Comparison of Stress Patterns in Edentulous Mandibular Bone around Two Implant Retained, Four Implant Retained Overdenture and All-On-Four Concept. - *A 3 Dimensional Finite Element Analysis*

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Abstract

Recently the use of tilted implants has been considered as a preferable option in case of atrophic edentulous arches. The tilted longer implants can be of use to ward off the important anatomical structures while also permitting cantilever reduction.

Since the load transfer mechanism of an implant can be altered significantly by the number of implants and its location in the edentulous ridge, the present study evaluates and compares the stress patterns in the edentulous mandibular bone around two implant retained, four implant retained over denture and all on four concepts under different loading conditions using finite element analysis.

Purpose: The biomechanical behaviour of the 'All-On-Four' system was compared with that of the two-implant-supported and four-implant supported mandibular overdenture using the three dimensional finite element method (FEM). Thereby evaluating the von Misses stresses induced on the implants under different loading simulations.

Materials & Method: Three dimensional models representing mandible restored with 'All-On-Four', two-implant-supported and four-implant-supported prosthesis were developed in the three dimensional design software and then transferred into FEM software. The models were then subjected to four different loading simulations (full mouth biting, canine disclusion, load on cantilever, load in the absence of cantilever). The maximum von Mises stresses were localized and quantified for comparison.[1]

Results: Among the three models, under all loading simulations, the maximum stress concentrations were along the neck of the implant. The stress levels for full mouth loading simulation was highest for two implant supported overdenture design and the least for All-On-Four overdenture design. In all three designs, the least stress was when the implants were loaded in a lateral direction. The stress levels for cantilever and non-cantilevered designs were nearly the same for all the simulated designs.

Conclusion: When tested under different loading simulations, the three models showed similar location and distribution of stress patterns. Thus from the study it can be concluded that the All-On-Four Concept is a

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clinically applicable treatment option for the atrophic edentulous ridges and induces least amount of stresses on the edentulous ridges. Therefore the overall longevity of the prosthesis is greatly enhanced.

Key words: *atrophic mandible, biomechanics, finite element analysis, implants supported prosthesis, tilted implants.*

Introduction

Dental implant treatment is considered as the most favorable treatment option for the partially or the completely edentulous patients.[1] Although implant treatment is well documented and reliable, implant placement may be limited by the anatomy of the patient like in regions of posterior maxilla or the posterior regions of mandible, the use of implants is usually limited by extensive bone resorption and poor bone quality. In addition to this, there are various anatomical limitations like presence of maxillary sinuses in the maxilla and superior position of the inferior alveolar nerve in the mandible.[2-5] Hence in such situations prosthetic rehabilitation of implants in the posterior region may necessitate the use of long cantilevered prostheses, thereby increasing the risk of implant failure.[6-8].

Recently the use of tilted implants has been considered as a preferable option in case of atrophic edentulous arches as confirmed from the study by Watanabe et al. The tilted longer implants can be of use to ward off the important anatomical structures while also permitting cantilever reduction. Hence to simplify the treatment of atrophic maxilla or mandible using tilted distal implants, a technique named, 'All-On-Four' was developed.[1]

The use of tilted implant concept offers good support by reducing cantilever length, enhancing primary stability by using areas of high density bone and also allows a favorable inter-implant distance. But poorly designed implants can create regions of increased stress in peri-implant bone and induce severe resorption, leading to gradual loosening and finally complete loss of implant [1,2,6,]

The stress and strain generated have been evaluated by methods like the photo elasticity, strain gauge analysis and finite element analysis. The photo- elasticity provides good qualitative information on the overall location and concentration of stresses but provides limited quantitative information. The strain gauge movements provide accurate data regarding strains only at the location of the gauge; the finite element method is capable of providing detailed quantitative data at any location within a mathematical model. Two and three dimensional finite element analysis has been used to evaluate the stresses around various dental implant systems. [2,5,10]

An in-depth understanding of stress profiles encountered by the implant and more importantly in the surrounding jawbone can be gained through the use of FEM. It is of great importance that the clinician gains an understanding of the methodology, applications, and limitations of FEA in implant dentistry, and become more confident to interpret results of FEA studies and interpret these results to clinical situations.[1,4,9]

Since the load transfer mechanism of an implant can be altered significantly by the number of implants and its location in the edentulous ridge, the present study is evaluating and comparing the stress patterns in the edentulous mandibular bone around two implant retained, four implant retained over denture and all on four concepts under different loading conditions using finite element analysis.

Aim

To compare the stress patterns in the edentulous mandibular bone around two implant retained, four implant retained overdenture and the prosthesis restored with All- On-Four Concept using finite element analysis.

Objectives

To compare the biomechanical behaviour of the prosthesis restored with All-

On-Four Concept with that of two implant supported and four implant supported mandibular overdenture using three dimensional finite element analysis..

