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Original Article

Dentistry Section

A Three-dimensional Finite Element Analysis of Effect of Abutment Materials on Stress Distribution around Peri-implant Bone in Immediate and Delayed Loading Conditions

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ABSTRACT

Introduction: Osseointegration is important for successful dental implant treatments. Abutment materials affect the load transfer to the implant and surrounding bone thus determining the long term implant survival.

Aim: To perform stress analysis around peri-implant hard tissue with different abutment materials and their comparative evaluation in immediate and delayed loading conditions using finite element analysis.

Materials and Methods: An in-vitro experimental study was carried out at Department of Prosthodontics at Subharti Dental College Meerut, Uttar Pradesh in December 2021. on a root form titanium grade IV Implant, assembled with an abutment Ø4.0-0.5GH and this test model was three-dimensional (3D) scanned, reconstructed on computer-aided design software CREO. Six abutment groups: group 1- zirconia with Delayed Loading (DL), group 2- Polyether Ether Ketone (PEEK) with DL, group 3- Titanium grade Extra Low Interstitial (ELI) with DL, group 4- zirconia with Immediate Loading (IL), group 5- PEEK with IL, group 6- titanium grade ELI with IL, were loaded from vertical, horizontal and oblique direction. Von Mises and principal stress analysis was done on the implant and the peri-implant bone using the finite element method and the statistical analysis was done.

Results: For delayed loading group, highest stresses were generated in group 1 (462.88 MPa), followed by group 3 (413.72 MPa) and least in group 2 (319.38 MPa). For immediate loading, highest to lowest stresses were in group 4 (694.32 MPa), group 6 (620.58 MPa) and group 5 (479.07 MPa). The principal stress analysis showed significant difference between all groups in cancellous bone and cortical bone except between titanium and customised zirconia abutment in cortical bone in delayed loading ($p=0.0846$) and in immediate loading ($p=0.1125$).

Conclusion: Change in abutment materials significantly affects the stress generated in and around the implant thus more studies must be carried out to reach a consensus on the most optimal material encouraging least dissipation in peri-implant hard tissues.

Keywords: Polyether ether ketone, Titanium, Zirconia

INTRODUCTION

With the development of osseointegrated dental implants, a new era for oral rehabilitation began. Clinicians and researchers all over the world are interested in the high success rate and long term follow-up (over 20 years) of patients treated with osseointegrated dental implants [1]. The existence of osseointegration is critical for successful dental implant treatments. Two procedures are included in Branemark's protocol. The implant is put and submerged under a hermetically sutured mucosa in the first stage to allow for normal healing without the risk of bacteremia in the absence of any functional stimulation. The implant is then exposed, an abutment is affixed, and a restoration is placed on the abutment if osseointegration has happened [2]. A one step surgical approach was developed to avoid the significant psychological, cosmetic, and functional handicaps associated with the four to six month healing period. Non submerged implants are used in this approach, and loading normally begins earlier than in Branemark techniques. Immediate loading is the term for this method [3]. Progressive loading refers to the process of gradually loading an implant from one transition stage to the next in order to reduce the risk of early failure or marginal bone loss [3-5]. At the start of prosthodontic treatments, progressive or gradual bone loading is critical, especially in less dense bone types. The implant's gradual loading allows the bone to remodel and arrange in line with Wolff's law, which stipulates that trabecular bone places and displaces itself in predictable patterns [6].

Digitalisation has introduced increasingly useful tools for the development of newer materials to achieve better clinical results in the biomedical sciences. Finite Element Analysis (FEA) is an engineering method to solve complicated mechanical problems by simulation of force upon a constructed or a scanned model [1,2].

Past three decades have extensively employed FEA to evaluate the stresses acting upon the implant fixture and the peri-implant bone tissue. Successful dental implant therapy depends upon optimum load transfer from different directions to the surrounding bone. Key factors that influence it are:

1) Implant bone interface

2) Dimensions

3) Surface characteristics

4) Prosthetic design [1].

Various authors have evaluated the role of different abutment materials in the load transfer to the implant and surrounding bone in order to determine the most favourable material for the purpose of long-term implant survival [2-5]. Although a critical variable to these simulations must be the bone implant interface, most FEA models assume optimal osseointegration which does not necessarily occur in every clinical situation [5]. With the world radically shifting towards immediate loading protocols, the imperfect bond between implant surface and the surrounding bone also must be evaluated. Consequently, the most favourable abutment choice and their relationship with the developing peri-implant stresses can be determined by calculated FEA simulations [7]. The current study was done to address a more specific situation i.e., the behaviour of the different abutment materials in immediate and delayed loading separately which has not been evaluated so far. This will differentiate the preferred abutment material in specific loading condition.

