Evaluation of stress generated with different attachment framework materials (cobalt chromium & zirconia) on multi-unit abutment in case of distally inclined implants in all on four concept under vertical loading for fully edentulous patients regarding the maxilla :In vitro study Three-Dimensional Finite Element Analysis

Abdulaziz Abdulrahman Ahmed Abdellah [1], Doaa El kady[2], Mohamed Farouk[3],

Nouran Abdel nabi[4]

1. **Department of Oral Implantology, Faculty of Dentistry, Cairo University.**

4 . lecturer department of prosthodontics -faculty of dentistry -Cairo University

2. professor in department of prosthodontics -faculty of dentistry -Cairo University.

3. professor in department of prosthodontics -faculty of dentistry -Cairo University.

Received:26-6 -2023 Accepted : 11/7/2023 Published : 4 /8/2023

ABSTRACT

Aim: To evaluate peri-implant stresses generated using finite element analysis for cobalt chromium and zirconium frameworks for a maxillary all on four prostheses.

Material and methods: Three-dimensional finite element models of an edentulous maxilla restored with a prosthesis supported by 4 implants were reconstructed to carry out this analysis. The anterior implants were placed vertically and bilaterally in the lateral-canine area, whereas the posterior implants were placed with a 17-degree distal angulation at the second premolar area. Multi-unit abutments were used for all implants. A framework of the first model made of zirconia was designed, while for the second model a cobalt-chromium framework was planned.

Results: The Von Mises stress of the posterior implant and multi-unit abutment was greater than anterior implants when using both frameworks.

The von miss stresses on the co-cr framework was 134.93MPa , compared to 131.88 Mpa for zirconia framework . Both framework showed very similar in von misses stresses.

Conclusion:

The use of either cobalt chromium or zirconium frameworks with an all on four prosthesis for the edentulous maxilla is considered to be a reliable treatment option.

INTRODUCTION

Implant-retained over-dentures have solved most of the problems of conventional complete dentures. Implant retained overdentures are significantly more stable, retentive and comfortable, with improved chewing ability that has impact on the patients quality of life and satisfaction **(Maheshwari, R., Hans. et al. 2016).**

The implant supported fixed prosthesis would have advantages of the maintenance of alveolar bone, Improve and preserve facial esthetics, and prevent food entrapment also improvement of patient bitting forcevalso improve phonetic, stability, retention and psychological health **(Resnik, R. 2020).**

When using the all-on-four concept the multi-unit abutment is always the abutment of choice. **(Kan J.Y.K., Rungcharassaeng K., Bohsali K. et al 1999) (Sahin S., Çehreli M.C. 2001).** The multi-unit abutment is selected when there is inadequate interocclusal space for the prosthetic restoration **(Wadhwani C .2016 ; Gervais M.J., Hatzipanagiotis. et al 2008).** Inaddition to that it is used for various soft tissue anatomies – both straight and angled 0°, 17°, 30° and 45° they are also available in several different collar heights.

Implant supported frameworks

Metal alloys are the most commonly used materials for implant-supported models. In dentistry, metals that are pure such as gold and platinum foil are present, but alloys, which are composed of combinations of two or more metals with a nonmetal. To reduce, several alternatives to gold have been proposed, which includes alloys of high noble and base metals, as well as titanium, both commercially pure (CP) and titanium alloys. Recently, cobalt-chrome alloys have become the most commonly used, due to their favorable positive mechanical characteristics, which aesthetic outcome is considered when dental porcelain is used to cover the frameworks.

- **Multi Unit Abutments:**

A multi-unit abutment (MUA) is a type of abutment that is most typically used with dental implants in "All-on-Four" technique. They are designed for screw-retained group restorations, which are frequently used in combination with tilted implants and full arch prosthesis, also fixation screw of zirconia or metal-ceramic bridges restorations to the implant (**Byrne, G. 2014)**

Brosh T, Pilo R, Sudai (1998) In an invitro study, strain gauges and the photo elastic method were used to compare the stress distributions of pre-angled as well as straight abutments. Straight abutments of fifteen and twenty-five degrees have been attached to each implant, and the stress distribution was determined. Compressive strain was found to be three times and 4.4-fold higher in fifteen degree and 25 degree angulated abutments when compared to standard abutments.

Sethi A, Kaus T, Sochor P (2000) performed a study with a total of 2,261 implants with angled abutments were studied for up to 96 months, implant groups with abutments angled 0 to 15 degrees and 20 to 45 degrees were compared. The results of this study revealed that there were no differences in implant survival based on the use of the angle abutments ranging from 0 to 45 degrees. The use of angled abutments resulted in good aesthetic and functional outcomes without affecting the implants' long-term survival.

Both types of retention have been used for single, multiple, and cross-arch fixed dental restoration. Long span prostheses should typically have a screw retained for ease of maintenance; long span restoration have also been discussed in the scientific literature as having a higher risk of complications. **(Salvi & Bragger 2009; Shadid R 2012)**. This should also apply to cantilevered FDP designs since they require more maintenance and service. **(Agljetta et al,. 2009; chee & Jivraj 2006).** It may also be less difficult to achieve sufficient retention to compensate for the extension's cantilever.

