

Influence of Occlusal Forces on Stress Distribution on Preloaded Dental Implant Abutment Screws: A Finite Element Analysis Study

RH Deepa, GP Surendra Kumar, CL Satish Babu, Shilpa Shetty, KR Jnandev, P Rohit, Mohammed Fayaz Pasha

ABSTRACT

Purpose: The aim of the study is to determine stress distribution on preloaded implant-abutment screws in three different implant systems under simulated occlusal loads.

Materials and methods: Three abutments to implant internal hex joint systems were simulated by using the 3-dimensional finite element analysis; (1) Nobel Biocare replace tapered (2) Uniti (3) Lifecare self-threaded tapered cement retained abutments. Thermal load and contact analysis were used to simulate preload resulting from the torque in implant screw joint assemblies. The simulated preload implants were then loaded with three static occlusal loads (10N horizontal; 35N vertical; 70N oblique) onto the crown into the implant complex.

Results: Under preload and static occlusal forces, maximum Von-Mises stresses were concentrated at the lower portion of abutment for all systems. Maximum stresses were concentrated at lower threaded portion of abutment screw in Nobel Biocare, Uniti but in Lifecare system, stresses were concentrated at the middle threaded portion. Maximum stresses were concentrated at middle threaded portion of implant in Nobel Biocare, Uniti but at the upper threaded portion in Lifecare. Stresses increased under static occlusal forces in abutment screw in Nobel Biocare and Uniti but were more under oblique forces. In Lifecare stresses decreased under horizontal forces and increased in vertical and oblique forces.

Conclusion: Although, an increase or decrease was demonstrated for the maximum calculated stress values in preloaded screws. After occlusal loads, these maximum stress values were well below the yield stress of abutment screw systems tested.

Keywords: Stress distribution, Static occlusal loads, Von-Mises stresses.

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INTRODUCTION

Osseointegrated implant support for dental restorations continues to be the best treatment option for replacing missing natural dentition. Primarily the abutment is retained by means of a screw.¹ The restoration on the abutment can be either screw retained or cement retained. Earlier practice

of cementing the abutment directly into the implant before placing the crown is no longer recommended.¹⁻⁷

Screws are an integral part of virtually all implant-retained crown systems.² Screw loosening seems to occur most often with the single tooth implant restorations and it has also been reported to occur in multiple unit situations. It is considered to be a common problem with both screw retained and cement retained restoration.⁷ Several complications can arise as a result of loose screws which retain the abutment or restorations. There can be granulation tissue between the loose abutment and implant leading to infection of the soft tissue and fistula formation. In addition, loose screws are more apt to fracture under load leading to long-term prosthesis complications.⁸ The most likely cause of screw loosening is inadequate tightening of the screw. Other possible factors include nonpassive frameworks, cantilevered framework, excursive contacts, off-axis centric contacts, angled abutment, wide occlusal table and interproximal contacts.^{9,10}

Bickford described the process of screw loosening in two stages. Initially, external forces such as mastication applied to the screw joint caused thread slippage, contributing to release of the preload of the screw. The second stage of loosening involves continual preload reduction below critical level, allowing threads to turn and loss of intended screw joint function.¹¹ Jorneus et al observed that if the bending force on a single restoration caused a load larger than the yield strength of the screw, there was a deformation of the screw and disengagement of the mating threads. In one study, nonlinear contact analysis method was used to determine distribution of stresses in the abutment and gold retaining screws. The author found that the maximum tensile stresses in both screws after preload were less than 55% of the yield stress. However, no studies were found in the literature that evaluated the effect of functional forces on preloaded implant screws.¹² The purpose of this *in vitro* finite element study was to investigate stresses within the preloaded implant screws in three different implant to abutment joint systems under simulated occlusal forces.

MATERIALS AND METHODS

Three-dimensional finite element models were created for three internal hex implant systems which included implant,

abutment, abutment screws and metal ceramic crown. The implant models were created for the following systems: (1) Nobel Biocare replace tapered implant 10 mm in length and 4.3 mm diameter, easy abutment 4.3 mm diameter with 1.5 mm collar width, (2) Uniti implant 10 mm in length with 4.3 mm diameter, 4.3 mm diameter abutment with 1 mm collar width, (3) Lifecare self-threaded tapered implant 10 mm in length with 4.2 mm diameter, abutment 4.2 mm diameter.

