Original Article

A three-dimensional finite element analysis of a passive and friction fit implant abutment interface and the influence of occlusal table dimension on the stress distribution pattern on the implant and surrounding bone

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Abstract

Aims: The aim of the study was to evaluate the stress distribution pattern in the implant and the surrounding bone for a passive and a friction fit implant abutment interface and to analyze the influence of occlusal table dimension on the stress generated.

Materials and Methods: CAD models of two different types of implant abutment connections, the passive fit or the slip-fit represented by the Nobel Replace Tri-lobe connection and the friction fit or active fit represented by the Nobel active conical connection were made. The stress distribution pattern was studied at different occlusal dimension. Six models were constructed in PRO-ENGINEER 05 of the two implant abutment connection for three different occlusal dimensions each. The implant and abutment complex was placed in cortical and cancellous bone modeled using a computed tomography scan. This complex was subjected to a force of 100 N in the axial and oblique direction. The amount of stress and the pattern of stress generated were recorded on a color scale using ANSYS 13 software.

Results: The results showed that overall maximum Von Misses stress on the bone is significantly less for friction fit than the passive fit in any loading conditions stresses on the implant were significantly higher for the friction fit than the passive fit. The narrow occlusal table models generated the least amount of stress on the implant abutment interface.

Conclusion: It can thus be concluded that the conical connection distributes more stress to the implant body and dissipates less stress to the surrounding bone. A narrow occlusal table considerably reduces the occlusal overload.

Key Words: Conical connection, friction fit interface, implant abutment interface, occlusal table dimension, passive fit interface, Tri-lobe connection

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INTRODUCTION

Dental implant-supported prostheses have become one of the significant treatment modalities for replacement of teeth, with reported success rates of over 98.2%.[1] The success of dental implants is highly dependent upon the integration between the implant and the intraoral hard/soft tissues. The long term success or survival of dental implants is determined by the transmission of occlusal load and resultant stress distribution in the surrounding bone. Load transfer at the bone-implant interface depends on: (1) The implant geometry and the design of implant abutment connection; (2) the loading protocol and the type of occlusion; (3) the number of implants and position; (4) the quality and quantity of the surrounding bone.[2-6]

It has been demonstrated that vertical and transverse masticatory loads induce axial forces and bending moments that results in stress gradients in the implant, as well as in the bone. Rieger *et al.*[7] reported that stresses in the range 1.4-5.0 MPa may be required for healthy maintenance of bone, stresses outside this range have been reported to cause bone resorption. According to Frost's mechanostat concept,[8] bone fractures at 10,000–20,000 microstrains. However, just 20% to 40% of the amount of strain required for fracture (i.e., 4,000 microstrains) may trigger cytokine to activate a resorptive response. A persistent load increases the stress and may provoke micro-fractures and osteoclastic activity in the bone.

There has been a continuous evolution of the implant abutment connection design with the intensions of reducing these stress concentrations. Based on the various prosthetic and biological complications encountered in the clinical scenario and the results of various studies, the initial external hex design which had the interface above the implant and the osseous crest, has evolved into the internal hex with the implant abutment interface being placed more apically and away from the osseous crest. More than 20 designs of the internal connections are currently being marketed.[9] These can be broadly categorized as follows.[10]

Passive fit implant abutment connections	Friction fit implant abutment connections
Nobel Replace (Tri-lobe connection)	Nobel active (internal conical with hexagonal interlocking)
XiVE® Sby Dentsply-Friadent, Core-Vent. (six-point internal hexagon)	Zimmer (tapered internal hex with friction fit)
Osseotite certain (12-point internal hexagon)	ITI Straumann, Ankylos (8° Morse taper)
Omniloc (internal octagon)	Astra (11° taper)
Frialit-2 (internal cylinder hex)	Bicon (1.5° tapered rounded channel)
Camlog (Cam tube connection)	

