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Research Article

Influence of Offset Placement of Mandibular Dental Implants Over the Stress Levels of Bone

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Abstract

Background: Bending moments resulting from non-axial loading should be avoided especially in molar implants due to increased stress concentrations in cortical bone. This research aimed to evaluate the influence of straight or staggered implant placement in mandibular posterior edentulism by finite element stress analysis.

Methods: Three finite element models which includes an edentulous mandible and a partial fixed prostheses supported by 3 implants placed at second premolar, first and second molar regions were simulated. In the first model three implants were placed in-line whereas the other two models simulated the offset placement of the middle implant buccally and lingually. Two types of force, vertical and oblique respectively, were considered in the simulations. For each loading mode, each implant was loaded separately with a force of 100 N. Stresses were investigated using the ANSYS 8,1 Workbench Program.

Results: For the cervical cortical bone region, in-line placement of implants caused increased stress levels under both loading modes. The results of this study demonstrated that lower stress values were recorded in cortical bone at the cervical region of implants for lingual offset placement in comparison to in-line placement under oblique loading modes. Under vertical loading mode, buccal offset placement was found to be beneficial over the in-line placement to decrease the bone stresses around the implants placed in mandibular posterior region.

Conclusions: When the width of the residual bone ridge is sufficient buccolingually, offset placement may be recommended for the clinicians' long term success. Further investigation is needed to compare the effectiveness of offset placement over increasing the implant diameter with in-line and offset placement.

***Keywords:** Dental Implant; Stress; Finite Element Analysis; Offset Placement; In-Line Placement*

Abbreviations

CT: Computed Tomography; FEA: Finite Element Stress Analysis; IP: In-line Placement; BO: Buccal Offset; LO: lingual Offset

Introduction

As the application of dental implants has been widely accepted for the treatment of partial and full edentulous patients, implant related failures and complications have been aroused the researchers'great interest [1-5]. Implant related complications can constitutively be classified as mechanical ones including loss of retention, screw loosening, and porcelain, framework or screw fractures, and as biological ones which comprimise crestal bone loss, starting with radiographic signs of loss of osseointegration with horizontal bone loss and vertical bone defects that may lead to implant failures [2,4-6].

One of the main causes of implant failures can be accepted as overloading. General agreement is that excess stresses to a bone-implant interface may lead to overload resulting with implant failure [1-4]. This may occur after surgery and may result in fibrous tissue formation. Also excess overload may be applied after succesful osseointegration of implants and result in failure too [2,4-7].

The biomechanics of implant-supported fixed partial dentures is more complicated than implant-supported crown restorations [3-7]. Compressive and/or tensile stresses/strains with differing degrees are generated in implant surrounding bone during chewing movement [2,3,7,8]. Clinical studies showed that, more implant failures have been observed in posterior implant-supported partial prostheses than the anterior ones [4,8]. In most situations, it is preferred to restore a posterior edentulous region having three missing teeth with two-implant-supported fixed partial prostheses. However, the anatomical limitations of the mandibular bone such as the inferior alveolar nerve, sublingual fossa and inadequate bucco-lingual bone width that prevents placement of implants with optimal dimensions and also occlusal risk factors such as parafunctional activities make it necessary to replace each missing tooth with an implant [1,2,4,7,8]. It is widely accepted that prostheses supported by one or two implants for the replacement of missing posterior teeth have an increased risk of bending overload potentially [2,4,9].

It is widely accepted that bending moments cause increased stresses on the implant and bone-implant interface resulting with failure [2]. Bending moments resulting from non-axial loading should be avoided especially in molar implants due to increased stress concentrations in cortical bone [2,4,9]. It has been demonstrated that placing implants along a straight line causes bending forces rather than axial forces [6,8,10-14]. Therefore, in-line implant placement especially at posterior regions may be considered as a risk factor [9-14].

Aim of the Study

This study aimed to evaluate the effect of in-line or staggered implant placement in mandibular posterior edentulism by 3-D finite element stress analysis (FEA). The null hypothesis was that staggered placement of implants will not cause different stress levels of bone over in-line placement.

Materials and Methods

An edentulous mandible taken from a human cadaver was scanned by computed tomography (CT) (Siemens Somatom AR.STAR, Siemens Medical Solutions, Erlangen, Germany) at frontal plane for 1 mm interval anterio-posterior sections. Scanned CT files were recorded to the computer, as a two dimensional 512 x 512 pixel resolution and 16-bit gray color depth DICOM format files (Figure 1). Scanned files were checked with SIENET MagicView 300-DICOM-Browser (Siemens Medical Solutions, Erlangen, Germany). From each CT DICOM image, material boundaries were defined by a 3D imaging program (Rapidform 2004, INUS Technology, Inc., Seoul, Korea) and the mesh model was gained. To have the cortical and trabecular bone volume seperately, the mesh model was transferred to 3D solid modeling program (Rhinoceros; Robert McNeel and Associates, Seattle, WA, USA) and cortical bone was modeled as 1.5 mm according to average amount gained from CT sections of mandible.

