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Original Article

Evaluation of the stress distribution in the cortical bone caused by variations in implant applications in patients with bruxism: A three-dimensional finite element analysis

Yakup Kantaci[1], Sabiha Zelal Ülkü[2]

[1] Harran University, Faculty of Dentistry, Department of Prosthodontics, Şanlıurfa, Turkey
[2] Dicle University, Faculty of Dentistry, Department of Prosthodontics, Diyarbakır, Turkey

Abstract

Aim: To evaluate the stress distribution in the cortical bone under parafunctional forces with different occlusal thicknesses, monolithic zirconia with different implant diameters, and number variations in implant-supported fixed prosthetic restorations applied in patients with bruxism.

Methodology: The tomographic sections of the previously registered mandible were used to model the mandible. Modeled bone height is 30 mm, cortical bone thickness is 1.5 mm, and trabecular bone thickness is modeled as 13 mm. By placing two implants in the created bone model, a three-member main model (Group 1), the number of implants was increased, three implants supported the Group 2 models, the diameter of the implants was increased, and the Group 3 models were created. The created Group 1, 2, 3 models, the occlusal thickness was divided into subgroups with 1.0, 1.5, and 2.0 mm, respectively (Groups A, B, and C). The groups were applied in two directions: vertical and 30o oblique. Stress values under forces were analyzed by finite element stress analysis.

Results: Under vertical loading, the maximum principal stress value in the cortical bone was found to be lowest in Group 2C, and the highest maximum principal stress value was found in Group 1A. The minimum principal stress value in the cortical bone was found to be the lowest in Group 3C, and the highest minimum principal stress value was found in Group 1A. Under oblique loading, the maximum principal stress value in the cortical bone was found to be the lowest in Group 3C and the highest maximum principal stress value was found in Group 1A. The minimum principal stress value in the cortical bone was found to be lowest in Group 3C, and the highest minimum principal stress value was found in Group1A.

Conclusion: Stresses caused by oblique forces are more than vertical forces. Increasing the occlusal thickness of the implant fixed prosthesis material, implant diameter, and number reduce the minimum and maximum principal stress values in the cortical

Keywords: bruxism, implant, monolithic zirconia, occlusal thickness, finite element stress analysis (FEA)

Correspondence:

Dr. Sabiha Zelal ÜLKÜ
Dicle University, Faculty of Dentistry, Department of Prosthodontics, Diyarbakır, Turkey.
E-mail:zelal_baskan@hotmail.com

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Introduction

Bruxism is defined as recurrent teeth grinding and/or clenching in the masticatory muscles that occur at night (nocturnal) and/or during the day (diurnal) (1, 2). Occlusal forces on the teeth increase due to the increase in muscle strength in patients with bruxism (3, 4). Increased occlusal forces do not constitute a contraindication for implant applications, but an increase in stress is observed in all components of the implant and cortical bone due to increased occlusal forces. For this reason, extra care should be taken to reduce the negative effects of increased occlusal forces and stress for the success of implant applications in patients with bruxism (5-9). The following methods are recommended to increase the success of implant applications in patients with bruxism: Increasing the diameter and length of the implant, avoiding the use of a cantilever, making necessary occlusal arrangements to reduce occlusal forces, using shock-absorbing material instead of porcelain as occlusal surface material, Botox applications, the use of grooved implants and occlusal splint applications (10).

The aim of this study is to evaluate the stress values of cortical bone under vertical and oblique forces, together with the use of monolithic zirconia ceramics at different occlusal thicknesses in fixed prosthetic restorations applied to patients with bruxism, using finite element stress analysis method.