1. Finite element analysis

The finite element analysis test is a computerized numerical method based on discretization. The method involved breaking up a continuous area into a number of straightforward shapes or components and connecting them at corner points (or "nodes") to one another. The set that results is referred to as the mesh, and it can be examined using software. **(Geng, J. P., et al. 2001).**

Advantages of finite element analysis:

It include excellent handling complex geometry and restrains as well as simulation of biological conditions to achieve reliable results, non-invasive stress analysis technique ,static load has a constant magnitude with respect to time, the study can be repeated as several times without the need for expensive equipment or a lot of time, dynamic loading is variable producing displacement and or changes in velocity either in the form of acceleration or deceleration which provides a more realistic masticatory function and finally that

Disadvantages of finite element analysis:

Because of their complexity and a lack of knowledge about their mechanical behaviour, modelling human structures is very challenging, certain assumptions are made such as the body to be modeled is homogenous and isotropic and their recallability depend on the personal involved in the process. Finite element analysis software needs good experience and judgment to construct accurate finite element analysis models, Powerful computer and reliable finite element analysis software are also required, susceptible to user introduced modeling errors like improper choice of boundary conditions, elements and nodes. **(Himmlova et al., 2004) (Chang et al., 2018).**

MATERIALS AND METHODS:

Pico:

P: 3Dsimulation of edentulous maxilla restored with all on four Implant supported prosthesis.

I: 3Dsimulation of edentulous maxilla restored with all on four Implant supportedprosthesis with zirconium framework.

C: 3Dsimulation of edentulous maxilla restored with all on four Implant supported prosthesis with Cobalt chromium framework.

O: Primary outcome: stresses induced in peri-implant bone.
Secondary outcome: Stress induced in the abutment screw.

A 3D surface model of the maxillary jaw was created using Materialise MIMICS software by using a cone beam computerised tomography (CBCT) image of a human with an edentulous maxilla. Thresholding enabled the segmentation of anatomical structures. Bones that are cancellous and compact were taken into consideration in this study. An STL binary file containing the 3D reconstruction was exported. (Fig 1)

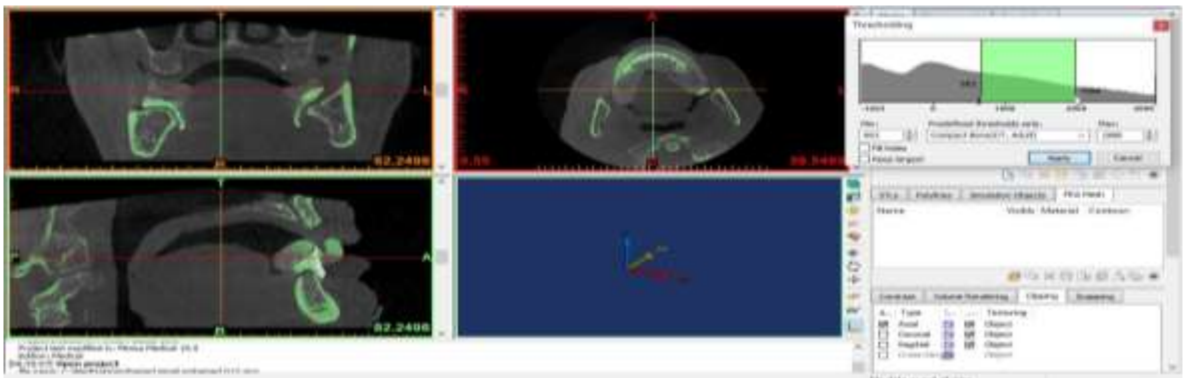


Figure (1): Segmentation of anatomical structures of an edentulous maxilla to generate a 3D surface model

Bio-CAD modeling

The STL Reverse Engineering The cancellous and compact bone were mentioned as a result of the MIMICS-based CT image segmentation approach, which produced 2 STL models. These STLs was imported into **3-Matic Medical 11.0 (x64)** [1] for further smoothening and exported as STL format. Further more imported to **Geomagic Design x**[2] software for reverse engineering and exported as solid parts ready for Boolean substraction and assembly in **Ansys finite**[3] element analysis software.

Three- dimensional modeling of Implants and screws.

A 4.1 mm diameter implant with 10 mm length **Zimmer implant**[4] was exported from **Blueskybio software**[5] implant library as STL file extension, creating a bridge between the outer and inner shell of the implant body, creating threads inside the implant body to accommodate a screw with the same dimensions and thread design then it was converted to a solid. The screw

[1]. Materialise, Leuven, Belgium

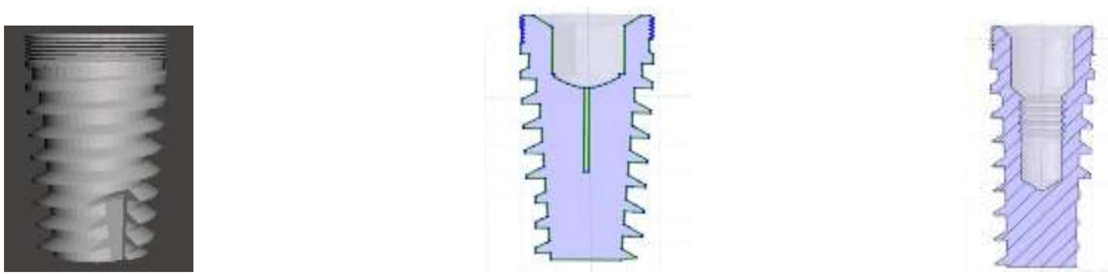
[2] Geomagic Design x, Senningerberg ,LUXEMBOURG**.**

[3] Ansys finite, Canonsburg ,USA.

