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ORIGINAL ARTICLE

Three Dimensional Finite Element Analysis of Stress Distribution Around Implant with Straight and Angled Abutments in Different Bone Qualities

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Abstract The aim of the study was to compare the stress distribution around implant in different bone qualities of D1, D2, D3, and D4 with straight and angled abutments using three dimensional finite element analysis. A three dimensional finite element model of the premaxilla region, and two solid 4.3 × 10 mm implant, one with a straight abutment and the other with an angled abutment was done. Four distinctly different bone qualities of D1, D2, D3, and D4 were made. A static load of 178 N was applied at the centre of incisal edge along the long axis of each abutment. The maximum equivalent von Misses stress values around the implants were recorded. The distribution of stresses changed considerably with abutment angulation. As angulation increased from 0° to 15° the concentration of Von Misses stresses shifted to the cortical layer of bone on the facial side of the fixture. Although Von Misses stress increased in straight abutment as the bone quality changed from D1 to D4, it was more noticeable under the loading side of the angulated abutments. The high stresses induced through angled abutments at the cervical zone of the implant due to forces and moments could be a dominant factor that may aggravate the peri-implant bone loss or changes the existing peri-implantitis direction.

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Introduction

In the anterior part of the maxilla the horizontal bone resorption is almost twice as pronounced as vertical resorption following tooth extraction [1]. Sufficient amount of bone for implant placement is an essential pre requisite for the long term success in oral implant therapy. Lack of bone volume always result in exposure of implant surface, decreased bone–implant interface and finally implant failure. This can be managed either by surgical correction or by positioning the implant in the area with the greatest available bone, with the intention of correcting the implant alignment at the time of implant restoration. This is made possible, in carefully planned cases, with the use of angled implant abutments. Eger et al. [2] and Sethi et al. [3] concluded that angled abutments may be considered a suitable restorative option when implants are not placed in ideal axial positions. The successful osseointegration of implant depends not only on the bone quantity but also on the bone quality [4]. The classification scheme for bone quality proposed by Lekholm and Zarb [5] has since been accepted by clinicians and investigators as standard in evaluating patients for implant placement. In this system, the sites are categorized into Type 1 (D1) to Type 4 (D4) on the basis of jawbone quality.

Implant manufacturers have introduced preangled abutments as a prosthetic option for dentitions that are otherwise difficult to restore because of implant location or angulation. The angulation of these abutments varies from 15° to 35°. Clinical comparative studies of implant with straight abutments and angled abutments showed that the bone loss or the survival of angled abutment was not significantly different from straight abutment [3, 6–8], however the Strain gauge measurements and photoelastic models of Brosh et al. [9] and the finite element analyses (FEA) of Canay et al. [10] and Clelland et al. [11] revealed that angled abutment were subjected to higher stress values around the cervical region than those observed for straight abutment.

Few investigators have studied the unavoidable situation of placing and loading implants at an angulation in the anterior maxilla, but they did not consider the variation in bone qualities which may influence the stress distribution around the implant with angled abutments. The aim of the present study was to compare the stress distribution around implant with straight and angled abutments in different bone qualities of D1, D2, D3, and D4 using three dimensional finite element analysis.

Materials and Methods

A three dimensional finite element model of premaxilla was created using a computerized tomography image. The scanned image was entered into a computer software program. Cross-sections were reassembled to get the three dimensional model of the premaxilla. Four distinctly different bone qualities of D1, D2, D3 and D4 were made. Two solid 4.3 × 10 mm screw type commercially pure titanium implant, (Nobel Biocare, Goteborg, Sweden) one with a straight abutment (M1) and the other with an angled abutment (M2) was placed in the central incisor region. Each of these implants was placed in four premaxilla models of distinctly different bone qualities D1, D2, D3, and D4 respectively.

Abutments have a base diameter equal to implant diameter of 4.3 mm with occlusal taper. Apart from the different angulations the 7-mm abutments were identical. Finite element models were simulated using Pro-engineering wild fire software (Parametric Technology Corp, Needham, MA, USA) and the analysis was performed using the software ANSYS Workbench 10.0 (Santa Monica, CA, USA).The models were processed in ANSYS to generate a meshed structure. Meshing divides the entire model into smaller elements which are interconnected at specific joints called nodes. The model for D1 bone had 30,243 elements and 16,820 nodes. D2, D3, and D4 models consisted of 38,908 elements and 20,878 nodes. In the current study, the materials used for the models were presumed to be linear, elastic, homogenous, and isotropic. The osseointegration of the implants was accepted as 100 %. The material properties were determined from values obtained from the literature [12–14] and are summarized in Table 1. A static load of 178 N was applied at the centre point of abutment fixture, along the long axis of each abutment. The amount of the load selected was based on the published average biting forces for incisor [15–17]. The applied forces were static. The maximum equivalent von Mises stress values around the implants were recorded. Von Mises stresses are most commonly reported in FEA studies to summarize the overall stress state at a point [18].