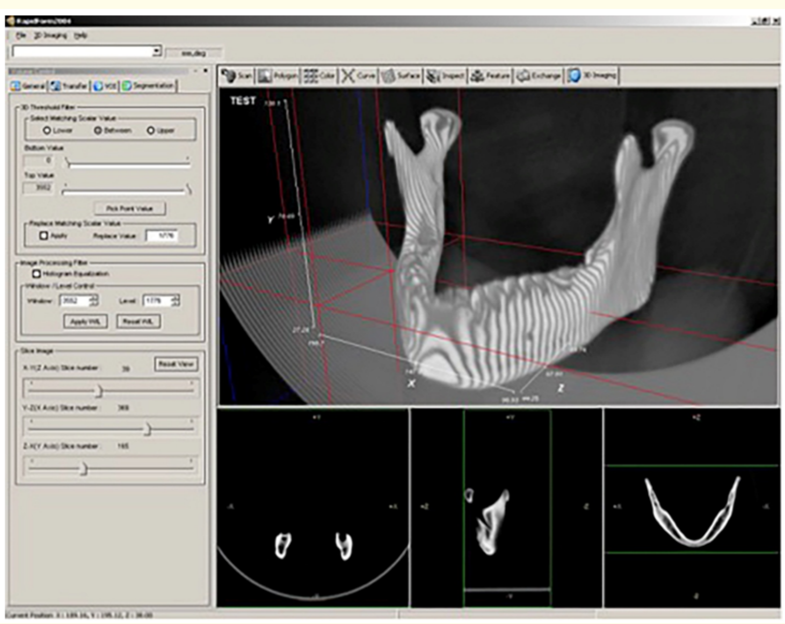

Figure 1: *Three-dimensional finite element model obtained from a scanned cadaver mandible.*

By using the CT images again, the exact placement of the mental foramen was detected on mandible. Assuming that the vertical line passing through the mental foramen collides with the distal margin of the crown on the 2nd premolar, the total mesio-distal size of the prosthesis and also the bone area were localized.

Several measurements were taken to obtain the optimum implant dimensions enabling the staggered placement of implants. Straumann standart implants (Straumann Dental Implant System, Waldenberg, Switzerland) with 4.1 mm diameter and 10 mm length and three standard regular neck solid abutments (Straumann Dental Implant System, Waldenberg, Switzerland) were chosen for the convenient bone region. Implants and abutments were modelled by Rhinoceros 3D program (Robert McNeel and Associates, Seattle, WA, USA) according to the dimensions given by the manufacturer (Figure 2). Three implants were marked as implant no.s 1 to 3 from mesial to distal directions respectively. The distances between the center of implants were defined as 9 mm for the 1st and 2nd implants whereas it was 11 mm for the 2nd and 3rd implants according to anatomical average tooth dimensions.

