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Evaluation of Stress Distributions in All Ceramic Conometric Single Crown Restorations: 3-Dimensional Finite Element Analysis

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ABSTRACT

Objective: The aim of the study is to compare the effect of monolithic translucent zirconia ceramic (TZI) and monolithic lithium disilicate glass ceramic (LDS) restorative materials on stress distributions in implant components and surrounding bone tissues in implant-supported conometric single crown restorations with a conical connection system by using 3D finite element analysis.

Methods: Restorations produced with two different all-ceramic materials using a conometric abutment and a conometric cap on the implant with a conical connection system were placed in the maxillary right second premolar region. 3D finite element analysis was used to examine the amount and distribution of stresses in implant components, in cortical and cancellous bone tissues surrounding the implant and in crowns under vertical and oblique loading. For the statistical analysis one-way ANOVA and independent samples t-test were used (p<.05).

Results: In oblique 100N simulation, maximum stress distribution in implant and its components occurred at the implant abutment contact as 475.63 MPa for the LDS. The screw's peak stress values were determined to be 239.09 MPa in the transition zone and 280.061 MPa in the thread. On the bone surface, maximum and minimum cortical principal stress values were 61.25 MPa and – 62.028 MPa. During oblique loading, LDS exhibited the greatest surface stress on the cap as 441.33 MPa. Generally, tapping phase showed the lowest stress (p<.05). There was no significant difference regarding the materials (p> .05).

Conclusion: von Misess and principal stresses are not very high in any location therefore conical connections are more promising in terms of future success.

Keywords: Conometric abutment, finite element analysis, stress, conical connection

1. INTRODUCTION

One of the most essential laws in dentistry is preserving the structural integrity of the tooth and restoring function without harming the surrounding tissues. Implant-retained fixed prostheses, conventional fixed prostheses and adhesive bridges are among the prosthodontic treatment options for missing single tooth (1,2). Due to the good survival rates, in cases when systemic and surgical implant applications are not contraindicated, the implant option has become a standard treatment for complete and partial edentulism. The success of implant therapies is dependent not only on osseointegration but also on the use of prosthetic superstructures (3). In implant therapies, complications can be classified as surgical complications and prosthetic issues. Implant treatments have a 90% brand-independent surgical survival rate, but mechanical and biological difficulties originating from prosthetic applications account for the bulk of failures. These problems include screw loosening, abutment fracture, screw fracture and cement-induced periimplantitis (4). Success in the prosthetic phase is dependent on the selected form of connection and retention, the emergence profile of the restoration and the subgingival and supragingival restoration materials (5). The connection between the implant and abutment is one of the key variables influencing the implant's biomechanical success over the long term. The implant-abutment interface is one of the biomechanical components that affect the strength, stability and lateral/rotational load resistance of the connection (6).

The connection at the implant-abutment fixture can be broadly categorized as either external or internal. Future bone resorption is more likely to occur as a result of microleakage and bacterial colonization due to micro gaps detected in Branemark's original external connection (7). The abutment is attached to the inner surface of the implant in the internal

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connection and is developed to eliminate the disadvantages of the external connection. With this sort of connection, the goal is to minimize the formation of micro-gaps, lower the stresses communicated to the implant and surrounding tissues after lateral loading and shield the abutment screw from excessive occlusal loads. The frictional force at the interface between the abutment wall and implant plays a role in the conical connection, which is a specific sort of internal connection (8). Due to this adaptation at the implant-abutment interface, occlusal loads and stresses can be adjusted and transmitted to the implant and surrounding tissues, resulting in a stronger connection between the two components (9).

When cement fixation is preferred for retention in implant-fixed prosthetic rehabilitation, the likelihood of uncontrolled cement escape to peri-implant tissues and subsequent peri-implantitis is relatively significant if the abutment margin/ margins are prepared subgingivally. Also, the screw hole causes aesthetic issues in screw-retained restorations (10). Conometric abutments are a sort of cone-in-cone connection brought to the market in order to remove the problems of screw and cement retention. In this kind of retention, the restoration is cemented to the conometric cap that will be put on the crown outside the mouth and it is frictionally connected to the abutment by applying a slight push (11).

