IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 24, Issue 12 Ser. 4 (December. 2025), PP 01-07
www.iosrjournals.org

Effect Of Variable Implant Diameter In Alveolus Of Same Width, On Crestal Bone Stress Prior To And After Osseointegration- A 3-D Finite Element Analysis

Mythili Kunta, Dr Farouq Afsha Md, Garimella Umadevi
(Department Of Prosthodontics, Care Dental College, India)
(Department Of Prosthodontics, Care Dental College, India)
(Department Of Oral And Maxillofacial Surgery, Care Dental College, India)

Abstract:
Purpose: *To assess whether the quantum of crestal bone around the implant neck, has an effect on the stress distribution with increase in the implant diameter prior to and after osseointegration*
Materials and Methods: *Six models of maxillary and mandibular segments (3 each)in the molar region featuring Nobel Replace tapered implant (Nobel Biocare, Kloten, Switzerland) with different implant diameters (3.5mm,4.3mm,5mm) of 11.5mm implant length,7.5mm alveolar bone width, its superstructures and crowns were constructed using a 3-D FEA (ANSYS 15.0, ANSYS Inc, USA). At the implant bone interface, the phase prior to osseointegration was simulated by assuming a frictional coefficient and after osseointegration was simulated by assuming a fixed bond. The crestal bone stresses were analyzed under axial load of 250N, non-axial load of 100N at 45⁰ and combined axial(250N) and non-axial(100N) loads before and after osseointegration using Von Mises Criteria*
Results: *Under axial and combined loads, before and after osseointegration with an increase in the implant diameter the crestal bone stresses decreased, in both maxilla and mandible. Under non-axial load, in both maxilla and mandible before osseointegration, with an increase in the implant diameter the crestal bone stresses decreased. Under non-axial load, after osseointegration in maxilla 4.3mm implant diameter showed least crestal bone stresses and in mandible, the crestal bone stresses decreased with an increase in the implant diameter*
Conclusion: *Wider implants can withstand stresses better than the narrow implants as there is decrease in crestal bone stresses with the increase in implant diameter even though there is less quantum of bone around the implant neck.*
Key Word: *Finite Element Analysis (FEA), Crestal bone, Implant Diameter, Implant length, Axial Load, Non-axial Load.*

Date of Submission: 02-12-2025 Date of Acceptance: 12-12-2025

I. Introduction

Dental implants are used to retain and support fixed and removable dental prostheses. Over the past several decades, dental rehabilitation with implants has been widely accepted by dentists and patients because of its reliable functional and aesthetic results. With the acceptance of osseointegration as a reliable and predictable phenomenon, the utilization of dental implants as a long-term treatment modality to replace missing teeth is on the rise.

In general, the success of dental implants depends upon the type of loading, the bone implant interface, the length and diameter of implant, the characteristics of implant surface, the prosthesis type and the quality and quantity of surrounding bone for success of the implant.[1,2] The relation between implant design and load distribution at the implant bone interface is an important issue to understand.

The direct bone-to-implant interface without intervening connective tissue is known as osseointegration. The concept of osseointegration was coined by Dr. Per Ingvar Branemark and the factors which control osseointegration are surgical (primary stability and surgical technique), tissular (quality and quantity of bone, healing, remodeling), implantological (macrostructure, microstructure, and dimensions), and occlusal/mechanical (forces and prosthetic design) and inadequate control of these factors compromises the stable anchorage of the implant to the bone tissue.[3,4] For osseointegration to be properly accomplished a stress-free environment should be established.

The stress beyond a certain threshold can result in micro-damage and bone resorption, according to bone physiology theories, this would seem to suggest that high crestal stress is a cause for crestal bone loss, peri-implantitis, and even the eventual failure of an implant. It is well known that implant diameter, shape, and load direction influence stress distribution.[5]So, investigating the stress distribution can provide important information for implant design and optimizing implant placement for various types of bone quality.