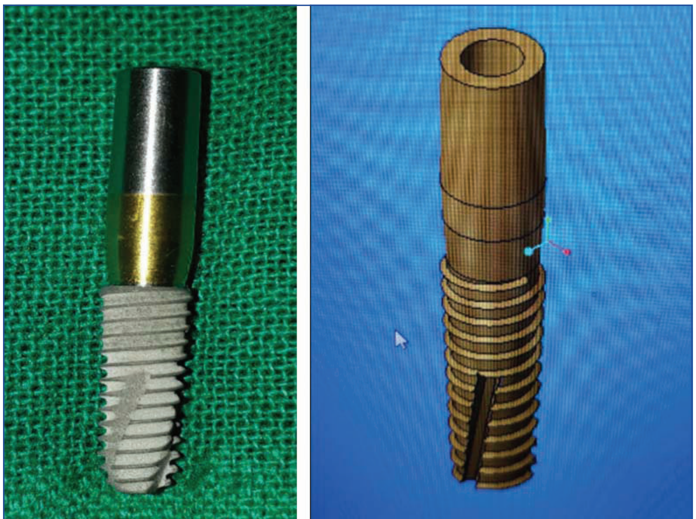
The objective of the present study was the analysis of von Mises, maximum and minimum principal stress pattern in peri-implant bone, before and after osseointegration. Also, to ascertain the most suitable material under different loading conditions. The null hypothesis was:

(a) There is no difference in von Mises stress patterns produced by titanium, zirconia and PEEK in delayed and immediate loading conditions.

(b) There is no difference in maximum and minimum principal stress patterns produced by titanium, zirconia and PEEK in delayed and immediate loading conditions.

MATERIALS AND METHODS

This in-vitro experimental study was carried out in the Department of Prosthodontics at Subharti Dental College Meerut, Uttar Pradesh in December 2021. In the preliminary step a root form Titanium grade IV Implant Ø 4.0-11.5L (Osstem TSIII SA fixture) was assembled with an abutment Ø4.0-0.5GH (Osstem Free Form ST) and this test model was 3D scanned using a 3D scanner (Artec Eva Lite [Table/Fig-1,2]. Preprocessing was done by generation of the 3D CAD model using CREO software. Thereafter the CAD model was imported into Ansys/Creo parametric Design Modeler.



[Table/Fig-1]: Osstem Implant TSIII SA fixture Ø 4.0-11.5 mm.
[Table/Fig-2]: 3D Scanned reconstruction of implant assembly. (Images from left to right)

To simulate biological entities the material properties were assigned to each part of the digitally reconstructed model of bone from reviewed literature [5,7-9]. Material properties of implant and the different abutment materials were sequentially entered to simulate their mechanical and biologic behaviour [Table/Fig-3] [5,7-9]. The bone was modelled as a cancellous core surrounded by a 1 mm thick cortical bone layer. It was 18 mm in height, 16 mm in buccolingual width, and 20 mm in mesiodistal length [9].

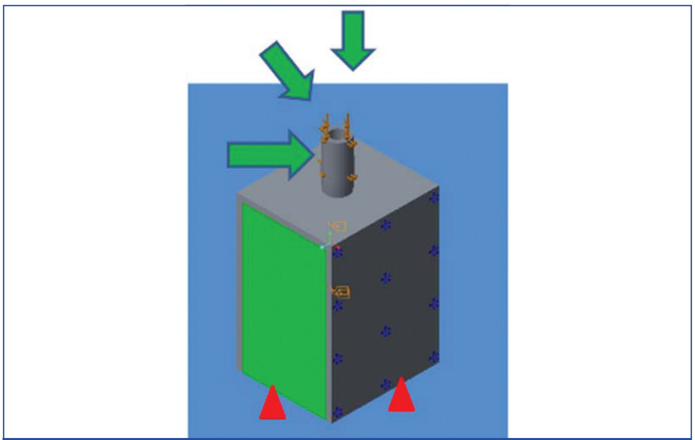
Material	Young modulus (GPa)	Poisson ratio
Cortical bone [8]	13.7	0.30
Cancellous bone [8]	1.37	0.30
Titanium grade IV implant [7]	114.0	0.37
Titanium grade ELI (abutment) [7]	113.8	0.34
Zirconia customised abutment [9]	210	0.30
PEEK customised abutment [5]	3.5	0.36

[Table/Fig-3]: Material properties [5,7-9].

