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Original Article

Effect of type of luting agents on stress distribution in the bone surrounding implants supporting a three-unit fixed dental prosthesis: 3D finite element analysis

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ABSTRACT

Background: Osseointegration of dental implants is influenced by many biomechanical factors that may be related to stress distribution. The aim of this study was to evaluate the effect of type of luting agent on stress distribution in the bone surrounding implants, which support a three-unit fixed dental prosthesis (FDP) using finite element (FE) analysis.
Materials and Methods: A 3D FE model of a three-unit FDP was designed replacing the maxillary first molar with maxillary second premolar and second molar as the abutments using CATIA V5R18 software and analyzed with ABAQUS/CAE 6.6 version. The model was consisted of 465108 nodes and 86296 elements and the luting agent thickness was considered 25 μm. Three load conditions were applied on eight points in each functional cusp in horizontal (57.0 N), vertical (200.0 N) and oblique (400.0 N, θ = 120°) directions. Five different luting agents were evaluated. All materials were assumed to be linear elastic, homogeneous, time independent and isotropic.
Results: For all luting agent types, the stress distribution pattern in the cortical bone, connectors, implant and abutment regions was almost uniform among the three loads. Furthermore, the maximum von Mises stress of the cortical bone was at the palatal side of second premolar. Likewise, the maximum von Mises stress in the connector region was in the top and bottom of this part.
Conclusion: Luting agents transfer the load to cortical bone and different types of luting agents do not affect the pattern of load transfer.

Key Words: Adhesive cement, dental implants, finite element analysis

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INTRODUCTION

Dental implants are widely used in the treatment of partially edentulous patients.[1] A dental implant consists of components, which transfer chewing forces to the jaw bone. In recent years, the effects of loading on implants and surrounding bone have been widely investigated to design dental implant systems.[2] Biomechanical, mechanical, chemical and biological aspects of dental implants are required to be considered to increase the success rate of dental implants.[3]

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Osseointegration and prognosis of dental implants are influenced by many biomechanical factors.[4] The most important factors that affect dental implant-bone interface include the type and direction of forces,[5] quantity and quality of the supporting bone[6] and materials of dental implant and prosthesis.[7] Dental implants and prostheses are attached using different types of luting agents, which are commonly used to increase retention and to improve the marginal seal of prosthesis.[8,9] To investigate the biomechanical factors, it is necessary to predict stress distribution on the implant structure. Stress is the consequence of masticatory load on the prosthesis.

In a study by De Jager *et al.*[10] investigated a simple model that imitated the contraction behavior of luting agents to evaluate the finite element model merit in predicating the contraction stress. They compared the experimental contraction stress by finite element method (FEM) analysis and demonstrated that it is a reliable method to predict the actual contraction stress in dental restorations when the luting agent thickness is uniform. In addition, the thinnest layer resulted in the smallest deformation and stress. Sannino *et al.*[11] evaluated the stress distribution of a three-unit zirconia based implant-supported fixed dental prosthesis (FDP), using the 3D-FEM with different load conditions. Accurate information about the clinical success of FDP was obtained by FEM. Furthermore, they found the highest von Mises stress in the cervical area of the frameworks and abutment. The maximum tensile stress and fracture risk occurs in the connector regions. Moreover, tensile stress values and stress distribution extremely depend on the loading condition.

Liu *et al.*[12] investigated the effect of luting agent types and thickness on the stress distribution within all-ceramic crowns using the FEM. The results of their study showed that luting agent thickness does not have a significant effect on stress distribution of the core or veneer. However, the loading conditions and elastic modulus of luting agents play a vital role in stress distribution.

Different luting agents have various properties such as modulus of elasticity, compressive and tensile strengths, toughness and poisson ratios.[13,14] The FEM is an efficient method to evaluate the effects of luting agents on the stress distribution. Recently, the FEM has been widely used in implant dentistry researches.[1,3,15,16] The aim of this study was to evaluate the effect of type of luting agent on stress distribution of the bone surrounding implants in a three-unit FDP using FEM analysis. The null hypothesis was that the type of luting agent does not have any effect on stress distribution pattern of a three-unit implant-supported FDP.