Another important issue in the success of implant treatments is the forces acting on the restoration surface and the material preferred in the prosthetic supra-structure. In the present study, the second premolar tooth area was preferred due to the greater effectiveness of chewing forces. Monolitic lithium disilicate glass ceramic (LDS, IPS emax CAD, Ivoclar Vivadent, Liechtenstein) and monolithic translucent zirconia ceramic (TZI, InCoris TZI, Dentsply Sirona, USA) materials were preferred due to their superior mechanical and aesthetic properties and widespread use in the studies. Unlike the recent similar study (20), it aims to affect the effect of the gingival level height of the abutment used on stress distribution.

The purpose of this study, which is unique as a retention type that does not involve cement or screws, was to compare the effect of monolithic TZI and LDS materials on stress distributions in the implant components and surrounding bone tissues in implant-retained conometric single crown restorations with a tapered connection system under functional loads using three-dimensional finite element analysis.

The first hypothesis of the present study is that there will be no difference in the stresses caused by the functional loads on the implant, abutment, abutment screw and the cortical and cancellous bone around the implant. The second hypothesis of the study is that the stresses induced by different restorative materials on the surface of the conometric cap will not differ.

2. METHODS

In the present study, bone level implant (AstraTech, OsseoSpeed EV, Dentsply Implants Manufacturing GmbH, Sweden) with 4.2 diameter 11mm length and 3mm gingival height was positioned on the right maxillary second premolar (15), along with a 5 mm diameter conometric abutment (Conometric Abutment EV, Dentsply Implants Manufacturing GmbH, Sweden) and conometric cap (Conometeric Final Cap, Dentsply Implants Manufacturing GmbH, Sweden).

For the modeling and analysis of the structures, a computer with an Intel i7-6850K 3.60 GHz processor, 2.5 Tb Harddisk, 64 Gb RAM, the Windows 10 Pro operating system, the three-dimensional modeling software MeshLab (Visual Computing Lab, Pisa, Italy) and the analysis software ANSYS 19 R2 (Southpointe 2600 Ansys Drive, Canonsburg, USA) were used.

2.1. Geometrical and Mathematical Modelling

Class III crest morphology and type3a bone density were employed to model the bone structure using geometric modelling (12,13).

A Nikon XT H 225 (Nikon Industrial Metrology, Japan) three-dimensional tomographic scanner was used to produce 3D images of the implant and its components. The dental anatomy book (14) was consulted for the images of the related teeth to be used in the study, and the crown model was kept constant for all situations. Using tetrahedral elements with 10 nodes, the mathematical models were constructed.

2.2. Boundary Conditions

The produced models were immobilized in the upper cross-sectional region of the bone. It was considered that the connection between the implant and bone was 100 percent osseointegrated.

2.3. Material Properties

It was determined that the cement thickness between the abutment and the cap was 30µm (15).

In the table below, Young's modulus and Poisson's ratios of the virtually visible structures are displayed (Table 1) (15,16,17).

Table 1. *Young's Modulus and Poisson's Ratios of the materials used in the study.*

Material	Young's Modulus (GPa)	Poisson Rate
Cortical Bone	13,7	0,30
Cancellous Bone	1,37	0,30
Titanyum Implant and Conometric Cap (Grade 4 Titanyum)	104,5	0,37
Conometric Abutment ve Abutment Screw (Grade 5 Titanyum)	114	0,33
Translusent monolitic zirkonya	210	0,26
Monolitic lithium disilicate glass ceramic	95	0,2
Resin cement	18,6	0,28

2.4. Loading Conditions

In the present investigation, a three-stage analysis of the conometric concept was conducted, which included preload, tapping, vertical (200 N) and oblique (100 N) masticatory force. The preload force, which is employed to hold the implant and its components together, was calculated using the formula of Bulaqi et al (18,19). For the computation of the tapping force, the silicone replica method was utilized to compute the amount of movement on the cap surface during the tapping action and the "Remote Displacement" function of the Ansys program was used to define a movement of 0.25 mm (20).

2.5. Assessment of Stresses

The interface surface of the abutment in contact with the implant, the screw transition zone, the screw groove zone, the surface of the implant in contact with the cortical bone, the surface of the implant in contact with the spongious bone and the surface of the cortical and cancellous bone in contact with the implant were identified as the critical areas for stress evaluation on the created virtual model (Figure 1).

