The effect of luting cement type and thickness on stress distribution in upper premolar implant restored with metal ceramic crowns

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Abstract

Objective: to study the effect of using two cement types, with three different thicknesses, on stress levels and distributions within bone around implant premolar using three-dimensional Finite Element Analysis techniques.

Materials & methods: A three 3D Finite Element models were built for this purpose. Threaded titanium dental implant was implemented in simplified geometry for jaw bone. While the crown geometry, was acquired by 3D scanner. Two cement materials (Zinc phosphate, Glass Ionomer), with three values of cement layer thicknesses (20, 40, and 60 μm) were investigated. Twenty-four case studies were reported within this research. Each case was analyzed under vertical and oblique loading at Palatal Cusp Tip and Central Fossa.

Results: Linear static stress analysis was performed. The results of the model showed the superiority of 60 μm thickness cement layer over the other two thicknesses.

Conclusions: Using thicker cement layer increase its lifetime, in addition to reducing the cortical bone Von Mises stress. While, the effect of cement layer thickness and type on spongy bone, is negligible.

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Keywords: Finite element method; Cement-retained implant; Cement type; Cement thickness

1. Introduction

Implant-supported fixed prostheses may be cemented or screw retained on the implant abutments [1]. The choice between these retention mechanisms has focused mainly on aspects such as retrievability [2], passivity, occlusion, and esthetics [3–5]. Therefore, cementation may be preferable, particularly in single-unit restorations or short-span prostheses [5].
Additional advantages have been suggested for cement-retained over screw-retained prostheses [6,7], preventing food impaction, including more equitable stress distribution [7], improved axial loading of implants [1], greater ease of superstructure adjustments [8,9], the elimination of the risk of screws loosening [6,10], and better esthetics due to the absence of screw access holes [11,11].

In addition, the cement-retained design permitting the development of the desired occlusal interdigitation, and correct loading characteristics. Abutment preparation designs and cementation techniques now mimic conventional fixed prosthodontic procedures for natural teeth. Moreover, the cement space that exists between the crown and abutment can help compensate for minor discrepancies in the fit of the prosthesis [12]. However, cementation of a superstructure makes removal of cemented restorations more difficult. But Retrievability may no longer be an essential requirement because of substantial increases in the success, predictability, and survival rates of dental implants [13].

The choice of the final cement in implant dentistry is more broad and varied than for natural teeth. Traditional dental cements can be used for cast restorations. The luting properties of cements traditionally used in dentistry have been reevaluated for implant dentistry where the adhesion occurs between two metallic components. Hence one of the first requirements in the selection of a class of luting agents are the type of cementation desired [14].

Zinc phosphate cement exhibits good compression and tensile strengths when in a 25-μm film thickness. A cooled glass slab allows the incorporation of more powder in the mix, which increases the compressive strength and reduces solubility after setting, i.e., the cooler the slab, the longer the working time. In general, most cement types do not reach their final strengths for 24 h [15].

Indeed, multiple abutments have more than adequate working time for proper cementation. Excess material is easy to remove without scratching the implant surface. The phosphorous acid is not a disadvantage, as with natural teeth. Zinc phosphate on an implant does not require a cavity varnish (as with teeth to protect the pulp), which reduces retention. Zinc phosphate often is the cement of choice for definitive cementation of an implant restoration [16–18].

Glass ionomer cements may adhere to enamel or dentine and release fluoride for an anticariogenic effect. Their properties for luting fixed restorations to natural teeth are excellent. However, their performance as luting agents on metallic abutments has raised controversy [6].

However, Glass-ionomer cements may be indicated for luting implant abutments because of their low coefficient of thermal expansion, ability to bond chemically to metal oxides, and the compressive strength of glass-ionomer cement has also been shown to increase over time [19].

It is known that the overall fracture resistance of all restorations is strongly dependent on the support material. Additionally, preparation design, dentin thickness, cement type and thickness can be influential factors [20].

