Scope
Volume 14 Number 02 June 2024

Comparative Evaluation of Stress Distribution in a Mandibular Implant Supported Overdenture with Different Mucosa Thickness using Two Attachment Systems- A Three Dimensional Finite Element Analysis

Dr. Ananya Babbar , Dr.Vidya K Shenoy, Dr. Shrinidhi Poonja,
Dr. Deeksha Shetty (BDS, MDS)
[1]Consultant, clove dental

Abstract:
Purpose: To analyze and compare the sress distribution pattern in an implant retained overdenture prosthesis using OT equator and ball attachments at two different collar height and varied mucosal thickness by using three dimensional finite element analysis(FEA), **Materials and methods:** Eight finite element models were modelled in an edentulous mandible with two bone level implants placed in the canine region and OT equator and ball attachments at heights 3mm and 4mm and mucosal thickness of 1.5mm and 3mm, were designed using ANSYS Workbench Software. Axial loads of 100(N) and oblique loads (100 N at 30 degree angle to the long axis of the implant were applied. Von Mises stress values were derived in MPa. **Results:** OT equator showed lower stress distribution values in all observed regions compared to the ball attachment. Increased in height and mucosal thickness resulted in increased stress values for both the attachment systems. Higher values were observed at the implant neck of all models, in comparison to body and apex. In the cortical bone when stresses were compared more variation was seen between ball and OT equator attachment on the left and right side under both loading conditions. **Conclusion:** Within the limitations of the study, OT equator attachment showed lesser stress distribution values in implant retained overdenture compared to ball attachment. The stresses developed within the supporting tissue increased, with the increase in height of attachment and mucosa thickness therefore, attachments should be of minimum height and wider diameter for more homogenous stress distribution

Key Words: Finite element analysis(FEA), ball attachment, OT equator attachment

Introduction

Edentulism is a condition that affects millions of people around the globe. Completely edentulous patients have difficulties using their conventional complete dentures due to lack of retention, stability and support. In such situations, implant supported overdenture provides a new dimension for rehabilitation of edentulous patients in terms of esthetics, function and comfort.

According to McGill and York consensus on overdentures, two implant- retained overdenture should now be considered as minimum standard of care for edentulous mandible.The implant retained overdenture offers several advantages like preservation of the residual alveolar ridge, improved retention and stability, increased comfort, and improved masticatory efficiency. The overdenture prosthesis are easier to maintain and cost effective. Thus, they provide greater satisfaction and improved quality of life for the edentulous patients.

In case of implant supported overdentures implants are generally placed in or slightly medial to the canine area, using various types of attachments for retention. The amount of stress transferred to the supporting tissues determines the success or failure rate of an implant. Several studies have shown that the stress distribution is independent of whether two or more implants are placed. Stresses within an optimum range promote dynamic bone remodeling whereas excessive stresses beyond the optimum will lead to bone resorption. In implant supported overdentures, attachment system used for retention of the prosthesis is paramount factor that determines the stress distribution pattern in the bone, implant and prosthesis. Various attachment systems are available to be used width implant retained overdenture. Ball and socket attachments have been used due to their simple design and reduced cost. OT Equator System is a stud type of attachment with reduced height and is useful when the interocclusal space is compromised.

The height of the attachment is one of the many criteria that influence the selection of an attachment system. It plays an important role in the biomechanics at the implant prosthesis junctions due to lever arm mechanics. It also influences the thickness of the overlying denture base. If the space required for the denture base is inadequate fracture or deformation of the denture base may occur. Thickness of the mucosa also may influence the stress distribution pattern and the selection of the attachment height. Thicker mucosa may necessitate the use of an attachment with increased collar height and vice versa. There are different attachment heights available with various implant systems ranging from 0-6mm.

Although studies have evaluated the effect of increased restorative space, very few studies have compared the effect of different attachment collar heights and varied mucosal thickness on the stress distribution patterns in the mandibular implant-retained overdenture.

Various methods like photoelastic stress analysis, two dimensional finite element analysis, mechanical stress analysis or strain gauge analysis are employed to analyse the stress, however all these methods have associated disadvantages. Finite element analysis (FEA)has several advantagesas it allows precise modelling of complex geometries, ability to quantitively assess the internal state of stressand easy model simulation.

The purpose of this study is to analyze and compare the effect of different collar heights and mucosal thickness between ball and OT equator attachment system on the stress distribution patterns within the supporting bone and the connecting mechanisms in mandibular implant supported overdentures.

The null hypothesis, is that the stress distribution is not influenced by the type of attachment and mucosal thickness.

Methodology

Study Design: Finite Element Analysis

Materials used in the Study

1. CBCT scan of human edentulous mandible. (Department of Oral Medicine and Radiology AJIDS, Mangalore)
2. Implant component to be used is threaded, internal hex standard platform bone level implant (4.2x10mm, MIS Implant Technologies Limited, Shlomi, Israel)
3. Attachment systems

a. Ball attachment
   Standard collar height 3mm (MIS Implant Technologies Limited, Shlomi, Israel)
   Standard collar height 4mm (MIS Implant Technologies Limited, Shlomi, Israel)

b. OT equator attachment
   Standard collar height 3mm (RHEIN 83, Bologna, Italy)

Standard collar height 4mm (RHEIN 83, Bologna, Italy)

4. Overdenture: Fabricated using Heat cure acrylic resin (Trevalon, Dentsply India Pvt Ltd, Gurgaon, Haryana, India), Teeth used: Cross linked acrylic teeth(Combination AcryRock, Ruthinium Dental Products, Gujarat, India)
5. 3D Modelling software

Softwares used in the Study-

6. 3D Generation- MIMICS 18.0 software (Materialize Interactive medical image control system software, Leuven, Belgium)
7. CATIA- V5 R19 software (Computer Aided 3D Interactive Application)
8. ANSYS workbench 19.0 (Analysis System)

Meshing

Geometric working models were then transferred to finite element mesh model using ANYSYS 19.0 software to generate finite element mesh.

Loading Conditions:

A compressive force of 100N was applied unilaterally in the central fossa region of the right first molar tooth in a vertical direction to analyse the stress distribution pattern. An oblique load of 100N was applied unilaterally at an angle of 30 degrees to the long axis of the implant in a bucco-lingual direction. The molar region was the point of load application.

Results

OT Equator attachments showed lower stress values when compared with the respective ball attachment models in the corresponding regions under similar loading conditions irrespective of the mucosal thickness and height of the attachment. Reduction in stress concentration between the models (OT Equator, 4mm height and 1.5mm mucosal thickness) and (ball , 4mm height and 1.5mm mucosal thickness) was most appreciable under vertical loading. Under non-axial loading conditions stress values were not substantially different.

von Mises stress (MPa) in FEA models of implant-retained over dentures with OT Equator attachment

	vertical load		oblique load	
	left	right	left	right
Model AH3T1- OT Equator (3mm height, 1.5mm mucosal thickness)				
Implant				
Implant neck	30.94	212.05	15.66	85.94
Implant body	5.61	40.2	3.65	17.86
Implant apex	6.47	99.15	7.70	36.70
Peri-implant bone				
Cortical bone	22.31	168.92	37.68	69.38
Model AH4T1- OT Equator (4mm height, 1.5mm mucosal thickness)				
Implant				
Implant neck	37.24	245.15	20.06	85.52
Implant body	7.17	41.69	4.41	17.86
Implant apex	6.94	100.87	9.30	34.70
Peri-implant bone				
Cortical bone	22.77	176.78	37.68	69.38
Model AH3T3- OT Equator (3mm height, 3mm mucosal thickness)				
Implant				
Implant neck	32.51	228.83	13.59	93.04
Implant body	6.14	43.88	3.36	19.53

