International Journal of Applied Dental Sciences 2022; 8(2): 309-317

ISSN Print: 2394-7489
ISSN Online: 2394-7497
IJADS 2022; 8(2): 309-317

www.oraljournal.com
Received: 13-02-2022
Accepted: 15-03-2022

Dr. Kaustubh Bhapkar
Department of Prosthodontics Crown, Bridge and Implantology, Jaipur Dental College, Jaipur, Rajasthan, India

Dr. Sunil Kumar MV
Department of Prosthodontics Crown, Bridge and Implantology, Jaipur Dental College, Jaipur, Rajasthan, India

Dr. Rajesh Kumar
Department of Prosthodontics Crown, Bridge and Implantology, Jaipur Dental College, Jaipur, Rajasthan, India

Dr. Rhythm Saxena
Department of Prosthodontics Crown, Bridge and Implantology, Jaipur Dental College, Jaipur, Rajasthan, India

Dr. Tanushree Khandelwal
Department of Orthodontics and Dentofacial Orthopaedics, Jaipur Dental College, Jaipur, Rajasthan, India

Dr. Vishal Rana
Department of Oral and Maxillofacial Surgery, Jaipur Dental College, Jaipur, Rajasthan, India

Corresponding Author:
Dr. Kaustubh Bhapkar
Department of Prosthodontics Crown, Bridge and Implantology, Jaipur Dental College, Jaipur, Rajasthan, India

A comparitive evaluation of stress distribution around implant with different abutment material at different abutment angulation: A finite element analysis study

Dr. Kaustubh Bhapkar, Dr. Sunil Kumar MV, Dr. Rajesh Kumar, Dr. Rhythm Saxena, Dr. Tanushree Khandelwal and Dr. Vishal Rana

DOI: https://doi.org/10.22271/oral.2022.v8.i2e.1524

Abstract
Aims: To evaluate the effect of abutment angulations and abutment material on stress distribution of maxillary anterior region. Finite element method was used to simulate the clinical situation of a maxillary anterior region restored by two different angulated abutments i.e. 15° and 25°, using two different abutment materials (Titanium and PEEK).
Material and Methods: For this research two 3 Dimensional Finite Element models were prepared simulating the angled abutments i.e. of 15º and 25º. Commercial engineering CAD/CAM package was used to model abutment (titanium and PEEK), implant, crown and bone in 3D. Load was applied on to the cingulum area i.e. of 178 N. The obtained results were then compared.
Results: The maximum displacement in full model was seen prominently in PEEK due to its low young's modulus when compared with the titanium as a result the displacement can be appreciated. When the abutment angulations increased to 25° the maximum displacement in full model increased subsequently. The maximum stress was seen around the implant abutment junction i.e. in the cortical bone because the young's modulus of the cortical bone is higher as compared to the cancellous bone. The stress on abutment is more in titanium when compared to that of PEEK because of its rigidity. The stress on implant was greater in PEEK and it increased with the increase in the abutment angle. The von mises stress was more in the crestal level when compared with middle and apical level.
Conclusion: The stress on whole implant system can be changed through the usage of different abutment materials at different abutment angulation.

Keywords: Finite element analysis, abutment angulation, abutment material, PEEK abutment, titanium abutment, angled abutment

Introduction

To restore the masticatory system and loss of missing tooth/teeth implant restoration has been widely permitted as one of the treatment modalities [1]. Sometimes the mechanical stress of occlusal forces can have both favorable and unfavorable outcome for bone as well as for tissues. Howbeit, it is arduous clinically to quantify the direction and magnitude of unfeigned occurring occlusal forces. Mechanical failure or failure in the osseointegration can take place any time due to increase in the load bearing capacity of osseointegrated oral implants or/and increase in the load bearing capacity of prosthesis due to occlusal forces [2]. This increase in the load can be classified as an 'overload' if this befalls [3].

The biomechanics plays a crucial role in implant design as all dental implants support forces *in vivo* [2]. The stability of implant is determined by the biomechanical properties of bone – implant interface. Bone - tissue quality around the interface and the outer portion of implant surface which is in contact with mineralized bone are the two major factors for bone implant interface [4].

The type and geometry of the prosthesis, location, prosthesis material, direction of occlusal forces, magnitude of the occlusal forces coming on to the prosthesis, superstructures fit, condition of the opposing arch (prosthesis vs. natural dentition), implant design (diameter and length), bone density, mandibular deformation, age of the patient and sex of the patient are the elements that may influence bone– implant interface [2]. The internal and external structure of bone tissue may get influence due to the abutment angulation which is a mechanical variable [5]. Thus, the action of the bone is associated to the distortion and stress acting on to it. The relation between angled abutments and stress is still a matter of debate [6].

The figure of bone loss cannot be accurately vaticinate when the tooth/teeth are lost in anterior maxilla [7]. This This leads to the placement of implant in different and exaggerated angulations due to alteration in bone morphology and also to content space as well as for esthetic purpose [8]. Most occlusal loads are at an angle to the long axis of the implants specifically in anterior region. But when the forces are off axis, the bone surrounding single-tooth implants may get into overload. This creates a contention when evaluating clinical reports given by Eger *et al.* [9] and Sethi *et al.* [10] These authors draw the inference that angulated abutments may be considered a satisfactory restorative preference when implants are not placed in supreme axial positions.

The forces on to the implants are directly pass on to the bone because there is no periodontal ligament around the implant [11]. The absence of PDL at the implant-bone interface causes moderation in the proprioception, which can sometime cause immoderation stress in the restoration and breakage of the porcelain restoration. The occlusal or incisal forces are transferred to the prosthesis, implant, and the bone around the implant, respectively. Prosthetic design and material selection influence the distribution of stress on prosthetic structures, implants, and bones. These stresses can lead to bone resorption around the implant and the loss of implants [12].

The poly-ether-ether-ketone (PEEK) material is a synthetic thermoplastic polymer evinces high mechanical performance [13]. PEEK was developed in 1978, used in industrial applications in 1980s and started in the medicinal field in the late 1990s [14, 15]. PEEK is a biologically inert material [16]. It is a degradation-resistant material during various sterilization processes. Furthermore, it is economical and allows magnetic resonance imaging (MRI) [17]. PEEK has low elastic of modulus which is close to the bone. Due to same intention, this material is used in fixed prosthetic treatment. It is light in weight, flexible, and hard to break material. Its quality of easy handling and easy to be processed in oral cavity also reinforce its use.

