Brazilian Dental Science
Ciência Odontológica Brasileira
unesp
UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Instituto de Ciência e Tecnologia
Campus de São José dos Campos

ORIGINAL ARTICLE
doi: 10.14295/bds.2017.v20i4.1484

Influence of the occlusal contacts in formation of Abfraction Lesions in the upper premolar

Influência dos contatos oclusais na formação de lesões de Abfração no pré-molar superior

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ABSTRACT

Objective: The aim of this study was to observe the influence of different occlusal contacts in a superior pre-molar structure using Finite Element Analysis. **Material and Methods:** A three-dimensional model of a superior pre-molar was designed to simulate three occlusion situations, namely central occlusion and two types of lateral occlusion contacts. The model presents enamel, dentin, a periodontal ligament and a fixation cylinder separately. All materials were considered isotropic, linear and homogeneous, and the contacts of each structure were perfectly bonded. On analysis software, a load was applied to an occlusal surface at 40° to the long axis on lateral contacts, and directed to the long axis on central occlusion contact. **Results:** The results were obtained in stress maps and the maximum values were then plotted in table for quantitative comparison, with the enamel concentrating more stress than dentin and the occlusal contact presenting the worst biomechanical behavior. **Conclusion:** Within the limitations of this study, it is possible conclude that: eccentric contacts have higher potential to develop abfraction lesions on the cervical region of teeth, thus increasing the magnitude of tensile and shear stresses.

KEYWORDS

Finite Elements Analysis, Abfraction; Stress distribution; Occlusion, Premolar.

RESUMO

Objetivo: observar a influência de diferentes contatos oclusais em uma estrutura pré-molar superior usando a análise por elementos finitos. **Material e Métodos:** um modelo tridimensional de pré-molar superior foi projetado para simular três situações de oclusão: oclusão central e dois tipos de contatos de oclusão lateral. O modelo apresentou esmalte, dentina, ligamento periodontal e um cilindro de fixação separadamente. Todos os materiais foram considerados isotrópicos, lineares e homogêneos, e os contatos de cada estrutura foram considerados perfeitamente ligados. No software de análise, aplicou-se uma carga na superfície oclusal a 40°, ao longo eixo do dente, nos contatos laterais e direcionada para apical no contato de oclusão central. **Resultados:** os resultados foram obtidos nos mapas de tensão e os valores máximos foram escritos em tabela para comparação quantitativa, com o esmalte concentrando mais tensão do que a dentina e o contato em cúspide de balanceio apresentando o pior comportamento biomecânico. **Conclusão:** dentro das limitações deste estudo, é possível concluir que: os contatos excêntricos facilitam o surgimento de lesões de abfração na região cervical dos dentes, pois aumentam a magnitude das tensões de tração e de cisalhamento.

PALAVRAS-CHAVE

Análise por Elementos Finitos, Abfração; Distribuição de Tensão; Oclusão, Pré-molar.

INTRODUCTION

Non-Carious Cervical Lesions (NCCL) is a class of tooth lesion that is not formed by the demineralizing action of cariogenic bacteria. This class of lesions includes Erosion, Abrasion, Attrition and Abfraction, capable of causing clinically visible loss of hard tissue over time in areas which are not usually compromised by cariogenic plaque [1].

Regarding form, these lesions may be wedge, disc, flattened or irregular shaped, varying in stress and depth [2]. The facial surfaces are usually the most committed, rarely being seen on lingual and proximal surfaces [3].

Abfraction lesions are influenced by occlusal loads, thus experiencing enamel and dentine fatigue due to structural flexure on a location away from the area where the load is being applied [4]. Clinically, a wedge shaped lesion can mainly be seen on the cervical region [2]. This term includes a series of lesions that compromise the subgingival area, where teeth surfaces have no contact with acids, other teeth or mechanical factors (as occurs in other NCCL) [5]. This also applies for cases in which the lesion only compromises a single tooth [6].

Regarding the etiology, past studies correlate occlusal and cervical loss of tissue in which more than 80% of the tooth affected by cervical lesions presents occlusal wear [7].It has also been observed that occlusal and cervical wear stress grew proportionally during a 14-year study [8]. Concerning the direction of the loads, it is known that loading dissipates more evenly over enamel and dentin when directed to the long axis; in contrast, lateral loading promotes structural flexure, and when occurring cyclically causes weakening and rupture of the bond between hydroxyapatite crystals [7]. Abfraction lesions are most seen in premolars, in both maxilla and the jaw [9].

