**Original Article**

# A Three-dimensional Finite Element Analysis of Stress Distribution in Inclined Placed Implants

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## Abstract

**Introduction:** Short implants are considered as a sole option in many patients due to anatomical limitations. It was aimed to assess the functional load stress at implants, surrounding bone and superstructures with different inclination angle. **Methods:** Seven finite element models with three implants (4 mm × 8 mm) and a separate model with longer implants (4 mm× 10 mm) with an angulation of 37° were designed. The implants were first placed vertically and then angled in distal direction preserving their parallelism increasing 6 ° at each step. Chromium-Cobalt was used to prepare superstructures. Oblique force of 100 N was applied on superstructures. **Result:** Inclined implant replacement did not significantly increase stress and compressive forces on bone, and the stress on implant surrounding bone decreased as inclination angle increased. On the other hand, in the model with linger implant more homogenous stress distribution was observed and implant's von Mises values decreased. **Conclusion:** Inclination of implants could have no detrimental effects on bone. Furthermore, inclination of implants provides the opportunity of placing longer implants and also more favorable stress distribution around the implants and in bone.

**Keywords:** Finite Element Analysis; Dental Implant; Fixed Partial Denture, Implant Inclination, Stress analysis

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## Introduction

Dental implant treatments became one of the main solutions for the treatment of partial and complete edentulous patients for several years. Implant supported fixed prosthesis is an emerging treatment method with high success rates (1). In certain cases, surgical placement of implant is modified by limitations like poor bone quality, minimal bone volume, and anatomical limitations of alveolar bone. Several techniques and procedures have been presented to address these limitations in the past decades. Management of atrophic ridges such as bone augmentation and grafting procedures, surgical displacement of inferior mandibular nerve and using zygoma for implant placement are such examples of these techniques (2-4). However, there are disadvantages such as long healing period for bone augmentation procedures, high costs, and surgical complications related to these grafting procedures (5). Long distal cantilevers on posterior regions could be destructive to bone and implant superstructures (6). Recently, inclined implants have been proposed in rehabilitation of edentulous ridges. Inclining implants toward the distal in the mandible could help avoiding the mental foramen area and prevent nerve damage. In maxilla, this could help avoiding the maxillary sinus and cancel the need for further grafting procedures in sinus cavity. With inclined placement of the implants, conventional size implants could be placed in bone instead of the short length implants to provide maximum contact with cortical bone (7-10). As a result, primary stability of these implants would improve (2, 11-13). The objective of present study was to assess stress distribution in bone under chewing forces in titled longer implants using 3-dimensional finite elements stress analysis method.

## Materials and Methods

Three dimensional finite element analysis (FEA) model was used to evaluate stress distribution and stress concentration level in models. Three implants supporting a five-unit restoration were analyzed in straight angle and different inclination degrees. A graphic processing program (Rhinoceros 4.0, McNeel, Seattle, USA and Algor Fempro, Algor Inc., USA) was used to create cortical and cancellous bone models as well as implants and superstructures. Implant and abutment geometries were created for this study. Seven finite element models were designed using 4.0 mm diameter and 8.0 mm long implants. The 8th model was designed using a 4.0 mm diameter and 10.0 mm long implant. Implants were positioned vertically in first model and in other models, implants inclined to distal with a 6 ° increasing angle in each sample compared to previous one. Parallelism between implants was maintained. The implant Superstructure was made using Chromium-Cobalt (Cr-Co) alloy with a thickness of 0.8 mm and only infrastructure was modeled. Five unit fixed restorations were placed on abutments in virtual environment. Since the entire mandible was not required in the study, the corresponding region was modeled as a box. Each model included approximately 30800 nodes. It was designed to use 8 node elements as much as possible. The calculation of each node displacement verified stress on the structure. The exterior nodes were fixed in all directions as boundary condition. All materials were considered to be isotropic, homogenous, and linearly elastic. Elastic properties of structures used in this study and their Poisson ratios were indicated in the Table I (14-16). An oblique load of 100 N was applied on superstructures with an angle of 45°. The Stress levels were calculated using von Mises stress values. The maximum values were used as a reference.