Materials and Methods

In the study, tomographic sections were used to model the mandible. Current tomography images were processed on axial, coronal, and sagittal axes, and 3D bone model was obtained with Rhinoceros 4.0 software. Modeled bone height is 30 mm, cortical bone thickness is 1.5 mm, and trabecular bone thickness is modeled as 13 mm (Fig. 1). The part of mandible model to be analyzed was removed from the rest of the model by the Boolean method. (Fig. 2)

Figure 1. Mandible models

Figure 2. Bone model created with the Baolen method

In this study, a three-member main model (Group 1) was prepared with two implants placed in the second premolar and second molar teeth in the mandible model. The diameter of the implants in the Group 1 model was 3.7 mm for the second premolar and 4.7 mm for the second molar (Fig. 3). In the second model (Group 2), the number of implants was increased without changing the diameter of the implants used in the main model, and three implant-supported models were created (Fig. 4). In the third model (Group 3), the diameters of the implants used in the main model were increased to 4.1 mm for the second premolar and6.0 mm for the second molar (Fig. 5). The length of the implants was fixed at 11.5 mm in all groups. The created Group1,2,3 models, the occlusal thickness was divided into subgroups with 1.0 mm, 1.5 mm, and 2.0 mm, respectively (Groups A, B, and C). The groups were applied in two directions, vertical and 30º oblique. As a result of all these variations, a total of 18 group models were created, including subgroups.

Figure 3. Group 1 Model (Main model)

Figure 4. Group 2 Model

Figure 5: Group 3 Model

After the models were created, they were transferred to Ansys software in .stl (stereolithography) format to be ready for analysis. The .stl format is universal for three-dimensional modeling, and there is no data loss when transferring between programs.

In this study, cortical and trabecular bone was accepted as isotropic, homogeneous, and linear elastic, and the osteointegration between the implant-bone was accepted as 100%.

The elastic modulus and Poisson values used to transfer the mechanical properties of the modeled materials to the computer are given in Table 1.

Table 1. Mechanical Properties of the Materials Used in the Study

Materials	Young Modulus (GPa)	Poisson rate	References
Titanium implant, abutment, screw	110	0.35	(11)
Cortical bone	13.7	0.30	(12)
Trabecular bone	1.37	0.30	(12, 13)
Monolithic zirconia	210	0.35	(14)

Vertical and 30° oblique directions were applied to the models to simulate bruxism. While applying force in the vertical direction, a total of 1000 N of vertical force was applied to all teeth, with a total of 200 N from two points determined from the inclined surfaces of the buccal and lingual tubercles of the second premolars and 800 N from three points determined from the buccal and lingual tubercles for the first molar and second molar (Fig. 5). While applying force in the oblique direction, a total of 500 N 30° of oblique force was applied, 100 N at two points determined on the buccal tubercle of the second premolars and 400 N from three determined points in the buccal tubercles of the first molar and second molar (Fig. 6). Forces were applied simultaneously in three directions (x, y, z axes), and time-dependent changes were simulated for 10 seconds during the application of a dynamic analysis force.