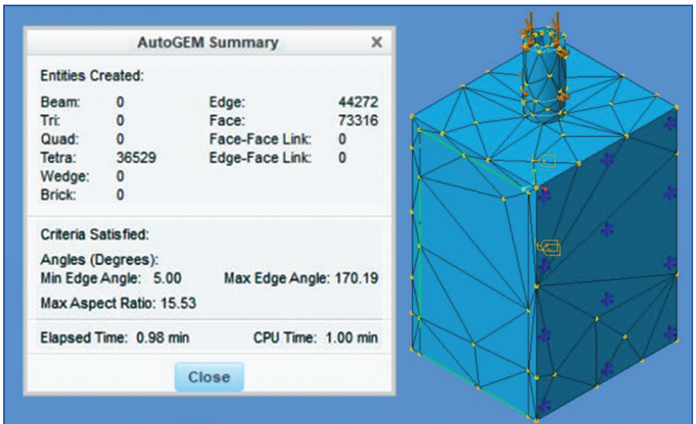
Study Procedure

Both cortical and cancellous bone were treated as homogeneous, isotropic and linearly elastic materials [10]. The implants were loaded statically under two conditions: before osseointegration (i.e., frictional interface between bone and implant) and after osseointegration (i.e., non frictional interface) (i.e., fully bonded interface between implant and bone). Stress and strain distributions were computed along the length of the bone implant contact [11]. To obtain initial stability for the situation of immediate loading after implantation, it was modelled using non linear frictional contact elements, which allowed minor displacements between implant and bone. Under these conditions, the contact zone transfers pressure and tangential forces (i.e., friction), but no tension. The friction coefficient was set to 0.3 [11].

After assigning the material properties and defining load, meshing was verified before running the final analysis [Table/Fig-4]. A total of 36529 elements and 7487 nodes were created [Table/Fig-5].



[Table/Fig-4]: Assignment of Load.



[Table/Fig-5]: Meshing.

In each model, the implants were loaded as:

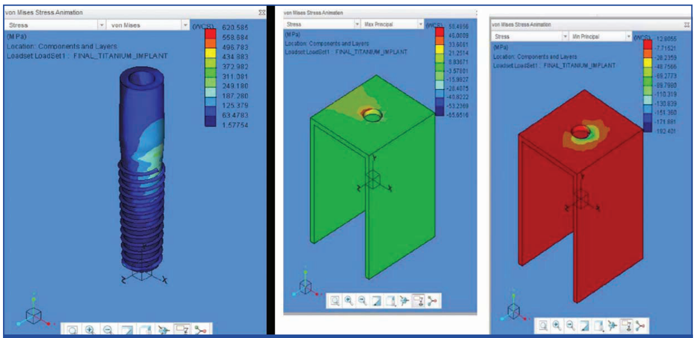
- Vertically in the top centre of abutment (200 N) [5].
- Obliquely at 300 from vertical from buccal aspect - (100 N) [5].
- Horizontally in buccolingual direction- (50N) [12].

The test models were divided into the six groups [Table/Fig-6].

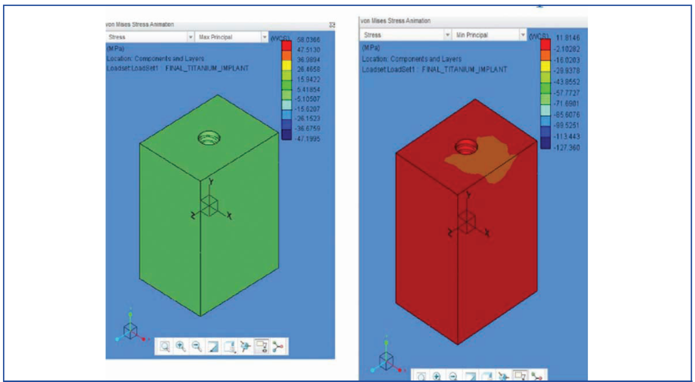
Group	Type
Group 1	Zirconia abutment with DL (Delayed loading conditions) at implant bone interface.
Group 2	Customized PEEK abutment with DL at implant bone interface.
Group 3	Titanium Grade ELI abutment with DL at implant bone interface.
Group 4	Zirconia abutment with IL (Immediate loading conditions) at implant bone interface
Group 5	Customized PEEK abutment with IL at implant bone interface.
Group 6	Titanium Grade ELI abutment with IL at implant bone interface

[Table/Fig-6]: Test groups.