MATERIALS AND METHODS

Preparation of the model

A 3D FE model of three-unit implant-supported FDP replacing the maxillary first molar with maxillary second premolar and second molar as the abutments was designed based on Wheeler's dental anatomy.[17] Figure 1 shows the geometric mesh of the modeled FDP. The mesh has been achieved after evaluating the dependency and sensitivity for discretization.

Generation of the numerical model

The maxillary second premolar and maxillary second molar were supported by two standard-plus screw-shaped implants (4.1 diameter, 043.152S for premolar and 4.8 diameter, 043.252S for second molar, Straumann AG, Waldenburg, Switzerland) with regular neck solid abutments (048.541, Straumann AG) with 5.5 height and 6° tapered tightened on the implants. A sanitary pontic was considered to replace the missing maxillary first molar. All superstructure materials used in this study had two 4-6 mm^2 connectors. A porcelain veneer with 1 mm thickness and a base-metal core from minimum 0.5 mm to maximum 1.5 mm thickness were established for porcelain fused to metal framework. Although the thickness of luting agent does not have an important effect on stress values,[12] the luting agent thickness was considered 25 μm.[11] The FDP model was designed using CATIA V5 R18 software (Dassault System, Suresnes Cedex, France)[18] based on Wheeler's anatomical teeth dimension.[17] Mesh design and FEM calculations were carried out using ABAQUS/CAE 6.6 version (Hibbitt, Karlsson and Sorensen Inc., Providence, Rhode Island, USA). The whole model was created with C3D4 elements (4-node linear tetrahedron). In total, the model was consisted of 465108 nodes and 86296 elements [Figure 1].

Loading condition

To simulate the model during mastication movements, three different loads were considered in oblique, vertical and horizontal directions. On the functional cusps of the FDP, 400 N oblique, 200 N vertical and 57 N horizontal loads were applied [Figure 2]. To simulate an oblique loading condition, a 400 N load was applied with θ = 120° according to the horizontal plane to the palatal cusps of each prosthetic unit.[19]

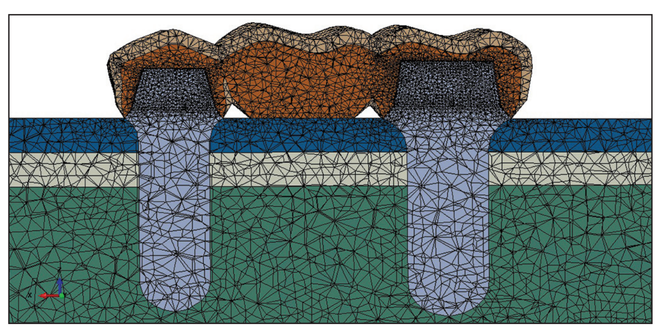

Figure 1: The geometric mesh of the modeled fixed dental prosthesis

Each load case was carried out separately and applied on 8 equal points of each unit.[12]

Materials properties

To apply the boundary condition, all nodes in the y–z plane at the end of the x-axis in both directions were fixed; no translation was allowed in any direction [Figure 2]. All the interfaces were merged together. All materials were assumed to be linear elastic, homogeneous, time independent and isotropic.[19-21] The material properties of the FDP unit[19] and different types of luting agents are listed in Tables 1 and 2 respectively.

RESULTS

Stress distribution in the supporting bone

The stress levels were calculated using von Mises stress value which is an appropriate criterion for stress evaluation of ductile materials. Contours of stress distribution on the cortical bone corresponding to three different loads are shown in Figure 3. The maximum stress occurred at oblique load. The maximum von Mises stress values were localized in the palatal side of second premolar supporting bone; particularly the area of cortical bone which has interaction with the implant. The maximum value was 48 MPa in all cases [Figure 3] and the minimum von Mises stress values occurred in the area far from the implants. To compare the results of simulation of the model with different types of luting agents, contours of the cross sectional view of the cortical bone are shown in Figures 4-6. As shown in these figures, there is a little difference between contours of stress distribution.

