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Investigation of the effect of implant crown ratio and material type on the force transmitted to the implant in implant-supported restorations: a finite element analysis study

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ABSTRACT

Aims: The crown implant ratio may pose a problem, especially when short implants are used. This condition is associated with marginal bone loss. Therefore, in this study, it was aimed to evaluate the stresses arising from the bone, implant and its parts and the restoration by finite element analysis (FEA), as a result of comparing a situation with ideal bone support and a similar situation with vertical bone loss. The null hypothesis is that the type of material and crown length chosen for implant-supported restorations will not make a difference in terms of stress on implants of different sizes.

Methods: For this study, 8 mm implants were placed in the 44-46 region and a group with a 3-unit 12 mm length fixed prosthesis and a group with 12 mm implants and a 3-unit 8 mm length fixed restoration were designed. The data of the implant parts were obtained from a implant company (Bilimplant, İstanbul, Turkiye) and placed in the appropriate position within a bone data drawn in the Solidworks 2013 software (Solidworks Corp., USA). Appropriate multi-unit parts were then added and 3-unit restorations were designed with exocad. Necessary arrangements were made in the Geomagic Design X 2020 (3D systems, Morrisville, NC, USA) program, the restorations were given the characteristics of 2 different materials (lithium disilicate and zirconia). Applying a force of 200 N on the occlusal direction, the maximum principal stress values occurring in the bone, implant, multi-unit, restoration and occlusal screw were recorded.

Results: Principal stress (Pmax) values recorded on the implant for the 1st premolar were higher on the 12 mm implant (B1 and B2 groups) and lower on the 8 mm implant. For the implant applied to the 1st molar region, higher stress values were observed in the groups with 8 mm implants (A1 and A2 groups), while lower values were observed with 12 mm implants (B1 and B2 groups).

Conclusion: As the crown/implant ratio increases in favour of the implant, the survival of the unit decreases. In addition, it is more appropriate to prefer rigid materials in implant restorations.

Keywords: CAD/CAM, finite element analysis, implant

INDRODUCTION

Advancing technology has made the use of implants appropriate for tooth deficiencies.[1] One of the most important factors in the success of implants is their strong connection with the bone tissue during the osseointegration process. As a result of successful osseointegrated implants, patients being rehabilitated both functionally and aesthetically.[2,3]

Another important factor affecting the success of the implant is the way the stress that the implant is exposed to is transmitted to the bone. This condition, also called implant biomechanics, is related to the shape, length, diameter and design of the implant. It is also known that the groove design observed in screw implants affects biomechanics. The contact of the implant with the surrounding bone is directly related to the stress factor that will occur in the bone.[4,5] The force generated by the transmission of stress to the bone is related to the design of the implant, its biomechanical properties and the destruction reactions that occur as a result of the strain reflected by the implant to the bone.[6] Due to anatomical limitations such as insufficient bone area, proximity to the maxillary sinus or inferior alveolar nerve, it may become impossible to place the implant in the ideal diameter and length. In order to eliminate these problems, additional surgeries such as bone grafting or sinus lift operations are required. In such cases, short (<10 mm) implants may be considered as an alternative.[1,3,7]

Implant restorations are divided into two parts: artificial tooth (crown) and implant. The crown part is defined as the area outside the alveolar bone and the implant part is

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defined as the area inside the alveolar bone. Crown-implant separation is defined as the physical relationship determined by radiography. In radiographic terms, the crown-to-implant ratio refers to the relationship between the length of the crown visible on radiographic images and the length of the implant. It is a measure of the ratio between the height of the crown and the portion of the dental implant embedded in the jawbone. This ratio gives preliminary information about the prognosis of implant treatment.[8,9] Disproportionate crown-to-implant ratios and reduced implant root surface can make the implant more vulnerable to trauma caused by occlusal forces. As a result of the literature review, it was found that excessive crown-to-implant ratios reduce the long-term survival rate of the implant.[8] Non-axial loading, which increases in direct proportion to the anatomical crown length, creates a significant lateral moment. This leads to stress concentration at the implant neck, which may result in technical complications of the prosthetic components.[10]