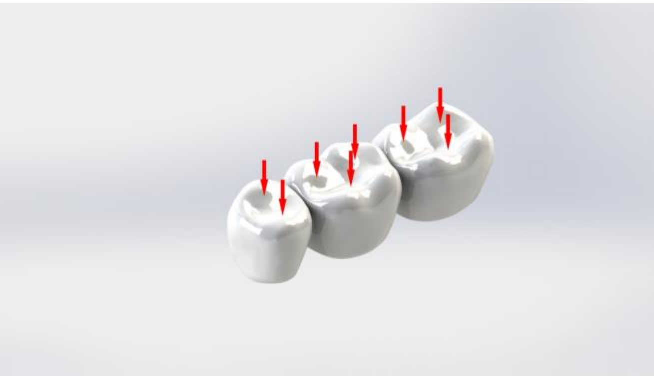


Figure 5: Vertical forces loading

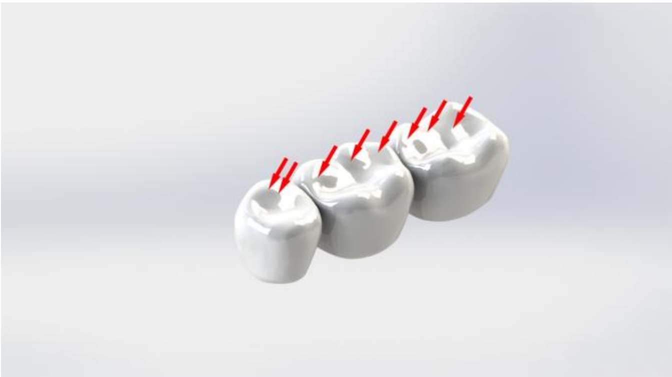


Figure 6: Oblique forces loading

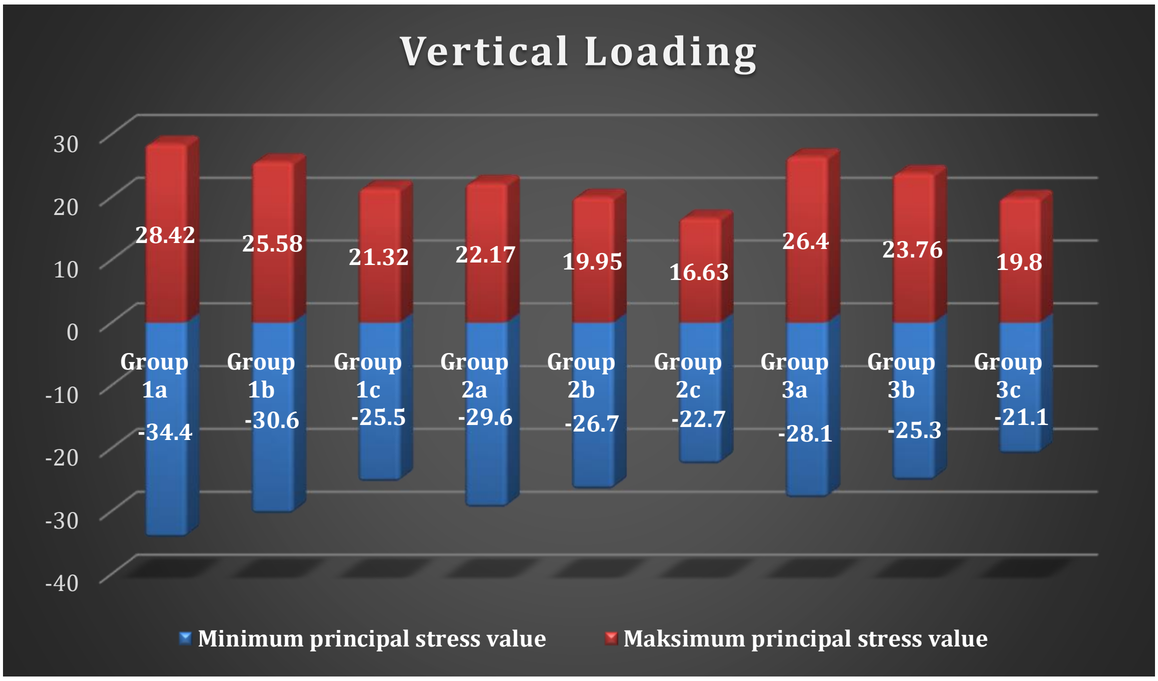
Statistical analysis

Many software is used in the finite element stress analysis method. In this study, a dynamic solution has been made using Ansys 14.0 software. In our study, as a result of finite element stress analysis, the minimum and maximum principal stress values in cortical bone were evaluated.