Finite element analysis has proven very useful in analyzing the distribution of strains and stress in the entire bone tissue, implant, and crown structure. It is defined by several characteristics, such as dimension (one-, two-, three-dimensional), the number of the element's nodes, the associated approximation functions and is based on the principle of dividing (mesh) a structure in to a finite number of small elements (finite element) that are connected to each other at the corner points or nodes.3D models are preferred over 2D models as they are much closer to reality both in geometric modeling accuracy loads application and in boundary conditions.[6,7]

Though there are many studies regarding crestal bone loss, little information is available in the literature regarding the relationship between width of implants and stress distribution around abundantly available crestal bone. The purpose of this 3D Finite element analysis study is to assess whether the quantum of crestal bone around the implant neck influences the stress distribution with an increase in the implant diameter, prior to and after osseointegration.

II. Material And Methods

Six models of maxillary and mandibular segment (3 each) in the molar region featuring with different implant diameters with alveolar bone width kept constant, its superstructures and crowns were constructed on a personal computer using a 3-D FEA program (ANSYS 15.0, ANSYS Inc, Canonshurg, PA, USA).

The models were provided in close approximation to the in vivo geometry. The steps involved in this study are as follows:

i. Finite element modeling

Construction of geometric models, mesh generation, specifying material properties, applying boundary conditions, and application of loads.

ii. Finite element analysis

Construction Of Geometric Model

Bone model

Maxillary and mandibular bone segments relevant to molar regions were modelled from CT (computed tomography) images. Bone segments were modelled with 2 volumes, an outer shell with thickness of 1 mm[8], representing the cortical bone layer, and an inner volume representing cancellous bone tissue, assumed to be perfectly connected with the cortical layer. The height of bone segments was 16 mm for the maxillary segment and 24 mm for the mandibular segment[9] and the width of the bone for both was 7.5mm. Properties of D3 bone (Lekholm and Zarb classification) were used for the maxillary segment and that of D2 bone was used for mandible since these types of bone are commonly seen in posterior maxilla and mandible.[10]

Implant model

Nobel Replace tapered implant (Nobel Biocare, Kloten, Switzerland) was selected for the simulation and six implants were modeled. The geometric models and dimensions of the implants were taken from computer-aided design data. The modeled implants had an implant length of 11.5mm with different implant diameters (3.5mm, 4.3mm, and 5mm). Abutment (Snappy Abutment Nobel Replace) used for this study, had the dimension of 5.5 × 1.5 mm with trilobe connection.

The implant abutment complex was placed in the middle of the molar region of the bone. The influence of the phase of osseointegration was simulated assuming a different type of bond at the interface between bone and implant. This is achieved by applying the implant-bone interface type as 'bonded' and the before osseous integration was achieved by applying the implant-bane interface as 'frictional' with a friction coefficient of 0.09. This results in the continuity of the displacement field at the implant-bone interface. Furthermore, displacement functions were assumed to be continuous at possible interfaces between different implant parts (abutment, internal screw, and implant). These interfaces are the type 'Frictional' with a friction coefficient of 0.36 in the contact region.[11]The platform of the implant was modeled as flush with the alveolar ridge surface to mimic effectively a real clinical situation.

The simulated crown consisted of framework material and porcelain. Cobalt-chromium was used as the crown framework material[12]and feldspathic porcelain was used for the occlusal surface.[13,14] The length and diameter of the crown were 8 mm and 6mm respectively.[12]Porcelain thickness used in this study was 2mm, and the metal thickness used was 0.8mm.[13]

Mesh Generation

The basic principle of the FE analysis is to divide a problem domain into a non-overlapping finite number of small elements. It is achieved by replacing the continum with a set of key points called nodes, which when properly connected form the elements. This connection of nodes and elements forms the finite element of mesh. The mesh generation can be carried out either manually or automatically. The number of elements used in a problem depends mainly on element type and accuracy desired. Generally, the larger the number of nodes and elements, the more accurate is the finite element solution. After placement of the implant, abutment and crown complex in the bone model, automatic mesh generation was done, and the model was divided into many elements and nodes. (Figure 1, Figure 2) Table 1 lists the number of nodes and elements of the six models with indication to the implant model geometry type.

