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Stress Distributions Created by Short and Regular Implants Placed in the Anterior Maxilla at Different Angles: A Finite Element Analysis

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Abstract

Although short implants are seen as alternative treatments that require additional surgical techniques in posterior region, they can be applied to anterior maxilla and various studies are required on this subject. The purpose of this study was to examine and compare the peak von Mises stress distributions in the crown, implant and abutment by using finite element analysis (FEA). Besides, a comparison of the implant-abutment connection types in the short implant with the FEA method was established. A short implant (4 × 5 mm) with a taper-lock connection and a regular implant (4 × 9 mm) with a screw connection were used in maxillary central incisor tooth area. Three different titanium abutments with 0˚, 15˚ and 25˚ angles were used for abutments. In addition, in order to determine whether the stress change in short implants is due to the length of the implant-abutment connection, a screw was designed for a short implant and it was also evaluated in the same three angles. A total of three groups and nine models were generated. 114.6N load was applied to the cingulum area of the crown at an angle of 135˚ to the long axis of the crowns. A torque load of 25 Ncm was applied to the regular and short implant screw. Von Mises stress distributions of implants, abutments and crowns were evaluated by using FEA. Increased angle in implants increased von Mises stress values of implant, abutment and crown. Screw connection was found higher at all angles in short implants. Close values were found at different angles in taper-lock short implant crowns. The length and the angle in the bone of implant with the type of implant-abutment connection results in the accumulated stress values. Clinical Implications Taper implant-abutment connection system was found to be more promising in terms of stress accumulation in crowns. Although the amount of stress on the abutment increased due to the length of the implant in short implants, taper implant-abutment connection system slightly reduced related to this increase.

Keywords

Anterior Maxilla, Finite Element Analysis, Von Mises, Short Implant

1. Introduction

There is a continuously growing demand for dental implants in recent years, and considerable attention has recently been devoted to the emergence of various dental implants which is led to an increase in the number of manufacturers [1] [2]. Even though they have attracted significant interest so far, the implementation of dental implants with desired functional and aesthetic expectations is still elusive. Accordingly, researchers should keep their knowledge updated and apply the latest technologies and treatments to their patients.

Due to the resorption of maxillary anterior bone from the buccal side to the palatinal side [3] [4] [5] [6] [7], the regular sized implants are placed towards the palatinal bone at an angle according to the anatomy of the tooth root position. Angled abutments have been generated to compensate for this angle. However, the oblique loads formed during function may cause some post-operative complications in the restoration or implant system. Hence, short implants have been generated for the anterior maxilla to be used in the presence of insufficient bone.

The angle of implant is an essential parameter that should be considered in the ideal three-dimensional (3D) positioning of implants in the anterior maxillary region. The implant should reasonably follow the root slope of the tooth or adjacent teeth, but this is not achieved in the ideal implant position [8]. It is recommended that the implant in the aesthetic area should be angled 5˚ - 10˚ more lingually than the location of the tooth root it replaces [9]. This recommendation was issued to maintain a thickness of over 1.5 - 2 mm in the buccal bone due to physiological resorption that occurs in the late loading protocol [8].

The maxillary incisors are positioned at an angle of 12˚ to 15˚ angle to the long axis of the mandibular incisors [10]. The facial angular position of the implant body is usually subjected to 15˚ off-axis loads [10]. This angled load causes an increase in the force applied to the implant system by 25.9% compared to the long axis load [11]. These external loads can cause loosening of the abutment screw, loss of crestal bone and disruption of cervico-gingival tissue [12]. The palatinal angled implants can induce aesthetic problems and increase the risk of complications [10].

FEA is a type of computerized analysis which is used to find a solution to a complex mechanical problem dividing the problem area into a collection of much smaller areas [13]. A constructed geometric structure is divided into small elements connected by nodes. There are interrelated equations that provide information about the stress distributions between elements and nodes, forming a finite set of equations accordingly [14]. After the creation of the finite element model, the properties and loading conditions of the materials are determined for the correct simulation [15]. FEA can be applied in 2D and 3D. Several studies have shown that 3D FEA method provides a more accurate analysis than 2D method in the analysis of stresses in dental structures [16] [17].