Mostly, all cements are soluble in oral fluids. The precision of the crown margin not only minimizes plaque retention and enhances soft tissue health but also minimizes the effects of cement solubility. Marginal gaps greater than 75 μm may lead to accelerated cement wash out and retention failure. In order to reduce the cement margin thickness, several approaches have been suggested. A groove may be placed in the preparation or the casting to act as an additional spacer or vent for the cement. In implant prostheses the casting is often thicker than on natural teeth. As a result, a groove may be placed inside the casting, from the occlusal (incisal) to a few millimeters above the margin. The cement seal may be reduced to almost one half of its thickness with this technique. Another method to reduce film thickness is the timing of the prosthesis insertion. Film thickness can be increased by 10 μm (or more) for every additional 30 s once the cement was properly mixed [21,22].

One of the most important properties of dental cements is resistance to dissolution after exposure to oral fluids at the restoration margin that could lead to cohesive failure of the cement. The dimension of the marginal gap could also affect dissolution with gaps under 100 μm showing similar dissolution rates [23,24].

In a FEA study that considered the effect of occlusal loads on the stress distribution in the luting agent beneath full coverage crowns, masticatory loads caused stresses well below the elastic limit of cement [25–27].

In previous study aimed to test the effects of crown margin type, cement type, cement thickness, loading direction, and loading magnitude on stress levels and distributions within luting cement that might lead to cement microfracture, using three-dimensional Finite Element Analysis techniques. It was concluded that the cement thickness minimally affected stress levels and distributions and greater stresses were found in cements with the greater Young's modulus [28].
The effects of dentin and cement thicknesses on stress level and distribution of crack propagation in ceramic-cement-dentin multilayer complex were analyzed by Cem et al. [29]. Custom-designed finite element analysis program was used to analyze the stress distribution and present the maximum principal stress locations. They found that the cement thickness had a minor influence, but the thickness and type of ceramic system played a significant role.

Less was known about the effect of cement type and thickness on stress transfer, therefore, the objective of this study was to test the effects of (1) cement type, (2) cement thickness on stress distributions within bone around implant upper premolar using three-dimensional Finite Element Analysis techniques. In the present study, FEA models were constructed. To avoid exceeding the elastic limit of each material and hence resulting in nonlinearity or plastic deformation, load values in the range of 100–200 N were chosen. Furthermore, for all models in this study, stress and strain was calculated at constant load.

2. Materials and methods

To investigate the effect of luting cement type and thickness on stress distribution in upper premolar restored, three 3D finite element models were developed. Bone geometry was simplified and simulated as two co-axial cylinders. The inner one represents the spongy bone (diameter 14 mm & height 22 mm) which fills the internal space of the outer cylinder (shell of 1 mm thickness) that represents cortical bone (diameter 16 mm & height 24 mm). The implant–abutment complex1 was drawn in three dimensions by commercial general purpose CAD/CAM software “Auto-Desk Inventor”2 version 8.0. The root form dental implant had nominal diameter of 3.7 mm, length of 13 mm and the shape of internal hex with hex width of 3.5 mm. The abutment was prepared for resting variable cement layer 20, 40, and 60 μm. These parts are regular, symmetric, and its dimensions can be simply measured with their full details.

On the other hand the “Premolar crown” has too complicated geometry, therefore a three dimensional scanner was utilized for its modeling, Roland Modela – MDX-15,3 to produce cloud of points or triangulations to be trimmed before using in any other application (see Fig. 1).

Roland Active Piezoelectric Sensor and computer graphics program (Dr. PICZA) were utilized in acquiring and producing a data file contains a large set of points’ coordinates, usually called cloud of points. An intermediate, software was required (Rhinoceros4 vr. 3.0) to find out a set of equally spaced planes intersecting the scattered points (Represent the scanned crown surface). Then each plane was divided into two parts, outer part (not required), and inner part represented the crown interior material. Finally, by the connection of these intersecting planes the crown geometry has been formed. The crown geometry was exported to finite element program as SAT file format [30].

On the finite element software environment ANSYS5 version 9, set of operations like subtracting volumes to form cavities which fit other parts to be assembled together in full contact. The final step was to ensure correct placement of the volumes and to secure error of overlapped materials during further analysis. All model parts were meshed (as presented in Fig. 2), by 8 nodes brick element Solid 45 [31] which has three translation degrees of freedom in the global axes directions. Meshing process resulted in huge number of nodes, and elements, which are listed in Table 1. A grid sensitivity study was performed to choose the most convenient number of elements (in terms of computational time and results accuracy), which assured an accurate description of sharp angles and curves. Crown material properties represent porcelain fused to metal (PFM), was calculated as weighted average of porcelain (55%), and NiCr (45%). While Table 2 lists the properties of the used materials.

