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3D Finite Element Study on Crown and Cement Materials Combination Effect on Implant-Bone Interface Stress Distribution

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ABSTRACT

Aim: This research investigates different crown and cement materials combination effect on implant-bone interface stress distribution. ***Materials and Methods:*** Premolar crown geometry was acquired by 3D scanner, while implant complex and bone components were modeled in 3D by engineering CAD/CAM software. All materials were assumed to be homogeneous, isotropic, and linear elastic. Load of 150 N was applied at central fossa, and then analysis results of the two selected categories were compared. Category I contained Enamic crown on Glass Ionomer cement, while Zirconia crown on Resin cement represented category II. ***Results:*** Enamic crown received 27 % more deformation and 50% less Von Mises stress than Zirconia one. Resin cement received about 10% more deformation and 50% less Von Mises stress in comparison to Glass Ionomer one.

Conclusions: Selecting lower rigidity crown material ensures better load distribution and transfer to underneath structures. Bone is insensitive to changing crown and cement materials.

Keywords: Finite Element Analysis; Enamic; Zirconia; Glass Ionomer cement; Resin cement.

Introduction

Dental implants offer elevated success rates in the rehabilitation of both aesthetic and functional restorations, in patients with either partial or complete dental loss. Since the introduction of dental implants, stress distribution at implant-bone interface has been of major interest for dentists. Achieving stress pattern as close to natural tooth as possible have been the goal of researchers since that time.

The key of success or failure in dental implants when subjected to occlusal loads is the pattern of stress distribution throughout the whole system. The created stress between implant and peripheral bone is affected by various factors such as the design and material of the implant, the abutment, the restorative crown (Liu *et al*., 2013), the direction of loading (de Faria *et al*., 2014), the type of cement, and quality and quantity of bone (Pauletto *et al*., 1999; Fanghänel *et al*., 2008).

When using prosthetic parts from different materials with different elastic moduli, these materials can generate different stress and strain in the implant and peri-implant bone. (Sertgoz, 1997). Considering the rigidity of these materials, the elastic modulus can vary from the modulus of a zirconia to that of a hybrid ceramic with high resilience (de Kok *et al*., 2015) due to its polymeric matrix.

The decision of choosing the crown material is very important. Ceramic materials were commonly used for dental prosthesis due to its good aesthetic and long-term resistance (Dal Piva *et al*., 2018). Also, on the long term, using ceramic crowns onto implants has been proven successfully.
Zirconia-based ceramics are one of the latest, current and widely applied ceramics in the advanced dental field. Zirconia Partially Stabilized by Yttrium (YTZP) has superior mechanical properties (Piconi *et al*., 1999) as hardness, flexural strength, compression resistance, toughness, corrosion resistance, elastic modulus, biocompatibility and good soft tissue stabilization (Hisbergues *et al*., 2009; Nevins *et al*., 2011; Dal Piva *et al*., 2018).

As a result of advances in CAD/CAM technology, monolithic zirconia restorations without veneering porcelain as (Lava Plus high translucency Zirconia (3M ESPE) have become widely used

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(Miyazaki *et al*., 2013; Stober *et al*., 2014). Its translucency was increased and full-contoured to eliminate the veneer cracking. Monolithic zirconia has been used in posterior or anterior regions, especially for single crowns due to its greater strength and improved esthetics (Piconi *et al*., 1999; Hisbergues *et al*., 2009). It has been highly recommended to be used in patients with limited inter-occlusal clearance because of its ability to resist high loads with minimum 0.5 mm occlusal thickness (Nevins *et al*., 2011).

Vita Enamic is the first hybrid dental ceramic in the world with a dual-network structure. The dominant network in this material (86% by wt.), is strengthened by a methacrylate polymer network, both networks are completely integrated with each other (Coldea *et al*., 2013).

Vita Enamic with flexural strength approximating 150–160 MPa has better abrasion behavior than composite and lower brittleness than pure ceramic. It is more appropriate to mill restorations with thinner walls for minimally invasive restorations. The excellent marginal stability of the material is due to very accurate and precise milling result for restorations (Coldea *et al*., 2013).