As far as we know, no previous research has investigated the stress distribution of single short implant treatment options applied to the anterior maxilla. Although short implants appear to be an alternative option to treatments that require additional surgical techniques in the posterior region, they can be applied to the anterior region of maxilla, and various studies on this issue are needed. Thus, this study aims to examine and compare von Mises stress distributions of crowns, implants and abutments in dental restorations using short and regular implants placed at bone level at 3 different angles to the maxillary right central incisor region by FEA. In addition, a comparison of implant-abutment connection types in a short implant with the FEA method will be implemented to determine the cause of the stress difference.

Two hypotheses have been established regarding this issue. The first hypothesis states that a short implant placed in an anatomical dental root position will induce less stress accumulation in the implant system compared to an angled regular implant, while the second hypothesis suggests that the screw and non-screw implant-abutment connections in a short implant will give different stress values from each other.

2. Material and Methods

This study was designed on 3 groups: Short-Taper (ST), Short-Screw (SS), and Regular (R). A total of 9 models were designed so that 3 different implants were placed in the maxillary right central incisor region at 3 different angles as they are presented in **Figure 1**. The von Mises stress distributions of crowns, implants and abutments were investigated by applying 114.6 N forces at an angle of 135˚ to the cingulum region of the restorations by FEA method [18]. A torque load of 25 Ncm was applied to the regular implant screw by following guidance of the company. The same torque load was applied to the short implant screw as the implant-abutment connection system was analyzed.

5 mm long short implant with 4 mm diameter (Max 2.5 System; Bicon, Boston, USA), 9 mm long regular implant with 4 mm diameter implant (Microcone IPS Implant System; Medentika, GERMANY), three titanium abutments with 0˚, 15˚ and 25˚ angle for short implant (Bicon Implant System; Boston, USA), three titanium abutments with 0˚, 15˚ and 25˚ angle for regular implant and its screw (2-90-02; Preface Abutment, Medentika, GERMANY) were scanned by optical scanner (Activity 880; Smart Optics Sensortechnik GmbH). The standard tessellation language (STL) data of each component were transferred into 3D modeling software (Rhinoceros 4.0; McNeel). To investigate the effect of the implant-abutment connection, a suitable screw for the short implant abutment was

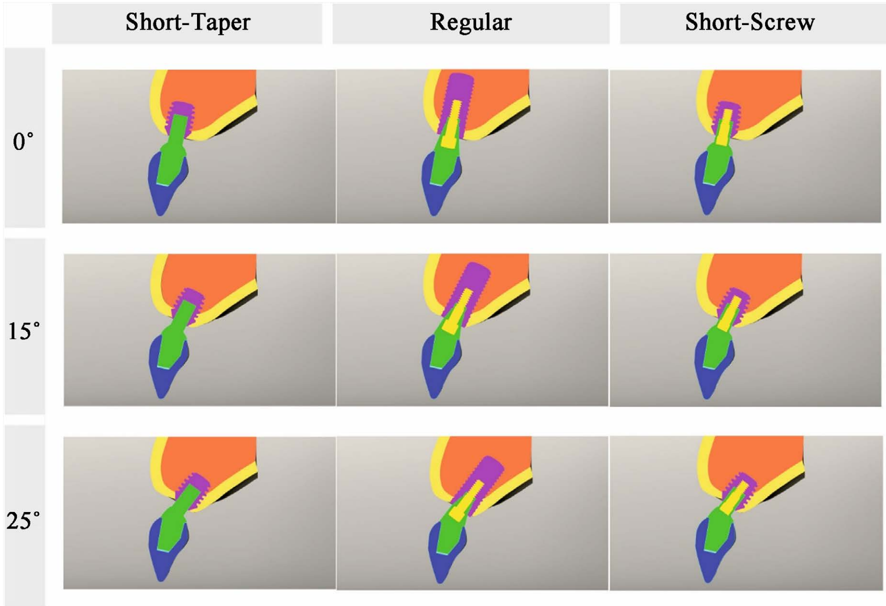

Figure 1. Render images of models.

designed and a screw hole was inserted into the abutment. The comparison between the short implant with the taper-lock (original) and the screw was analyzed with the newly-developed design. This new abutment and screw designs are modeled in the same 3D modeling software. A rounded shoulder finish line design was selected for the abutments. Edge depths of the abutments were designed as 0.5 mm. Total occlusal convergence (TOC) angles were determined as 10˚ and a taper angle of 5˚ was prepared on each axial wall. The occluso-cervical length of the abutments was determined to be 4.5 mm.