Measurements of all the implant components were made with a coordinate measuring machine from the original components of the three systems. These measurements were transferred to a computer to construct three-dimensional finite element models. The simulated metal-ceramic crown (mandibular second premolar) was made of nickel-chromium alloy coping and porcelain superstructure. The length of crown was 8.5 mm with a diameter of 7 mm. The porcelain thickness used in this study was 1.5 mm and the metal coping thickness was 0.3 mm. All materials used were presumed to be linear, homogenous and isotropic.

The corresponding elastic property, such as Young's modulus and Poisson's ratio were obtained from the literature and is summarized in Table 1.

Finite element study on 3-implant systems was carried out to determine and compare the stresses with respect to the vertical, horizontal and oblique load conditions along with pretension (torque) in the inner screw. The geometric models of all 3-implant systems were modeled using 'Solid Works' software by using reverse engineering technique

(measuring the dimensions of the implant systems using precision tools). The geometric models (surface and line data) are then imported into 'Hypermesh' software for meshing. In Hypermesh the individual components are discretized (meshing) and assembled. The process of converting geometric model into finite element model is called meshing. Meshed model are called finite element model. Finite element model consist of nodes and elements. Total numbers of elements present in the models (Nobel Biocare, Life Care and Uniti) were 79815, 68198 and 52533 respectively. Numbers of nodes present in the models (Nobel Biocare, Life Care and Uniti) were 13147, 13782 and 11324 respectively. Assembled finite element model of each implant system is then imported into ANSYS software for analysis. Preprocessing, solving and postprocessing are three stages in ANSYS. The material properties (young's modulus and Poisson's ratio) of the implant system and that of cement and crown are entered in the preprocessing stage. Three forces which included a horizontal force of 10N, a vertical load of 35N and an oblique force of 70N were used as mentioned in the literature. The loads and boundary conditions mentioned are applied in the solving stage and each load cases processed. In postprocessing, the results and capturing the displacement and Von-Misses stress contours of each individual part in the system was done. Stress levels were calculated using Von-Mises stress values. These stresses are most commonly reported in the finite element analysis studies to summarize the overall stress state at a point.

Table 1: Young's modulus and Poisson's ratio of materials

Materials	Young's modulus	Poisson's ratio
Titanium implant and abutment	117 GPa	0.30
Ni-Cr alloys	218 GPa	0.33
Porcelain	68.9 GPa	0.28
Zinc phosphate cement	13.5 GPa	—

RESULTS

Maximum Von-Mises stresses occurred at the abutment screw, abutment and implant for all models after applying preload and occlusal forces are presented in Tables 2, 3 and 4. Preload formed in Nobel Biocare was 500N, in Lifecare it was 535.71N and in Uniti system it was 535.7N.

Table 2: Results of Nobel Biocare implant system

	Preload		Resultant					
	A	P	10N		35N		70N	
			A	P	A	P	A	P
Von Mises stress (MPa)	69.94	82.95	69.86	82.9	70.42	83.35	69.61	83.61
Displacement (mm)	0.542×10^{-3}	0.89×10^{-3}	0.0012	0.89×10^{-3}	0.533×10^{-3}	0.895×10^{-3}	0.0027	0.0019

Table 3: Results of Uniti implant system

	Preload		Resultant					
	A	P	10N		35N		70N	
			A	P	A	P	A	P
Von Mises stress (MPa)	17.56	45.53	17.65	45.5	17.96	45.85	34.3	45.77
Displacement (mm)	0.17×10^{-3}	0.553×10^{-3}	0.0015	0.553×10^{-3}	0.348×10^{-3}	0.555×10^{-3}	0.0038	0.849×10^{-3}

Table 4: Results of Lifecare implant system

	Preload		Resultant					
			10N		35N		70N	
	A	P	A	P	A	P	A	P
Von Mises stress (MPa)	20.26	29.84	21.52	29.81	19.28	30.43	24.21	30.87
Displacement (mm)	0.191×10^{-3}	0.344×10^{-3}	0.001	0.93×10^{-3}	0.352×10^{-3}	0.354×10^{-3}	0.0026	0.0022

Nobel Biocare System (Figs 1 to 6)

- Under preload and static occlusal forces, maximum Von-Mises stress concentrations were observed at lower portion of abutment, lower threaded portion of abutment screw, middle threaded portion of implant bore threaded surface.
- Resultant stresses under three static occlusal forces, increased abutment under vertical force and decreased under horizontal and oblique forces. Increase in abutment screw was even more under oblique force. Increased in implant under horizontal, oblique forces and decreased under vertical force.