Finite Element Analysis (FEA) is a well-explored tool in dentistry which can simulate teeth and other natural tissues [10], as well as restored teeth [10], prostheses [11] and dental implants [12].

Previous studies have already evaluated the behavior of dental elements under several types of loadings using finite element analysis, in favor of analyzing the occurrence of abfraction lesions in premolars over two-dimension analysis [13,14]. When simulated loadings are analyzed over three-dimensions, they have mainly aimed to evaluate the centric and malocclusion contacts [15]. The present study aims to compare dental structure behavior under centric loadings and in lateral loadings with balance contact and group function contacts which are physiologically observed in the mouth.

Therefore, this work uses Finite Element Analysis with the aim of observing the stress distribution that occurs on the teeth over three types of occlusal loading – centric contact, working contact and balancing contact – to be compared from the biomechanical point of view in attempt to verify the contacts with greater potential to generate Non-Carious Cervical Lesions, which are increasingly being observed in day-to-day clinics.

MATERIAL AND METHODS

Finite Element Analysis (FEA)

A previously validated human first premolar [16] was selected for this study. The file was accessed by CAD software in STL format (Rhinoceros 5.0 McNeel North America, USA) and anatomic lines were drawn based on the Biocad method [17]. After delimitation, the lines were smoothened and split so that the surfaces could be created [2]. Every single surface was modeled using three or four anatomic lines until obtaining a volumetric solid of every individual structure.

The modeled dental structure included enamel, dentin, the pulp chamber and a periodontal ligament. A fixation cylinder was used to contain the teeth and simulate the bone tissue using material validated for laboratorial analysis (Figure 1).

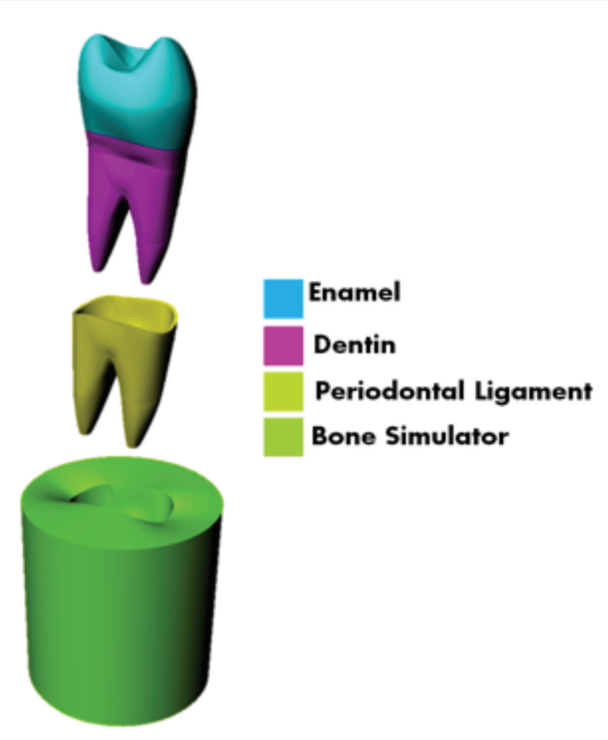

Figure 1 - 3D geometry created in computer aided design software

After modeling, the solids were imported to analysis software (ANSYS 15.0, ANSYS Inc., Houston, TX, USA) and the contacts which were considered perfectly bonded between all the structures and the system were closed on the cylinder base. The meshes were generated through tetrahedral elements and a convergence test (10%) determined the number of nodes (126980) and elements (72460) in the model. The mechanical properties of each figure were obtained through the literature (Table I) [18-20] and inserted in the software for static structural analysis. Different axial loadings were simulated to perform the situation proposed for this study: central occlusion (directed to the long axis of the tooth), laterality on the work cusp (at 40°), and interference contact to balance movement on the facial cusp (at 40°) (Figure 2).

The selected analysis criterion was the maximum principal stress and maximum shear stress on dentin and enamel, aiming to evidence the future failing areas after applying the loadings. Regarding the periodontal ligament, the analysis criterion was the equivalent strain as this structure does not fracture. Each of the dental element geometries were analyzed in colorimetric scale for qualitative comparison of each of the simulated occlusion situations. The peak stress values were then plotted on a table.

