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FIXED PROSTHODONTICS AND DENTAL MATERIALS

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THREE DIMENSIONAL FINITE ELEMENT ANALYSIS OF STRESSES INDUCED AROUND INCLINED IMPLANTS WITH DIFFERENT FRAMEWORK MATERIALS IN MAXILLARY COMPLETE ARCH PROSTHESES (ALL ON 4)

Mohamed Abdel Hakim Abdel Aal*

ABSTRACT

The aim of the study is to compare stresses induced onto implant-bone interface, implants & denture bases on using cobalt Chromium. (Cr-Co) and Titanium (Ti) framework materials.

Methodology: Three dimensional finite element models of completely edentulous maxilla rehabilitated with ALL on 4 implant prostheses, (Two vertical anterior implants & two posterior implants 20°, 30° and 45° mesially tilted), Cr-Co & Ti framework materials were constructed. Bilateral axial load of 100 N was applied onto the palatal cusps of maxillary posterior teeth. The resultant equivalent Von Misses stresses at areas of interest were calculated.

Results: The Von Mises stresses induced in bone were 5.132 & 6.144 Mpa in model I & IV / 2.403 & 2.272 Mpa in model II & V /13.937 & 14.591 Mpa in model III & VI respectively . The stresses induced in denture bases were 225.25 & 218.91 Mpa in model I & IV, 156.74 & 170.19 Mpa in model II & V, 227.25 & 159.99 Mpa in model III & VI respectively. The stresses induced in implants were 26.591 & 31.315 Mpa in model I & IV, 18.322 & 26.42 Mpa in model II & V / 117.29 & 117.66 Mpa in model III & VI respectively.

Conclusions: Within the limitations of this study, we may conclude:

- The more rigid the framework, the less stress dissipation onto the surrounding structures.
- Posterior implants tilted mesially may reduce the stresses induced onto implants & surrounding structures.

KEYWORDS: All on four, Maxilla, FEA, implant tilting, framework

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*Associate Professor of Removable Prosthodontics, Faculty of Dental Medicine, Beni-Suef University.

INTRODUCTION

Maxillary residual bone anatomy forms a limitation in placement of dental implants in case of extremely atrophic maxilla and maxillary sinus pneumatization (1, 2). In implant rehabilitation for atrophic maxilla, bone is not sufficient for standard implant length installation (3), sinus lifting and advanced augmentation procedures to achieve adequate bone support for placing standard implants are a sort of treatment; however, such method may result in infection and loss of the graft material.(4)

Using short or tilted implants may be an alternative treatment option, according to Maló et al (5) four implants will be adequate for complete restoration of the maxilla by placing two implants in the anterior area of the jaw with two others placed posteriorly (the all on four concept), anterior implants are inserted parallel and posterior implants are placed tilted at an angle of 30°–45°. (5)

As clinical success are largely controlled by the mechanical setting in which the endosteal implants function(6), tilting distal implant in atrophic posterior maxilla allows reducing the cantilever length and better biomechanical results in full arch implant rehabilitation(7,8).It also permits engagement of sinus wall and nasal fossa by the implants. (5, 9, 10, 11) but unfortunately tilted implants may lead to an increase in the peri-implant bone stress due to bending. (12, 13), however with the prostheses rigidity, this may reduce implant bending. (14)

Prosthesis design, mechanical properties, size, number and change of the major axis of implants influences the quantity of stress/deformation transferred to peri-implant bone and implant. (15)

Prosthetic frameworks may compensate for the slight increase in the stresses on the abutments and screws in the fewer implants placed in all on 4 concept. The prosthetic framework materials influence the loading stress pattern as it transfers the stresses to the underlying bone as well as the dental implants; consequently will lead to resorption of bone around the implants ultimately leading to its failure. So selecting a prosthetic framework that can dampen these massive loads and transfer the favorable loads onto the underlying bone becomes mandatory. (16-19)