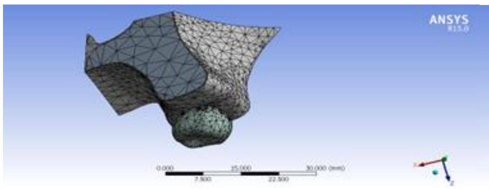


Fig:1 Maxillary mesh model

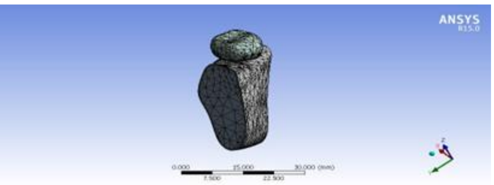


Fig:2 Mandibular mesh model

Table no 1: Shows the number of nodes and elements of the six models with indication to the implant model geometry type.

Implant diameter	3.5mm		4.3mm		4.3mm	
	Maxilla	**Mandible**	**Maxilla**	**Mandible**	**Maxilla**	**Mandible**
Nodes	44,120	43,421	44,376	40,237	44,636	40,461
Elements	23,954	21,853	24,078	21,987	24,202	22,108

Specifying material properties

For the execution and accurate analysis of the program and interpretation of the results, two material properties were utilized, i.e., Young's modulus and Poisson's ratio.[12,15] All the materials used in this study were considered isotropic, homogenous, and linearly elastic. The physical properties of different components used in this study were illustrated in Table 2.

Table no2: MATERIAL PROPERTIES

MATERIAL	ELASTIC MODULUS (G Pa)	POISSON'S RATIO (v)
Titanium alloy	110 G Pa	0.35
Cortical bone	13.7 G Pa	0.30
Cancellous bone	1.37 G Pa	0.31
Co-Cr alloy	218 G Pa	0.33
Feldspathic porcelain	82.8 G Pa	0.35

Load Application

Finite element simulations for the implants were developed considering a static load applied on top of crowns at midpoint of the implant. The non-axial load, 45 degrees to the bucco-lingual axis, was 100N, and the axial load was 250N. [16](Figure 3 and 4).

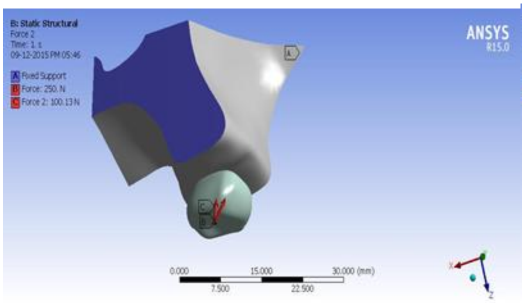


Fig 3 shows axial and non –axial load on maxilla

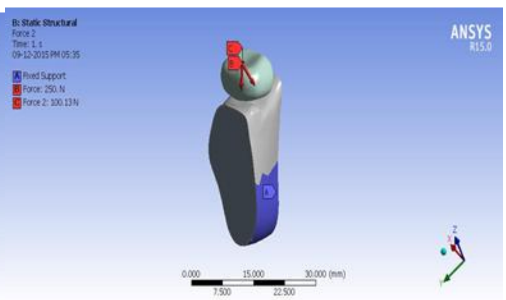


Fig:4 shows axial and non-axial load on mandible

After applying load on each model, a record of the patterns and values of stress developing around the implant in the crestal bone was displayed using different colors showing different range of stresses in the bone.

III. Result

Stresses were calculated using Von Mises Criteria (equivalent stress, abbreviated EQV stress), which represented the distribution of stresses in color-coded maps from blue to red, EQV stress patterns are shown as contour lines with different colors connecting equivalent stress points between certain ranges. Stress is expressed in MPa.

The stress fields at the crestal bone were calculated by the application of axial load (250N) along long axis of implant, non-axial load (100N) obliquely at 45 degrees and combined axial(250N) and non- axial(100N) loads on each model.

Influence of varying implant diameter

Implant diameter is the dimension measured from the peak of the widest thread to the same point on the opposite side of the implant.[17] The color plots obtained in the bone surrounding the implant were studied, the average von Mises stress were noted and tabulated for each condition.