The development of these implant abutment interfaces have reduced the amount of stress that is transmitted to the implant or the surrounding bone and therefore considerably reducing the crestal bone loss, although not entirely eliminated indicating a multi-factorial cause. The structural complexity of implant abutment interface design due to the continuous improvement in the geometry has made it difficult to evaluate occlusal forces in the bone around the dental implant and the stresses within the implant. Finite element analysis (FEA) is a useful tool for the prediction of the effects of stress on the implant and its surrounding bone.[11] The use of the finite element method to analyze stress concentrations was initially introduced into implant dentistry by Weinstein *et al.* in 1976.[12] In FEA, the mechanical performance of the implant abutment interface could be evaluated by Von Misses stresses. Von Misses stress criterion is important to interpret the stresses within the ductile material, such as the implant material; as deformation occurs when the Von Misses stress value exceeds the yield strength. Finite element studies comparing different connections and the effect of the change in occlusal table width dimensions on stress distribution pattern in and around the implant abutment interface are limited. In this study, an attempt is made to compare the stress distribution pattern of a passive fit and friction fit implant abutment interface in different areas of the implant and bone and the influence of occlusal table width on stress distribution.

MATERIALS AND METHODS

Finite element analysis is a computerized numerical technique used to determine the stress and displacements through a predetermined model. FEA solves a complex problem by dividing it into a series of interrelated simple problems. A mesh is needed in FEA to divide the complex geometry into smaller elements in which the field variables can be interpolated with the use of shape functions. The process of creating the mesh, elements, their respective nodes and defining boundary conditions is referred to as "discretization" of the problem domain.[13]

Construction of geometric model

The study models were constructed using reverse engineering technique in PRO-ENGINEER 05 through three-dimensional (3D) optical scanning and point cloud data extraction. The reverse-engineering process involves measuring an object and then reconstructing it as a 3D model. Two CAD models of implants were constructed with two different types of implant abutment connections currently available in the market, the passive fit or the slip-fit represented by the Nobel Replace Tri-lobe connection (Nobel Replace, Tapered Groovy, RP 4.3 mm × 13 mm) and the friction fit or active fit represented by the Nobel active conical connection (Nobel active, Internal RP 4.3 mm × 13 mm) along with their respective snappy abutments.

The bone structure was modeled through a computed tomography (CT) scan that can provide results closer to a real scenario, because there is a difference in the behavior of stresses in work conducted with elliptical models, cobblestones, and CT scan data.[14] The thickness of the cortical bone was kept 2 mm, and a uniform layer of cortical bone was modeled on the outer surface of the cancellous core. A bone block model was constructed based on a cross-sectional image of the human mandible in the premolar region, 25 mm high, 12 mm wide, and 10 mm thick consisting of a spongy center surrounded by a 2-mm cortical bone.

Three crowns with different occlusal table dimensions were constructed by changing the buccolingual dimensions and keeping mesiodistal and the cervicoocclusal length constant. The dimensions of a mandibular premolar are 7.5 mm buccolingually, 9 mm mesiodistally, and 8 mm cervicoocclusally. The buccolingual dimension with 7.5 mm was considered as ideal, and then crowns with narrow and wider occlusal tables were constructed with 6 mm and 10 mm buccolingual dimension, respectively. They were then placed over the passive connection and the friction connection making a total of six models. The implant abutment complex thus constructed using reverse-engineering technique was then positioned in the cortical and cancellous bone block.

Mesh generation of the model

The 3D models corresponding to the geometric model was meshed using HYPERMESH 10 and then imported into ANSYS 13 software to perform the numerical simulation. All the components were meshed with solid 92 elements. It is a 2nd order Tetra Element which has a Quadratic displacement behavior and is well suited to model irregular meshes. The element is defined by 10 nodes having 3° of freedom at each node and 3 translations in nodal X, Y, and Z directions. The numbers of nodes in friction connection for ideal, narrow, and wider occlusal table are 80,786, 82,047, and 83,972; and the number elements are 57,082, 57,737, and 58,931, respectively. The numbers of nodes in passive connection for ideal, narrow, and wider occlusal table are 76,330, 77,469, and 79,527; and the number elements are 53,569, 54,137, and 55,414, respectively. Meshed models of passive-fit connection and friction fit connection are shown in Figure 1a.

