AJDS ALAZHAR
Al-Azhar Journal of Dental Science
Vol. 26- No. 3- 283:289- July 2023
Print ISSN 1110-6751 | online ISSN 2682 - 3314
https://ajdsm.journals.ekb.eg
Restorative Dentistry Issue (Dental Biomaterials, Operative Dentistry, Endodontics, Removable & Fixed Prosthodontics)

3D FINITE ELEMENTS ANALYSIS OF STRESS DISTRIBUTION ON THE POSTERIOR TILTED IMPLANTS ON ALL ON 4 CONCEPT

M.Shalaby [1*] , H. Bahnassawi [2] , Y. Baraka [3]

ABSTRACT

Objective: The purpose of this 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" by 3D finite elements analysis. **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, then exported as SAT files. These components were assembled in ANSYS environment. The model was subjected to two loading conditions of 200N, vertically unilateral and, vertically bilateral at molar regions respectively. **Results:** All values of deformations and stresses appeared on the model components (overdenture, implants, angled base, abutment, cortical and cancellous bones) were within physiological limits under all loads application. **Conclusion:** Tilted implants at molar area did not affect the system behavior (did not show peak of stresses or deformation) and all values of deformations and stresses that appeared on the model parts (cortical, spongy bone, implant, base, abutment, and overdenture) were within physiological limits under all cases of load application.

KEYWORDS: all-on-four, stress distribution, finite elements, tilted implants.

INTRODUCTION

Use of conventional complete dentures is associated with several problems, such as insufficient of denture stability, support and retention. These problems lead to discomfort, reduction in chewing ability and, at times, may be socially embarrassing [1].

The osseointegrated implants introduced new methods for treating these patients. The implant supported overdenture are recommend to overcome these drawbacks mainly in mandibular removable dentures. These prostheses have many advantages including good stability, good retention, improve function, esthetic and reduce residual ridge resorption [2].

Biomechanical studies had showed that the implants overload is the main factor responsible for bone resorption, as functional loads are distributed directly to the bone. The excess of functional loads produces stresses that are receded from the retention system to fixtures and supporting structures, and the severity and extent of bone resorption is detected by the transmission and distribution mechanism of each retention system [2].

1. Masters Candidate, Sinai University
2. Assistant Professor Removable Prosthodontics, Faculty of Dental Medicine, Boys, Cairo, Al-Azhar University
3. Assistant Professor Removable Prosthodontics, Faculty of Dentistry, Sinai University

• ***Corresponding author*:** *m.saad55518@gmail.com*

DOI: 10.21608/ajdsm.2021.80868.1205

The methodology of using titled implants maximizing the use of the sufficient bone without grafting has been reported, leading to successful clinical outcomes[3-5]. As compared as the traditional implant treatment in which inadequate bone in the posterior area requires bone-grafting procedures involving greater chair time for the patient in addition to increasing cost and number of procedures.

It is approved that the two implant over denture is not the gold criterion of implant therapy, it is the minimum criterion that should be adequate for most people, taking in account achievement patient gratification, cost and clinical time [6].

All-on-Four concept is a treatment modality to avoid unfavorable posterior areas is the use of inclined implants to allow for a preferable anteroposterior spread of dental implants. Thus, four implants are placed axially in the anterior region of edentulous jaw, while the posterior implants are inclined distally to maximize implant length and avoid vital structures [7].

Variety of techniques and methods have been employed for assessing and analyzing the stresses transmitted through fixed implant-supported prostheses designs to their abutments and supporting structures. Finite elements analysis (FEA) is a numerical method of analysis for stresses and deformations in structures of any given geometry. The structure is modeled and then discretized into smaller and simpler domains called ”finite elements“. These elements are connected together through nodes forming a meshwork. Boundary conditions, Materials properties and loads are assigned and then the calculations are made to come up with the results. The type, arrangement and total number of elements affect the accuracy of the results. Finite element analysis (FEA) has been used widely to portend the biomechanical interpretation of different dental implant designs as well as the effect of clinical factors on the success of implantation. As more in-depth understanding of stress profiles encountered by the implant, and more importantly in the surrounding jawbone, could be gained through the use of finite element method (FEM) [8].

