**ORIGINAL RESEARCH**

# Influence of Occlusal Contact Area on Cusp Deflection and Stress Distribution

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**ABSTRACT**

**Objective:** The purpose of this study was to evaluate the effect of occlusal contact area for loading on the cuspal deflection and stress distribution in a first premolar restored with a high elastic modulus restorative material.

**Materials and methods:** The Rhinoceros 4.0 software was used for modeling the three-dimensional geometries of dental and periodontal structures and the inlay restoration. Thus, two different models, intact and restored teeth with three occlusal contact areas, 0.1, 0.5 and 0.75 mm$^2$, on enamel at the occlusal surface of buccal and lingual cusps. Finite element analysis (FEA) was performed with the program ANSYS (Workbench 13.0), which generated a mesh with tetrahedral elements with greater refinement in the regions of interest, and was constrained at the bases of cortical and trabecular bone in all axis and loaded with 100 N normal to each contact area.

**Results:** To analysis of maximum principal stress, the smaller occlusal contact area showed greater compressive stress in region of load application for both the intact and inlay restored tooth. However, tensile stresses at the occlusal isthmus were similar for all three tested occlusal contact areas (60 MPa). To displacement of the cusps was higher for teeth with inlay (0.46-0.48 mm). For intact teeth, the smaller contact area showed greater displacement (0.10 mm). For teeth with inlays, the displacement of the cusps were similar in all types of occlusal area.

**Conclusion:** Cuspal displacement was higher in the restored tooth when compared to the intact tooth, but there were no significant variations even with changes in the occlusal contact area.

**Relevance clinical:** Occlusal contacts have a great influence on the positioning of teeth being able to maintain the position and stability of the mandible. Axial loads would be able to generate more uniform stress at the root presenting a greater concentration of load application in the point and the occlusal surface. Thus, is necessary to analyze the relationship between these occlusal contacts as dental wear and subsequent occlusal interferences.

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## INTRODUCTION

Dental occlusion is a fundamental factor to the overall success of dental treatments. Ideal occlusion involves balanced occlusal loads and simultaneous occlusal contact of teeth in the intercuspal position. This provides an even distribution of occlusal force, as well as stabilization of teeth in the both arch mesiodistally and buccal-lingually.

In order to maintain equilibrium within the periodontal structures, the final vector of an occlusal force on a tooth posterior must be directed as close to the long axis as possible. However, as there are multiple and simultaneous occlusal contacts, we cannot assume that the applied forces are uniformly distributed. Previous studies have demonstrated that during parafunctional habits dental clenching for example, forces applied to the molars are greater than those applied to the incisors.[1] In addition, increased frequency of a particular parafunctional habit can also influence the distribution of occlusal forces. Based on these results, it was concluded that increased chewing may alter occlusal contact.[1]

Some studies have suggested that the occlusal contact area, masticatory efficiency and the pressure of occlusion bite force could be useful for understanding the masticatory function in patients suffering orofacial.[2,3]

When the mandible establishes intercuspation in response to the action of the mastication muscles, opposing teeth are in contact. These contacts typically possess factors of location, distribution, number, sequence and intensity.[2]

For successful oral rehabilitation, it is necessary to have a working knowledge of anatomy and physiology to understand those chain reactions resulting from efforts to compensate and maintain functional demand in a response to anatomical or physiological changes.

These reactions may initially be considered healthy, but if left untreated for prolonged times can lead to an over stressing of the system.

The loss of tooth structure from cavity preparation or trauma often results in a significant loss of dental resistance, thereby increasing cuspal deflection when subjected to occlusal load. These factors that affect the deflection of the cusp include the quantity of lost dental tissue, location of the loss, and resulting decreased rigidity of the overall dental structure.[3,4]

The interaction among restorative procedures, high occlusal forces, and multiple occlusal contacts results in undesirable effects. These relationships can also lead to an increased susceptibility to fracture, even in cases of intact teeth and when considering that stresses generated during the friction of occlusion are absorbed by the periodontal ligament.[5-10] The depth of the cavity preparation and removal of structures, such as marginal ridges, increase cuspal deflection as well as the risk of fracture. The ultimate goal of a dental restoration is to minimize or control the deformation of surrounding tooth structure. In turn, risk of failure is also reduced.

The finite element analysis (FEA) method has previously been applied in efforts to study the dynamics of the stomatognathic system.[11,12] It has shown promise in analysis of the intensity, frequency, duration, and direction of occlusal forces, as well as contributing to understanding the influence of these limiting factors on tooth stability. The use of FEA allows for the study of a single tooth, a set of teeth, and even the intermaxillary relationship based on biomechanical models and presumptions.[13] With this methodology, it is therefore possible to have both quantitative and qualitative evaluations of dental and mandibular biomechanics to evaluate tensions, strains, and displacements that may occur within these structures,[13,14] and to determine the best mode of treatment for a variety of clinical situations.

