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A Comparative Evaluation of Stress Distribution at the Implant Abutment Interface between Platforms Switched Morse Taper and Pseudo Platform Switched Internal Hex Connection Implant – A 3D Finite Element Analysis

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ABSTRACT

Aim: The purpose of the study was to evaluate and compare the stress distribution at the implant abutment interface in a platform switched Morse taper and pseudo platform switched internal hex connection implant system under simulated load using a 3D finite element analysis.

Materials and Method: In the study ANKYLOS which is a Morse taper platform switching implant system (Group A) and XiVE having an internal hex connection which forms a pseudo platform switched implant system (Group B) were used. The geometric properties of implant systems were modeled using 3D finite element analysis. The masticatory forces of 200 N, 500 N and 1000 N were applied axially to both the implant systems with the abutment screw tightening torque of 110 Nm^2, 320 Nm^2 and 550 Nm^2. Von Mises stress distribution pattern was analyzed considering the objectives of the study. In order to interpret the result, the data generated by finite element analysis (FEA) were statistically analyzed.

Results: There was better stress distribution for Group B at the neck of implant as compared to Group A but on screw Group A showed more decrease in force concentration and therefore better stress distribution.

Conclusion: Stress concentration on connecting screw of pseudo platform switch implant was more and may lead to fracture or loosing of screw than platform switched Morse taper implant.

Keywords: Dental implants, Finite element analysis, Dental implant abutment design, Platform switching.

INTRODUCTION

Implants are widely used to support and retain both fixed and removable dental prostheses. Rapid technological advances along with the wide use of implants in dentistry have resulted in a variety of different implant systems. Binon[1] stated that rotational movement or stability of the abutment screw is directly correlated with the fit tolerances of the flat-to-flat of the implant hexagon to the abutment internal hexagon walls. Ohrnell et al[1] recommended that the external hexagon connection should have a minimum of 1.2 mm height to provide both lateral and rotational stability, particularly in single-tooth applications.

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The aim of this study was to evaluate and compare the stress distribution at the implant abutment interface in a platform switched Morse taper and pseudo platform switched internal hex connection implant system under simulated load using a 3D finite element analysis.

Null Hypothesis: There is no difference between Group A and Group B stress distribution on the screw of implant with tightening torque of 110 Nm^2, 320 Nm^2 and 550 Nm^2 and force of 200 N, 500 N and 1000 N.

OBJECTIVES

1. To evaluate the stresses distributed at the neck of the implant and on the connecting screw for platform switched Morse taper connection implant systems and pseudo platform switched internal hex implant systems under the tightening torque of 110 Nm^2, 320 Nm^2 and 550 Nm^2 with the simulated axial load of 200 N, 500 N and 1000 N.

2. To compare the amount of stress distribution at the neck and connecting screw of implant between platform switched Morse taper connection implants and pseudo platform switched internal hex implant systems under the tightening torque of 110 Nm^2, 320 Nm^2 and 550 Nm^2 with the simulated load of 200 N, 500 N and 1000 N.

METHOD

Grade II titanium ANKYLOS implants and Grade IV abutment which is a Morse taper platform switching implant system (Figure 1) and a Grade II titanium XIVE implant and abutment having an internal hex connection which forms a pseudo platform switched (mismatch implant abutment diameter) implant system was used (Figure 2).

Platform switched Morse taper connection implant: It refers to the use of an abutment of smaller diameter connected to an implant neck of larger diameter. It has an alternative connection system, based on the internal opposition of implant and abutment walls with an angle ranging from 8 to 11° or one with an internal hexagon-like format involving different implant-free expanded platform.

Pseudo platform switched implant: It is also called as mismatched implant abutment or non-platform switching.

They were divided into two groups depending on the type of connection that is Morse taper and platform switched implant (ANKYLOS) as Group A (Figure 3) and internal hex geometry and pseudo platform switched implant (XIVE) as Group B (Figure 4). Finite Element Analysis was done in Preprocessor, Processor, Postprocessor steps.