Boundary conditions and constraints

In this study, we assumed the implant, abutment, and screws were homogeneous, linear elastic, and isotropic mechanical properties. However, cortical and cancellous bones were treated as anisotropic. Material properties for bone and implant components [Table 1] were collected from reliable resources and published data.[15-20] The implant was pure titanium, and other components were titanium alloys, with homogeneous and isotropic elastic properties. It was assumed that there is complete osseointegration between the implant and the surrounding bone.

Loading conditions

A distributed force of 100 N was applied onto the top surface of the crown vertically along the long axis and then obliquely at 45° to the longitudinal axis of the implant. For a direct and systematic comparison, the same loading conditions, boundary conditions, and constraints was applied in all the models. The vertical and oblique loading directions on a meshed model of a passive fit connection as an example are shown in Figure 1b.

RESULTS

The data obtained from ANSYS calculation can be presented in a stress distribution map with a color scale, which makes it possible to compare directly the stress level in various component structures of all models. The amount of stress and the pattern of stress generated after applying a load of 100 N on each model in vertical and oblique direction were recorded on a color scale. The values obtained are summarized in the Table 2. The Figures 2-4 shows the Von Misses stresses during vertical and oblique loading with 100 N on a narrow occlusal table in different regions of friction fit and passive fit implant abutment interface and Figures 5 and 6 show graphs of Von Misses stress (in MPa) on narrow, ideal, and wider occlusal tables in vertical and oblique loading on implant, implant abutment interface, and bone in friction fit and passive fit connections.

From the values given in Table 2 the following data and results have been obtained:

- The overall maximum Von Misses stress on the implant is more significant for friction fit than the passive fit implant abutment interface in both vertical and oblique loading for all the models tested
- At the implant abutment interface and at the neck of the

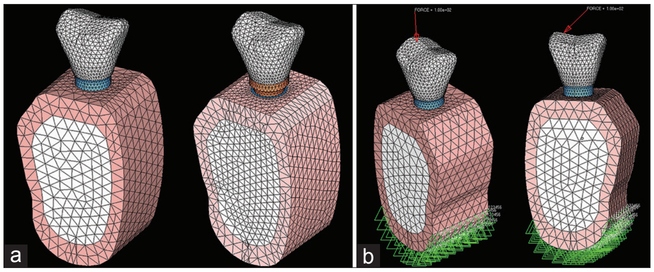

Figure 1: (a) Meshed models of passive fit connection and friction fit connection. (b) The vertical and oblique loading directions on a meshed model of a passive fit connection

Table 1: Mechanical properties of different materials.

Material	Youngs Modulus (MPa)	Poissons ratio
Cancellous bone	1100	0.30
Cortical bone	13700	0.30
Titanium (implant)	110,000	0.33
Titanium alloy (abutment and Screw)	110,000	0.33
Cobalt chromium (metal coping)	87900	0.30
Porcelain	70,000	0.19

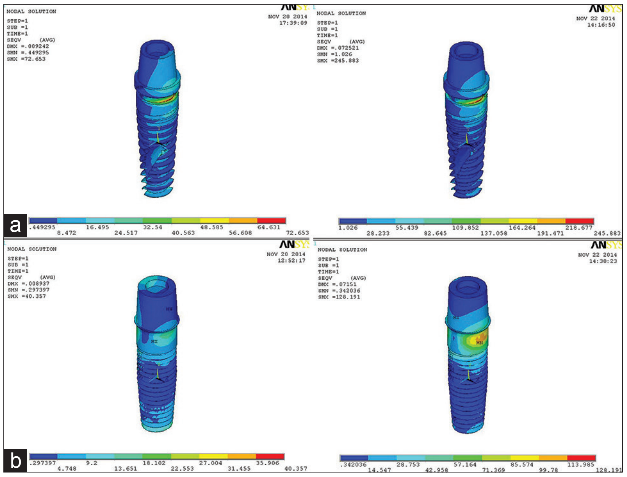

Figure 2: (a) Von Misses stress on an implant with friction fit connection and passive fit connection during vertical loading with a load of 100 N in models with narrow occlusal table. (b) Von Misses stress on an implant with friction fit connection and passive fit connection during oblique loading with a load of 100 N in models with narrow occlusal table

