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Comparative analysis of internal and external-hex crown connection systems - a finite element study

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ABSTRACT

Objectives: The abutment connection with the crown is fundamental to the structural stability of the implant system and to the prevention of mechanical exertion that can compromise the success of the implant treatment. The aim of this study is to clarify the difference in the stress distribution patterns between implants with internal and external-hex connections with the crown using the Finite Element Method (FEM). Material and Methods: The internal and external-hex connections of the Neoss and 3i implant systems respectively, are considered. The geometrical properties of the implant systems are modeled using three-dimensional (3D) brick elements. Loading conditions include a masticatory force of 200, 500 and 1000N applied to the occlusal surface of the crown along with an abutment screw torque of 110, 320 and 550Nmm. The von Mises stress distribution in the crown is examined for all loading conditions. Assumptions made in the modeling include: 1. half of the implant system is modeled and symmetrical boundary conditions applied; 2. temperature sensitive elements are used to replicate the torque within the abutment screw. Results: The connection type strongly influences the resulting stress characteristics within the crown. The magnitude of stress produced by the internal-hex implant system is generally lower than that of the external-hex system. The internal-hex system held an advantage by including the use of an abutment between the abutment screw and the crown. Conclusions: The geometrical design of the external-hex system tends to induce stress concentrations in the crown at a distance of 2.89mm from the apex. At this location the torque applied to the abutment screw also affects the stresses, so that the compressive stresses on the right hand side of the crown are increased. The internal-hex system has reduced stress concentrations in the crown. However, because the torque is transferred through the abutment screw to the abutment contact, changing the torque has greater effect on this hex system than the masticatory force. Overall the masticatory force is more influential on the stress within the crown for the external-hex system and the torque is more influential on the internal-hex system.

Keywords: Component; Biomedical modelling; Dental implant; Finite element technique

1. INTRODUCTION

Dental implants are a consistently accepted form of dental treatment. Clinical research in oral implantology has led to advancements in the biomechanical aspects of implants, implant surface features and implant componentry. These advancements in implant componentry include the modification of the external-hex connection between the abutment and crown to the currently used internal-hex (**Figure 1b**)). Although both internal and external-hex connected implant systems are extensively used, distinctly different performances are on offer in terms of the stress characteristics produced within the crown. Observations by practitioners have aided the identification of implant components which lead to mechanical failure of the crown and implant [1-3]. Failure may be defined as the point at which the material exceeds the fracture stress, as indicated by its stress strain relationship. There are two major factors which can cause the crown and implant to fail. These are described below;

- typically, over tightening of the abutment screw causes failure of the crown for internal and external-hex systems.
- failure of the implant may also be a result of over tightening of the abutment screw or excessive masticatory loads being transferred from the occlusal plane of the crown to an area of stress concentration at the interface between the abutment and implant body.

Using theoretical techniques, such as the FEM, all mechanical aspects that could affect the implant success can be evaluated. FEM has been used extensively to evaluate the performance of dental implant prosthesis [4-15]. Studies by Maeda *et al.* (2006), Merz *et al.* (2000) and Khraisat *et al.* (2002) have all considered the behavior of the stress within the abutment screw however disregarding the stress within the crown. To date no published research appears to have investigated the stress characteristics in the crown due to an internal or external-hex system. Ultimately, the outcome of this study will facilitate dental practitioners to identify locations within the implant system that are susceptible to stress concentrations.

2. METHODOLOGY

The modeling and simulation herein are performed using the Strand7 Finite Element Analysis (FEA) System (2004). The first step of the modeling is to define the geometry of the implant system. This is then followed by specifying the material behavior in terms of the Young's modulus, Poisson's ratio and density for the implant and componentry. After applying the appropriate loading and restraint conditions, the internal and external-hex systems can be evaluated for their contributions to the stress characteristics within the crown.