Table I: Materials and Bone Properties

| Material | Elastic Modulus (GPa) | Poisson’s ratio |
|---|---|---|
| Cortical Bone | 13.7 | 0.30 |
| Trabecular Bone | 1.37 | 0.30 |
| Titanium | 110 | 0.35 |
| Cr-Co | 210 | 0.35 |

## Results

When maximum principal stress is applied based on implant inclination, stress concentrations were mostly observed in buccal cortical bone. (Fig. 1, 2) When implants were inclined up to 12 °, stress was observed around implant number 45 and it increased as the angle increased (Fig. 3). At 18 ° angle and higher, stress decreased and stress-concentration regions were observed differently. Stress was concentrated in buccal of implant number 45 at 18 ° and 24 ° inclination (Fig. 4, 5), in buccal of the implant number 47 at 30 ° (Fig. 6), and in buccal of the implant number 43 at 37 °. (Fig. 7) In the 10 mm long implant model, stress values decreased at all sites while only stress in buccal of implant number 45 increased at 37 ° angle. (Fig. 8) When minimum principal stress is applied based on implant inclination, stress concentrations were observed mostly in lingual cortical bone. In vertical implants, stress was first concentrated in lingual of implant number 43 and at 6 ° and 12 ° stress was observed in lingual of implant number 45. At 18 ° and the subsequent angles, stress was again concentrated in lingual of implant number 43. Starting from 24 degrees implants, an increase in stress was observed with an increase in the angle. However, at 30 degrees angles and more, stress levels started to decrease. Comparison of the model with 8 mm implant and the model with 10 mm implant at 37 ° demonstrated that all stress values were reduced in longer implants. When von Mises stress on implants was examined, stress values up to 12 ° angle were concentrated around implant 45. At 18° angles and higher, stress values were concentrated in lingual area of implant 43. In models with angles up to 24 °, an increase in the stress value in proportion to the angle was observed. At 30 degree and higher implants a decrease in stress around implants was observed. Comparison of 8 mm implant model with 10 mm implant model at 37 ° demonstrated that all von Mises stress values decreased when long implant was used. Comparison of stress values for implants demonstrated that inclination of implants and extension of the implant length reduced stress values.

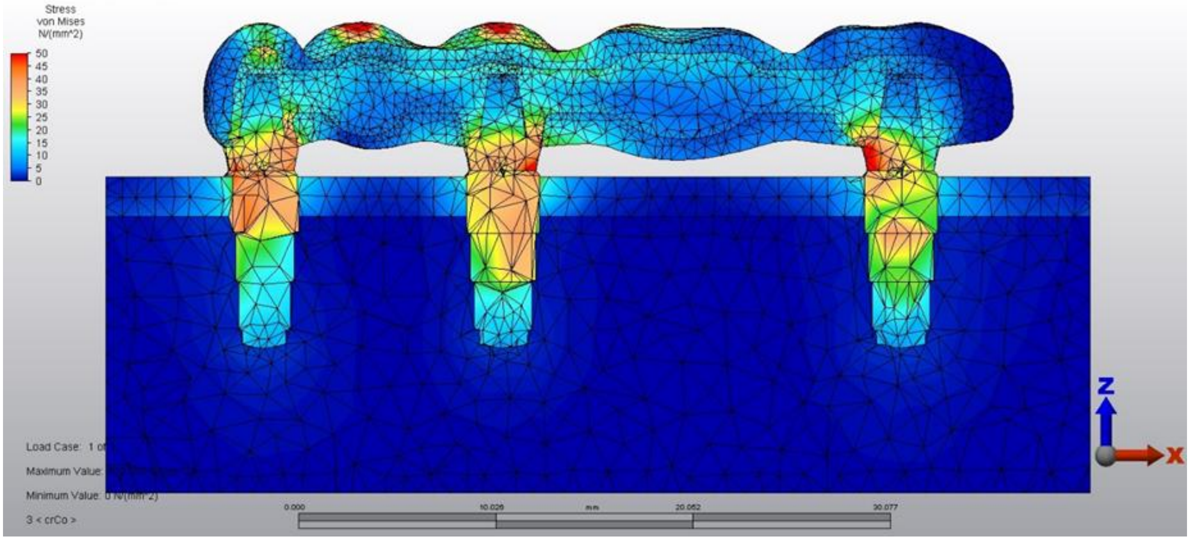


Figure 1: Stress concentrations in the bone and implants under loading (Parallel/ 0°)