Various techniques based on strain-gauge, photoelasticity and finite element analysis (FEA) based studies have been used to study stress around implant region and in the components of implant-supported with fixed restorations [18].

To investigate the effect of the biomechanical properties of prostheses, abutment, and screw on dental implants, Finite element analysis (FEA) is an essential tool [19]. It is extensively used in implant dentistry to evaluate the complication from a biomechanical point of view. FEA is a numerical stress analysis technique and simplifications and assumptions are the limitations of FEA studies. Despite the fact that advanced computer technology is used to recover results from simulated models, numerous factors affecting clinical features such as implant macro and micro design, material properties, loading conditions and boundary conditions are neglected. Therefore, correlating preclinical and long-term clinical studies with FEA results may assist to validate research models [18].

Materials and Methods

Sample Size

In this study a maxillary and a mandibular arch were modeled on the basis of their CBCT images.

Armamentariums

The following Software was used

- DELL ALIENWARE intel i7 2.9 GHz processor with 32 GB RAM and 8 GB dedicated graphic hardware.
- GEOMAGIC modelling software was used for the construction of geometric model.
- ALTAIR HYPERMESH by Altair Engineering Inc. (Troy, Michigan, United States) software was used to create mesh models with 4 different defects.
- ALTAIR HYPERMESH by Altair Engineering Inc. (Troy, Michigan, United States) for windows was used to fuse the model of maxilla with PDL, Bone etc.
- ALTAIR OPTISTRUCT by Altair Engineering Inc. (Troy, Michigan, United States) Finite Element (FE) solver was used to perform the simulation.
- ALTAIR HYPERVIEW by Altair Engineering Inc. (Troy, Michigan, United States) was used to read finite element results, generate result images & extract stress data from simulation.

Selection Criteria

Inclusion Criteria

1. Digitalized maxillary and mandibular model with all permanent teeth present.
2. Class I occlusion.
3. Ideal tooth anatomy.

Exclusion Criteria

1. Maxillary and mandibular model comprising of deciduous or mixed dentition.
2. Class II & class III occlusion.
3. Root canal treated tooth.
4. Tooth having any kind of prosthesis.

Materials

- A Cone Beam Computed Tomography (CBCT) of the maxillary jaw of fully developed adult skull with maxillary bone was taken.
- CBCT output was taken as an *.stl file & was sent for processing.
- Computer Aided Design (CAD) was constructed using the information of CBCT.
- A Finite Element Model (FEM) was created with the help of a CAD model.

Model details

Implant: Implant used in this study was Noble Biocare.

Source: Noble Biocare – Noble replace and Replace Select Tapered Procedures manual Catalogue pg. no. 14 & 15. Implant sketch & dimensions are taken from the same catalogue. Fig.1 and table 1

From the table: RP 4.3: 4.3 x 11.5 mm Implant was selected.

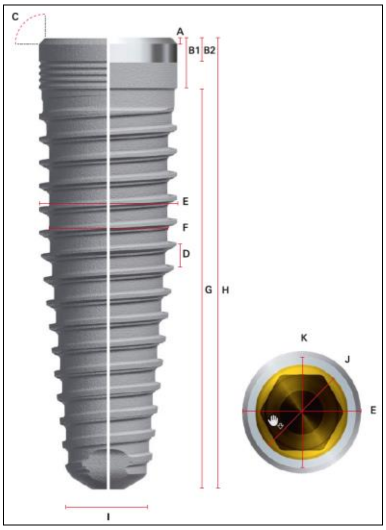

Fig 1: Implant sketch from Nobel biocare – Noble Biocare – Noble replace and Replace Select Tapered Procedures manual Catalogue

Table 1: Implant dimensions from Nobel biocare – Noble Biocare – Noble replace and Replace Select Tapered Procedures manual Catalogue

		A	B		C	D	E	F	G	H	I	J	K
Platform		Bevel height	Doha, height		Bevel angle	Thread pitch	Major diameter	Minor diameter	Thread height	Overall length	Tip diameter	Abutment interface	Bridge interface
			B1	B2									
RP 4.3	4.3x11.5mm	0.2	1.5	0.75	45°	0.71	4.3	3.67	10. 5	12.1	2.50	34	3.9
	4.3v13mm	0.2	1.5	0.75		0.71	4.3	3.67	12.07	13.6	2.50	3.4	3.9
	4.3x10rnin	0.2	1.5	0.75	45°	0.71	4.3	3.67	15.12	16.6	250	3.4	3.9

Cad model images

The CAD model images for implant, screw, abutment and complete assembly, crown on abutment are shown in Fig. 2 (The image is not an engineering drawing and are not to scale).

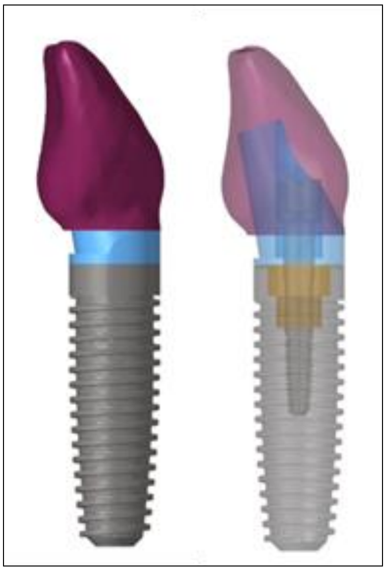

Fig 2: The CAD model images showing implant, screw, abutment and crown on abutment

Material properties

All the components were presumed to be isotropic, linear elastic and homogenous. The Poisson's ratio and Young's modulus of elasticity of the materials were assimilated into the model. The corresponding mechanical properties (Young's modulus and Poisson's ratio) were obtained from the literature. (Table 2)

Table 2: Material properties

Anatomic structure	Young Modulus (MPa)	Poisson's Ratio (μ)
Cortical Bone	17400	0.3
cancellous Bone	1740	0.3
Titanium	110000	0.35
PEEK	4100	0.4
Zirconia	205000	0.2
Glass Ionomer (GIC)	12000	0.25

Boundary conditions

Validation of Model

This was a stage for trial run of FEA. It was a stage for element quality check. Element qualities like Warpage and Aspect Ratio were checked & required modifications were done in the model to improve the element quality.