The same software program was used for maxillary modeling. In order to isolate the area to be evaluated, a box model was obtained from the maxillary model by using Boolean method [19]. Then the 3D model of the implants was placed in the bone structure with 100% osseointegration [20]. The gingiva was ignored for all models.

In this study, a maxillary right central incisor was used and images of the corresponding tooth were taken from the Wheeler Atlas [21] and modeled in the same software program. Monolithic zirconia (Lava Plus; 3M ESPE, GERMANY) was preferred as a restorative material. The cement thickness, which was not generally considered in FEA studies due to the low effect rates, was examined in this study and it was determined as 0.2 mm on the occlusal surface and 0.03 mm on the other surfaces [22]. Dual-cured resin cement due to the low light transmission of monolithic zirconia was adopted and modeled in the same software program. 3D images of the structures are presented in **Figure 2**.

A discretization process with 8 nodes of quadratic tetrahedral elements was conducted for all 3D models by using meshing software (VRMesh Studio; VirtualGrid Inc). For practical results, a large number of elements were selected without exceeding the program's capability. The number of elements and nodes used in mathematical models including scenarios are given below (**Table 1**). The meshed models were transferred to the FEA software (Algor Fempro; ALGOR) for stress distribution analyses. All models were considered homogeneous, isotropic, and linearly elastic.

After the models were designed compatible with Algor software, they were introduced to the software according to their material type. Each of the structures that make up the models was given material values (modulus of elasticity and

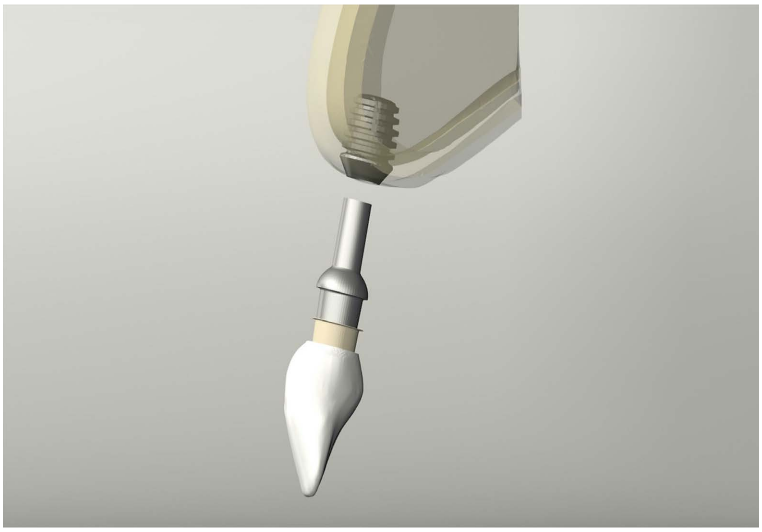

Figure 2. 3D image of the short implant in the bone.

Table 1. The number of elements and nodes used in mathematical models.

Model 1	ST 0˚	Number of nodes = 66,379 Number of elements = 313,488
Model 2	ST 15˚	Number of nodes = 67,014 Number of elements = 315,933
Model 3	ST 25˚	Number of nodes = 66,459 Number of elements = 313,143
Model 4	R 0˚	Number of nodes = 148,157 Number of elements = 782,901
Model 5	R 15˚	Number of nodes = 147,992 Number of elements = 781,115
Model 6	R 25˚	Number of nodes = 147,176 Number of elements = 775,516
Model 7	SS 0˚	Number of nodes = 83,980 Number of elements = 384,001
Model 8	SS 15˚	Number of nodes = 84,285 Number of elements = 385,129
Model 9	SS 25˚	Number of nodes = 83,341 Number of elements = 380,250

R, Regular. SS, Short-Screw. ST, Short-Taper.

Poissson ratio) that define their physical properties (**Table 2**). The constraints were set to no movement in the x, y, and z axes at the mesial and distal exterior surfaces of the bone structure.

3. Results

The results of the von Mises stress analyses are presented in **Figure 3**. The highest von Mises stress value in implants was ST15˚ with 401.69 MPa, and the lowest value was R0˚ with 277.17 MPa. Stress accumulations were found to be concentrated in the platform areas of the implants and decreased towards their apex. The highest stress values were found to be on the buccal surfaces of the implants. The stress on the ST0˚ implant was found to be 7.7% less than on the R15˚ and R25˚ implants. It was found that the von Mises stress value of the ST0˚ implant generated 13.2% less than the ST15˚ and ST25˚ implants. In the SS implants, there is generally higher stress accumulation than STs at all angles. **Figure 4** is shown stress concentrations in implants.