Implant apex	7.23	109.06	7.37	40.86
Peri-implant bone				
Cortical bone	22.34	179.84	35.29	84.97

Model AH4T3 -OT Equator (4mm height, 3mm mucosal thickness)				
Implant				
Implant neck	47.4	282.8	18.53	98.30
Implant body	8.79	48.64	3.99	17.65
Implant apex	12.04	117.37	9.06	45.04
Peri-implant bone				
Cortical bone	25.22	170.71	38.19	78.76

Table 7- Maximal principal stresses (MPa) in FEA models of implant-retained overdentures with OT Equator attachment

	vertical load		oblique load	
	left	right	left	right
Model AH3T1- OT Equator (3mm height, 1.5mm mucosal thickness)				
Implant				
Implant neck	30.94	212.05	15.66	85.94
Implant body	5.61	40.2	3.65	17.86
Implant apex	6.47	99.15	7.70	36.70
Peri-implant bone				
Cortical bone	22.31	168.92	37.68	69.38
Model AH4T1- OT Equator (4mm height, 1.5mm mucosal thickness)				
Implant				
Implant neck	37.24	245.15	20.06	85.52
Implant body	7.17	41.69	4.41	17.86
Implant apex	6.94	100.87	9.30	34.70
Peri-implant bone				
Cortical bone	22.77	176.78	37.68	69.38

Model AH3T3- OT Equator (3mm height, 3mm mucosal thickness)				
Implant				
Implant neck	32.51	228.83	13.59	93.04
Implant body	6.14	43.88	3.36	19.53
Implant apex	7.23	109.06	7.37	40.86

Peri-implant bone				
Cortical bone	22.34	179.84	35.29	84.97

Model AH4T3 -OT Equator (4mm height, 3mm mucosal thickness)				
Implant				
Implant neck	47.4	282.8	18.53	98.30
Implant body	8.79	48.64	3.99	17.65
Implant apex	12.04	117.37	9.06	45.04
Peri-implant bone				
Cortical bone	25.22	170.71	38.19	78.76

Table 8- von Mises stress (MPa) in FEA models of implant-retained overdentures with Ball attachment

	vertical load		oblique	
	left	right	left	right
Model BH3T1- BALL (3mm height, 1.5mm mucosal thickness)				
Implant				
Implant neck	31.20	270.28	15.72	112.58
Implant body	5.55	42.54	3.74	15.80
Implant apex	6.26	99.88	8.15	36.01
Peri-implant bone				
Cortical bone	16.54	143	36.95	95.59

Model BH4T1- BALL (4mm height, 1.5mm mucosal thickness)				
Implant				
Implant neck	41.78	283.64	19.54	88.8
Implant body	7.15	44.43	4.35	17.03
Implant apex	6.57	104.17	9.26	36.78
Peri-implant bone				
Cortical bone	21.38	137.68	41.24	77.253

Model BH3T3- BALL (3mm height, 3mm mucosal thickness)				
Implant				
Implant neck	35.14	315.25	15.99	120.8
Implant body	6.32	49.53	3.55	17.17
Implant apex	7.68	113.09	7.04	43.76
Peri-implant bone				

Cortical bone	18.95	158.94	34.91	97.35

Model BH4T3 -BALL (4mm height, 3mm mucosal thickness)				
Implant				
Implant neck	46.62	337.43	18.87	112,67
Implant body	8.47	51.37	3.27	17.64
Implant apex	10.18	121.59	7.92	46.65
Peri-implant bone				
Cortical bone	27.52	195.27	38.13	85.26

Table 9- Maximum stresses (MPa) in FEA models of implant-retained overdentures with Ball attachment

	vertical load		oblique	
	left	right	left	right
Model BH3T1- BALL (3mm height, 1.5mm mucosal thickness)				
Implant				
Implant neck	31.20	270.28	15.72	112.58
Implant body	5.55	42.54	3.74	15.80
Implant apex	6.26	99.88	8.15	36.01
Peri-implant bone				
Cortical bone	16.54	143	36.95	95.59

Model BH4T1- BALL (4mm height, 1.5mm mucosal thickness)				
Implant				
Implant neck	41.78	283.64	19.54	88.8
Implant body	7.15	44.43	4.35	17.03
Implant apex	6.57	104.17	9.26	36.78
Peri-implant bone				
Cortical bone	21.38	137.68	41.24	77.253

Model BH3T3- BALL (3mm height, 3mm mucosal thickness)				
Implant				
Implant neck	35.14	315.25	15.99	120.8
Implant body	6.32	49.53	3.55	17.17
Implant apex	7.68	113.09	7.04	43.76
Peri-implant bone				
Cortical bone	18.95	158.94	34.91	97.35

Model BH4T3 -BALL (4mm height, 3mm mucosal thickness)				
Implant				
Implant neck	46.62	337.43	18.87	112,67
Implant body	8.47	51.37	3.27	17.64
Implant apex	10.18	121.59	7.92	46.65
Peri-implant bone				
Cortical bone	27.52	195.27	38.13	85.26

Discussion

For both Ball and OT Equator models, as the height increased the stress values also increased in all regions under both loading conditions. The null hypothesis was rejected, as the type and the height of the attachment system as well as mucosal thickness influenced the stress distribution patterns observed in the finite element models. The results of the study demonstrated that OT equator attachment exhibited lower stress values compared to ball attachment in all examined regions under both loading conditions.

The shorter height and wider diameter of equator attachment allows favourable stress distribution onto the implant and surrounding structures. In contrast, smaller ball diameter, acts as a point of stress concentration and transmits excessive stresses to the implant and peri implant bone. Since stresses increased with increase in height, any treatment plan should consider use of attachments with least permissible height.

Conclusion

Within the limitations of this study, the following conclusions were drawn:

1. Under vertical and oblique loading, all models showed greater stress concentration on the ipsilateral side of the load application.
2. Maximum stresses were seen on the implant neck under both loading conditions, as compared to the implant body and implant apex.

3. OT equator attachments exhibited lower and more homogenous stress distribution in the implant overdenture and supporting structures compared to ball attachments.
4. In both ball and OT equator attachments, an increase in height increased von Mises stress.
5. In both ball and OT equator attachments an increase in mucosal thickness increased von Mises stress.

References

1. Assunção WG, Barão VA, Tabata LF, De Sousa EA, Gomes EA, Delben JA. Comparison between complete denture and implant-retained overdenture: effect of different mucosa thickness and resiliency on stress distribution. Gerodontology. 2009 ;26(4):273-81.
2. Thomason JM, Kelly SA, Bendkowski A, Ellis JS. Two implant retained overdentures––A review of the literature supporting the McGill and York consensus statements. Journal of dentistry. 2012 ;40(1):22-34.
3. Khurana N, Rodrigues S, Shenoy S, Saldanha S, Pai U, Shetty T, Mahesh M, Hegde P. A Comparative Evaluation of Stress Distribution with Two Attachment Systems of Varying Heights in a Mandibular
4. Implant-Supported Overdenture: A Three-Dimensional Finite Element Analysis. Journal of Prosthodontics. 2019 ;28(2):e795-805.
5. Barão VA, Assunção WG, Tabata LF, de Sousa EA, Rocha EP. Effect of different mucosa thickness and resiliency on stress distribution of implant-retained overdentures-2D FEA. Computer methods and programs in biomedicine. 2008 ;92(2):213-23.
6. Linkevicius T, Apse P, Grybauskas S, Puisys A. Reaction of crestal bone around implants depending on mucosal tissue thickness. A 1-year prospective clinical study. Stomatologija. 2009;11(3):83-91.
7. Ozyilmaz OY, Aykent F, Sayin Ozel G. Effect of mucosa thicknesses on stress distribution of implant- supported overdentures under unilateral loading: Photoelastic analysis. Journal of applied biomaterials & amp; functional materials. 2019;17(4):2280800019882645.
8. Chugh T, Jain AK, Jaiswal RK, Mehrotra P, Mehrotra R. Bone density and its importance in orthodontics. Journal of oral biology and craniofacial research. 2013 ;3(2):92-7.
9. Haruta A, Matsushita Y, Tsukiyama Y, Sawae Y, Sakai N, Koyano K. Effects of mucosal thickness on the stress distribution and denture stability of mandibular implant-supported overdentures with unsplinted attachments in vitro. Journal of Dental Biomechanics. . J Dent Biomech. 2011;2011:894395.
10. Hu F, Gong Y, Bian Z, Zhang X, Xu B, Zhang J, Shi X, Yu Y, Song L. Comparison of Three Different Types of Two-Implant-Supported Magnetic Attachments on