Table I - Mechanical properties of the materials used in the analysis

Material	Elastic Modulus (GPa)	Poisson coeficient	Reference
Enamel	84	0.30	Versluis et al.
Dentin	18	0.23	Versluis et al.
Periodontal Ligament	1.18×10^{-5}	0.45	Rundguist et al.
Polyurethane	3.6	0.3	Souza et al.

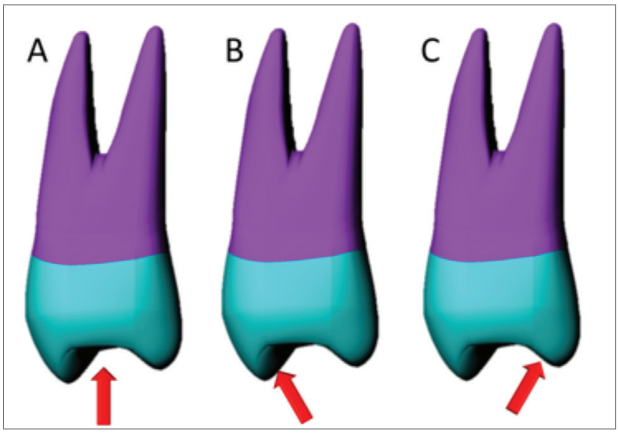

Figure 2 - Simulated occlusal contacts on: A) centric occlusion, B) working contact and C) balancing contact

RESULTS

The colorimetric graph shows the stress distribution focusing on the tensile areas on the dental element during all the loadings. Stress distribution was the most homogeneous during the central occlusion position on all the dental element's faces (Figure 4) when compared to the other simulated positions. There were more higher stress concentration areas on the cement-enamel junction region on the cervical portion for both work and balance lateral contact positions, thus suggesting a greater probability of problems in those areas. The main difference between the two eccentric simulated movements was that the stress was concentrated on the opposite side of the loading cusp – therefore, the contact on the work surface generated stress on the facial surface, and the contact on the balance cusp generated stress on the buccal surface.

DISCUSSION

Previous researches have studied the type of loading as to the stress promoted on the dental element [13,15]. It is a consensus that centric loadings are best absorbed by the dental structure, not only generating less stress but being distributed more evenly along the tooth. Furthermore, the centric contacts do not produce considerable structural flexure – they only promote compressive stress, against which the dental element presents high resistance when its mineralized structures are intact.

Using the central contacts as a parameter, the loadings on work and balance cusps are more harmful for teeth. Under lateral loading, it was demonstrated that the generated stress is of greater magnitude, being distributed in a more harmful way over the structure, and mainly concentrating on cervical areas to the point of breaking the chemical bonding between the enamel prisms [21,22]. The results of this paper demonstrated that the balance contact is more willing to cause cervical losses, followed by the work cusp occlusal contact, and lastly the most even situation is the maximum intercuspation position (Figure 3-5). These results corroborate with previously studies [15] which verified greater stress values in the superior premolar when malocclusion problems were present.

As considered in the literature, [13,14] the surface that anatomically presented smaller quantities of enamel suffer stress concentration to a greater degree; these studies showed higher stress concentration on the cervical region of the inferior premolar's facial surface when the loadings were applied on the lingual cusp. The same is verified in the present study on the cervical region of the superior premolar's facial surface when oblique loadings are applied to the palatal cusp (Figure 3,4). The simulated contacts in this present study are the most harmful for the dental structure, those being the lateral contacts that occur in the internal slopes of the cusps (Figure 5). Moreover, the previously studies [13,14] shows very similar values observed in loadings on both facial and lingual cusps. In this study, it was shown that the higher concentrations were found on facial enamel for balance contacts; a fact which justifies the highest occurrence of cervical lesions on facial surfaces as clinically observed.

The stress found in our study results are based on the theory of abfraction by overload. This theory defines that the cusps are submitted to axial compression loading during tooth structural flexure, thus resulting in cervical stress similar to a diametric compression application. This then results in degradation of the links between hydroxyapatite crystals, which leads to crack formation and eventually results in enamel loss on these areas [14,23].

