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Using 3D Finite Elements Analysis to Evaluate Stress around the Implants in All-on-four Concept

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Implant supported prothesis are used in rehabilitation of cases with sever resorption of alveolar bone. However, the limitations due to the close proximity between critical anatomical structures (as maxillary sinus, inferior alveolar nerve) and crest of the ridge sometimes lead to difficulties in implant placement. All on four technique was developed by placing four implants in the anterior maxilla or mandible, the two most distal implants was angulated to overcome bony deficiencies or anatomical structures and maximizing the available bone used without grafting. Biomechanical studies showed that the implants excess loading is the significant factor cause bone resorption. The goal of the Study was to evaluate the stress distribution of fixed implant-supported prostheses using "all-on-four" concept for the treatment of mandibular completely edentulous ridge "in vitro study".

Materials and Methods: The finite element model components as the overdenture, mucosa, implants, angled base, abutment, cortical and cancellous bones were created in "Autodesk Inventor. The model was subjected to Six loading conditions of 100N, 50N vertically and oblique (antroposterior) at central incisors respectively. In addition to 200N and 100N unilaterally vertically

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and oblique (buccolingual) at molar region respectively, 200N and 100N bilaterally vertically and oblique (antroposterior) at molar regions respectively were investigated.
Results: All values of deformations and stresses appeared on the all model components were within physiological limits under all cases of load application.
Conclusion: tilted implants at molar area did not affect the system behavior (did not show beak of stresses or deformation).

Keywords: Tilted implants; all on four concept; finite elements analysis; stress analysis; stress distribution; implant-supported overdenture.

1. INTRODUCTION

Implant supported systems are used in prosthetic rehabilitation of atrophic alveolar bone [1]. In Systematic Review by Alan Gt Payne et al, for comparing different attachment systems for implant overdentures they concluded that there is insufficient evidence to determine the relative effectiveness of different attachment systems. Only there is some evidence that are insufficient to show a difference. Also It was not possible to choose an ideal attachment system for implant overdentures [1].

Implant supported dentures are effective in providing long-term success in rehabilitation of edentulous mandible. However, the limitations due to the close proximity between anatomical structures and alveolar ridge sometimes lead to difficulties in implant placement in edentulous cases [2].

In study for evaluation Stress Distribution on “All-on-Four” concluded that “All-on-Four” design caused damaging stresses on mandibular bone and implant surfaces; and using short implants would be more appropriate in severely resorbed mandible [3].

Management and preservation of completely edentulous ridge are still considered as big dilemma that meet the prosthodontists. In the trial of preserving the residual ridge and solving this problem; few years ago, the all-on-four technique was developed by Dr. Paulo Maló,4 implants, modifying the angulations of the two most distal to the midline, the all-on-four technique is a system that allows complete rehabilitation with maxillary and / or mandibular implants in the toothless patient total. This technique can be applied with success rates more than 95%, even in situations of extreme resorption the lower ridge [4,5].

Biomechanical studies had showed that the implants excess loading is the key factor lead to bone resorption, as functional loads are distributed directly to the bone. The excess of functional loads generates stresses that are dissipated from the retention system to implants and supporting tissue, and the intensity and amplitude of bone resorption is determined by the transmission and distribution mechanism of each retention system [6].

Finite elements analysis (FEA) is a numerical method of analysis for stresses and deformations in structures of any given geometry. Many studies had been carried out to evaluate the stress distribution around dental implants supported overdentures using FEA [7-12]. FEA has become a powerful tool to predict stress and strain within structures in a realistic situation that cannot be solved by conventional linear static models [12,13].

The mandible was restored by an immediate fixed full-arch prosthesis according to the all-on-four concept [14].

As far as implant shape, design parameters, implant diameter and the length of the bone-implant interface is concerned. To increase the surface area for ossteointegration, threaded implants are generally preferred to smooth cylindrical ones. So threaded implants was selected in this study [15].

Using tilted implants to maximizing the available bone used without grafting has been testified, leading to successful clinical results [16-17]. Conventional implant treatment needs bone-grafting procedures, more chair time and cost due to insufficient bone in the posterior region.

Published data on the all-on-four concept reported increasing survival rates between 92.2% and 100%. The all-on-four concept has been reported predominantly in the literature with the Branemark system dental implants [9,13].