Results

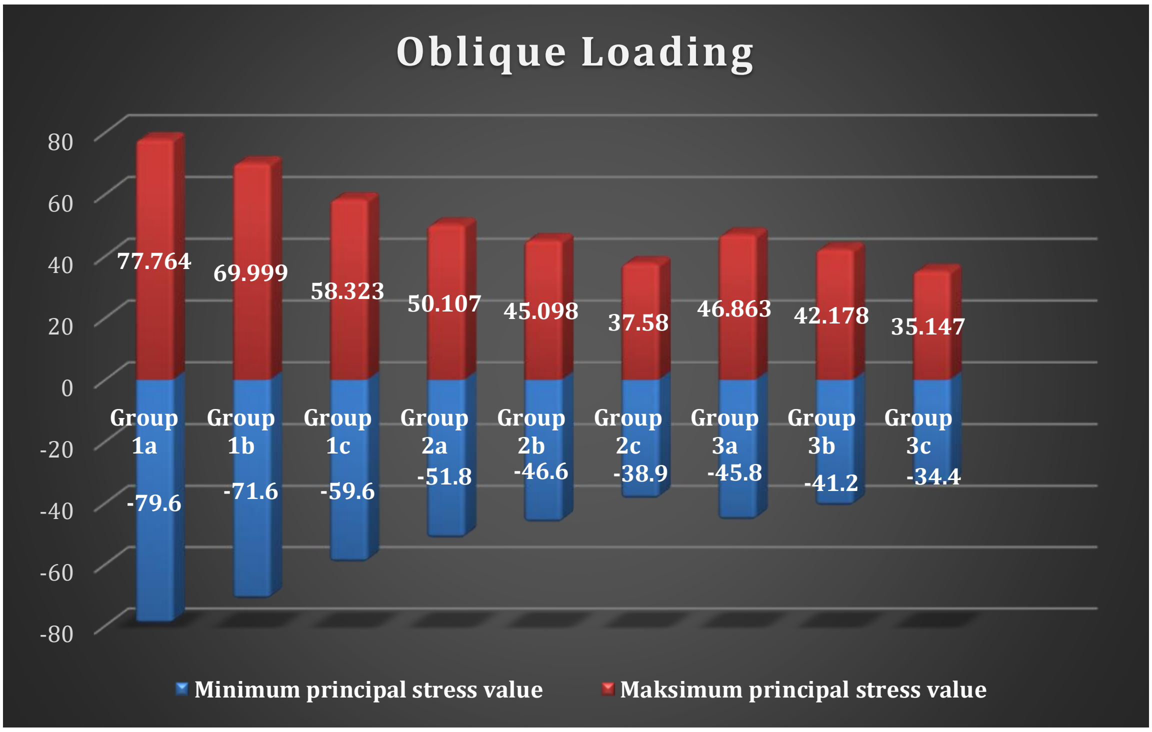
When all groups were compared, under vertical loading, the maximum principal stress value in the cortical bone was found to be lowest in Group 2C, and the highest maximum principal stress value was found in Group1A. The minimum principal stress value in the cortical bone was found to be the lowest in Group 3C, and the highest minimum principal stress value was found in Group1A. (Table 2)

Table 2: Minimum and maximum principal stress values occurring in the cortical bone under vertical loading.



When all groups were compared, under oblique loading, the maximum principal stress value in the cortical bone was found to be the lowest in Group 3C, and the highest maximum principal stress value was found in Group 1A. The minimum principal stress value in the cortical bone was found to be lowest in Group 3C, and the highest minimum principal stress value was found in Group 1A. (Table 3)

Table 3: Minimum and maximum principal stress values occurring in cortical bone under oblique loading.



In our study, the maximum principal stress values were observed in the buccal and lingual neck regions of the implants under vertical loading (Fig. 7) The minimum principal stress values were concentrated in the cortical bone in the lingual neck region (Fig. 8).