the Stress Distribution in Edentulous Mandible. Computational and mathematical methods in medicine. Comput Math Methods Med.2019 Apr 8;2019:6839517. 2019.PMID: 31089390

11. Ozan O, Ramoglu S. Effect of implant height differences on different attachment types and peri-implant bone in mandibular two-implant overdentures: 3D finite element study. Journal of Oral Implantology. 2015 ;41(3):e50-9.

3D Model of edentulous mandible

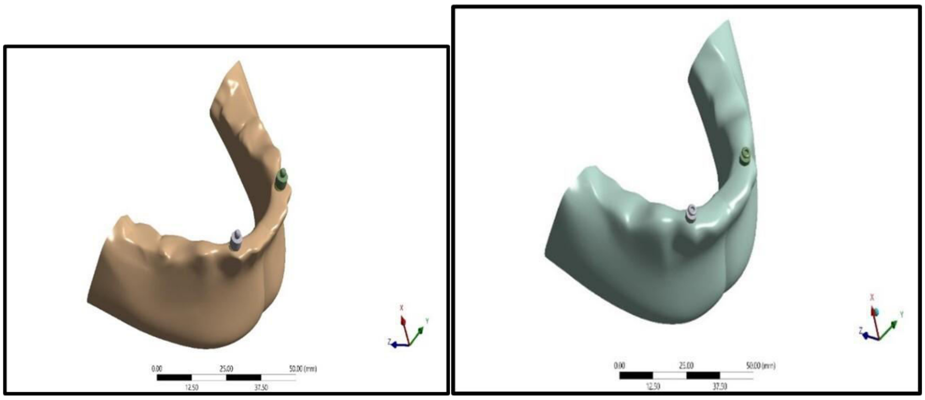
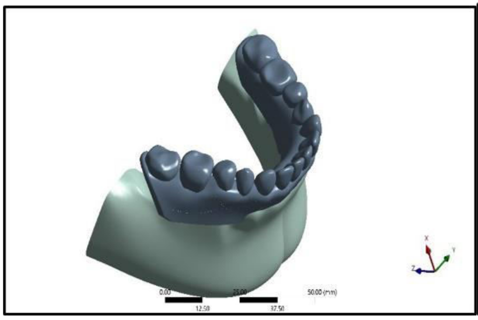


Fig 2: 3-D model of edentulous mandible with ball and OT equator attachment system without overdenture



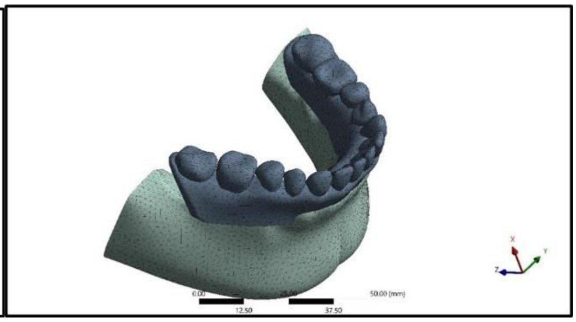


Fig 3: 3-D model of edentulous mandible with overdenture

Fig 4: Complete meshed models with overdenture

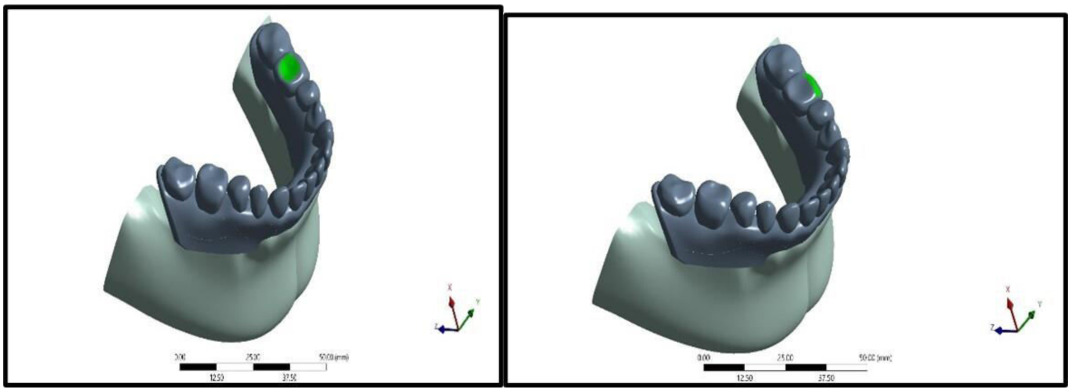


Fig 5: Application of vertical and oblique loading in the molar region

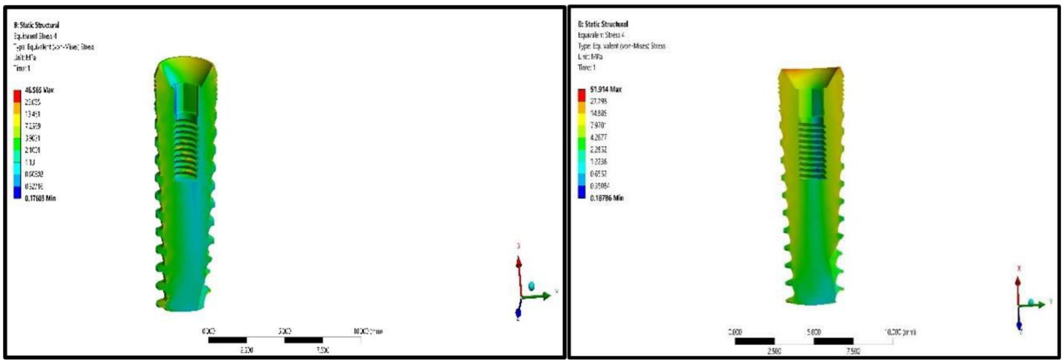


Fig 6: von Mises stress seen in longitudinal cross section of the 3-D finite element model of the implant on the left side and right side implant using OT Equator attachment of 3mm height and 1.5mm mucosa thickness under oblique and vertical loading