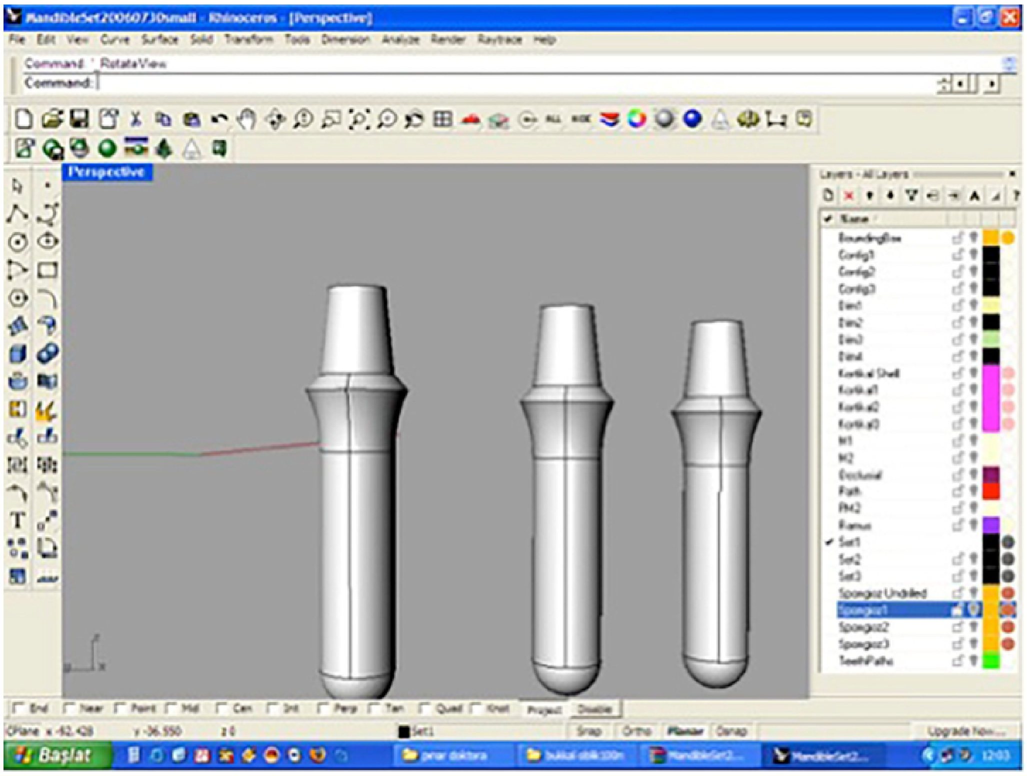

Figure 2: *Modelling of Straumann implants for the mathematical model.*

According to all calculations three geometrical models were formed representing the in-line and two staggered placement with 2 mm offset amount (Figure 3). The prosthesis was geometrically modelled as composed of three units with 9 mm^2 connection area, 28.5 mm mesio-distal and 10.5 mm buccal width. Ni-Cr metal alloy was chosen as the prosthesis material. For converting these geometrical models to finite element models, some necessary information was saved on the computer as type of element, number of nodes and material properties (Tables 1, 2 and Figure 4). Three finite element models which includes an edentulous mandible and a partial fixed prostheses supported by three implants were constructed (Figure 5). Two types of forces, vertical and oblique respectively, were considered in the simulations. For each loading mode, each implant was loaded separately with a force of 100N. Vertical forces were applied parallel to the long axis of the implants along the central fossa region of the prosthesis which comes into contact with the antagonist cusps during mastication. Oblique forces were applied with an angle of 30° to the lingual inclination of functional buccal cusp of the prosthesis simulating the functional occlusion (Figure 6). Material properties were saved on computer and stresses were investigated using the ANSYS 8.1 Workbench Program (Ansys Inc., Canonsburg, USA) finite element analysis scale.

Model	Number of elements	Number of nodes
Model I (IP)	165093	254079
Model II (BO)	165159	254132
Model III (LO)	165148	254111

Table 1: *Element and node numbers of the models.*

Material	Young's modulus	Poisson's ratio
Trabecular bone	1 370	0,3
Cortical bone	13 400	0,3
Titanium	110 000	0,35
Ni-Cr alloy	10 000	0,35

Table 2: *Material properties used in FEA.*

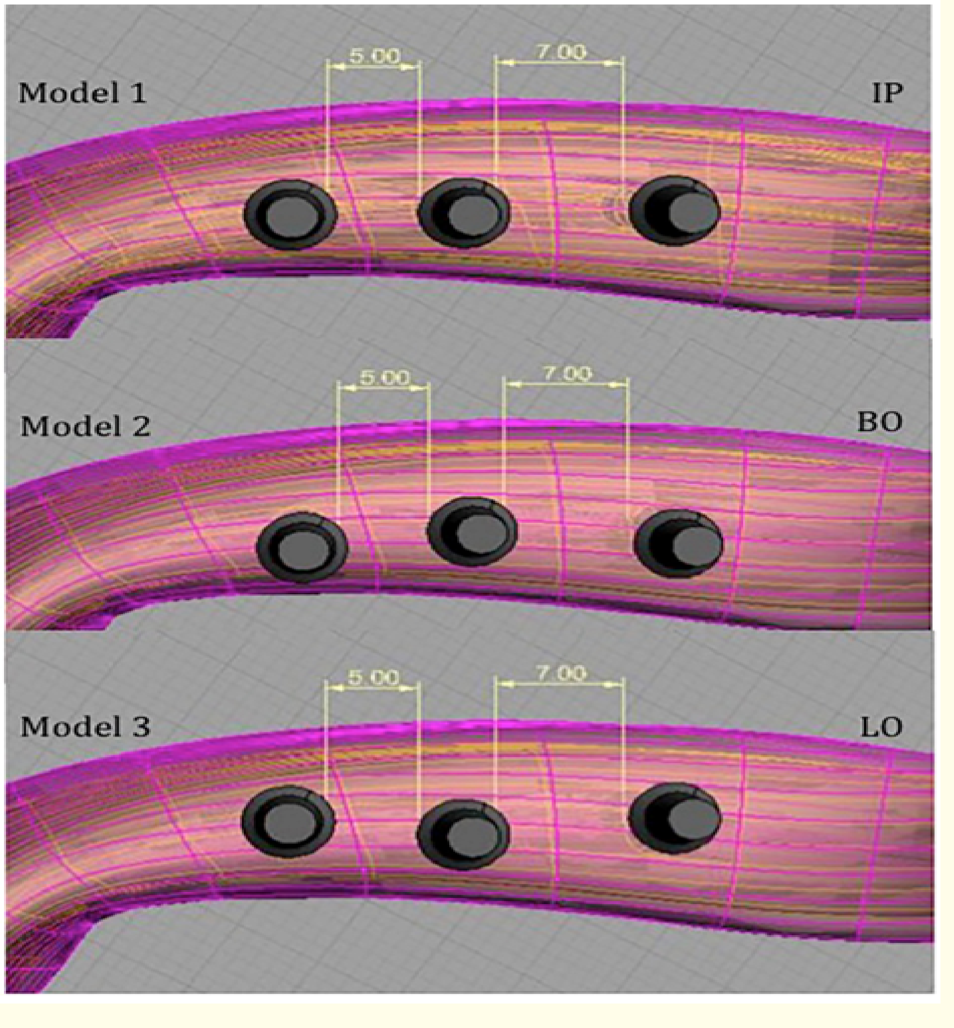

Figure 3: *Three models representing in-line placement, buccal offset, and lingual offset.*