2.1. Modelling

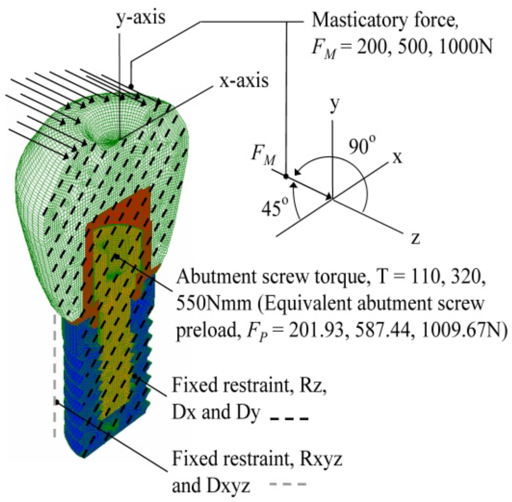
Data acquisition for the internal and external-hex systems are obtained from the manufacturer's data. Shown in **Figure 1b**) are details of the Neoss (2006) and 3i (2006) systems.

Shown in **Figure 1a**) are the detailed variables considered in this study. The implant is conical with 2 degrees of taperage, a helical thread, diameter of 4.5mm, and length of 11mm. Different fixed restraints are applied to the symmetrical edge of the implant system as compared to the outer edge of implant thread. The symmetrical edge is restrained from rotating around the z-axis and translating through the x- and y-axis. The outer edge of the implant thread is restrained from deforming in any direction. Note that these loading and restraint conditions are the same for both internal and external-hex systems.

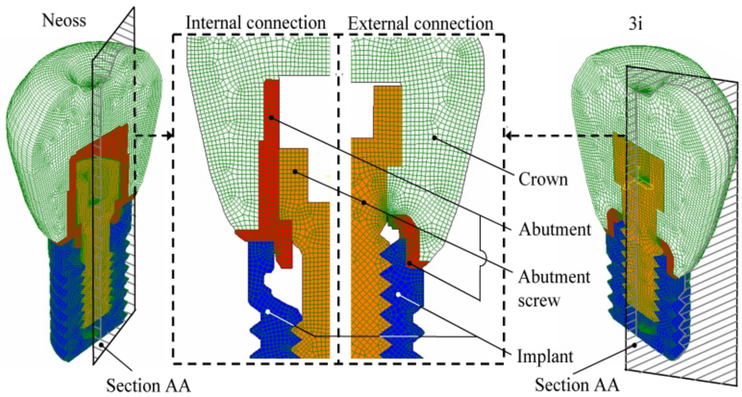
For the Neoss and 3i finite element models, the total numbers of elements are respectively 13464 and 30420 for the implant, 3564 and 9108 for the abutment, 17424 and 25956 for the abutment screw, 38484 and 47052 for the crown. The total number of nodal points for the entire Neoss and 3i models are 82547 and 122688 respectively.

2.2. Stress Measuring

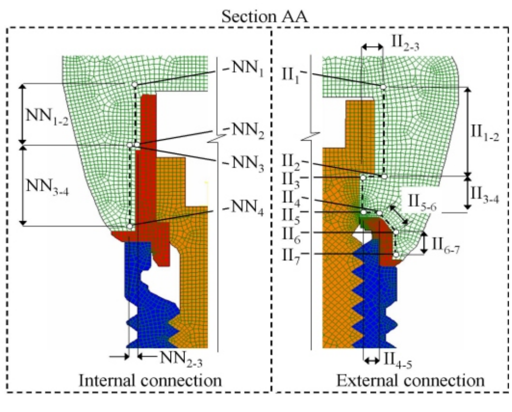
As indicated in **Figure 1c**) the von Mises stresses along the lines NN (NN_{1-2}, NN_{2-3} and NN_{3-4}) and II (II_{1-2}, II_{2-3}, II_{3-4}, II_{4-5}, II_{5-6} and II_{6-7}) for the Neoss and 3i systems respectively, are measured for all possible combinations of loading. Note that, for example, along the line II_{1-2} the beginning location of the line is identified as II_1 and the end as II_2. These locations are believed by clinicians to be critical for examining the stress levels in the crown. Note that both lines NN and II are chosen on Section AA because the highest stress magnitudes (compressive is prominent over ten-



a) Loading and restraint conditions (with detailed variables)



b) Implant systems



c) Locations for measuring stress profile and contour

Figure 1. Finite element model of internal and external-hex systems.

sile) occur on this plane due to the masticatory loading characteristics.