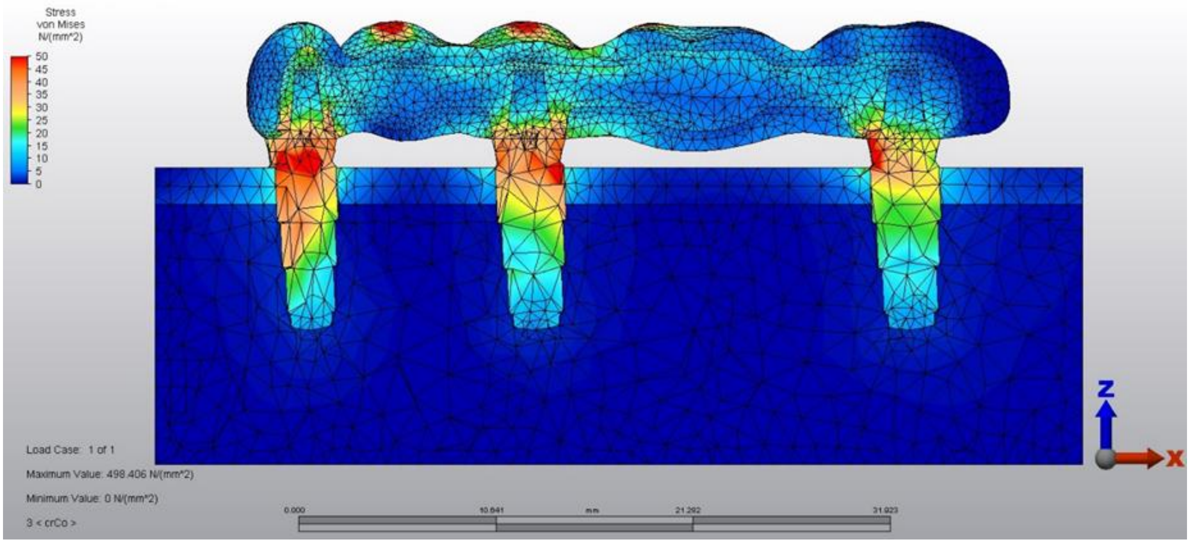


Figure 2: Stress concentrations in the bone and implants under loading (6°)