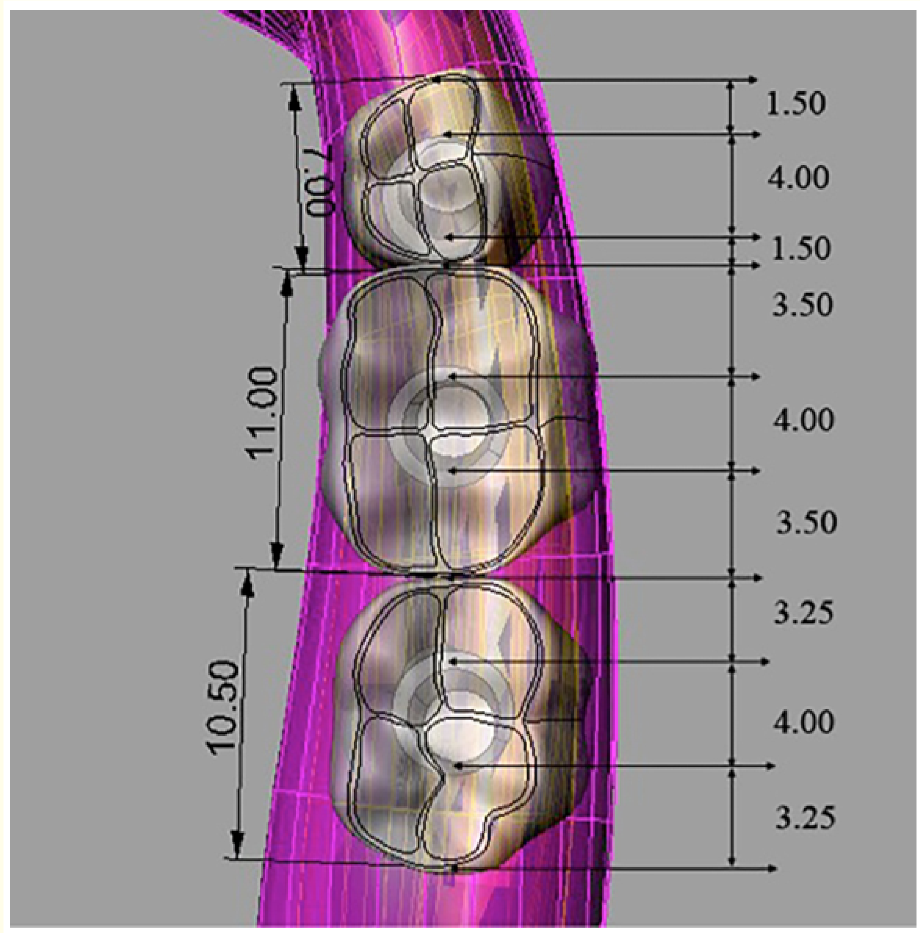

Figure 4: *Fixed prosthodontics dimensions for modelling.*

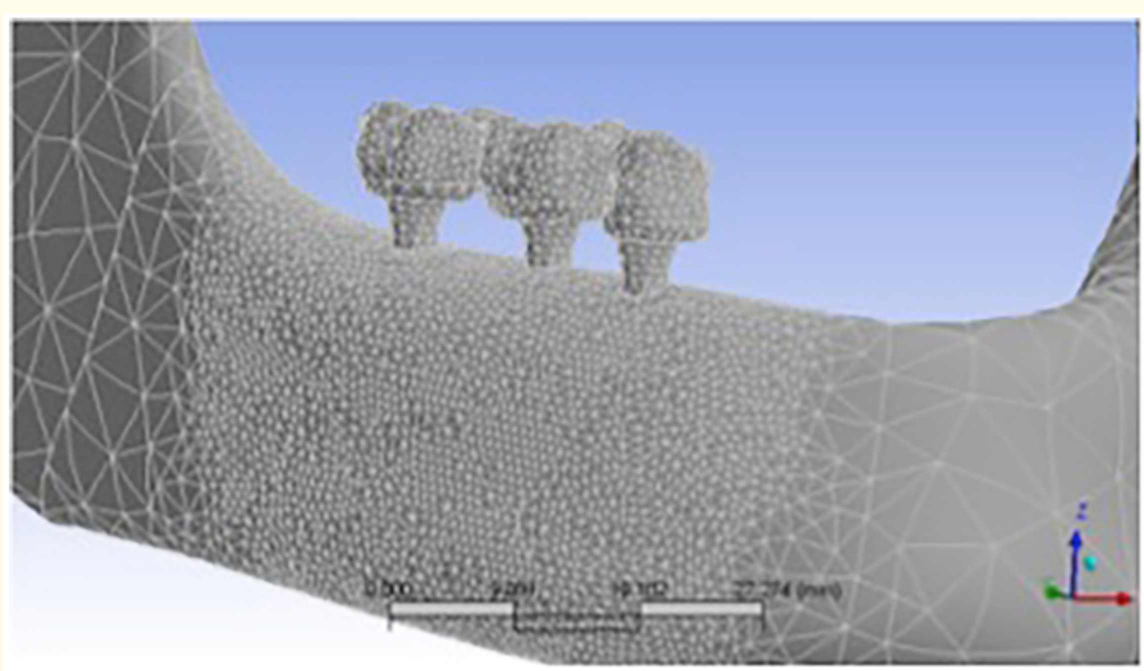

Figure 5: *Final model with increased node and element numbers locally.*

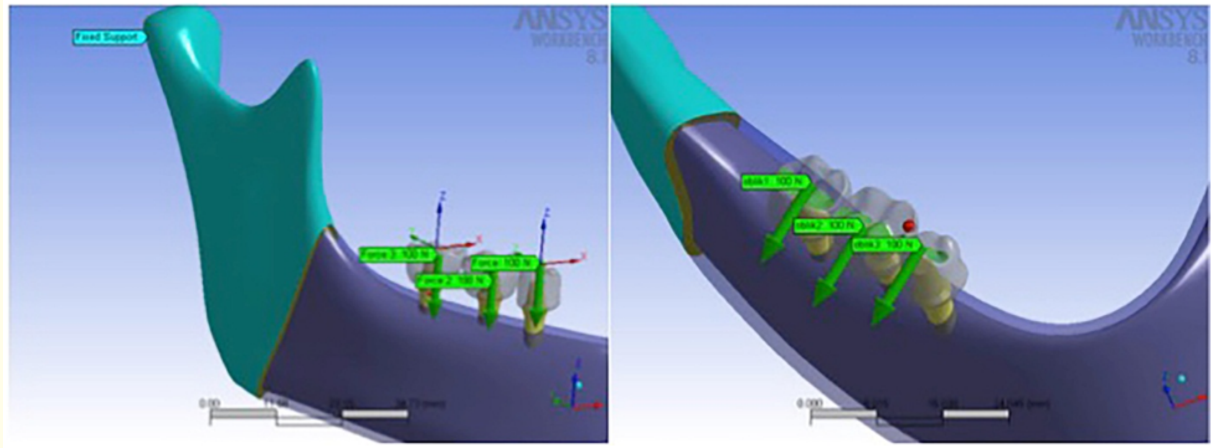

Figure 6: *Loading forces in vertical and oblique directions.*

Results

For each implant, maximum Von-Mises stress values, as the potential risk index for bone, occured in the crestal region in the cortical bone, and near the apex of the implant in the trabecular bone. Under vertical loading, in case of all three placements the greatest value of maximum Von-Mises stresses were determined at the lingual crestal bone around the 3rd implant and decreased towards the 1st implant bone (Table 3 and Figures 7-10). Under vertical loading for each implant maximum Von-Mises stress values were determined biggest in case of in-line placement while the buccal offset condition caused the lowest stress values (Table 3 and Figures 7-9). Under oblique loading, same as vertical loading, for all three placements, stresses were biggest at the 3rd implant bone and lowest at the first implant crestal. Under oblique loading, for all implant regions maximum Von-Mises stress values were determined lowest in case of lingual offset. The stress values of lingual offset were less than those of in-line placement for all three bone region (Table 3 and Figures 7-10).

Implant no (Tooth region)	Model	Vertical Loading (MPa)	Oblique Loading (MPa)
1st implant (2nd premolar)	IP	13.637	59.510
2nd implant (1st molar)	IP	14.910	64.852
3rd implant (2nd molar)	IP	22.833	91.007
1st implant (2nd premolar)	BO	8.898	65.671
2nd implant (1st molar)	BO	10.627	73.661
3rd implant (2nd molar)	BO	17.032	75.047
1st implant (2nd premolar)	LO	9.691	52.623
2nd implant (1st molar)	LO	12.903	61.309
3rd implant (2nd molar)	LO	17.359	75.866

Table 3: *Maximum Von-Mises stress values of crestal cortical bone.*

Model abbreviations. IP: In-line Placement; BO: Buccal Offset; LO: Lingual Offset.