To localize and quantify the Von Mises stresses induced on the implants under different loading simulations.

Material & Method

Poorly planned implant placement can create regions of increased stress in peri-implant bone and induce severe resorption, leading to gradual loosening and finally complete loss of implant. Hence a detailed analysis needs to be done to evaluate the stress distribution with various implant designs.

The present study was carried out at the

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Armamentarium used for the study

● CT Scan of edentulous mandible

● Replace Select Tapered TiU NP 3.5 x 13mm (Nobel Biocare)

● The Profile Projector (METZ- 801)

● Cylindrical Retainer of 4mm diameter.

● ANSYS - 11 Workbench Software.

Preparation of FEM model of the Edentulous Mandible. [1-4]

A Computerized tomography image of the human edentulous mandible was obtained and introduced into the Computer Aided Design Software. Using the ANSYS software, the CT image of the mandible was later simplified into an arc shaped bone block with dimensions of 7.5 mm thick and 15mm high. A 1mm cortical bone layer was established overlying the entire mandible whereas trabecular bone was used in the internal structure, simulating the type III bone. Once the computerized 3-Dimensional model was obtained, incorporation of the implant design into the model was planned.

Preparation of the FEM implant model

The study was done to compare the stress patterns in the edentulous mandible under various implant supported overdenture designs, so the accuracy and contour of the threaded implant was a major concern. But the contour, shape and depth of the threads in the implant could not be evaluated and reproduced in the 3-dimensional model with the help of the computerized tomography, hence an instrument called 'Profile Projector Optical System' was used in this study. The values that were obtained from the profile projector were then used to prepare an accurate 3-D model of the threaded implant along with the retainer.

Profile Projector (METZ -801) Optical System

All profile projectors display magnified images on an appropriate viewing screen, as an aid to more precise determination of dimension, form and occasionally physical characteristics of sample parts. These optical projectors are able to display a two dimensional projection of a part rather than a simple linear dimension as with most other gauging devices.

This instrument creates work piece image on the projection screen at desired magnifications (10x, 20x, 50x) to provide accurate dimensional measurement as well as inspection of the contour and surface condition of the work piece.

The METZ- 801 features a large Projection Screen 300mm diameter and the combination of high performance projection lens and an optical system minimizing the magnification error, which may occur due to insufficient or improper focusing and ensures accurate measurements over the entire projection screen. The accuracy of this instrument is known to be 0.001mm.

Preparation of the working model

Three dimensional working models were constructed using 3D computer aided design software (ANSYS). The models represented the mandible restored with 2 - implant supported prosthetic design, 4 implant supported prosthetic design, and the design restored with the All On Four Concept. A rigid type III gold prosthetic bar, 6mm thick and 4mm high and in the shape of an arc was then designed and joined to the abutments.[1]

For the 3-Dimensional two implant supported prosthesis model, the threaded implants were strategically placed vertically in the region of lateral incisors bilaterally.

For the 3- Dimensional four implant supported prosthesis model, in addition to the mesial implants placed bilaterally, distal implants were vertically placed bilaterally in the premolar region.

For the 3- dimensional 'All-On-Four' model, Two anterior implants were placed vertically in the position of the lateral incisors and two implants were placed bilaterally in the position of second premolars and tilted distally to 30º angle.

● Loading 1: Full mouth biting – bilateral and simultaneous vertical static loads of

- 200 N was applied on the occlusal surface of the first molars (Cantilevers)

- 150 N on the occlusal surface of second premolars

- 150 N on the occlusal surface of first premolars

- 100 N on the distal of canines

● Loading 2: Lateral Load – Unilateral static load of 50 N applied in the region of left canine.

● Loading 3: Cantilever Load – Unilateral vertical static load of 200 N was applied on the left cantilever.

● Loading 4: Load without the cantilever - Unilateral vertical static load of 200 N was applied in the region adjacent to the left second premolar, simulating absence of cantilever.

The results of the mathematical solutions were later converted into visual results and expressed in colour gradients, ranging from shades of red, orange, yellow, green and blue, with red representing highest stress values. The stress values in the three models were collected and compared, with the points of greatest magnitude identified by the Von Mises equivalent stress levels.

Loading Situation

This study was carried out on FEM models simulating two implant retained prosthesis, four implant retained prosthesis and the prosthesis restored with the All-On-Four Concept under a) Full mouth load, b) Lateral load, c) Cantilever load, d) Load without cantilever.

Results

The results of the numerical analysis are shown in Table 2 for Von Mises stresses occurring for the FEM models simulating

Graph 1 represents the biomechanical behavior of the two implant supported overdenture FEM modes when subjected to different loading simulations. The graph depicts maximum stress levels during full mouth loading simulation which was 2226.7 Mpa followed by cantilever loading simulation which was 813.09 Mpa and load without cantilever shown as 531.39 Mpa. The least stress for this model was found during the lateral loading simulation which was 64.76 Mpa.