[4] zimmer implant , Warsaw, Indiana, USA.

[5] Blueskybio software,USA.

was drowned inside **Solidworks software 2016** [6] and exported as a solid file (Fig 2),A,B and C)



A **B** **C**

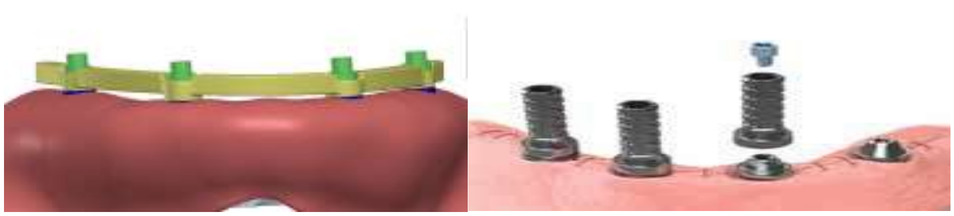
Figure (2): A: Zimmer implant, **B:** Cross section before solid conversion, **C:** Cross section after solid conversion & thread incorporation

Assembling the components

All solid parts were imported and assembled in Ansys software and checked for interference-by-interference detection tool. Firstly, Compact and cancellous bone parts were assembled inside each other. Secondly, computer guide stent for each model was imported and seated correctly on compact bone. Thirdly, implants were imported and inserted through the guide stent holes into their correct position with bone level and with correct angle for each model. After that a Boolean subtraction of the implants from compact and cancellous bone was carried out to make osteotomies perfectly.

Four inter-foraminal implants were installed in both models, the anterior implants were installed vertically in the lateral-canine area bilaterally, while the posterior implants were installed with a 17-degree distal angulation at the second premolar region. Multi-unit abutments were used for all implants for both models. A framework made of zirconia was designed for the first model, while for the second model a cobalt-chromium framework was planned (Fig 3).

The multi-unit abutment, a temporary abutment was screwed. And a framework was then designed to splint all of the temporary abutments, Then the acrylic denture base with the teeth was then cemented to form a screw- retained prosthesis.



[6] solidworks software 2016, Waltham, USA.

Figure (3): showing the four installed implants with the distal implants angulated at 17 degree, and the framework splinting all of the implants through the multi-unit abutments.

The constructed framework was designed and was seated in their correct position inside the implant internal connection and then covered with the acrylic prosthesis which consisted of acrylic flanges and acrylic teeth were set on top. Finally tightened with the screw parts to form the final model (Fig 4).

Figure (4): The full Maxillary, installed implants and 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. The contacts were defined either as "bonded" or "slip (no penetration)" contacts (Fig 5).

Bonded contact interface: This type of contact was defined between: The cortical and cancellous bony parts, the bony parts and implant, and the metal framework and gingiva.

Slip (no penetration) contact interface: This type of contact was defined between: the implant, metal framework and the retaining screw complex (Fig 5).

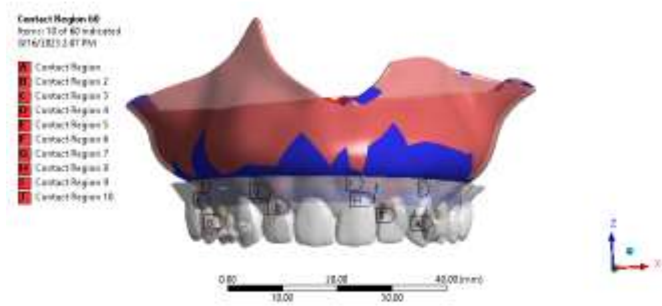


Figure (5): showing the bonded and slip contact interface for the designed framework with the acrylic prosthesis on top.

Meshing

Each model was divided during this process into tiny pieces called elements that were joined at points called nodes to form a mesh structure. A fine solid mesh was created using solid elements that are parabolic tetrahedral. A Simple unstructured tetrahedral mesh generation was specially performed for complex geometries was used, with variable mesh density lower than 0.2 mm element size around the implants and the peri-implant bone and widening and with higher mesh density away from the interes, with a tolerance value of 0.045 and a global element size of 0.9 mm.

The total number of elements and nodes for each framework is listed in Table 1.

For file size reduction and decreasing the time required for solving and running the analysis e differential meshing was carried out by reducing the mesh size around implants and the peri implant bone and widening the mesh size away from the area of interes.