A key factor for implant success is the optimal transfer of stresses to peri-implant bone; this stress transfer cannot be assessed clinically. Instead, stress distribution can be predicted through finite element analysis (FEA), which is often used before planning laboratory tests and clinical trials. (20)

The FEA is used in engineering fields, biological systems as well as with dental implants (21-23). Stresses created under mechanical loading at the implant interface can be detected by FEA. In the application of FEA, the object is simulated by a geometrical model that consists of small, refined elements that are connected to each other by nodes (24). By calculating the interactions of these pieces through several numerical methods, stress distribution can be determined. (25)

Using the 3D finite element analysis, this study aims to compare the stress distribution on distal implants in the "All-on-Four" situation in maxilla with varying implant angulations with different framework materials.

MATERIALS AND METHODS:

Ethical Aspect:

An unconditional approval (Approval number: #REC-FDBSU/01122022-07/AM, Date : 12/2022) was received from Faculty of Dentistry- Beni-Suef university Research Ethics Committee (FDBSU-REC), Egypt.

ALL ON FOUR implant prostheses were utilized to rehabilitate a completely edentulous Maxillary arch with different implant angulations & two different framework materials. Consequently, six finite element (FE) models were made as follows:

Model I: 20^0 mesially angulated implants with multi-unit abutments & two axially placed implants in the anterior region restored with chrome cobalt (Cr- Co) framework.

Model II: 30^0 mesially angulated implants with multi-unit abutments & two axially placed implants in the anterior region restored with a chrome cobalt framework.

Model III: 45^0 mesially angulated implants with multi-unit abutments & two axially placed implants in the anterior region restored with a chrome cobalt framework.

Model IV: 20^0 mesially angulated implants with multi-unit abutments & two axially placed implants in the anterior region restored with a Titanium (Ti) framework.

Model V: 30^0 mesially angulated implants with multi-unit abutments & two axially placed implants in the anterior region restored with a Titanium framework.

Model VI: 45^0 mesially angulated implants with multi-unit abutments & two axially placed implants in the anterior region restored with a Titanium framework.

I. Modeling Of The Maxillary Arch:

A) *IMAGING ACQUISITION.*

Cone-beam CT scan of completely edentulous patient were used for 3D reconstruction using **MIMICS SOFTWARE** (Materialise®, Belgium). The segmentation of anatomical structures was performed by thresholding. The 3D reconstruction was exported as binary STL format.

B) *BIO-CAD MODELING:*

STL Reverse Engineering Approach from the CT radiograph segmentation by ***MIMICS*** resulted in two STL models referred to compact & cancellous bone. These STLs was imported into ***3-MATIC MEDICAL 11.0 (x64)*** for further smoothening and exported as STL format to ***Geomagic Design X*** software for reverse engineering and exported as solid parts ready for ***Boolean*** subtraction and assembly in ***ANSYS*** finite element analysis software.

II. Three- Dimensional Modeling Of Implants And Screws:

- Zimmer implant (Zimmer Biomet Dental, Gillette, New Jersey) of 4.1 mm diameter implant & 10 mm length were exported from ***BLUESKYBIO SOFTWARE**** Implant library as STL file extension, creating a bridge between the outer & inner shell of the implant body, creating threads inside the implant body to accommodate a screw with the same dimensions and thread design then converted to a solid body. The screw was drowned inside SOLIDWORKS ***software 2016*** and exported as a solid file. ***Fig (1)***

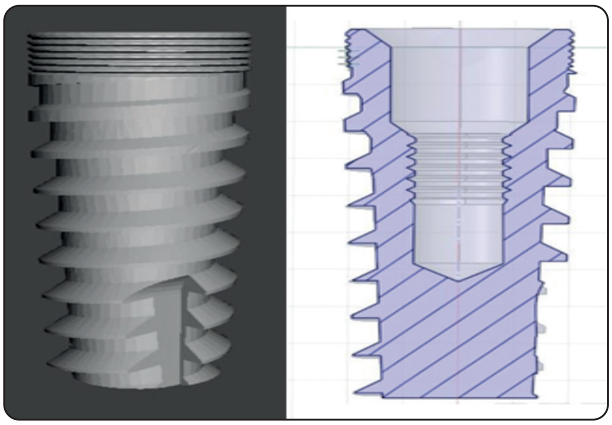

Fig. (1) Zimmer implant cross section after solid conversion

Assembling the components:

All solid parts were imported & assembled in ANSYS software then checked for interference by interference detection tool.