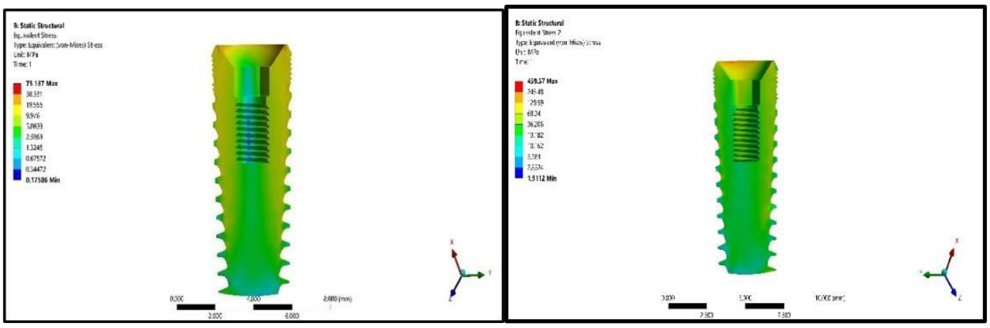


Fig 7: von Mises stress seen in longitudinal cross section of the 3-D finite element model of the implant on the left side and right side implant using ball attachment of 3mm height and 1.5mm mucosa thickness under oblique and vertical loading

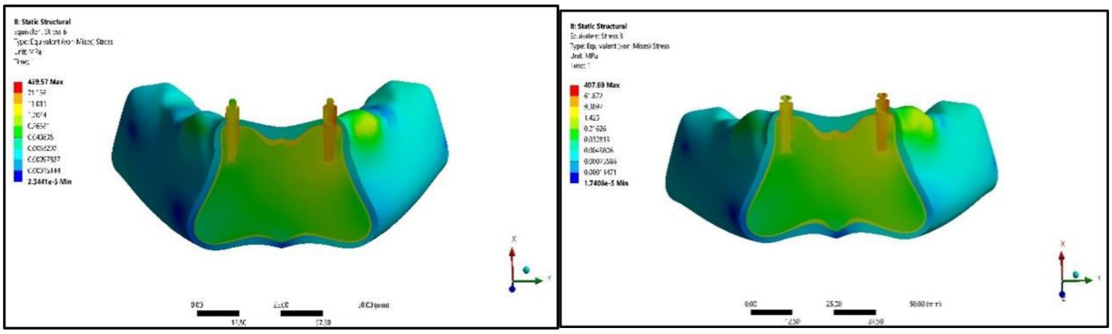
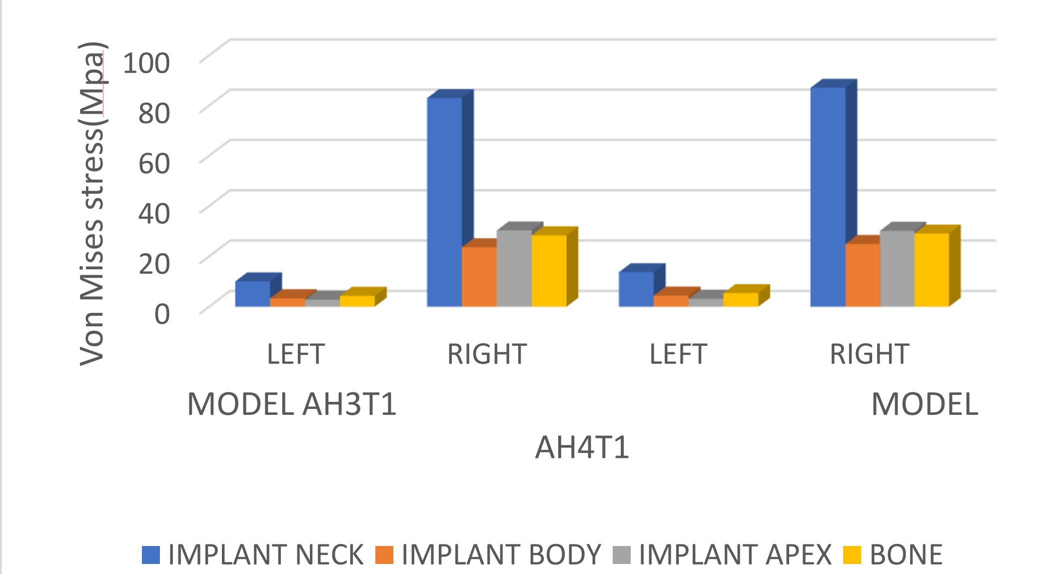
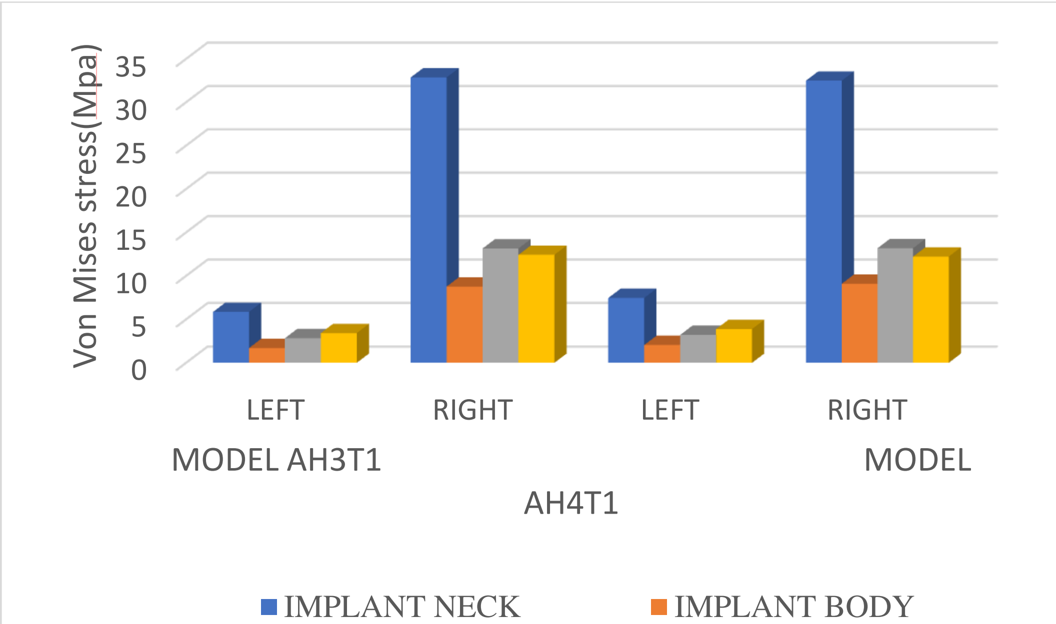


Fig 8: von Mises stress on peri implant bone as seen in frontal section of the 3-D finite element model of the implant retained overdenture complex using ball(top) and OT equator attachment(bottom) of 3mm height under vertical loading