The model was subjected to four different loading conditions by applying vertical and oblique loading as; two forces at Palatal Cusp Tip and Central Fossa each of 150 N, and two forces at Palatal Cusp Tip and Central Fossa as 200 and 100 N respectively. The base of hollow cylinder representing the cortical bone was set to be fixed as a boundary condition. Linear static analysis was performed on a personal computer Intel Pentium Core 2 Duo, processor 3.0 GHz, 4.0 GB RAM.

3. Results

Twenty-four cases were analyzed in this study. That resulted in a huge number of graphical representations (ANSYS screen shots) of different types of stresses, deformations, and strains.

1 Zimmer dental Inc, USA.
2 Autodesk Inc., San Rafael, CA, USA.
3 Roland DG Corporation of Hamamatsu, Japan.
4 McNeel North America, Seattle, WA, USA.
5 ANSYS Inc., Canonsburg, PA, USA.
**Fig. 3** represent crown Von Mises stress and total deformation under vertical loading of two forces at Palatal Cusp Tip and Central Fossa each of 150 N, that cemented by a layer of Zinc phosphate of 20 μm thickness. The maximum Von Mises stress and total deformations, was located directly under the applied load position.

Maximum Von Mises stress appears on cement layer top edges towards the Palatal Cusp Tip that the applied load vertical components resultant is nearly above this point. **Fig. 4** showed Zinc phosphate cement layer with 60 μm thickness Von Mises stress distribution under vertical and oblique loading of 150 N at Palatal Cusp Tip and Central Fossa.

Maximum Von Mises stress, and total deformation, distributions on implant—abutment complex underneath 40 μm Zink phosphate cement layer are presented in **Fig. 5**. Such distributions represent the implant—abutment complex under vertical loading of 200 N at Palatal Cusp Tip and 100 N at Central Fossa showed typical place of maximum Von Mises stress at implant neck towards the palatal cusp tip.

Cortical bone maximum Von Mises stress was found at the bone-implant connection, while symmetric vertical deformation was expected due to unbalanced oblique loading by 200 N at Palatal Cusp Tip and 100 N at Central Fossa as illustrated in **Fig. 6**.

<table>
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<th>Table 1</th>
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<tr>
<td>Number of nodes and elements in all parts of the model.</td>
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<td>Model part</td>
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<td>Crown</td>
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<td>Abutment</td>
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<td>Jaw bone 1: Cortical</td>
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<td>Jaw bone 2: Spongy</td>
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<th>Table 2</th>
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<td>List of material properties used in the finite element analysis.</td>
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<td>Model part</td>
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<tr>
<td>Crown</td>
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<tr>
<td>Cement type 1</td>
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<td>Abutment</td>
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<td>Jaw bone 1</td>
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<td>Jaw bone 2</td>
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Shear stress dominated stress case on spongy bone. Fig. 7 showed stress intensity and vertical deformation distributions on spongy bone, under oblique loading by 200 N at Palatal Cusp Tip and 100 N at Central Fossa and 60 µm Glass ionomer cement layer.

In Fig. 8, maximum Von Mises stress values under vertical loading were compared for cement layer and cortical bone. That cement layer thickness variation and cement type effect on bone indicated the superiority of thicker cement layer (60 µm).

The findings of this study indicated that the cortical bone showed the same response to increasing the cement layer thickness regardless the cement type. Increasing the cement layer thickness up to 40 µm had
no changes on both types bone. On the other hand, cement layer thickness increase from 40 to 60 µm reduced the maximum Von Mises stress by 6.5% on cortical bones, while its effect was negligible on spongy bone.

It has been shown that the value of compressive stress gradually decreases as the distance from the loading point increases. Under vertical loading, increase cement layer thickness from 20 to 40 µm reduced the maximum Von Mises stress by 20% and 7% for Glass ionomer and Zinc phosphate respectively. While the thickness increase from 40 to 60 µm reduced the maximum Von Mises stress by less than 2% for both types. These findings are in agreement with conclusions reported by Cem et al. [29].