1. Compact & cancellous bony parts were assembled inside each other.
2. Computer guide stent for each model was imported and seated correctly on compact bone.

3. Implants were imported & inserted through the guide holes into their correct position with bone level & with correct angle for each model. ***Fig (2)***
4. Thereafter, Boolean subtraction of the implants from compact & cancellous bone was made to create implant beds perfectly.
5. The metallic framework of the implant prostheses was imported & seated in their correct position onto the implant abutments.
6. Then acrylic denture base was finally added & tightened with the screw parts to create the final model. ***Fig (3)***

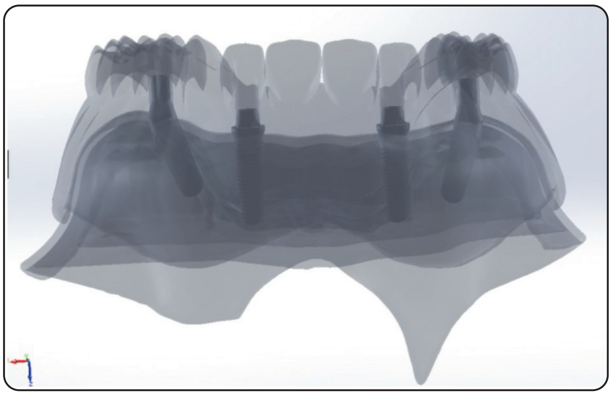

Fig (2) Implants inserted through the guide holes into their correct position

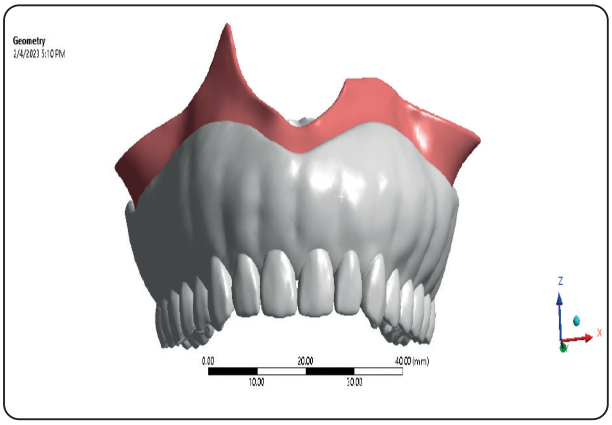

Fig (3) The Geometric model of Maxillary arch, implant & prosthesis assembly

Defining the contact conditions:

All the contacting structures were assumed to possess 100% contact at the interface. The nature of contact between the components was defined using the ***"contact /Gap"*** property. ***Fig (4)***

Any contacting objects react as one unit to the applied forces. ***This type of contact was defined between:***

- The cortical & cancellous bone, the bony parts & implant as well as the metallic framework and denture base.

b) Slip (no penetration) contact interface

This type of contact, the two contacting objects react as one unit only under compression, but can be separated on tensile force application. This type of contact was defined between:

- The implant, metal framework and retaining screw complex.