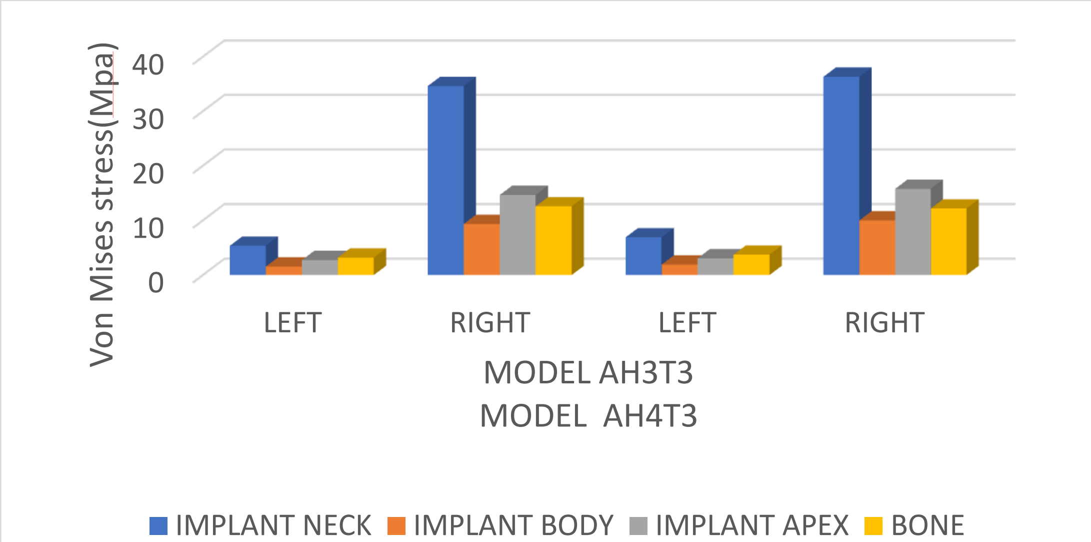
GRAPHS



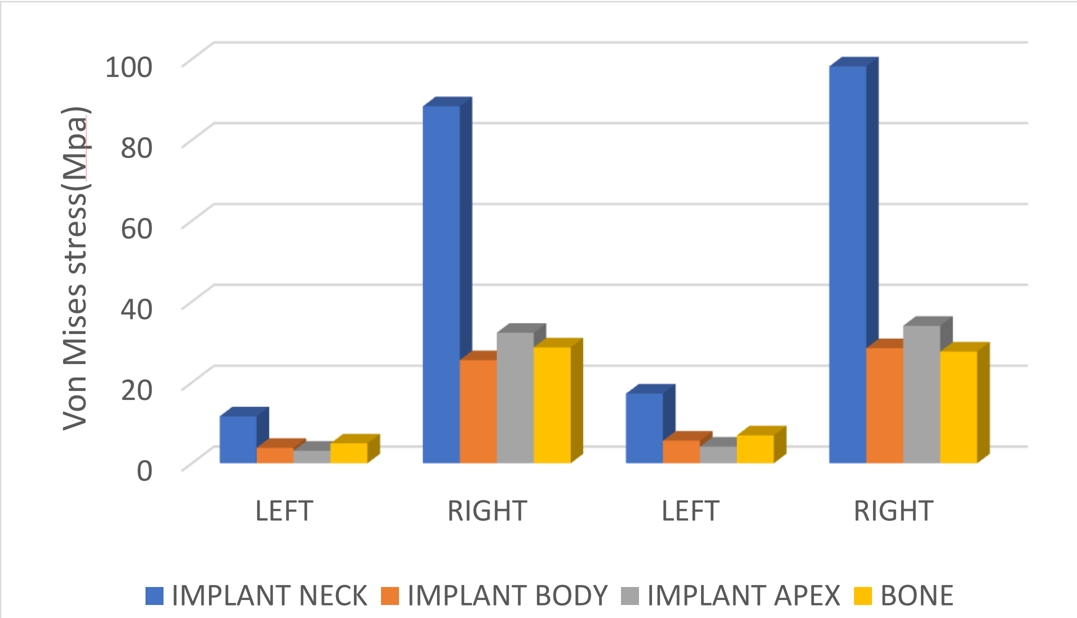
Graph 1- Comparison of von Mises stress values in different regions of model AH3T1, AH4T1 under vertical loading



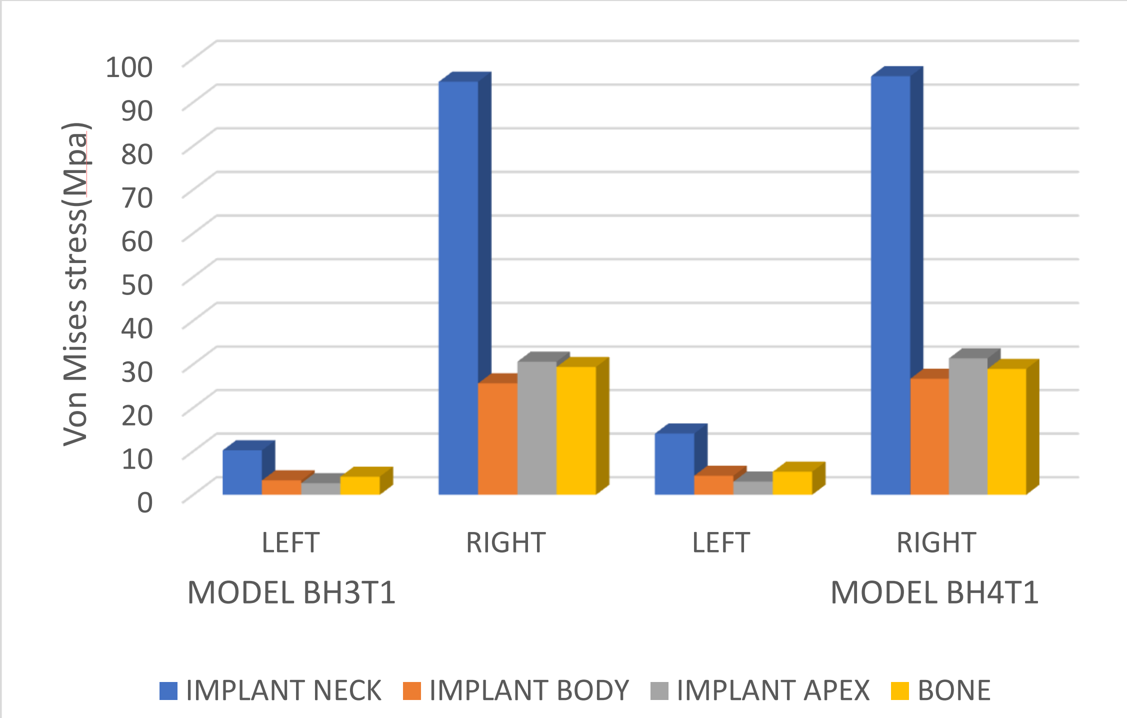
Graph-2- Comparison of von Mises stress values in different regions of model AH3T1, AH4T1 under oblique load



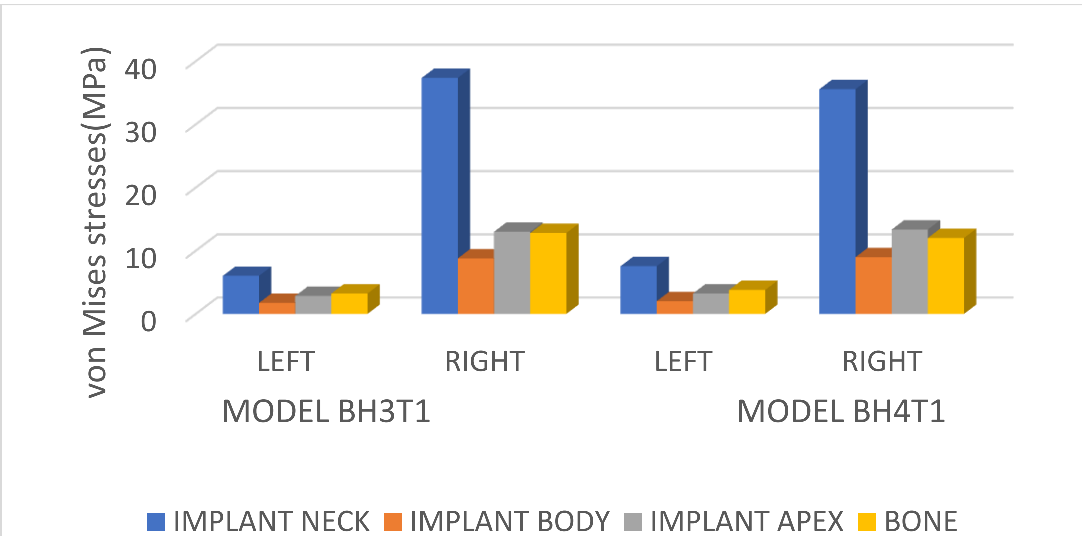
Graph 3- Comparison of von Mises stress values in different regions of model AH3T3, AH4T3 under oblique loading