Under axial load (250N) in both maxilla and mandible the crestal bone stresses decreased with progressive increase in implant diameter before and after osseointegration. (Table 3) Under non-axial load of 100N, in both maxilla and mandible, the crestal bone stresses decreases with progressive increase in implant diameter before osseointegration. After osseointegration, in maxilla the least crestal bone stresses were observed for 4.3mm diameter implant and further increase in implant diameter to 5mm the crestal bone stresses increased. But, in mandible after osseointegration the crestal bone stresses increased with progressive increase in implant diameter. (Table 4)

Under axial and non-axial loads in both maxilla and mandible, the crestal bone stresses decreases with progressive increase in implant diameter before and after osseointegration. (Table 5). Hence, before and after osseointegration for 11.5 mm implant length under axial load (Figure 5) and combined loads (Figure 7) 5mm implant diameter showed the least crestal bone stresses in both maxilla and mandible. But it was observed that in the maxilla, under non-axial loads, 5mm implant diameter (Figure 6) and 4.3 implant diameter (Figure 7) showed least crestal bone stresses before and after osseointegration respectively. In mandible under non- axial load before and after osseointegration, 5mm implant diameter showed least crestal bone stresses (Figure 6).

Table no 3: Von Mises equivalent stress (in MPa) for 11.5 mm implant length at crestal bone under axial load(250N)

Implant length	Implant diameter	Maxilla		Mandible	
		IBJ		IBJ	
		Before osseointegration	After osseointegration	Before osseointegration	After osseointegration
11.5mm	3.5mm	36.119MPa	32.503MPa	32.381MPa	29.057MPa
11.5mm	4.3mm	31.727MPa	27.888MPa	25.861MPa	22.123MPa
11.5mm	5.0mm	25.497MPa	20.971MPa	23.207MPa	18.6MPa

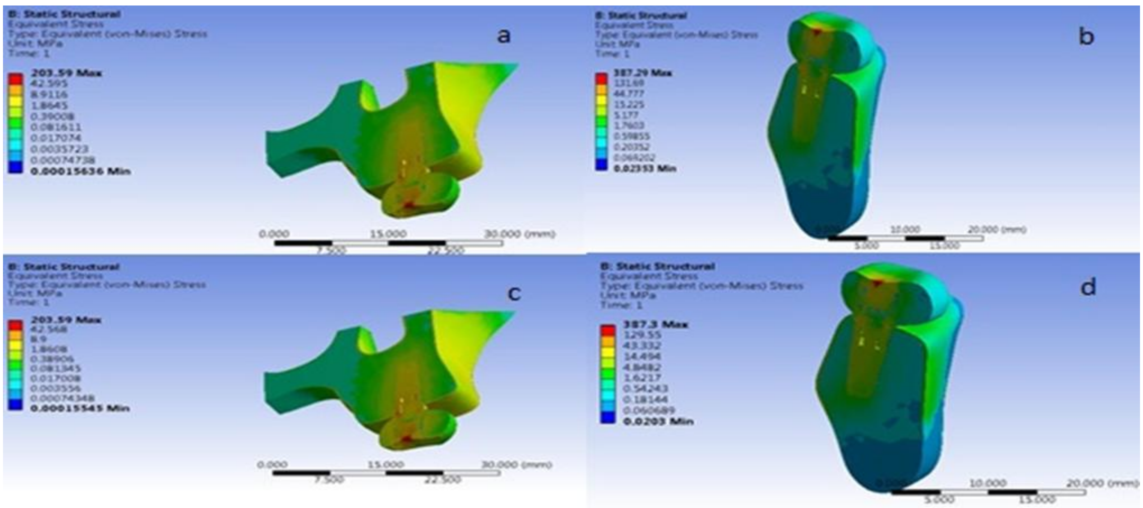


Fig: 5 Von Mises equivalent stress (in MPa) for11.5 mm implant length at crestal bone under axial load(250 N)

Table no 4 : Von Mises equivalent stress (in MPa) for 11.5mm implant length at crestal bone under non- axial load