2.3. Loading Conditions

Masticatory force, F_M, is applied to the occlusal surface of the crown at 100, 250 or 500N, inclined at 45° along the x- and y-axis (**Figure 1a**). The preload, F_P, of 100.97, 293.72 or 504.84N is applied to the abutment screw through the use of temperature sensitive elements (**Figure 1a**)). Note that F_M and F_P are set to half of the total magnitude because only half of the implant system is modelled. Therefore the total F_M modelled is 200, 500, 1000N and F_P is 201.93, 587.44, 1009.67N. The manner of modelling the masticatory forces and the preload applied to the abutment screw is described by van Staden *et al.* (2008). In this study both the abutment screw preload, F_P, and surface area between abutment and abutment screw are halved when compared with that used by van Staden *et al.* (2008) due to the modelling assumption aforementioned. Calculations for the abutment screw surface pressure, q, confer identical results than that found by van Staden *et al.* (2008).

For the present study a negative temperature (-10 Kelvin, K) is applied to all the nodal points within the abutment screw, causing each element to shrink. A trial and error process is applied to determine the temperature coefficient, C, for both the Neoss and 3i systems (i.e. C_{Neoss} and C_{3i}) that can yield an equivalent q. It is found that when F_P=201.93, 587.44 and 1009.67N then C_{Neoss}=-3.51×10^{-4}, -9.28×10^{-4} and -15.60×10^{-4} /K, and C_{3i}=-0.98×10^{-4}, -1.80×10^{-4} and -2.68×10^{-4} /K, respectively.

Table 1. Material properties.

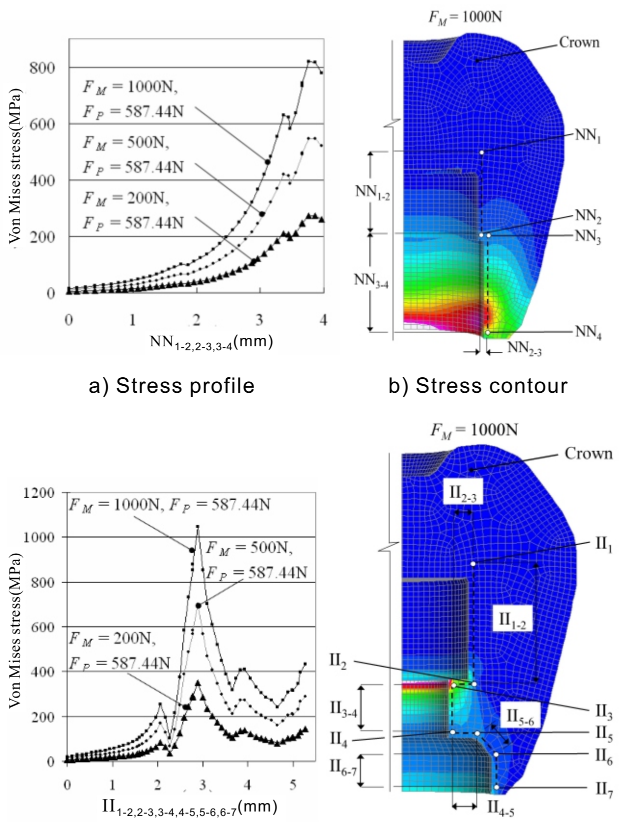
Component	Description	Young's modulus,E(Gpa)	Poisons ratio,v	Density,p (g/cm3)
Implantand abutment	Titanium (grade4)	105.00	0.37	4.51
Abutment screw	Gold(precisionalloy)	93.00	0.30	16.30
Crown	Zirconia(Y-TZP)	172.00	0.33	6.05

2.4. Material Properties

The material properties used are specified in terms of Young's modulus, Poisson's ratio and the density for the implant and all associated components (**Table 1**). All material properties are assumed to be linear, homogeneous and elastic in behavior.