In spite of there are many studies had been carried out to evaluate the stress distribution around the implant supported overdenture prosthesis the "all on-four" concept is still considered as a new technique and there are little data available in the literatures regarding the stress distribution around the implants of fixed implant-supported prostheses for mandibular completely edentulous cases that treated with "all on-four" concept. Therefore**,** this report was aimed to evaluate fixed implant-supported prostheses using "all on-four" concept for the treatment of mandibular completely edentulous ridge.

2. MATERIALS AND METHODS

2.1 Geometric Model

Models with specific heights and width measured the constructed model was drawn using CAD/CAM software" AutoDesk Inventor version 8.0. (Autodesk Inc., San Rafael, CA, USA), and it was used for define the sites for implants placement. Two anterior implants were positioned at site of canine areas parallel to each other and perpendicular to occlusal plane. Distal two implants were positioned at first molar area, also distal implants were tilted distally to form a 30-degrees angle to the occlusal plane. The 3D FEA model components as the overdenture, mucosa, implants, angled base, abutment, cortical and cancellous bones were created in "Autodesk Inventor" Version 8, then exported as SAT files (Standard ACIS Text). These components were assembled in Analysis System (ANSYS environment), (ANSYS Inc., Canonsburg, PA, USA). The design of the implant was taken from the manufacturer data. The system analyzed in this investigation consisted of the commonly available root form threaded titanium dental implant (Dentium NR line Inc, Korea) and angled base. The root form dental implant had a nominal diameter of 3.1 mm and length of 11.mm (Implant GFX 30 11 S, Platform 3.2).

The simulated peri-implant bone included an inner layer representing cancellous bone of 22 mm height and 14 mm width covered by an outer thin layer of cortical bone of 2 mm thickness. The simulated covering mucosal layer was of 2 mm thickness [18,19]. All parts of implant complex, mandible and their assembly as appeared on Inventor screen. All these parts in addition to the implant and abutment were exported from Inventor as SAT files [20]. Then set of Boolean operations were carried out to assemble all the model components before meshing.

All materials to be used in this study were assumed to be isotropic, homogenous and linearly elastic and its properties are listed in Table 1.

2.2 Meshing

Set of Boolean operations between the modeled components were performed before obtaining the complete model assembled. The meshing of these components was done by 3D solid element (SOLID187) which has three degrees of freedom (translation in main axes directions) [22].

2.3 Loads and Boundary Conditions

The model was subjected to six loading conditions as the following: 100 Newton **(**N) at the central incisor (Vertical), 50 N at central incisor (Oblique), 200 N at first molar (Unilateral Vertical), 100 N at first molar (Unilateral Oblique), 200 N at first molar (Bilateral Vertical), and 100 N at first molar (Bilateral Oblique), the model was investigated after each loading condition. The lowest plane of the model was considered fixed in the three directions as a boundary condition.

3. RESULTS

All model components (the overdenture, mucosa, implants, angled base, abutment, cortical and cancellous bones) were demonstrated in each run (case study). The model components results were taken as screen shots from ANSYS. The definition of most important results obtained and demonstrated shown below as follows;

- S_1: Max tensile stress
- S_{int}: Max Stress Intensity (shear indicator)
- S_{von}: Von Mises (Equivalent) stress

Table 1. Material properties of used in the finite element model

Material	Young's Modulus [MPa]	Poisson's Ratio
Cortical [18]	13,700	0.30
Cancellous [18]	1,370	0.30
Implant – abutment – (Ti) [21]	110,000 (Per ASTM E8-04)	0.35
Mucosa [22]	10	0.40
Overdenture [8]	2,700	0.35

3.1 Central Incisor (Vertical)

The Von Mises stress distribution computed for the abutment evaluated under vertical load were 14.462 MPa. The maximum stress intensity of overdenture and abutment appeared on labial surface of over denture and abutment at canine implant. The maximum tensile stress of implant, cortical and spongy bone appeared at distal surface on top of canine implant, and that of mucosa appeared mesially (Fig. 1) and Table (2).

3.2 Central Incisor (Oblique)

The Von Mises stress distribution computed for the implant evaluated under oblique load were 14.462 MPa. The stress intensity was distributed between the two canine implants and the maximum stress intensity was centralized between them in overdenture. The maximum Von Mises stress of implant, mucosa and spongy bone appeared on distal side at first molar while appeared on the mesial top of angled base of abutment and appeared on lingually in cortical bone (Fig.2) and Table (3).