Implant length	Implant diameter	Maxilla		Mandible	
		IBJ		IBJ	
		Before osseointegration	After osseointegration	Before osseointegration	After osseointegration
11.5mm	3.5mm	53.404 M Pa	47.915 M Pa	48.337 M Pa	44.434 M Pa
11.5mm	4.3mm	41.453 M Pa	34.304 M Pa	35.016 M Pa	31.396 M Pa
11.5mm	5.0mm	38.705 MPa	37.607 MPa	33.235 MPa	28.7 M Pa

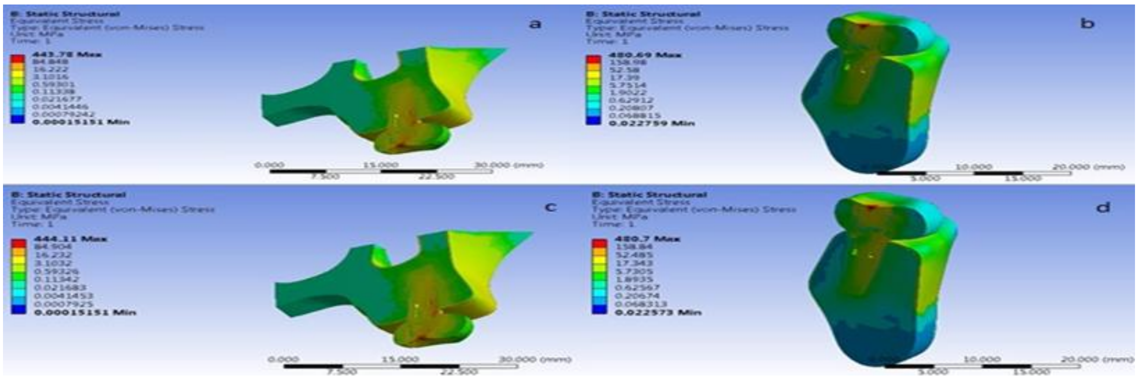
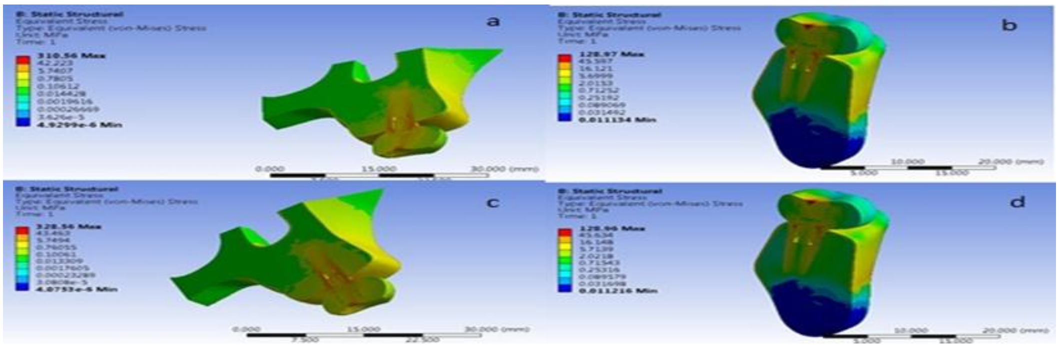


Fig: 6 Von Mises equivalent stress (in MPa) for11.5 mm implant length at crestal bone under non-axial load (100 N

Table no 5: Von Mises equivalent stress (in MPa) for 11.5mm implant length at crestal bone under axial and non axial load.

Implant length	Implant diameter	Maxilla		Mandible	
		IBJ		IBJ	
		Before osseointegration	After Osseointegration	Before osseointegration	After osseointegration
11.5mm	3.5mm	80.952MPa	71.043 M Pa	77.3 M Pa	70.67 M Pa
11.5 mm	4.3mm	61.907MPa	51.868 M Pa	55.188 M Pa	45.542 M Pa
11.5mm	5.0mm	55.395 MPa	49.411 M Pa	49.881 MPa	44.54 M Pa

Fig: 6 Von Mises equivalent stress (in MPa) for11.5 mm implant length at crestal bone under axial and non-axial load



IV. Discussion

The results of the present study on maxillary and mandibular models before and after osseointegration showed that, under axial loading conditions (250N), increasing implant diameter reduces the intensity of stresses at crestal bone. This finding was in accordance with previous studies. Pierrisnard and colleagues[18], using the finite element method, showed that increasing implant diameter reduced the intensity of stresses at crestal bone and concluded that, to increase the load-bearing capacity of implant prostheses, one could suggest using wider implants instead of longer implants. Iplikcioglu and Akca [19]in a finite element study showed that the change in the length of implants did not decrease the stress levels whereas lower stress values were observed in the bone for wider implant placement configurations.