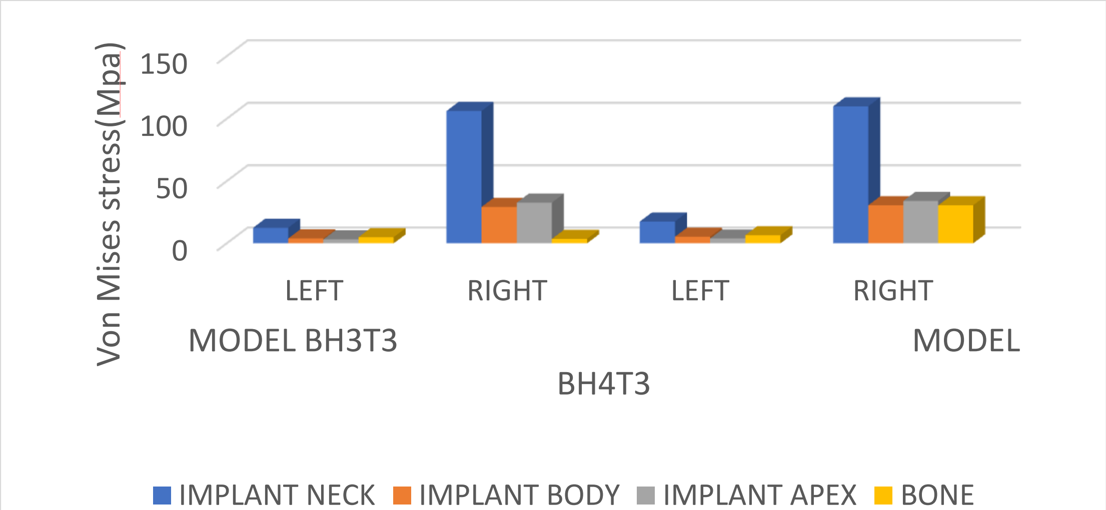
Graph 4- Comparison of von Mises stress values in different regions of model AH3T3, AH4T3 under vertical load



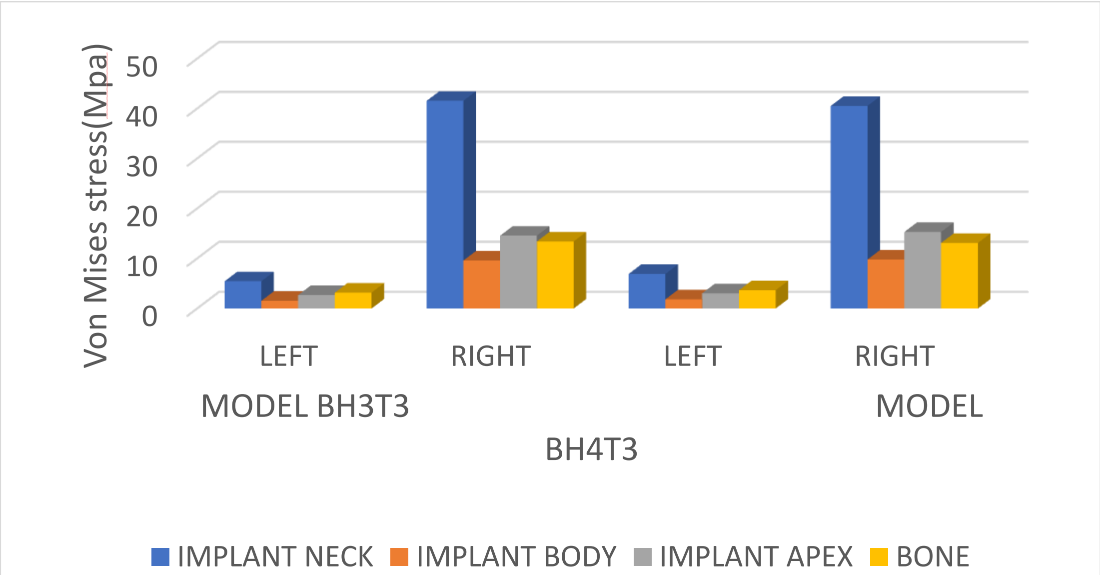
Graph 5- Comparison of von Mises stress values in different regions of model BH3T1, BH4T1 under vertical load



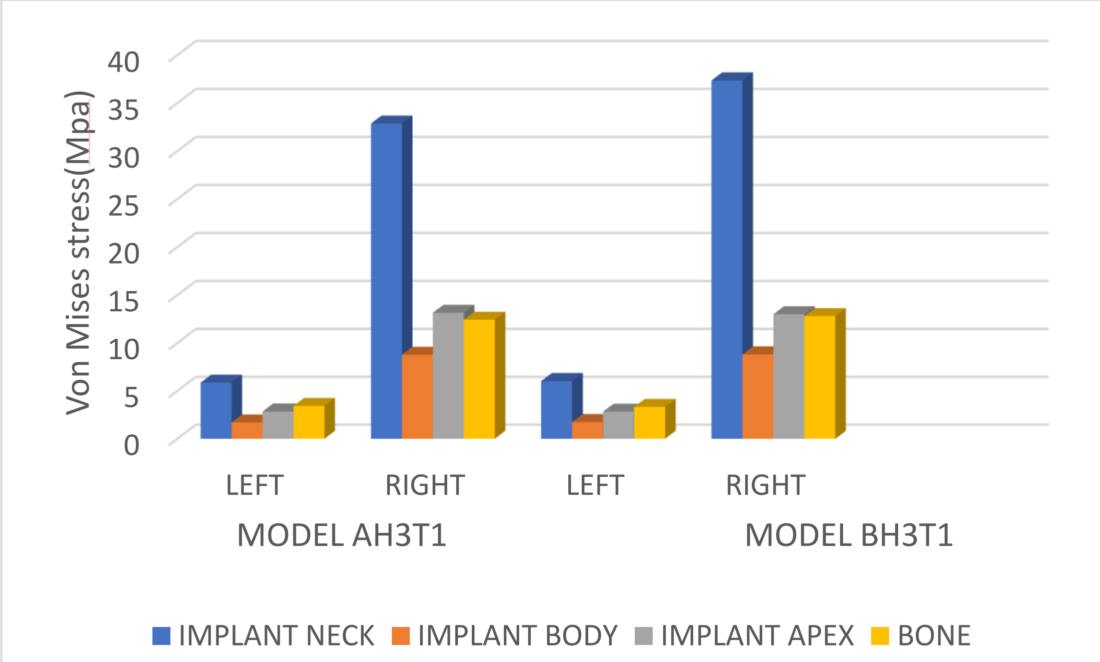
Graph 6- Comparison of von Mises stress values in different regions of model BH3T1, BH4T1 under oblique loading