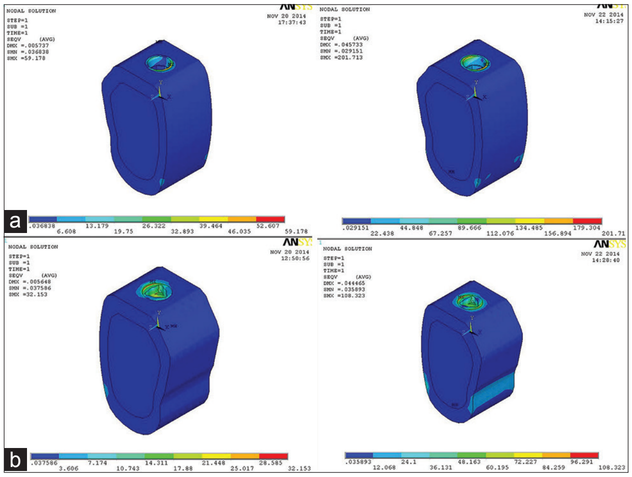

Figure 3: (a) Von Misses stress on an implant abutment interface with friction fit connection and passive fit connection during vertical loading with a load of 100 N in models with narrow occlusal table. (b) Von Misses stress on an implant abutment interface with friction fit connection and passive fit connection during oblique loading with a load of 100 N in models with narrow occlusal table

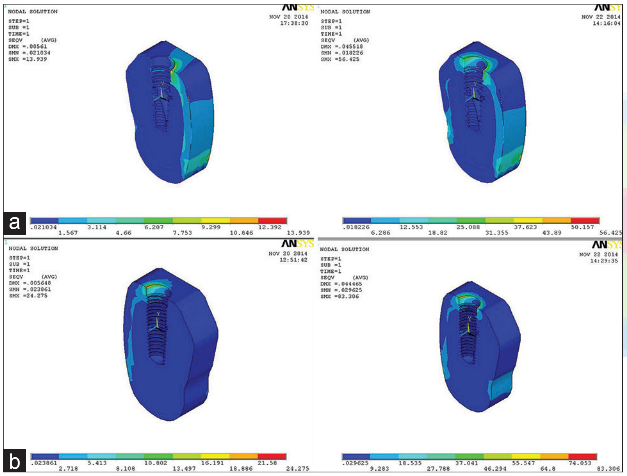

Figure 4: (a) Von Misses stress on the bone with friction fit connection and passive fit connection during vertical loading with a load of 100 N in models with narrow occlusal table (b) Von Misses stress on the bone with friction fit connection and passive fit connection during oblique loading with a load of 100 N in models with narrow occlusal table

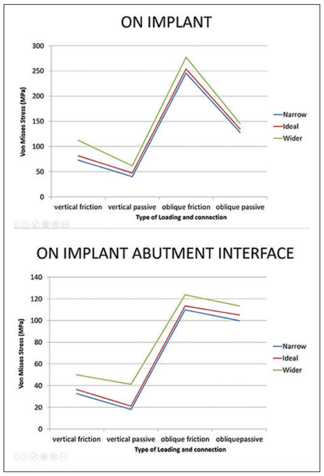

Figure 5: Graph showing Von Misses stress (in MPa) on narrow, ideal, and wider occlusal tables in vertical and oblique loading on implant and implant abutment interface in friction fit and passive fit connections

implant, the Von Misses stress was higher for the friction fit. Whereas on the outer surface of the abutment and on the internal surface of the fixture; the passive fit shows lesser stress in both vertical and oblique loading for all the models tested