I. Preprocessor

The dimensions of implant systems used were 5.5 mm width x 11.5 mm length for both the groups. The dimensions of implant abutment used were 5.5 mm width x 3 mm collar height for ANKYLOS (Group A) and 3.8 mm width x 3 mm collar height for XiVE (Group B). A three dimensional finite element mesh was created using the ANSYS Version 12.0 software (Figure 5 and Figure 6). The element size (0.2 mm) was selected according to default setting. The solid 187 type of element suitable for the particular study was 10 nodes tetrahedron element. The completed Group A model consisted of 25096 nodes, 14551 elements with 6 degrees of freedom and Group B model consisted of 33929 nodes, 20370 elements with 6 degrees of freedom. All the structures depicted in the models were assumed to be linearly elastic, homogeneous and isotropic. Constraints were applied on the distal end of the model in all the three axes.

The magnitude of the applied loads was within physiologic limits and direction of application of the loads simulated the clinical conditions. The abutment screw was tightened by using torque of 110 Nm^2, 320 Nm^2 and 550 Nm^2. Loading conditions included a masticatory force 200 N, 500 N and 1000 N applied in axial direction on both implants. A total of 9 models of each group of implant system were made. The pattern was analyzed considering the objectives of the study.

II. Processor

Once the geometry was converted to the finite element, its analysis was done by the solver which was the part of the software (ANSYS version 12.0). The results were generated after all the equations were solved. The solver generated element matrices, computed nodal displacement values, derived and solved governing matrix equations.

III. Post processor

This step involved going through large amount of data generated during the solving stage and was converted to a form that was easily understood by the operator. The stress was visualized on the coloured contour maps and its stress pattern was seen as color coded bands. The results involved the calculation of stress by Von Mises criteria for each node. The results obtained were noted and analysed.

RESULTS

The aim of this study was to evaluate and compare the stress distribution at the implant abutment interface in a platform switched Morse taper and pseudo platform switched internal hex connection implant system under simulated load using a 3D finite element analysis.

After the data was generated by the software, the following steps are followed:-

1) The stress contours were plotted in various colours
2) Analysis of the results was carried out.

The stress analysis executed by ANSYS software provided results that enabled visualization of Von Mises stress fields in the form of colour coded bands. Each colour band represented a particular range of stress value which was given in mega Pascal.

Observation of stress distribution pattern on models

The stress distribution pattern on the finite element analysis models for Group A and Group B at different forces were plotted in colour. The maximum stress was indicated by the red zone and minimum was indicated by the blue zone. By observing the colour code, the stress distribution at the neck and on the surface of screw was tabulated and results were obtained.

Analysis of the different stress distribution patterns

The stress pattern was seen as colour coded bands. By analyzing the bands it was understood which areas were being stressed. In order to interpret the result, the data generated by finite element analysis were statistically analyzed. The Z test was applied and percentage difference was seen to find the level of significance.

It was seen that the stress distribution for Group A and Group B at the neck of implant increased when the amount of force increased at the same torque. However when the screw was tightened with the higher torque the difference seen between the various loads decreased.

It was seen that, on screw head of Group A implant with 110 Nm^2 torque the force increased leading to increased stress. At 320 Nm^2 torque with 200 N force the stress was 578.83 Mpa but with 500 N and 1000 N the stress was same (568.13 Mpa); at 550 Nm^2 torque, even if the force increased the stress decreased.

It was seen that, on screw head of Group B implant at torque of 110 Nm^2 and 320 Nm^2 the stress distribution increased on the head of the screw till 500 N force whereas with force of 1000 N the stress distribution decreased. With the torque of 550 Nm^2 with increased force the stress distribution decreased. The stress distribution for Group A and Group B at the apex of the screw increased when the amount of force increased at the same torque. However, at the apex of the screw the stress seen was less as compared to the head of the screw and the amount of stress at the apex of screw of Group A was less as compared to Group B. Table 1 shows that the Z test applied for the neck of the implant showed significant difference as the p value was less than 0.05 but with the torque of 110 Nm^2 and force 500 N, the statistical analysis was not significant. Hence there was better stress distribution for Group B at the neck of implant as compared to Group A (Figure 7).

