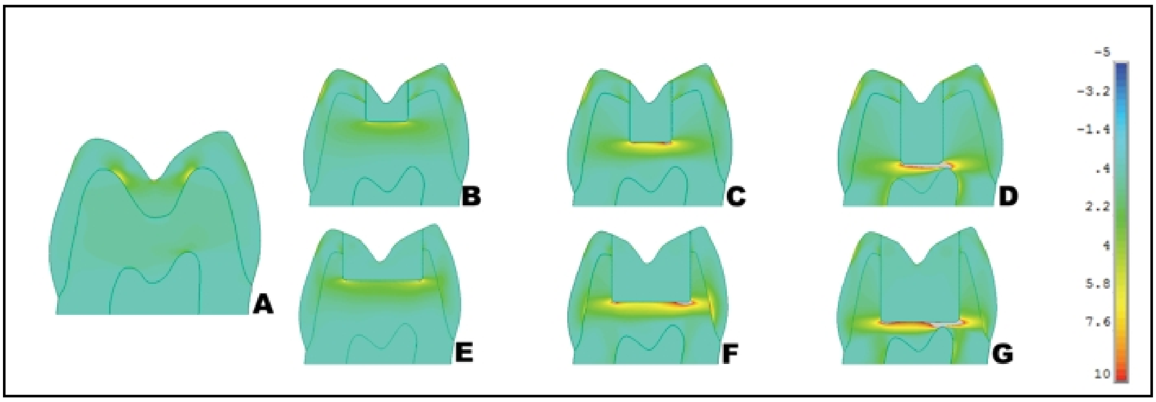


Figure 5. Von Mises criteria values (MPa).

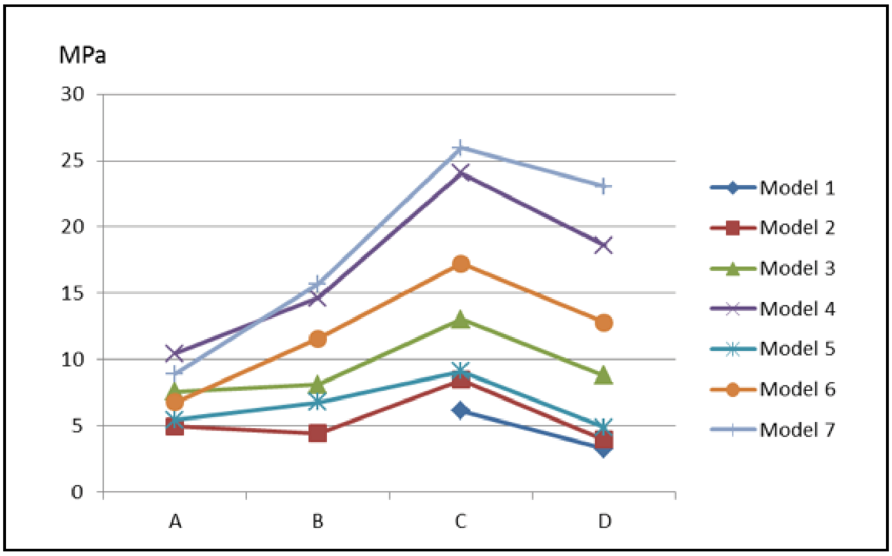
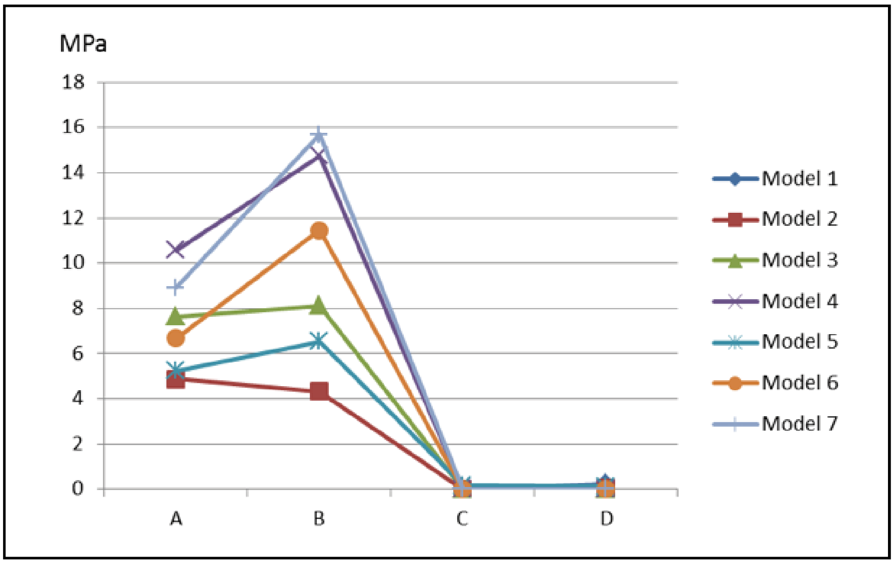


Figure 6.Maximum principal stress values.