Table (1): The sum of the elements and nodes for the zirconium framework, and cobalt chromium framework.

Model	Element	Node
Maxillary frameworks (Zirconium)	955726	1562020
Maxillary frameworks (Cobalt chromium)	955980	1562820

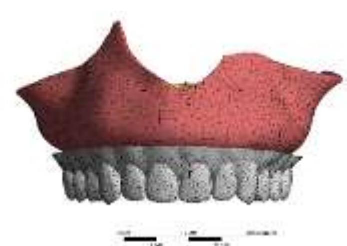
Defining the material properties

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 Table 2, Fig 6.

Table (2): Showing the ultimate strength, yield strength, compressive strength, flexible modulus, and dense Poisson's ratio, cancellous bone, gingiva, and both frameworks used ; Cobalt-Chromium and Zirconium.

Material	Modulus of elasticity	Poisson's ratio
Compact bone	13700 MPa	0.3
Cancellous bone	7930 MPa	0.3
Gingiva	680 MPa	0.45
Cobalt-chromium alloy	200000 Mpa	0.29
Zirconium	200000 Mpa	0.3
Ti-6Al-4V alloy (Implant , Abutment and screw)	107200 Mpa	0.3
Acrylic resin (denture base)	3000 MPa	0.30

A



B

Figure (6): Showing the maxillary all on four A) maxillary framework, B) Maxillary prosthesis after meshing

Defining loads and restraints

Initially all the screws were tightened to the implants by applying 30 Ncm tightening torque at the implant restoration interface through 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 load bilaterally on the central fossae of the posterior teeth on the 1^{st} molar and 50 N on the two premolars, for each model (Fig 7).

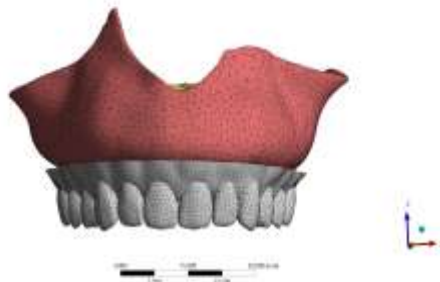


Figure (7): Showing a 100 N vertical load bilaterally on the central fossae of the posterior teeth on the 1st molar and 50 N on the two premolars, for each model.

Running of the analysis and collection of data

After meshing the analysis was performed using an iterative method to compute the stresses, strains and displacements. After termination of the analysis procedure, the maximum equivalent stresses (von Misses stresses) were collected from the different zones of the implant and Multiunit-abutments while on the other hand Maximum principal stresses on the peri-implant bone of each model. The results were then tabulated, and compared.

RESULTS:

Stresses were found in each model's nodes using Finite Element Analysis (FEA). These findings were represented by stress contours superimposed on the original model. Colour graphics were created from the calculated numerical data for stress, deformation, and safety factor in the models. The colour coding for the appropriate conditions is used to present the numerical values for the stress, deformation, and safety factor.

The von Mises stress, Maximum principal stress and Directional deformation were all recorded for each model using the two different frameworks: Zirconium and Cobalt- Chromium.

Von Mises stress was calculated using $(S1-S2)^2+ (S2-S3)^2+ (S3-S1)^2= 2Se^2$ Where S1, S2 and S3 are the principal stresses and Se is the equivalent stress, or "von Mises Stress".

Maximum Principal Stress was used to measure Peri-implant Bone.

Directional deformation: The assembly's screws' internal and external deformations can be calculated. It was used to determine the micro motions on the screws inside the abutment in order to estimate screw loosening.

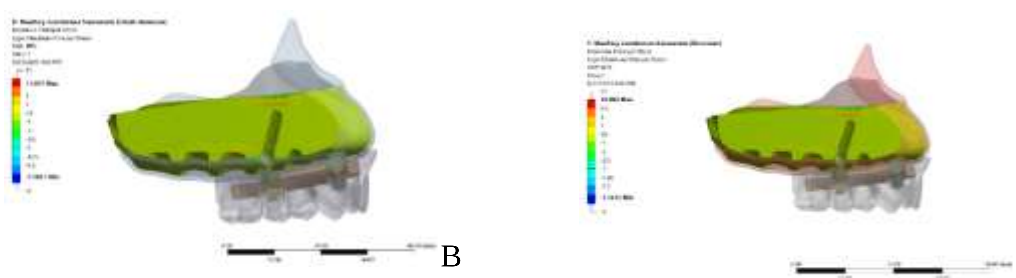
Table (3): showing the Von Misses (VM) stresses on the screw retained prosthesis and implants, and the Maximum principal stresses on bone and the Directional deformation of the bolts for both the zirconium and the cobalt chromium framework.

Case		Von Misses (VM) stresses on screw retained Prosthesis Mpa)	Von Misses (VM) stresses on Framework Mpa)	Maximum principal stresses on bone (Mpa)	VM Stresses implant (Mpa)	Directional deformation of bolts (microns)
Material of the frameworks	**Zirconium**	16.255	131.88	10.983	28.495	4
	Cobalt chromium	16.287	134.93	11	28.293	4

Deformation was calculated in the world coordinate system relative to the part or assembly. $U^2 = (Ux^2 + Uy^2 + Uz^2)$ Ux, Uy and Uz are the three components of Deformation.

