Stresses Transmitted to Tilted One-Piece Narrow-Diameter Implants Retaining Mandibular Over Dentures (A 3 Dimensional Finite Element Stress Analysis)

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Abstract: <u>Aim of the Work</u>: This study aimed to evaluate the stress distribution in and around one-piece narrow diameter implants, placed in tilted position, with different degrees of angles retaining mandibular overdenture. <u>Materials and methods</u>: Five finite element models (ABAQUS 13), were created to simulate five proposed groups for this study. Each model composed of the anterior region of edentulous mandible, in which 2 implants were virtually placed on the canine area retaining mandibular overdenture. Vertical, horizontal and oblique loads (35 N), were applied respectively, bilaterally on the both dental implants at the same time, through the overdenture. The maximum stress values (MSV) transmitted to the dental implants and peri-implant bone were analyzed by using finite element analysis (FEA) and compared with the yield strength values of the dental implant, cortical bone and cancellous bone. <u>Results and conclusions</u>: 1.The recordings of MSV at the dental implants and the cortical bone with all of the different proposed groups and loading conditions, were below their yield strength values. While the MSVs at the cancellous bone, exceeded its yield strength value, specially with the vertical load condition applied on the dental implants placed in a tilted position. 2. The MSVs taken from the dental implants and its surrounding bone, that placed vertically were less than the MSVs in and around the dental implants placed in the tilted position. 3. For the dental implants and its surrounding bone, placed with an equal degree of a tilted position, the MSVs decreased when the angle of placement increased.

Keywords: Mandibularoverdenture, tilted implant, narrow diameter implants, stress distribution, Finite element analysis

1. Introduction

The Complete dentureswere the only treatment option for edentulous patients until the emergence of dental implants [1,2].

Edentulous patients' major problem has been the lack of satisfaction with their complete dentures, especially the instability of the lower dentures [3-5]

Various modalities have been used for retaining and stabilizing dentures on edentulous mandibular ridge [6,7].

Osseointegrated dental implants are an ideal treatment alternative to enhance the retention and stability of complete dentures [3-5].

Sufficient amount of bone for implant placement is an essential prerequisite for the long term success in oral implant therapy [8].

In some real clinical situations, severely resorbed bone may result in inappropriate implant alignment [9].

This can be managed either by surgical correction or by using the narrow diameter and tilted implants [10-16].

The key factors for the success or failure of dental implants is the manner in which stresses are transferred to the surrounding bone [17]. The current study was performed to evaluate the stress distribution in and around the dental implants placed with different tilted positions retained mandibular overdenture; that will show and detect the extent to which we can make use of the available bone through tilted narrow diameter implants, instead of complex surgical procedures through this minimally invasive treatment option.

As, it is difficult to assess the generated forces clinically, a finite element analysis was chosen for the present study as it is useful tool in estimating stress distribution in the contact area of the implant with the bone.

2. Material and Methods

This study carried out in the Removable Prosthodontic, Faculty of Dentistry, and Marine Engineering and Naval Architecture Department, Faculty of Engineering, Alexandria University.

This study was conducted by using a precise finite element analysis models simulating the anterior region of the mandible and two screws, each screw was a one-piece narrow diameter implants were placed in the canines (cuspid) area with different angles on opposing sides in the mandible, used to retain mandibular overdenture.

The materials used in this study can be summarized as follows:

Volume 5 Issue 5, May 2016

<u>www.ijsr.net</u>

Paper ID: NOV163794

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Five models were constructed to simulate five proposed groups, each model composed of the mandibular anterior segment with the layers of the bone (cortical and cancellous bone), one-piece narrow diameter implant with length of 10mm and a diameter of 2.8mm (Mini1 Sky, Bredent Medical), dental implant housing, nylon rubber O-ring and the mandibular overdenture.

The basic mandible model consisted of a curved beam with a 15mm radius, 69.0mm in length, 14.0mm in height, and 6.0mm in width. This beam was covered with a 1.0mm thick layer on the buccal, occlusal, and lingual surfaces and a 3.0mm layer at the base to simulate cortical bone; the final external dimensions were $71.0 \times 18.0 \times 8.0$ mm [18]. (Figure 1)



Figure 1: The dimensions of the mandible model. A: The body of the mandibular model, B: Posterior end of the model. Two implants were placed bilaterally in the alveolar ridge at the inter-canine region, 22mm apart, to resemble the distance between the two natural canines, to retain the mandibular overdenture[19].

Five groups (I, II, III, IV and V) were proposed for this study according to the tilting degree of the implants placement.