- The overall maximum Von Misses stress on the bone is significantly less for friction fit than the passive fit in both vertical and oblique loading for all the models
- Irrespective of the type of abutment connection used, the maximum Von Misses stress was seen in the region of the cortical or the marginal bone. It is showed that a significant reduction in Von Misses stress was observed at the boundary between cortical bone and cancellous bone in both loading conditions
- The narrow occlusal table, irrespective of their connection type has reduced the stress generated. This shows that the width of the occlusal table has got a significant influence on the stress generated on the implant, as well as on the bone.

DISCUSSION

The aim of the study was to analyze the influence of two different types of implant abutment connection on the stress distribution pattern in the implant and the surrounding bone. The implant abutment interface that have been analyzed in the study represent two broad categories of implant abutment connection currently available in the market, the passive fit or the slip-fit represented by the Nobel Replace Tri-lobe

Table 2: Von misses stress (in mpa) on the implant abutment complex with prosthesis having narrow, ideal and wider occlusal tables

Site	Vertical loading						Oblique loading					
	Friction-fit connection			Passive-fit connection			Friction-fit connection			Passive-fit connection		
	Narrow	Ideal	Wider	Narrow	Ideal	Wider	Narrow	Ideal	Wider	Narrow	Ideal	Wider
On Implant	72.653	81.335	112.188	40.357	47.345	61.714	245.883	253.761	277.244	128.191	134.872	145.683
Outer surface of abutment	8.105	9.413	12.492	9.474	11.257	14.695	27.346	28.219	30.835	32.287	33.71	35.941
At the implant abutment interface	32.54	36.384	50.082	18.102	21.149	41.202	109.852	113.374	123.604	99.78	104.969	113.471
At the neck	59.178	66.068	87.278	32.153	38.667	55.025	201.713	207.974	223.665	108.323	115.236	128.427
Internal surface of the fixture	13.179	14.688	19.419	14.311	17.20	24.472	22.433	23.131	24.882	24.10	25.654	28.574
On bone	13.939	15.072	18.71	24.275	28.947	38.819	56.425	57.037	58.245	83.306	87.661	95.781
On crestal bone	12.392	15.072	18.71	16.191	19.304	21.577	25.088	25.361	25.898	27.788	29.241	31.942
At the neck	1.567	1.682	2.106	2.718	3.232	4.335	6.286	6.356	6.49	9.283	9.767	10.663
At the apex	0.0210	0.0083	0.0301	0.0238	0.0178	0.0244	0.0182	0.0205	0.0203	0.0296	0.0308	0.0230
On Crown	249.52	319.832	437.956	293.504	479.77	502.735	426.103	460.666	698.032	455.591	462.675	701.436

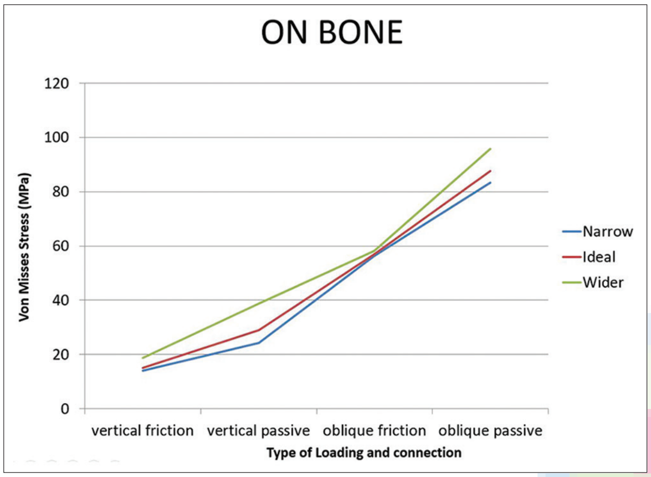

Figure 6: Graph showing Von Misses stress (in MPa) on narrow, ideal, and wider occlusal tables in vertical and oblique loading on bone in friction fit and passive fit connections

connection and the friction fit or active fit represented by the Nobel active conical connection. The stress distribution pattern was studied at different occlusal dimension. Six models were constructed in PRO-ENGINEER 05 of the two implant abutment connection for three different occlusal dimensions each. The implant and abutment complex was placed in cortical and cancellous bone modeled using a CT scan. This complex was subjected to a force of 100 N in the axial and oblique direction. The amount of stress and the pattern of stress generated were recorded on a color scale.