Table 1: Shows Z test for stress distribution at the neck of implant for both the groups of implant.

Group A					
Force	Torque	% Difference	Z value	P value	Interpretations
200N	110Nmm	30.49%	2.496	0.0126	significant
	320Nmm	30.55%	3.765	0.0002	Highly significant
	550Nmm	49.44%	9.1	<0.0001	Highly significant
500 N	110Nmm	5.48%	54	0.59	Not significant
	320Nmm	42.23%	6.54	<0.0001	Highly significant
	550Nmm	40.83%	7.62	<0.0001	Highly significant
1000N	110Nmm	25.94%	3.83	0.0001	Highly significant
	320Nmm	13.24%	1.76	0.07	Highly significant
	550Nmm	30.48%	5.58	<0.0001	Highly significant

Table 2: Shows Z test for stress distribution on screw of both the groups of implant.

Group A					
Force	Torque	% Difference	Z value	P value	Interpretations
200N	110Nmm	74.98%	8.25	<0.0001	Highly significant
	320Nmm	88.87%	20.28	<0.0001	Highly significant
	550Nmm	88.87%	26.56	<0.0001	Highly significant
500 N	110Nmm	49.99%	5.62	<0.0001	Highly significant
	320Nmm	83.32%	18.38	<0.0001	Highly significant
	550Nmm	85.70%	22.33	<0.0001	Highly significant
1000N	110Nmm	49.99%	7.94	<0.0001	Highly significant
	320Nmm	66.65%	13.76	<0.0001	Highly significant
	550Nmm	74.98%	18.46	<0.0001	Highly significant
Group B					
200N	110Nmm	66.615	6.28	<0.0001	Highly significant
	320Nmm	85.24%	9.44	<0.0001	Highly significant
	550Nmm	66.65%	11.99	<0.0001	Highly significant
500 N	110Nmm	0%	0	1	Not significant
	320Nmm	66.62%	10.45	<0.0001	Highly significant
	550Nmm	60.90%	10.58	<0.0001	Highly significant
1000N	110Nmm	99.63% (increased)	5.57	<0.0001	Highly significant
	320Nmm	49.93%	6.89	<0.0001	Highly significant
	550Nmm	49.94%	8.1	<0.0001	Highly significant

Fig 1: Morse taper connection (ANKYLOS) implant with abutment.

Fig 2: Internal hex connection (XiVE) implant with abutment.

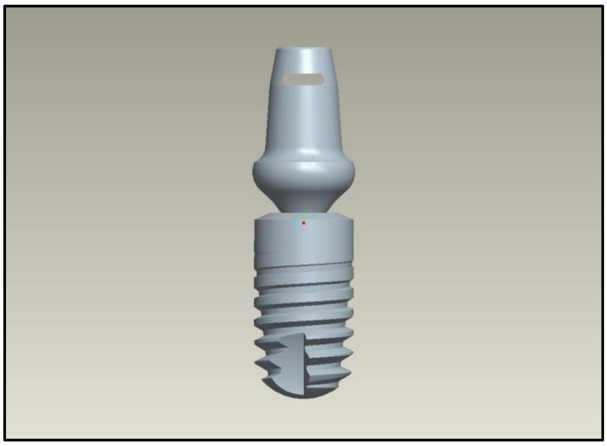

Fig 3: FEA model Of Morse taper connection (ANKYLOS) implant with abutment.