Application of Boundary Conditions

Boundary Conditions define the way model is held or fixed in the FE space & the way forces are applied on the model.

Fixing the Model

Base of the Bone was fixed and locked for moving in any direction. As per FEM, nodes on the selected surfaces were locked in all Degrees of Freedom. This restricted the displacement of these nodes in all direction. This way model was locked / fixed in the FEA space for further evaluation and solving. Fig.3

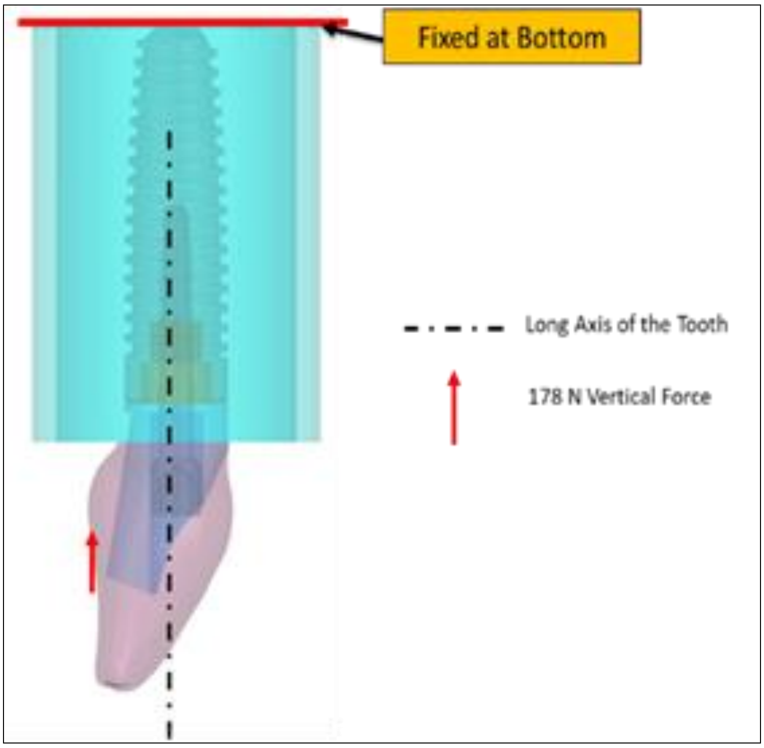

Fig 3: Locking of model and nodes and the vertical load is applied for further evaluation.

Results

The stress distribution in full model, implant, abutment, cortical bone and cancellous bone with different abutment material and different abutment angulation in the maxillary central incisor sections were compared under vertical loading forces.

When making comparisons, maximum stress values were considered for both abutment material and abutment angulation conditions. (Table: 3-6)

Data for von Mises stresses were produced numerically, color-coded and compared among the models. (Fig. 4-8)

The current FEM study attempts to evaluate and compare von mises stress at different abutment angulation that is 15° and 25° with different abutment material ie. Titanium and PEEK. The von mises stress and signed von mises stress is evaluated in cortical and cancellous bone and also in abutment and implant.

Table 3: Describes the the max Von. Mises and max. Signed Von Stress distribution in full model, implant, abutment, cortical bone and cancellous bone with different abutment material and different abutment angulation in the maxillary central incisor sections.

					Max. Stress Von. Mises Stress (Mpa)					Max. Signed Von. Mises Stress (Mpa)			
S. No	Abutment Angle	Model	Abutment	Max. Displacement in Full Model (mm)	Max. Stress in Full Model	Cancellous Bone	Cortical Bone	Abutment	Implant	Tension Stress in Cancellous Bone	Compression Stress in Cancellous Bone	Tension Stress in Cortical Bone	Compression Stress in Cortical Bone
1	15°	Model - 1	Titanium	0.031	358	4.4	49.74	140.58	102.61	2.86	4.31	27.38	49.74
2		Model - 2	Peek	0.044	358	4.49	102	79.62	115	2.98	4.31	57.83	102.27
3	25°	Model - 3	Titanium	0.033	371	4.35	49	124.86	103	4.04	4.08	28.06	48.65
4		Model - 4	Peek	0.047	373	4.83	79.65	59.87	120.77	4.41	4.08	54.66	79.65

Table 4: Describes the the max Von. Mises and Signed Von mises Stress at different implant levels i.e. at crestal level, middle level, apical level.

				Max. Von. Mises Stress (Mpa)			Max. Signed Von. Mises Stress (Mpa)					
							Crestal		Middle		Apical	
#	Abutment Angle	Model	Abutment	Crestal	middle	Apical	Tension Stress	Compression Stress	Tension Stress	Compression Stress	Tension Stress	Compression Stress
1	15	Model - 1	Titanium	102.61	71.05	32.83	83.66	102.61	45.94	71.05	21.54	32.83
2		Model - 2	Peek	115	53	23	92.28	115.04	27.86	53.35	21.51	21.83
3	25	Model - 3	Titanium	103	71	26	79.59	103.47	45.29	70.7	23.83	23.42
4		Model - 4	Peek	120.77	57.69	25.97	86.19	120.78	25.59	57.7	23.87	22.12

Table 5: Evaluates the stress distribution was evaluated at abutment – implant junction with 15^0 and 25^0 abutment angulation in PEEK and Titanium

Max. Von. Mises Stress for Abutment Implant Junction (Mpa)					
#	**Abutment Angle**	**Model**	**Abutment**	**Magnitude**	**Location**
1	15	Model – 1	Titanium	140	Abutment
2		Model – 2	Peek	115	Implant
3	25	Model – 3	Titanium	125	Abutment
4		Model – 4	Peek	120	Implant

Table 6: Evaluates the stress distribution was evaluated at abutment – screw junction with 15^0 and 25^0 abutment angulation in PEEK and Titanium