The highest von Mises stress value in abutments was ST25˚ with 411.92 Mpa, while the lowest von Mises stress value was R0˚ with 254.52 MPa. Stress values of abutments were found to be lower in the R group at all angles than in the ST group. In general, stress values of SS abutments were found to be higher than those of STs at all angles. It was observed that the amount of stress in all groups increased with increasing angles as they are presented in **Figure 5**.

Maximum stresses in all crowns were detected in the cingulum regions where the force was applied. The highest values after the maximum values were taken into account. **Figure 6** is shown stress accumulation areas in crowns. Although the values of crowns were close to each other in the ST group; in the R group,

Table 2. Young modulus and Poisson ratio of each material.

Materials	Young Modulus (MPa)	Poisson Ratio
R implant (grade 4) [66]	103,000	0.35
R abutment (grade 5) [66]	113,000	0.35
R screw (grade 5) [66]	113,000	0.35
SS implant (grade 5) [66]	113,000	0.35
SS abutment (grade 5) [66]	113,000	0.35
SS screw (grade 5) [66]	113,000	0.35
ST implant (grade 5) [66]	113,000	0.35
ST abutment (grade 5) [66]	113,000	0.35
Crown (monolithic zirconia) [67]	210,000	0.30
Cortical bone [68]	13,700	0.30
Cancellous bone [69]	1370	0.30
Dual polymerized resin cement [67]	6500	0.30

R, Regular. SS, Short-Screw. ST, Short-Taper.