- Maximum Stresses and micro-motion upon the two models (MPa Microns):

When comparing the VM stresses recorded on the screw retained prosthesis and the bone between the zirconium and cobalt chromium framework, the stresses were very close to each other zirconium framework recorded 131.88 Mpa stresses over the prosthesis compared to 134.93 Mpa stresses recorded by the cobalt chromium. Similarly, to the VM stresses recorded by the implants (Table 3). Regarding the maximum principal stresses, it was nearly equally for the zirconium framework (10.983 Mpa), and the Cobalt chromium framework (11 Mpa) (Table 3). The directional deformation was equal for both frameworks (Table 3) (Fig 8).



A B

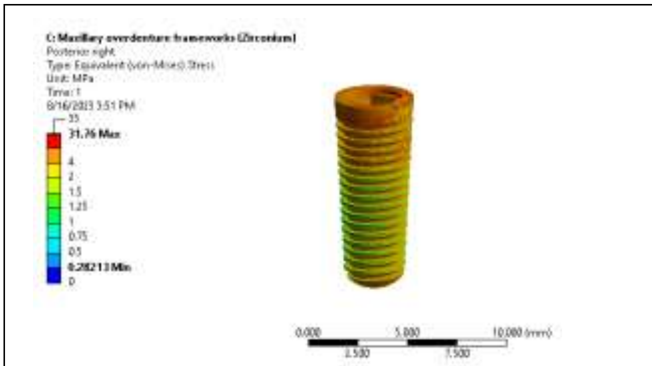
Figure (8): showing Maximum principal stresses on bone
A: Zirconium frame work, **B:** Cobalt chromium framework

Von-Misses stresses on Posterior and Anterior implants and Multi-unit abutments for the Zirconium framework (MPa)

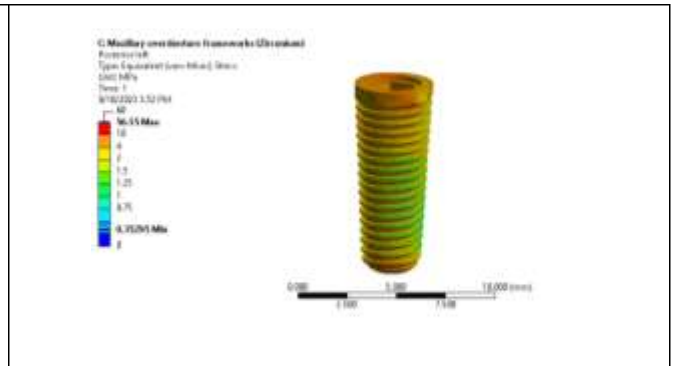
Table (4): showing the Von Misses stresses (Mpa) on the implants and Multi-unit abutments recorded by the Zirconium frameworks for the right and left implants.

		Implant	Multi-unit-Abutment
Posterior	Right (R)	31.76	115.23
	Left (L)	56.55	111.9
Anterior	Right (R)	9.501	14.948
	Left (L)	6.601	10.697

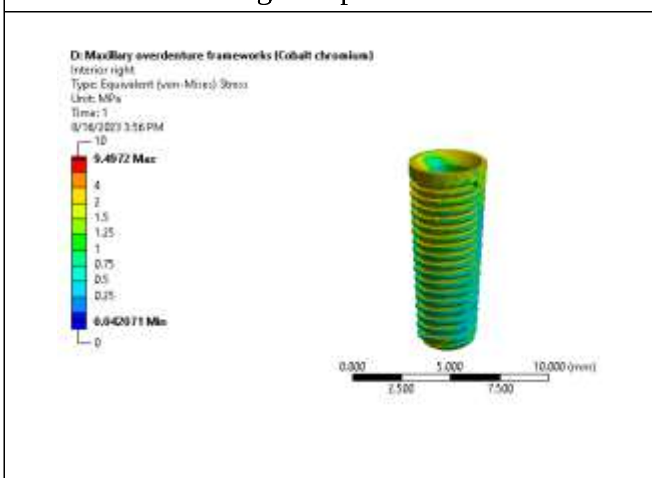
When comparing between the Von Misses stresses on the implants and abutments for the maxillary zirconium frameworks it was found that the posterior left implant (56.55 Mpa) recorded higher stresses than the right implant (31.76 Mpa), while the stresses on the posterior abutments were nearly similar with the right abutment recording slightly higher stresses than the left (Table 4). While for the anterior implants the right implant recorded higher stresses (9.5 Mpa) compared with the left implant (6.6 Mpa) (Table 4). The right and left anterior abutments recorded stresses very close to each other with the right abutment recording slightly higher stresses than the left (Table 4) (Fig 9). The posterior implant showed higher VM stresses (R=31.7Mpa, L=56.5 Mpa) when compared to the anterior implants (R=9.5, L=6.6 Mpa) (Table 4). The posterior multi-unit abutments showed slightly greater VM stresses compared to the anterior (Table 4).