Stress distribution in the connectors

Figure 7 shows the stress distribution in connectors region under horizontal, vertical and oblique load

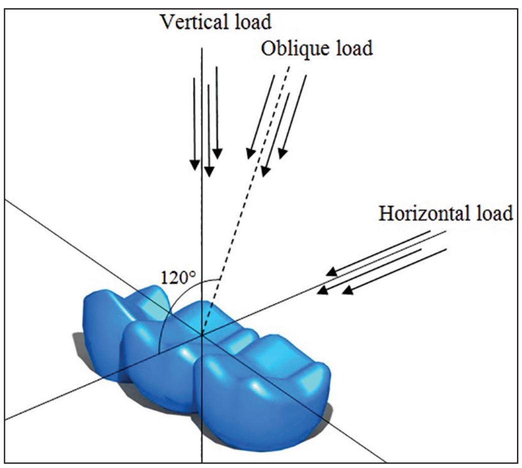

Figure 2: The directions and magnitudes of three load conditions

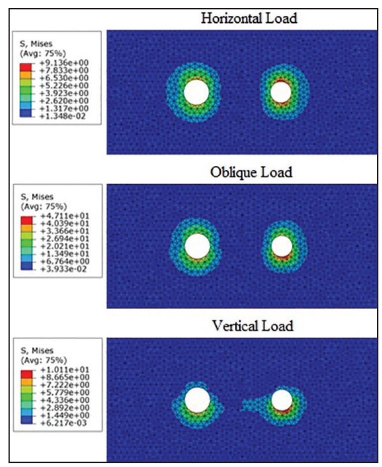

Figure 3: Von Mises stress values (MPa) and distribution patterns on the cortical bone when the different loads were applied

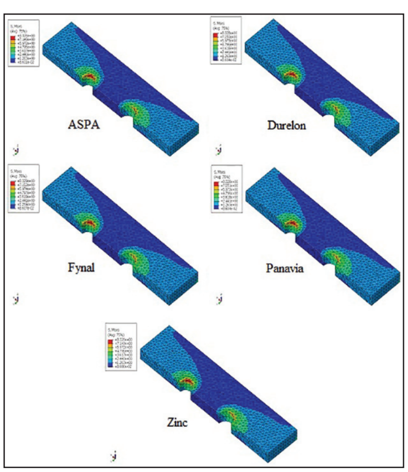

Figure 4: Comparison of applying different types of luting agent materials to cortical bone stress distribution (horizontal load)

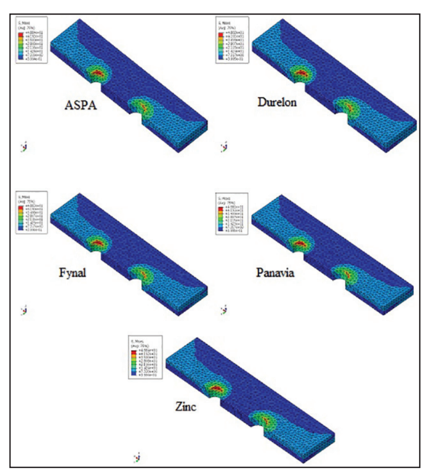

Figure 5: Comparison of applying different types of luting agent materials to cortical bone stress distribution (oblique load)

conditions. The horizontal load condition generated almost the same stress pattern along the connector while the maximum stresses were in the top and bottom of the connector due to stress concentration [Figure 7a]. Under vertical load condition [Figure 7b], shearing load behavior appeared in the bottom of the connectors which was much more than von Mises stress in the horizontal load condition. The oblique load condition is a superposition of horizontal and vertical load conditions, which resulted in the maximum stress in the bottom of the connector [Figure 7c].

Stress distribution in implant

Figure 8 shows the stress distribution in implant and abutment regions. The stress distribution patterns were similar among all luting agents. There was no significant difference between the premolar and molar implants. Moreover, the maximum von Mises stress was seen in the vertical load direction.

DISCUSSION

The failure is defined by the criteria which depend on stress distribution and material property. Therefore, the stress distribution for each part of the model is of interest. The FEM is used to evaluate the stress distribution in a structure. The FEM can employ structures of various shapes with many elements defined with specific Young's modulus and Possion's ratio values. The 3D FE model was designed of three-unit implant-supported FDP to determine the influence of different types of luting agents on stress distribution pattern of the unit.