The stress distribution in the implant and abutments was evaluated through the von Mises stress analysis, and the stress distribution in the peripheral bone was examined through the maximum and minimum principal stress analysis [Table/Fig-7] [5]. After collecting the data, results were tabulated, statistically analysed and compared [Table/Fig-8,9].



[Table/Fig-7]: Von mises stress analysis on implant fixture.
[Table/Fig-8]: Maximum and minimum principal stress analysis in cortical bone.
(Images from left to right)



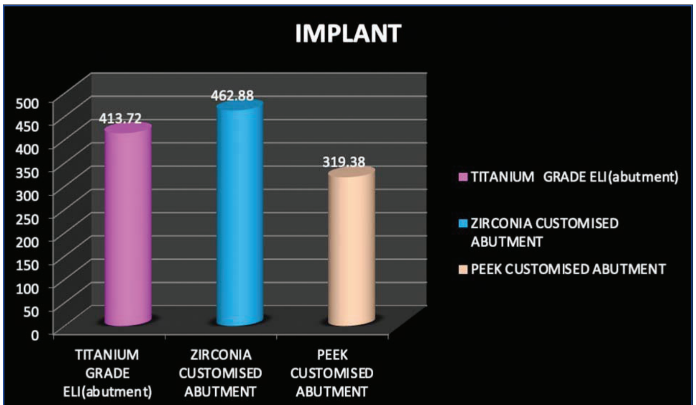
[Table/Fig-9]: Maximum and minimum Principal stress analysis in cancellous bone.

STATISTICAL ANALYSIS

The results obtained were compiled, tabulated and subjected to z-test double sample proportion test for comparison between groups. For this purpose, Statistical Package for the Social Sciences (SPSS) software, version 24 was used on a computer (Windows (x86-64)). According to the study objectives, separate analysis of results was done in delayed loading and in immediate loading for all abutments in pairs and the p value was obtained for each pair by calculating the differences in the stress values among them. The same procedure was followed to evaluate both von Mises stresses in implant body and the principal stresses in peri-implant hard tissues. Another dimension to the study was added by obtaining the difference and significance of the same abutment material by comparing them in immediate and delayed loading.

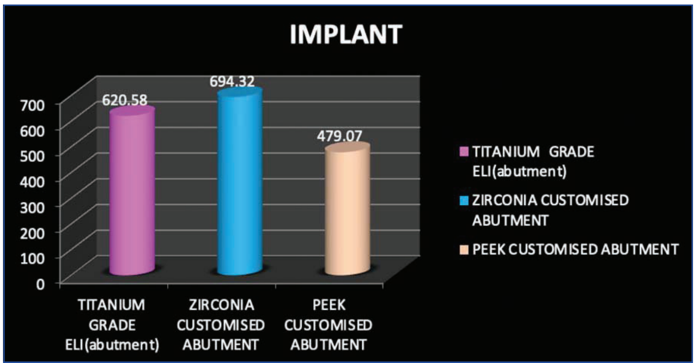
RESULTS

The result of von Mises analysis showed the highest generated stresses in the customised zirconia abutment assembly (462.88 MPa) in the delayed loading condition, followed by titanium grade ELI (413.72 MPa) abutment assembly and least in PEEK (319.38 MPa) customised abutment assembly [Table/Fig-10].



[Table/Fig-10]: Bar Diagram of von mises stress (MPa) In three different assemblies in delayed loading condition.

Similar results of stress patterns were obtained for the immediate loading condition where PEEK abutment transferred the lowest stress values in the fixture [Table/Fig-11]. Highest stresses were generated in group 4 i.e. customised zirconia abutment assembly (694.32 MPa), followed by group 6 i.e., titanium grade ELI abutment assembly (620.58 MPa) and least in group 5 i.e., PEEK customised abutment assembly (479.07 MPa). The statistics for von Mises obtained according to z-test (double sample proportion test) showed a significant difference in all assemblies to reject the null hypothesis except when comparison was done between titanium grade ELI (abutment) and zirconia customised abutment which showed a non significant (p=0.0811 in DL and p=0.0618 in IL) difference among the two [Table/Fig-12].