Results

Stress distribution was represented numerically and was colour coded. The von Mises stress for the straight abutment showed almost even distribution of stress in buccal and lingual side of both cortical and cancellous bone (Table 2). The distribution of stresses changed considerably with abutment angulation. As angulation increased from 0° to 15° the concentration of stresses shifted to the cortical layer of bone on the facial side of the fixture (Table 3). The von Mises stress around M1 and M2 was higher in cortical bone 3.66–20.83 than in cancellous bone 0.133–2.09.

Irrespective of the bone quality and angulation of the abutment the highest stress values were obtained at the crestal region of implant (Figs. 1, 2, 3, 4, 5, 6, 7, 8). The stresses on the buccal side of cortical bone in M1 and M2 increased in magnitude as the bone quality differed from D1 to D4. In all the four bone types the stress values in cortical and cancellous bone on the buccal side of M2 was found to be higher than the stress values on the buccal side of M1 (Table 1). The maximum von Mises stress of 20.832 was recorded in D4 cortical bone on the buccal side of M2 (Table 3). The stress values were found to be lower on the lingual side of implant with angled abutment in D2, D3, D4 bone types, when compared to the implant with straight abutment. The increase in stress in the buccal cortical bone when angled abutment used was greatest for D1 bone and least for D2 bone.

Table 1 Material properties used in the FE study

Material	Youngs modulus (GPa)	Poisons ratio
Titanium abutment and implant [12]	110	0.35
Dense trabecular bone (D2 and D3 bone) [13, 14]	1.37	0.30
Low density trabecular bone (D4 bone) [13]	1.10	0.30
Cortical bone [13, 14]	13.7	0.30

Table 2 Von Mises stress for the models with straight abutment

Bone quality	Buccal		Lingual	
	Cortical	Cancellous	Cortical	Cancellous
D1	4.033		3.66	
D2	9.538	0.774	7.595	1.061
D3	13.126	1.868	9.102	1.517
D4	15.696	1.110	11.838	1.223

Table 3 Von Mises stress for the models with angled abutment

Bone quality	Buccal		Lingual	
	Cortical	Cancellous	Cortical	Cancellous
D1	13.022		4.73	
D2	13.99	1.699	2.535	0.201
D3	19.261	2.097	2.545	0.517
D4	20.832	1.856	2.129	0.133

Discussion

The bone morphology of premaxilla often dictates placement of implants with the long axis in different and exaggerated angulations. The implant alignment is corrected at the time of restoration with the use of angled abutment. Due to the unfavorable loading direction that angled abutments have, it is important to understand the stresses transferred through angled abutment to the surrounding bone, through which we can prevent less than ideal stress transfer conditions. The correlation of poor bone quality and implant failure has been well established, but the precise relation between bone quality and stress distribution when angled abutment was used is not adequately understood. In the present study the stress distribution around implant in different bone qualities of D1, D2, D3, and D4 with straight and angled abutments was studied using three dimensional finite element analysis. The implant abutment complex was modeled as a one piece structure and the crown restoration was omitted because the primary aim of the study was to analyze the stress distribution around the implant and not to study the stress distribution at the implant–abutment or the abutment–prosthesis interfaces [19].

The stresses around M1 and M2 in all the bone qualities were found to be concentrated within the cortical bone around the neck of the implants. This conforms to other studies on the biomechanical behavior of implants which have concluded that the stresses tended to be concentrated at the cortical bone around the neck of the implant closest to the load, whereas stresses in cancellous bone were considered low [20–22]. This is likely due to the difference in the modulus of elasticity in cortical and cancellous bone. Cortical bone having a higher modulus of elasticity is more resistant to deformation and will bear more load than cancellous bone. The other reason for the higher stress concentration in cortical bone is due to that the mechanical stress distribution occurs primarily where bone is in contact with the implant. The amount of implant to bone contact is related directly to the density of bone. The percentage of bone contact is significantly greater in cortical bone than in cancellous bone [23].