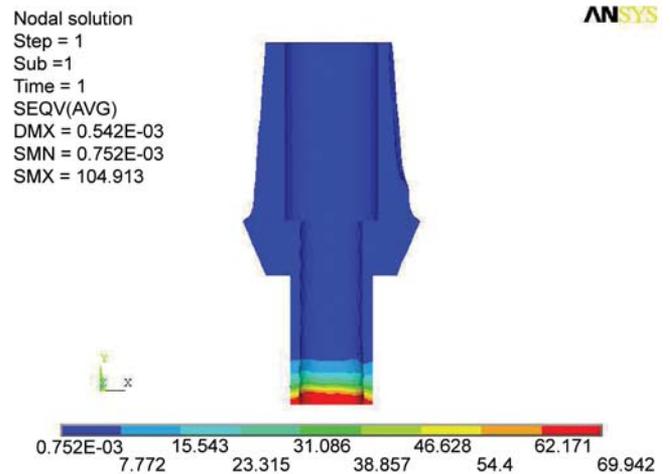


Fig. 1: Stress distribution in abutment (preload)

Uniti System (Figs 7 to 12)

- Under preload and static occlusal forces, maximum Von-Mises stress concentrations were observed at lower portion of abutment under horizontal and vertical forces whereas under oblique force, stress was concentrated at middle portion of abutment, lower threaded portion of abutment screw, middle threaded portion of implant bore threaded surface.
- Resultant stresses under three static occlusal forces, increase in abutment under three static occlusal forces and was more under oblique force. Increase in abutment screw and was even more under oblique force. Increase in implant under vertical force, oblique forces and decreased under horizontal force.

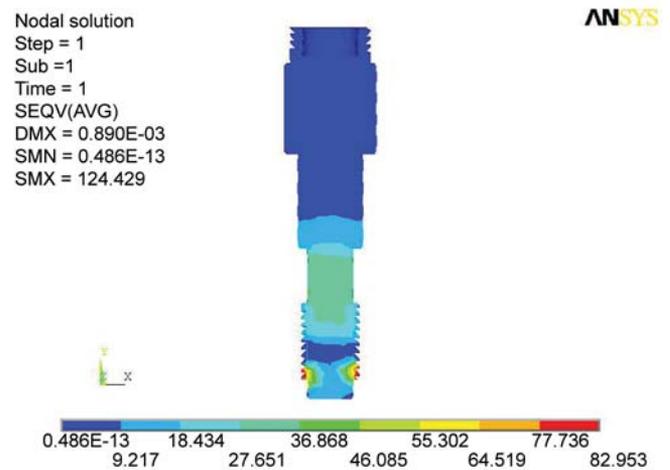


Fig. 2: Stress distribution in abutment screw (preload)

Lifecare System (Figs 13 to 18)

- Under preload and static occlusal forces, maximum Von-Mises stress concentrations were observed at lower portion of abutment, middle-threaded portion of abutment screw, upper-threaded portion of implant bore threaded surface.
- Resultant stresses under three static occlusal forces, increased in abutment under horizontal and oblique forces and decreased under vertical force, increased in abutment screw under vertical, oblique forces and decreased under horizontal force, increased in implant under vertical, oblique forces and decreased under horizontal force.

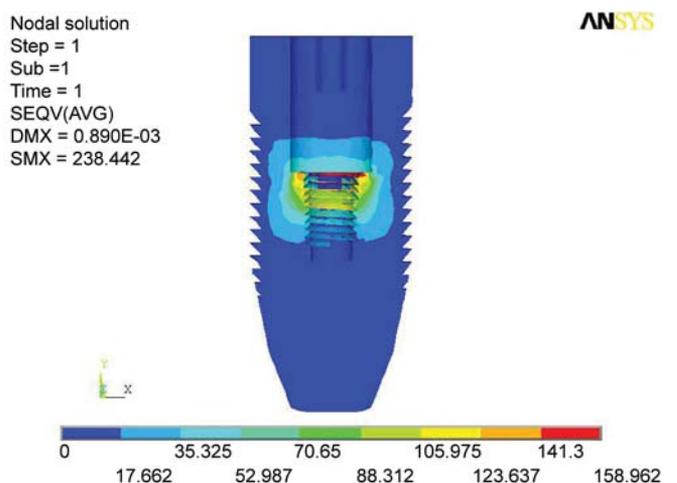


Fig. 3: Stress distribution in implant (preload)