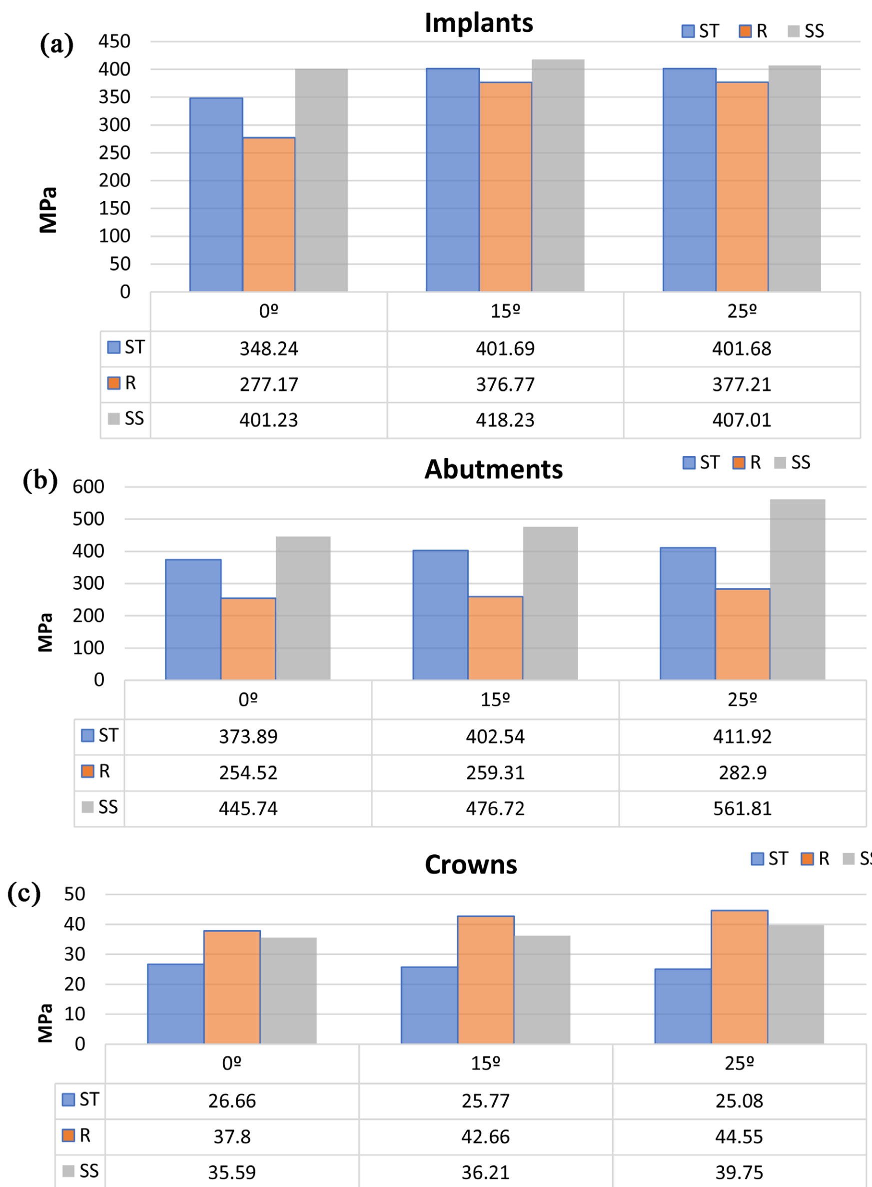

Figure 3. Von Mises stress values in (a), implants; (b), abutments; (c), crowns. ST, Short-Taper; R, Regular; SS, Short-Screw.

the values were observed to increase moderately with the angle increment. The lowest von Mises value was ST25˚ with 25.08 MPa, while the highest von Mises value was R25˚ with 44.55 MPa. The value of von Mises in ST0˚ was determined as 40% lower than R25˚. The values in the SS group tended to be increased partially as the angle increased. In general, stress values of SS crowns were found to be higher than STs at all angles. The maximum stress on the ST0˚ crown was found to be 25% lower than the ST0˚ crown.

4. Discussion

In this study, stress distributions caused by implants applied to the maxillary right central region at different angles were compared and demonstrated here

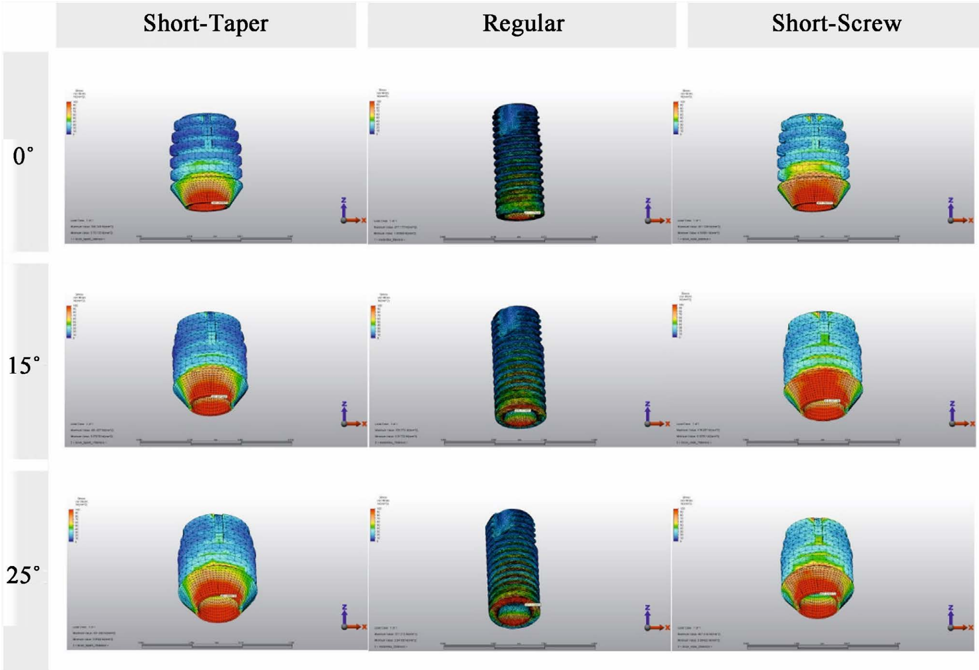

Figure 4. Stress concentrations in implants.