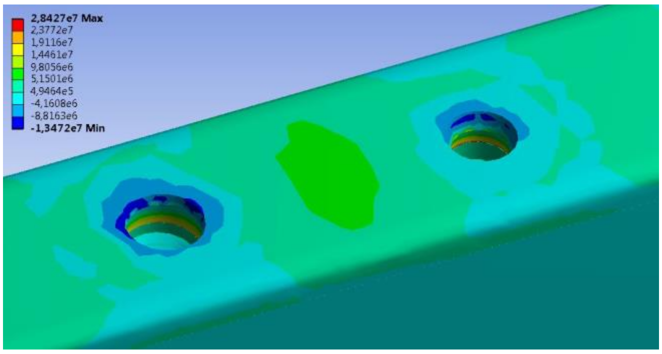


Figure 7: Maximum principal stress areas observed under vertical loading

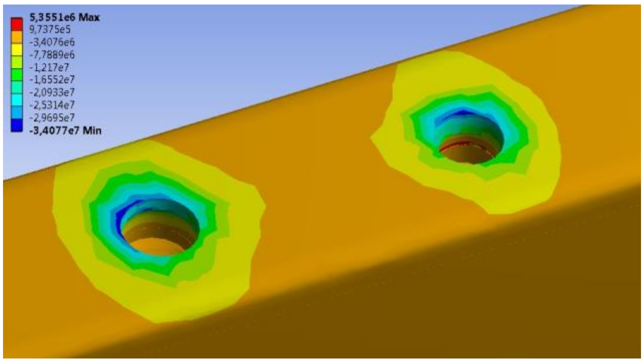


Figure 8: Minimum principal stress areas observed under vertical loading

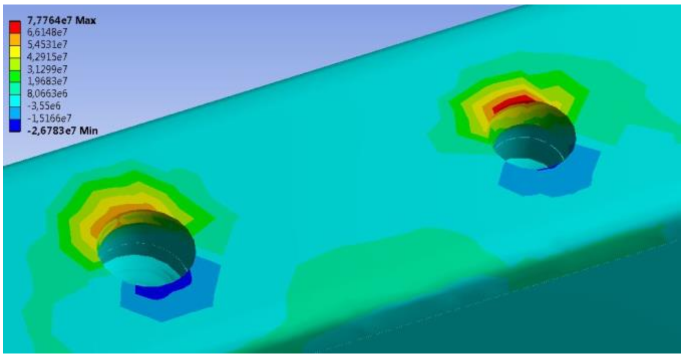


Figure 9: Maximum principal stress areas observed under oblique loading

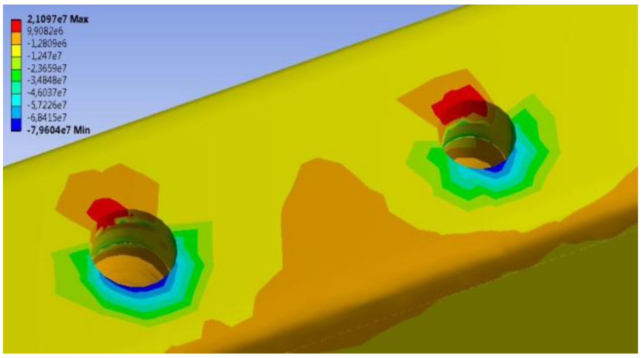


Figure 10: Minimum principal stress areas observed under oblique loading

Minimum principal stress defines compression stresses, and maximum principal stress defines tensile stresses (15). According to the results of our study, it was determined that the absolute values of maximum and minimum principal stress under vertical and oblique loading were close to each other, and the highest tensile and compression values were found in the Group1A model. When the maximum and minimum principal stress values are close to each other, the effect of the maximum principal stress should be considered because the tensile stress causes more destructive consequences.

Discussion

Finite element stress analysis methods are frequently preferred in order to examine the effects of biomechanical factors in implantology research (16-18). The numerical values obtained in the finite element stress analysis method are constant and statistical analysis is not used in the evaluation of the findings due to the absence of variance. The main purpose of the finite element stress analysis is to ensure that the models to be created are similar to the real tissue, organ, tool, or restorative material as much as possible and functionally resemble the forces actually acting on the organism in terms of direction, intensity and type (19). When the finite element stress analysis method was compared with other methods, the results were found to be compatible with each other (19-22). Since the structure of no material in all planes is the same, accepting the modeled material as homogeneous and isotropic will not affect the accuracy of the analysis results (23-25).