Max. Von. Mises Stress for Abutment Screw Junction (Mpa)					
#	**Abutment Angle**	**Model**	**Abutment**	**Magnitude**	**Location**
1	15	Model – 1	Titanium	140	Abutment
2		Model – 2	Peek	105	Screw
3	25	Model – 3	Titanium	125	Abutment
4		Model – 4	Peek	110	Implant

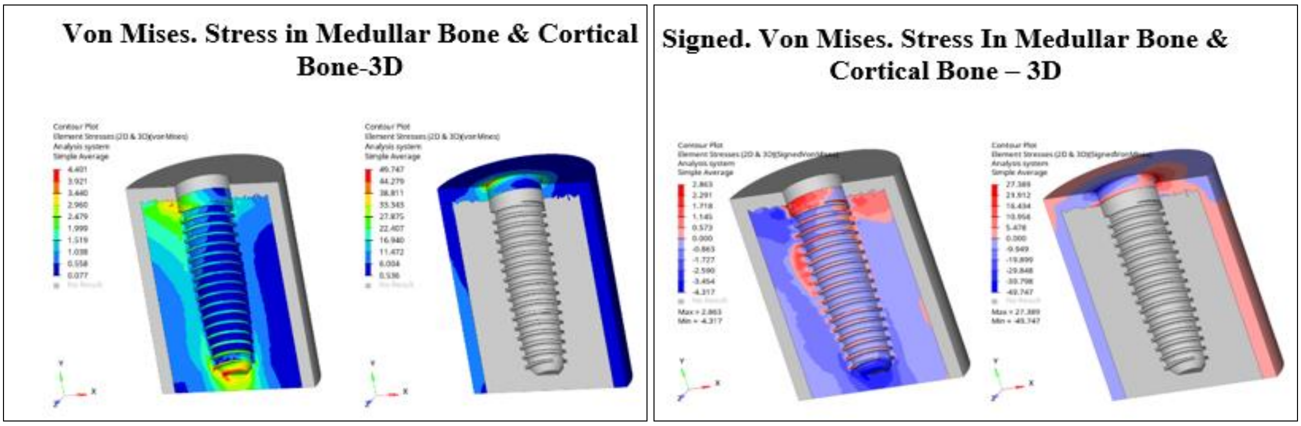

Fig 4: 15° Abutment – Material Titanium

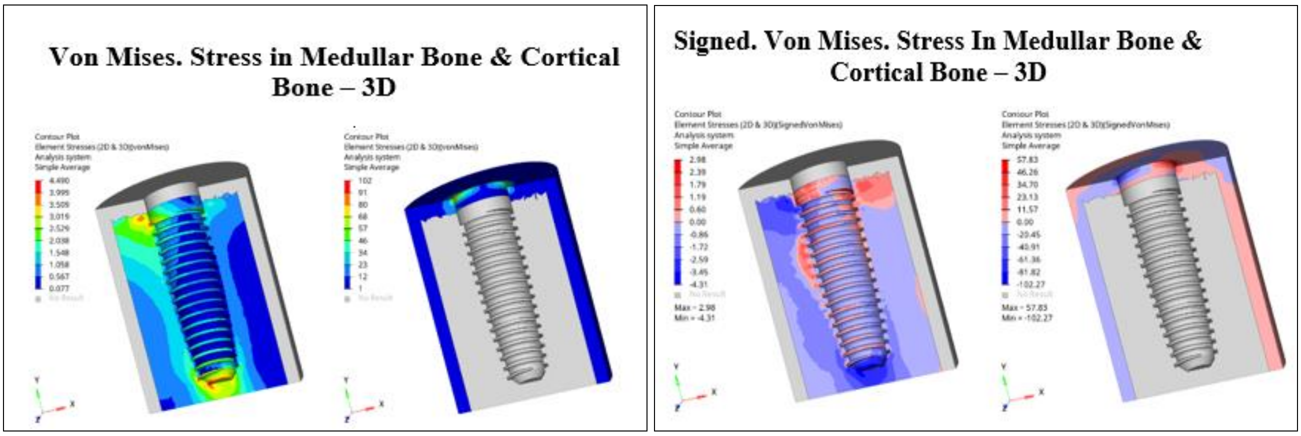

Fig. 5: 15° Abutment – Material PEEK

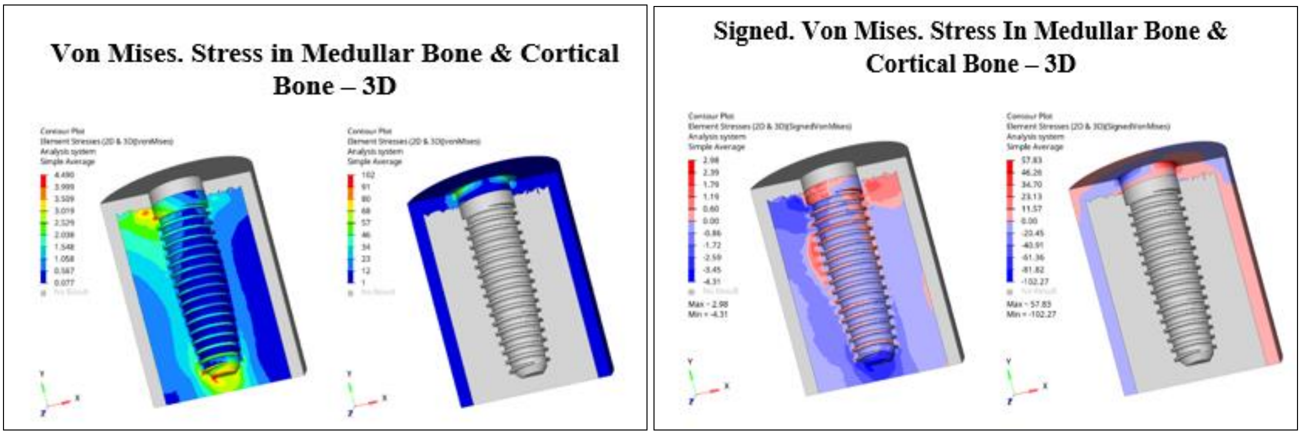

Fig 6: 25° Abutment – Material Titanium

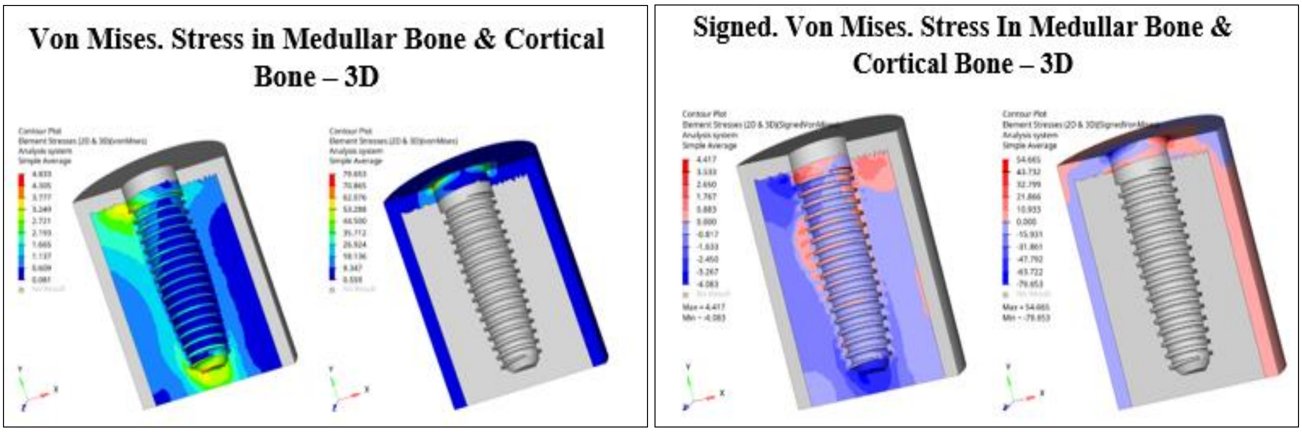

Fig 7: 25° Abutment – Material PEEK

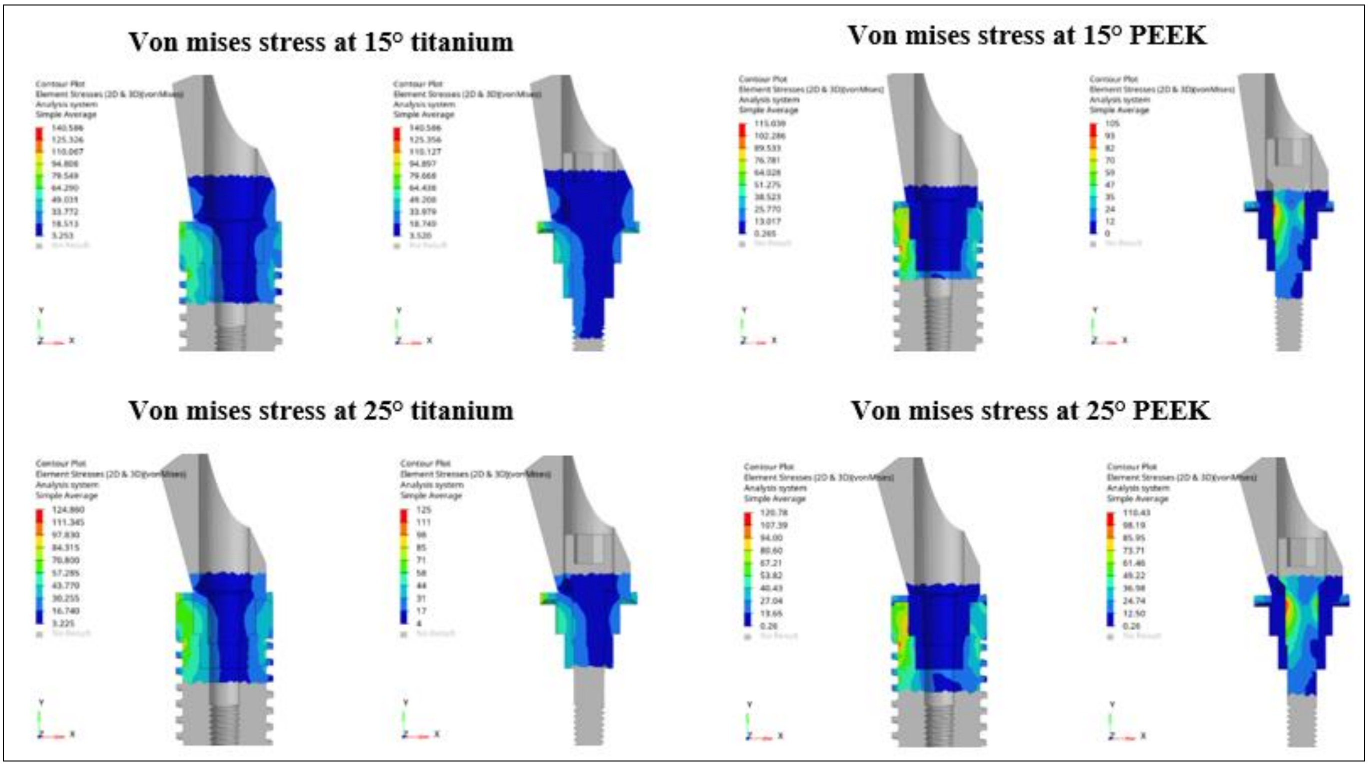

Fig 8: Implant-Abutment & Abutment-Screw Junction

Discussion

In 1976, Weinstein *et al*. were the first to use FEA in implant dentistry; subsequently. FEA was applied rapidly in the field of implant dentistry [20]. 3-D FE analyses are preferred to 2-D techniques because they are more representative of stress behavior on the supporting bone [21, 22].

Stresses were calculated after applying load of 178N in vertical direction on the palatal surface of crown of maxillary central incisor region. According to the study done by Sumedha Kapoor [23] during centric occlusion the lower incisors are close to the palatal surface of upper incisors and the load comes to the cingulum region which is in a labial-apical direction. Nancy L. Clelland [24] stated in their study that occlusal load of 178N was applied along the long axis of each abutment. The amount and direction of the load selected was based on study by Eva Helkimo [25] and Gustaf Hellsing [26]. Ming-Lun-Hsu [27] further described in their study that occlusal forces at various angles affect the stress/strain distribution within different bone quality.