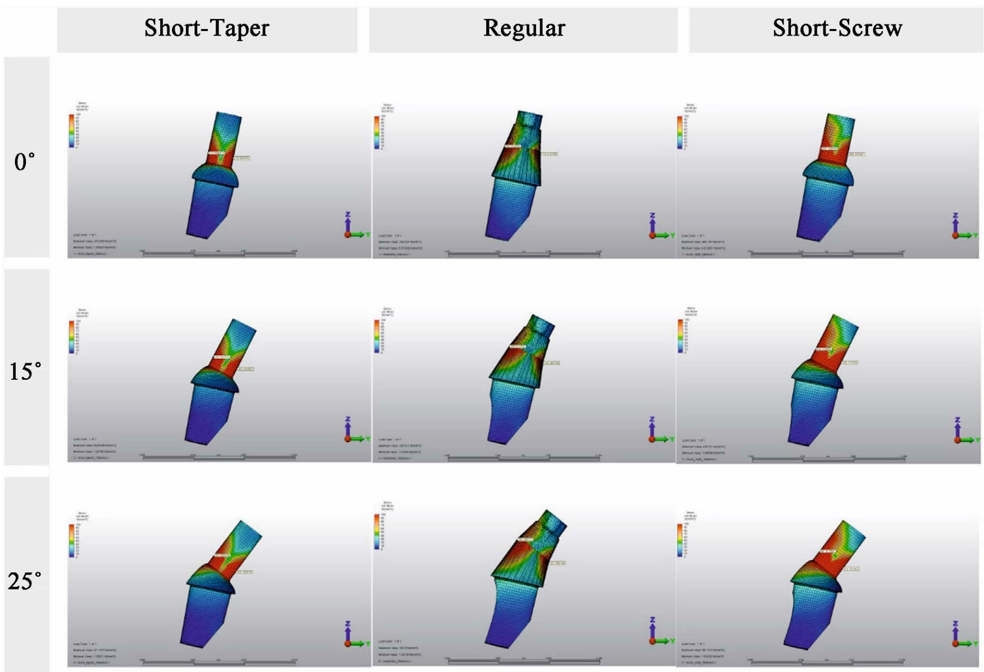

Figure 5. Stress concentrations in abutments.

has not been reported before. According to these results, a short implant placed at an angle of 0˚ generated less von Mises stress values in terms of crowns and implants than a regular implant placed at an angle, and the first hypothesis was partially accepted. In addition, the non-screw system in the short implant would cause less von Mises stress values than the screw system in terms of crowns, implants, and abutments, and the second hypothesis was accepted.

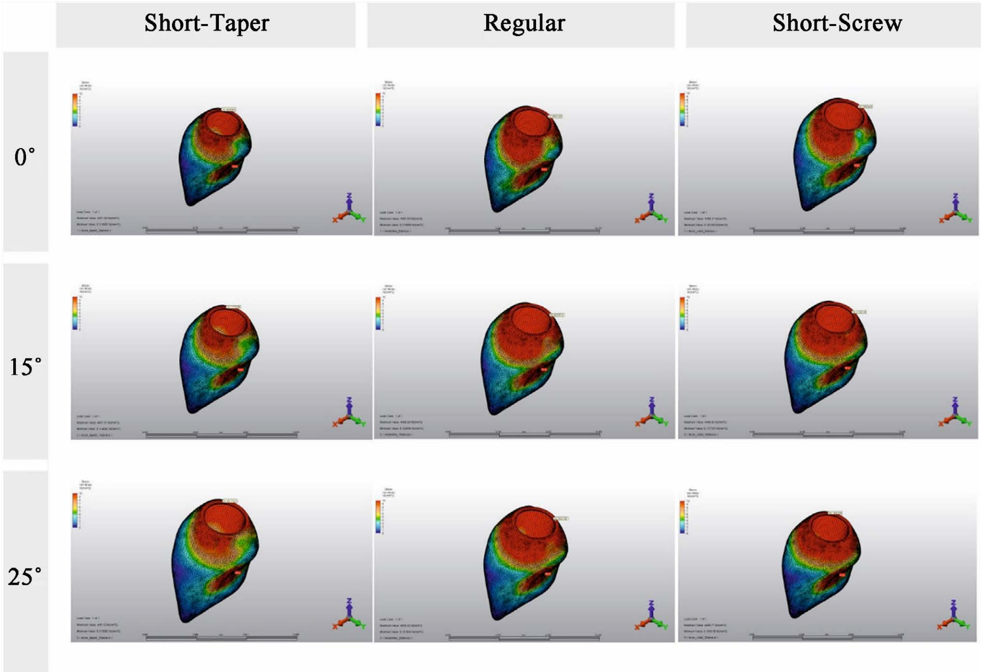

Figure 6. Stress concentrations in crowns.