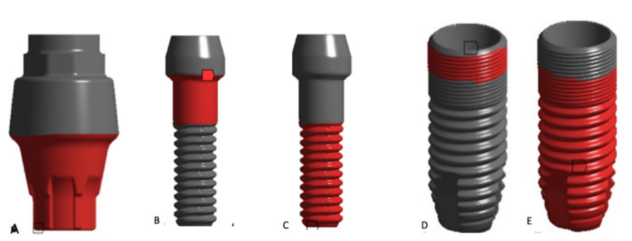

Figure 1. *Critical locations for stress assessment A: The interface of the abutment in contact with the implant B: the screw passage area C: the screw thread area D: the surface of the implant in contact with the cortical bone E: the surface of the implant in contact with the cancellous bone*

In the stress evaluation phase, von mises stress values for resorbable structures like titanium and maximum main stress values for brittle structures (crown, cortical and spongious bone) were evaluated (16). The mean and maximum stresses at critical areas were compared. LDS and TZI were statistically compared using the independent sample t-test and the stages were compared using the one-way ANOVA test (preload, tapping, vertical and oblique). The alpha value of statistical testing was .05. The stress levels in the implant, implant components and bone surface were interpreted based on their yield strengths, whereas the stress levels in the crown material were interpreted based on their biaxial bending strengths.

3. RESULTS

von Mises stress values in critical areas were shown in Table 2. Critical areas where the highest values are observed were the interface of the abutment in contact with the implant, the screw thread area and the surface of the implant in contact with the cancellous bone (Figures 2A-2C).

In the LDS material, the oblique 100N force stage frequently exhibited the greatest stress values at all critical surfaces identified by the present stress study. To study the stress distributions in the screw region, it was separated into two sections: the screw passage and the screw thread. The thread region of the screw had the highest stress in the LDS material, as preload: 286.31 MPa, tapping: 285.22 MPa vertical: 275,38 and obligue: 280,61 (Figure 2B).

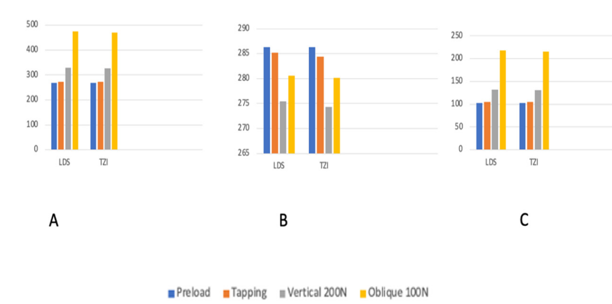

Figure 2. *Critical locations with the highest Von mises stresses A: The surface of the abutment in contact with the implant, B: the screw thread area C: the surface of the implant in contact with the cancellous bone*

Table 2. *von Mises stress values at critical areas.*

Location	Preload	LDS			TZI		
		Tapping	Vertical 200N	Oblique 100N	Tapping	Vertical 200N	Oblique 100N
Interface of the abutment in contact with the implant	267,29	273,38	328,78	475,63	272,09	327,07	470,27
Screw passage area	220,75	219,77	210,94	239,09	219,15	210,11	238,08
Screw thread area	286,31	285,21	275,38	280,61	284,39	274,28	280,13
Surface of the implant in contact with the cortical bone	73,574	74-523	83,906	199,12	74,221	83,482	195,82
Surface of the implant in contact with the cancellous bone	102,69	105,62	132,08	218,85	105,08	131,34	215,91

In the simulations of vertical 200N and oblique 100N chewing forces, the maximum stress distribution at the interface of the abutment in contact with the implant occurred at the oblique 100N stage with 475,63 MPa (Figure 2A). The highest stress value of the surface of the implant in contact with the cancellous bone was 218, 85 MPa in the LDS material oblique simulation. In the chewing force simulation, the LDS material induced more stress concentration, similar to the preload and tapping stages. The stresses at the implant abutment interface and the implant surfaces in contact with the cancellous bone increased as simulations progressed from preload to masticatory forces, whereas stresses in the screw groove area decreased (Figures 2A-2C).

When the principal stresses on the bone surface were examined (Figure 3), higher stress distribution occurred in the cortical bone. Under an oblique force of 100N, the cortical bone surface experienced a maximum principal stress of 61.65 MPa and a minimum stress of – 61,02 MPa. Stress values of 61,65 MPa and minimum stress principal: – 61,02 MPa were observed in LDS material (Figure 3).