Two recent systematic reviews investigated the long-term success of implant-supported single crowns and fixed dental prostheses in relation to survival and complication frequency, regardless of the difference between ceramics and metal ceramics. The systematic review by Jung et al.[11] found that the 5-year survival rate of implant-supported single crowns was 96.3% (95% CI: 94.2-97.6%).[11] Another result concluded that zirconia implant abutments have been considered successful over the past decade and that the survival results are on par with metal abutments.[12] However, whether the prognosis of zirconia implant-supported restorations is similar to that of metal ceramic implant restorations has not been fully elucidated to date.[11-13] Lithium disilicate and monolithic zirconia materials are increasingly being used due to their high biocompatibility and mechanical properties.[14] In a study conducted by De Angelis et al.[15] monolithic lithium disilicate and monolithic zirconia crowns showed comparable clinical results with a 100% survival rate in both groups.[15] No significant difference was found between the technical complications and the opposing teeth. Another review showed that double-layered lithium disilicate restorations are a viable treatment alternative to monolithic zirconia implant restorations with similar biological complications and fewer aesthetic issues. In terms of fracture strength, lithium disilicate shows similar properties to zirconia material.[16,17]

Finite element analysis (FEA) is used to evaluate the mechanical behavior of complex structures and to support in vitro experiments. It is basically a computational technique used to simulate and predict how materials will react when subjected to different forces. A working hypothesis can be simulated to evaluate the stress exerted on teeth under varying masticatory conditions. However, issues such as material properties, limitations, mesh distribution and calculation can easily affect the result of FEA. In order to create a virtual model and to have confidence in the FEA results, the data should be supported by in vivo and in vitro studies.[18-20]

The aim of this study was to evaluate the stresses on different materials at different implant crown length ratios using FEA and to diagnose the possible risks of using short implants. The null hypothesis was that there would be no difference in stress distribution between restorations created with monolithic zirconia and lithium disilicate materials with different implant crown ratios.

METHODS

The study was carried out with the permission of Necmettin Erbakan University Dentistry Non-drug and Non-medical Device Researches Ethics Committee (Date: 25.07.2024, Decision No: 2024/463). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

The bone tissue model was created with Solidworks 2013 software (Solidworks Corp., USA). Based on the data from Bilimplant®, the model was created using short (8 mm) and long (12 mm) implants. Then, multi-unit parts compatible with the gingival height were selected and 3-unit restorations were designed using Exocad (Dental Cad3.1 Rijeka, EXOCAD, Darmstadt, Germany). For group A, implants with a length of 8 mm were placed in the bone model corresponding to the 44 and 46 regions and restorations with a crown length of 12 mm were designed on them. As a control group, group B was formed by placing implants with a length of 12 mm into the bone and restorations with a crown length of 8 mm were designed on them, shown in Table 1. The data obtained were then exported as Standard Tesselation Language (STL) files. The models were edited using Geomagic Design X 2020 (3D systems, Morrisville, NC, USA). To simplify the complexity of the three-dimensional finite element models, bone was assumed to have isotropic and linear elastic properties. The implants were assumed to be fixed in the bone.

Table 1. Describing the subgroups

Length of the implant	Lithium disilicate	Zirconia
8 mm	A1	A2
12 mm	B1	B2

With the Exocad program, A1, A2, B1, B2 groups were formed by making the necessary arrangements in the design of 3-membered multi-unit restorations with monolithic zirconia and lithium disilicate materials on a 12 mm long crown in group A and 8 mm long crown in group B (Table 1). Additional modifications were also made in Geomagic Design X 2020 (3D systems, Morrisville, NC, USA) program, then transferred to Solidworks 2013 software (Solidworks Corp., USA). All parts were merged. The data were transferred to the ABAQUS 2020 finite element analysis program (ABAQUS, 2020 Dassault Systems Simulation Corp., Johnston, RI, USA) and the restorations were characterized by 2 different materials (lithium disilicate and zirconia). An isotropic linear elastic simulation was performed for the restorative materials. A load of 200 N was applied to the model in each group in accordance with the oral environment and the required pressure was calculated. FEA was then done using ABAQUS software to evaluate the stress distribution. A force of 200 N was applied in the occlusal direction. The maximum principal stress (Pmax) values occurring in the bone, implant, restoration and occlusal screw were recorded.