The clinician can position an angled abutment to attain prosthetically desired parallelism between implants or teeth. The use of angled abutments has become an increasingly common practice because of patient's and clinician's expectations [28]. According to Dorothy E. Eger [9] report, In patients with distorted bony anatomy, an angled abutment permits the placement of implants in the most approving quantity and quality of available bone. Gelb and Lazzara [29] discussed the use of pre-angulated abutments as the treatment of choice when anatomic restrictions debar the axial placement of an implant.

Since many years, for superior results in implant treatment there have been consistent attempts to develop more aesthetic materials. Abrahamsson *et al*. made a claim that the prevention of soft tissue recession and crestal bone loss can be achieved by the material of the abutment [30].

Titanium for many years was the material of choice as an abutment due to material strength and resistance to distortion [31]. A systematic reviews by Sailer *et al*. [32] have shown outstanding results promoting titanium abutments as dependable material. However, a study done by Park *et al*. [33] stated that the major disadvantage of these abutments is their dark color can reflect through soft peri-implant tissues, creating a grayish appearance of implant mucosa, which is not esthetical.

Steven M. Kurtz [15] reviewed that PEEK has shown excellent results as an alternative to titanium material. Due to its high biocompatibility, PEEK has been used to make implants, provisional abutments, healing abutments, and implant-supported hybrid prostheses in dental implantology [34]. The PEEK material is a biologically inert material. According to Shariq Najeeb [35] It shows good mechanical and thermal resistance and is resistant to hydrolysis and chemical abrasion.

The current FEM study attempts to evaluate and compare von mises stress at different abutment angulation that is 15° and 25° with different abutment material ie. Titanium and PEEK. The von mises stress and signed von mises stress is evaluated in cortical and cancellous bone and also in abutment and implant.

The Max Von Mises stress in cancellous bone was 4.4Mpa and 4.49Mpa for Titanium and PEEK and for cortical bone it was 49.74 Mpa and 102 Mpa at 15^0 abutment angle respectively. Values for stress in 25^0 abutment angle in cancellous bone was 4.35Mpa and 4.83Mpa for Titanium and PEEK and 49Mpa and 79.65Mpa in cortical bone respectively, which states that when abutment angulation is increased the von mises stress in bone reduces significantly in PEEK. According to Merve TERZİ [28] stress values for bone are close to each other when using Chrome-Cobalt, Zirconium and Titanium as the abutment material, but it has a higher value when using PEEK.

While using PEEK material as abutment Maximum von-Mises stress values were obtained while using titanium as abutment minimum stress values were obtained. According to S Tekin *et al.* [11] the use of PEEK abutments with low-elasticity modulus, PEEK provides less stress on abutment by transmitting the stress to implant and screw. Maniamuthu Ragupathi *et al.* [36] did an *in vitro* study in which they revealed statistically insignificant wear among the two implant abutment materials after cyclic loading.

Hence, PEEK material could prove to be a feasible alternative to titanium material to use as an implant abutment depending on the clinical condition of the patients. The values for signed von mises stress at 15° abutment angle in titanium and PEEK was 2.86 and 2.98 for tension stress and 4.31 and 4.31 for compression stress and 27.38 and 57.83 for tension stress and 49.74 and 12.27 for compression stress in cancellous and cortical bone respectively. This signifies that signed von mises stress is more in cortical bone as compared to cancellous bone.

According to Koosha S [37] maxillary and mandibularbone consist of a mainly of cancellous bone and a surrounding layer of cortical bone. Young’s modulus of cortical bone is higher than that of cancellous bone. Thus, the cortical bone absorbs most of the stress while the stress coming on to the cancellous bone gets distributed. Xavier E. Saab *et al.* [8] also stated that cortical bone would absorb most of the stresses. Fahimeh Hamedirad [38] did FEA study in which highest von Mises stresses were found in the cortical bone. Elasticity coefficient of cancellous bone was lower than cortical bone. For this reason, the cortical bone was compact and more resistant against changes. Consequently, the amount of stress reported in the trabecular bone was lower than the cortical bone. This similar result was also found in a study conducted by Atilla Sertgoz *et al.* [39]

For titanium and PEEK abutment material the tension and compression stress in cacellous and cortical bone was found to be 4.04Mpa, 4.41Mpa; 4.08Mpa, 4.08Mpa and 28.06Mpa, 54.66Mpa; 48.65Mpa, 79.65Mpa at 25°abutment angulation, which also states that when we increase the abutment angulation tension stress increased while the compression stress was reduced. Danza *et al.* [40] studied the stress distribution around a spiral implant in D1 and D4 bone with 0°, 15° and 25° angulated abutment using 3D FEA and concluded that maximum stress was obtained in 15° angled abutment. Sumedha Kapoor [23] researched that the maximum stress was seen at 25° angulated abutment followed by 15° and 0° angled abutment under axial loading. Author also stated that the maximum stress was seen in the cortical bone.

In 15° abutment angle the von mises stress on abutment in titanium and PEEK was 140.58Mpa and 79.62Mpa and in 25° the von mises stress was 124.86Mpa and 59.87Mpa respectively. This shows that when von mises stress for titanium is significantly higher compared to that of PEEK. S Tekin *et al*[11] did a FEM study in which they observed that stress on the abutment was examined in all groups, it was more affected by the change of abutment material than crown material, and with the use of PEEK as abutment material with low-elasticity modulus, PEEK material provides less stress on abutment by transferring the stress to screw and implant. A randomized, controlled clinical trial conducted by Koutouzis *et al.* [41] suggested that there was no significant difference in the bone resorption and soft tissue inflammation around PEEK and titanium abutments. Merve TERZİ [28] concluded in their literature that For Abutment, PEEK received the lowest values where as Co-Cr received the highest stress values. The stress values on the abutment are affected by the elasticity Modules of the material. According to Necati Kaleli *et al.* [42] all titanium base abutments showed higher von Mises stress values under vertical loading.