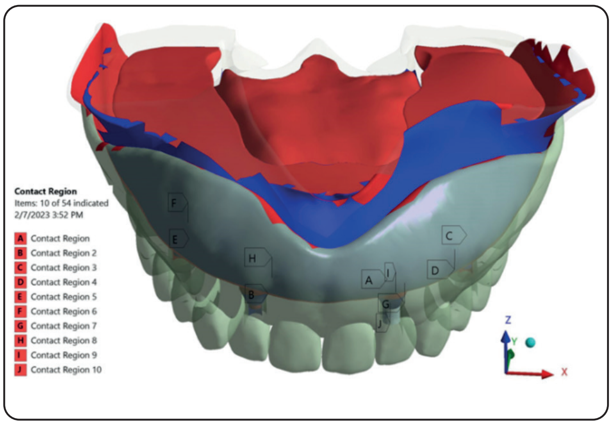

Fig (4) Contacting Surfaces interfaces

Meshing of the models

During this process each model was divided into small parts called elements connected together at points called nodes forming a mesh structure. Parabolic tetrahedral solid elements were utilized to form a fine solid mesh.

A Simple unstructured tetrahedral mesh

generation ***Fig (5)*** is specially performed for complex geometries with variable mesh density. Element size is less than 0.2 mm around implants & at bone/ implant interface. Widening of the mesh density was made away from the interfaces with element size 0.9 mm, this was made to decrease the number of elements in areas away from the implants & consequently reducing the file size & decreasing the time required for solving and running the analysis.

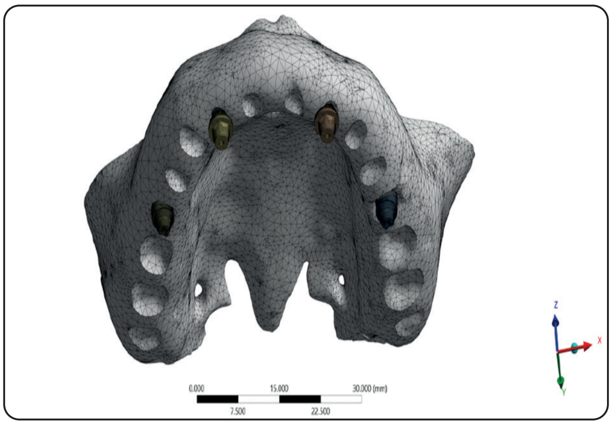

Fig (5) Differential meshing unstructured tetrahedral mesh

TABLE (1) Total number of elements and nodes for each model

Model	Element	Node
Model I 20° Cr-Co	**965128**	**1582495**
Model II 30° Cr-Co	**960048**	**1574189**
Model III 45° Cr-Co	**960048**	**1574189**
Model IV 20° Ti	**965128**	**1582495**
Model V 30° Ti	**960048**	**1574189**
Model VI 45° Ti	**960048**	**1574189**

Defining the material properties:

For each component the material properties, namely the ultimate strength, yield strength, compressive strength, modulus of elasticity and Poisson's ratio were identified to the software according to the values reported in the literature

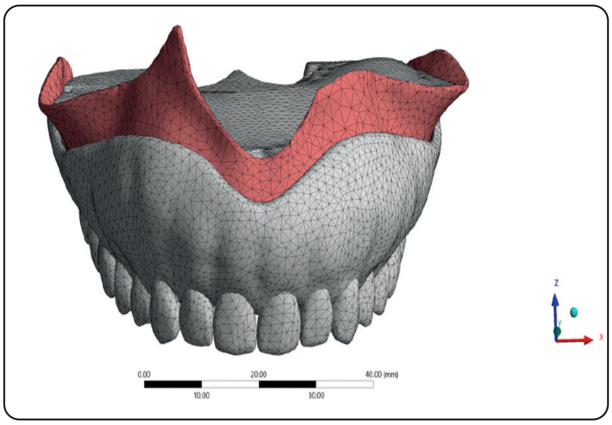

Fig (6) Finite Element Model after full Meshing

TABLE (2) Material properties for each component

Material	Modulus of elasticity	Poisson's ratio
Compact bone	13700 Mpa	0.3
Cancellous bone	7930 Mpa	0.3
Mucosa	680 Mpa	0.45
Cobalt chromium alloy	200000 Mpa	0.29
Titanium alloy	110000 Mpa	0.33