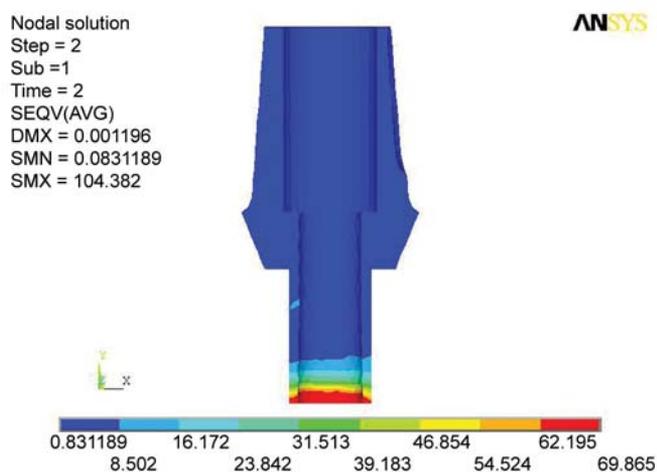


Fig. 4: Stress distribution in abutment (10N; horizontal force)

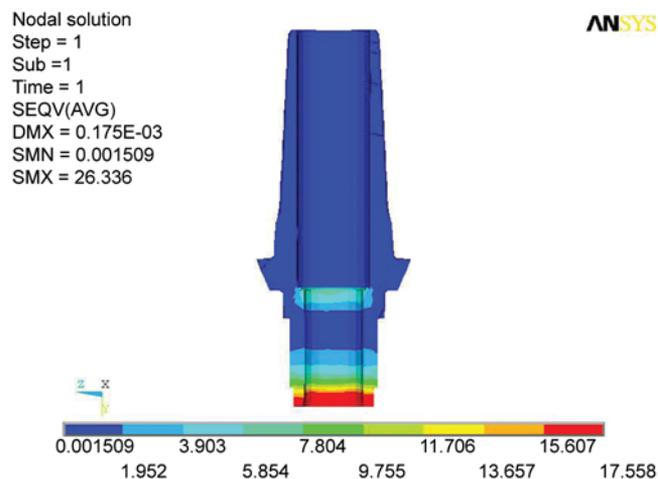


Fig. 7: Stress distribution in abutment (preload)

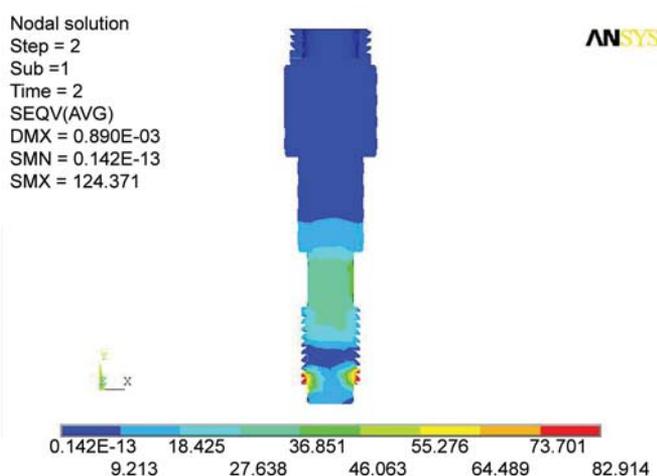


Fig. 5: Stress distribution in abutment screw (10N; horizontal force)

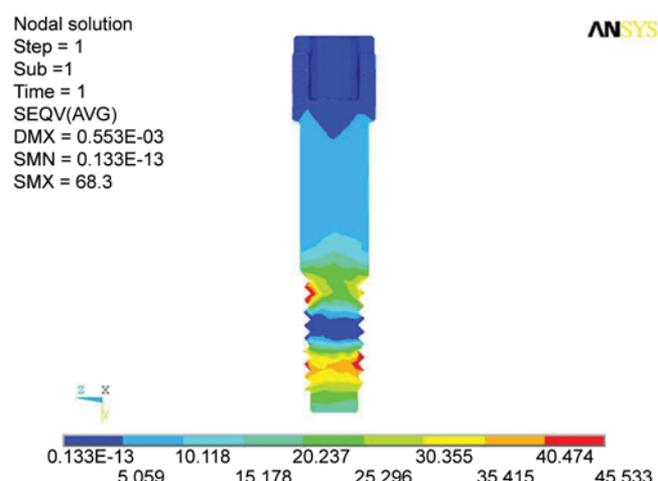


Fig. 8: Stress distribution in abutment screw (preload)

