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FIXED PROSTHODONTICS AND DENTAL MATERIALS

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PERI-IMPLANT STRESS DISTRIBUTION IN MAXILLARY ALL-ON-4 PROSTHESIS FABRICATED ON MULTI-UNIT ANGLED ABUTMENT WITH COBALT CHROMIUM FRAMEWORK VERSUS THOSE WITH TITANIUM FRAMEWORK: A 3D FINITE ELEMENT ANALYSIS

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ABSTRACT

Aim: To use finite element analysis to evaluate the peri-implant stresses caused by the cobalt-chromium and titanium frameworks for maxillary all on four prostheses.

Material and methods: Three-dimensional finite elements modeling of an edentulous maxilla restored with a hybrid fixed prosthesis supported by four implants was done for this study. Anterior implants were placed vertically and bilaterally in the lateral-canine area. At the second premolar region, posterior implants were placed with a 17-degree distal angulation. Every implant featured a multi-unit abutment. The titanium framework for the first model was designed, and the cobalt-chromium framework for the second model was proposed.

Results: Von Mises stress, maximum stress, and directional deformation were assessed in the peri-implant bone area. Von Mises stresses on the screw-retained prosthesis were very similar in cobalt chromium and titanium frameworks compared to the underlying bone and implants.

Conclusion: For edentulous maxilla, the use of titanium or cobalt-chromium frameworks in conjunction with an all-on-four prosthesis is regarded as a dependable therapeutic alternative**.**

KEYWORDS: Bone-implant contact, Finite Element Analysis, Abutment angulation, Multi unit abutment, Framework Design, Cobalt chromium, Titanium, Von Misses stress, Maximum principal stress.

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INTRODUCTION

Many problems of conventional complete dentures were solved by Implant-retained over-dentures. This prosthesis provides a more stable, retentive and comfortable solution improving the chewing ability modifying the quality of life and patient satisfaction (1). Moreover, these implants supported fixed prosthesis maintains the alveolar bone, re-establish and maintain the vertical dimension. This would preserve facial esthetics, prevent food impaction, and improve occlusion and phonetics (2). Paulo Malo first proposed the "all on four" idea. It has been the treatment of choice for severely resorbed maxillary or mandibular arches that would require a fixed implant supported prosthesis. Four dental implants are used in this treatment model to restore totally edentulous ridges with fixed restorations. Two implants are positioned vertically (i.e., at an angle of 0°) in the front jaw region, and two more implants are positioned distally (17° to 45°) in the posterior alveolar ridge region. Numerous academics have reported on the all-on-four concept's predictability and safety (3,4,5).

Prosthetic framework has an important role in transmission of the occlusal forces and stress to the underlying implants in addition to the peri-implant alveolar bone region (6). To prevent cantilever deformation in implant-supported full-arch prosthetic operations, framework materials with sufficient tensile strength (>300 MPa) and elastic modulus (>80 GPa) must be used. Cobalt chromium and Titanium are the most utilized material. This is attributed to excellent mechanical qualities, affordability, low density, and biocompatibility. However, there are some controversies regarding the stress transmitted by frameworks fabricated by cobalt chromium (6,7).

MATERIALS AND METHODS

Three-dimensional simulation of maxilla

A cone beam computed tomography (CBCT) image of an individual with an edentulous maxilla was utilized to create a 3D surface model of the maxillary jaw using MIMICS software. Thresholding makes it feasible to segment anatomical structures. In this investigation, compact and cancellous bone were considered. The three-dimensional reconstruction was exported as an STL binary file.

Three-dimensional simulation of screws and implants

From the Blueskybio software's implant library, a Zimmer implant with dimensions of 4.1 mm in diameter and 10 mm in length was exported as an STL file extension. This threaded the implant's body to receive a screw with the same dimensions and thread design, so creating a bridge between the outer and inner shells of the implant. Next, the implant was made solid.

Assembling the components

All of the solid components were put together and added to the Ansys software using an interference detection tool. Segments of cancellous and compact bone were initially fused together inside. Second, for each model, a computer guide stent was imported and properly placed on a compact bone. Thirdly, using the guide stent holes, implants were imported and positioned into each model at the appropriate angle and bone level. The implants were Boolean subtracted from cancellous and compact bone to produce optimal osteotomies. The anterior implants were placed in the lateral-canine region in a bilateral and vertical configuration.