The mean values of overall stress on the implant with friction fit connection were 88.725 for vertical load and 258.962 for oblique load whereas on passive fit were 49.805 and 136.249, respectively, indicating that friction fit produced higher overall stress on the implant than the passive fit. The mean values of overall stress on the bone for vertical and oblique loading on friction fit connection were 15.907 and 57.236 whereas on a passive fit connection were 30.680 and 88.983, respectively. This show that the stress generated by passive fit connection on bone is almost double the stress generated by the friction fit connection. The mean values of the overall stresses on the implant and the bone shows that the friction fit connection absorbs more stress and dissipates less stress to the surrounding bone. The larger contact area and deeper position inside the implant for friction fit connection allowed for better stability and broader stress distribution, as has been observed in several other studies.[21-23]

Conical connections were developed to achieve friction-based fit of the implant components.[24-26] This frictional fit creates wedging effects to improve the implant abutment joint stability against the lateral force and helps to transfer the loading force along the conical surface to distribute the stress on the implant, ultimately reducing biological and biomechanical complications.[27,28] The internal conical connections help the abutment screw retain greater preload after repeated loads since the loading stress is not entirely concentrated on the screw as in the external hex butt joint implant systems. The friction-locking mechanics and the solid design of the friction fit connections provided greater resistance to deformation and fracture under oblique compressive loading when compared to the passive fit connection.[29]

In passive fit connection, the cold welding does not occur when the abutments are tightened thus an inevitable gap between the implant and abutment may still exist.[30,31] This can cause micro-motion at the interface during clinical loading, which in turn may contribute to stress on the screw and therefore loss of preload and loosening of abutment thereby leading to bacterial colonization of the micro gap. The threshold of deleterious micro-motion level asserted by various researchers' lies within the range of 50–150 µm.[32-34] Beyond these levels of micro-motion, stress concentration may occur around inserted dental implants leading to crestal bone loss.

The mean values of stress on the crestal bone for vertical and oblique loading on friction fit connection were 15.391 and 25.449 whereas on a passive fit connection were 19.024 and 29.674, respectively. The highest stress occurs in the implant's most cervical region when an occlusal load is applied upon an implant, and the load is partially transferred to the bone. This phenomenon is due to one of the principles of engineering, that is, when two materials are in contact with each other, and one of them is loaded, the stresses will be higher at the materials' initial point of contact. This explains why the cervical region of the implant is the site where the greatest micro-deformations occur independently of the type of bone and the design of the implant, the configuration of the prosthesis and the load.[4] The results of the current FEA for the osseointegrated model are in accordance with the findings of Hansson.[35] Using FEA, Hansson showed that a conical implant abutment interface at the level of the bone crest decreases the peak bone-implant interfacial stress as compared with the flat top interface. For the friction fit implant abutment interface, this peak interfacial shear stress was located at some depth in the marginal bone.

The mean values of stress on the apical area of bone for vertical and oblique loading on friction fit connection were 0.019 and 0.021 whereas on a passive fit connection were 0.0215 and 0.0278, respectively. In this study, significantly larger stress values were seen in the neck area versus the apex area among all models in all conditions, which is consistent with the results of other studies. Stresses induced by occlusal load are initially transferred from implant to the cortical bone, and a small amount of remaining stress spreads to cancellous bone. Higher stress values are observed in cortical bone because of higher modulus of elasticity and bone density compared to the cancellous bone.