MATERIALS AND METHODS

Anterior implants were positioned at canine area parallel to each other and perpendicular to occlusal plane. Distal implants were positioned at first molar, also distal implants were inclined distally to form a 30-degree angle to the occlusal plane [9] .

The model was virtually planned with On-Demand 3D software to define the sites for implant application.

Implant installation

On the planned virtual model:

Four threaded titanium dental implants (Dentium NR line Inc, Korea), the root form of dental implant had a nominal platform diameter of 3.2 mm, a length of 11 mm and the shape connection of internal 10° conical with body diameter 3.1 mm [10].

Geometric Model: The 3D FEA model components as the overdenture, mucosa, implants, angled base, abutment, cortical and cancellous bones were created in “Autodesk Inventor” Version 8 (Autodesk Inc., San Rafael, CA, USA), then exported as (Standard ACIS Text) SAT files. These parts were assembled in ANSYS environment (ANSYS Inc., Canonsburg, PA, USA). The design of the implant was taken from the manufacturer data. The system analyzed in this investigation and formed of the available root form threaded titanium dental implant (Dentium NR line Inc, Korea) and angled base. The root form of 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 involved an inner layer representing spongy bone was of 22 mm length 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[11,12]. All parts of implant complex, mandible and their assembly are appeared on Inventor screen. All these parts in addition to the fixture and abutment were exported from Inventor as SAT files [13]. Then set of Boolean operations were accomplished to assemble all the model parts before meshing.

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

TABLE (1) Material properties of used in the finite element model.

Material	Young's Modulus [MPa]	Poisson's Ratio
Cortical [11]	13,700	0.30
Cancellous[11]	1,370	0.30
Implant – abutment – (Ti) [14]	110,000 (Per ASTM E8-04)	0.35
Mucosa [15]	10	0.40
Overdenture[16]	2,700	0.35

Meshing: Set of Boolean operations between the modeled components were performed before getting the complete model assembled. The meshing of these parts was done by 3D solid element (SOLID187) which has three degrees of freedom (translation in main axes directions) [15].

Loads and boundary conditions: The model was subjected to two loading conditions as 200 N at first molar (Unilateral Vertical), and 200 N at first molar (Bilateral vertical), the model was investigated after each loading condition. The lowest plane of the model was considered fixed in the three dimensions as a boundary condition.

The model was proved against similar studies[12,13] and showed very good result. The Linear static analysis was performed on a Workstation HP Z820 (Dual processors, 2.1 GHz, 32 GB RAM), using a commercial multifunctional finite element software package (ANSYS version 16.0).

RESULTS

Two loading conditions were analyzed as follows;

1 -Uni L6 - V200

2 – Bi L6 - V200

All model components (the overdenture, mucosa, implants, angled base, abutment, cortical and spongy bones) were demonstrated in each run (case study). The model parts 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

1- First molar (Unilateral Vertical)

The Equivalent 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 shear stress of abutment, cortical and cancellous bone appeared on mesiolingual surface of first molar implant while in implant appeared on occlusally (Fig.1) and table (2).

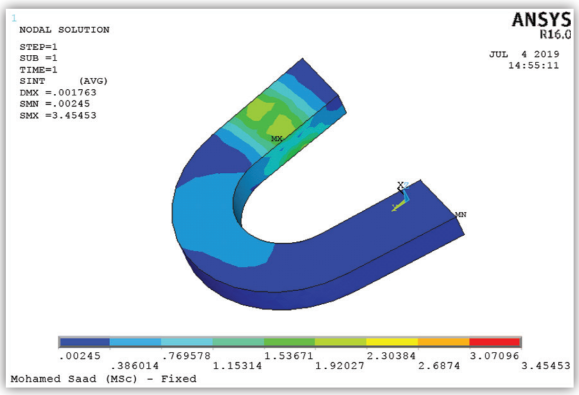

FIG (1) Overdenture result, the maximum stress intensity appeared on lingual surface at first molar implant.