The objective of this study was to evaluate the influence of occlusal contact area and the presence/absence of a feldspathic ceramic restorative inlay of a first premolar on the stress distribution and cuspal deflection using the FEA method.

## MATERIALS AND METHODS

### Generation of Geometry

For the 3D models, a Stereolithography (STL) format file was selected from the Center for Information Technology Renato Archer (CTI - Campinas, SP, Brazil) database. This was then transferred to the Computer Aided Design (CAD) software Rhinoceros 4.0 (McNeel North America - Seattle - USA) where models were produced according to the BioCad protocol.[15]

The structures considered for inclusion in the model were: coronal and root enamel and dentin, tooth pulp, the periodontal ligament, as well as cortical and trabecular bone. Models were generated from lines drawn on the STL image. Then, lines the user selects the main anatomical marks around which these lines are to be generated, and the resulting lines serve as reference to the model's surface. Following formation of the model's surface, these lines were then transformed into solids and exported in the Standard for the Exchange of Product Model Data (STEP) form to be imported into the FEA software.[16]

### Preprocessing of the FEA

In this study, all materials were considered isotropic, homogeneous, and linearly elastic, and a static structural analysis was carried as an appropriate representation of the compression test. As such, each case of geometry has specific properties characterizing its behavior in a test of linearity within the limits as listed in Table 1.

### Generation of Meshes

For the generation of finite element meshes in three-dimensional biological geometry, the software ANSYS 13.0. (Canonsburg-Pennsylvania-USA) was selected, and a quadratic tetrahedral element meshes, as characterized by pyramids with a triangular base, a node at each corner and in the center of each edge, were utilized. At ten nodes per element, a total of 562.845 elements and 836.800 nodes resulted.

Simplifications of the model were performed to reduce mesh density in regions of more complex geometries, but in regions of greatest interest the model was well refined.

**Table 1:** Mechanical properties of materials used on finite element analysis

| Properties | Young's Modulus GPa | Poisson's ratio | Reference |
| --- | --- | --- | --- |
| Dentin | 17.6 | 0.31 | Craig et al, 1961 |
| Enamel | 48 | 0.3 | Holmes et al, 1996 |
| Ligament | 0.0689 | 0.45 | Holmes et al, 1996 |
| Osso cortical | 13.7 | 0.3 | Holmes et al, 1996 |
| Trabecular bone | 1.37 | 0.3 | Holmes et al, 1996 |
| Composite resin | 11.6 | 0.3 | Owner characterization |

## Loading and Fixation

The base of both cortical and trabecular bone was fixed in all directions of space with a force of 100 N[17] normal to each contact area of 0.1, 0.5 or 0.75 mm$^2$.

## Postprocessing

The display of FEA results is visually performed using a scale of colors in which each image tonality represents a strip of stresses or distortion generated in the tested structures. In this study, the fields of displacement, von Mises stress, and maximum principal stress were analyzed.

## RESULTS

To evaluate the coherence of geometry, the resulting von Mises stress (VMS) and total displacement were investigated. Following this analysis, the maximum principal stress (MPS) was studied where positive values corresponded to tension and negative values to compression stresses.

When analyzing the tension von Mises, both an intact and restored tooth, the distortional energy flows, reducing gradually without abrupt changes in other areas. The area of highest concentration is in the regions of load application (Figs 1 and 2). In the restored tooth, there is a higher energy concentration closer to the region where the geometry changes and where the material properties are dissimilar (tooth-ceramic interface) (Fig. 2).

In the analysis of MPS, the smaller the occlusal contact area, the greater the compressive stress in the region of load application for both the intact and inlay restored tooth. However, tensile stresses present in the tooth structure, particularly at the occlusal isthmus, were similar for all three tested occlusal contact areas (Figs 1 and 2).

The displacement of the cusps was higher for restored teeth. The smaller the contact area, the greater the displacement intact teeth. For restored teeth, the displacement of the cusps were similar in all types of occlusal area (Fig. 2).

## DISCUSSION

In this study, FEA was used to investigate the mechanical behavior of isotropic intact teeth and those restored with a higher young modulus material, feldspathic ceramic inlay, when subjected to occlusal loading of three different contact areas.

The analysis of total displacement, consistency and connectivity of the mesh, and von Mises criterion, of the models demonstrated that this is a feasible model for the analysis of stress distribution by means of a 3D finite element method (Figs 1 and 2).