The anterior teeth were subjected to maximum compressive stress during incising and the force would be directed along the long axis of the tooth. In implant with straight abutment the force was directed along the long axis of abutment and implant, which results in even distribution of stresses on the buccal and lingual side in all the four bone qualities (Table 2). In angled abutment the force would be directed to the area of bone opposite to that of abutment inclination. The present study shows that the stress values on the buccal bone were found to be higher when the abutment was inclined 15° palatally. Although von Mises stress increased in straight abutment as the bone quality changed from D1 to D4, it was more noticeable under the loading side of the angulated abutments. The elastic modulus of bone is less than titanium, so when the

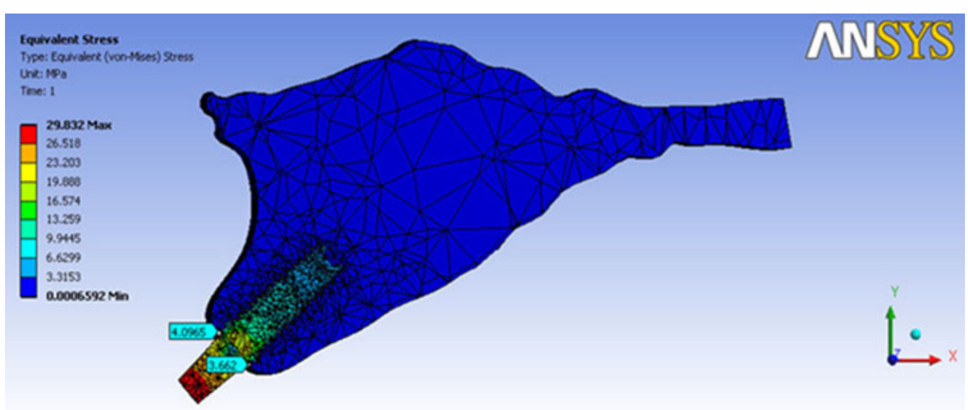

Fig. 1 Von Mises stress around implant with straight abutment in D1 bone

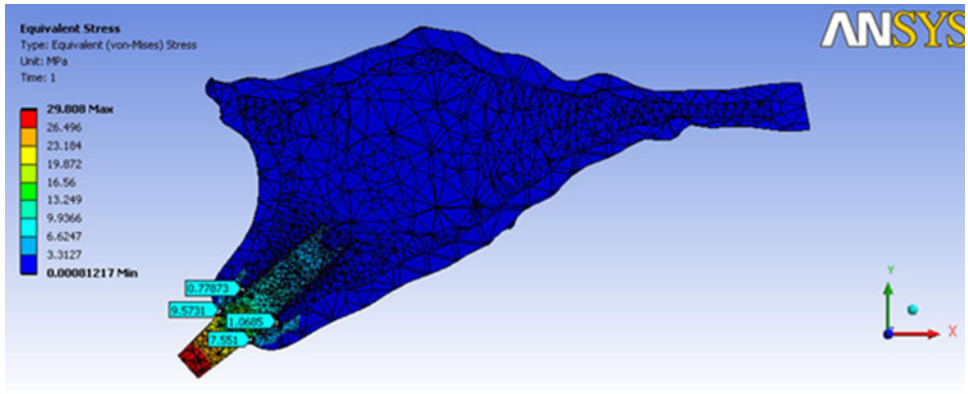

Fig. 2 Von Mises stress around implant with straight abutment in D2 bone

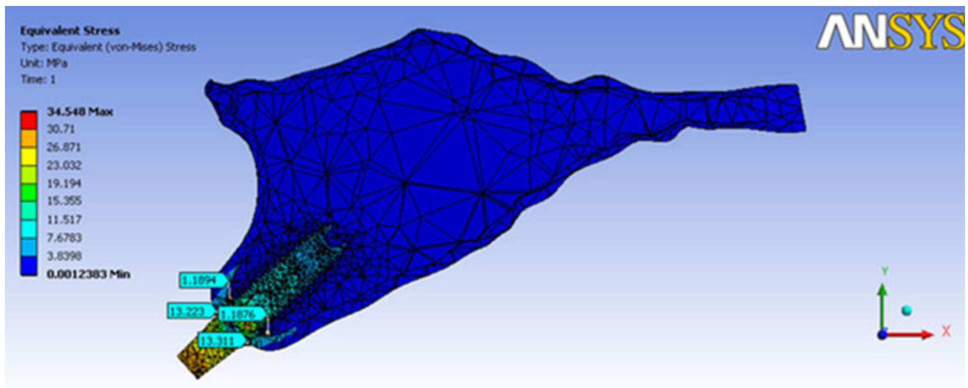

Fig. 3 Von Mises stress around implant with straight abutment in D3 bone

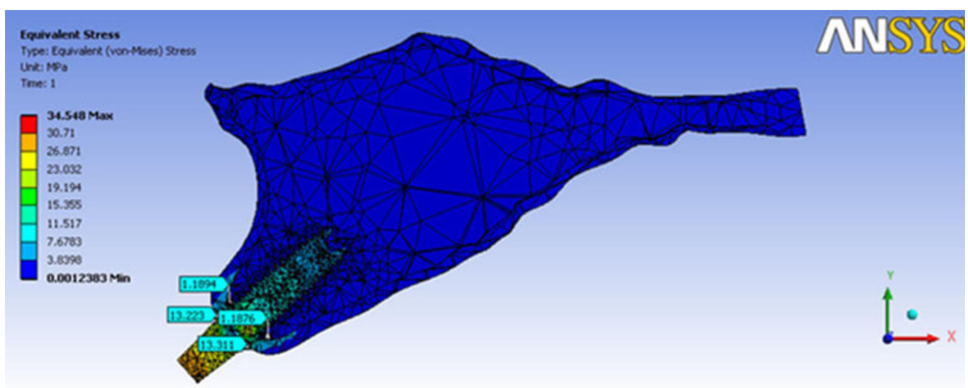

Fig. 4 Von Mises stress around implant with straight abutment in D4 bone

stresses applied to the implant are high, the microstrain difference between the titanium and bone is maximized. The maximum stress around D4 bone coupled with low elastic modulus may cause implant in D4 bone to lose osseointegration. Lin et al. [24] who conducted an analysis of stress on single implants noted that the cortical bone strain was higher for an angled abutment of 20° than that for straight abutments and the bone strain increased as bone density decreased. Danza et al. studied the stress distribution around a spiral implant with a straight abutment, 15° and 25° angulated abutment in D1 and D4 bone using 3D FEA and found out that maximum bone stress was obtained with 15° angulated abutment [25]. Results of finite element analysis done by Kao et al. [26] showed that abutment angulation up to 25° can increase the stress in the peri-implant bone by 18 % and the micromotion level by 30 %. The results of the study leads to the inference that, if a case is planned for angled abutment, sufficient thickness and better quality (D1, D2, or D3) of bone should be available on the site opposite to that of abutment