Cement-retained prostheses have several advantages as preventing food impaction, more equitable stress distribution (Maeyama *et al*., 2005), improved axial loading of implants (Hebel *et al*., 1997), better superstructure adjustments, avoiding the risk of screws loosening (Squier *et al*., 2001; Behneke *et al*., 2000), and more esthetics according to the absence of screw access holes (Avivi-Arber & Zarb 1996; Hebel *et al*., 1997). Also, the cement-retained pattern allows the development of the desired occlusal interdigitation and corrects loading characteristics.

The selection of final cement in implant dentistry where the adhesion occurs between two metallic components is different from that of natural teeth. So, the most important requirement, is the type of cementation required (Misch, 2005).

Because of their ability to bond chemically to metal oxides and low coefficient of thermal expansion; Glass-ionomer cements (GIS) may be the best for luting implant abutments. Also, the compressive strength of glass-ionomer cement has also been shown to increase over time (Kerby *et al*., 1992).

Resin-based cements are popularly used as cements of choice for ceramic restorations because of the disadvantages of other types of cement as lack of solubility, support, and adhesion. It has many advantages as low solubility, high bonding and compressive strength (Seung-Ryong, 2015).

Several methods have been used to study the stress/strain in bone and dental implants. Three-dimensional (3D) finite element analysis (FEA) is an analytic solution to evaluating stress distributions in complex geometries such as implant-bone interfaces (Maurer *et al.*, 1999; De Tolla *et al*., 2000). It is capable of providing detailed quantitative data at any location within mathematical model. Thus, FEA has become a valuable analytical tool in the assessment of implant systems in dentistry (Lan *et al*., 2010).

Less was known about the effect of crown cement materials combination effect on stress transfer at the implant-bone interface. Therefore; the objective of this study was to test the effects of (1) Crown type; Zirconia monolithic crown and Enamic Vita crown and (2) Cement type; Glass Ionomer cement and Resin cement, on stress distribution within bone around implant of an upper premolar using three-dimensional Finite Element Analysis techniques.

Materials and Methods

Starting by resin model of an upper first premolar crown, a 3D scanner was used to scan its surface, Roland MDX-15 (Roland DG Corporation of Hamamatsu, Japan). The scanner produced a cloud of points or triangulations (Al Qahtani *et al*., 2018) to be trimmed before use in any other application as presented in Figure 1.

The implant–abutment complex was modeled in 3D using the commercial general-purpose CAD/CAM software 'Auto-Desk Inventor' version 8.0 (Autodesk Inc., San Rafael, California). Root form Titanium implant fixture (Sky implant system by Bredent, Chesterfield, UK) of 12mm length, and 4mm diameter was used as supporting structure. These parts are regular and symmetric, and their dimensions can be simply measured with their full details (Figure 2). On the other hand, bone geometry was simplified and simulated as cylinders that consist of two coaxial cylinders. The inner one represents the spongy bone (diameter 14mm and height 22 mm) that fills the internal space of the other cylinder (shell of 1mm thickness), which represents cortical bone (diameter 16mm and height 24mm) (El-Anwar *et al,* 2013).

Mesh density is a specification that enhances the results accuracy and eliminates artificial peak stresses by enhancing the representation of the actual geometry. The effect of mesh density was evaluated before carrying out the final simulations. The number of nodes and elements in each component are listed in Table 1.

Table 1: Components mesh density

	Components	Nodes	Elements
1	**Abutment**	2.102	25.540
2	**Screw**	2.407	20.022
3	**Implant**	24.669	174.210
4	**Cortical**	1.150	51.341
5	**Spongy**	6.166	50.289
6	**Crown**	2.232	16.807
7	**Cement**	1.000	22.872

All materials were supposed to be homogeneous, isotropic, and linearly elastic and its properties based on the manufacturer's information are listed in Table 2.