3.3 First Molar (Unilateral Vertical)

The Von Mises stress distribution computed for the overdenture evaluated under unilateral vertical load were 3.019 MPa. The maximum stress intensity of overdenture and mucosa appeared on lingual surface at first molar implant. The maximum stress intensity of abutment, Cortical and spongy bone appeared on mesiolingual surface of first molar implant while in implant appeared on occlusally (Fig. 3) and Table (4).

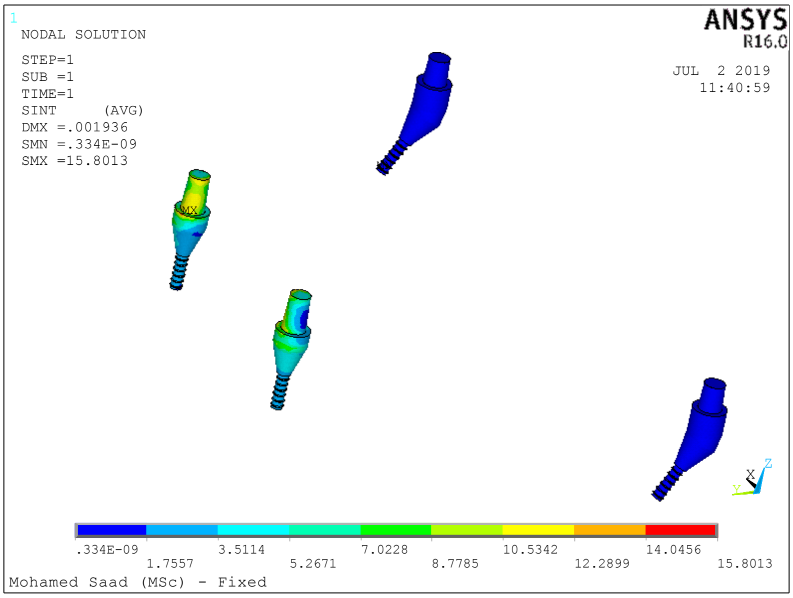

Fig. 1. Abutment result, the maximum stress intensity appeared on labial surface abutment base connection at canine implant

Table 2. S_{von} , S_1 and S_{int} result of vertical load 100 N at Central incisor

Model components	Central incisor (Vertical) 100 N		
	S_{von}:	S_1:	S_{int}:
Overdenture	3.26345	1.80579	3.41711
Implants	12.662	5.48178	13.7791
Abutment	14.4652	6.23135	15.8031
Angled base	14.4652	6.23135	15.8031
Mucosa	0.3033	0.187959	0.33817
Cortical bones	3.86329	5.1834	4.13384
Cancellous bones	1.05138	1.04362	1.16473

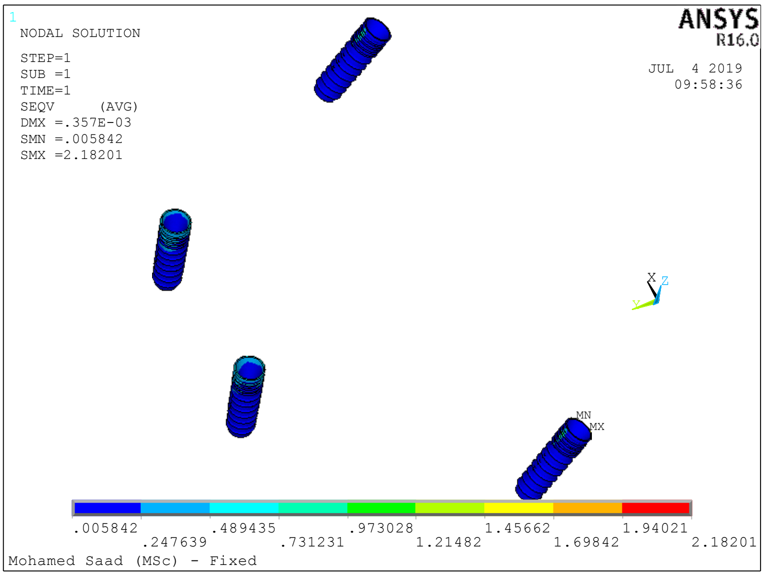

Fig. 2. Abutment result, the maximum Von Mises stress appeared on distal side at first molar implant

Table 3. S_{von} , S_1 and S_{int} result of Oblique load 50 N at Central incisor