3. RESULTS DISCUSSION

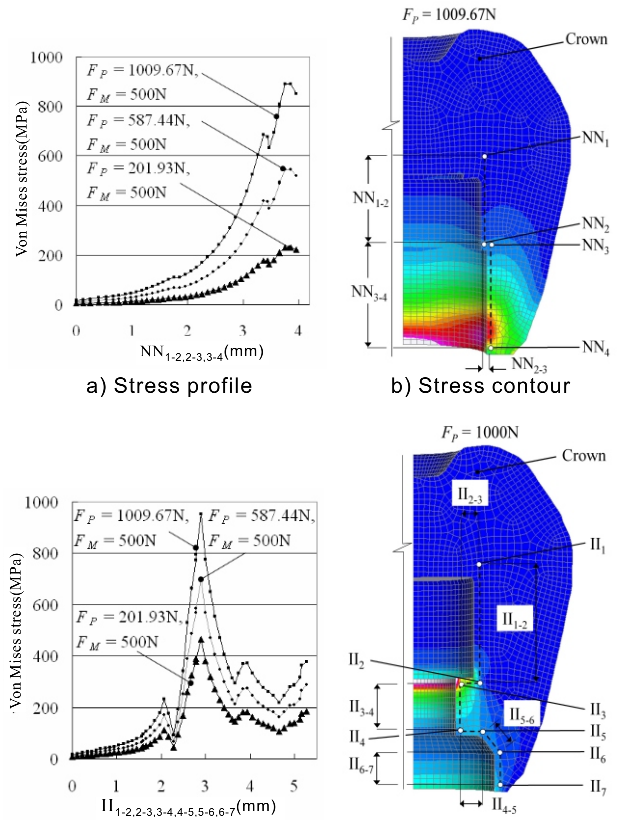
Zirconia typically used as a dielectric material has proven adequate for application in dentistry. With its typical white appearance and high Young's moduli it is ideal to be used in the manufacturing of sub frames



a) Stress profile b) Stress contour

c) Stress profile d) Stress contour

Figure 2. Stress characteristics when varying F_M.



a) Stress profile b) Stress contour

c) Stress profile d) Stress contour

Figure 3. Stress characteristics when varying F_P.

for the construction of dental restorations such as crowns and bridges, which are then veneered with conventional feldspathic porcelain. Zirconia has a fracture strength that exceeds that of Titanium therefore it may be considered as a high strength material. However with cyclic preload and masticatory loads the compressive strength of 2.1GPa (Curtis *et al.* 2005) can easily be exceeded especially for implant systems with external-hex connections, as confirmed during this study.

The distribution of von Mises stresses in the crown is discussed for both the internal and external-hex systems for all combinations of masticatory and preload forces. Shown in **Figure 1c**), are the von Mises stresses measured between locations NN_{1-2} (0-1.76mm), NN_{2-3} (1.76-1.87mm) and NN_{3-4} (1.87-3.96mm) for the Neoss system. For the 3i system the von Mises stresses are measured between locations II_{1-2} (0-2.38mm), II_{2-3} (2.38-2.78mm), II_{3-4} (2.78-3.67mm), II_{4-5} (3.67-4.06mm), II_{5-6} (4.06-4.65mm) and II_{6-7}(4.65-5.27mm), as shown in **Figure 1c**).

3.1. Masticatory Force, F_M

The distributions of von Mises stresses along the lines NN and II for all values of F_M are shown in **Figure 2**. Note that the preload, F_p, is set at its medium value, i.e. 587.44N.

In general, when the applied masticatory force, F_M, is increased, the von Mises stresses also increase proportionally, because the system being analysed is linear elastic. When F_M increases the stress along the line NN increases showing two peaks along the line NN_{3-4} (refer to **Figure 2a**)). The larger of these two peaks occurs at a distance of ±3.8mm in length from NN_1. This stress peak (as can be identified in **Figure 2b**)) is caused by a sharp corner and sudden change in section at this point.

