

## Stress Distribution in Luting Cement Layer in Implant Supported Fixed Partial Dentures Using Finite Element Analysis

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### Abstract

**Background and Aim:** Luting cements are necessarily used to increase retention and enhance the marginal seal of fixed partial dentures (FPDs). In this study, the finite element method (FEM) was used to investigate the effect of different types of luting agents on stress distribution in the luting cement layer in a three-unit implant-supported FPD.

**Materials and Methods:** A three-dimensional (3D) FE model of a FPD was designed from the maxillary second premolar to the second molar teeth using CATIA V5R18 software, and analyzed by ABAQUS/CAE version 6.6 software. Three load conditions were statically applied to eight points in each functional cusp in horizontal (57.0 N), vertical (200.0 N) and oblique (400.0 N,  $\theta=120^\circ$ ) directions. Five luting agents including glass ionomer, zinc polycarboxylate, polymer-modified zinc oxide eugenol (ZOE), composite resin and zinc phosphate were evaluated.

**Results:** The stress distribution pattern in the luting cement layer was almost uniform in all luting cements. In addition, the maximum von Mises stress in the luting cement layer (39.96 MPa) was at the cervical one-third of the palatal side of the second premolar when oblique force was exerted on zinc phosphate cement. Moreover, the minimum von Mises stress in the luting cement layer (0.41 MPa) was at the lateral side of the coronal one-third when the horizontal force was applied to the Polymer-modified ZOE cement. Likewise, the luting cement layers in the premolar tooth showed greater von Mises stress than that in molar tooth.

**Conclusion:** The type of luting cement has no significant effect on the stress distribution pattern in the luting cement layer; however, von Mises stress values were different in various types of luting agents. USE of zinc phosphate cement is associated with more limitations.

**Key Words:** Luting agent, Dental implant, Finite element method, Fixed partial denture

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### Introduction

Dental implants are presently a popular treatment option for replacement of the lost teeth and demand for this treatment is increasing [1]. Results of a systematic review conducted in Iran revealed that the prevalence of edentulism varies from 0.3% in 3

year-olds to 70.7% in individuals over 70 years of age [2].

Success of dental implant treatments depends on several factors including their biocompatibility, biofunctional, biomechanical, mechanical, chemi

cal and biological properties as well as their appropriate clinical application [3-6]. These factors must be carefully considered to increase the success rate of implant treatments [4]. When dental implants are subjected to occlusal loads, the key to their success or failure of is the pattern of stress distribution in them. The created stress depends on the type and direction of the load applied [4, 7], physical and surface characteristics of the implant [4, 8] and quality and quantity of bone [4, 9].

Finite element analysis is a suitable technique to assess stress distribution and has been widely used in dental implant studies in the past two decades [4, 10-12]. De Jager et al [13], used a simple model simulating the setting behavior of luting cements to test the accuracy of the FEA for prediction of the magnitude of the setting stresses occurring clinically in cements. They stated that FEA was a reliable method to predict the actual stresses created in dental restorations. Shahrbaaf et al [14], evaluated the effect of different tooth preparation designs and the luting cement properties on the stress distribution in crown-tooth complex and demonstrated that both the tooth preparation design and the elastic modulus of the cement affect the stress state in the crown-tooth complex.

Liu et al [15] assessed the effect of different luting cements and their thickness on stress distribution in all-ceramic crowns using FEA. They reported that although the loading conditions or cement moduli play a significant role in stress distribution, the cement thickness has no important effect on stresses in the core or veneer.

Different cements have variable characteristics in terms of modulus of elasticity, tensile strength, compressive strength, toughness and Poisson's ratio; thus, naturally they can influence the magnitude and pattern of distribution of stress due to occlusal loads [16, 17]. This study aimed to assess the effect of different cements on stress distribution within the cement layer in implant-supported FPDs using FEA.

### Materials and Methods

In this study, using FEA, a 3D model of a three-unit, implant-supported FPD from the maxillary second premolar to the second molar of the same side was designed. Figure 1 shows the geometric elements of the model. A threaded, standard plus

implant system (ITI Dental Implant System, Institute Straumann AG, Waldenburg, Switzerland) for the maxillary second premolar (regular neck implant with 4.8mm shoulder diameter, 3.3mm implant diameter and 10mm length) and a regular neck implant with 4.8mm shoulder diameter, 4.8mm implant diameter and 10mm length for the maxillary second molar were used. RN solid abutments (ITI Straumann AG, Waldenburg, Switzerland) with 6° taper and 5.5mm length were designed and placed over the two implants. A sanitary pontic was also designed to replace the lost maxillary first molar tooth. The connectors of this three-unit FPD were designed in 6x4 mm<sup>2</sup> dimensions. To fabricate porcelain fused to metal (PFM) framework, porcelain veneer with one millimeter thickness and a base metal core with a minimum of 0.5mm thickness were designed. The thickness of the luting cement was considered to be 25μ [13]. The three-unit FPD was designed by CATIA V5 R18 software (Dassault Systems Inc., Suresnes Cedex, France) [18] and meshed using ABAQUS CAE version 6.6 software (Hibbit, Karlsson & Sorensen, Inc., Providence, Rhode Island, USA). For FEA calculations, ABAQUS CAE 6.6 commercial finite element package was used. The entire model was meshed using C3D4 (4-node linear tetrahedron). The model had 465108 nodes and 86296 elements (Figure 1).