Defining loads and restraints

Initially all the screws were tightened to the implants by applying 30 Ncm tightening torque at the implant restoration interface using the "Bolt connector" property. The defined coefficient of friction between the titanium parts was 0.3220. For each model, the prosthesis was loaded with 100 N vertical loads bilaterally on the palatal cusps of the maxillary posterior teeth for each model ***Fig(7)***; maxillary bodily displacement was prevented by applying fixed restraints on the superior border of the maxillary arch model. ***Fig (8)***

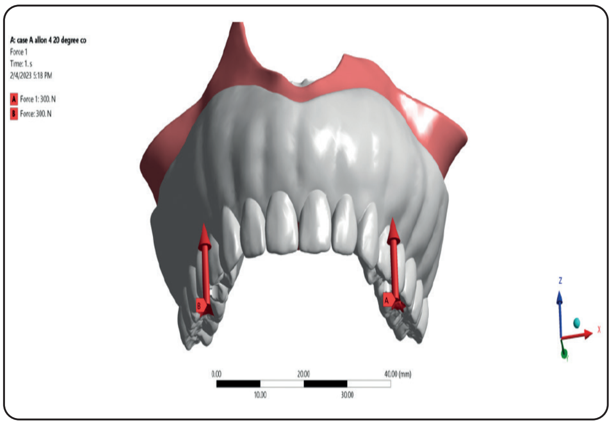

Fig (7) Load application

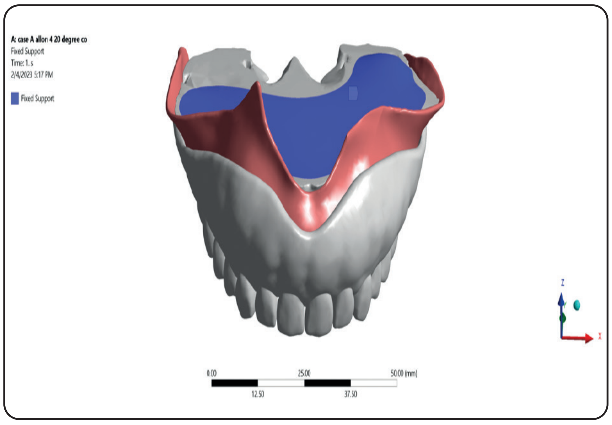

Fig (8) Maxillary Restrains

Running of the analysis and collection of data

After meshing, analysis was performed using an interactive method to compute the stresses, strains and displacements. After termination of the analysis procedure, the maximum equivalent stresses (Von Mises stresses) were collected from the different zones of the peri-implant bone, implant and denture base of each model. The results were then tabulated, and compared.

RESULTS

I. Results of Model I, II & III (all on four maxillary prostheses with mesially inclined posterior implants 20^0 , 30^0 & 45^0 with Cr- Co. Framework"

The results of the present study are showing that the maximum Von Mises stresses in areas of posterior implants are as follows:

- The highest Von Mises stresses detected in the areas of palatal cortical plates around the posterior implants was 5.132 Mpa in model I 2.403 Mpa in model II & 13.937 Mpa in model III ***Fig (9)***
- On the other hand, the maximum Von Mises stresses detected in areas of the denture base was as follows: 225.25 in model I, 156.74 Mpa in model II & 227.25 Mpa in model III. ***Fig (10)***
- However, the stresses detected in implants & implant -abutment connections were as follows: 26.591 Mpa in model I, 18.322 Mpa in model II & 117.29 Mpa in model III. ***Fig (11)***