Graph 2 represents the biomechanical behavior of the four implant supported overdenture FEM models under different loading simulations. The maximum stress level in this model was found during the full mouth loading simulation which was 303.51 Mpa followed by load simulating cantilever loading which was 187.34 Mpa and load simulating load without cantilever which was 125.09 Mpa. The least stress was found during lateral loading shown as 57.35 Mpa. The stress levels in the four implant simulation were comparatively much less than the two implant supported overdenture model.

Graph 3 illustrates the graphical representation of the biomechanical behavior of the FEM model simulating the prosthesis restored with the All-On-Four Concept. The maximum stress in this simulation was found during full mouth loading which was 253.37 Mpa followed by load simulating lateral load which was 88.01 Mpa and load simulating the cantilever load which was 85.22 Mpa. The least stress was found when load without cantilever was simulated which was 60.21 Mpa.

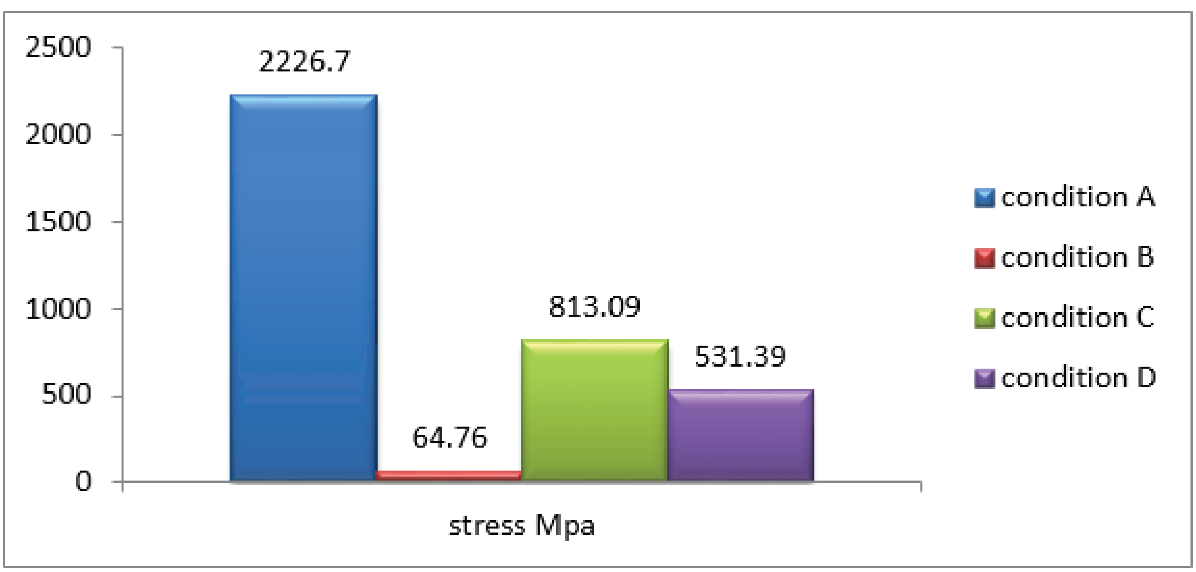
From the graphs it can be inferred that among the three models, the stress levels for full mouth loading simulation was highest for two implant supported overdenture design and the least for All-on-four overdenture design. For all three designs, the least stress was when the implants were loaded in a lateral direction. The stress levels for cantilever and non-cantilevered designs were nearly the same for all the simulated designs.