**Figure 1.** The shape and geometry of the meshed three-unit FPD model Model/Luting cement layer/ Supra-structure

To simulate masticatory cycles, oblique load at 120° angle (400.0N), horizontal load (57.0 N) and vertical load (200.0N) were applied. Static loads were separately applied to the functional cusps of

FPD. Also, each functional cusp was divided into 8 equal areas and each load was exerted on these areas instead of only one point. In other words, the loads were applied to eight points on each functional cusp of each unit of FPD [15].

All nodes were fixed in the y-z plane at the end of the x axis in both directions. No movement was allowed in any direction.

All interfaces were merged. All materials were assumed to have linear elasticity (no permanent deformation occurs in these materials; in other words, after eliminating the loads, they return to their primary dimensions).

Tables 1 and 2 summarize the physical properties of the materials used in the current study.

**Table 1.** The physical properties of the materials used in the 3D FEA

Material	Modulus of elasticity (GPa)	Poisson's ratio
Cortical bone	13/7	0/3
Spongy bone	1/85	0/3
Titanium	110	0/35
Mucosa	$0/345 \times 10^{-2}$	0/35
Feldspathic porcelain (Vita VMK 68)	70	0/19
PFM gold alloy (Ceramco)	86/2	0/33

**Table 2.** The physical properties of luting cements and the maximum von Mises stress for each load applied

Product	Modulus of elasticity (GPa)	Poisson's ratio	Horizontal load (MPa)	Vertical load (MPa)	Oblique load (MPa)
ASPA	9/8	0/3	4/97	12/78	38/59
Durelon	4/4	0/3	4/20	11/54	33/75
Fynal	3/04	0/3	3/79	10/57	30/97
Panavia	4/04	0/3	4/11	11/36	33/14
Zinc cement improved	13/7	0/3	5/22	13/12	39/96

## Results

The von Mises stress was calculated; which is a good criterion for the calculation of fracture strength or combination of stresses in two or three dimensions. It is calculated by the comparison of the results of tensile strength of materials during load application in one dimension. Stress distribution was almost similar in all cements when horizontal, vertical and oblique loads were applied. The maximum von Mises stress was found to be in the cervical one-third (marginal) of the cement layer especially at the palatal side. The minimum von Mises stress was found to be in the coronal one-third of the cement layer particularly in the lateral side (Figures 2-4). The area with maximum von Mises stress was larger in the molar cement layer; but, the maximum von Mises stress in the premolar cement layer was higher than that in the molar cement layer (Figures 2-4).

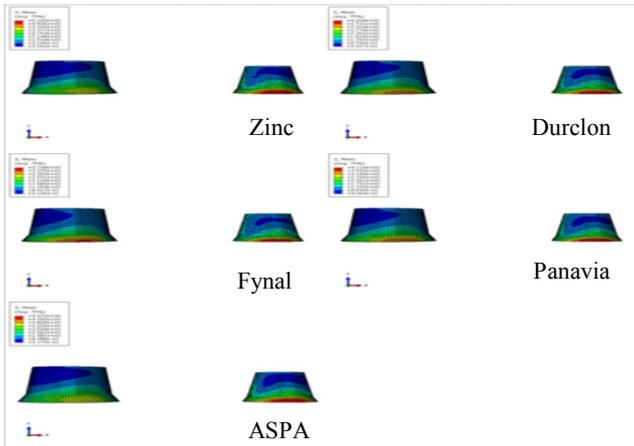
In all cements, oblique load caused the highest stress and the horizontal load caused the lowest stress with a statistically significant difference with loads in other directions (Table 2).

The highest and the lowest amounts of maximum stress were seen in zinc phosphate and polymer-modified ZOE, respectively (Table 2).

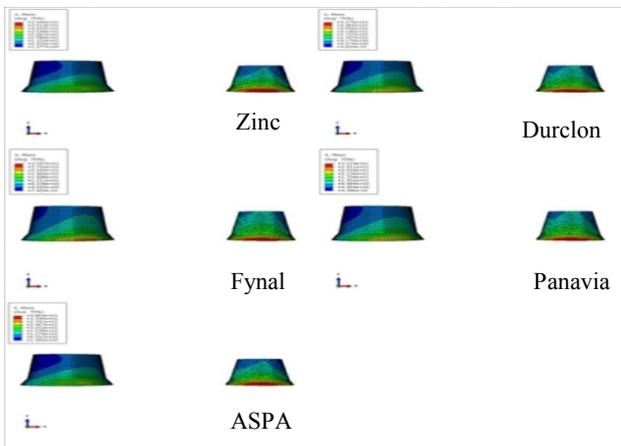
## Discussion

In the current study, a 3D finite element model of a three-unit, implant-supported FPD was designed to assess the stress distribution in different cement layers. The maximum von Mises stress was found to be significantly different in the same cement when loads of different directions were applied; which indicates that stress distribution greatly depends on the load conditions. This finding is similar to the results of Liu et al [15].