These angles were measured from the vertical line at the high point of the implants. Additionally, all implants were tilted mesially. (Table 1)

Table 1: The	proposed	groups of	the study
	proposed	groups or	the study

Group	Right side	Left side
1	90°	25°
2	90°	15°
3	15°	15°
4	25°	15°
5	25°	25°

These models were molded as a separate structures following the solid modeling technique (extraction and revolution), then drawn, meshed and assembled by using ABAQUS version 13 finite element software. (Figures2,3)



Figure 2: The Models showing A: the dental implant,B: dental implant housing cap, C: rubber O-ring, D: anterior segment of the mandible, E: cortical and cancellous bone,F:overdenture



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International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064 Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391



Figure 4: Mesh Mandible

constructed. (Table 3)

Poisson's ration) of each model were fed into the software to be able to identify the material from which each model was

International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064 Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

Table 5. We change properties of the materials.				
	Material properties			
Materials	Modulus of	Poisson's ratio		
	elasticity (MPa)			
Cortical bone [20]	13700	0.30		
Cancellous bone[20]	1370	0.30		
Grade 4 titanium [21]	110000	0.30		
Heat-curePMMA [21]	3000	0.35		
Nylon rubber [22]	5	0.45		

Table 3: Mechanical properties of the materials.

The boundary condition was defined to simulate the real condition by releasing and restraining some nodes from movement or rotation according to the nature of the 3D models. The models were restrained at their posterior border. (Figure 9)



Figure 9: Model showing the constrained end

Vertical (90°), oblique (45°) and horizontal (0°) loading conditions with 35 N were applied separately over the dental implants, through the overdenture on both sides at the same time. (Figures 10-12)



Figure10: Vertical occlusal load 90°







Figure 12: Oblique occlusal load 45°

The stress distribution pattern around each implant was provided in the form of three dimensional static cartoon models, made up dental implants and its surrounding bone together with stresses. Color-coded zones represented each of these. The color and size of each zone represented the stresses.

3. Results

Data were collected, tabulated and statistically presented to showthe maximum stress values(MSVs) on the cancellousbone, cortical bone and dental implant with each direction of the loads as follows:

I- Results of stress analysis in and around the dental implants in group (I) $(90^\circ\text{-}25^\circ)$

Table (4) and Graph (1,6) show the maximum stress values at the cancellousbone, cortical bone and the dental implant.

After applying a 35 N force; the maximum stress values with the horizontal loads in this group are as follows:

The MSV in the cancellousbone was 1.04 MPaon the left side, and in the cortical bone it was 7.2 MPaon the right side. While in the dental implant it was 26.9 MPaon the right side.(Figure 13)

The maximum stress values with the oblique loads in this group are as follows:

The MSV with the oblique loads in cancellousbone was 13.93 MPaon left side, and in the cortical bone it was 2.173 MPaon both sides, while in the titanium dental implant it was 31.2 MPaon the left side.(Figure 14)

The maximum stress values with the vertical loads in this group are as follows:

The MSV with the vertical loads in cancellousbone was 13.36 MPaon left side, and in the cortical bone it was 23.92 MPaon left side, while in the titanium dental implant it was 22.5 MPaon the left side. (Figure 15)

Table 4: Maximum suess values in group I.			
Load direction	Cancellous	Cortical	Dental
Load direction	bone	bone	implant
lorizontal load	1.04	7.2	26.9

2.173

23.92

 Table 4: Maximum stressvalues in group I.

13.93

13.36

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Oblique load

Vertical load

31.2

22 5



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Figure 13: The stress distribution along the bone and dental







Figure 15: The stress distribution along the bone and dental implants with vertical loads.

II- Results of stress analysis in and around the dental implants in group (II) $(90^\circ$ - $15^\circ)$

Table (5) and Graph (2,6) show the maximum stress values at the cancellous bone, cortical bone and the dental implant.

After applying a 35 N force; the maximum stress values with the horizontal loads in this group are as follows:

The MSV with the horizontal loads in the cancellous bone was 0.708 MPaon the left side, and in the cortical bone it was 7.45 MPaon the right side, while in the dental implant it was 8.3 MPaon the left side.(Figure16)

The maximum stress values with the oblique loads in this group are as follows:

The MSV with the oblique loads in the cancellous bone was 0.603 MPaon the left side, and in the cortical bone it was 2.39 MPaon the left side, while in the titanium dental implant it was 9.9 MPaon the left side. (Figure17)

The maximum stress values with the vertical loads in this group are as follows:

The MSV with the vertical loads in the cancellous bone was 9.87 MPaon left side, and in the cortical bone it was 14.4 MPaon the left side, while in the titanium dental implant it was 31.5 MPaon the left side. (Figure 18)

|--|

Cancellous	Cortical	Dental
bone	bone	implant
0.708	7.45	8.3
0.603	2.39	9.9
9.87	14.4	31.5
	Cancellous bone 0.708 0.603 9.87	Cancellous Cortical bone bone 0.708 7.45 0.603 2.39 9.87 14.4



Graph 2: Maximum stress distribution patternsfor group II.