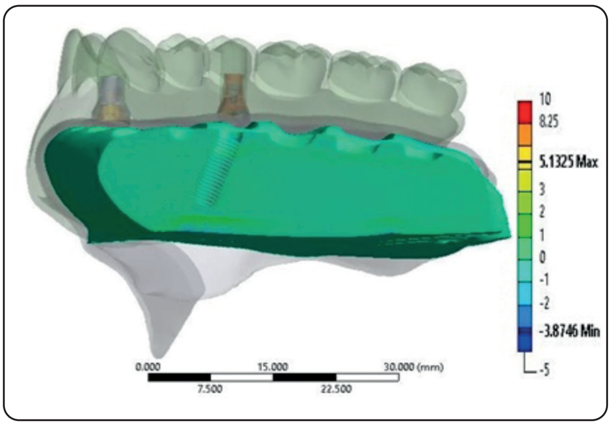

Fig (9) stresses in bone

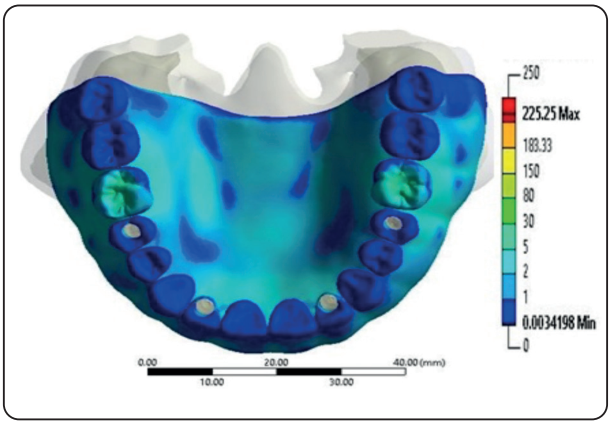

Fig (10) stresses in denture base

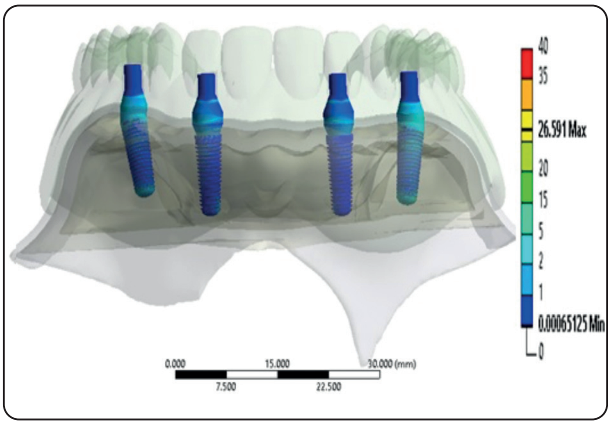

Fig (11) stresses in implants

II. Results of Model IV, V& VI (all on four maxillary prostheses with mesially inclined posterior implants 20⁰, 30⁰ & 45⁰ with Titanium Framework"

- The results of the present study are showing that the highest Von Mises stresses detected in the areas of palatal cortical plates around the posterior implants are 6.144 Mpa in model IV, 2.272 Mpa in model V & 14.591 Mpa in model VI. ***Fig (12)***

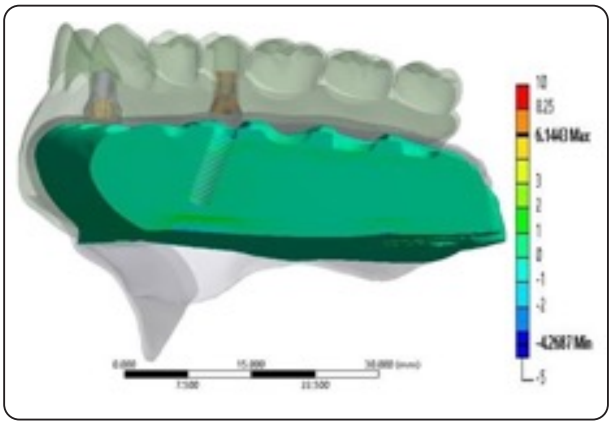

Fig (12) stresses in bone

- On the other hand, the maximum Von Mises stresses were detected in areas of the denture base as follows: 218.91 Mpa in model IV, 170.19 Mpa model V and 159.99 Mpa in model VI. ***Fig (13)***

- However, the stresses detected in implants & implant -abutment connections were as follows: 31.315 Mpa model IV, 26.42 Mpa model V and 117.66 Mpa in model VI. ***Fig (14)***