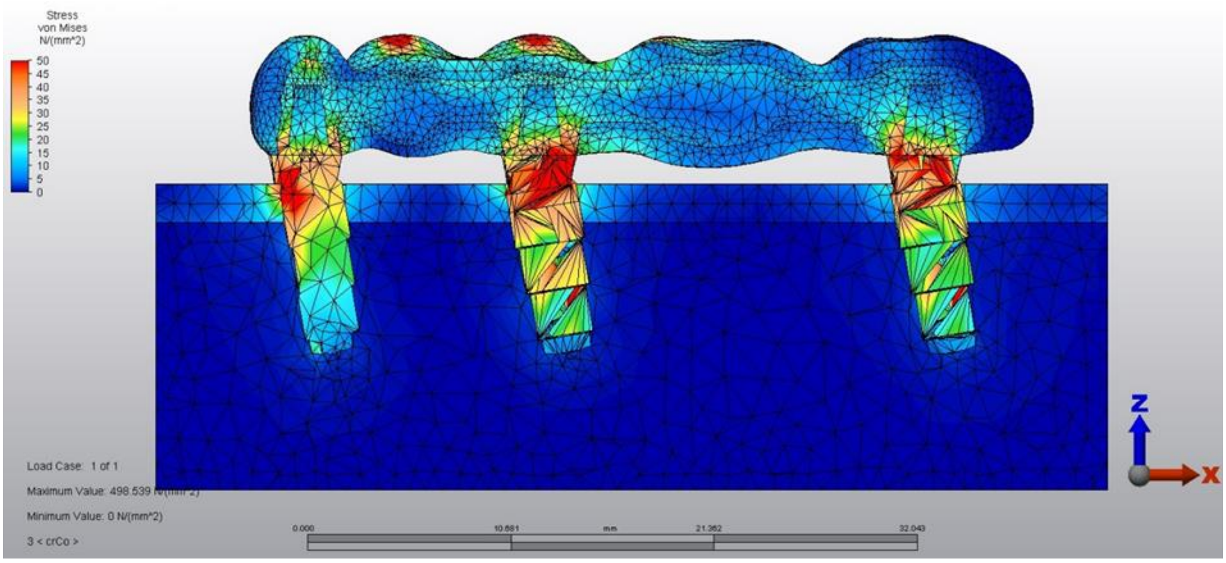


Figure 3: Stress concentrations in the bone and implants under loading (12°)

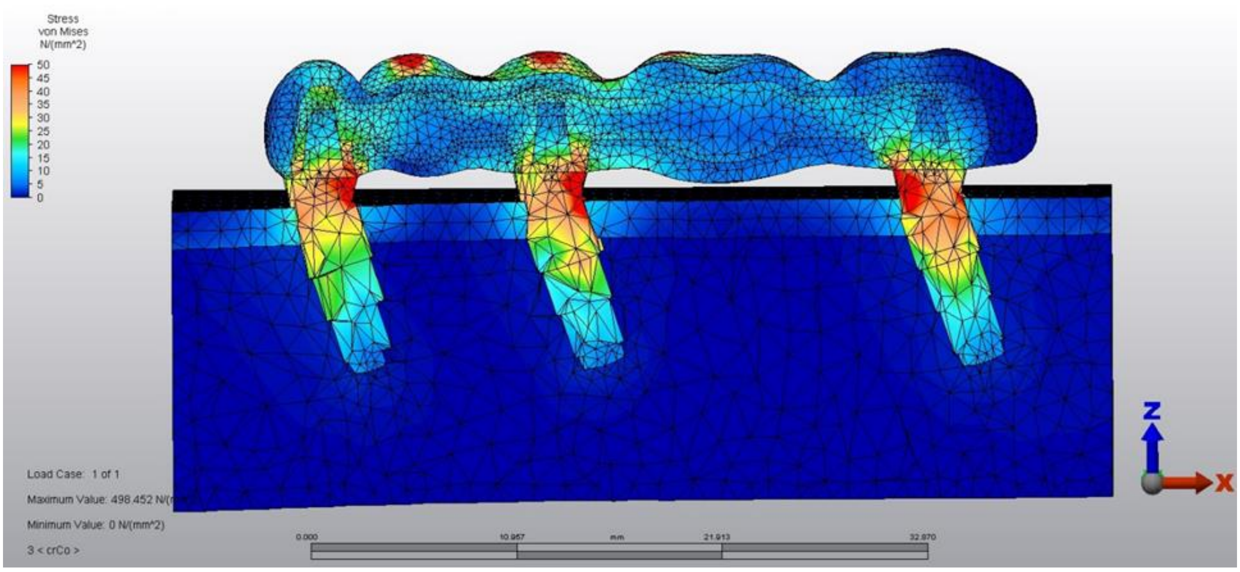


Figure 4: Stress concentrations in the bone and implants under loading (18°)