[Table/Fig-11]: Bar diagram of von Mises stress (MPa) In three different assemblies in Immediate Loading condition.

S. No.	Pair of different assemblies		Difference in von mises stress (MPa) and it's significance (by z-test double sample proportion test)	
			Implant In delayed loading condition	Implant in immediate loading condition
1	Titanium grade ELI (abutment)	Zirconia customised abutment	49.16 p=0.0811	73.74 p=0.0618
2	Zirconia customised abutment	Peek customised abutment	143.50 p=0.0001*	215.25 p=0.0001*
3	Titanium grade ELI (abutment)	Peek customised abutment	94.34 p=0.0016*	141.51 p=0.0001*

[Table/Fig-12]: Statistical analysis between different groups for von mises stress results. (both delayed and immediate loading conditions).
*Shows a significant change in von misses stress (MPa) at 0.05 level of significance (p<0.05)

The results of the maximum and minimum principal stress in cortical and cancellous bones showed varied values. For delayed loading, According to the results, in the cortical bone highest maximum and minimum stress values were obtained in group 2 i.e., PEEK customised abutment with titanium implant, followed by group 3 i.e., titanium grade ELI abutment and least value in group 1 i.e., zirconia customised abutment assembly. In the cancellous bone highest maximum and minimum stress values were obtained in group 1 followed by group 3 and least value in group 2 [Table/Fig-13].

In immediate loading, in the cortical bone highest maximum and minimum stress values were obtained in group 5 i.e., PEEK customised abutment with titanium implant. However, in the cancellous bone highest maximum and minimum stress values were obtained in group 4 followed by group 6 and least value in group 5 [Table/Fig-14].

The pairs of different assemblies in both cortical and cancellous bone in delayed loading condition were analysed for their maximum and minimum principal stress values [Table/Fig-15]. There was no significant difference between group 1 and group 3 for the maximum principal stresses in cortical bone (p=0.0846). All other groups showed significant difference among them for the maximum and minimum principal stress generated in both cortical and cancellous bone.

Similar results were obtained for the immediate loading condition. There was no significant difference between group 4 (zirconia

Assembly	Group	Load direction	Load (N)	Stress (MPa) cortical		Stress (MPa) cancellous	
				Maximum	Minimum	Maximum	Minimum
Zirconia customised abutment	Group 1	Vertically loading	200	34.07	4..98	44.39	16.01
		Obliquely at 30˚	100				
		Horizontally loading	50				
PEEK customised abutment	Group 2	Vertically loading	200	152.69	26.12	11.58	2.04
		Obliquely at 30˚	100				
		Horizontally loading	50				
Titanium grade ELI (abutment)	Group 3	Vertically loading	200	38.99	8.53	38.69	7.87
		Obliquely at 30˚	100				
		Horizontally loading	50				

[Table/Fig-13]: Maximum and Minimum Principal stress values in cortical and cancellous bone in delayed loading condition.

Assembly	Group	Load direction	Load (N)	Stress (MPa) cortical		Stress (MPa) cancellous	
				Maximum	Minimum	Maximum	Minimum
Zirconia customised abutment	Group 4	Vertically loading	200	51.11	7.47	66.59	24.02
		Obliquely at 30˚	100				
		Horizontally loading	50				
PEEK customised abutment	Group 5	Vertically loading	200	229.04	39.18	17.37	3.08
		Obliquely at 30˚	100				
		Horizontally loading	50				
Titanium grade ELI (abutment)	Group 6	Vertically loading	200	58.49	12.08	58.03	11.81
		Obliquely at 30˚	100				
		Horizontally loading	50				

[Table/Fig-14]: Maximum and Minimum Principal stress values in cortical and cancellous bone in Immediate loading condition.

S. No.	Pair of different assemblies		Comparative analysis by z-test double sample proportion test			
			Cortical		Cancellous	
			Maximum	Minimum	Maximum	Minimum
1	Titanium grade ELI (abutment)	Zirconia customised abutment	p=0.0846	p=0.0006*	p=0.0003*	p=0.0004*
2	Zirconia customised abutment	Peek customised abutment	p=0.0001*	p=0.0002*	p=0.0004*	p=0.0002*
3	Titanium grade ELI (abutment)	Peek customised abutment	p=0.0002*	p=0.0001*	p=0.0005*	p=0.0004*

[Table/Fig-15]: Delayed loading- individual element analysis and significance of maximum and minimum principal stress analysis between pairs of different abutment assemblies.
*Shows a significant change in von misses stress (MPa) at 0.05 level of significance ($p<0.05$)

customised abutment in IL) and group 6 (titanium grade eli abutment in IL) for the maximum principal stresses in cortical bone. All other groups showed significant difference among them for the maximum and minimum principal stress generated in cortical and cancellous bone [Table/Fig-16].