Table 1: Elastic properties of the materials used

Material	Elastic modulus (GPa)	Poisson's ratio
Cortical bone	13.7	0.3
Cancellous bone	1.85	0.3
Titanium	110	0.35
Mucosa	0.345×10^{-2}	0.35
Porcelain feldspathic (Vita VMK 68)	70	0.19
Gold alloy PFM (Ceramco)	86.2	0.33

The periodontal ligament is absent in implant-supported FDP, hence the stress occurs as a result of functional forces, which are directly transmitted to the supporting bone. A study by Bozkaya *et al.*[22] showed that occlusal loads more than 1000 N will overload the compact bone and change its geometric shape. Different types of loading were applied to the framework; the maximum mastication load cases were considered as 400 N oblique, 200 N vertical and 57 N horizontal. As shown in the results, the maximum stress values in surrounding bone, connectors, implants and abutments occurred in the oblique load. The applied oblique load has the maximum value compared with the vertical and horizontal load cases. In addition, the oblique load contains vertical and horizontal components, which can yield horizontal and vertical load effects.

Adhesive cements are commonly used to enhance the retention, marginal adaptation and fracture resistance of the restored teeth. Moreover, these types of luting agents are different in terms of chemical and physical properties. For example, zinc phosphate luting agent has the highest modulus of elasticity (13.5 GPa), which protects the supra-structure material of prosthesis from destructive occlusal forces.[13] Furthermore,

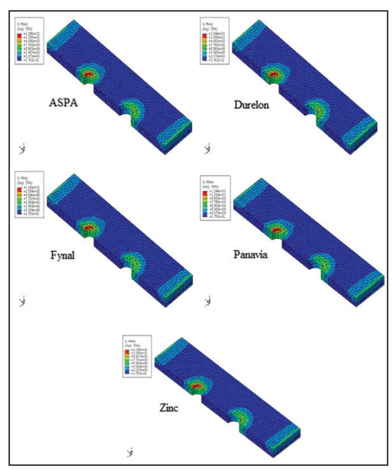

Figure 6: Comparison of applying different types of luting agent materials to cortical bone stress distribution (vertical load)

Table 2: Luting agents used

Luting agent type	Product	Elastic modulus (GPa)	Poisson's ratio
Glass ionomer	ASPA IV (Dentsply, York, Penn, USA)	9.8	0.30
Resin-composite	Panavia F 2.0 (Kuraray America, NY, USA)	4.04	0.30
Polymer-modified zinc oxide eugenol	Fynal™ (Patterson. St. Paul, MN, USA)	3.04	0.30
Zinc phosphate	Zinc cement improved (SS White, Prima Dental Group. Gloucester, UK)	13.7	0.30
Zinc polycarboxylate	Durelon (3M ESPE. MN, USA)	4.4	0.30

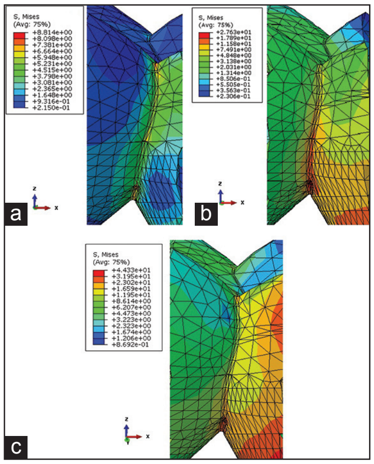

Figure 7: Stress distribution in connector regions (a) horizontal, (b) oblique, (c) vertical