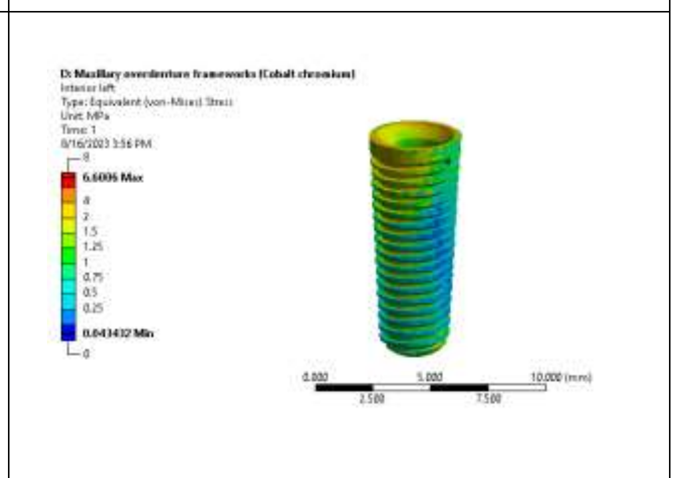


A. Posterior Right Implant



B. Posterior Left Implant





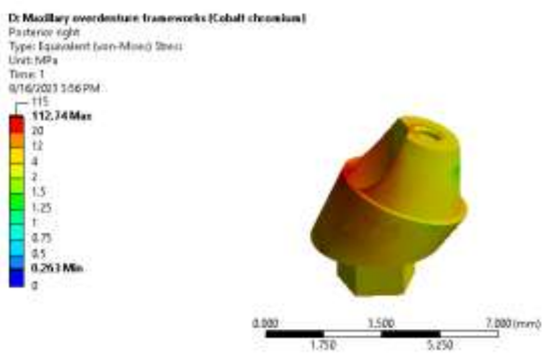
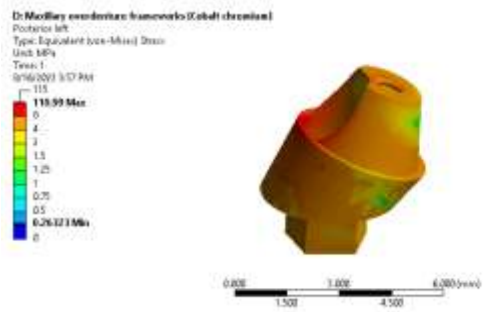
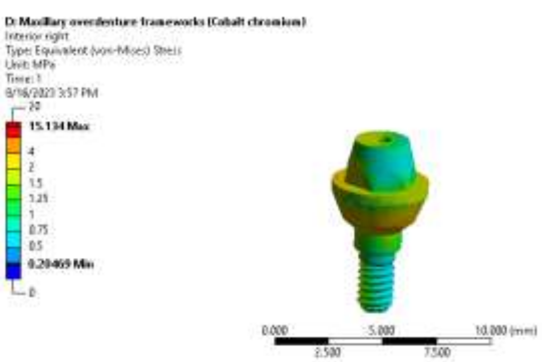
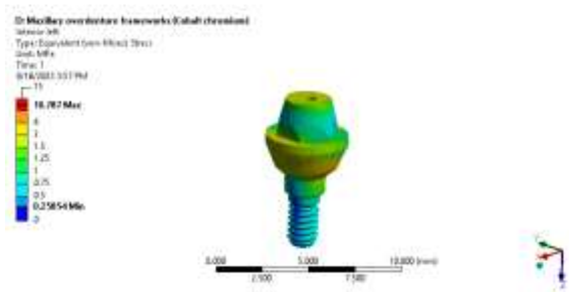
C. Anterior Right Implant	D. Anterior Left Implant
	
E. Posterior Right Multi-unit abutment	F. Posterior Left Multi-unit abutment
	
G. Anterior Right Multi-unit abutment	H. Anterior Left Multi-unit abutment

Figure (9): Showing Von Misses stresses on the posterior and anterior implant and abutments Right and Left for zirconium framework; A: Posterior Right Implant , B: Posterior Left Implant, C= Anterior Right Implant, D: Anterior Left Implant, E: Posterior Right Multi-unit abutment, F: Posterior Left Multi-unit abutment, G: Anterior Right Multi-unit abutment, H: Anterior Left Multi-unit abutment

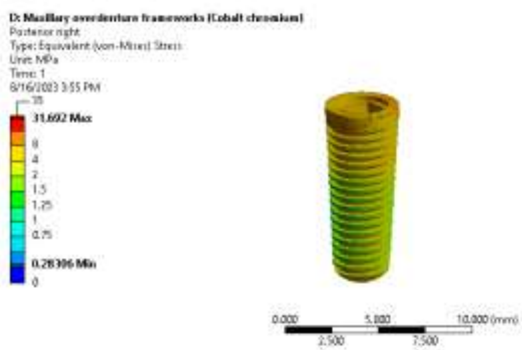
Table (5): showing the Von Misses stresses (Mpa) on the implants and abutments recorded by the Cobalt-chromium frameworks for the right and left implants.