Figure 16: The stress distribution along the bone and dental implants with horizontal loads.



Figure 17: The stress distribution along the bone and dental implants with oblique loads.



Figure 18: The stress distribution along the bone and dental implants with vertical loads.

III- Results of stress analysis in and around the dental implants in group (III) $(15^{\circ} - 15^{\circ})$

Table (6) and Graph (3,6) show the maximum stress values at the cancellous bone, cortical bone and the dental implant.

After applying a 35 N force; the maximum stress values with the horizontal loads in this group are as follows:

The MSV in the cancellous bone was 0.81 MPaon both sides, and in the cortical bone it was 12.65 MPaon the right side, while in the dental implant it was 14.4 MPaon the right side. (Figure 19)

The maximum stress values with the oblique loads in this group are as follows:

The MSV in the cancellous bone was 0.69 MPaon both sides, and in the cortical bone it was 9.74 MPaon the left side, while in the titanium dental implant it was 8.96 MPaon both sides. (Figure 20)

The maximum stress values with the vertical loads in this group are as follows:

The MSV in the cancellous bone was 16.1 MPaon the left side, and in the cortical bone it was 20.3 MPaon the left side, while in the titanium dental implant it was 75.5 MPaon the left side. (Figure 21)

Table 0. Maximum suess values in group in			
T and dimention	Cancellous	Cortical	Dental
Load direction	bone	bone	implant
Horizontal load	0.81	12.65	14.4
Oblique load	0.69	9.74	8.96
Vertical load	16.1	20.3	75.5

Table 6. Maximum stressvalues in group III















Figure 21: The stress distribution along the bone and dental implants with vertical loads.

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Table (7) and Graph (4,6) show the maximum stress values at the cancellous bone, cortical bone and the dental implant.

After applying a 35 N force; the maximum stress values with the horizontal loads in this group are as follows:

The MSV in the cancellous bone was 21.08 MPaon the right side, and in the cortical bone it was 17.09 MPaon both sides, while in the dental implant it was 32.6 MPaon the right side.(Figure22)

The maximum stress values with the oblique loads in this group are as follows:

The MSV in the cancellous bone was 19.79 MPaon the right side, and in the cortical bone it was 5.355 MPaon both sides, while in the titanium dental implant it was 18.6 MPaon the right side.(Figure23)

The maximum stress values with the vertical loads in this group are as follows:

The MSV in the cancellous bone was 14.94 MPaon the right side, and in the cortical bone it was 1.98 MPaon both sides, while in the titanium dental implant it was 7.4 MPaon both sides. (Figure 24)

Table 7: Maximum stressvalues in group IV

Load direction	Cancellous bone	Cortical bone	Dental implant
Horizontal load	21.08	17.09	32.6
Oblique load	19.79	5.35	18.6
Vertical load	14.94	1.98	7.4





Figure 22: The stress distribution along the bone and dental implants with horizontal loads.



Figure 23: The stress distribution along the bone and dental implants with oblique loads.





V- Results of stress analysis in and around the dental implants in group (V) $(25^{\circ} - 25^{\circ})$

Table (8) and Graph (5,6) show the maximum stress values at the cancellous bone, cortical bone and the dental implant.

After applying a 35 N force; the maximum stress values with the horizontal loads in this group are as follows:

The MSV in the cancellous bone was 1.88 MPaon the right side, and in the cortical bone it was 12.5 MPaon the right side, while in the dental implant it was 8.5 MPaon both sides. (Figure 25)

The maximum stress values with the oblique loads in this group as are follows:

The MSV in the cancellous bone was 1.25 MPaon the left side, and in the cortical bone it was 6.16 MPaon both sides, while in the titanium dental implant it was 7.6 MPaon both sides. (Figure 26)

The maximum stress values with the vertical loads in this group are as follows:

The MSV in the cancellous bone was 2.23 MPaon the right side, and in the cortical bone it was 5.23 MPaon both sides, while in the titanium dental implant it was 15.3 MPaon both sides. (Figure 27)

Table 8: Maximum s	stressvalues in	group V	1.
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Load direction	Cancellous	Cortical	Dental
Load direction	bone	bone	implant
Horizontal load	1.88	12.5	8.5
Oblique load	1.25	6.16	7.6
Vertical load	2.23	5.23	15.3



Graph 5: Maximum stress distribution patternsfor group V.