Table 2: Material properties imported to the Finite Element program

Material	Young's modulus [MPa]	Poisson's ratio
Bone: Cortical	13.700	0.30
Spongy	1.370	0.30
Implant Complex		
Implant complex *Titanium* (Ti)	110.000	0.33
Implant, Screw, Abutment		
Category I		
Cement: Glass Ionomer (ASPA 40 µm layer)	9.800	0.30
Crown: Vita Enamic	30.000	0.23
Category II		
Cement: Resin (Panavia 40 µm layer)	4.040	0.30
Crown: Lava Plus Zirconia	210.730	0.34

Category I contained Enamic crown with Glass Ionomer cement, while category II included Zirconia crown with Resin cement.

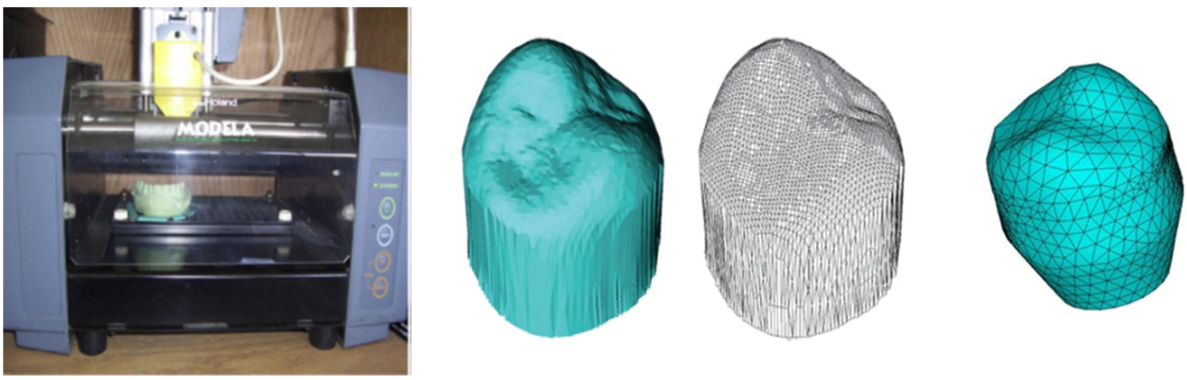


Fig. 1: 3D scanner and resultant surface after trimming and volume meshing

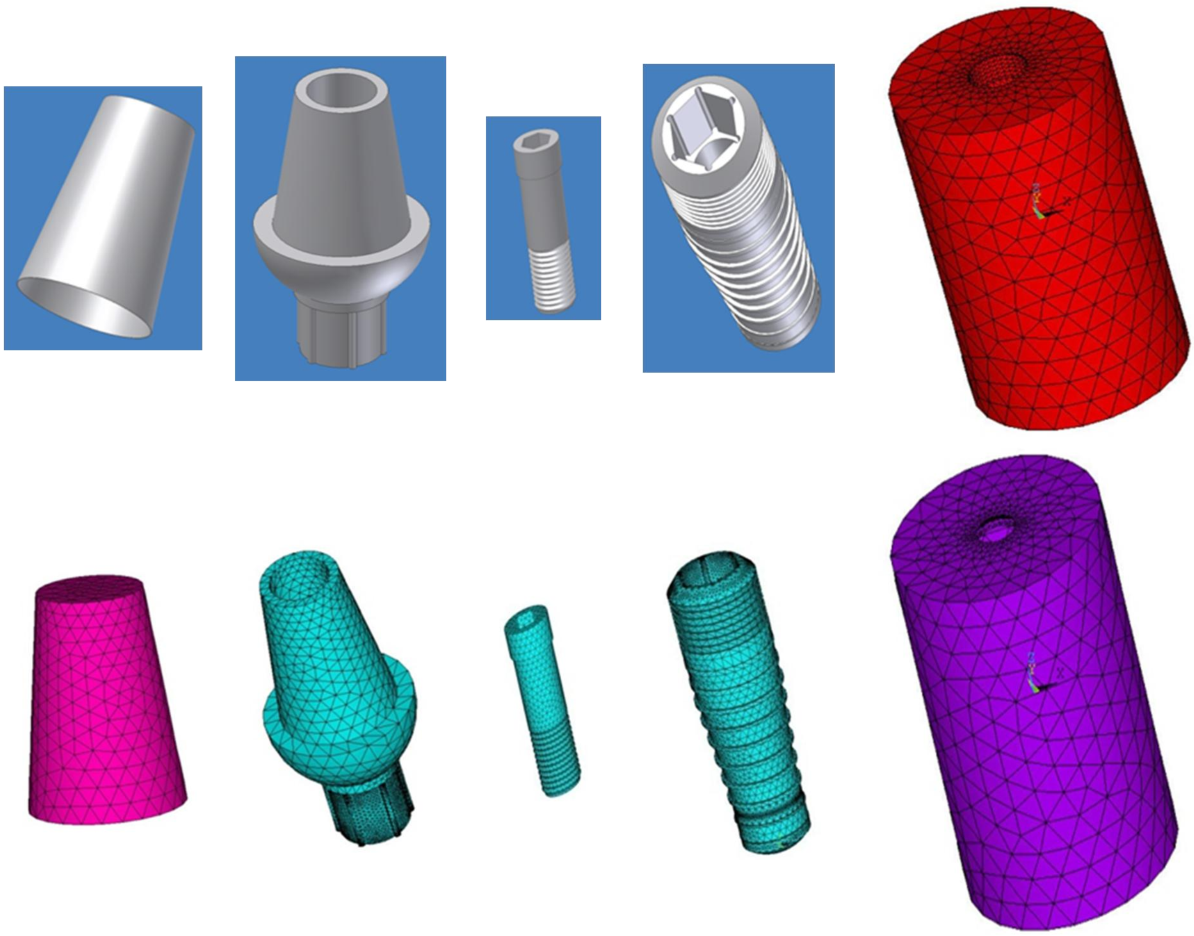


Fig. 2: Modeled and meshed model components