Elevated stress concentrations are identified at the beginning of the line II_{3-4} (**Figure 2c**) and **Figure 2d**)). This stress peak, as can be identified in **Figure 2c**), is caused by a sharp corner at this point. For the 3i system, the volume of the crown exceeds that of the Neoss system, thereby suggesting that the 3i crown may endeavor greater resistance to the applied masticatory forces. However, even though the Neoss crown has a thinner wall thickness along the line NN_{3-4}, reduced stresses are still evident due to the abutments high Young's modulus. Overall, the design differences between the Neoss and 3i systems ultimately results in the 3i system having higher stresses when F_M is increased.

3.2. Preload Force, F_P

To investigate the effect of different preload F_P, F_M is kept as a constant and its medium value, i.e. 500N is considered herein. The distributions of von Mises stresses along the lines NN and II for all values of F_P are shown in **Figure 3**.

As found for F_M, when F_P increases the stresses calculated along the line NN increase, showing two peaks along the line NN_{3-4} (refer to **Figure 3a**) and **Figure 3b**)). Also, as found for F_M, elevated stress peaks are identified at the beginning of the line II_{3-4} (**Figure 3c**) and **Figure 3d**)). Overall, all values of F_M cause greater stresses along lines NN and II, than do varying values of F_P.

4. DISCUSSION

FEA has been used extensively to predict the biomechanical performance of the jawbone surrounding a dental implant [21, 22]. Previous research considered the influence of the implant dimensions and the bone-implant bond on the stress in the surrounding bone. However, to date no research has been conducted to evaluate the stress produced by different implant to crown connections (i.e. internal and external-hex). The analysis completed in this paper uses the FEM to replicate internal and external-hex systems when subjected to both F_M and F_P loading conditions. As shown in **Table 2**, two stress peaks were revealed along the lines NN and II at locations 3.76 and 2.89mm from the top. The stress values shown were calculated with the other variables (i.e. F_M or F_P) set to its average.

The mastication force F_M is applied on the occlusal surface of the crown, evenly distributed along 378 nodal locations (**Figure 1a**), and orientated at 45° in the x-y plane. This induces compressive stresses in the right hand side of the crown and tensile in the left. Varying F_M from 200 to 1000N for the internal and external-hex systems results in a change in von Mises stress of 545.64 (818.47-272.82MPa) and 698.09MPa (1047.14-349.05MPa) respectively. The geometrical design of the external-hex system tends to induce stress concentrations, located 2.89mm from the apex in this study. For this system, a stress concentration at this point is also induced by F_P, increasing the compressive stresses on the right hand side of the crown. Increasing F_P from its minimum to maximum values, for the external-hex system, increases the stress by 485.46MPa (951.67-466.21MPa).

The internal-hex system has reduced stress concen-

Table 2. Von Mises stress (MPa) in crown (location of stress recording in brackets).

Variables / Line	F_M (N)			F_P (N)		
	200	500	1000	201.93	587.44	1009.67
NN (3.76mm)	272.82	545.64	818.47	231.55	545.64	891.83
II (2.89mm)	349.05	698.09	1047.14	466.21	698.09	951.67

trations, demonstrating that this design is less susceptible to stress concentrations within the crown. However, because of the transfer of the preload through the abutment screw to abutment contact, changing F_P is more influential on this hex system than F_M. Overall F_M is more influential on the stress within the crown for the external-hex system and F_P is more influential on the internal-hex system.

5. CONCLUSION

This research is a pilot study aimed at offering an initial understanding of the stress distribution characteristics in the crown under different loading conditions. Realistic geometries, material properties, loading and support conditions for the implant system were considered in this study. The geometrical design of the external-hex system tends to induce stress concentrations in the crown at a distance of 2.89mm from the apex. At this location, F_P also affects the stresses, so that the compressive stresses on the right hand side of the crown are increased. The internal-hex system has reduced stress concentrations in the crown. However, because the preload is transferred through the abutment screw to the abutment contact, changing F_P has greater effect on this hex system than F_M. Overall F_M is more influential on the stress within the crown for the external-hex system and F_P is more influential on the internal-hex system.

Future recommendations include the evaluation of other implant variables such as the implant wall thickness and thread design. Ultimately, all implant components can be understood in terms of their influence on the stress produced within the implant itself.

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