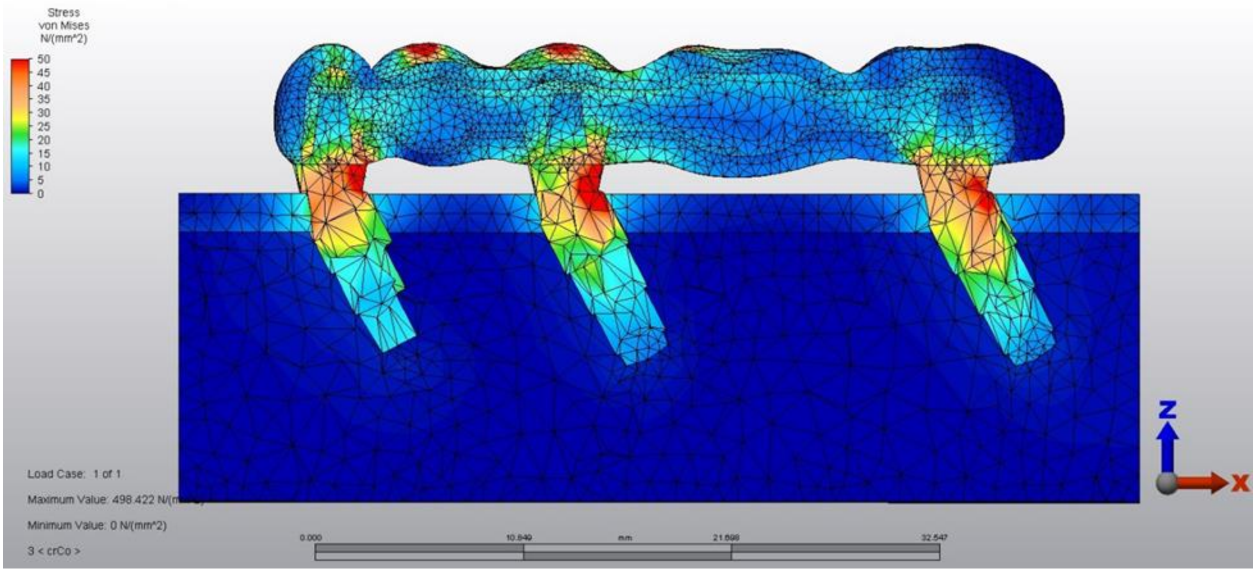


Figure 5: Stress concentrations in the bone and implants under loading (24°)

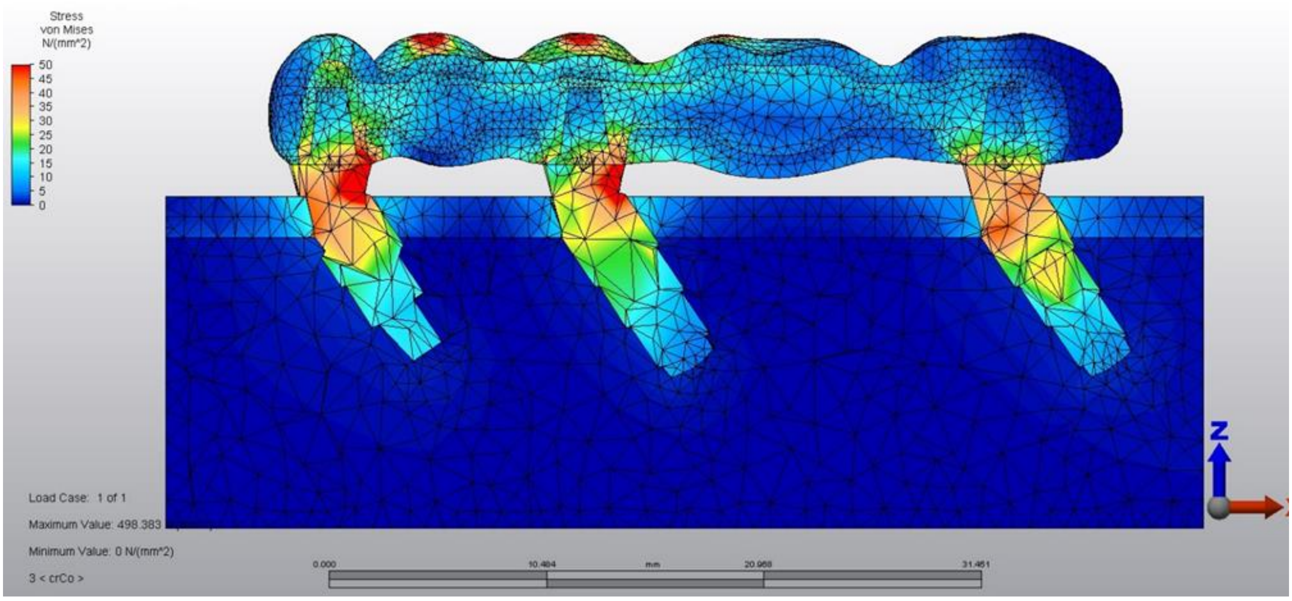


Figure 6: Stress concentrations in the bone and implants under loading (30°)