Loading of 150N was applied vertically (z-axis) as a compressing load on three selected nodes on central fossa, while the cortical bone cylinder base was set to be fixed in place as boundary condition.

The used finite element package was ANSYS APDL (Al Qahtani *et al*, 2018) version 16 (ANSYS Inc., Canonsburg, PA, USA) to be assembled and analyzed. While, the solid modeling and finite element analysis (linear static analysis) were performed on Workstation HP Z820, with Dual Intel Xeon E5-2660, 2.2 GHz processors, 64GB RAM.

Results

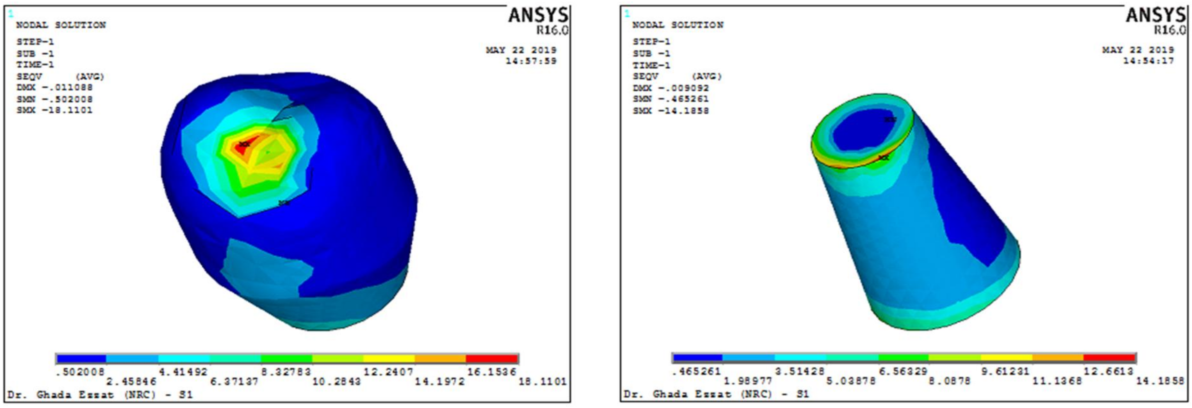
Two analyses were performed for the two categories to extract the following results.
Enamic crown is less rigid in comparison to Zirconia one, it received 27% more deformation and 50% less Von Mises stress (Figure 3).