Figure 25: The stress distribution along the bone and dental implants with horizontal loads.



Figure 26: The stress distribution along the bone and dental implants with oblique loads.



Figure 27: The stress distribution along the bone and dental implants with vertical loads.

The maximum stress distribution levels were compared with the yield strength of the dental implants and peri-implant tissues (cortical and cancellous bone). The yield strength of the dental implant was (483 MPa) and it was (133 MPa) in the cortical

bone, while in the cancellous bone it was (2 MPa)[23,24].

The maximum stress distribution levels at the dental implants and the cortical bone were below the yield strength value, of both of them, with all models, while it is exceeded the yield strength value at the cancellous bone with different groups and various loading conditions.





Fibution patterns. B: 90° - 25° O Load D: 90° - 15° H Load F: 90° - 15° V Load H: 15° - 15° O Load J: 25° - 15° H Load L: 25° - 15° V Load N: 25° - 25° O Load

4. Discussion

Edentulous patients' major problem has been the lack of satisfaction with their complete dentures, especially the instability of the lower dentures. Osseointegrated dental implants are an ideal treatment alternative to enhance the retention and stability of the complete dentures [3-5].

In some real clinical situations, severely resorbed bone may result in inappropriate implant alignment [9]. This can be managed either by surgical correction or by using the narrow diameter and tilted implants [10-16].

The key factors for the success or failure of dental implants is the manner in which stresses are transferred to the surrounding bone[25].

The current study was performed to evaluate the stress distribution in and around the dental implants, placed with different tilted positions retained mandibular overdenture; that will show and detect the extent to which we can make use of the available bone through tilted narrow diameter implants, instead of complex surgical procedures through this minimally invasive treatment option.

The biomechanical analysis of an implant-retained mandibular overdenture could be done with various methods. While computer modeling offers many advantages over other methods in considering the complexities that characterize clinical situations, it should be noted that these studies are extremely sensitive to the assumptions made regarding model parameters such as; loading conditions, boundary conditions, and material properties [26]. FEA allows investigators to predict stress distribution in the contact area of the implants with bone using a mathematical model of the structures [27].It was for this reason we chose it for this study.

According to Holmgrem et al., [28] complex forces are present in the mouth. The study of stress on implants must include not only vertical and horizontal forces, but also combined or oblique forces, since these represent realistic bite directions and may produce greater forces that cause greater damage to the cortical bone.

For this study, each 3D finite element model of the anterior segment of the mandible with two implants inserted at the inter-canine (cuspid) area, on both sides, retained mandibular overdenture assumed to subject separately to 35 N (3.5 kg), Once as a horizontal load(0°), once as an oblique load (45°) and once as a vertical load (90°) on both implant, through the overdenture at the same time.

After analyzing the stress distribution with the various groups, the stress values were as follow:

In group I, the stress distribution values were less, and more fluent at the vertically placed dental implant and its surrounding bone with the vertical and oblique load conditions, but with the horizontal load condition the stresseswere less, and more fluent at the dental implant, and its surrounding bone, that was placed in a tilted position.

In group II, the majority of the stress values were less, and more fluent with the horizontal, oblique and vertical load conditions at the dental implant and its surrounding bone, that was placed vertically with an angle 90°.

In group III, the lowest stress distribution values at the dental implant, and its surrounding bone, were taken from the oblique load condition, while the highest values were taken from the vertical load condition.

In group IV, the recordings of stress distribution values at the cancellous bone were higher around the dental implant placed with an angle of 25° with the horizontal, oblique and vertical load conditions.

There were no differences in the stress values at the cortical bone, around the dental implants, placed with the angles 15° and 25° from the horizontal, oblique and vertical load conditions.

The recordings of stress distribution values were higher at the dental implant placed with the angle 25°, with the horizontal and oblique load conditions, but there were no differences in the stress values on both of the dental implants, with the vertical load condition.

In group V,the lowest stress distribution values at the dental implant and the cancellous bone, were taken from the oblique load condition, while the highest values on both of them were taken from the vertical load condition. The lowest stress distribution values at cortical bone were taken with the vertical load condition, while the highest values were taken with the horizontal load condition.