The maximum von mises stress on implant at 15° abutment angulation was 102.61Mpa and 115 Mpa and for 25° it was found to be 103 Mpa and 120.77 Mpa for titanium and PEEK respectively. It can be interpreted that von mises stress on implant is more with the use of PEEK abutment material as compared to titanium abutment material. Mohamed I. El-Anwara [2] did a FEM study in which they concluded that as abutment material rigidity decreased it will absorb less energy and transfers more load to the following parts of the studied model. S Tekin [11] observed that the use of titanium abutments with more elastic modulus reduced the stresses that occurred on the implant. He also concluded that PEEK provides less stress on abutment by transmitting the stress to implant and screw.

At 15° abutment angulation the von mises stress on implant at crestal, middle and apical were 102.61Mpa, 115Mpa; 71.05Mpa, 53Mpa; 32.83Mpa, 23Mpa for titanium and PEEK abutment material respectively. At 25° the von mises stress on implant were 103Mpa, 120.77Mpa; 71Mpa, 57.69Mpa; 26Mpa, 25.97Mpa for titanium and PEEK material. It can be inferred that the young’s modulus of PEEK is less due to which the stress which is occurring on to the abutment body is dissipated to the peri implant region. As a result the von mises stress is increased in PEEK abutment material at crestal, middle and apical region. As mentioned in multiple studies the stress increases with increase in abutment angulation, therefore the von mises stress at 25º abutment angulation is more as compared to 15° abutment angulation in PEEK.

The maximum von mises stress for abutment implant junction at 15° abutment angulation was 140Mpa and 115Mpa for titanium and PEEK respectively and at 25° abutment angulation the values were 125Mpa and 120Mpa. The maximum stress located on to the abutment implant junction was at abutment in case of titanium and in PEEK material it was at implant. This is because the titanium abutments has more elastic modulus which reduces the stresses that occurred on the implant [11].

The maximum von mises stress for abutment screw junction at 15° abutment angulation was 140Mpa and 105Mpa for titanium and PEEK respectively and at 25° abutment angulation the values were 125Mpa and 110Mpa. The maximum stress located on to the abutment screw junction was at abutment in case of titanium and in PEEK material it was at screw. This is because PEEK provides less stress on abutment by transmitting the stress to implant and screw [11].

Conclusion

Based on the results obtained we can conclude that

1. The maximum displacement in full model was seen prominently in PEEK due to its low young's modulus when compared with the titanium as a result the displacement can be appreciated. When the abutment angulation was increased to 25° the maximum displacement in full model increased subsequently.
2. The maximum stress in full model increased when abutment angulation was increased.
3. The maximum stress was seen in the cortical bone which surrounding the implant abutment junction because the cancellous bone has a young's modulus lower than that of cortical bone. Thus, the applied loads distribute in cancellous bone, while the cortical bone absorbs most of the stress.
4. The stress on abutment is more in titanium when compared to that of PEEK due to its rigidity.
5. The stress on implant was greater in PEEK and it increased with the increase in the abutment.
6. The von mises stress was more in the crestal level when compared with middle and apical level.

References

1. Anwar MI, Azrag KE AL, Ghazy MH, Dawood LE. Influence of implant-abutment angulations and crown material on stress distribution on central incisor: A 3D FEA. Braz J Oral Sci. 2015;4(4):323-29.
2. Anwar MI, Fawzy UM, Mohamad HA, Tamam RA, Yousief SA. Effect of different abutment materials of implant on stress distribution using three dimensional finite element analysis. Med Res J. 2013;12(2):115-23.
3. Isidor F, Lang NP, Karring T, Lindhe J. Occlusal loading in implant dentistry. Proceedings of the Third European Workshop on Periodontology Implant Dentistry, 1999, 35875.
4. Mathieu V, Vayron R, Richard G, Lambert G, Naili S, Meningaud J. Biomechanical determinants of the stability of dental implants: Influence of the bone–implant interface properties. J Biomech. 2014;47(3):3-13.
5. Bidez MW, Misch CE. Force transfer in implant dentistry: Basic concepts and principles. J Oral Implantol. 1992;18(3):64-74.
6. Hasan I, Roger B, Heinemann F, Keilig L, Bourauel C. Influence of abutment design on the success of immediately loaded dental implants: Experimental and numerical studies. Med Eng Phys. 2012;34(7):817-25.
7. Atwood DA. Some clinical factors related to rate of resorption of residual ridges. J Prosthet Dent 1962;12(1):441-50.
8. Saab XE, Griggs JA, Powers JM, Engelmeier RL. Effect of abutment angulation on the strain on the bone around an implant in the anterior maxilla: A finite element study. J Prosthet Dent. 2007;97(2):85-92.
9. Eger D, Gunsolley JC, Feldman S. Comparison of angled and standard abutments and their effect on clinical outcomes: a preliminary report. Int J Oral Maxillofac Implants. 2000;15(6):819-23.
10. Sethi A, Kaus T, Sochor P. The use of angulated abutments in implant dentistry: five-year clinical results of an ongoing prospective study. Int J Oral Maxillofac Implants. 2000;15(6):801-10.
11. Tekin S, Değer Y, Demirci F. Evaluation of the use of PEEK material in implantsupported fixed restorations by finite element analysis. Niger J Clin Pract. 2019;22(9):125-28.
12. Şahin S, Çehreli MC, Yalçın E. The influence of functional forces on the biomechanics of implant-supported prostheses-A review. J Dent. 2002;30(7-8):271-82.
13. Liebermann A, Wimmer T, Schmidlin PR, Scherer H, Löffler P, Roos M, *et al*. Physicomechanical characterization of polyetheretherketone and current esthetic dental CAD/CAM polymers after aging in different storage media. J Prosthet Dent. 2016;115(3):21-28.
14. Kurtz SM. PEEK Biomaterials Handbook. 1st ed. Waltham, MA: Elsevier Science, 2012, 1-7.
15. Kurtz SM, Devine JN. PEEK biomaterials in trauma, orthopedic, and spinal implants. Biomaterials. 2007;28(4):845-69.
16. Briem D, Strametz S, Schröder K, Meenen, NM, Lehmann W, Linhart W, *et al*. Response of primary fibroblasts and osteoblasts to plasma treated polyetheretherketone (PEEK) surfaces. J Mater Sci Mater Med. 2005;16(7):671-7.
17. Korn P, Elschner C, Schulz MC, Range U, Mai R, Scheler U. MRI and dental implantology: Two which do not exclude each other. Biomaterials. 2015;53:634-45.
18. Gultekin BA, Gultekin P, Yalcin S. Application of finite element analysis in implant dentistry. Intech Open Access Publisher. 2012;11(6):85-91.
19. Bevilacqua M, Tealdo T, Menini M, Pera F, Mossolov A, Drago C. The influence of cantilever length and implant inclination on stress distribution in maxillary implant-supported fixed dentures. J Prosthet Dent. 2011;105(1):5-13.
20. Premnath K, Sridevi J, Kalavathy N, Nagaranjani P, Sharmila RN. Evaluation of Stress Distribution in Bone of Different Densities Using Different Implant Designs: A Three-Dimensional Finite Element Analysis. J Indian Prosthodont Soc. 2013 Dec;13(4):555-59.
21. Darbar UR, Huggett R, Harrison A. Stress analysis techniques in complete dentures. J Dent. 1994;22(5):259-64.
22. Cift¸ci Y, Canay S. Stress distribution on the metal framework of the implant supported fixed prosthesis using different veneering materials. Int J Prosthodontics. 2001;14(5):406-11.
23. Kapoor S, Rodrigues S. Evaluation of Stress Generated with Different Abutment Materials and Angulations under Axial and Oblique Loading in the Anterior Maxilla: Three-Dimensional Finite Element Analysis. International Jo. of Dentistry. 2021;7:1-11.
24. Clelland NL, Lee JK, Bimbenet OC, Branthy WA. A Three-Dimensional Finite Element Stress Analysis of led Abutments for an Implant Place 8 in the Anterior Maxilla. J Prosthod. 1995;4(2):95-100.