Due to the geometrical complexity of the model, appropriate discretization of the models (division of the structure finite number of elements; 10% convergence) was necessary to ensure the quality of results would not be compromised.
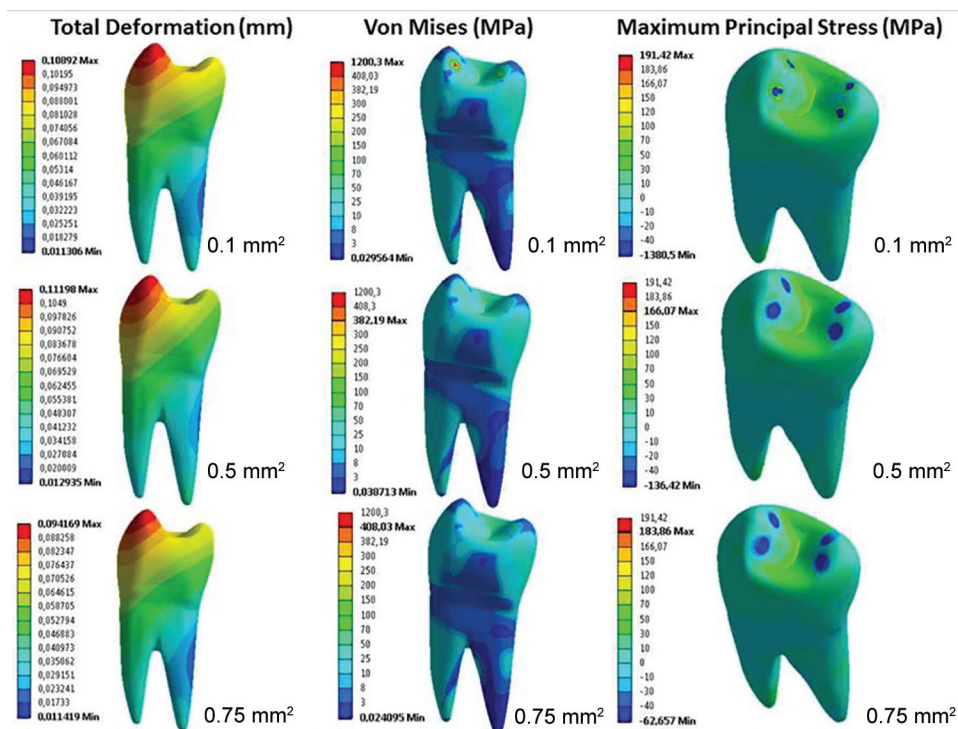


**Fig. 1:** Total deformation, Von Mises and maximum principal stress of intact teeth with the three types of occlusal contact area
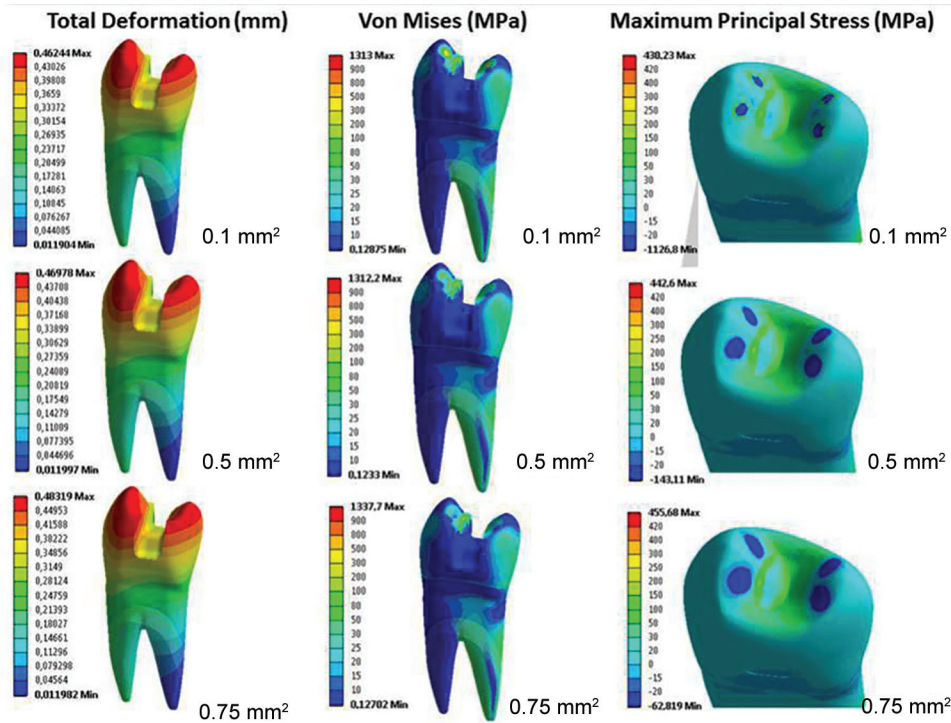
**Fig. 2:** Total deformation, von Mises and maximum principal stress of restored teeth with the three types of occlusal contact area