		Implant	Abutment
Posterior	Right (R)	31.692	112.74
	Left (L)	56.641	110.99
Anterior	Right (R)	9.497	15.134

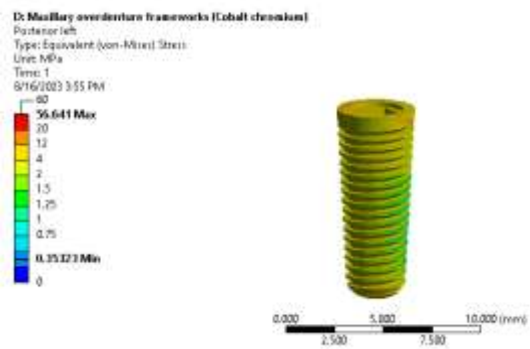
	Left (L)	6.6	10.787

Regarding the Cobalt chromium framework, the posterior left implant recorded higher stresses (56.64 Mpa) compared to the right implant (31.69Mpa) (Table 5). While the stresses on the posterior abutments were nearly similar to the right abutment, the right recorded slightly higher stresses than the left implant (Table 5).

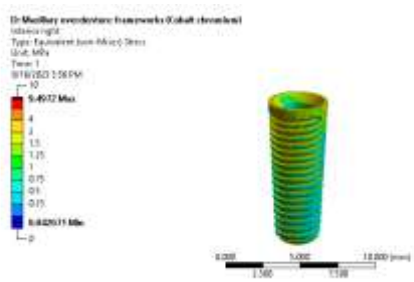
While for the anterior implants the right implant recorded higher stresses (9.497 Mpa) compared with the left implant (6.6 Mpa) (Table 5). The right and left anterior abutments recorded stresses very close to each other with the right abutment recording slightly higher stresses than the left (Table 5). The posterior implant showed higher VM stresses (R=31.6Mpa, L=56.64 Mpa) when compared to the anterior implants (R=9.49, L=6.6 Mpa) (Table 5). The posterior multi-unit abutments showed slightly greater VM stresses compared to the anterior (Table 5) (Fig 10).



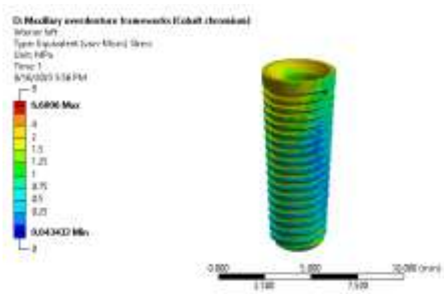
A. Posterior Right Implant



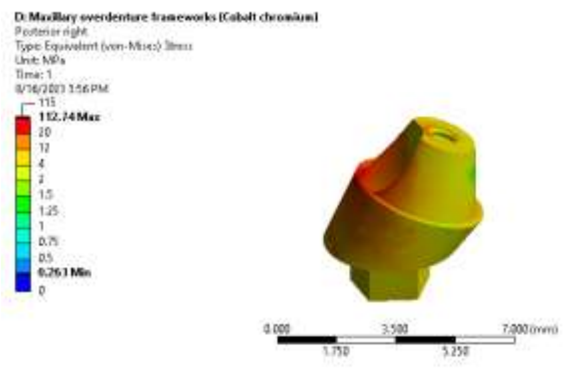
B. Posterior Left Implant



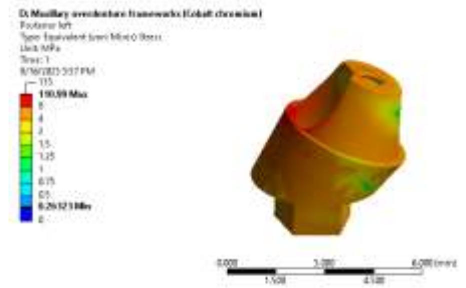
C. Anterior Right Implant



D. Anterior Left Implant

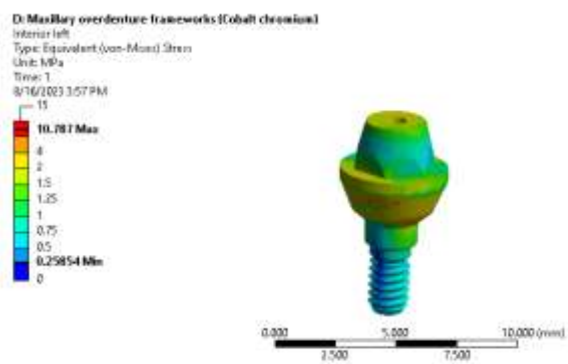


E. Posterior Right Multi-unit abutment



F. Posterior Left Multi-unit abutment

G. Anterior Right Multi-unit abutment



H. Anterior Left Multi-unit abutment

Figure 10: Showing Von Misses stresses on the posterior and anterior implant and abutments Right and Left for Cobalt-chromium framework; A: Posterior Right Implant , B: Posterior Left Implant, C= Anterior Right Implant, D: Anterior Left Implant, E: Posterior Right Multi-unit abutment, F: Posterior Left Multi-unit abutment, G: Anterior Right Multi-unit abutment, H: Anterior Left Multi-unit abutment.