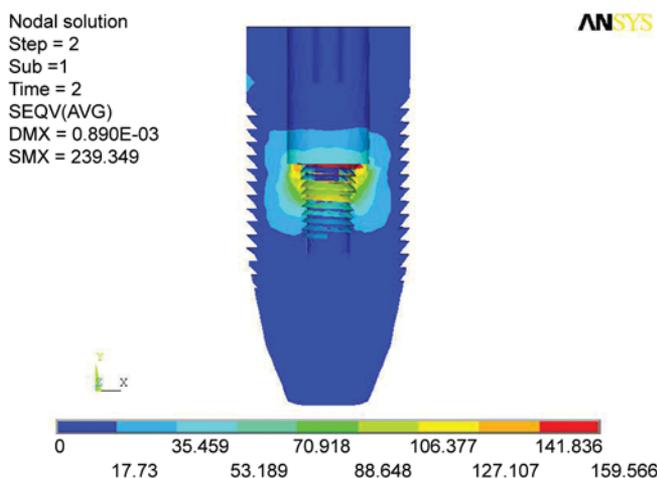


Fig. 6: Stress distribution in implant (10N; horizontal force)

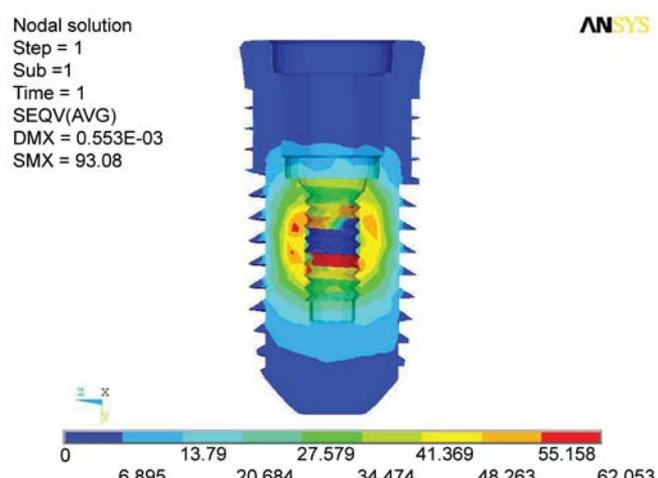


Fig. 9: Stress distribution in implant (preload)

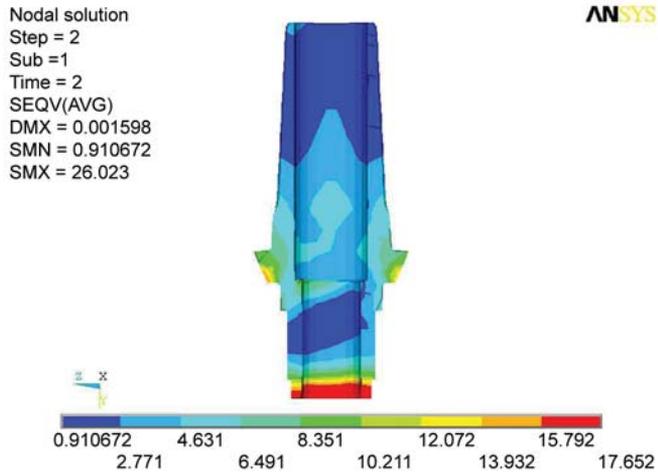


Fig. 10: Stress distribution in abutment (10N; horizontal)

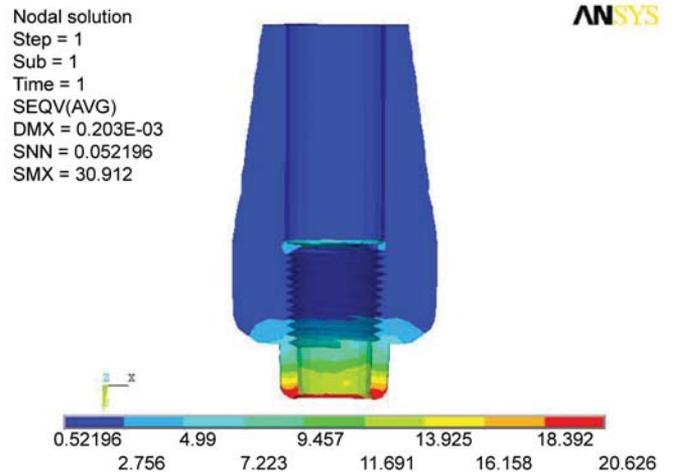


Fig. 13: Stress distribution in implant (preload)