RESULTS

The distribution of the basic maximum stress values of all components over the complements is shown in Table 2. The maximum stress value of the cortical bone was observed in the lithium disilicate material designed on an 8 mm implant in group A1, while the minimum value was seen in the zirconia material applied on a 12 mm implant in group B2 (Figure 1). The values seen on the occlusal screw were independent of the implant site (1st premolar and 1st molar), shown in Figure 2, 3. The maximum principal stress (Pmax) was seen in group B1 (lithium disilicate material designed on a 12 mm implant), and the minimum stress values were seen in the group with zirconia material designed on an 8 mm implant (Figure 4).

Table 2. Distribution of principle maxium stress values on complements, (MPa value)

	A1	A2	B1	B2
Cortical bone	93.56	92.85	48.62	46.56
Occlusal screw 1st premolar	9.43	5.56	20.43	13.37
Occlusal screw 1st molar	8.04	5.05	10.03	5.99
Implant 1st premolar	46.16	45.63	220.8	213.5
Implant 1st molar	87.07	86.19	43.93	40.86
Restoration	32.35	40.37	12.92	12.40

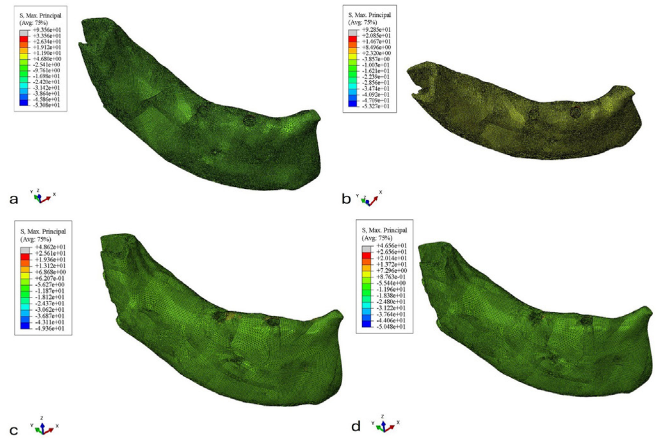

Figure 1. Stress values in cortical bone, a; 8 mm implant lithium disilicate restoration, b; 8 mm implant zirconia restoration, c; 12 mm implant lithium disilicate restoration, d; 12 mm implant zirconia restoration stress distribution in cortical bone

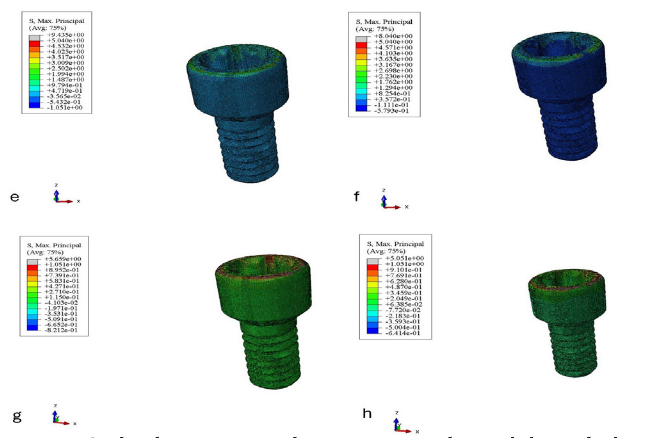

Figure 2. Occlusal screw stress values on 8 mm implant, e; lithium disilicate rest, 1st premolar, f; lithium disilicate rest, 1st molar, g; zirconia rest, 1st premolar, h; zirconia rest, 1st molar occlusal screw stress distribution

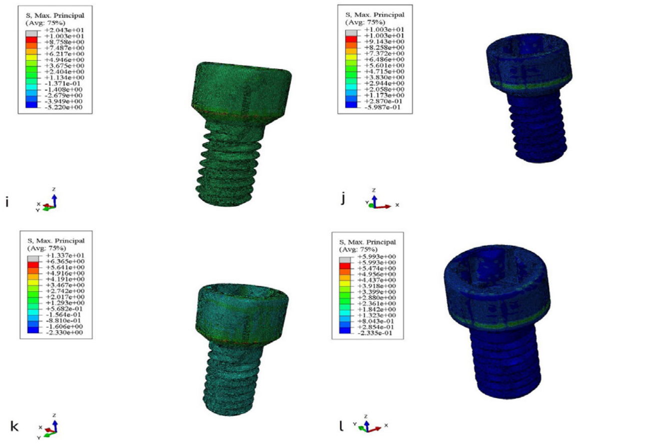

Figure 3. Occlusal screw stress values on 12 mm implant, i; lithium disilicate rest, 1st premolar, j; lithium disilicate rest, 1st molar. k; zirconia rest, 1st premolar, l; zirconia rest, 1st molar occlusal screw stress distribution