S. No.	Pair of different assemblies		Comparative analysis by z-test double sample proportion test			
			Cortical		Cancellous	
			Maximum	Minimum	Maximum	Minimum
1	Titanium grade eli (Abutment)	Zirconia customised abutment	p=0.1125	p=0.0004*	p=0.0004*	p=0.0004*
2	Zirconia customised abutment	Peek customised abutment	p=0.0011*	p=0.0031*	p=0.0022*	p=0.0012*
3	Titanium grade eli (Abutment)	Peek customised abutment	p=0.0010*	p=0.0012*	p=0.0015*	p=0.0004*

[Table/Fig-16]: Immediate loading (individual element analysis- significance of maximum and minimum principal stress analysis.
*Shows a significant change in von misses stress (mpa) at 0.05 level of significance ($p<0.05$) by z-test double sample proportion test

It was observed that when individual abutments were compared in immediate and delayed loading conditions there was significant difference achieved for the von Mises values. The results are tabulated in [Table/Fig-17]. On the contrary, the compressive and tensile stresses in the peripheral bone tissue was mostly non significant in the two loading conditions. As per the results of z-test, the stress in cortical bone for maximum principal stress in the PEEK abutment assembly had significantly higher stress dissipation during immediate loading. All other groups had no significant difference [Table/Fig-18].

Assembly	Stress (MPa) implant
Zirconia customised abutment	p=0.0003*
Peek customised abutment	p=0.0015*
Titanium grade ELI (abutment)	p=0.0133*

[Table/Fig-17]: Differences in von mises stresses b/w delayed loading condition and immediate loading condition and it's significance (double sample difference test/z-test).
*Shows a significant change in von misses stress (MPa) at 0.05 level of significance ($p<0.05$)

Assembly	Stress (MPa) cortical (Difference of stress value in immediate and delayed loading for the same abutment group), p-value		Stress (MPa) cancellous (Difference of stress value in immediate and delayed loading for the same abutment group), p-value	
	Maximum	Minimum	Maximum	Minimum
Zirconia customised abutment	17.04 p=0.1887	2.49 p=0.3884	22.20 p=0.0988	8.01 p=0.2654
Peek customised abutment	76.35 p=0.0043*	13.06 p=0.2655	5.79 p=0.3211	1.04 p=0.5442
Titanium grade ELI (abutment)	19.50 p=0.1465	3.55 p=0.3644	19.34 p=0.1465	3.94 p=0.3639

[Table/Fig-18]: Differences in principal stresses b/w delayed loading condition and immediate loading condition and it's significance (double sample difference test/z-test).
*Shows a significant change in von misses stress (MPa) at 0.05 level of significance ($p<0.05$)

DISCUSSION

In comparison to Two Dimensional (2D) models, a 3D FEA is an effective technique for standardising these characteristics and obtaining a consistent outcome [1]. The geometry, quantity, length, diameter, and angulations of implants, as well as the position of the implant(s) in the arch, all influence load distribution on implants, according to Sahin S et al., [13].

The outcomes of the current study indicate that the implant abutment assembly of the exact dimensions embed in a homogenous bony structure and subjected to similar forces will create a unique spectrum of stress with a change in abutment material. Also, the same assemblies will exert more stress in the implant and surrounding bone in immediate loading of the implants (incomplete osseointegration) compared to the delayed loading (assuming complete osseointegration has occurred).

Çaglar A et al., concluded that zirconia implant produced the lowest stresses in both the implant and the cortical bone, while values of von Mises and compressive stresses were lower in zirconia abutment than the titanium abutment [14]. Linkevicius T et al., carried out a systematic review in which data for titanium versus aluminium oxide showed no statistically significant differences in crestal bone loss [3]. Lastly, human histological data indicated better reaction of zirconium than titanium but no controlled studies tested zirconium oxide abutments to titanium abutments. This FEA study tested both types in a controlled in-vitro simulation and established better reaction of zirconia abutments to peri-implant health.