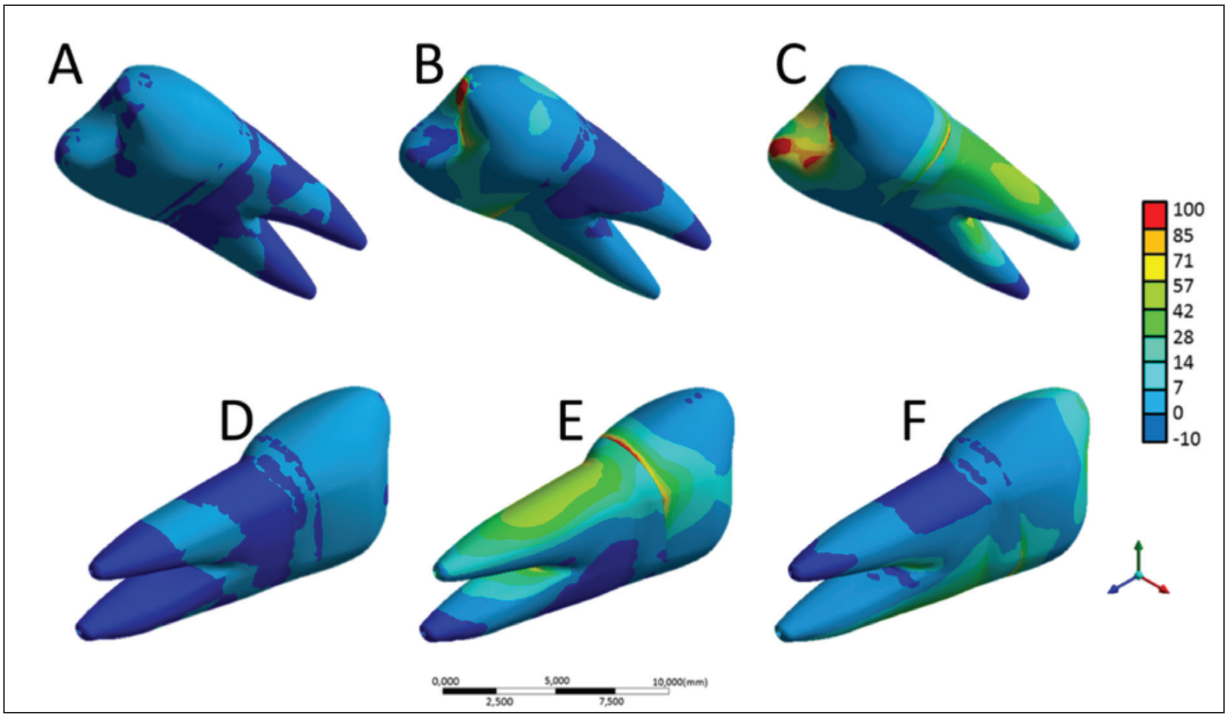

Figure 3 - Maximum principal stress in premolar during contact: A) on central occlusion, buccal perspective; B) on work cusp, buccal perspective; C) on work cusp, buccal perspective; D) on central occlusion, palatal perspective; E) on balance cusp, palatal perspective; F) on balance cusp, palatal perspective