TABLE (2) 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		
	Svon:	**S1:**	**Sint:**
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

The equivalent stress distribution computed for the abutment evaluated under unilateral vertical load was within the physiological limit (44.5922MPa) which was < 0.3-0.5 % of Young's Modulus of abutment (110,000 MPa).

2- First molar (Bilateral Vertical)

The Equivalent stress distribution computed for the mucosa evaluated under bilateral vertical load were 11.412MPa. The maximum Equivalent stress of overdenture, cortical and spongy bone appeared mesiobuccal surface of first molar implant. The maximum Equivalent 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.2) and table 3.

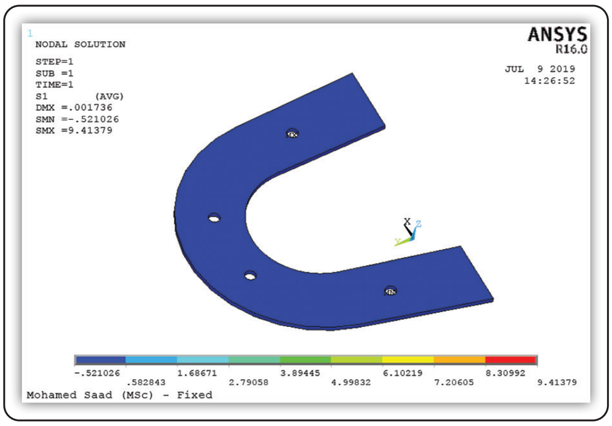

FIG (2) Mucosa result: the maximum tensile stress appeared at the crest of first molar implant

TABLE (3) 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		
	Svon:	**S1:**	**Sint:**
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

The equivalent stress distribution computed for the overdenture evaluated under bilateral vertical load was within the physiological limit (3.10709MPa) which was <0.3-0.5% of Young's Modulus of overdenture (2,700 MPa).

The equivalent stress distribution computed for the mucosa evaluated under unilateral and bilateral vertical load was not within the physiological limit (9.66059 MPa) and (11.412 MPa) respectively which was > 0.3-0.5 % of Young's Modulus of mucosa (10 MPa).

All values of deformations and stresses that appeared on the model parts (cortical, spongy bone, implant, base, abutment, and overdenture) were within physiological limits under the two cases of load application.

DISCUSSION

The all on-four treatment concept appears as a trial to allow treatment with adequate time and cost through immediate implant-supported prosthesis, providing relatively the most simple and predictable treatment in edentulous patients with atrophic jaws[15, 16].

The all-on-four protocol is 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 fixtures in the edentulous patient. This technique can be applied in a high percentage of cases with success rates above 95% [17, 18].

In this study short and narrow implants were placed in the model, this concept is an alternative prosthetic option for atrophic ridge which may provide several surgical advantages including reduced treatment time and costs and less skill necessary to perform the surgical intervention, less morbidity by avoiding more extensive bone augmentation procedures, easier removal in case of failure, and predominantly, an increased number of sites available for implant therapy [10]. To improve the surface area for ossteointegration, threaded implants are generally preferred to smooth cylindrical ones. So threaded implants were selected in this study [19].

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

In this condition CAD/CAM software" AutoDesk Inventor version 8.0 "is used in drawing the models with specific heights and width measured from the constructed model as these parts were exported as SAT file then imported into the finite element analysis used. The latter has been usually used for 3D modeling as it allows the fulfillment of reliable analytic or free form parts depending on an efficient management of curves and surfaces [20].

The different loading conditions that were mentioned in this study were according to other investigators, 3D finite element models of a 3-unit cantilever bridge were subjected to 150 N occlusal load to assessed two different superstructure materials and two several implant designs, To assess the distribution of stresses within the bone surrounding the implants, 3-dimensional finite element analysis was conducted using four mathematical models of unilateral 3-unit cantilever fixed partial dentures supported by two implants [21].