Short implants are a more practical option than regular implants especially in complex surgical technique required cases [23] [24]. Although, according to Griffin and Cheung [25], short implants were associated with low success rates, Misch *et al.* [26] and Ravidà *et al.* [27] claimed that the short implants showed good survival rates and therefore they can be considered as an option in atrophic bones. Lee *et al.* [22] examined the risk of fracture in four short implants and reported that the fracture occurred in only one model, and no fractures were found in the remaining 10^7 cycles. Short implants seem to be an alternative treatment option to regular implants in some cases with the technology advances.

The success criteria of implant-supported prostheses are related to the accumulation of stress that they are exposed to. Therefore, it is essential to evaluate biomechanical factors for the long-term success [28]. Biomechanical analysis becomes complicated due to the dental anatomy, microstructural differences and diversity of biomaterials. It is impracticable to determine the effect of these differences on implants and surrounding tissues with in vivo tests due to high cost and ethical problems [29]. Thus, in-vitro studies gain importance. In recent years, the FEA method has started to be used in stress analysis of dental structures [29] [30] [31] [32]. FEA is an analytical method used to standardize the properties of materials [13] [33] [34] [35] and assess stress accumulations in complex structures [13].

In the FEA, it is not specifically defined whether the entire body to be evaluated or only the area to be examined should be modeled. In their study, Meijer *et al.* [36] created 3 different models: the full model of mandibula, 3D and 2D models of the mental foreman region. They stated that the 3D model, only the region to be studied, is sufficient for evaluation and will be time-saving of the researcher and ease of analysis [36]. Texeira *et al.* [37] concluded that bone structures modeled at a distance of 4.2 mm from the implants did not affect in the analysis. Tada *et al.* [38] stated that more accurate and rapid results can be obtained with box-shaped modeling of mandibula. Taking in account all these results, it was preferred to model only the region to be analyzed in this study.

When the maxillary anterior loading conditions are examined, there is no consensus on how much force is applied in which direction [18] [39]-[45]. In this study, the amount of 114.6 N applied to the cingulum region at an angle of 135˚ to the long axis of the implant, which is thought to best mimic the clinical conditions, was preferred [18] [39] [40].

For this study, the abutment finish line design was selected as the rounded shoulder type.

Miura *et al.* [46] noted that the rounded shoulder finish line generates lower stress values regardless of the abutment material, and has an appropriate geometry to minimize stress. Rounded shoulder and chamfer finish line types are recommended by various ceramic system manufacturers. However, Yu *et al.* [47] noted that ceramic restorations with chamfer finish lines have wider marginal gaps than those with shoulder finish lines. In addition, recommended finish line depths for all-ceramic crowns are range from 0.5 to 1.0 mm [48] [49] [50] [51] [52]. Consequently; a rounded shoulder finish line with a depth of 0.5 mm at the restoration margin was adopted.

Total occlusal convergence (TOC) is the sum of the angles between the two axial walls, which forms one of the basic principles of dental preparation [53]. Wilson and Chan [54] reported in 1994 that maximum retention occurred between 6˚ and 12˚ TOC. Shillingburg *et al.* [48] stated that for adequate retention, this angle must remain between 10˚ and 22˚. Tiu *et al.* [55] found that the recommendations on this issue increased from 2˚ - 5˚ to 10˚ - 22˚. Goodacre *et al.* [53] supported the ideal TOC between 10˚ and 20˚. In this study, the TOC was determined as 10˚ and a taper angle of 5˚ was prepared on each axial wall.

Occluso-cervical length is one of the important parameter for dental preparation. Maxwell *et al.* [56] stated that in maxillary anterior restorations with minimal TOC (6˚), the occluso-cervical length should be a minimum of 3 mm. Woolsey and Matich [57] noted that the 3 mm occluso-cervical length provides sufficient resistance at only 10˚ TOC. Goodacre *et al.* [53] determined that the occluso-cervical length should be at least 3 mm in incisors with a TOC of 10˚ to 20˚. Therefore, the occluso-cervical length of the abutments was determined as 4.5 mm for the following study.

Due to its low effects in FEA studies, the type and the thickness of cement are usually not among the main parameters. Lee *et al.* [22] determined the cement range at 0.2 mm occlusal surface and 0.03 mm on other surfaces in their study, in which they compared internal and external abutment connections in short implants. In this study, these values were also considered.