Model components	**Central incisor (Oblique) 50 N**		
	S_{von}:	**S_1:**	**S_{int}:**
Overdenture	1.04764	1.21526	1.13568
Implants	2.18201	1.51943	2.51687
Abutment	3.30345	3.15807	3.59621
Angled base	3.30345	3.15807	3.59621
Mucosa	6.44297	7.15693	6.58958
Cortical bones	3.01157	3.83974	3.39442
Cancellous bones	0.121116	0.091471	0.13072

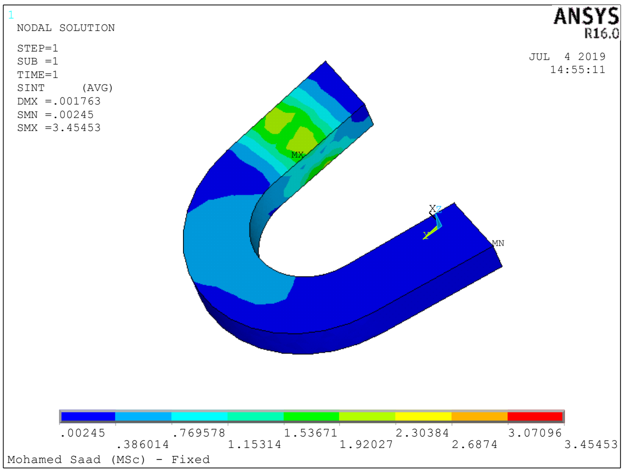

Fig. 3. Overdenture result, the maximum stress intensity appeared on lingual surface at first molar implant

Table 4. S_{von} , S_1 and S_{int} result of Unilateral Vertical load 200 N at First molar

Model components	First molar (Unilateral Vertical) 200 N		
	S_{von}:	S_1:	S_{int}:
Overdenture	3.01923	3.83353	3.45453
Implants	6.68657	2.56641	7.41907
Abutment	44.5922	13.9544	46.9865
Angled base	44.5922	13.9544	46.9865
Mucosa	9.66059	7.33823	10.2673
Cortical bones	6.80554	2.73361	7.22124
Cancellous bones	0.570417	0.328891	0.629773

3.4 First Molar (Unilateral Oblique)

The Von Mises stress distribution computed for the Spongy bone evaluated under unilateral oblique load were 0.2756MPa. The maximum stress intensity of overdenture appeared lingual to first molar implant, while appeared occlusally in cortical bone. The maximum stress intensity of abutment and implant appeared on mesial side on top of angled base at first molar implant, while appeared distally in spongy bone (Fig.4) and Table (5).

3.5 First Molar (Bilateral Vertical)

The Von Mises stress distribution computed for the mucosa evaluated under bilateral vertical load were 11.412MPa. The maximum von mises stress of overdenture, cortical and spongy bone appeared mesiobuccal surface of first molar implant. The maximum von mises stress of abutment appeared mesial side on top of angled base at first molar implant and in mucosa appeared crestally, while in implant appeared lingually (Fig.5) and Table (6).

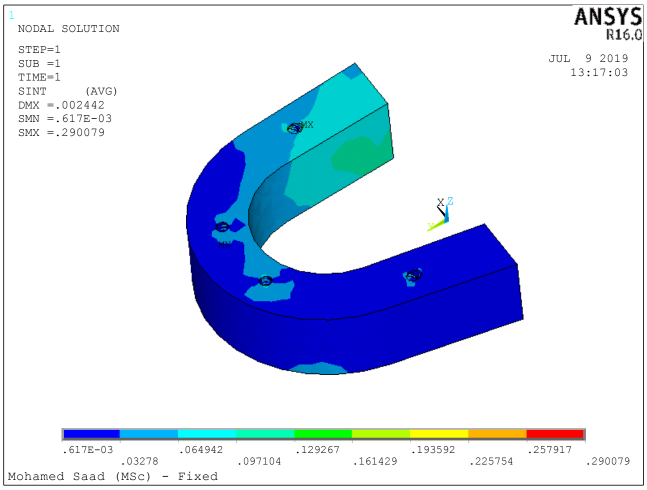

Fig. 4. Spongy bone: the maximum stress intensity appeared on distal surface at first molar implant

Table 5. S_{von} , S_1 and S_{int} result of Unilateral Oblique load 100 N at First molar.