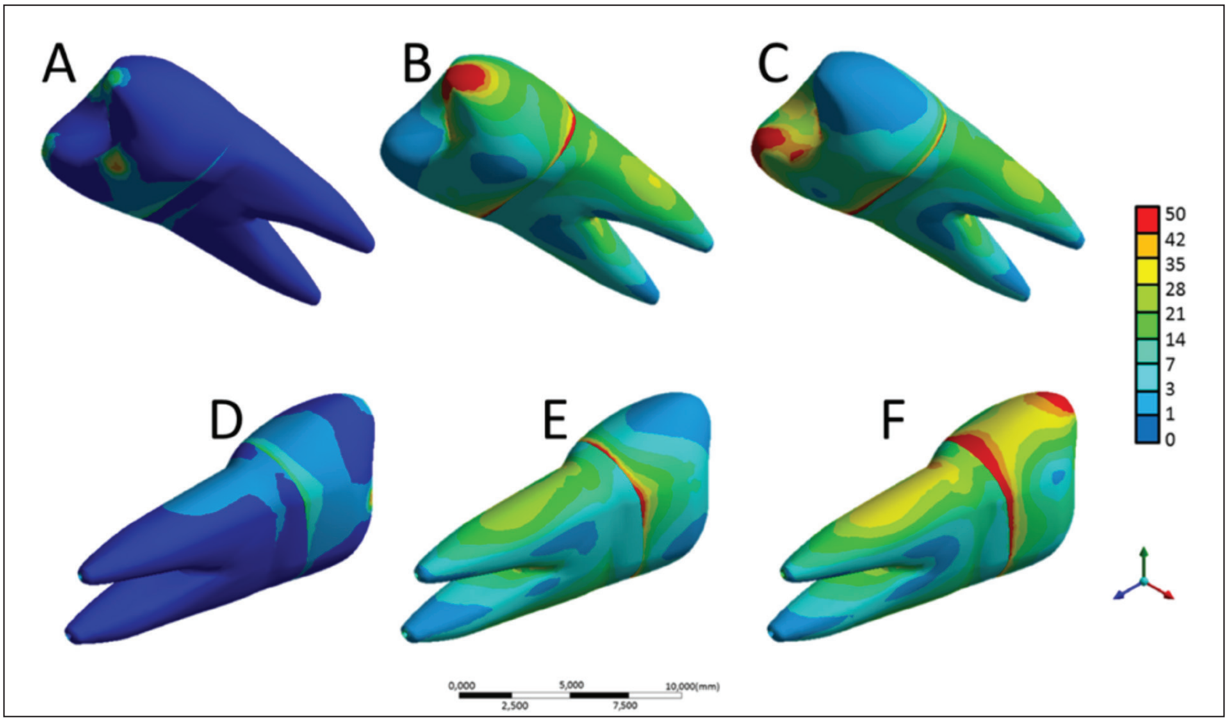

Figure 4 - Maximum shear stress in premolar during contact: A) on central occlusion, buccal perspective; B) on work cusp, buccal perspective; C) on work cusp, buccal perspective; D) on central occlusion, palatal perspective; E) on balance cusp, palatal perspective; F) on balance cusp, palatal perspective

The stress concentrates in a higher magnitude on the cervical area on the opposite surface when loadings are applied to a premolar cusp, and more specifically tensile stress; with the tensile being (as known) more harmful for the dental enamel than shear (Table II). These results were supported by literature relates with similar condition [18-21]. This is contrary to the studies of Spears et al. [25] which shows the opposite when applying loadings over a premolar lingual cusp, resulting in stress concentrations on the cervical area of the lingual aspect itself, probably because the author has used different stress criteria.

The prevalence of class V lesions is more common in inferior premolars when compared to superior ones [26]. Some authors state that the higher moisture content being associated with lingual orientation of the inferior tooth makes them more susceptible to fail under tensile forces [21,25,27]. However, this work shows that, when the loading occurs on a larger cusp (facial), higher tensile stress values are found on the cervical region, but this loading is uncommon in the superior tooth and would only happen in unusual circumstances. Thus, based on our studies we can suggest that the lower prevalence of class V lesions on superior premolars also occurs because of the work cusp being palatal.

Table I - Tensile and shear stresses peaks according to the load and local of concentration

Load Type	Local	Tensile Stress (MPa)	Shear Stress (MPa)
Centric Occlusion	Buccal Dentin	0.53	1.1
	Palatal Dentin	0.37	6.8
	Buccal Enamel	1.09	5.4
	Palatal Enamel	1.34	20.1
Working Contact	Buccal Dentin	5.02	24.1
	Palatal Dentin	36.44	17.3
	Buccal Enamel	2.15	60.4
	Palatal Enamel	79.46	30.5
Balancing Contact	Buccal Dentin	40.68	17.2
	Palatal Dentin	6.64	31.2
	Buccal Enamel	100.85	49.3
	Palatal Enamel	4.09	105.1