RESULTS

In the qualitative analysis of stress distribution by von Mises criteria (Figure 3) was possible to observe that the greater the depth extent of MOD cavity, the greater the stress generated in the cavity pulp wall and in the cervical region of the tooth. Increasing the extension of the cavity isthmus intensifies stress in these regions and generates stress concentration on palatal and vestibularfaces (Figures 3.G). Analysis of Maximum principal stress (Figure 4) showed that the stress generated in the cavity pulp wall were predominantly tensile stress. The stress values in thecavity cavosurface angles and the cervical region agreed with the qualitative analysis (Figures 5 and 6).

DISCUSSION

It is scientifically proven that premolars are the teeth that most fracture in the oral cavity[7-9]. Studies indicate endodontic treatment as the main factor leading to fracture [28, 29]; however it is probably related with the loss of marginal ridges and axial walls during access preparation. Reeh et al[30] performed a nondestructive test of cuspal stiffness that allowed sequential testing on the same tooth. Endodontic access was evaluated both before and after cavity preparation. It was concluded that endodontic procedures had only a small effecton tooth strength (5%). Rather, it was the advancing preparation that caused reduction in the relative stiffness of the tooth (63% reduction relative to intact teeth). Steele et al[31] confirmed this finding. Similar fracture resistance was found in endodontically treated teeth with canal access only, as compared to intact natural teeth. The significantly lowest compressive strength was found in teeth with MOD cavities.

Based on the results of this study it is possible to infer that class II MODcavities leads to an unfavorable stress distribution pattern that can be related to cusps deflection, which makes the tooth susceptible to fracture, particularly in deep preparations, because of thegenerated stress concentration at the base of the cusps.Also the extension of the MOD cavity isthmus has a harmful effect on stress distribution in tooth structure because it is directly related to greater concentration of tensile stresses at the cavity pulp wall. These results agree with the study by Lin et al[14] which, by finite element method, evaluated the influence of MOD cavitiesconfiguration on stress distribution and pointed out the depth extension as the most aggravating factor in the risk of fracture of upper premolars.

For a better stress distribution, both in remaining tooth structure and in the filling material, the adhesive materials are indicated, because they have favorable mechanical properties such as modulus of elasticity similar to tooth structure lost, the ability to adhere to the remaining dentin and thereby strengthen and preserve the remaining structure and minimize the risk of fracture.[10, 12, 15, 21, 22, 24, 32, 33]Studies evaluated different kinds of materials to restore premolars with class II MOD preparation and showed that the composite resin has the ability to make the fracture strength and stress distribution at or close to anintact tooth.[10, 34-38]A study performed by Cerutti et al[39] evaluated cuspal deflection in intact tooth and endodontically treated teeth restored with amalgam or composite resin. The results showed that teeth restored with amalgam recover cuspal deflection in a rate of 17% while a counterpart restored with composite resin, from 54 to 99% according to the composite resin used.

Computational methods allow evaluating the behavior of different restorative materials. From the load application on a structure, stresses concentration are generate and it may results in structural strain; if these are intensified beyond the elastic range it may result in rupture of the structure. Destructives laboratory tests are important means of analyzing the behavior of the tooth in case of application of point loads and high intensity. However, have limitations with respect to obtaining information from the internal behavior of the tooth-restoration complex and do not highlight important steps of loading before the moment of failure.

Finite Element Analyses (FEA)seems to be a valid aid for predicting and evaluating the behavior of internal dental structure and restorative materials. Valid FEA have clarified how static load generates stresses that are distributed within the restorative material and the tooth tissues. It is a methodology pre-injury, which can provide information of the dental structure on receiving a load and that may justify fracture pattern and the influence of different restorative materials in dental behavior.

The results of this study showed stress, especially tensile stress, at the bottom of the cavity preparation especially associating greater depth and greatest extent of the isthmus.This shows that although the composite resin has favorable properties it cannot generate completely the stress distribution pattern of a healthy tooth. On the other hand, as its direct technique doesn'trequire previous cavity preparation, it allows greater structure conservation, which is critical fortooth and the restorative treatment longevity. Therefore, the composite resin is still a great option for treating teeth that have lost marginal ridges.

CONCLUSION

Based on the results of this study it was concluded that great depth MOD cavities generates stress concentration in the pulp wall and in the cervical region of premolars and that, when combined with extensive isthmus these tensions intensify and stress concentration is generated in the buccal and palatal tooth.

The loss marginal ridges influence the stress distribution pattern of upper premolars, even when restored with adhesive material with properties similar to dentin, such as composite resin.

It is indicated restorative techniques that allow greater conservation of tooth structure. This makes composite resin a great restorative material in treating premolars that have lost the marginal ridges.

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