El-anwar MI et al., stated there was no significant effect over stress and deformation values in cortical and spongy bone [2]. The FEA results showed that the crown and implant receive lesser stress in order of decreasing abutment rigidity from alumina (530.67 MPa), zirconium (561.71 MPa) and titanium (624.83 MPa). This can be attributed to the fact that total stress and deformation increase upon the implant as the abutment material stiffness increases. A similar trend was observed in the current study, with increased abutment material rigidity, there was increased energy absorption in the implant material.

Kapoor S et al., in their study, applied 178N unidirectional axial and oblique stresses on angulated titanium and zirconia abutments (FEA) [15]. The implant and adjacent bone were less stressed by zirconia abutments than by titanium abutments. The stress observed in the cortical bone was higher than that recorded in the cancellous bone. As a result, higher modulus of elasticity zirconia abutments will absorb more load and transmit less stress to the implant and peri-implant bone as is analogous to current study. Another study revealed, titanium and carbon fibre reinforced PEEK implants with angled abutments had a detrimental effect on bone as they generated more stresses under parafunctional loading and hence should be avoided [10]. The biomechanical performance of one piece zirconia dental implant abutments in the peri-implant bone is superior to that of others. It distributes the applied load more efficiently, has a more homogenous stress distribution, and has less deformation than other materials as concluded by Shash M et al., [16].

Li ZY et al., observed that at 6,12,18, and 24 months following restoration, neither ceramic nor titanium abutments had a detrimental effect on peri-implant tissue [17]. According to Kaleli N et al., stress values of zirconia customized abutments were higher than those of PEEK customized abutments. Changes in customized abutment material and restoration had minimal effect on distribution of stress in the peripheral bone and implant, according to their findings. It was observed, in comparison to most ceramic materials, resin matrix ceramics have a low elastic modulus [5]. This dissimilarity may emerge as the restorative crown, cement layer, inner screw, and abutment are all involved in conveying masticatory stresses to implants and peripheral bone and these factors were not considered in the current study [5]. Although, the zirconia abutments reduced the stress in implant body in both studies. Tretto PH et al., concluded that implants made of materials having a lower elastic modulus resulted in higher stress and strain in peri-implant bone tissue i.e., for PEEK and reinforced fibreglass composite [18]. They also had a larger stress concentration in the implants.

A von Mises stress value should not exceed 550 MPa which is the yield strength of a titanium implant, as failure may occur if this value is exceeded [19]. The highest value obtained as per this study was using zirconia abutment in the immediate loading group i.e., 694. 32 MPa which would lead to imminent failure. While in the delayed loading conditions all the values were within the acceptable range with PEEK emerging as the most conducive material.

Recently the use of PEEK as an implant material, framework material and as abutment has captured popular interest. Its compatible elastic modulus seems to reduce the stresses incurred on the peripheral bone [20]. The titanium abutments are the most frequently used abutment choice for its safe load transfer and excellent biocompatibility [2]. Least conducive material for immediate loading as an abutment material is zirconia which largely exceeds the maximum bearable stress generated in the implant as per the current study [19]. Although it can be safely used after optimal osseointegration of the implant. No studies have compared the difference in stresses generated with these abutment groups for immediate and delayed loading. The immediate loading produces larger stresses affecting the longevity of the implant treatment. PEEK abutment produced significantly higher stress in cortical bone compared to titanium and zirconia. Titanium and zirconia did not show and significant difference when compared to each other for maximum principal stress in cortical bone in both immediate and delayed loading conditions. More studies are needed for evaluation of most favourable material.

Limitation(s)

Limitations of the present study include the static loading of the FEA models was not compared to a dynamic model with a range of elastic moduli for the fixture [1]. The consequences of dynamic loading should be investigated further. Bone model was assumed to be homogeneous and isotropic that differs from reality.

CONCLUSION(S)

Within the limitations of this study, it can be concluded that a change in abutment material does affect the stress generated in the implant and the peri-implant tissue. PEEK abutment showed significantly less von Mises stress in the implant body when compared to titanium and zirconia in both delayed and immediate loading condition. There was no superiority of one abutment material over another in terms of stress distribution on bone since PEEK was more optimal for cancellous bone and zirconia for cortical bone in both delayed and immediate loading conditions. All materials produced more stress on implant upon immediate loading, although the stress produced on bone were not significantly different in two loading conditions except for maximum principal stress in PEEK.

More research is needed to obtain a consensus on the most optimal abutment material for minimising stress in the implant body and peri-implant hard tissues. The pattern of stress transfer around different abutment materials must also be considered for future studies to explore the most favourable abutment for specific clinical situation.