Resin cement is more elastic in comparison to glass ionomer one, it received about 10% more deformation and 50% less Von Mises stress (Figure 3).

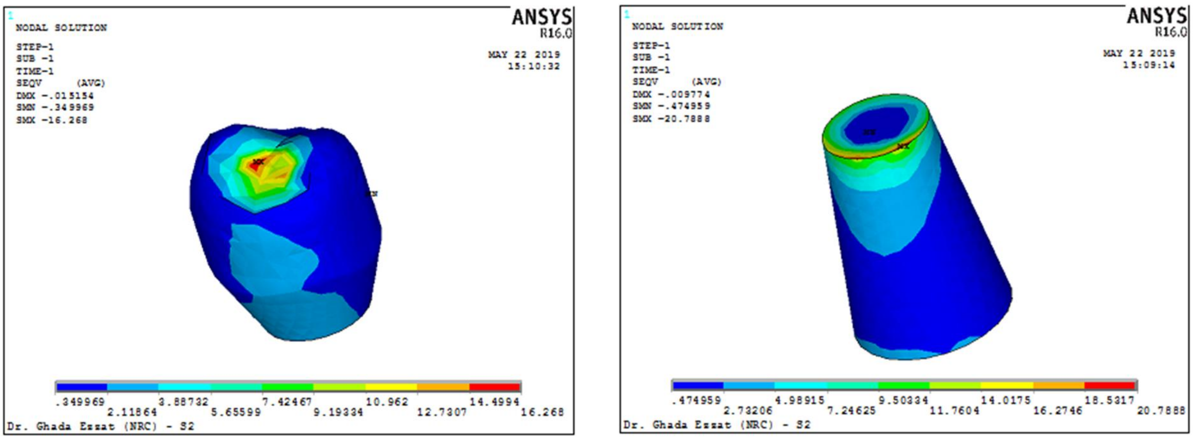
Figures 4 and 5 demonstrate Von Mises stress distribution and total deformation distributions on other components under the crown and cement in the two categories.

Significant increase in implant complex components stresses was recorded with more rigid crown (Zirconia) and slight or negligible increase in more rigid cement.

It is clear from Figure 6 that, cortical and spongy bone, were insensitive to changing crown and cement materials.



a



b

Fig. 3: Von Mises stress distribution on crown and cement;
(a) Category I (b) Category II