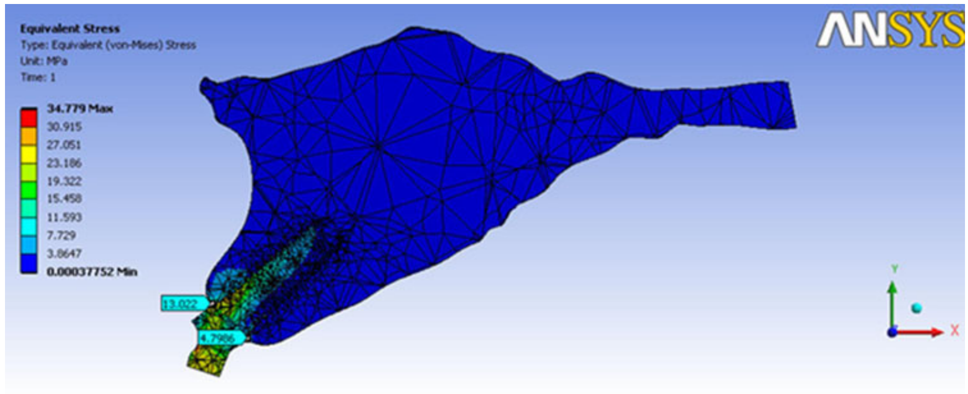

Fig. 5 Von Mises stress around implant with angled abutment in D1 bone

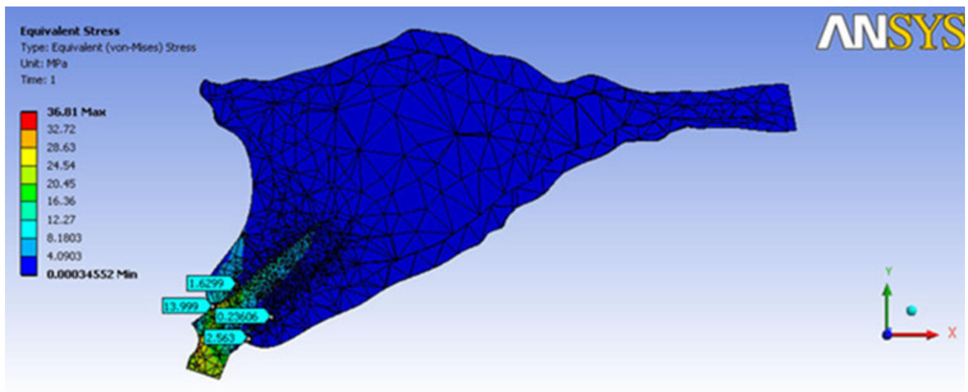

Fig. 6 Von Mises stress around implant with angled abutment in D2 bone

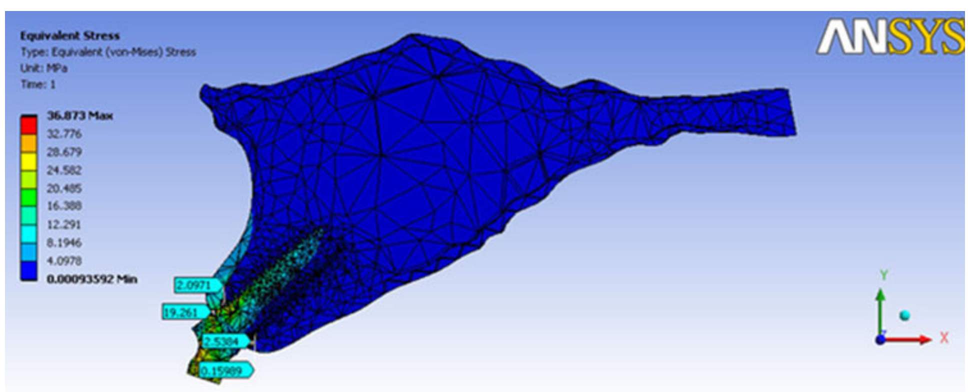

Fig. 7 Von Mises stress around implant with angled abutment in D3 bone

inclination to withstand higher stresses. Spray et al. [27] examined buccal bone thickness during implant placement and found that 1.8 mm of buccal bone thickness was the critical thickness required to prevent bone loss in that area.

The increase in stress values from D1 to D4 cortical bone may be due to, the D1 bone comprised of entire cortical bone was able to distribute the stress evenly, whereas in D4 bone stresses were principally concentrated in the thin layer of cortical bone. The higher Von Misses stress value in D2 bone than in D1 is due to the volume of compact bone was less in D2 than in D1 bone quality. The D4 bone had the same cortical bone configuration as for D3 bone but the stress was found to be higher in the cortical bone of D4 than in D3 bone (Table 2). This may be because the D4 bone comprised of low density trabecular bone was not capable to withstand high stresses, so most of the stresses had to be borne by the cortical