In this study, loads will apply on the occlusal aspects of the superstructure 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 fixtures 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 aspects of the fixtures. However, in this study a 200 N vertical Unilateral and Bilateral loads were used. Simulating such a loading condition can be assumed as a realistic masticatory pattern.

The result was in harmony with Maló et al.[22] who reported with excellent prognosis with percentage 97.2% and 100% for the mandible in a 1- year prospective study when 92 Nobel- Speedy implants were placed in 23 sequentially treated patients, also it was in agreement with Balshi et al. [23] who conducted a retrospective study (up to 6 years follow-up) of 152 patients with 200 arches rehabilitated with 800 implants using the all on-four treatment concept and reported a progressive implant success rate of 97.8% for the mandible.

Monje et al. [24] in a meta-analysis investigating if we compare between cervical bone resorption surrounding the tilted and straight implants, we find no importance difference in weighted mean cervical bone resorption between tilted and straight fixtures in the short and medium terms.

Also result of this study are in accord with retrospective studies[25, 26] based on biomechanical properties, which demonstrated that tilted implants, have a good clinical outcomes on the load distribution. In addition, a biomechanical rationale in tilting distal implants allows decreasing in cantilever length because of the more posterior location of the tilted implants, leading to a more appropriate stress distribution[25, 27].

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

This report suggests long-term clinical research to assessed the effect of the observed stress levels on the surrounding structures and implants [28].

CONCLUSION

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

- All values of deformations and stresses that appeared on the model parts (cortical, spongy bone, implant, base, abutment, and overdenture) were within physiological limits under all cases of load application.
- Tilted implants at molar area had no significance the system behavior (did not show peak of stresses or deformation).

REFERENCES

1. Warreth A, Byrne C, Alkadhimi AF, Woods E, Sultan A. Mandibular implant-supported overdentures: attachment systems, and number and locations of implants–Part II. J Ir Dent Assoc. 2015;61(3):144-8.
2. Korkmaz FM, Korkmaz YT, Yaluğ S, Korkmaz T. Impact of Dental and Zygomatic Implants on Stress Distribution in Maxillary Defects: A 3-Dimensional Finite Element Analysis Study. J Oral Implantol. 2012;38(5):557-67.
3. Pomares C. A retrospective clinical study of edentulous patients rehabilitated according to the'all on four'or the'all on six'immediate function concept. Eur J Oral Implantol. 2009;2(1):55–60.
4. Aparicio C, Perales P, Rangert B. Tilted Implants as an Alternative to Maxillary Sinus Grafting: A Clinical, Radiologic, and Periotest Study. Clin Implant Dent Relat Res. 2001;3(1):39-49.
5. Testori T, Del Fabbro M, Capelli M, Zuffetti F, Francetti L, Weinstein RL. Immediate occlusal loading and tilted implants for the rehabilitation of the atrophic edentulous maxilla: 1-year interim results of a multicenter prospective study. Clin Oral Implants Res. 2008;19(3):227-32.
6. Thomason JM, Kelly SAM, Bendkowski A, Ellis JS. Two implant retained overdentures—A review of the literature supporting the McGill and York consensus statements. J Dent. 2012;40(1):22-34.
7. Stanford C. All on four-where are we now. Int J Oral Maxillofac Implants. 2014;29(2):1-9.
8. Van Staden RC, Guan H, Loo YC. Application of the finite element method in dental implant research. Computer Methods in Biomechanics and Biomedical Engineering. 2006;9(4):257-70.
9. Krekmanov L, Kahn M, Rangert B, Lindström H. Tilting of posterior mandibular and maxillary implants for improved prosthesis support. International Journal of Oral & Maxillofacial Implants. 2000;15(3).
10. Thoma DS, Cha J-K, Jung U-W. Treatment concepts for the posterior maxilla and mandible: short implants versus long implants in augmented bone. Journal of Periodontal & Implant Science. 2017;47(1):2.
11. El-Anwar MI, Yousief SA, Soliman TA, Saleh MM, Omar WS. A finite element study on stress distribution of two different attachment designs under implant supported overdenture. Saudi Dent J. 2015;27(4):201-7.
12. Geng J, Yan W, Xu W. Application of the finite element method in implant dentistry: Springer Science & Business Media; 2008.
13. El-Anwar M, editor Simple technique to build complex 3D solid models. Proceeding of 19th international conference on computer Theory and Applications (ICCTA 2009); 2009.
14. Huang HL, Chang CH, Hsu JT, Faligatter AM, Ko CC. Comparison of Implant Body Designs and Threaded Designs of Dental Implants: A 3-dimensional Finite Element Analysis. International Journal of Oral & Maxillofacial Implants. 2007;22(4):551-62.
15. Liu J, Pan S, Dong J, Mo Z, Fan Y, Feng H. Influence of implant number on the biomechanical behaviour of mandibular implant-retained/supported overdentures: A three-dimensional finite element analysis. J Dent. 2013; 41(3):241-9.