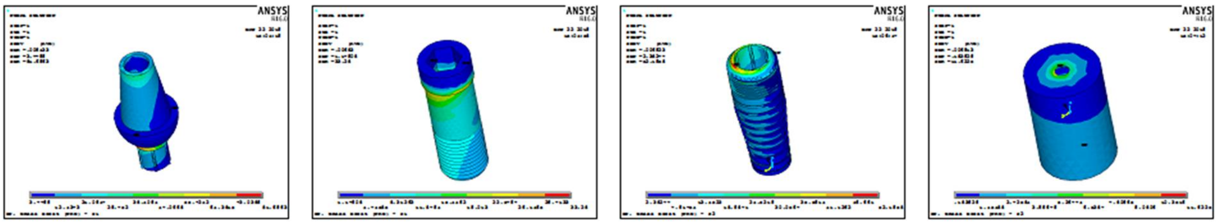


Fig. 4: Von Mises stress distribution on category I components

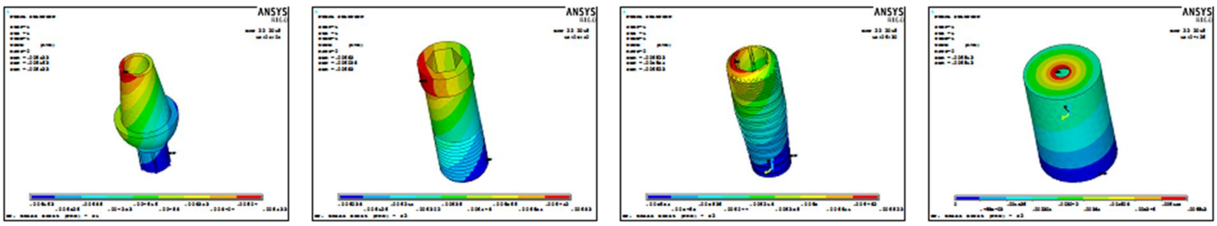


Fig. 5: Total Deformation distribution on category II components

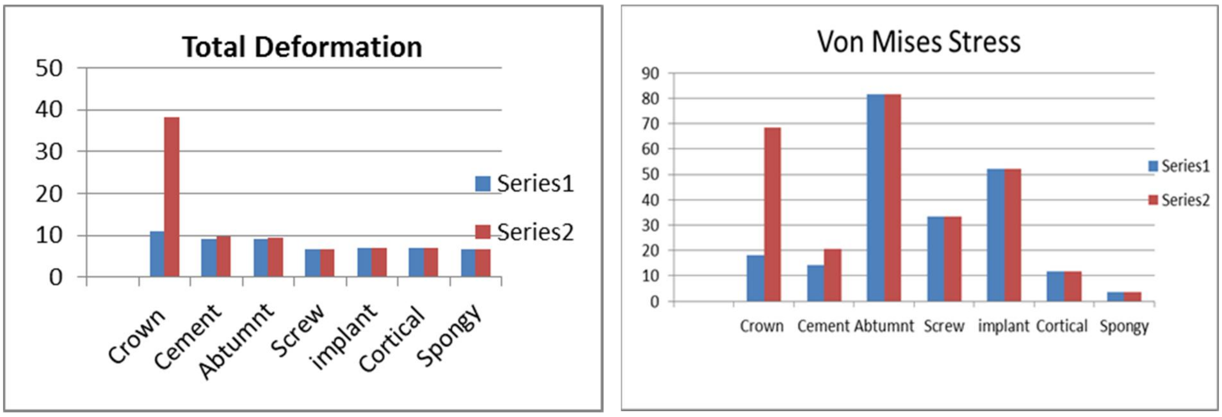


Fig. 6: Comparison between the two categories results

Discussion

Selection of the crown and cement materials are important factors in studying the stress exerted over the bone surrounding dental implant. An appropriate stress distribution on a large area of bone is preferred for the long-term success of implants (El-Anwar *et al*., 2012).

The decision of choosing the material of the crown is very important because it could affect the cases of parafunctional habits or excessive biting force. Also, according to the fact that bone behavior depends on load magnitude, it could prevent bone tissue damage (Frost, 2004).

The applied load energy will be distributed among all parts of the studied system; starting from the crown, the cement, the implant-abutment complex, to the jaw bones (cortical/spongy) (El-Anwar *et al*., 2013).

Materials with low young's modulus values (lower rigidity) have the ability to absorb more energy from the applied load, which means less energy will be transferred to the next part of the system which reduces the stresses generated on the jaw bone (cortical and spongy) , thus decreases its effect on the bone implant interface (El-Anwar *et al*., 2014).

Therefore two different crown materials (Enamic and Zirconia), and two different cements (Resin cement and Glass Ionomer cement) were investigated in this study to find out a suitable selection criterion.

In the current study, a 3D finite element model of an upper premolar was designed to assess the stress distribution using different cement and crown materials combinations.

The advantages of FEA method over *in vitro* studies are less expensive, allowing samples standardization and have fewer factors influencing the results. Also, it allows inferences in a simulated bone tissue as *in vivo* tissue (El-Anwar *et al*., 2012).

This study showed that Enamic crown is less rigid in comparison to Zirconia one, it received 27% more deformation and 50% less Von Mises stress (El-Anwar *et al*., 2012).

Therefore, crowns made from Enamic are more able to lessen stresses from occlusal forces than crowns made of Zirconia and ceramic material. (Menini *et al*., 2013; Coldea *et al*., 2013).