Himmlova et al [20]and Tawil et al[21] also indicated that implant diameter was more important for improved stress distribution than length. The stress distribution on the effect of diameter variation indicates that if the diameter of implant is increased, the contact surface also increases and simultaneously stress patterns are reduced. Increasing the implant diameter effectively increase the contact area between the implant and the bone, and thus increase the stability of the implant. Finite element analysis has shown that the occlusal forces are distributed primarily to the crestal bone, rather than evenly throughout the entire surface area of the implant interface,[22,23] and therefore, the wider area of contact in the cervical portion of the implant may better dissipate the masticatory forces.

Under non-axial load of 100N, the stresses at the crestal bone in all maxillary and mandibular models were more when compared to that in axial loading conditions. This may be explained by the theoretical analyses of Rangert et al[23]; who suggested that axial loads are more favorable for uniform stress distribution surrounding the implant, while the non-axial forces generate a severe moment. Similarly, Papavasiliou et al [24] demonstrated that non-axial forces increased the stress concentration in the implant and bone.

The results of the present study showed that, under non-axial loading conditions for maxilla and mandibular models before osseointegration, increasing implant diameter reduces the intensity of stresses at crestal bone. But, after osseointegration for 10mm, 11.5mm, 13mm implant length maxillary models the least crestal stresses was observed for 4.3mm diameter implant and further increase in implant diameter to 5mm increased the crestal stress concentration values in maxilla. Whereas in mandible after osseointegration, increasing implant diameter reduces the intensity of stresses at crestal bone.

Even though finite element method is an accurate and precise method for analyzing structures, the present study had certain limitations. The bone was modelled as isotropic and homogenous when in fact it is anisotropic and inhomogeneous. As FEA is a computer simulation factors such as restrictions of models, material properties, load values, and the application type could change the results and are limited as compared to clinical situations. These limitations should be further investigated in future studies. Moreover, although static oblique and vertical load were suggested to represent a realistic occlusal load other loading conditions combined with implant positions may also be considered in future investigations

V. Conclusion

Within the limitations of the present study, following conclusions can be drawn:

- Under axial loading conditions, before and after osseointegration, with an increase in the implant diameter, the crestal bone stresses decreased in both maxilla and mandible.
- Under non-axial loading conditions, before osseointegration, with an increase in the implant diameter the crestal bone stresses decreased in both maxilla and mandible.
- Under non-axial loading conditions, after osseointegration 4.3mm implant diameter showed least crestal bone stress values suggesting that it is the most biomechanically suitable implant for non-axial loading conditions in maxilla.
- Under non-axial loading conditions, after osseointegration, with an increase in the implant diameter, the crestal bone stresses decreased in mandible.
- Under combined (axial and non-axial) loading conditions, before and after osseointegration, with an increase in the implant diameter, the crestal bone stresses decreased in both maxilla and mandible.
- There was no significant difference between stress values before and after osseointegration irrespective of varying implant diameter.

References

[1]. Carr AB. Successful Long-Term Treatment Outcomes In The Field Of Osseointegrated Implants: Prosthodontic Determinants. Int J Prosthodont 1998;11(5):502-512.

[2]. Garber GA, Belser UC. Restoration-Driven Implant Placement With Restoration-Generated Site Development. Compend Contin Educ Dent 1995;16(8):796-804.

[3]. Weyant R. Short-Term Clinical Success Of Root-Form Titanium Implant Systems. J Evid Based Dent Pract 2003; 3:127-130.

[4]. Adell R, Lekholm U, Rockler B, Branemark PI. A 15-Year Study Of Osseointegrated Implants In The Treatment Of The Edentulous Jaw. Int J Oral Surg 1981;10(6):387–416

[5]. Mcglumphy EA, Mendel DA, Holloway JA. Implant Screw Mechanics. Dent Clin North Am 1998; 42:71–89.