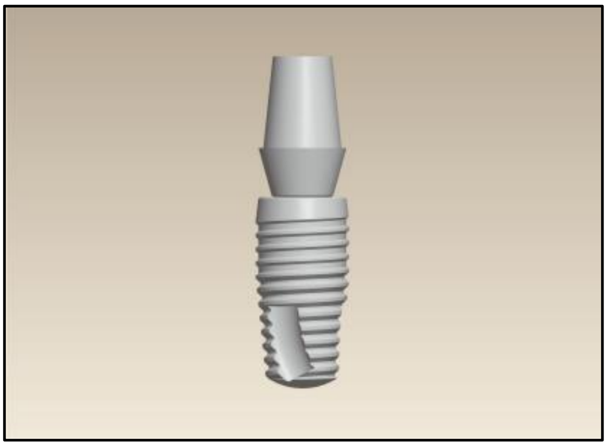

Fig 4: FEA model of internal hex connection (XIVE) implant with abutment.

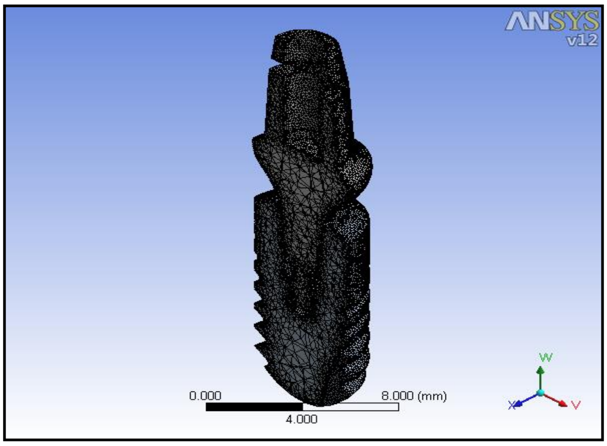

Fig 5: Cross section of wire mesh work in Group A implant.

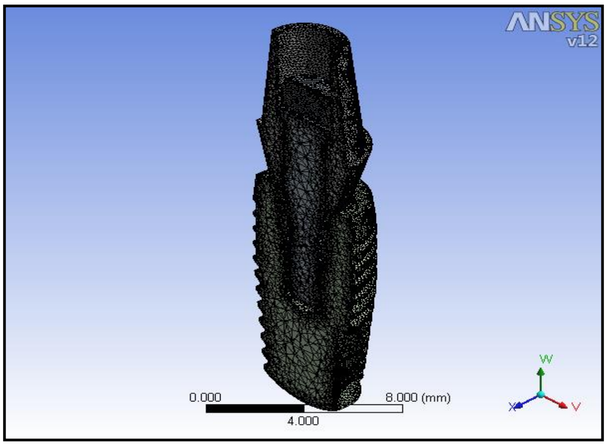

Fig 6: Cross section of wire mesh work in Group B implant.

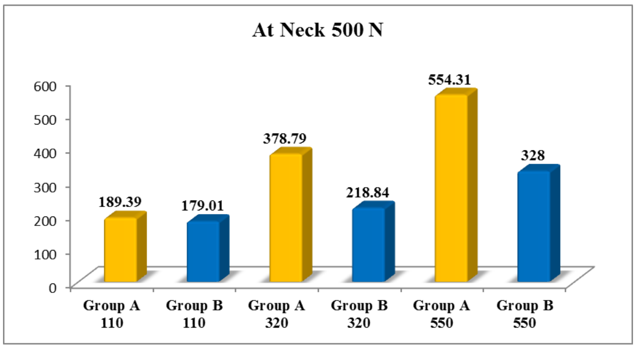

Fig 7: Stress distribution at the neck of implant with force 500 N for both the groups of implant.

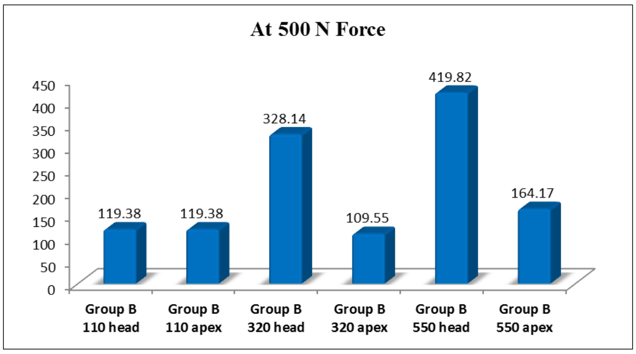

Fig 8: Stress distribution on the screw of implant with force 500 N for the groups B implant.