Posterior implants were positioned at the second premolar area with a 17-degree distal angulation. All of these had multi-unit abutments. Two frameworks were obtained that was categorized as following: **Model A:** Titanium framework and **Model B:** Cobalt chromium framework. Following proper placement of the framework within the internal connection of the implant, an acrylic prosthesis with anatomical acrylic teeth was placed over it. The finished model was eventually created by tightening it with the screw components. (Figure 1).

Determining the contact conditions

It was assumed that every contacting structure had complete contact at the interface. The type of contact between the components was defined by the "contact/Gap" attribute. Either "bonded" or "slip (no penetration)" connections were used to describe the contacts.

Bonded contact interface: The cortical and cancellous bony parts, the metal framework and gingiva, and the implant and bony components were found to be in contact with one another in this manner.

Slip (no penetration) contact interface: The retaining screw complex, the metal framework, and the implant made this type of contact. (Figure 2).

Determining loads and restraints

By applying 30 Ncm of tightening stress at the implant interface, all of the screws were first tightened to the implants using the "Bolt connector" feature.

The prosthesis was loaded on each model by applying 50 N to each premolar and 100 N vertically and obliquely (45 °mesio-distally) on the central fossae of the first molar. (Figure 3 and 4).

Data collecting and analysis operations

An iterative technique was employed in the finite element analysis to calculate the displacements, stresses, and strains. The maximum equivalent stresses, or von Misses stresses, were provided by

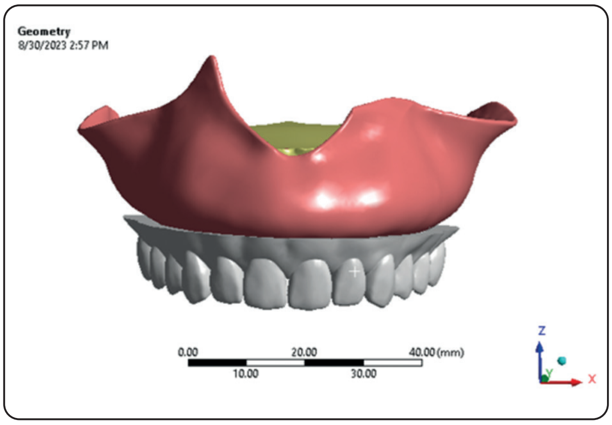


Fig. (1): The maxillary model with the prosthesis assembly, framework, and implants in place.

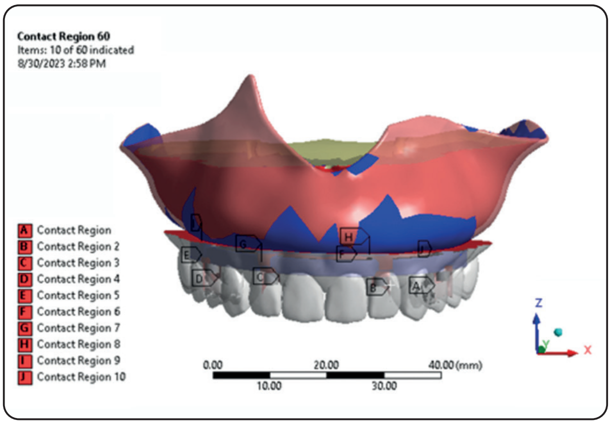


Fig. (2): The bonded and slip contact interfaces for the maxillary model.

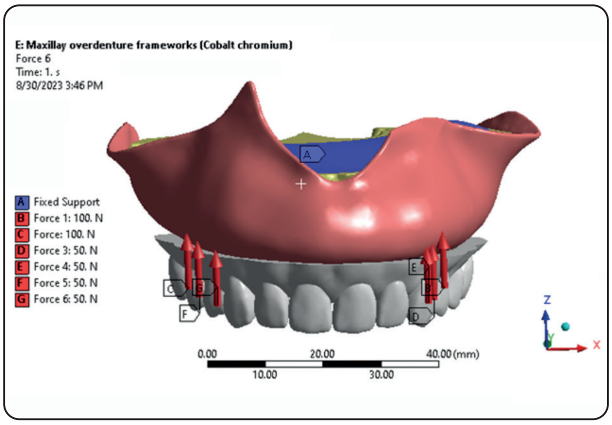


Fig. (3): Vertical loading in each model: 50 N on each premolar (D - G) and 100 N on the central fossae of the first molar (B - C), bilaterally.