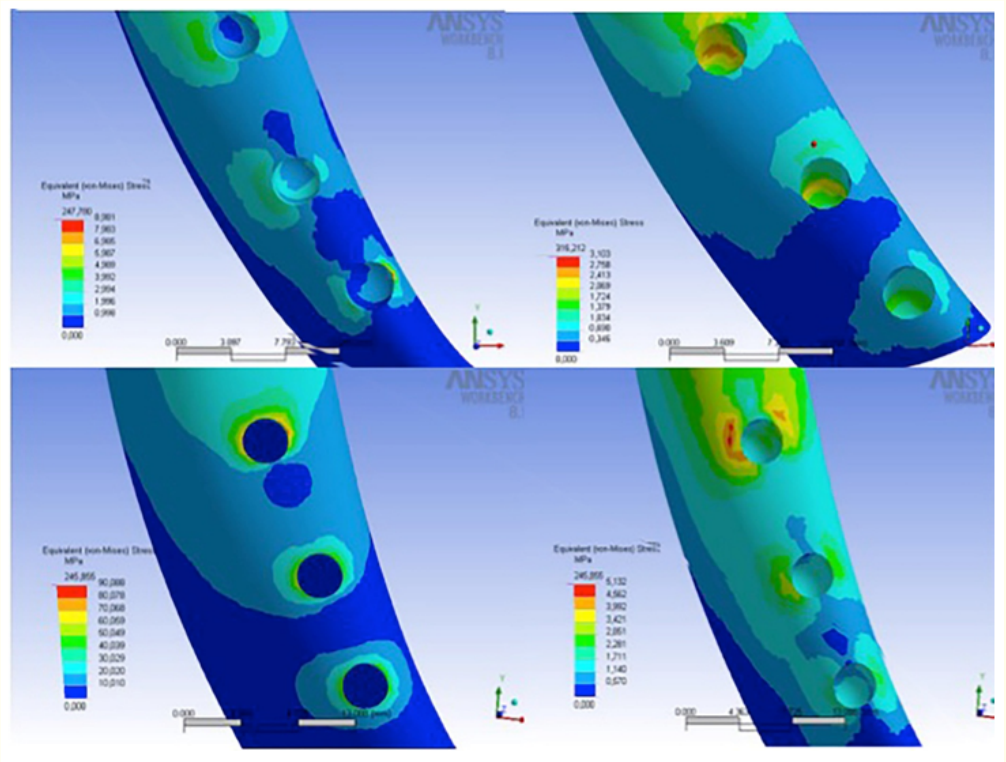

Figure 7: *Stresses for in-line placement model. Upper photos are the stress levels for vertical loading of corticaland spongiosis bone. Lower photos are the stress levels for oblique loading of cortical and spongiosis bone.*

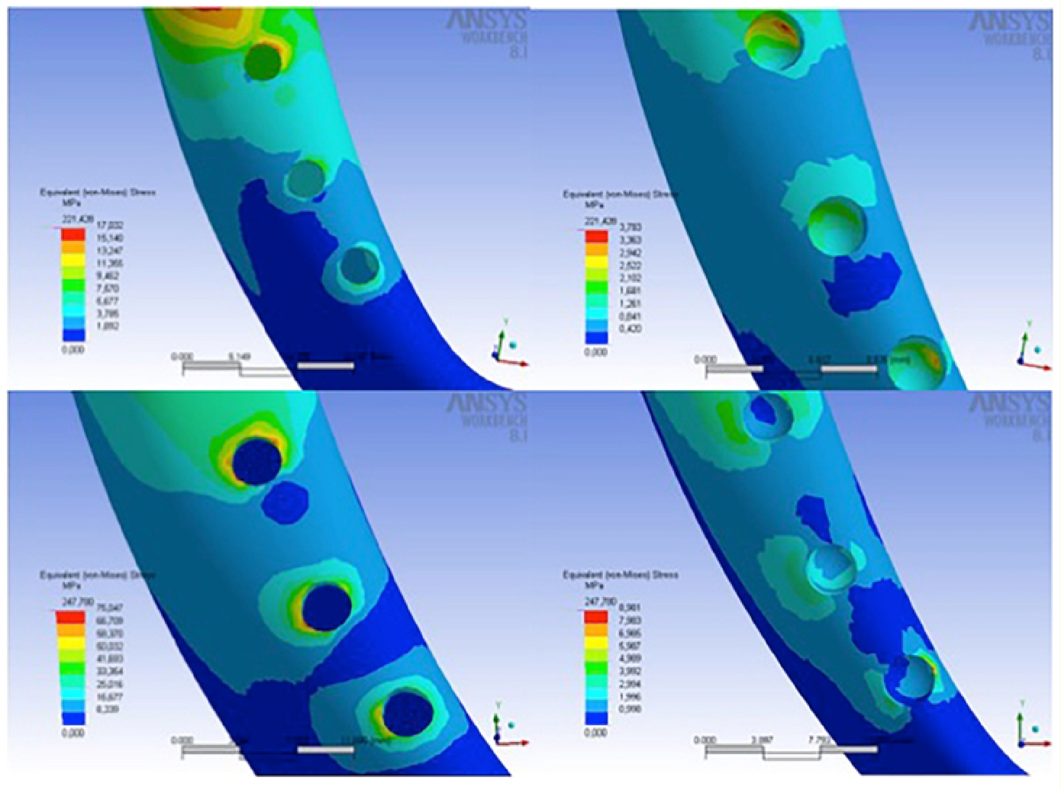

Figure 8: *Stresses for buccal offset placement model. Upper photos are the stress levels for vertical loading of cortical and spongiosis bone. Lower photos are the stress levels for oblique loading of cortical and spongiosis bone.*