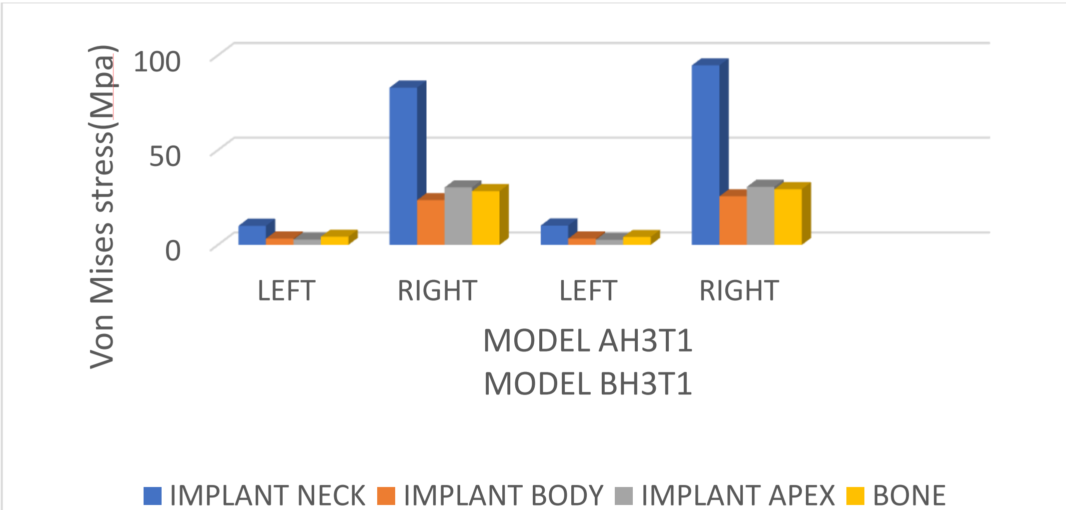
Graph 7- Comparison of von Mises stress values in different regions of model BH3T1, BH4T1 under oblique loading



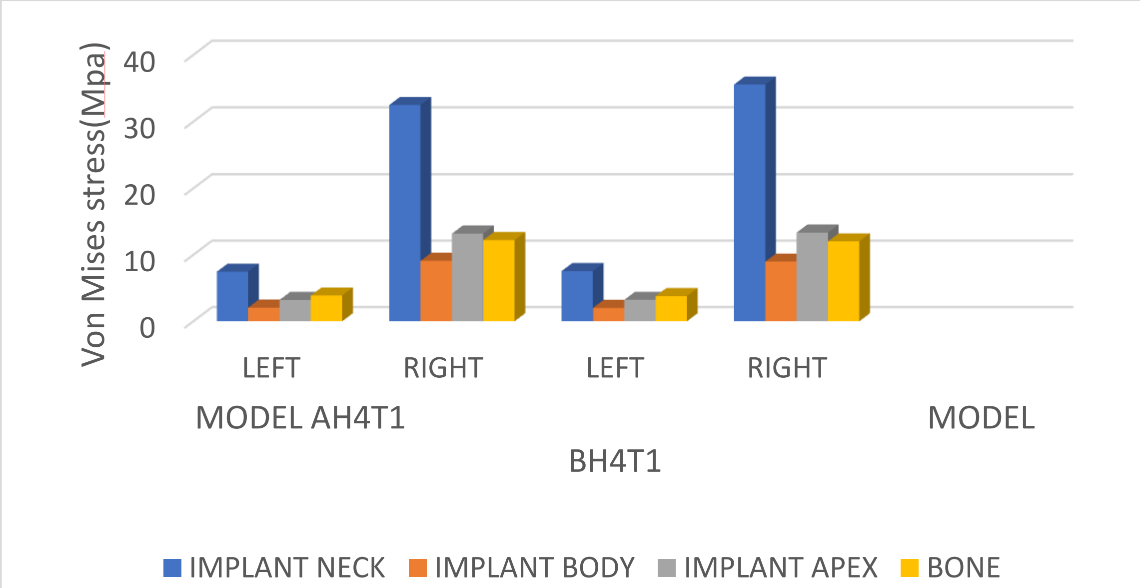
Graph 8- Comparison of von Mises stress values in different regions of model BH3T3, BH4T3 under oblique load



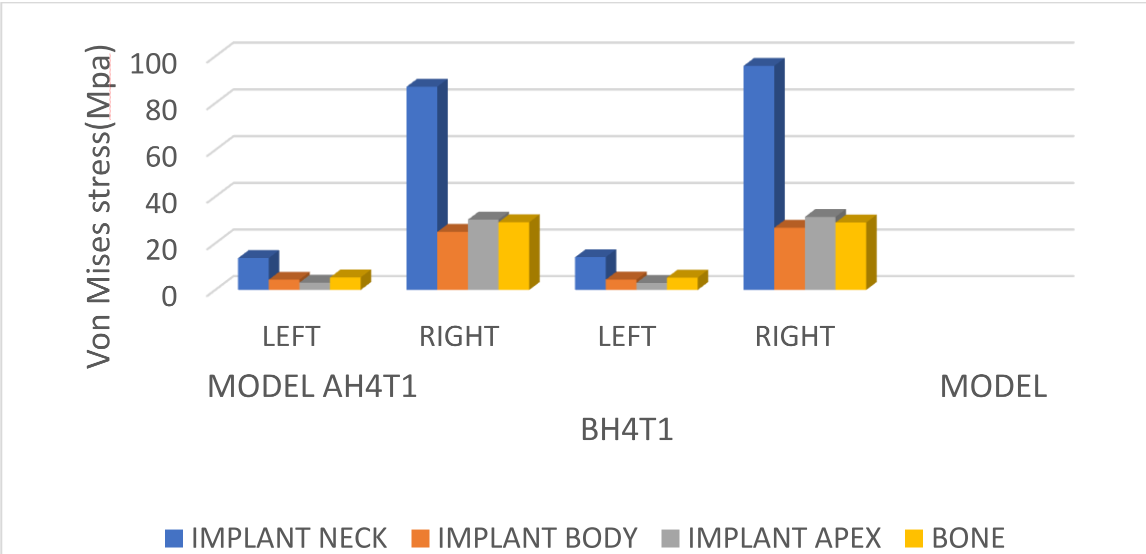
Graph 9- Comparison of von Mises stress values in different regions of model AH3T1, BH3T1 under oblique load



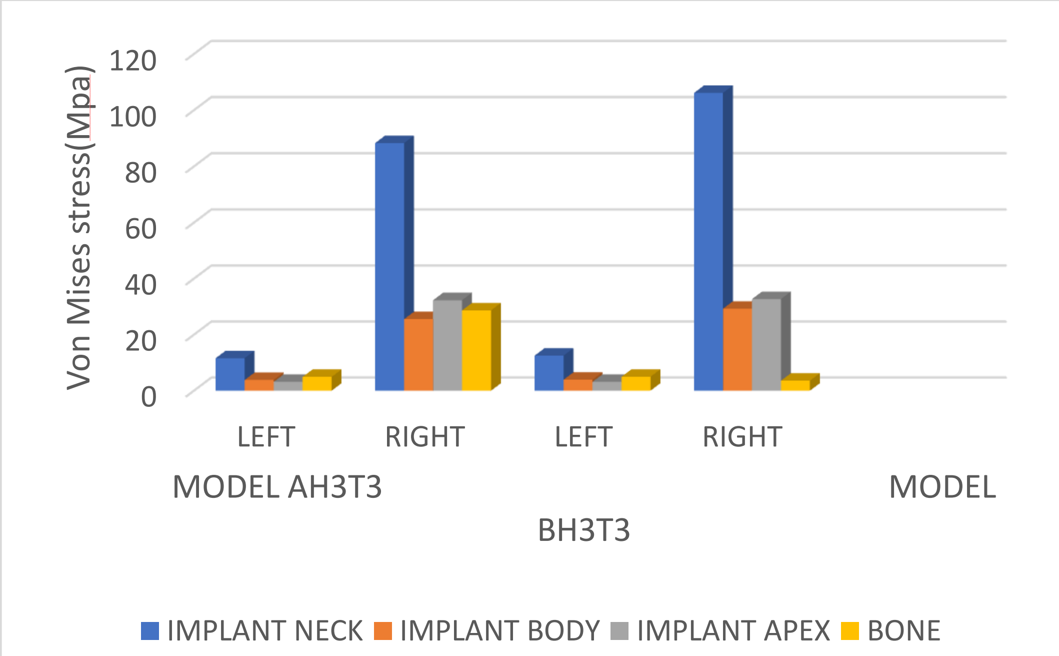
Graph 10- Comparison of von Mises stress values in different regions of model AH3T1, BH3T1 under vertical load