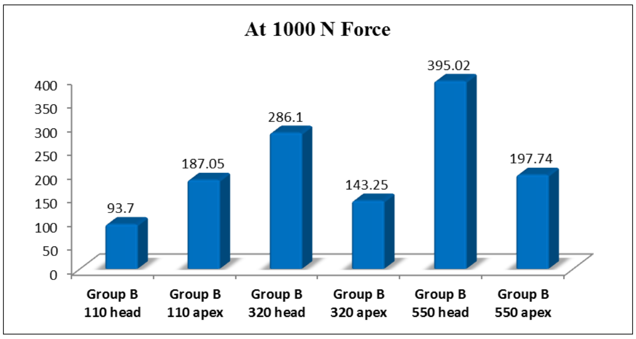

Fig 9: Stress distribution on the screw of implant with force 1000 N for the groups B implant.

In Group B, when tightening torque increased, percentage of stress difference decreased and force concentration reduced. However, in lower occlusal force of 200 N and 500 N, it is seen that at 320 Nm^2 torque percentage decrease of, stress concentration was maximum. At torque of 110 Nm^2 and 500 N force, there was 0% difference which is statistically significant (Figure 8) and at the torque of 110 Nm^2 and 1000 N force, there was 99.63% difference. This shows that the statistically significant result was reversed (Figure 9). In Group A, there was a generalized increase in the percentage difference between the various torques when the amount of force increased. This shows more decrease in force concentration and therefore better stress distribution (Table 2).

Alternate Hypothesis: There is difference between Group A and Group B stress distribution on the screw of implant with tightening torque of 110 Nm^2, 320 $Nm^2$and 550 Nm^2 and force of 200 N, 500 N and 1000 N.

DISCUSSION

The platform switching concept was developed by Dr. Richard Lazzara[3] for limiting circumferential bone loss around dental implants. It refers to the use of an abutment of smaller diameter connected to an implant neck of larger diameter; this connection shifts the perimeter of the implant-abutment junction inwards towards the central axis (the middle of the implant) improving the distribution of forces[2].

In the Ankylos system, the dimensions of the connection are always the same, so that any endosseous component can be combined with any abutment as required. The tapered connection can always be assembled precisely[3]. However, when platform switching is not incorporated within the design of the implant it is called pseudo platform switching.

Pseudo platform switching implant is also called as mismatched implant abutment or non-platform switching. This is done by using a smaller diameter abutment for larger platform implant keeping the concept of platform switching or platform shifting. The platform shifting in this is done by operator[4].

The use of the finite element method to analyze stress concentrations was initially introduced into implant dentistry by Weinstein et al (1976). Using theoretical techniques, such as the FEA, all mechanical aspects that could affect the implant success can be evaluated[5]. The models used can be bidimensional or three dimensional[1]. Holmgren stated that implant diameter, shape, and load direction influence stress distribution[6].

This study was carried out to evaluate and compare the stress distribution at the implant abutment interface in a platform switched Morse taper and pseudo platform switched internal hex connection implant system under simulated load using a 3D finite element analysis.

The output from the finite element analysis is primarily in the numerical form. Graphical output and displays are more informative. The output is primarily in the form of colour coded maps. The qualitative analysis is determined by interpreting these maps.

In the present study Grade of titanium of implant system was important for the application of Poisson's ratio and knowing the yield strength of that particular material. These properties can be modeled in FEA as isotropic, transversely isotropic, orthotropic and anisotropic. In an isotropic material, the properties are the same in all directions[7].