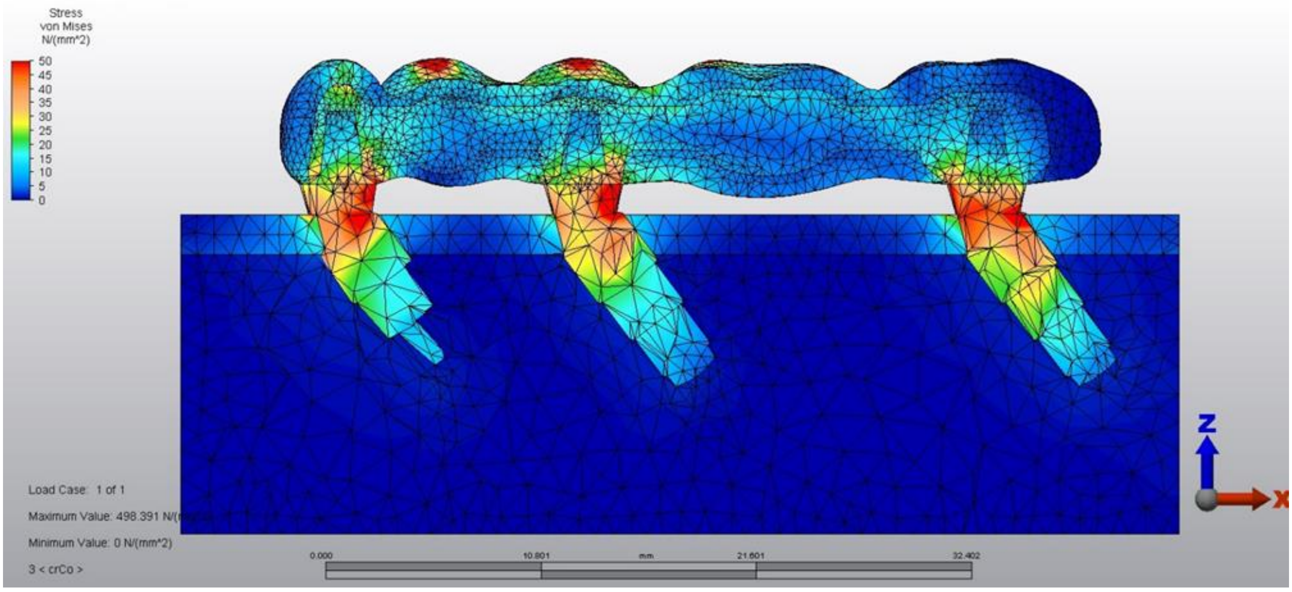


Figure 7: Stress concentrations in the bone and implants under loading (37°-8mm length)