Implant-abutment complex showed safe behavior under all studied cement types and thickness and the applied loading conditions. For zinc phosphate cement,
Vertical loading by 150 N at Palatal Cusp Tip and Central Fossa generates Von Mises stress about 15% less than the other loading conditions by 200 N at Palatal Cusp Tip and 100 N at Central Fossa. Similarly, oblique loading produce similar results with only 5% difference under the same amount of applied stress. Also, Glass ionomer cement layer deforms under loading by 200 N at Palatal Cusp Tip and 100 N at Central Fossa up to 20% more than the case of 150 N at Palatal Cusp Tip and Central Fossa. This may be referred to the finding of the greater Young's modulus cements led to greater stresses within the cement [28].

Higher stress values would not necessarily create problem when the cement had a high enough ultimate strength to withstand occlusal stress levels. The zinc phosphate cement had the worst combination of values, highest Young's modulus (22,400 MPa) and relatively low ultimate tensile strength, which could lead to cement microfracture. On the other hand, Glass ionomer resin cements, which has medium range Young's modulus values (12,000 MPa) and high strength, is the better choice for resisting microfracture in the clinical situation, but this combined with other factors may need further clinical investigations necessary to verify this hypothesis as; (1) effect of non-uniform cement thickness, (2) consideration of other materials and marginal configurations, (3) consideration of flaws in dental cements, (4) determination of ideal cement properties to resist microfracture, and (5) modeling of a bonded interface in cement mode.

4. Discussion

Cement-retained, implant-supported prostheses have gained popularity because they allow completion of clinical procedures using conventional fixed prosthodontic techniques. In the absence of occlusal screw access openings, cemented implant-supported restorations offer enhanced esthetics and an increased number of occlusal contacts. Cemented restorations compensate for minor fit discrepancies through use of a luting agent [32].

Film thickness of luting agents can directly affect long-term clinical success. In determining the film thickness of luting cement, the experience of the dentist with the material, as well as the mixing technique, ratio and temperature, are important factors. Nonetheless, the major factor is the viscosity of the cement. Therefore, in real clinical situations, actual thickness of the cement varies due to dentist experience and the material used [29].

It was not surprising to find the stress values under oblique stressing conditions to be much higher than axial stressing conditions. This was true for all combinations of models, regardless of the type of cement, cement thickness. Higher stresses are expected under oblique loading as the load generates bending moments, that, Zinc phosphate cement layer deforms under oblique loading about 500% more than the vertical one, regardless the layer thickness and loading position. That indicates cement failure under such level of oblique loading because it has low value of ultimate tensile strength [28].

4.1. Clinical significance

The stresses distributions on cortical bone was not significantly affected by cement type but affected more by cement thickness. In addition, using cement type with greater Young's modulus led to greater stresses within the cement layer in the acceptable range. Zinc phosphate cement had the worst combination of high Young's modulus and a relatively low ultimate tensile stress which could lead to large cement deformation. While Glass-Ionomer resin cements have medium range Young's modulus values and high strength is the better choice for resisting deformation in the clinical situation, but this combined with other factors may need further clinical investigations necessary to verify this hypothesis as; (1) effect of non-uniform cement thickness, (2) consideration of other materials and marginal configurations, (3) consideration of flaws in dental cements, (4) determination of ideal cement properties to resist microfracture, and (5) modeling of a bonded interface in cement mode.

5. Conclusions

Within the limitations of this study, the following points can be concluded;

1 Increasing the Cement layer thickness(within limits) ensures longer life-time of the crown fixation because increasing cement layer thickness reduced the maximum Von Mises stress, and slightly increase its total deformation induced on the cement layer.

2 Regardless the cement type, thicker cement layer (60 µm in this study) is preferred to reduce cortical
bone stresses by about 6.5%. While, spongy bone is insensitive to cement type or its layer thickness.

3 The prosthetic material of crown is minimally affected by the type and thickness of cements used in this study.

**Ethical approval**

This research doesn’t require ethical approval and followed the Helsinki declaration.

The authors declare that they have no conflict of interest.

**Acknowledgment**

None.

**References**