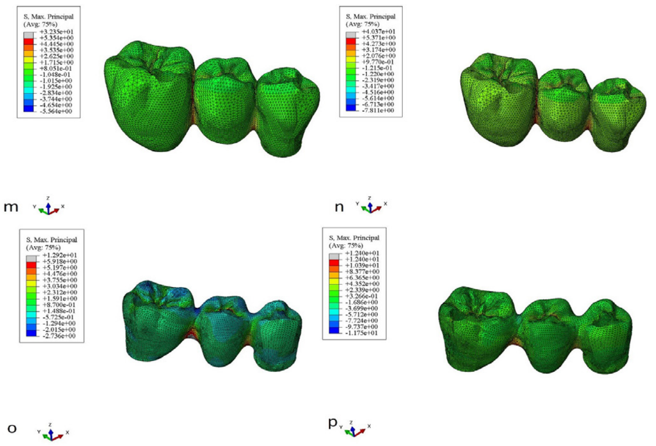

Figure 4. Stress values in restoration, m; 8 mm implant lithium disilicate restoration, n; 8 mm implant zirconia restoration, o; 12 mm implant lithium disilicate restoration, p; 12 mm implant zirconia restoration stress distribution in restoration

Principal stress (Pmax) values on the implant for the 1st premolar were higher on the 12 mm implant (B1 and B2 groups), shown in Figure 5 and lower on the 8 mm implant. For the implant applied to the 1st molar region, higher stress values were observed in the groups with 8 mm implants (A1 and A2 groups) shown in Figure 6, while lower values were observed with 12 mm implants (B1 and B2 groups).

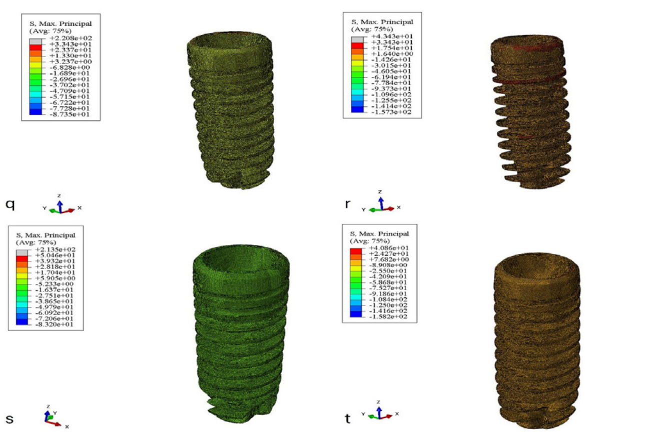

Figure 5. Stress values on 12 mm implant, q; lithium disilicate rest, 1st premolar, r; lithium disilicate rest, 1st molar, s; zirconia rest, 1st premolar, t; zirconia rest, 1st molar 12 mm implant stress distribution

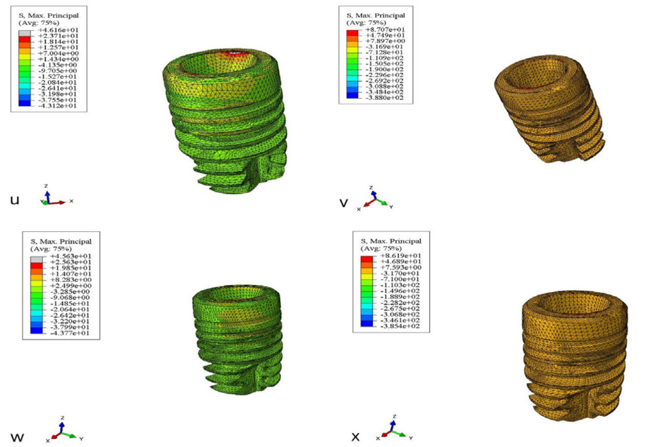

Figure 6. Stress values on 8 mm implant, u; lithium disilicate rest, 1st premolar, v; lithium disilicate rest, 1st molar, w; zirconia rest, 1st premolar, x; zirconia rest, 1st molar 8 mm implant stress distribution

In the restoration, the maximum principal stress value (Pmax) against the applied force was recorded in the zirconia material applied on the 8 mm implant (40.37 MPa), while the minimum value was recorded in the zirconia restoration designed on the 12 mm implant.