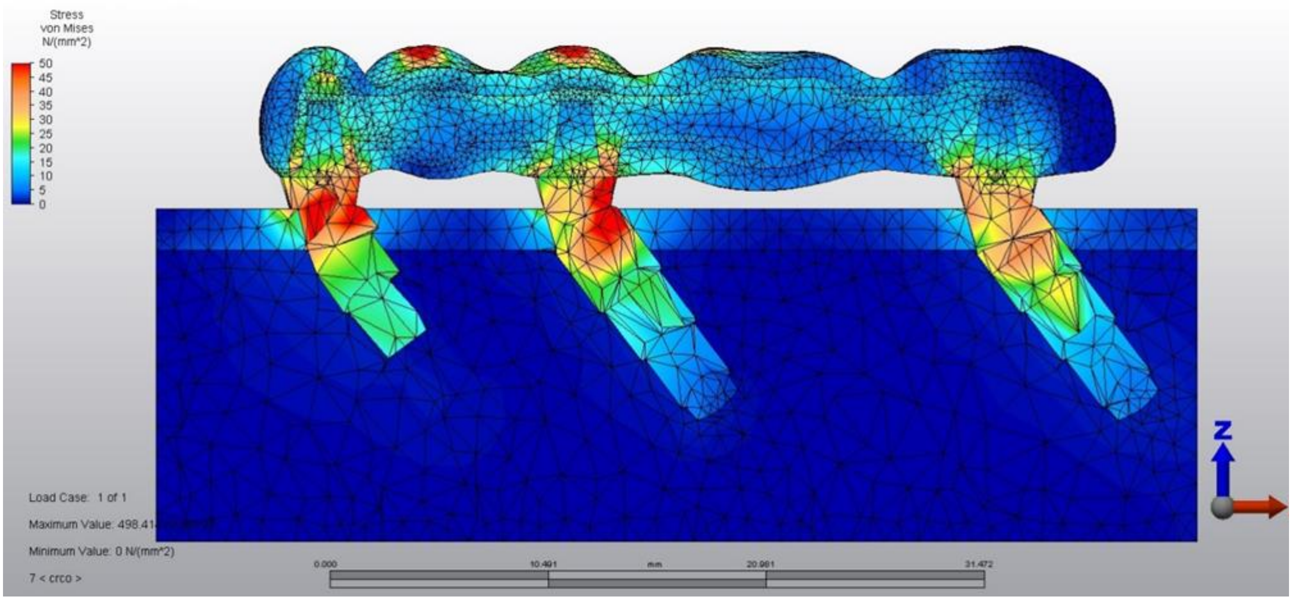


Figure 8: Stress concentrations in the bone and implants under loading (37°-10mm length)

**Discussion**

In several previous studies, it was demonstrated that inclined placement of implants led to positive results (6,18-22). Although there were opposing opinions (6), many researchers indicated that the inclination of the implant does not adversely affect the osseointegration process and there is no significant difference in marginal bone loss between vertical and inclined implants (2, 11, 16, 17, 23-27).

However, inclined placement of a single implant caused excessive stress on the bone under occlusal forces (1, 17, 27-31). It was reported that, a more pronounced rotational momentum was observed in tilted implants, could increase stress on bone surrounding the neck region of implant (28). The inclined placement of implants is advantageous if implants are splinted with the superstructure. Thus, in a single implant placement, inclined placement is an undesirable condition. In the present study, multiple implants were used and implants were splinted with a rigid superstructure. As the inclination degree increased, stress on bone around the implant and stress within the implants decreased. Our results are in contrast with Gumrukcu et al. (32) However, they also declared a report that states multiple implant supported prostheses might decrease stress level by increasing the inclination degree. Also, inclinations of implants in posterior region offers placing longer implants, provides better primary stability by cortical anchorage and reduced cantilever length (10, 32).

Previously, the common concept of implant length was that it should be as long as possible to achieve success. Length was defined only by anatomic limitations (33). Longer implants could be beneficial for implant primary stability and more evenly stress distribution (12, 34).

In the present study, implants were placed at an angle to enable the use of longer implants. In the long implant model, stress in bone was only increased locally and decreased in other regions. Also, stress in implants bodies decreased. Considering results of previous studies and our study, it could be discussed that increasing length of implants is a significant factor in long term success. Placement of long implants has several advantages over implementation of short implants (10, 34, 35). Peixoto et al. (37) also reported that lower stress values were observed on prosthetic screws within inclined implants. This may reduce screw loosening or fracture.

In the current study a model that was representing mandible was used. A 5 unit fixed restoration supported by three implants was used instead of a more complicated all-on-four restoration. A simple restoration design could help to focus on inclination effects of implants, while more biomechanical factors would affect behavior of a cross arch restoration like in all-on-four. The outcomes of current study may be helpful to understand behavior of inclined implants, either in conventional or in all-on-four restorations.

## Conclusion

Our study results showed that implant and bone are not significantly affected by stress when implants are inclined and splinted with superstructure. In addition, inclined implants allow placement of longer implants. Hence, inclining the implants should be considered opposing to placement of short implants. This decision could be considered especially in posterior mandible where anatomical limitations like proximity to inferior alveolar nerve canal is a major challenge.

## Conflict of Interest

Authors claim no conflict of interest.


## Acknowledgment

There is no acknowledgment for this study.


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