REFERENCES

[1] Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: A review of the literature. J Prosthet Dent. 2001;85(6):585-98.

[2] El-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. Medical Research Journal. 2013;12(2):115-23.

[3] Linkevicius T, Apse P. Influence of abutment material on stability of peri-implant tissues: A systematic review. Int J Oral Maxillofac Implants. 2008;23(3):449-56.

[4] Carvalho MA, Sotto-Maior BS, Cury AA, Henriques GE. Effect of platform connection and abutment material on stress distribution in single anterior implant-supported restorations: A nonlinear 3-dimensional finite element analysis. J Prosthet Dent. 2014;112(5):1096-102.

[5] Kaleli N, Sarac D, Külünk S, Öztürk Ö. 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.

[6] Appleton RS, Nummikoski PV, Pigno MA, Cronin RJ, Chung KH. A radiographic assessment of progressive loading on bone around single osseointegrated implants in the posterior maxilla. Clin Oral Implants Res. 2005;16(2):161-67.
[7] Chun HJ, Shin HS, Han CH, Lee SH. Influence of implant abutment type on stress distribution in bone under various loading conditions using finite element analysis. Int J Oral Maxillofac Implants. 2006;21(2):195-202.
[8] Sevimay M, Turhan F, Kiliçarslan MA, Eskitascioglu G. Three-dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant-supported crown. J Prosthet Dent. 2005;93(3):227-34.
[9] Sannino G, Gloria F, Ottria L, Barlattani A. Influence of finish line in the distribution of stress trough an all ceramic implant-supported crown: A 3D finite element analysis. Oral Implantol. 2009;2(2):14.
[10] Mourya A, Nahar R, Mishra SK, Chowdhary R. Stress distribution around different abutments on titanium and CFR-PEEK implant with different prosthetic crowns under parafunctional loading: A 3D FEA study. J Oral Biol Craniofac Res. 2021;11(2):313-20.
[11] Gao J, Matsushita Y, Esaki D, Matsuzaki T, Koyano K. Comparative stress analysis of delayed and immediate loading of a single implant in an edentulous maxilla model. J Dent Biomech. 2014;5:1758736014533982.
[12] Kitamura E, Stegaroiu R, Nomura S, Miyakawa O. Influence of marginal bone resorption on stress around an implant–a three-dimensional finite element analysis. J Oral Rehabil. 2005;32(4):279-86.
[13] Şahin S, Cehreli 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.
[14] Çağlar A, Turhan Bal B, Karakoca Ş, Aydın C, Yılmaz H, Sarısoy S. Three-dimensional finite element analysis of titanium and yttrium-stabilized zirconium dioxide abutments and implants. Int J Oral Maxillofac Implants. 2011;26(5):961-69.
[15] Kapoor S, Rodrigues S, Mahesh M, Shetty T, Pai U, Saldanha S, et al. Evaluation of stress generated with different abutment materials and angulations under axial and oblique loading in the anterior maxilla: Three-dimensional finite element analysis. Int J Dent. 2021;2021:9205930.
[16] Shash M, Nazha H, Abbas W. Influence of different abutment designs on the biomechanical behavior of one-piece zirconia dental implants and their surrounding bone: A 3D-FEA. Irbm. 2019;40(6):313-39.
[17] Li ZY, Niu W, Fang W, Hu J, Wang YN. Clinical evaluation of ceramic and titanium abutment for implant-supported all-ceramic single crown. Zhonghua Kou Qiang Yi Xue Za Zhi. 2007;42(7):391-94.
[18] Tretto PH, Dos Santos MB, Spazzin AO, Pereira GK, Bacchi A. Assessment of stress/strain in dental implants and abutments of alternative materials compared to conventional titanium alloy—3D non-linear finite element analysis. Comput Methods Biomech Biomed Engin. 2020;23(8):372-83.
[19] Akça KI, Iplikçioğlu H. Finite element stress analysis of the effect of short implant usage in place of cantilever extensions in mandibular posterior edentulism. J Oral Rehabil. 2002;29(4):350-56.
[20] Khurshid Z, Hafeji S, Tekin S, Habib SR, Ullah R, Sefat F, et al. Titanium, zirconia, and polyetheretherketone (PEEK) as a dental implant material. InDental Implants. Woodhead Publishing. 2020; pp. 5-35.

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