The greatest natural forces exerted against teeth and implants occur during mastication. These forces are primarily perpendicular to the occlusal plane in the posterior regions, are of short duration, occur only during brief periods of the day. The natural forces against teeth are primarily in their long axis, less than 30 psi and for less than 30 min for all normal forces of deglutition and mastication[8].

Finite Element Analysis was done in Preprocessor, Processor, Postprocessor steps and the Von Mises stresses were evaluated and maximum and minimum values were acquired for each implant-abutment interface. The readings were calculated and statistically analyzed using 'Z' test.

From Z test, in Group B, when the tightening torque increased percentage of stress decreased and force concentration reduced. This could be due to the material properties which being grade II titanium which is soft, which could lead to distortion or fracture of the screw. However, in lower occlusal force of 200 N and 500 N, it is seen that at 320 Nm^2 torque percentage decrease of stress concentration was maximum. At torque of 110 Nm^2 and 500 N force, there was 0% difference which is statistically significant and at the torque of 110 Nm^2 and 1000 N force, there was 99.63% difference. The reading of the result showed that they were reversed. In Group A, there was a generalized increase in the percentage difference between the various torque when the amount of force increased. This shows more decrease in force concentration and therefore better stress distribution. This could be due to the Morse taper connection which forms or may result in cold welding and also due to higher grade of titanium (Grade IV) which is harder and does not allow for deformation.

Results of this study showed that the stress distribution of Group A and Group B at the neck of implant increased when amount of force increased at the same torque. When compared and statistically analyzed the result showed that there was better stress distribution for Group B at the neck of the implant than Group A which means XiVE with internal hex geometry and pseudo platform switched implant showed better stress distribution at the neck of the implant than ANKYLOS with Morse taper and platform switched implant. This might be because of the tapered connection at the neck of platform switched Morse taper connection when compared to the flat surface junction of the pseudo platform switching. It is known that flat surface dissipates stress better than any other surface. However at the apex of the screw the stress concentration is less compared to the surface of the screw and the amount of stress at the apex of screw of Group A is less compared to Group B.

The yield strength of Group A abutment is 480 Mpa and that of Group B is 275 Mpa. Though the amount of stress seen at the apex of the screw is less than the yield strength values of Group A and Group B abutment, the chances of the screw getting loosen or fracture for Group B may be more compared to Group A.

The ideal natural force is approximately 738 N. The abutment screw can bear the applied vertical force 200 N, 500 N but if the force is increased to 1000 N the screw may not be able to bear the stress and may show the mechanical failure.

The results were not in accordance to study done by Segundo RMH[9] who concluded that a large amount of stress was located around the implant neck and little stress was concentrated along the abutment screw. Van Staden RC[5] performed FEA using internal and external hex connection of the Neoss and 3i implant systems respectively. They concluded that the external hex system tends to induce stress concentrations whereas the internal-hex system showed reduced stress concentrations. Lang LA[10] studied the dynamic nature of developing the preload in an implant complex using finite element analysis. They analyzed the stress distribution pattern which clearly demonstrated a transfer of preload force from the screw to the implant during tightening and concluded that a torque of 320 Nm[2] applied to the abutment screws in the implant assemblies studied in the presence of a coefficient of friction of 0.26 resulted in a lower than optimum preload for the abutment screws. Asvanund P, Morgano SM[11] compared the load transfer characteristics of a complete arch restoration supported by 4 implants with external and internal implant-abutment connections. They found that the internal-implant abutment connection produced less stress when compared with the external-implant abutment connection.

Due to the Morse taper connection of platform switched implant the stress concentration on the screw was less and the stress was getting distributed along the surface of the screw However, in the internal hex connection the stress seen at the screw was not being dissipated as the difference between the head and apex of the screw was decreased. This may lead to screw loosening or inturn fracture. The concept of Morse taper connection design includes a tapered projection from the implant abutment which fits into a tapered recess in the implant. There is a friction fit and cold welding at the implant-abutment interface. This implant abutment connection depends on this friction fit for elimination of rotation at the implant-abutment interface and subsequent abutment screw loosening[12]. Hence the Morse cone connection, compared with other types, is more efficient in the dissipation of forces exerted on the prosthesis and consequently on the supporting bone tissue[13]. Results reported by Norton MR[14,15] showed that the incorporation of conical connections between implant and abutment dramatically enhanced the ability of the system to resist bending forces.