Richter[36] has reported that the highest stress in the crestal bone is a result of a transverse load and clenching at centric contacts. The width of almost every natural tooth is greater than the width of the implant used to replace the tooth. The greater the width of a transosteal structure, the lesser the magnitude of stress transmitted to the surrounding bone. The cross-sectional shape of the natural tooth at the crest is biomechanically optimized to resist lateral loads, implants, however, are almost round in cross-section, which is less effective in resisting lateral bending loads thereby concentrating loads in the crestal region.[37] The mean values of axial displacement of teeth in the socket are 25-100 μm, whereas the range of motion of osseointegrated dental implants has been reported approximately 3-5 μm.[38] The elastic modulus of the tooth is closest to bone compared to the available implant biomaterials. Hence, under similar loading conditions implant generates greater stresses and strain at the crest of bone than a natural tooth.

From the results of the study, it is shown that the narrow occlusal table, irrespective of their connection type has reduced the stress generated. This shows that the width of the occlusal table has got a significant influence on the stress generated on the implant, as well as on the bone. Typically, a 30% to 40% reduction in the occlusal table in a molar region has been suggested because any dimension larger than the implant diameter can cause cantilever effects and eventual bending moments in single-implant prostheses.[3,39] A narrow occlusal table reduces the chance of offset loading and increases axial loading, which eventually can decrease the bending moment. Misch has described how a narrow occlusal table can improve oral hygiene and reduce the risk of porcelain fracture. The proposed key factors to control bend overload in posterior restorations were reduced the inclination of cusps, centrally oriented contacts with a 1–1.5 mm flat area, a narrowed occlusal table, and elimination of cantilevers.[40] As the wider occlusal table will increase stress on the abutment screws, the occlusal table should be reduced in width compared with natural teeth in nonesthetic regions of the mouth.

Analysis of finite elements was shown to be a versatile and promising methodology for analyzing stress concentrations in implant dentistry, but it is worth emphasizing that the FEA is an approximate virtual simulation of clinical situations, presenting certain limitations.[41] Hart *et al.* demonstrated that FEA models with more than 10,420 nodes showed convergent results.[42] The present study models featured an average of 80,021 nodes and 56,145 elements. Therefore, the results derived from this FEA may be considered to be reasonably accurate and acceptable.

CONCLUSION

Within the limits of the present study, the following conclusions can be derived:

- The overall maximum Von Misses stress on the implant is significantly more for friction fit connection than the passive fit connection in both vertical and oblique loading in all the models; whereas the overall maximum Von Misses stress on the bone is significantly less for friction fit connection than the passive fit connection in both vertical and oblique loading in all the models. The overall maximum Von Misses stress values on the implant and the bone show that the friction fit connection absorbs more stress and dissipates less stress to the surrounding bone. Further studies on the permissible amount of micro-movement allowed in a passive fit implant abutment interface may need to be conducted
- Irrespective of the type of abutment connection used the maximum Von Misses stress was seen in the region of the cortical or the crestal bone. It is shown that a significant reduction in Von Misses stress was observed at the boundaries between cortical bone and cancellous bone in both loading conditions because of relatively low elastic modulus of cancellous bone

- On comparing the stresses on narrow, ideal and wider occlusal tables for both frictions fit connection and passive fit connection, the results show that the narrow occlusal table has the least stress followed by ideal and the wider occlusal tables. The narrow occlusal table irrespective of their connection type has reduced the stress generated. This shows that the width of the occlusal table has got a significant influence on the stress generated on the implant, as well as on the bone.

The friction fit connection is superior to the passive fit connection, as the friction fit creates wedging effects to improve the implant abutment joint stability against the lateral force and helps to transfer the loading force along the conical surface to distribute the stress on the implant, ultimately reducing biological and biomechanical complications. A narrow occlusal table may increase axial loading and decrease nonaxial loading for the implants thereby reducing the stress on the implant, implant abutment interface, and bone. Thus, it is recommended that the size of the occlusal table to be 30% to 40% smaller for molars.

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