Theoretically, the production of torque is dependent on the position and direction of the force relative to the position of the implant [29].

Bone resorption and higher stress concentrations have been reported in the cortical bone around excessively inclined implants [15, 29] these findings support our results.

For dental implants, FEA studies have reported that tilting single implants increases peri-implant bone stress compared to stresses observed around vertical implants [30,31] which support our findings from group I and II. Bevilacqua et al [31] reported that stress at the bone-implant interface increased with increasing implant inclinations. This result conflicts with our findings in the comparison of stress levels between groups III and V.

Other Reports have documented that excessive occlusal load is generated when the implant is inclined[29]. These results support our findings in groups I, II and IV.

Takahashi et al, found the use of inclined implants induces an increase in stress on peri-implant cortical bones [32]. This support our results in groups I and II.

Many authors have reported that stresses tend to be concentrated in the cortical bone around the occlusal aspect of the implant closest to the load [27]. This may be because the elastic modulus of the cortical bone is higher than that of the cancellous bone, resulting in greater resistance to deformation [27,33], these findings support our results.

Gul and Suca (2014) [34] Reported the stress with a 150 N oblique load, 120 degree angled to the long axis of the denture teeth on the horizontal plane was applied from the labial side of the mandibular central incisors of the overdenture; the stress values decreased and the load distribution is more fluent at the inclination of the implants increased and they also stated the connected tilted implants had better stress distribution than vertical implants. Stress occurring in the implant and surrounding bone decreases when the angle increased. These results also suggest that a mesial inclination similar to the direction of the occlusal force is desirable. Therefore departure from the planned perpendicular placement relative to the occlusal plane should be considered when placing interforaminal implants. The findings of these studies support our results from the comparisons between groups III and V.

Numerous investigators who have used various FEA models have reported decreased peri-implant bone stress around tilted implants [27,35,36].

The mechanical distribution of stress occurs primarily where bone is in contact with the implant. When all factors are equal, the smaller the area of bone contacting the implant body, the greater the overall stress will be [37]. This could be the reason for the lower stress values around inclined implants in various loading conditions. As the implants had been inclined, the implant bone contact area increased. Satoh et al., (2005) [38] studied inclined implants in the posterior mandible and stated that, stress levels in the cervical area of the mesial and distal implants and the surrounding bone were higher with 0M than 5M, 10M and 20M. These results conflicted with our findings in groups I and II.

Many authors have reported that increasing the implant diameter and tilting the distal implants have been proposed to improve the biomechanical behavior by increasing the contact surface area and reducing the average cantilever length of the prosthesis [31,32,39-41].

The numeric values reported in this study must be considered as biomechanical indications within the limitations of the model presented, since the 3D finite element models represent a simplification of the investigated structures. It should also be emphasized that the aim of the study was not to report the absolute values of stress but to compare the stress levels in different implant inclinations. Despite these limitations, the method used in the current investigation can be useful for further in vivo studies on the use of tilted implants for improving prosthodontic supports in specific clinical situations.

5. Conclusions

After analysis of stress distribution by using finite element analysis (FEA), it can be concluded that:

- The recordings of the maximum stress distribution levels of the dental implants and the cortical bone were both below their yield strength values. This was the case with all of the different proposed groups and loading conditions.
- The recordings of the maximum stress distribution values, at the cancellous bone, exceeded their yield strength value, especially with the vertical load condition applied on the dental implants placed in a tilted position.
- The readings of maximum stress distribution levels taken from the dental implants and its surrounding bone, placed with an angle of 90°, were less than the stress values in and around the dental implants placed in the tilted position.
- The stress distribution levels increased in groups I and II when the angle of implant placement increased at the tilted implant.
- In group (IV), the recordings of the stress distribution levels taken from the dental implant and its surrounding bone, placed with an angle of 15°, were less than the stress distribution levels in and around the dental implant placed with an angle 25°.
- For the dental implants and its surrounding bone, placed with an equal degree of a tilted position, the stress values decreased and the loading distribution was more fluent when the angle of placement increased.
- With all groups, the stress was concentrated on the dental implants and the cortical bone, except in group IV, the stress was concentrated on the cancellous bone, with the vertical and oblique load conditions, around the dental implant placed with the angle 25°.
- Regarding the FEA results, it was found that the highest stress values were found around the neck of the dental implants and the lowest were found at the first third of the implants (apex). These indicate the wide distribution of the

stresses at the peri-implant area to produce a more functional, stable and retained overdenture.

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