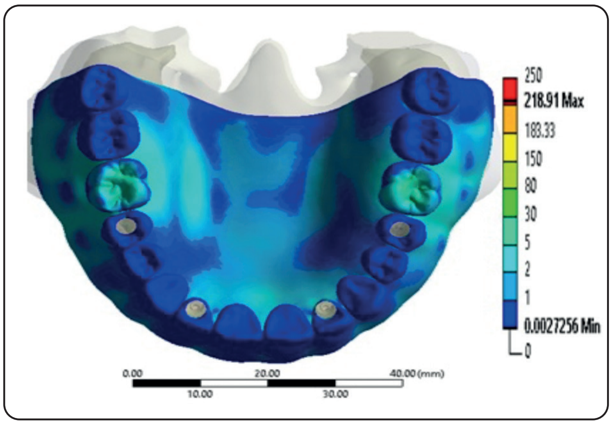

Fig (13) stresses in denture base

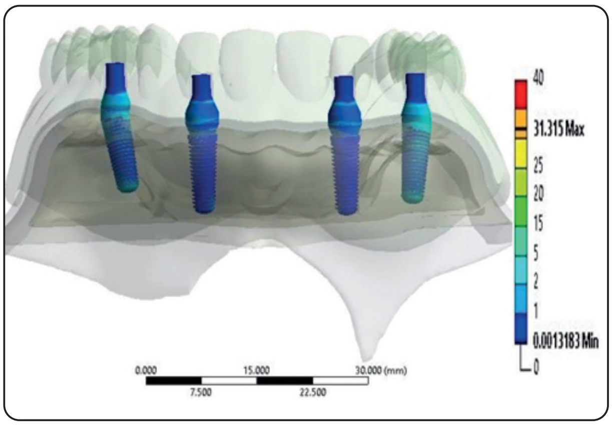

Fig (14) stresses in implants

III. Stresses between different models

- ***In bone :*** The stresses induced in bone in the studied models were 5.132 Mpa in model I & 6.144 Mpa in model IV, 2.403 Mpa in model II & 2.272 Mpa in model V and 13.937 Mpa in model III & 14.591 Mpa in model VI.

Consequently, it is clear that stresses are increased in bone surrounding posterior implants with titanium frameworks than Cr-Co with implant angulation 20° and 45°, however with implant angulation 30° there was less stresses.

- ***In denture base :*** The stresses induced in denture bases were as follows: 225.25 Mpa in model I & 218.91 Mpa in model IV, 156.74 Mpa in model II & 170.19 Mpa in model V and 227.25 Mpa in model III & 159.99 Mpa model VI.

This means that the stresses were less in denture bases with the use of Titanium frameworks than with Cr- Co with implant angulation 20° and 45°, except with implant angulation 30° there was more stresses.

- ***In implants and abutments:*** The stresses induced in implants & implant -abutment connections were 26.591 Mpa model I & 31.315 Mpa model IV, 18.322 Mpa in model II & 26.42 Mpa model V and 117.29 Mpa in model III & 117.66 Mpa in model VI.

Apparently, stresses induced in implants & implant -abutment connections were higher with the use of titanium framework with the three different implant angulations.

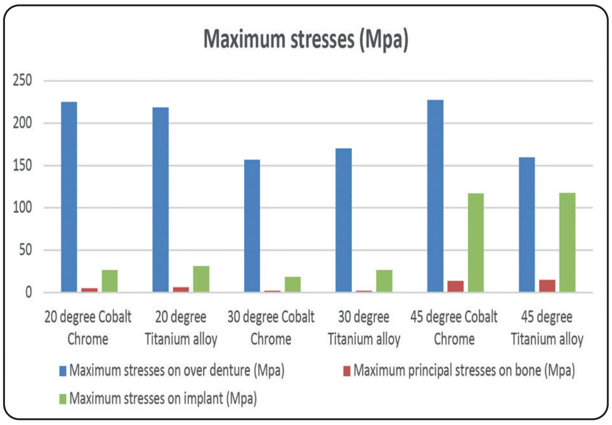

Fig (15) stresses with different implant angulation and different framework materials