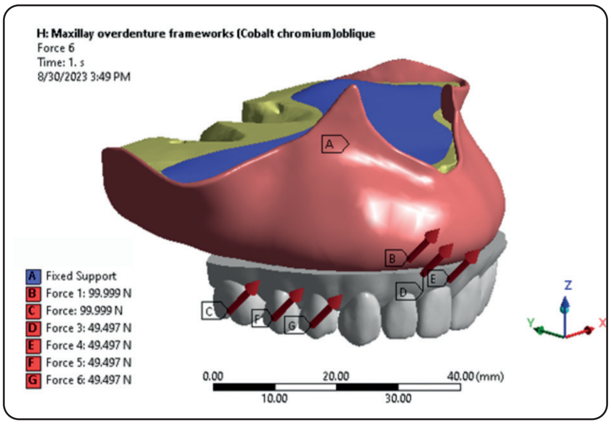


Fig. (4): Oblique loading in each model: 50 N on each premolar (D - G) and 100 N on the central fossae of the first molar (B - C), bilaterally.

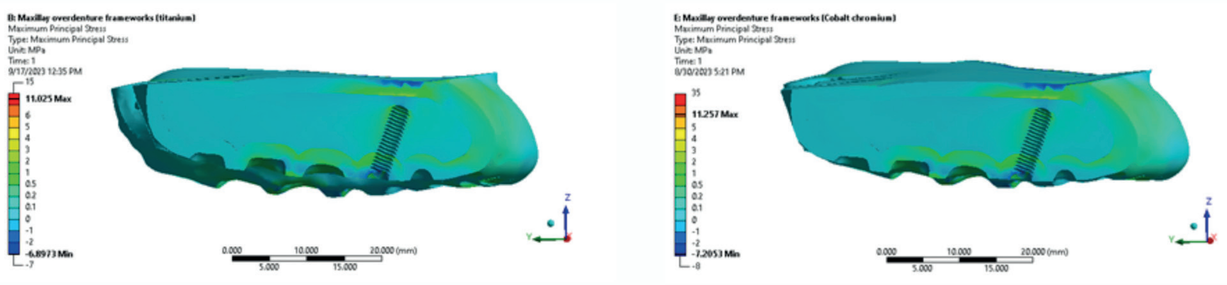
the multi-unit abutments and the various zones of the implant after the analysis procedure was completed. The maximum principal stresses on the peri-implant bone of each model were identified. The results were then totaled and compared after that.

RESULTS

The stresses in the nodes of each model were determined using Finite Element Analysis (FEA). To illustrate these conclusions, the original model's stress contours were added. The models computed numerical data for stress, deformation, and safety factor, which were then used to create color visuals. The numerical values for the stress, deformation, and safety factor are presented using the color coding of the appropriate conditions. (Figure 5 and 6). Using the two different frameworks, cobalt-chromium and titanium, the von Mises stress, maximal principal stress, and directional deformation were assessed for each model. The following formula accustomed to determine von Mises stress: (S1-S2)2+ (S2-S3)2+ (S3-S1)2 is equal to 2Se2. where Se is the equivalent stress, or "von Mises Stress," and S1, S2, and S3 are the main stresses. The measurement of the maximum principal stress (peri-implant bone) was almost similar in both frameworks under axial & oblique loadings, Von Misses stresses on framework itself was significantly greater in cobalt chromium framework under axial & oblique loadings. This is presented in Table (1).

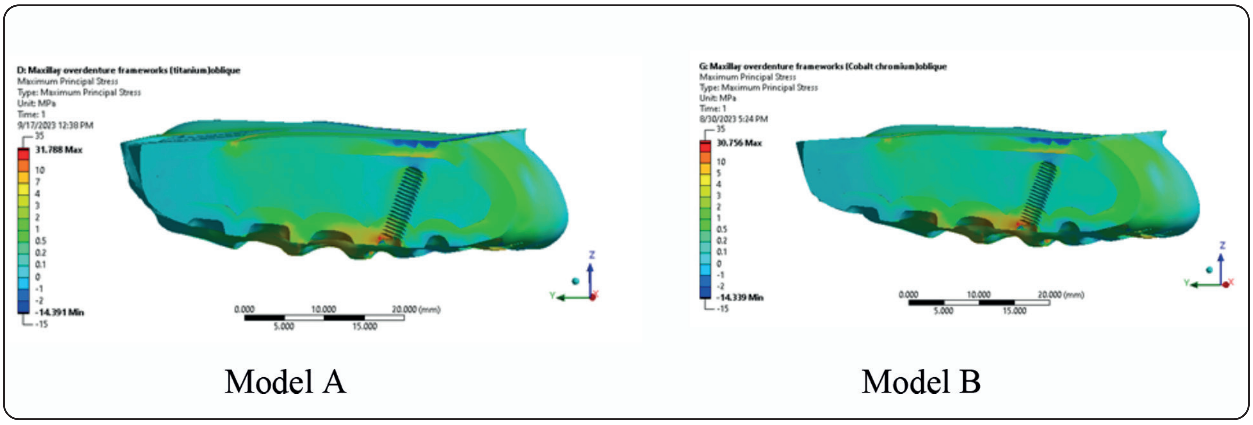
TABLE (1) Von misses stresses on framework, Considering both models, the maximum principal stresses on the bone and the direction of deformation of the bolts under axial and oblique loading.