Table 1 – Young's Modulus & Poisson's Ratio used in the study

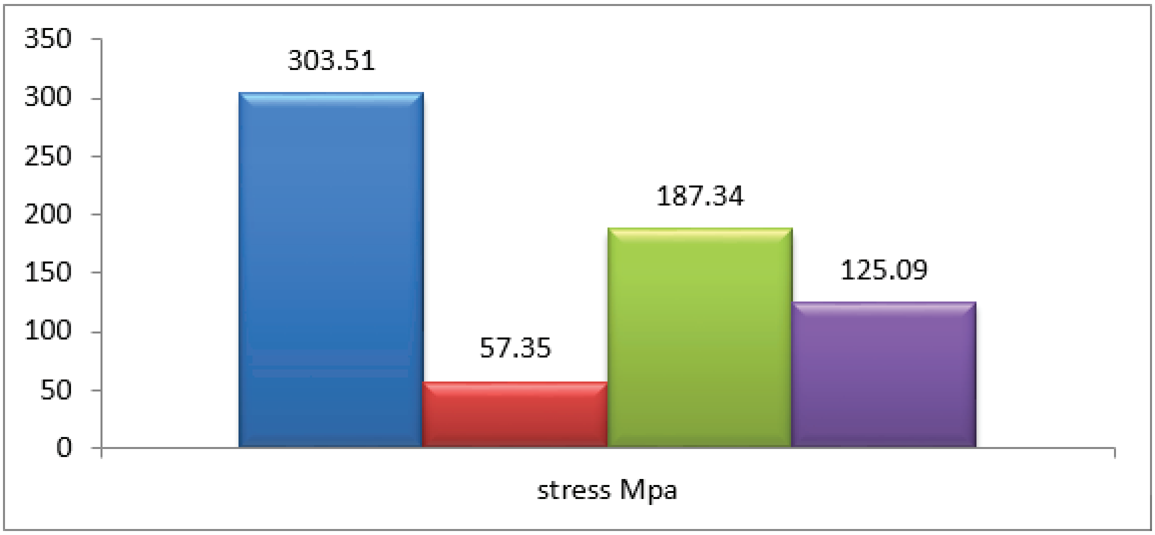
MATERIAL	YOUNG'S MODULUS (Mpa)	POISSON'S RATIO
Cortical Bone	13.7	0.30
Trabecular Bone	1.37	0.30
Titanium	115	0.35
Type III Gold	100	0.30

Table 2 – Maximum Stress values recorded during different simulations.

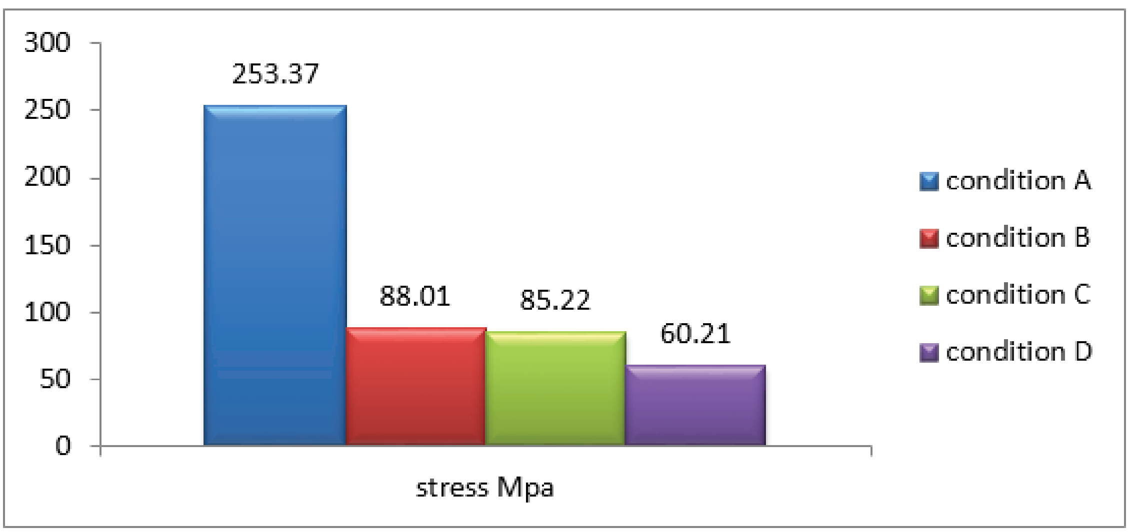
IMPLANT	TWO IMPLANT (Mpa)	FOUR IMPLANT (Mpa)	ALL–ON-FOUR(Mpa)
Full mouth biting	2226.7	303.51	253.37
Lateral Load	64.76	57.35	88.01
Cantilever Load	813.09	187.34	85.22
Load without Cantilever	531.39	125.09	60.21



Graph 1- Peak stresses in Two implant supported overdenture



Graph 2 – Peak stresses in Four implant supported overdenture



Graph 3 – Peak stresses in All-On-Four concept.

Discussion

Various studies revealed that the occlusal load was one of the main contributing factors. The load transfer from implant to the surrounding bone depends on type of loading, bone- implant interface, length and diameter of implants, shape & characteristics of the implant surface, prosthesis type and quantity & quality of the surrounding bone. So the dentist has specific responsibilities to minimize overload to the bone implant interface. These include a proper diagnosis leading to a treatment plan providing adequate support [2,4,9].

Among the various methods for the stress - strain analysis, the finite element method is capable of providing detailed quantitative data at any location within a mathematical model. Two and three dimensional finite element analyses have been used to evaluate the stresses around various dental implant systems.

Keeping in mind the consequences of unwanted stresses, this study was an attempt to compare the Von Mises Stresses around the implant by different loading conditions, on three different finite element models. The models were simulated on the basis of implant number, position, angulation and the type of prosthesis which is a Type III gold bar.

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