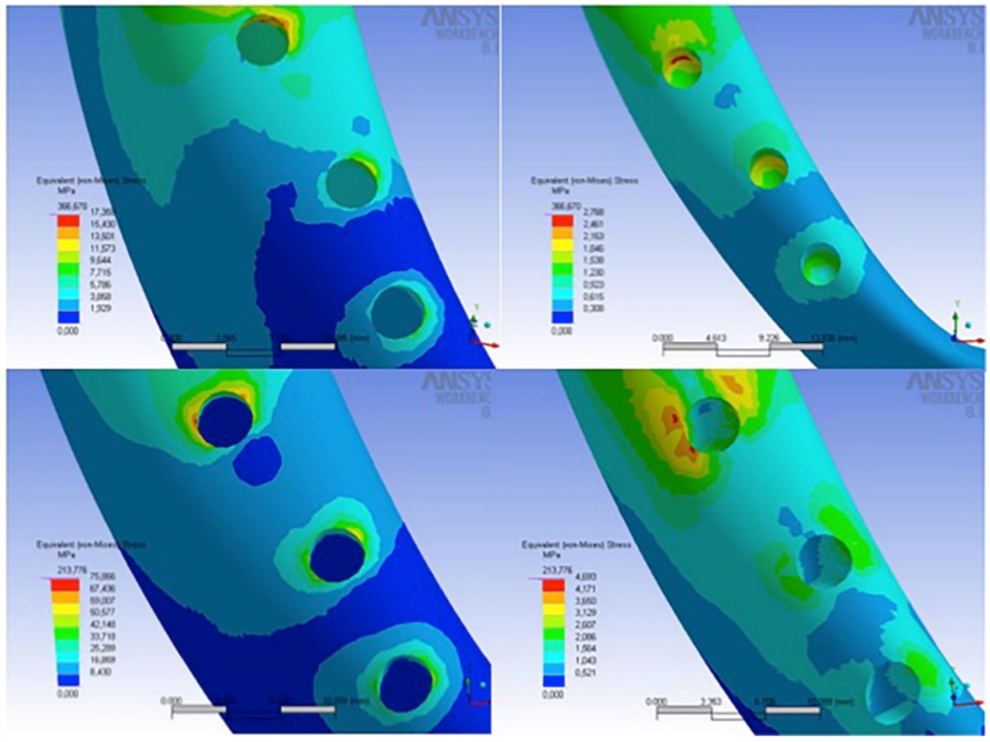

Figure 9: *Stresses for lingual offset placement model. Upper photos are the stress levels for vertical loading of cortical and spongiosis bone. Lower photos are the stress levels for oblique loading of cortical and spongiosis bone.*

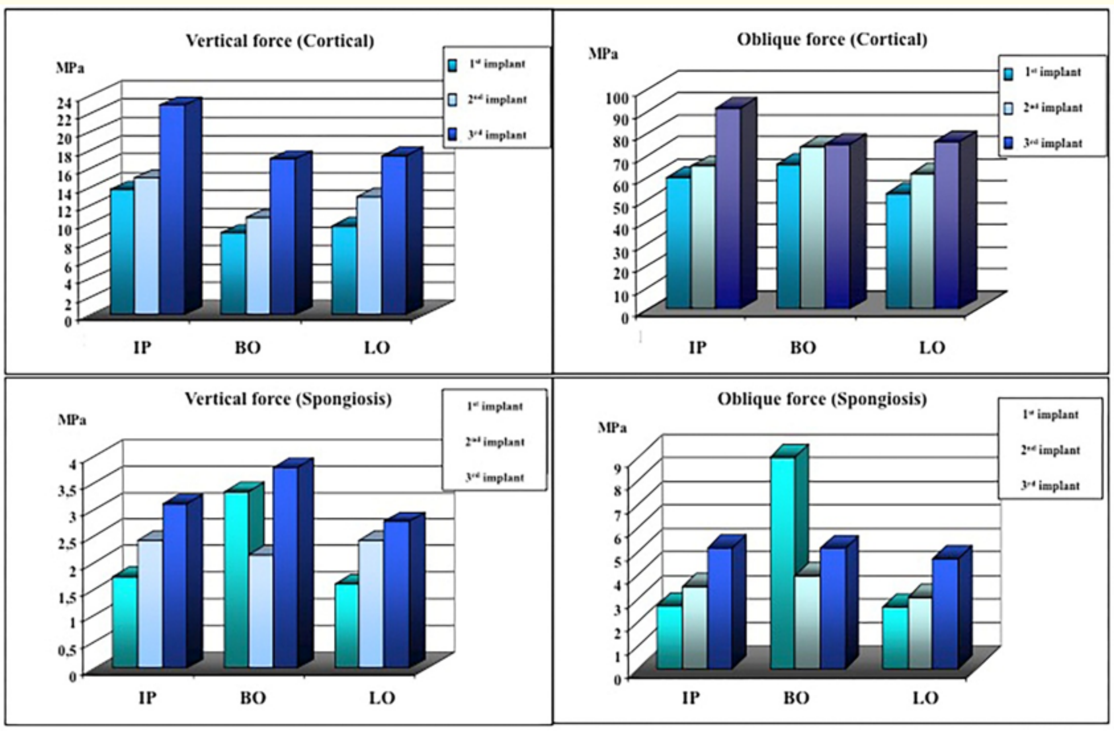

Figure 10: *Graphic of stresses evaluated in cortical and spongiosis bone regions for all models under both loading modes.*

Discussion

The results of the present study exhibited that for both force directions offset placement caused decreased stress levels at the cortical bone in comparison to in-line placement. Therefore, the null hypothesis was rejected. The study results showed that buccal offset of dental implants is beneficial for vertical forces whereas the lingual offset helps decreasing the stress levels under oblique forces.