A comparison of the Von misses stresses (Mpa) between the zirconium and cobalt chromium framework for the posterior and anterior implant and abutments, Right (R) and Left (L).

Table (6): The Von misses stresses (Mpa) between the zirconium and cobalt chromium framework for the posterior and anterior implant and Multi-unit abutments, Right (R) and Left (L).

		Zirconium Framework	Cobalt chromium Framework
Posterior implant	Right (R)	31.76	31.692
	Left (L)	56.55	56.641
Anterior implant	Right (R)	9.501	9.497
	Left (L)	6.601	6.6
Posterior Multi-unit abutment	Right (R)	115.23	112.74
	Left (L)	111.9	110.99
Anterior Multi-unit abutment	Right (R)	14.948	15.134
	Left (L)	10.697	10.787

When comparing the Von Misses stresses on the implants between the zirconium and Cobalt chromium framework, the right and left implants showed very similar stresses, with the Von Misses stresses on the zirconium framework (L=56.55 Mpa, R=31.76Mpa) slightly greater than the Cobalt chromium framework (L=56.64 Mpa, R=31.69 Mpa) (Table 6). While for stresses on anterior implants were similar for both frameworks (Table 6).

Regarding the Von misses stresses on the Multi-unit abutments, the stresses on the posterior and anterior abutments for both zirconium and Cobalt chromium frameworks very similar to each other (Table 6).

References

Maheshwari, R., Hans, S., Mittal, S., Aneja, S. & Duhan, J. (2016). Implant Supported Mandibular Overdenture with Bilateral Balanced Occlusion : A Case Report. 9, 0–3 .

Resnik, R. (2020). Misch's contemporary implant dentistry. Elsevier Health Sciences.

Kan J.Y.K., Rungcharassaeng K., Bohsali K., Goodacre C.J., Lang B.R. (1999) Clinical methods for evaluating implant framework fit. J Prosthetic Dent;81: 7–13.

Sahin S., Çehreli M.C.(2001) The significance of passive framework fit in implant prosthodontics:Current status. Implant Dent;10: 85–92.

Wadhwani, C., & Piñeyro, A. (2009). Technique for controlling the cement for an implant crown. *Journal of Prosthetic Dentistry*, *102*(1), 57-58.

Wadhwani C., (2016) Prosthetic options for Dental implants. Decisions in dentistry, May, pp 24- 26.

Gervais M.J., Hatzipanagiotis, Wilson P.R. Cross-pining: the philosophy of retrievability applied

Byrne, G. (2014). Fundamentals of implant dentistry. John Wiley & Sons.

Brosh, T., Pilo, R., & Sudai, D. (1998). The influence of abutment angulation on strains and stresses along the implant/bone interface: comparison between two experimental techniques. *The Journal of prosthetic dentistry*, *79*(3), 328-334.

Sethi, A., Kaus, T., Sochor, P., Axmann-Krcmar, D. & Chanavaz, M. (2002). Evolution of the concept of angulated abutments in implant dentistry: 14-year clinical data. Implant Dent. 11, 41–51 .

Shadid, R., & Sadaqa, N. (2012). A comparison between screw-and cement-retained implant prostheses. A literature review. Journal of Oral Implantology, 38(3), 298-307.

Salvi, G. E. & Brägger, U. (2009). Mechanical and technical risks in implant therapy. Int. J. Oral Maxillofac. Implants 24 Suppl, 69–85 .

Aglietta, M., Siciliano, V. I., Zwahlen, M., Brägger, U., Pjetursson, B. E., Lang, N. P., & Salvi, G. E. (2009). A systematic review of the survival and complication rates of implant supported fixed dental prostheses with cantilever extensions after an observation period of at least 5 years. Clinical oral implants research, 20(5), 441-451.Overall, screw retained FDPs have the advantage of more predictable retrievability. They require a minimal amount of interocclusal space (min. 4 mm).

Chee W, Felton D, Johnson PF, Sullivan DY. (1999) Cemented versus screwretained implant prostheses: which is better? J Oral Maxillofac Implants.;14:137-141.

Chee, W., & Jivraj, S. (2006). Screw versus cemented implant supported restorations. British dental journal, 201(8), 501-507.

Geng J.P., Tan K.B., Liu G.R. (2001) Application of finite element analysis in implant dentistry: a review of the literature. J Prosthet Dent.;85:585–598. [PubMed].

Himmlová, L., Dostálová, T., Kácovský, A. & Konvičková, S. (2004). Influence of implant length and diameter on stress distribution: A finite element analysis. J. Prosthet. Dent. 91, 20–25 .

Chang, T., Maruyama, C., White, S. N., Son, S. & Caputo, A. A(2005).. Dimensional accuracy analysis of implant framework castings from 2 casting systems. The International journal of oral & maxillofacial implants 20, 720–725 .