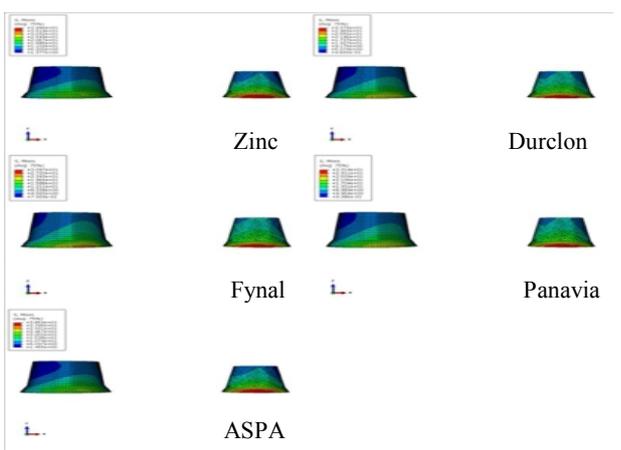
In our study, the maximum oblique load of 400N, vertical load of 200N and horizontal load of 57N



**Figure 2:** Comparison of stress distribution in the cement layer in different groups when horizontal load is applied



**Figure 3.** Comparison of stress distribution in the cement layer in different groups when vertical load is applied



**Figure 4.** Comparison of stress distribution in the cement layer in different groups when oblique load is applied

were applied to simulate occlusal loads in the clinical setting. The highest von Mises stress in the luting cement layer occurred when oblique load was applied to all cements; this finding is due to the higher magnitude of the oblique load applied and the direction of this load, which is the resultant of horizontal and vertical components.

In the current study, the thickness of the luting cement was considered to be  $25\mu$ . Kamposiora et al, [19] in their study using 3D FEA stated that the  $25\mu$  thickness of luting cements only slightly affects the stress distribution pattern. The higher the luting cement thickness, the greater the stress. Thickness of the luting cement thinner than  $50\mu$  decreases the bond failure. The results of the current study showed that the maximum von Mises stress was at the cervical one-third (marginal) of the cement layer. By increased thickness of the luting cement, the stress concentration at the margins and along the stress bearing area significantly increases [20].

The highest and the lowest values of maximum stress were observed in the zinc phosphate and the polymer modified ZOE cements, respectively. In dental implants, luting cements are widely used to increase retention and marginal fit. Different luting cements have variable chemical and physical properties. For instance, zinc phosphate cement has the highest modulus of elasticity (13.5 GPa) and protects the implant prosthesis against destructive occlusal loads. The polycarboxylate cement has lower compressive strength (55-85 MPa) and higher tensile strength (8-12 MPa) than the zinc phosphate cement; resulting in its greater plastic deformation and thus, it is not suitable for high occlusal loads [21]. In the current study, the highest von Mises stress was observed in the zinc phosphate cement layer, with the highest modulus of elasticity. The lowest von Mises stress was noted in the polymer modified ZOE, with the lowest modulus of elasticity. Using 2D FEA, Agnihotri et al. [22] concluded that the failure threshold of the luting cements is influenced by the elastic modulus of the luting cements as well as the type of crown. Kamposiora et al, [19] in a 3D FEA study evaluated the microfracture of different luting cements under crowns. They reported higher stress in luting cements with higher modulus of elasticity. Moreover, glass ionomer and composite resin with more fa-

avorable mechanical properties than those of zinc phosphate and zinc polycarboxylate were more resistant against microfractures. However, the difference between the maximum von Mises stress in the luting cement layers during the application of three loads or using cements with different tensile moduli was not significant. The highest difference in modulus of elasticity of luting cements was 10.66 GPa; but, the highest difference in oblique, vertical and horizontal loads was 8.99, 2.63 and 1.43 MPa, respectively; which were not significant. Al-Wahadni et al. [23] stated that the fracture resistance of In-Ceram and IPS Empress-2 crowns was not influenced by the type of luting cement.

The maximum von Mises stress in the premolar cement layer was higher than that in the molar cement layer; thus, failure of the premolar cement may occur sooner than the molar cement. The reason may be that the load is applied to a smaller area in the premolar cement layer. Also, the screw-retained abutments for premolar fixtures may be superior to the cement-retained abutments; but, further clinical studies are required in this respect.

One limitation of our study was using the simplified model of the jaw due to the high cost of simulation of the entire jawbone. Moreover, only the properties of highly popular cements were investigated in this study and all cements available in the market were not evaluated. Similar studies are required to assess all cements available in the market under in-vitro and in-vivo conditions.

## Conclusion

The type of luting cement has no significant effect on the stress distribution pattern in the luting cement layer; however, the highest von Mises stress was noted in the cervical one-third (marginal) of the palatal side of the premolar cement layer as the result of an oblique load applied to the zinc phosphate cement.

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