Although there is a rationale defending that a triangulated base used to support a prosthesis is more stable than the one that has all supports in a straight line, researchers evaluating the straight and staggered placement of implants reported quite incompatible results [6-8,10-15]. Weinberg and Kruger [10] evaluated the torque values and exhibited the efficiency of staggered implant placement supporting our study results. Akça and İplikçioğlu [13] revealed that offset placement reduced the amount of stress but lower stresses were observed in cortical bone when wider implants were placed in-line rather than staggered placement of narrow implants. Similarly, Huang., *et al.* [6] found that offset implant placement showed no obvious advantage on reducing stresses over the in-line placement. However Sütpideler., *et al.* reported that offset placement reduced the stresses effectively in the cervical bone surrounding implants showing parallelism with our results [14].

In spite of using the same analysis method, great differences existed among the mentioned studies about the conditions like geometry, node-element numbers and material properties [6-8,10-15]. In previous FEA models few number of elements were used in order to record the stress values in offset placement. Also the models and the material properties were insufficient to constitute the real anatomical structure [6-8,10-15]. The probable reason for incompatible amount of stress values between those studies may be the contribution of different models and material properties.

Some of the previous studies found that offset placement has no evident advantage over the straight placement, however in mentioned studies offset placement of smaller implants were compared to in-line placement of wider implants [6,13]. Therefore, as a recommendation to the clinicians it may be suggested to remember that whenever the width of the available bone ridge is sufficient buccolingually for offset placement of dental implants, it may be advantegous to use wide implants staggered over to use wide implants on a straight line.

Ash and Nelson told that the buccolingual dimension of natural posterior teeth at the cervical region is, on average, 8 mm or less [16]. In relation to the mentioned study, Sütpideler., *et al.* [16] reported that assessment of a clinically relevant offset must be limited to an offset of 3 mm or less when using implants with 4.0 mm prosthetic platforms. Therefore, the offset amount of 2 mm was chosen while designing the present study models. In some of the studies single load instead of multiple loads have been applied on prostheses [11,12]. Also Weinberg and Kruger used unsplitted crowns for FEA analysis ignoring the loading interaction of adjacent crowns which may fail in reflecting clinical conditions [10]. In the present study, vertical and oblique forces simulating the intraoral conditions and also splitted crowns increasing the biomechanical strength of the supported fixed prosthesis were chosen in order to reflect the clinical circumstances. Correspondingly, present study may have been accepted as one the most reliable and realistic finite element analysis studies among the previous ones.

Although offset placement decreased the bone stresses around some implants, some implant regions suffered from raising stress values with staggered placement. In our study it was noted that loading the 3rd implant caused higher stresses than the first and second implants for all FEA models. A possible explanation for this issue may be because of the greater dimensions of molars than premolars and also the existence of a mesiodistal connection of the 2nd implant in comparison to the unilateral connection of the 3rd implant [15].

Techniques such as photoelastic stress analysis, three-dimensional finite element stress analysis (3D FEA) and strain-gauge analysis are used to evaluate the biomechanical loads on implants comprising the use of mathematical calculations [4,5]. The basic purpose of these methods is to estimate the findings related with the risk factors instead of experiencing them clinically. Comparative studies revealed that 3D FEA seems to be advantegous rather than other stress analysis methods in order to predict the stress amount and localization around the implants [4,17]. By using finite element method it is possible to calculate the amount of stress and evaluate the stress localization on the bone, implants and also fixed prostheses [5,17,18-21]. Otherwise accurate material properties provide exact simulation of bone, implants and implant supported prostheses as far as possible.

FEA is a technique developed for solving a complex mechanical problem by cutting the problem domain to a collection of much smaller and simpler element pieces [4,17,22]. It means that the analysis enables formulating and evaluating the solution functions for each finite element and combining them properly to obtain the solution to the whole domain instead of searching a solution function for the entire body. As dental implant-bone systems have components with extremely complex geometries, FEA has been widely accepted as the most suitable research technique for evaluating them [4,5,17,18,23].

The results of the present study revealed that in-line placement of implants caused increased stress levels under both loading modes. Lower stress values were recorded in cortical bone at the cervical region of implants for lingual offset placement in comparison to in-line placement under oblique loading modes. Under vertical loading mode, buccal offset placement was found to be beneficial over the in-line placement to decrease the bone stresses around the implants placed in mandibular posterior region. There is a lack of information about offset placement of wider implants over offset placement of narrower, or in-line placement of wider implants. Therefore, it could be proposed for further consideration that whenever the buccolingual width of the residual bony ridge is sufficient for staggered implant placement, placement of wider implants along a straight line may be much easier and more functional for stress distribution.

Conclusion

The conclusions of the present finite element stress study are limited to the assumptions designed by the geometrical model and its material properties. Within the limitations of this study, lower stresses were observed in cortical bone at the cervical region of mandibular posterior implants when implants were placed in buccal and lingual offset rather than in-line placement under both vertical and oblique force directions. For mandibular posterior splinted implant-supported prostheses, offset placement of dental implants may be recommended to reduce the stress level at the cervical bone region of the implants in case of sufficient bone volume exists.

Conflict of Interest

The author declare that there is no existing financial or conflict interest.

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