Model components	First molar (Unilateral Oblique) 100 N		
	S_{von}:	S_1:	S_{int}:
Overdenture	2.33643	2.7224	2.64977
Implants	4.31685	3.01045	4.96197
Abutment	8.00922	4.87124	8.35572
Angled base	8.00922	4.87124	8.35572
Mucosa	15.242	9.5807	17.0197
Cortical bones	4.25578	4.85602	4.84943
Cancellous bones	0.275665	0.193958	0.290079

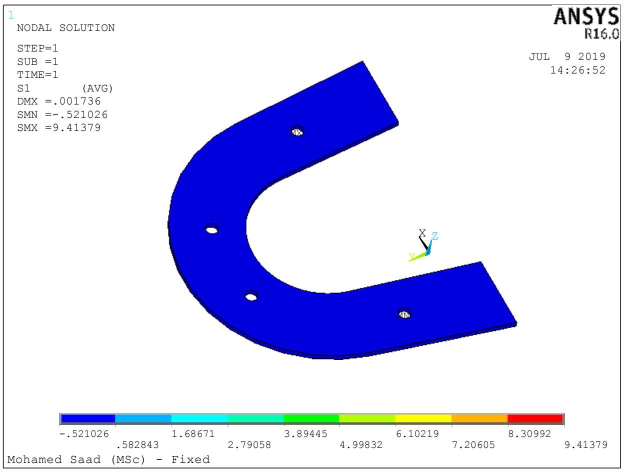

Fig. 5. Mucosa result: the maximum tensile stress appeared at the crest of first molar implant

Table 6. S_{von} , S_1 and S_{int} result of Bilateral Vertical load 200 N at First molar

Model components	First molar (Bilateral Vertical) 200 N		
	S_{von}:	S_1:	S_{int}:
Overdenture	3.10709	4.06993	3.57946
Implants	9.47198	2.96867	10.8456
Abutment	44.0273	13.7582	46.3648
Angled base	44.0273	13.7582	46.3648
Mucosa	11.4126	9.41379	12.0744
Cortical bones	10.2534	10.6889	10.8477
Cancellous bones	0.574631	0.47783	0.634146

3.6 First Molar (Bilateral Oblique)

The Von Mises stress distribution computed for the cortical bone evaluated under bilateral oblique load were 8.979MPa. The tensile stress of overdenture was equally distributed between the two canine implants and the maximum tensile stress was centralized between them. The maximum von mises stress of cortical bone appeared crestally (Fig. 6). The maximum von mises stress of abutment, mucosa and spongy bone appeared mesial side on top of angled base at first molar implant while, appeared distally in implant, (Table 7).

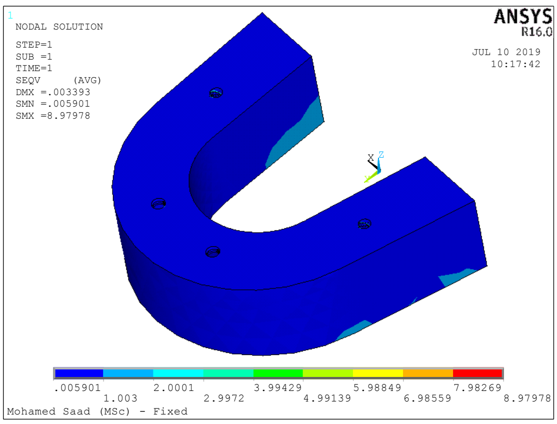

Fig. 6. Cortical bone result: the maximum von mises stress appeared crestally to the first molar implant

Table 7. S_{von} , S_1 and S_{int} result of Bilateral Oblique load 100 N at First molar

Model components	First molar (Bilateral Oblique) 100 N		
	S_{von}:	S_1:	S_{int}:
Overdenture	4.115	4.52211	4.69055
Implants	6.52539	4.55684	7.51633
Abutment	24.8965	9.17792	26.5237
Angled base	24.8965	9.17792	26.5237
Mucosa	21.329	13.5014	23.8466
Cortical bones	8.97978	6.86353	10.3427
Cancellous bones	0.386676	0.354716	0.446495

4. DISCUSSION

The all on-four concept get up as an effort to allow treatment with inexpensive and time saving through immediate implant-supported restorations, providing successful and expectable treatment in edentulous patients with severe resorbed jaws.

Concentrating on the mandible, the idea of the all on-four concept is based on: a) use of four implants in the anterior interforaminal mandibular area, b) the two posterior implant are with angulation with the apices of the implant towards the anterior, so that the insertion point can be distal to mental foramen, to decrease the posterior cantilever of the final prosthesis.