bone. The Implant dentistry would greatly benefit if it were provided the means to predict how bone and implant components would behave considering each patient's unique jaw anatomy, quality of bone, amount of occlusal force exerted on the prosthesis, angulation of abutment etc. FEA, with all its

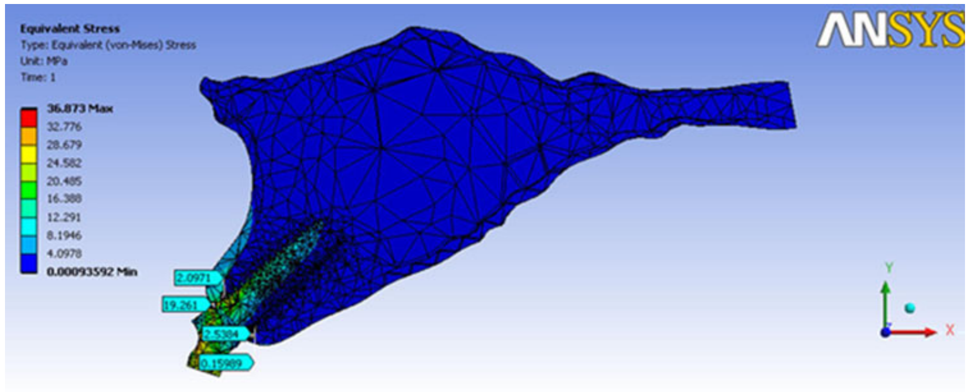

Fig. 8 Von Mises stress around implant with angled abutment in D4 bone

inherent limitations [28, 29] is a valuable instrument in pursuing that goal.

Conclusion

The Von Misses stress values were increased as the bone quality changes from D1 to D4. This was more pronounced when angled abutment was used. In D4 bone the angled abutment has to be used judiciously as the Von Misses stress concentration was maximum. The high stresses induced through angled abutments at the cervical zone of the implant due to forces and moments could be a dominant factor that may aggravate the periimplant bone loss or changes the existing peri-implantitis direction. An alternative treatment plan, such as inserting the implant in perfect alignment, concomitant with autogenous bone graft and membrane should be considered to minimize the use of preangled abutments and to avoid the much higher stresses induced by them.

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