One other structure analyzed in our study is the periodontal ligament, as the Finite Element Method is accepted to analyze the problems related to dental movement, especially when the displacement force distribution is being studied [28]. As such, the required results were in equivalent deformation and not stress, because the fracture of this structure does not occur in the mouth. By analyzing what we have found, it may be observed that functional maxillary positions (work and central relation) generate more and less deformation, respectively, than a less common situation (balance contacts), which allows us to suppose that any unusual contact would not generate damage to the periodontal ligament (Figure 6). This situation is hypothetical and based on theoretical results of a linearly elastic and homogeneous isotropic model, which is a limitation. Therefore, our results show that the masticatory load can facilitate the emergence of cervical lesions, especially when the contact occurs on the balance cusp, and that this contact may not be capable of sensitizing the periodontal ligament as much as a physiological work contact. This may also be one of the reasons why cervical lesions are more common in older patients [29], because more harmful contact in the long run and without being uncomfortable, could be responsible for cervical enamel loss. The prevention or reduction of the magnitude of generated tensile stresses in the dental element can be achieved by adjustment of the occlusal contacts [10]. The present study results shows that, when a constant loading is applied over a magnified area, the resultant of forces orientation tend to the long axis of the tooth and the generated stresses are better distributed over the tooth structure and periodontal ligament. These findings suggest that the adjustment should be made in a way of achieving best exploitation of the occlusal area of the dental crown, by distributing the occlusal contact points.

Concerning biting force, higher magnitude masticatory forces do not coincide with the perpendicular position to the occlusal plane, reinforcing the idea that a patient's occlusion must be clinically watched carefully, and together with other etiological factors of the non-carious cervical lesions (erosion, abrasion and attrition) they can generate structural loss and the characteristic lesions observed [30].