The present report used 3D models to evaluate the stress distribution in implant-retained overdentures. The models of this study were allowed to evaluating the stress distribution on buccal and lingual mesial and distal implants areas.

In this study CAD/CAM software" AutoDesk Inventor version 8.0 " was used in drawing the models with specific heights and width measured from the constructed model as these components were exported as SAT file then imported into the finite element package was used. The latter has been commonly used for 3D modeling as it allows the achievement of reliable analytic or free form parts based on an efficient management of curves and surfaces [23].

The different loading conditions that were used in this study were according to other investigators [10].

In the current report loads are applied to the occlusal surfaces of the superstructure in order to simulate real masticatory movements, but with a FEA, precise calculations cannot be made, because there is great variation in the magnitude of the mechanical factors for bone, and in addition, masticatory movements and their magnitude vary enormously between the individuals.

Theoretically, the problem of predicting loads on the implants is a statistically indeterminate problem in mechanics. In most cases occlusal loads lie between 50 N and 2400 N. Furthermore, the masticatory loads are dynamic and oblique relative to occlusal surfaces of the implants. However, in the current study a 50 N, 100 N and 200 N vertical and oblique loads were used. Simulating such a loading condition can be considered as a realistic masticatory pattern.

The Von Mises stress distribution computed for the abutment evaluated under vertical load was within the physiological limit (14.462 MPa) which was < 0.3-0.5 % of Young's Modulus of abutment (110,000 MPa).

The Von Mises stress distribution computed for the implant evaluated under oblique load was within the physiological limit (2.182 MPa) which was < 0.3-0.5 % of Young's Modulus of implant (110,000 MPa).

The Von Mises stress distribution computed for the overdenture evaluated under unilateral vertical load was within the physiological limit (3.019 MPa) which was < 0.3-0.5 % of Young's Modulus of overdenture (2,700 MPa).

The Von Mises stress distribution computed for the Spongy bone evaluated under unilateral oblique load was within the physiological limit (0.2756 MPa) which was < 0.3-0.5 % of Young's Modulus of Spongy bone (1,370 MPa).

The Von Mises stress distribution computed for the mucosa evaluated under bilateral vertical load was not within the physiological limit (11.412 MPa) which was > 0.3-0.5 % of Young's Modulus of mucosa (10 MPa).

The Von Mises stress distribution computed for the cortical bone evaluated under bilateral oblique load was within the physiological limit (8.979 MPa) which was < 0.3-0.5 % of Young's Modulus of cortical bone (13,700 MPa).

All values of deformations and stresses that appeared on the model components (cortical, spongy bone, implant, base, abutment, and overdenture) were within physiological limits under all cases of load application. The pervious result was in agreement with Malo´ et al. [14] who reported a high clinical success rate from 97.2% up to 100% for the lower jaw in a first year, also it was in agreement with Balshi et al. [24] who reported an increasing implant survival rate of 97.8% for the lower jaw, after observing and follow-up of 152 patients up to 6 years using the all on-four treatment idea and they mentioned that there was no significant difference in the outcome was observed between arches, genders, or implant orientations.

Monje et al. [25] compared marginal bone loss around tilted and straight implants, they found no significant difference in marginal bone loss between tilted and straight implants in the short and medium terms.

Retrospective studies [11,26] showed that there is no negative effect on the load distribution based on biomechanical measurements, when studying tilted implants. In addition, decrease in cantilever length due to the more posterior position of the tilted implants, resulting in a more favorable stress distribution [11,13].

The finite element modeling technique used in the present study has some limitation when predicting the response of biologic systems to applied loads, as do all modeling systems, including photoelastic analysis and strain gauges measurement. However, the findings of this report may provide a broader understanding about the potential stress concentration locations.

This report suggests long-term clinical research to evaluate the influence of the observed stress levels on the supporting structures and implants.

5. CONCLUSION

Within the limitations of this study, the following conclusion can be drawn:

- All values of deformations and stresses that appeared on the model components (cortical, spongy bone, implant, base, abutment, and overdenture) were within physiological limits under all cases of load application.
- Tilted implants at molar area did not affect the system behavior (did not show beak of stresses or deformation).
- Recommendation; Long-term clinical research is required to determine the influence of the observed stress levels on the tissue and prosthesis function

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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