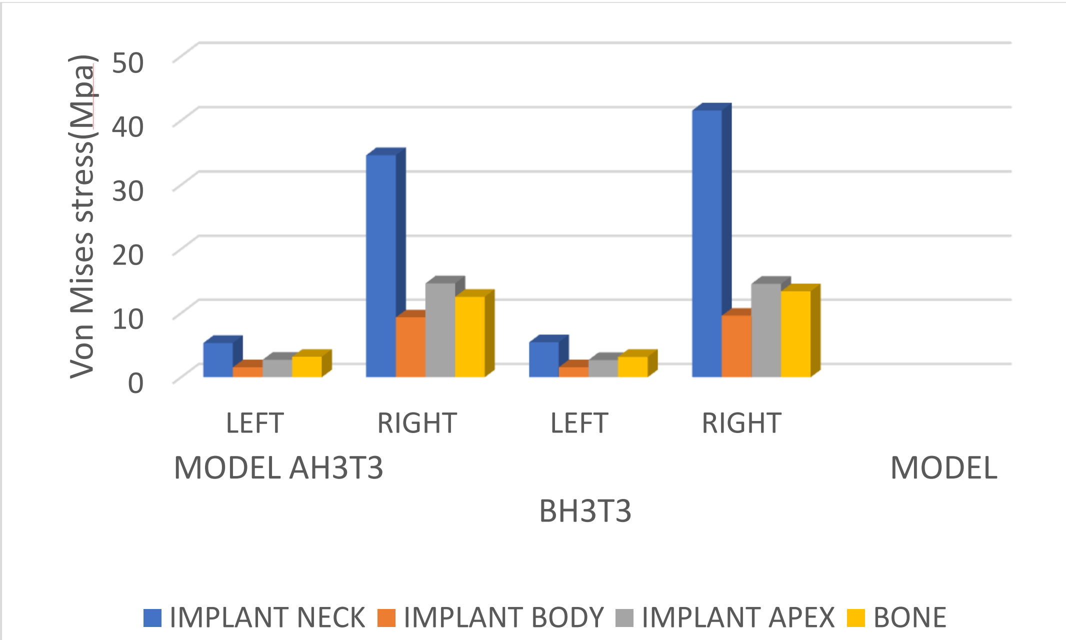
Graph 11- Comparison of von Mises stress values in different regions of model AH4T1, BH4T1 under oblique load



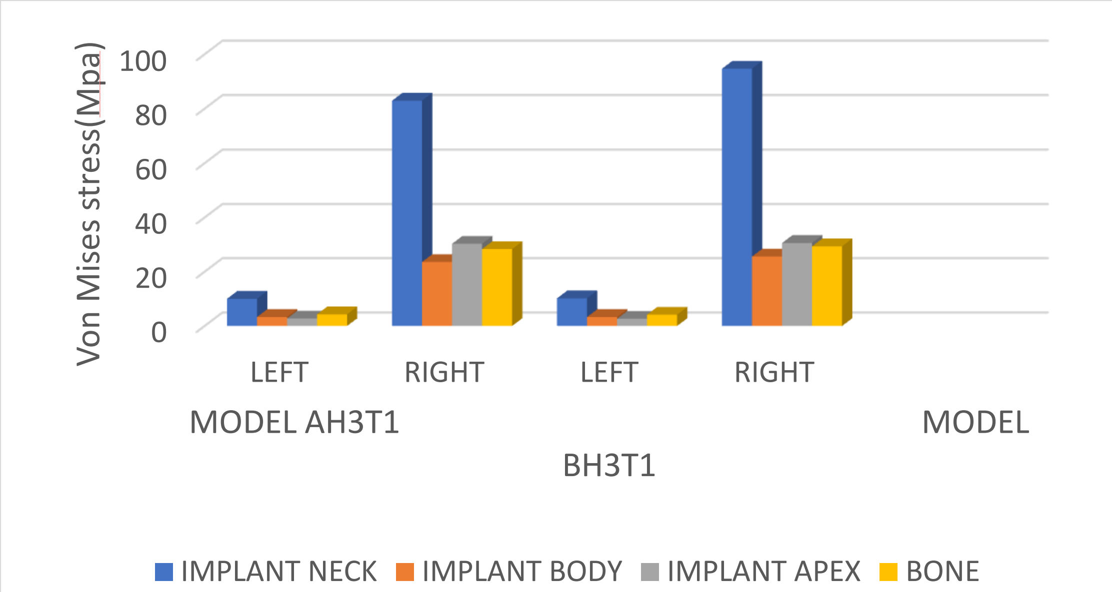
Graph 12- Comparison of von Mises stress values in different regions of model AH4T1, BH4T1 under vertical load



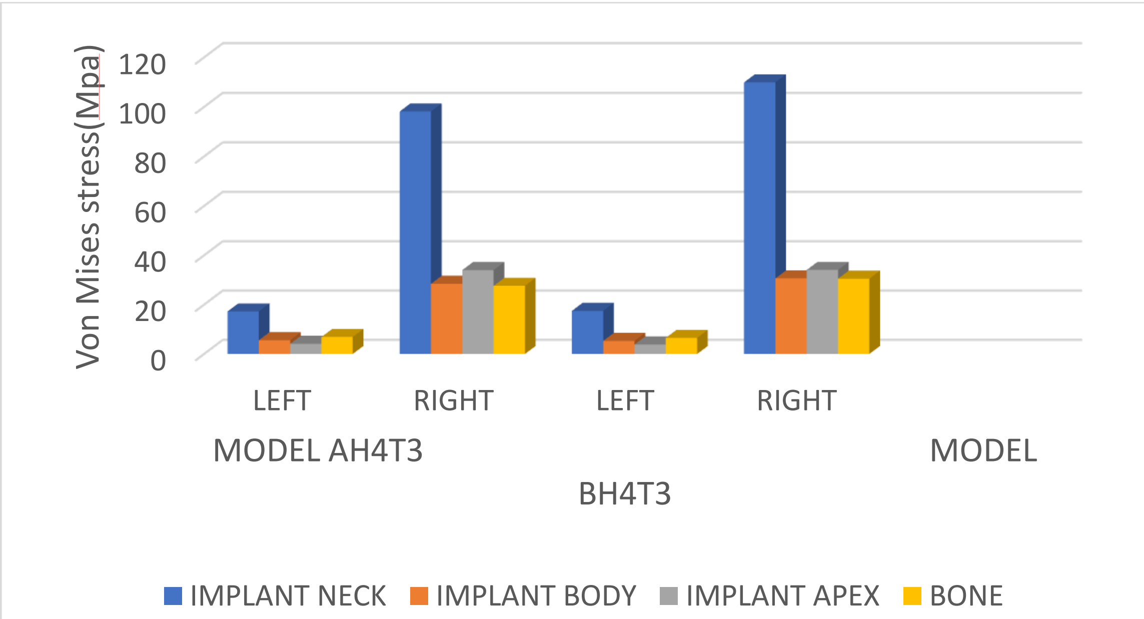
Graph 13- Comparison of von Mises stress values in different regions of model AH3T3, BH3T3 under vertical load



Graph 14- Comparison of von Mises stress values in different regions of model AH3T3, BH3T3 under oblique load



Graph 15- Comparison of von Mises stress values in different regions of model AH3T1, BH3T1 under vertical load



Graph 16- Comparison of von Mises stress values in different regions of model AH4T3, BH4T3 under vertical load