These results agree with (Geng *et al*., 2001; El-Anwar *et al*., 2012; and Soliman *et al*., 2015). They discovered that crown materials with low young's modulus values absorb more energy especially if it has the capability to deform freely. In other words, less energy will be transferred to the next part of the system. In addition, the highest deformation and stresses will appear on the crown and cement layers. Lower rigidity crown received slightly less stresses and higher deformation, in other words it absorb more energy than the more rigid one.

On the other hand, Bassit *et al*., (2002) stated that using different occlusal surface materials does not produce different stresses in implants.

Also, we found that bone showed no change in stress or deformation by changing the crown material, i.e. bone was insensitive to crown materials. The maximum stresses were considerably below the ultimate tensile and compressive strength of bone.

These finding is in accordance with Soliman *et al*., (2015) and Wazeh *et al*., (2018), they found that Von Mises stress on jaw bones are not affected by changing crown material. This also is augmented by results of a study (de Kok *et al*., 2015) proving that zirconia prosthesis with proper thickness has low-stress levels. Also in an important study, (Güngör & Yılmaz, 2016) proving our results, it was found that the crown material does not affect the bone stresses.

Implant stability for implant-fixed restorations can be influenced by the type of cement. Resistance to dissolution, a strong bonding, high strength under tension, good manipulation properties, and biocompatibility are properties of suitable cement.

When choosing cement materials, clinical experience should be considered (Frost, 2004). For the present study, they were the glass ionomer cements (Geng *et al*., 2001), and resin cements.

Glass Ionomer cements (GIC cements) exhibit several clinical advantages, including low thermal expansion coefficients and long-term release of fluoride. However, the use of GIC in high stress-bearing areas is limited due to low mechanical strength. In addition, GIC is not suitable for ceramics that require support from the cement (Kerby *et al*., 1992).

Resin-based cements are popularly used as cements of choice for ceramic restorations because of, its high bonding ability, low solubility and high compressive strength (Seung-Ryong, 2015).

This study showed that Resin cement received about 10% more deformation and 50% less Von Mises stress in comparison to Glass Ionomer one. This proves that cement elastic modulus affects the crown-implant system stress distribution.

A study by Liu *et al*., (2013) assessed the effect of different luting cements on stress distribution in all-ceramic crowns using FEA. They found that cement moduli play an important role in stress distribution in the crown.

In an investigation aimed to assess the effect of different cements on stress distribution within the cement layer in implant-supported FPDs using FEA. They reported that variable characteristics of different cements such as modulus of elasticity, compressive strength, tensile strength, Poisson's ratio and toughness can influence the magnitude and pattern of distribution of stress due to occlusal loads (Stober *et al*., 2014).

Also, Shahrbaf *et al*. (2013) in a study included 4 kinds of commercially available resin cements and extremely high value hypothetical cement. They studied the effect of the design of tooth preparation and the cement elastic moduli. The results showed that both affect the stress distribution of the restored crown-implant system.

Also, in a study of Seung-Ryong in (2015) he concluded that materials of low rigidity produce a lower stress distribution in the cement layer and transfer less stress to the prepared tooth.

Our results showed that spongy bone is insensitive to cement type or its layer thickness. Bone showed no change in stress or deformation by changing the crown and cement materials, i.e. bone was insensitive to crown and cement materials.

This is matched with the study of Yossef, *et al*., (2019) who reported that no effect of cement type, or layer thickness on bone. The prosthetic material of crown is minimally affected by the type and thickness of cements used.

Conclusions

Within the limitations of this research, we can conclude that using variable dental crowns and cements with different moduli of elasticity strongly affects the stress distribution of the crown, cement layer and implant. Crown and cement materials with low elastic moduli (lower rigidity) have the ability to absorb more energy from the applied load, which means less energy will be transferred to the next part of the system. Bone showed no change in stress or deformation by changing the crown and cement materials, i.e. bone was insensitive to crown and cement materials.

Ethical Approval

This research did not require ethical approval and followed the Helsinki declaration.

Conflict of interest

The authors declare that they have no conflict of interest.

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