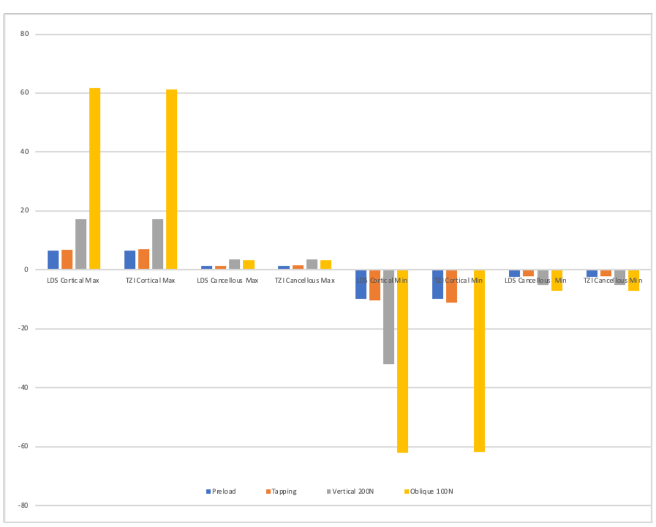

Figure 3. *Maximum and minimum principal stress values on cortical and cancellous bone surface*

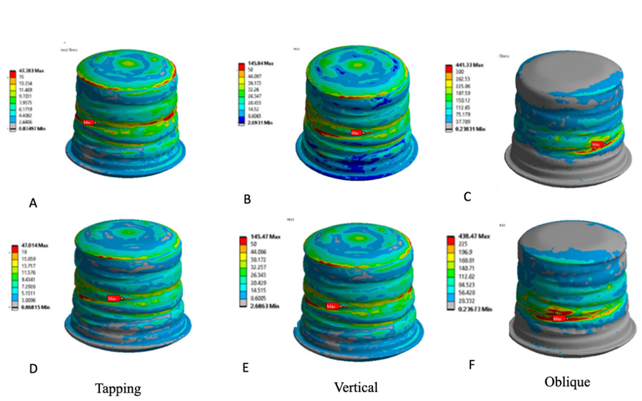

Figure 4. *Von Mises stress values on the cap surface A, B, C: Tapping, vertical, oblique force steps for the LDS crown. D, E, F: Tapping, vertical, oblique force steps order for the TZI crown.*

During oblique loading of the conometric cap surface, the LDS material was stressed by 441.33 MPa (Figure 4). There is no statistically significant difference between the average Von Mises stress values on the cap surface in terms of material ($p > .05$).

Tapping simulation stage presented the lowest stress value at critical areas while vertical loading stage presented the lowest stress value at conometric cap surface ($p < .05$).

4. DISCUSSION

Implant treatments are dependent on the stress delivered to the bone tissue surrounding the implant. The distribution of stress depends on the diameter of the implant, the type of connection and retention used and the bone quality. Finite element analysis enable to analyze stress values. To evaluate the stress values, the design of mathematical models should be performed with care and should reflect reality, necessities such as boundary conditions, material properties and loading conditions should be defined (22). Although cortical and cancellous bone has an anisotropic, viscoelastic, and inhomogeneous structure, finite element analysis studies record it as homogeneous and isotropic (23,24). Contrary to reality, cortical and cancellous bone was represented as homogenous, linear elastic and isotropic in the present study, similar to the other studies (15,20). Although 100% osseointegration at the bone implant interface is not observed clinically, finite element stress analysis accepts that the bone implant contact is 100% osseointegrated. Similar to the literature (24,25), 100% osseointegration was assumed and analyzed at the bone implant interface in the present investigation.

A large number of elements and nodes should be employed to improve the accuracy and reliability of the finite element approach (23,26,27). In a study conducted by Kaleli et al., 52451 nodes and 207931 elements were utilized, while in a study conducted by Kitagawa et al., 255106 nodes and 161485 elements were utilized. For the analysis of the present study, there are 721234 elements and 1077879 nodes, since it contains more elements and nodes than many previous studies (28,25,29,15,30). Thereby, higher quality mesh structure has been developed in an effort to improve the precision of the results.

Linkevicius et al., reported that the choice of cement retention resulted in cement-related problems in the peri – implant tissues (31). Wittneben et al., stated that the screw hole in screw-retained prostheses creates aesthetic and occlusion problems (42). The absence of cement and screw connection in the conometric retention type emphasizes the clinical importance of the retention type (32).