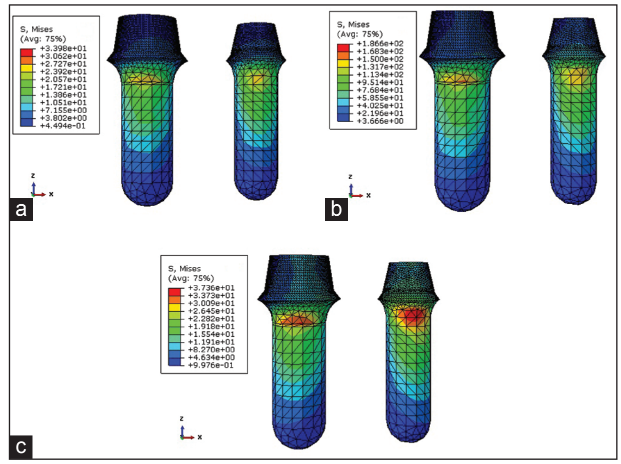

Figure 8: Stress distribution in implant and abutment regions (a) horizontal, (b) oblique, (c) vertical

polycarboxylate luting agent has lower compressive (55-85 MPa) and higher tensile (8-12 MPa) strength than zinc phosphate agent, that result in more deformation which is not suitable for high force concentration in occlusal area.[13,19] Covey *et al.*[23] demonstrated that permanent luting agents like zinc phosphate agent generate uniaxial retention forces from 2.5 to 4.7 times greater than provisional luting agents such as zinc oxide eugenol. Nejatidanesh *et al.*[24] in their study have reported a significant difference between the mean retention values of different luting agents. Moreover, the results of their study showed that resin luting agents had the highest retention. On the other hand, resin modified glass ionomer, zinc phosphate, zinc polycarboxylate and Panavia F2 have been suggested for definitive cementation of single implant-supported restorations.[25]

The result of the present study showed that the maximum von Mises stress of the cortical bone was at palatal side of the second premolar. Sevimay *et al.*[7] evaluated the influence of various occlusal materials on the stress transferred to implant-supported prostheses and supporting bone using the FEM. The results of their study showed that von Mises stress increased in the coronal one-third and two-third of the lingual surface of the cortical bone. The modulus of elasticity of cortical bone is higher than spongy bone and for this reason, cortical bone is stronger and more resistant to deformation. Hence, higher stress values can be seen in cortical bone compared to spongy bone.[7]

The results of this study showed that there were no significant changes in the cortical bone, implant and abutment stress distribution pattern for different luting agent materials. Similar results were observed by comparing Panavia F and Variolink II resin composite luting agents.[12] One may conclude, the luting agent plays a role in transferring the load to cortical bone, implant and abutment, but different types of luting agents may not affect the pattern of transferring load to the cortical bone. However, different types of luting agents might slightly change the direction of the load transferred to the bone due to different displacement field of luting agents under the same mastication load. Due to the palatal direction of oblique force on functional cusps, maximum von Mises stress values were observed in the palatal area between the cervical region of the implant and supporting bone.

Several FEM studies have been carried out on FDP's connector that evaluated height,[26] type[27] and design of connectors.[28] In the present study, the effect of type of luting agent on stress distribution in the FDP's connectors was evaluated and the maximum stresses in the FDP were in the top and bottom of the connector region that was due to stress concentration in the sharp edges. Therefore, connectors are weakest region in FDPs. It has been reported that regardless of types of connectors' material, it is the weakest part of the FDP and also connectors are more likely to fail.[29-32]

In the implant part for all load cases, the stresses were concentrated in the neck of implant due to the rigid connection between implant and bone which was similar to Oruc *et al.* study.[27]

In the present study, all luting agents were not observed and only well-known luting agents were evaluated. In addition, due to high calculation cost for simulation of whole jaw bone, the model of jaw bone was simplified. The achieved results using some assumptions regarding material properties in each layer of the FE model were compared qualitatively with each other in the current study. Therefore, stress distribution patterns may have been different depending on the material properties assigned to each layer of the FE model and the model used in the experiments. Thus, as many *in vitro* studies, it is difficult to extrapolate the results of this study directly to the clinical situation and the inherent limitations in this study should be considered.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn:

1. The stress distribution depends on the loading conditions.
2. The highest stress value was observed at oblique load condition.
3. The maximum von Mises stress was in the palatal side between the cervical region of the implant and supporting bone.
4. The type of luting agents did not affect stress distribution and stress values at the bone surrounding implant.
5. The maximum tensile stress and fracture risk occurs in the connector regions.

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