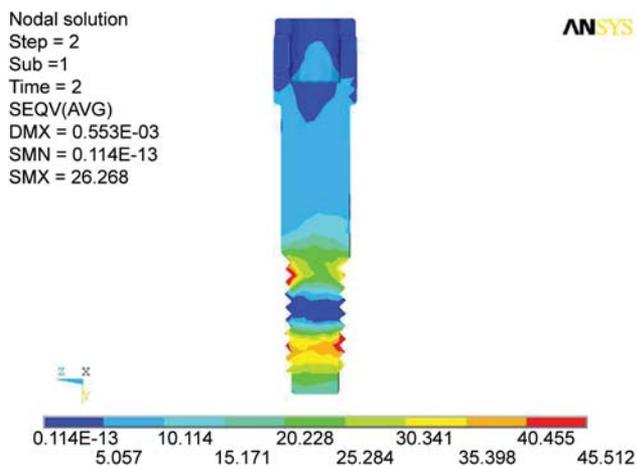


Fig. 11: Stress distribution in abutment screw (10N; horizontal)

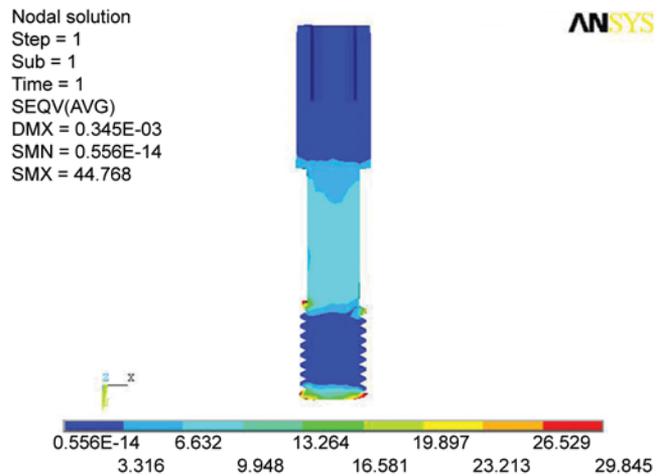


Fig. 14: Stress distribution in implant (preload)

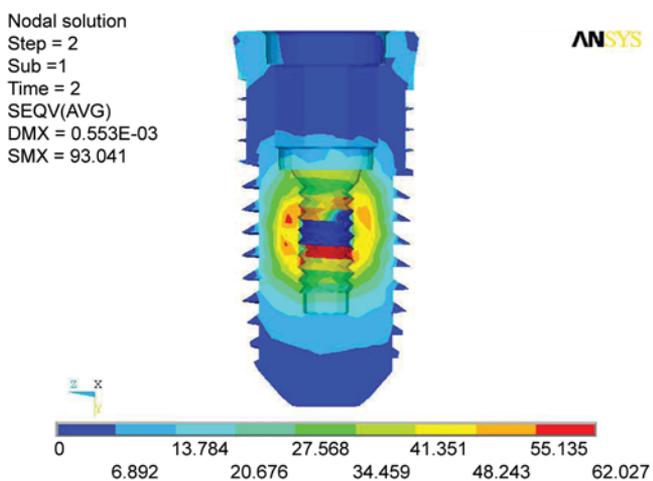


Fig. 12: Stress distribution in implant (10N; horizontal)

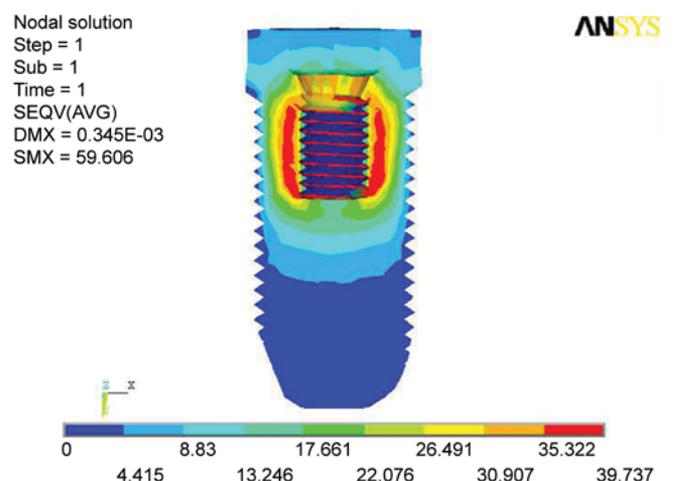


Fig. 15: Stress distribution in implant (preload)