[6]. Goodacre CJ, Kan JY, Rungcharassaeng K. Clinical Complications Of Osseointegrated Implants. J Prosthet Dent 1999; 81:537–552.

[7]. Freitas AC, Bonfante EA, Martins LM, Et Al. Reliability And Failure Modes Of Anterior Single-Unit Implant Supported Restorations. Clin Oral Implants Res. 2012; 23:1005–1011.

[8]. Niznick GA. The Core-Vent™ Implant System. The Evolution Of The Osseointegration Implant. Oral Health 1983;73(11):13-17.

[9]. Mollersten L, Lockowandt P, Linden L-A. Comparison Of Strength And Failure Mode Of Seven Implant Systems: An In Vitro Test. J Prosthet Dent 1997; 78:582-591.

[10]. Tang CB, Liu SY, Zhou GX, Yu JH, Zhang GD, Bao YD, Et Al. Nonlinear Finite Element Analysis Of Three Implant-Abutment Interface Designs. Int J Oral Sci 2012;4(2):101-108.

[11]. Finger IM, Castellon P, Elian N. The Evolution Of External And Internal Implant/Abutment Connections. Pract Proced Aesthet Dent 2003; 8:625–634.

[12]. Ding TA, Woody RD, Higginbottom FL, Miller BH. Evaluation Of The ITI Morse Taper Implant/Abutment Design With An Internal Modification. Int J Oral Maxillofac Implants 2003; 18:865-72.
[13]. Shafie, H.R. Clinical And Laboratory Manual Of Dental Implant Abutments. 1st Ed. Wiley-Blackwell, Hoboken, NJ; 2014:66–69.
[14]. Monin JC, Monin A.Implant Abutment Connectioncone Morse Taper . Dent Implantol 2010; 10:131-139.
[15]. Merz BR, Hunenbart S, Belser UC. Mechanics Of The Implant-Abutment Connection: An 8-Degree Taper Compared To A Butt Joint Connection. Int J Oral Maxillofac Implants. 2000; 15:519-526.
[16]. Shafie, H.R. Clinical And Laboratory Manual Of Dental Implant Abutments. 1st Ed. Wiley-Blackwell,Hoboken, NJ; 2014:33-34
[17]. Chatzivarou M, Kanoy BE, Cooper L. Fracture Resistance Influence On The Implant Connection. Implant. 2003; 9:165-179.
[18]. Pierrsnard L, Renouard F, Renault P, Barquins M. Influence Of Implant Length And Bicortical Anchorage On Implant Stress Distribution. Clin Implant Dent Relat Res 2003; 5:254-262.
[19]. Iplikcioglu H, Akca K. Comparative Evaluation Of The Effect Of Diameter, Length And Number Of Implants Supporting Three Unit Fixed Partial Prostheses On Stress Distribution In The Bone. J Dent 2002; 30:41-46.
[20]. Himmlova L, Dostalova T, Kacovsky A, Konvickova S. Influence Of Implant Length And Diameter On Stress Distribution: A Finite Element Analysis. J Prosthet Dent 2004; 91(1): 20-23.
[21]. Tawil G, Aboujaoude N, Younan R. Influence Of Prosthetic Parameters On The Survival And Complication Rates Of Short Implants. Int J Oral Maxillofac Implants 2006; 21:275-282.
[22]. Zhang Y, Et Al. Stress Analysis On Different Diameter Implants In Varying Bone Densities Using Nonlinear FEA.J Mech Behav Biomed Mater. 2022;125:104980.
[23]. Rangert BO, Jemt T, Jorneus L. Force And Moments On Branemark Implants. Int J Oral Maxillofac Implants 1989; 4:241-247.
[24]. Papavasiliou G, Kamposiora P, Bayne SC, Felton DA. Three Dimensional Finite Element Analysis Of Stress Distribution Around Single Tooth Implants As A Function Of Bony Support Prosthesis Type, And Loading During Function. J Prosthet Dent 1996;76:633-640.