		Maximum Principal Stresses On Bone (Mpa)	Von Misses (VM) streeses on framework (MPa)	Directional deformation of bolts (microns)
MODEL BASED ON THE FRAMEWORK MATERIAL			**Under Axial Loading**	
	MODEL A-TITANIUM	11.025	95.272	4
	MODEL B-COBALT CHROMIUM	11.257	137.06	4
			Under Oblique Loading	
	MODEL A-TITANIUM	31.788	144.45	4
	MODEL B-COBALT CHROMIUM	30.756	182.64	4



Model A Model B

Fig. (5) Maximum principal stresses in peri-implant bone below axial loading A: Titanium framework, B: Cobalt chromium framework



Model A

Model B

Fig. (6) Maximum principal stresses in peri-implant bone under oblique loading A: Titanium framework, B: Cobalt chromium framework

Von-Misses stresses on the anterior and posterior multi-unit abutments and the anterior and posterior implants for the two models.

Upon applying axial loading to the cobalt chromium and titanium frameworks. Von Misses stresses on the anterior implants for the cobalt-chromium and titanium frameworks were extremely similar. Also results were similar for both frameworks' posterior implant stresses. Von Misses's analysis of the multi-unit abutments under axial loading showed that, for both the titanium and cobalt chromium frameworks, the anterior abutment stresses were nearly equal, with the cobalt chromium framework exhibiting slightly higher stress. Conversely, the posterior multi-unit abutments demonstrated higher stresses under axial loading in case of titanium. This was presented in Table (2).

The Von Misses stresses on the posterior implants were quite similar for the titanium and cobalt chromium frameworks under oblique loading, with the titanium framework exhibiting somewhat higher stress. For anterior implant stresses, the outcomes from both frameworks were remarkably similar. The Von Misses stresses on the multi-unit abutments revealed that, under oblique loading, the cobalt-chromium framework had slightly higher stresses on the anterior abutments, while the titanium framework had greater stresses on the posterior multi-unit abutments. This is presented in Table (3).

TABLE (2) The multi-unit abutments and implants' Von Misses stresses (MPa) (right and left) in both models under axial loading

AXIAL LOADING		**TITANIUM FRAMEWORK (MODEL A)**	**COBALT CHROMIUM FRAMEWORK (MODEL B)**
POSTERIOR IMPLANT	Right (R)	56.534	57.693
	Left (L)	31.638	31.999
ANTERIOR IMPLANT	Right (R)	6.785	6.753
	Left (L)	9.611	9.524
POSTERIOR MULTI-UNIT ABUTMENT	Right (R)	124.61	113.06
	Left (L)	143.18	112.75
ANTERIOR MULTI-UNIT ABUTMENT	Right (R)	9.514	10.974
	Left (L)	12.474	15.359

TABLE (3) The multi-unit abutments and implants' Von Misses stresses (MPa) (right and left) in both models under oblique loading

Oblique Loading		**Titanium Framework (Model A)**	**Cobalt chromium Framework (Model B)**
Posterior implant	Right (R)	85.267	83.902
	Left (L)	88.058	86.557
Anterior implant	Right (R)	28.23	28.829
	Left (L)	36.786	37.612
Posterior Multi-unit abutment	Right (R)	148.04	133.58
	Left (L)	131.62	111.99
Anterior Multi-unit abutment	Right (R)	47.92	49.232
	Left (L)	71.881	78.082

DISCUSSION

It is imperative that in vitro research be conducted, particularly to investigate the strain and stress that implants and surrounding bone experience under varying loads. This is done to identify risk factors that could affect the outcome of osseointegration. Finite Element Analysis (FEA) would measure the stress, strain, and implant displacement, superstructures, and nearby bone. This study's objective is to examine the peri-implant stresses for a maxillary all-on-four prosthesis between titanium and cobalt-chromium frameworks. Since stress analysis is crucial to regulating all the variables involved in successful osseointegration, finite element analysis (FEA) was utilized (8).