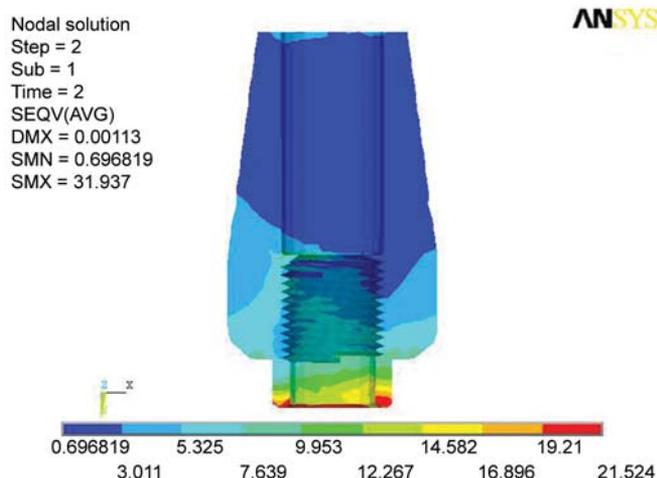


Fig. 16: Stress distribution in abutment (10N; horizontal)

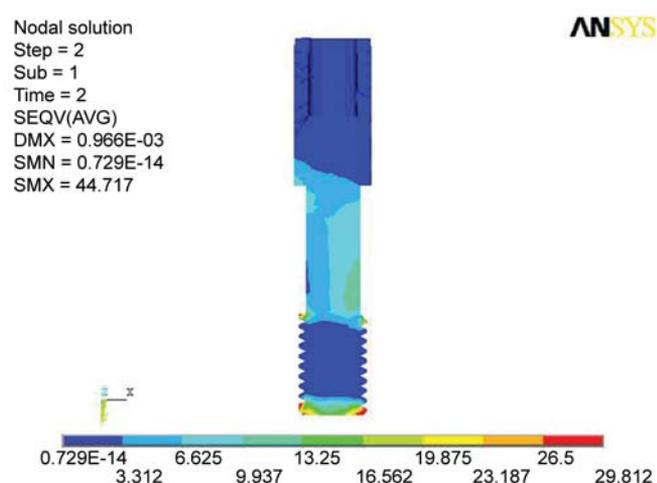


Fig. 17: Stress distribution in abutment (10N; horizontal)

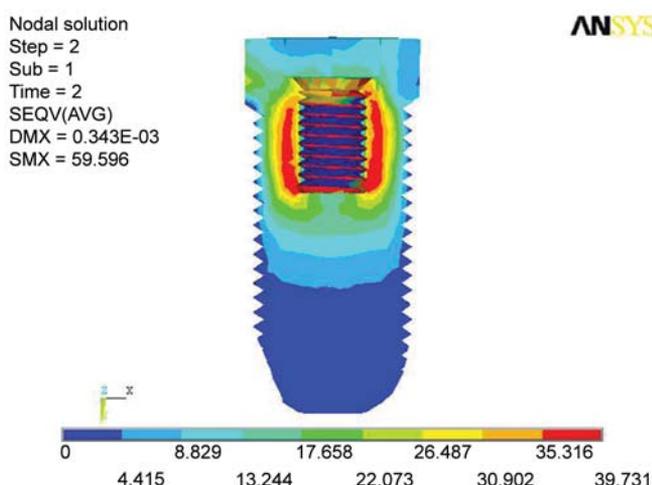


Fig. 18: Stress distribution in abutment (10N; horizontal)

Horizontal displacement of the components under occlusal loading is noted under horizontal and oblique forces for abutment and abutment screw in all three systems. Compared to all the three systems least stresses was observed in Lifecare and highest was seen in Nobel Biocare. For all the three system, maximum Von-Mises stress in abutment screw did not reach the yield strength. Maximum occlusal force the abutment screw can withstand without failure was around 650N to 1000N and for the crown was between 580N and 620N.