It was observed in all models, that compressive stress was present at the region of load application, and that as the contact area increased this compressive stress decreased. This is most likely a result of the law of physics whereby the area over which a force is exerted is inversely proportional to pressure which promotes strain and stress.

The objective of this study was to observe the behavior of the dental structure, not only in the load surface, due to failures occur more frequently far from the load application surface, and the models of intact teeth showed a similar distribution of tensile stress. This demonstrated that occlusal contact area does not influence the stress distribution in dental crown, and in regions away from the load application surface. The punctual stress depends of the force applied and the contact area. The stress is higher to the 0.1 mm area, but this is a singularity zone, easily explained by Saint-Venant's principle. This was also observed in teeth restored with the feldspathic ceramic inlay.

For the intact and restored tooth models, as the contact area changed, stress fields inside did not show significant discrepancies. However, for an intact tooth with the largest occlusal contact area, bands of traction had higher values across a wider area of both the crown and root (Fig. 1).

The great frequency in the population is the condition occlusal where a tooth is related cusp-ridge. In the case of a premolar, the occlusal contacts occur in areas of marginal ridge and palatal cusp. When the occlusion occurs in the region of transverse edges the occlusal forces directs to tooth long axis presenting a better situation.

In the restored tooth, while the tensile stress (green band-50 to 100 MPa), Figure 2, is less frequent in the region of the principal groove as compared to the intact tooth, it is more concentrated in the tooth-restoration interface.

The way of the stress distribution changes in the root of the intact tooth (higher concentration of traction in the buccal root) compared to the restored tooth (higher concentrations of traction in the palatal root, with tensile values higher in the furcal than of the intact teeth) (Figs 1 and 2). It appears as though the change from intact to restored tooth, results in a greater difference in the stress field than does a change in occlusal contact area for other tooth model; perhaps this data can help explain the higher incidence of maxillary buccal fractures,[18] when considering the values obtained for intact teeth.

Studies suggest that the anatomy of the tooth has a direct relationship with the different fracture cusps.[18-21] As buccal cusps of the upper teeth and lingual cusps of the lower as well as differences in size between the width of the cusp as a consequence of the cavity preparation.

In another analysis, unrestored teeth showed less movement than those which had been restored on account of the removal of structures, such as the marginal ridge, the restored tooth showed greater cuspal deflection

(Figs 1 and 2), similar to the study in Dall Agnol et al,[22] in 2012 and Jantarat et al,[23] in 2001 observed that intact teeth showed significantly lower deflection of the cusps. This small deflection probably occurs due to the biomechanical behavior of enamel/dentin junction allowing a strong connection between these two substrates.[24] The intact teeth, which present throughout the enamel surface is rigid and occlusal load only causes a small deformation. The deformation is dependent on the intensity of the applied force.[10,23] Thus, the teeth with a solid structure distribute more evenly the load stress because the enamel is not deformed, and the deformation is transferred to the dentin that is more resilient.[25] When the continuity of the enamel is lost as a result of a cavity preparation, the properties of dentin have an important part in the behavior of the deflection of the cusp[26] and are critical for the recovery of the rigidity of the teeth after restoration.

The absence of important structures will negatively influence the fracture resistance. Soares et al,[27] in 2008, showed that the location of lost tooth structure is as relevant as the amount and as such, maximum preservation of regions such as the tooth edge and marginal ridges are imperative.

The both models showed the same behavior of total displacement, but had no difference among the three contact areas, although higher value was observed at restored model than intact and the restorative material did not reinforce the total structure even the higher elastic modulus.

## CONCLUSION

The cuspal displacement was higher in the intact tooth as compared to the restored tooth, but there were no significant variations even with changes in the occlusal contact area.

The stresses generated in intact tooth were lower than in the restored, but occlusal contact area had no significant influence.

## RELEVANCE CLINICAL

Occlusal contacts have a great influence on the positioning of teeth being able to maintain the position and stability of the mandible. Axial loads would be able to generate more uniform stress at the root presenting a greater concentration of load application in the point and the occlusal surface. Thus, is necessary to analyze the relationship between these occlusal contacts as dental wear and subsequent occlusal interferences.

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