Numerous studies have been conducted on the determination of preload force. In a number of experiments, Kaleli et al., (15) ignored the preload value, while Jörn et al., (43) reported that the preload force should be 65-75% of the screw yield strength, and Bulaqi et al., (18) used a special formula to calculate the preload value. In the present study, the preload was computed to be 473. 94 N using a formula (18). This preload value was applied to the screw of abutment using the '' Bolt Pretension'' function of the Ansys program (35) and the stress values for all components were collected at this point.

As prosthetic possibilities for conometric restorations, monolithic zirconia, monolithic lithium disilicate and fluorapatite-containing lithium disilicate have been described in the literature (32, 36, 37). While Degidi et al., (11) reported that no complications were observed in the 2-year follow-up of conometric restorations produced with LDS material, another study stated that no problems were encountered on the restoration and cap surface in the 5-year follow-up of conometric restorations produced with monolithic zirconia (32). Similar to previous researches (11,32,36), the present study employed monolithic TZI and LDS materials for the implant supported conometric restoration. On the conometric cap, conometric abutment, abutment screw and implant surface, greater von Mises stress concentrations were seen in the simulation with LDS, even though there was no statistically significant difference between the materials.

In the present investigation, stress analysis was performed at critical locations (Figure 2) using Grade 4 titanium implants and Grade 5 titanium abutments and abutment screws. Grade 5 titanium has an 835 MPa yield strength, while Grade 4 titanium has a 485 MPa yield strength (21). The maximum von-Mises stresses during the tapping, vertical and oblique force phases for two distinct crown materials did not surpass the yield value at any crucial surface. Maximum and average von-Mises stress values at selected important points and the cap surface were higher at the oblique 100N stage, refusing the first hypothesis.

Stresses in fragile structures such as bone should be evaluated according to the maximum and minimum principal stress values (15). In the present study, both the maximum (61.65 MPa) and minimum (-62.028 MPa) primary stress values in cancellous and cortical bone were less than the yield strength of bone (114 MPa) (21). Similar to the literature, the cortical bone exhibited the highest primary stress values (29, 38, 39, 40).

Frictional adhesion exists between the Grade 4 titanium conometric cap and the conometric abutment (20). The surface strains of the conometric cap reached 441 MPa at LDS. The values on the cap surface approach the yield strength of Grade 4 titanium, indicating that deformation may occur on the cap surface. Although there is no significant difference between two materials, TZI material resulted in reduced surface stresses. Consequently, second hypothesis was likewise invalidated.

Various applications exist for assessing the loading conditions in many researches (33, 34, 22). Lemos et al., in a recent study where they evaluated the effect of implant abutment connection, retention and restorative material type on stress distribution, applied a vertical force of 200 N and an oblique force of 100 N. More stress distributions were observed during the oblique loading phase like the present study. Cement retention caused more screw stress than screw retention. Lemos et al., reported that the Morse taper implant type may be a biomechanically better alternative in terms of the stresses arising from bone and screw changes (41).

The number of finite element analysis studies in which the conometric retention type is preferred is quite limited. Tezulas examined the stress distributions induced by two distinct restorative materials placed on Ti-base and conometric abutments in single crowns on implants (20). Crown material and oblique loading conditions were similar to the present study. In contrast to present study, a conometric abutment with a gingival height of 1 mm was utilized and the vertical loading condition was applied as 100 N from each tubercle, for a total of 200N. Although the critical areas such as bone and conometric cap surface stress values of the recent study, were higher than present study. Tezulas reported that the material difference did not have a significant effect on the stress distribution in the implant components, conometric abutment, conometric cap and surrounding bone tissue, like in the present study (20).

The method of finite element analysis is a hypothetical simulation of reality. The limitation of the present study is that the value of the tapping force is not known exactly. Therefore, more investigations are needed to determine the numerical value and effects of the tapping force and also enable the conometric retention type to be used in bridge restorations.

5. CONCLUSION:

The results of stress distributions in the implant components and surrounding bone tissues and conometric cap are between the reference yield and fracture strength values. While the simulation with the TZI material revealed the lowest stresses, there was no statistically significant difference between the stress values for any material. The use of LDS material in the conometric concept carries the risk of deformation on the cap surface over time, as it causes more stress on the cap surface under oblique force. However, further in vitro studies are needed to increase the usability of the conometric concept and to determine the effect and numerical value of the tapping force.

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