DISCUSSION

This study used the 3D finite element analysis (FEA) method to determine and compare the stress distribution in a preloaded implant abutment screws in three different implant systems. FEA has become an increasingly useful tool for the prediction of the effects of stress on the implant and its surrounding bone. Vertical and transverse loads from mastication induce axial forces and bending moments and result in stress gradients in the implant as well as in the bone. A key factor for the success or failure of a dental implant is the manner in which stresses are transferred to the surrounding bone. Load transfer from implants to surrounding bone depends on the type of loading, the bone-implant interface, the length and diameter of the implants, the shape and characteristics of the implant surface, the prosthesis type and the quantity and quality of the surrounding bone.^{13,14}

FEA¹⁵ 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.

The 3D finite element method used in the present study has been viewed as a suitable tool for analyzing complex dental structures. However, certain assumptions regarding material properties and boundary conditions were made to make the modeling and solving process possible. In the present study, a distance of 0.005 mm between the contacting elements in finite element models was assumed. In addition, a coefficient of friction of 0.3 between the contacted surfaces was used. However, it may not be possible to have a completely smooth surface between the

screws and mating surfaces clinically. Even a carefully machined screw surface is slightly rough when viewed microscopically.¹⁶ Because of this microroughness, no 2 surfaces may be in complete contact with one another. The coefficient of friction value was based on the literature. The effect of surface irregularities on this value is unknown. In the present study, three static loads were applied to finite element models.¹⁷

Preload formed in Nobel Biocare was 500N, in Life Care it was 535.71N and in Uniti system it was 535.7N. Under preload and static occlusal forces, maximum Von-Mises stress were concentrated at the lower portion of abutment for all the three systems. In Uniti system stress concentrated in the middle portion of abutment under oblique forces. Under preload and static occlusal forces, maximum stresses were concentrated at lower threaded portion of abutment screw in Nobel Biocare, Uniti systems whereas in Lifecare systems stress were concentrated at the middle threaded portion of the abutment screw. Under preload and static occlusal forces, maximum stresses were concentrated at middle threaded portion of implant in Nobel Biocare, Uniti and upper threaded portion of Life Care systems.¹⁸

Stresses increased under static occlusal forces in abutment screw in Nobel Biocare and Uniti and were more under oblique forces. In Life Care stresses decreased under horizontal forces and increased in vertical and oblique forces. Compared to all the three systems least stresses was observed in Life Care and highest was seen in Nobel Biocare.

The stability of the connection between different implant parts is important for the overall success of the restoration. Different systems vary in connection geometry, material and overall screw mechanics. The design of the screw (shape, thread style, head design), screw material and tightening force are all important parameters for screw joint stability.¹⁹ Difference in the material properties of abutment screw causes variation in preload. Preload works to resist external stress and it is desirable that the preload remains virtually unchanged for as long as possible. However, it is known when tightening an abutment screw, the latter is damaged by friction between abutment screw and the internal thread of the implant. It was said that this friction caused creeping, which reduced the tightening torque by 2 to 10%. It is therefore recommended that in clinical practice, the abutment screw be tightened once with the recommended torque and then tightened again 10 minutes later.^{20,21}

Because of the complete mechanical nature of the study there were some limitations in this study, such as the loading conditions simulated in this study were not as realistic as clinical findings and are only approximated. Therefore, these results of the modeling procedure give only a general insight

into tendencies of stress/stains variations under average conditions, without attempting to simulate individual clinical situations.

From the observations on the stress concentration for the various models of this study, inferences can be drawn for the occlusal management of patients with implant-supported prosthesis. Occlusal contacts that distribute the stresses axially, such as contacts in centric occlusion, are most favorable. Nonaxial loading is harmful. During eccentric movements the implant-supported prosthesis should allow only minimal functional contact to avoid oblique forces with increased stress level.²²

CONCLUSION

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

1. For the three different implant/abutment joint systems tested, the maximum stresses were concentrated at the connection between the shank and first thread of abutment screws in Uniti system whereas in Lifecare and Nobel Biocare systems, maximum stresses were concentrated at last threaded portion after preload and three different occlusal loadings.
2. After the simulated horizontal loading, stresses increased in the abutment screws of Uniti and Nobel Biocare systems. For vertical and oblique static load conditions, stresses increased in all the three system.
3. For the three static loading conditions tested, the maximum stress values did not reach the yield strength of abutment screws of the three different implant systems evaluated.

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