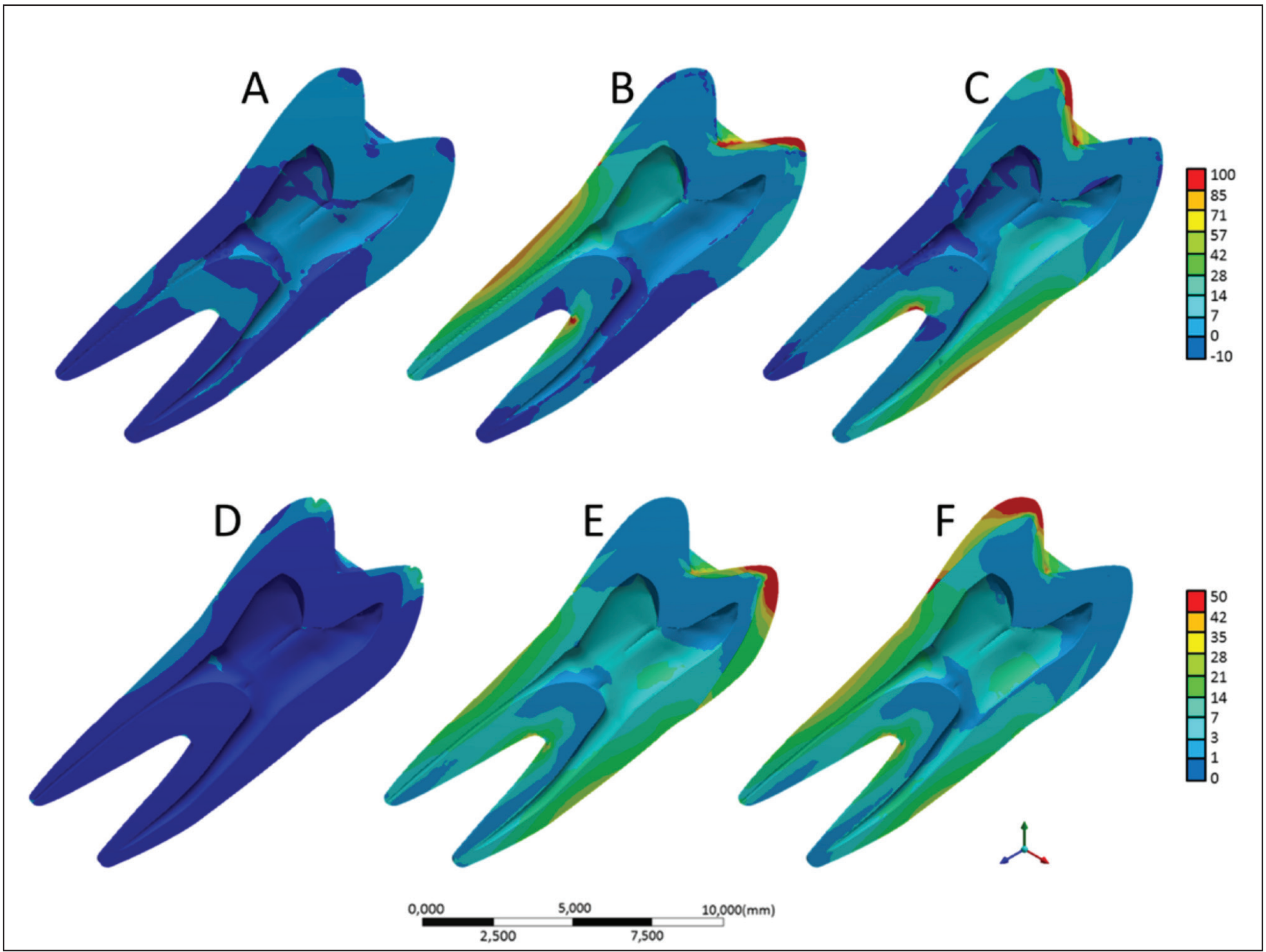

Figure 5 - Sagital view of tensile stress (first row) and shear stress (Second row).A,D) centric occlusion; B,E) Working contact and C,F) Balancing contact

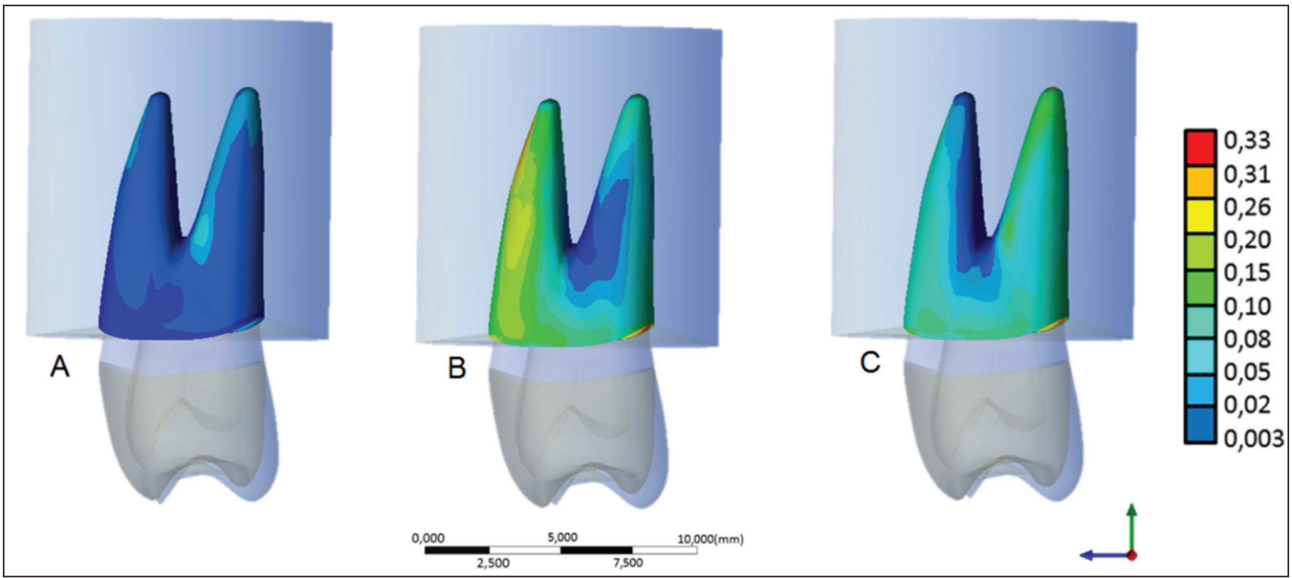

Figure 6 - Equivalent strain on periodontal ligament during occlusion contact in: A) central occlusion; B) work cusp and C) balance cusp

CONCLUSION

Within the limitations of this study, we can conclude that the stress concentration in a superior premolar is most common when eccentric contacts are exercised. The balancing contacts generate higher tensile and shear stress on the cervical area and must be prevented once observed.

ACKNOWLEDGES

The authors would like to thank the Foundation for Research Support of the State of São Paulo (FAPESP) for the scholarship, through the process number 2016/20021-0.

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Date submitted: 2017 Oct 09

Accept submission: 2017 Dec 13