The stress and strain analysis would be significantly affected by the material properties of implant fixtures, abutments, and restorations. These characteristics would be demonstrated by FEA as orthotropic, transversely isotropic, which anisotropic, and isotropic. To enable a FEA to produce results that are clinically applicable, interface, loading conditions, and material properties need to be taken into account because they have an impact on accuracy. As a result, it was believed that the material's characteristics were isotropic, linear, and homogeneous(9). One of the most important FEA considerations is the bone to implant interface(10). FEA software comes with a variety of contact algorithms that can mimic different sorts of real-world implant to bone contacts. The implant bone interface can be described by the bonded contact type, which is the no separation contact type, and the frictionless contact type (11).

The Von Mises criterion, known as VMS, is a method to predict failure in ductile materials under complex stress. It evaluates stresses in various directions within a body, comparing them to the material's yield strength to determine potential failure. This criterion is commonly applied in assessing stresses on components like MU-Abutments and implants to ensure structural integrity and reliability. In both in vitro and in vivo settings, the FEA is a useful method for studying non-standard conditions. The validity of FEA would depend on how closely the geometry, material properties, interface state, support, and loading accurately reflected reality. Because the values obtained from FEA stress analysis are variances resulting from non-mathematical calculations, no statistical analysis are performed (12).

Comparing Von misses stresses between the posterior and anterior implants with both frameworks, the posterior implants that were installed at the 17 degree angle showed slightly greater stresses than the anterior implants. Tilting of implant would increase the stresses directed towards the implant. When comparing a maxillary all-on-four configuration with posterior implants inserted at 15 degrees and 30 degrees, Sannino et al. (2015) found that while distal implant loading and tilting will enhance the peri implant bone stresses, there was no change related to Von Misses stresses. Stress levels at the bone–implant contact increased when posterior implants were put at a 45-degree angle(13). Furthermore, the maximum stress values were always located distally when implants are tilted.

When implants are connected by a framework in implant-supported restorations, it reduces implant bending and improves stress distribution. This explains why stresses on multiunit abutments are similar for posterior and anterior implants. By reducing cantilever length and increasing inter-implant distance, tilting these splinted implants enhances load distribution and offers a reliable treatment method. (14, 15).

In order to determine the maximum and minimum principle stresses for bone tissues and compare them with the tensile and compressive strengths, the principal stress failure hypothesis was utilized (16). For normal-density cortical bone, the allowable tensile and compressive limits are 66.6 & 93.3 MPa when using a 1.5 safety factor. The allowable limits for compressive and tensile strength for spongy bone exhibit a similar tendency in both groups when it comes to the peri-implant bone. Model B recorded maximum principal stress under axial loading of (11.257 MPa), While Model A recorded maximum principal stress of (11.025 MPa). Under oblique loading, Model B recorded 30.756 MPa, whereas Model A recorded 31.788 MPa. This clearly shows that in both cases, the maximum principal stresses of the cortical bone did not exceed the allowed limits. The Von Misses stresses comparison between the titanium and Cobalt chromium frameworks revealed similar recorded stresses under axial and oblique loadings. In comparison to Model B, Model A only registered higher stresses for the multi-unit abutments on the posterior side.

CONCLUSION

It is possible to reach the following conclusions regarding All-in-four implant-supported fixed maxillary prosthesis with 17° angulated distal (posterior) implants, taking into account the limitations of this in vitro study:

1. Titanium and Cobalt chromium frameworks have resulted in very similar behavior in the superstructure, peri-implant bone, implants and anterior multi-unit abutments stresses under axial and oblique loadings.
2. Cobalt chromium showed higher stress transmitted to the framework itself under axial and oblique loading.
3. Stresses under oblique loading & axial loading were greater for the posterior multi-unit abutments in case of titanium framework over cobalt chromium framework.
4. Posterior implants installed at 17 degrees showed higher Von misses stress compared to the anterior implants when using the titanium and Cobalt chromium frameworks.

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