16. Abdelhamid AM, Neena AF. Three dimentional finite elements analysis to evaluate stress distribution around implant retained mandibular overdenture using two different attachment systems. J Dent Health Oral Disord Ther. 2015;2(5):00065.
17. Eckert SE, Carr AB. Implant-retained maxillary overdentures. Dent Clinic North Amer. 2004;48(3):585-601.
18. Misch C. Densidad ósea: factor determinante en el plan de tratamiento. In: Misch C, editor. implantología contemporanea, 3rd ed. Canada: Mosby Elsevier; 2007. p. 130-46.
19. De Santis D, Cucchi A, Longhi C, Vincenzo B. Short threaded implants with an oxidized surface to restore posterior teeth: 1-to 3-year results of a prospective study. International Journal of Oral & Maxillofacial Implants. 2011;26(2).
20. Santos Filho SB, Barros MEBd, Gomes RdS. A Política Nacional de Humanização como política que se faz no processo de trabalho em saúde. Interface - Comunicação, Saúde, Educação. 2009;13(suppl 1):603-13.
21. Culhaoglu A, Ozkir S, Celik G, Terzioglu H. Comparison of two different restoration materials and two different implant designs of implant-supported fixed cantilevered prostheses: A 3D finite element analysis. European J Gen Dent. 2013;2(2):144.
22. Malo P, de Araujo Nobre M, Lopes A. The use of computer-guided flapless implant surgery and four implants placed in immediate function to support a fixed denture: Preliminary results after a mean follow-up period of thirteen months. J Prosthetic Dent. 2007;97(6):S26-S34.
23. Balshi TJ, Wolfinger GJ, Slauch RW, Balshi SF. A Retrospective Analysis of 800 Brånemark System Implants Following the All-on-Four™ Protocol. J Prosthodont. 2013;23(2):83-8.
24. Monje A, Chan H-L, Suarez F, Galindo-Moreno P, Wang H-L. Marginal bone loss around tilted implants in comparison to straight implants: a meta-analysis. nt J Oral Maxillofac Implants. 2012;27(6).
25. Bellini CM, Romeo D, Galbusera F, Agliardi E, Pietrabissa R, Zampelis A, et al. A finite element analysis of tilted versus nontilted implant configurations in the edentulous maxilla. Inter J Prosthodont. 2009;22(2).
26. Bellini CM, Romeo D, Galbusera F, Taschieri S, Raimondi MT, Zampelis A, et al. Comparison of tilted versus nontilted implant-supported prosthetic designs for the restoration of the edentuous mandible: a biomechanical study. International Journal of Oral & Maxillofacial Implants. 2009;24(3):511–7.
27. Zampelis A, Rangert B, Heijl L. Tilting of splinted implants for improved prosthodontic support: A two-dimensional finite element analysis. J Prosthetic Dent. 2007;97(6):S35-S43.
28. Academyprosthodontics. The glossary of prosthodontic terms. J Prosthetic Dent. 2005;94(1):10-92.