25. Helkimo E, Carlsson GE, Helkimo M. Bite force and state of dentition. Acta Odont. Scand. 1977;35(6):297-03.
26. Hellsing G. On the regulation of inter incisor bite force in man. Journal of Oral Rehabilitation. 1980;7(5):403-11.
27. Hsu ML, Chan FC. Influence of off axis loading of anterior maxillary implant: 3D- Finite Element Analysis. Int. Jo. Of oral & ma. Implant. 2007;22(2):301-09.
28. Terzi M, Güvercin Y, Melih S, Sekban DM, Yaylaci M. Effect of different abutment materials on stress distribution in peripheral bone and dental implant system. sigma J Eng Nat Sci. 2020;38(3):567-89.
29. Gelb DA, Lazzara RJ. Hierarchy of objectives in implant placement to maximize esthetics: Use of pre-angulated abutments. Int J Periodontics Restorative Dent. 1993;13(3):277-87.
30. Çaglar A, Bal BT, Karakoca S, Aydın C, Yılmaz H, Sarısoy S. Three dimensional finite element analysis of titanium and yttrium-stabilized zirconium dioxide abutments and implants. The International Journal of Oral & Maxillofacial Implants. 2011;26(3):961-69.
31. Linkevicius T, Vaitelis J. The effect of zirconia or titanium as abutment material on soft peri-implant tissues: a systematic review and meta-analysis. Clin. Oral Impl. Res. 2015;26(11):139-47.
32. Sailer I, Philipp A, Zembic A, Pjetursson BE, Ha¨mmerle CHF, Zwahlen M. A systematic review of the performance of ceramic and metal implant abutments supporting fixed implant reconstructions. Clin. Oral Impl. Res. 2009;20(4):4-31.
33. Park SE, Da Silva JD, Weber HP, Nagai NI. Optical phenomenon of peri-implant soft tissue. Part I. Spectrophotometric assessment of natural tooth gingival and peri-implant mucosa. Clin. Oral Impl. Res. 2007;18(5):569-74.
34. Stawarczyk B, Beuer F, Wimmer T, Jahn D, Sener B, Roos M, *et al*. Polyetheretherketone A suitable material for fixed dental prostheses? J Biomed Mater Res B Appl Biomater. 2013;101(12):09-16.
35. Najeeb S, Khurshid Z, Matinlinna JP, Siddiqui F, Nassani MZ, Baroudi K. Nanomodified Peek Dental Implants: Bioactive Composites and Surface Modification-A Review. International Journal of Dentistry. 2015;5(2):33-38.
36. Ragupathi M, Mahadevan V, Azhagarasan NS, Ramakrishnan H, Jayakrishnakumar S. Comparative evaluation of the wear resistance of two different implant abutment materials after cyclic loading - An *in vitro* study. Contemp Clin Dent. 2020;11(3):229-36.
37. Koosha S, Jalalian E, Safari S, Zandrahimi S. Effect of Abutment Angulation and Material on Stress and Strain Distributions in Premaxillary Bone: A Three Dimensional finite element analysis. J Res Dentomaxillofacial Sci. 2017;2(4):1-8.
38. Hamedirad F, Ghaffari T, Mehanfar N. Evaluation of stress distribution in bone and three-unit fixed implant-supported prostheses with zirconia and titanium abutments: A 3D finite element analysis. JODDD. 2018;12(4):258-63.
39. Sertgo A. Finite Element Analysis Study of the Effect of Superstructure Material on Stress Distribution in an Implant-Supported Fixed Prosthesis. Int. Jo. of Prostho. 1997;10(1):19-27.
40. Kumar GA, Mahesh B, George B. Three Dimensional Finite Element Analysis of Stress Distribution around Implant with Straight and Angled Abutments in Different Bone Qualities. Indian Prosthodont Soc. 2013;13(4):466-72.
41. Koutouzis T, Richardson J, Lundgren T. Comparative soft and hard tissue responses to titanium and polymer healing abutments. J Oral Implantol. 2011;37(1):174-82.
42. Kaleli N, Sarac D, Külünk S, Öztürk O. Effect of different restorative crown and customized abutment materials on stress distribution in single implants and peripheral bone: A three-dimensional finite element analysis study. J Prosthet Dent. 2018;119(3):437-45.