DISCUSSION

The all-on-four dental implant concept provides a reliable treatment option for patients with severely resorbed ridges with high patient satisfaction (26)

FEA had been utilized as a non-invasive preliminary evaluating method that can predict the behavior of the materials without any morbidity to the patients. (27, 28)

Moreover, FEA is an appropriate technique for measuring complex structures that cannot be standardized clinically (28-30).

The prosthetic materials may play an important role in the stresses induced at implant/bone interface [30, 31].

The present study had utilized FEA to evaluate the stress distribution patterns on using two different framework materials with different mechanical properties & different implant angulations of posterior implants at the implant-bone interface, implants & denture base in maxillary all-on-four implant prostheses.

The anterior implants were vertically placed in all study models; however, the distal implants were tilted mesially at 20^0, 30° and 45^0 with Cr- Co & Titanium framework materials in all on 4 implant maxillary prostheses. Six models were constructed according to implant angulations & framework materials. Vertical load was applied on palatal cusps of maxillary 2nd premolar & 1st molar bilaterally. Von Mises equivalent stresses (S.equiv.) were selected as they are the most commonly reported in FEA studies to summarize the overall stress state at a point.

As the results of FE analysis are results of mathematical calculations without variance; it is not possible to make statistical analysis of these results.

The results of this study had shown that the equivalent stresses decreased on increasing posterior implant angulations from 20^0 to 30^0 in cortical bone plates surrounding implant necks, implants as well as denture bases with Cr-Co & Ti frameworks.

This may be explained by: The distal implants tilting allow for decrease in the prosthesis cantilever arm length; consequently less stresses will be transferred to implant-bone interface, denture base & the implants. Moreover, distal implant angulation may lead to analysis of forces applied into vertical

& horizontal vector components, which effectively reduces the load distribution in the adjacent bone tissue (32-35).

The least equivalent stress values were detected with models of 30^0 implant angle, this finding may agree with previous studies (36-38) that this angulation may provide the ideal length of the prosthesis cantilever arm that minimizes stress transfer onto the bone, implant & denture base.

On the other hand, increasing the implant tilting to 45^0 had induced high stress values in all models; this may be due to the increased horizontal vector of axially applied forces that may induce higher stresses.

On comparing the effect of framework materials; the results of this study had shown that stresses induced in bone surrounding implants were comparable between Cr-Co & Ti framework as they are both rigid materials allowing minimal stress dissipation into the surrounding bone & consequently it is recommended to be used as frameworks to preserve remaining supporting structures.

The results had also shown that stress values recorded in denture bases & implants were high with both Cr-Co & Ti; as the rigid framework materials may themselves absorb higher stresses than flexible ones as reported with Tribst et al (30); these stresses may be dissipated to areas in close proximity to the frameworks as the denture bases & implant -abutment interface leading to high stress values detected in these structures.

Moreover, the stresses induced onto the implants were slightly higher in Titanium than Cr-Co ; this finding may be explained by the less rigidity of Ti (Modulus of elasticity 110000 Mpa) in comparison with Cr-Co (Modulus of elasticity 200000Mpa), which allows Ti to absorb less stresses than Cr-Co, consequently more stresses would be dissipated into denture base & implants with Ti framework, this agree with a FEA study conducted by Tribst et al.(30) who reported that an increase in the elastic modulus of the framework reduced the stresses transmitted to the implants and surrounding bone.

Within the limitations of this study various conclusions could be drawn:

- All on four implant concept may provide better stress distribution pattern on implant / bone interface
- Tilting of posterior implants may improve implant/ prosthesis survival rates for maxillary all-on-four implant treatment
- Cr-Co & Titanium are rigid metallic framework materials which are excellent in load dissipation & for preserving the surroundings structures.

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