While principal stresses are used in the assessment of stresses in structures such as bone, von Mises stress values calculated from principal stresses are used in the assessment of stresses in retractable materials such as implants (11, 26, 27). In the finite element stress analysis method, the presence and thickness of cortical bone in models is one of the important properties that affect the result. Clelland et al. reported that the maximum principal stress value in the bone decreased by 50% as a result of increasing the cortical bone thickness from 1.5 mm to 3.0 mm in the bone model (28). Similarly, Okumura et al. found the highest stress values in models with only trabecular bone without cortical bone (27).

There are varying data in the literature regarding the magnitude of chewing forces. These data; varies according to gender, existing muscle structure, muscle tone, age, presence of tooth deficiency, parafunctional habit, presence of bruxism, and the difference in measurement methods performed in the mouth (29, 30). In studies performed on patients with bruxism, the maximum bite power was found to be 911 N in molar teeth of male patients and 569 N in female patients

(31). In our study, occlusal values were used similar to the literature.

Variations to increase the length, diameter, and number of dental implants are recommended to reduce the stresses caused by occlusal forces (32). Petrie and Williams (8), Johansson et al. (33) reported that an increase in implant diameter significantly reduces the stress on implants and crestal bone and will be beneficial for mechanical complications. Eazhil et al. stated in their finite element study that the increase in implant diameter and number significantly decreased the von Mises stress values in the implant and surrounding tissues (32). Lobbezzo et al. stated that among the measures that can be taken in dental implant applications in individuals with bruxism, increasing the number and diameter of implants would be beneficial in preventing implant complications biomechanically (10). Similar to the literature, in our study, a decrease was observed in all principal stress values in the surrounding bone tissues by increasing the number and diameter of the implant.

While von Mises stress values that occur as a result of vertical loading are transferred from the cervical region of the implants to the apical region of the implant by distributing along the implant body, it has been reported in many studies that most of the stresses are concentrated in the cervical region, especially in oblique loads (34-36).

There are various opinions in the literature about the minimum occlusal thickness of the material in fixed prosthetic restorations using monolithic zirconia (37). Jasim et al. stated that 0.5 mm restorations with reduced occlusal thickness can still tolerate occlusal forces, while restorations with 1.0 mm occlusal thickness have higher fracture resistance (37). Park et al. in their study evaluating the resistance to fracture of zirconium in different thicknesses adhered to implant components, they stated that a thickness of 0.5 mm to 1 mm was sufficient to fracture resistance (38). Rekow et al. stated that the occlusal thickness of the material used is an important factor on stress distribution (39). Lan et al. reported that there is a decrease in von Mises stress values as a result of increasing the occlusal thickness of monolithic zirconia crowns in patients with bruxism (40). Although there are many studies in the literature that increasing the number and diameter of the implant reduces the stresses on the implant and surrounding tissues, there are very few studies on the effect of using monolithic zirconia with different occlusal thicknesses on the stress values in the implant and surrounding tissues.

In our study, a decrease was observed in the stress values in the cortical bone as a result of increasing the thickness of the occlusal material, the number, and diameter of the implant

Conclusions

In conclusion, in our study, the stresses caused by oblique forces are higher than vertical forces, and the maximum and minimum principal stress values observed in the bone tissue surrounding the implant under vertical and oblique loading were observed in the part corresponding to the cervical region of the implant. Increasing the diameter or the number of implants used reduces the stresses on the cortical bone. Increasing the amount of occlusal thickness of the monolithic zirconia used as a fixed bridge prosthesis material on the implant decreases the minimum and maximum principal stress values in cortical bone.

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