DISCUSSION

The flexural strength of zirconia material is higher than that of lithium disilicate and the transformation toughness effect due to the stress it is exposed to increases the strength of the material. Known et al.[21] reported a difference in strength between 3 y-tzp, 5 y-tzp and lithium disilicate.[21] Roberts et al.[17] reported that lithium disilicate material may be an alternative to zirconia hybrid abutment material due to its high fracture strength. The fact that the value between groups B1 and B2 is close to the maximum stress (Pmax) values seen in the restoration with a crown length of 8 mm may be related to this.[17]

De Angelis et al.[14] reported a high survival rate (100%) for implant-retained restorations in both groups of monolithic lithium disilicate and monolithic zirconia crowns. The importance of a reduced occlusal table, reduced load and load direction to prevent overloading of the restoration is also related to the survival of the implant restoration. Therefore, it can be said that the high presence of crowns and the maximum stress on them in groups A1 and A2 are related to each other.[14]

Patients with bruxism can apply a force of up to 700 N to the fixed prostheses in their mouths. Therefore, the treatment plan for posterior implants should be carefully considered when the crown length is high (12 mm) in patients with high occlusal forces.[22]

Malchiodi et al.,[23] conducted a study using 5 mm high implants, stated that the crown/implant ratio is the main parameter that can affect the success of the restoration and the loss of crestal bone from a biomechanical point of view. High stress applied to the implant can lead to crestal bone resorption and loss of the implant. Therefore, it is important that the forces applied to the restoration should not be too much.[23]

In some cases, the bone-implant interface can tolerate occlusal forces without adverse effects on bone tissue. The increase in occlusal forces causes crestal bone loss, and if the increase in force is continuous, implant loss may occur.[24,25]

Blanes et al.[26] it has been suggested that a higher clinical crown/implant ratio causes less crestal bone loss, and this is due to splinting of implant restorations. In conclusion, it can be said that the use of implant restorations with a crown-to-implant ratio of 2/3 in the posterior region can provide successful results.[26]

In our study (Table 2), the correlation between restoration and stress sources on the cortical bone was determined.The high stress on the cortical bone in the A1 and A2 groups with high crown/implant ratio can be explained by the high crown length and the use of short implants (8mm). Accordingly, the null hypothesis that there would be no difference in stress distribution between restorations created with monolithic zirconia and lithium disilicate materials with different implant/crown ratios was rejected.

Nissan et al.[27] they stated that screw fracture was more common in 15 mm crowns and the complication rate was less in short crowns.[27]

The stress distributions of restorations made from different materials differ from each other. Screw loosening is more common in implant-supported single crowns. Implant-supported fixed bridge components are predicted to be more stable under force and able to move more integrally against anti-rotation.[28-30]

Yilmaz et al.[22] found that the survival of the implant complex with a crown length of 14 mm was lower than that of 10 mm. Despite the excessive height of the crowns, a crown-to-implant ratio of 1/1 and 1.4/1 was found in the 10 and 14 mm groups. However, the crown implant ratio is important, since the crown screw is the primary unit that stabilizes the crown in the implant.[22] The reason why the stress on the occlusal screw was less in the A1 and A2 groups and more in the B1 and B2 groups may be due to the distribution of stress to other elements in the implant system.

Limitations

Limitations of this study include the fact that only two different sized implants were used. It is thought that more accurate results will be obtained by working with more implant groups. With finite element analysis, material properties are considered linear isotropic and elastic, but this may not reflect the clinical situation accurately. Therefore, it would be appropriate to support future studies with more groups and material studies.

CONCLUSION

As the crown/implant ratio increases in favor of the implant, the survival of the unit decreases. In addition, the use of more rigid materials in the application of over-implant restorations has produced better results.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was carried out with the permission of Necmettin Erbakan University Dentistry Non-drug and Non-medical

Device Researches Ethics Committee (Date: 25.07.2024, Decision No: 2024/463).

Informed Consent

No biological material was used in the study, informed consent is not required as it is a laboratory study on dental implant material.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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