According to Binon, the mechanical problems such as loosening of prosthetic abutment screws, their fractures and sometimes implant fractures might be caused, mainly due to inadequate torque, prostheses lacking adaptation and passive fit, occlusal overload and unsuitable retainer screw design[9].

According to Wiskott, there is a directly proportional relationship between the preload applied on abutment screws and their resistance to fatigue, which may cause severe mechanical problems[9].

Implant-abutment connections with an unstable mating interface place undue stress on the screw that connects the implant to the abutment. Mechanical testing has demonstrated a direct correlation between the tolerance of the flat-to-flat dimension of the external hex and the stability of the abutment or prosthetic screw. Binon suggested that a mean flat-to-flat range of less than 0.005 mm on the same hex and a flat-to-flat rang of less than 0.015 mm for the entire sample results in a more stable screw joint[16].

It is seen that as the hex height increases, the load on the abutment screw decreases. Likewise, as the diameter of the implant platform increases, the load on the abutment screw decreased. It is important to reduce the load on the abutment screw so not to load it beyond the yield strength of the material. In addition, abutment screws are typically torqued during the restoration of the implant to preload the screw and provide a clamping load for the abutment to the implant. This preload is essentially an axial load along the screw that loads the material within its elastic range and is commonly within 75% of yield strength. Additional axial loads can have a cumulative effect with the preload and load the material into the plastic region therefore exceeding the yield strength. When yield strength is exceeded, plastic deformation occurs and the screw will begin to deform because of axial load and bending. Understanding the implant-abutment connection, hex height and implant platform diameter are important design considerations to prevent screw loosening[16]. Complications in dental implant therapy such as implant and prosthetic component fracture and prosthetic screw loosening adversely affect the acceptance and growth of implant dentistry.

Limitations of the study:

1. It is an in-vitro simulation of an in-vivo situation.

2. The data is gathered from an actual case scenario, any anatomic variations should be accounted for.
3. Masticatory forces are dynamic in nature, whereas this study was conducted under static loads.
4. The location and magnitude of stresses generated in response to the load applied in the study are pertaining to the finite element model design in this study. This may vary if there are alterations in model design, elastic properties incorporated and the direction of forces applied.

The clinical significance is that the screw loosening or fracture is avoided by applying adequate torque.

CONCLUSION

Within the limitation of the study, the following conclusions could be drawn:

1. In platform switched Morse taper connection better stress distribution was seen on the connecting screw between the implant and abutment when subjected to the tightening torques of 110 Nm^2, 320 Nm^2 and 550 Nm^2 under the simulated occlusal load of 200 N, 500 N and 1000 N. However there was decrease in stress distribution at the neck of the implant.

2. In pseudo platform switched internal hex connection better stress distribution was seen at the neck of implant between the implant and abutment when subjected to the tightening torques of 110 Nm^2, 320 Nm^2 and 550 Nm^2 under the simulated occlusal load of 200 N, 500 N and 1000 N. However there was decrease in stress distribution on the connecting screw between the implant and abutment.

3. The pseudo platform switched internal hex implant systems showed better stress distribution at the neck of the implant than platform switched Morse taper connection implant under the torque of 110 Nm^2, 320 Nm^2 and 550 Nm^2 with the simulated load of 200 N, 500 N and 1000 N and the difference was statistically significant.

4. The platform switched Morse taper connection implant showed better stress distribution on the screw than the pseudo platform switched internal hex implant systems under the torque of 110 Nm^2, 320 Nm^2 and 550 Nm^2 with the simulated load of 200 N, 500 N and 1000 N and the difference was statistically significant.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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