The von Mises analysis is used for ductile materials rather than maximum and minimum principle stress analysis. The material is initiated to be plastic and loses its elasticity beyond the yield strength and this makes the yield strength essential for von Mises stress values [58]. Chelland *et al.* [43] stated that occlusal loads do not cause metal fatigue under ideal conditions. While the yield strength point of grade 4 titanium material is 485 MPa, the yield strength point of grade 5 titanium material is calculated between 729 - 817 MPa [59]. All titanium structures except the normal implant used in this study are grade 5 titanium, and none of the stress values exceeded the specified yield point. There is no failure observed in implant and abutment structures according to the highest von Mises stress values.

The macro-design of an implant is very crucial in terms of functional load transmission and primary stability [10]. Bourauel *et al.* [60] compared 8 short and 13 mini implant brands with different macro-design, sizes and diameters with the FEA. Bozkaya *et al.* [61] examined the effect of external geometries on stress distribution in 5 different implant systems using FEA. Although the FEA is an in vitro study, the main purpose of FEA is to mimic the clinical condition and provide a preliminary idea for clinicians regarding potential complications during treatment.

The stresses formed in the crowns differ according to implant length and implant-abutment connection type. The increase in implant length significantly increased with the amount of stress that comes to restoration. This increase approached 100% in the R25˚ crown as compared to the ST0˚ crown. The stress value in the R0˚ crown was measured to be higher than the ST0˚ and similar to the SS0˚ crown and it was concluded that the implant-abutment connection was an important determinant in this regard. The advantages of the taper-lock connection are also seen in terms of the stress accumulated in the restoration. The accumulated stress at all angles was found to be very low in the non-screw connection type. Additionally, Guguloth *et al.* [62] determined in their results that stress accumulation of restoration in angled abutments would be greater than the straight one, and this finding coincided with this study.

Rendohl and Brandt [63] noted an increase in stress accumulations when using angled abutments in implant systems with a morse-taper implant-abutment connection system compared to straight abutment components. This increase in von Mises stress values in abutments was turned out to be consistent with an increase in short implant abutments with a taper implant-abutment connection used in this study. Von Mises stress values in the ST implants tended to rise to an angle of 15˚ and this result was also consistent with the study of Rendohl and Brandt [63]. Both ST and R implants indicate a similar trend in von Mises stress values at 15˚ and 25˚ angles. Rendohl and Brandt [63] used only 0˚ and 20˚ angled abutment systems in their study. As a consequence, in further studies, it will be beneficial to evaluate von Mises stresses in implant-abutment systems with varying angles between 0˚ and 15˚.

García-Braz *et al.* [64] proposed that the morse-taper implant-abutment connection offers a lower stress concentration in the implant platform area and marginal bone crest than the screwed one under axial and oblique loads, so that the adjacent bone can be better protected. In the assessment formed in this study, the taper-lock connection system is also more advantageous in terms of stress accumulation than the screw one.

In their FEA study of the anterior maxilla, Wu *et al.* [65] held the positions of the implants the same in the bone and thus creating variations in the angles of the abutments. In this study, keeping the positions of the crowns constant would be more beneficial in terms of the clinical accuracy of the analysis instead of the positions of the implants. However, this study is limited to three different aspects. Therefore, the upcoming FEA studies should emphasize the stress values that implants with different angles in the bone will create.

In this paper, the effect of short and regular implants placed on the anterior maxilla was investigated at different angles under functional load on the stress distribution using the FEA method in a single-implant restoration with standard bone density. Additionally, the effect of implant-abutment connection on this issue was evaluated. This study is arranged as an in vitro study in which clinical conditions are tried to be mimicked as much as feasible and the results based on interpretation are obtained through mathematical models. The FEA method provides information about dental implant systems that are intended to be used. But the results should not be taken with certainty, and the limitations of the SESA method should be kept in mind at the stage of evaluating the results.

5. Conclusions

The following results were obtained within the limitations of this study:

1) In the implant-supported single dental restorations of the anterior maxilla, the stress accumulation occurred at the platform level of the implant.

2) An increase in the angle of the implant and abutment increased von Mises stress values in the crown. But close values were found at different angles in the taper implant-abutment connection system. In terms of stress accumulation in crowns, the taper implant-abutment connection system was found to be more promising.

3) ST implant and R implant did not result in stress changes in the implant at angles greater than 15˚.

4) An increase in the angle of the implant and abutment increased the stress values of von Mises in the abutment. In short implants, the amount of stress on the abutment increased due to the length of the implant. The taper implant-abutment connection system in the short implant reduced this increase somewhat.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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