Research Article

Evaluation of the Effect of Complete and Partial Osseointegration in Stress Development at Bone-Implant Interface: A 3D Finite Element Study

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ABSTRACT

Introduction: Mini-implant has been in use as temporary anchorage device in orthodontics. Various factors like length, type of osseointegration, magnitude and direction of force, insertion angle of the mini-implant affect the stress development at the bone and implant interface. Development of undesirable stress at the bone-implant interface can lead to bone defect and failure of the implant. Various opinions regarding the need of osseointegration have been reported.

Objective: To study the effect of complete and partial osseointegration on Von Mises stress distribution at the bone-implant interface.

Materials & Method: Finite element model of 9mm × 1.5mm mini-implant and bone segment of 1.5mm were constructed to simulate the biomechanical response of the bone to the mini- implant by using CATIA V5-6R 2013 software. Stress developed on implant and bone were analyzed by using ANSYS: 13 2013 version software for both complete and partial level of osseointegration.

Result: Maximum Von Mises stress in complete osseointegration was 14.49 Mpa in cortical bone, 0.551 Mpa in cancellous bone and 50.76 Mpa in implant. In partial osseointegration, it was 18.68 Mpa in cortical bone, 1.23 Mpa in cancellous bone and 66.80 Mpa in mini-implant.

Conclusion: In partial osseointegration, stress developed was higher but well below the yield strength of respected continuum. So the partial osseointegration is a good compromise between the necessity of reducing mobility of implant and the necessity for easier screw removal.

Key words: cancellous bone, cortical bone, Finite element analysis, mini-implant, Von Mises stress

INTRODUCTION

"*Implants- Alloplastic device which are surgically inserted in to or on to the jaw bones*"- Boucher

In dentistry, it is widely used as a dental implant for prosthetic tooth in Prosthodontics and as temporary anchorage device (TAD) in Orthodontics. Implant used as TAD is of smaller dimension and is known as mini-implant. When implant is inserted into the bone and force is applied, stress is developed over implant and bone which play a substantial role in implant success or failure since it affects bone remodeling process around the implant.[1] Osseointegration is one amongst many other factors which affect the stress development.

There are two views regarding the implantation and time of force application; one is immediate loading and another is waiting for osseointegration to take place. Chen *et al* supported immediate loading using Finite element analysis (FEA)[2] whereas others believed that immediate loading or early loading of mini-implant caused decreased stability and spontaneous fracture of the bone.[3,4] Liou *et al*[5] hypothesized the increased chances of screw movement in non osseointergated TAD which was supported by the FEA study by Gracco *et al*.[6]

Various methods have been used to study the stress/strain in bone and dental implants. There are different types of stress analysis: photoelasticity, interferometric holography, strain gauges, Finite element analysis. Amongst them 3D finite element method is preferable as it provides more reliable data and represent non-linear and anisotropic materials more accurately.[7] This study was conducted to evaluate the effect of complete and partial osseointegration in stress development at the interface of implant, cortical bone and cancellous bone and also to study whether complete osseointegration is mandatory during implant placement in orthodontic department in term of stress distribution or not.

MATERIALS AND METHOD

Three dimensional finite element analysis is a method in which instead of seeking a solution function for the entire domain, one formulates the solution functions for each finite element and combines them properly to obtain the solution to the whole body. FEA is gaining popularity because of its ability to accurately assess the complex biomechanical behavior of irregular and heterogeneous material in a non-destructive and repeatable manner, and simulates the intraoral environment.[8,9]

The materials used in the study were:

- A computer software (ANYS: 13 version) for finite element analysis
- Computer aided designed (CAD) Model of Implant
- CAD Model of Bone

Implant: CAD model of conical mini-screw was generated with the dimension of diameter 1.5 mm and 9 mm (Figure 1 and Figure 2). Thread pitch, thread height, thread width at base and at tip were kept 0.4 mm, 0.2 mm, 0.2 mm and 0.4 mm respectively (Figure 3).[10]

The material was assumed to be Titanium homogeneous, liner elastic with Young's modulus of E = 110000 Mpa and Poisson's ratio of V= 0.3 mm.

Bone: The bone surrounding the mini screw was modeled in the CAD environment. The cortical bone of 1.5 mm thickness with E=13700 Mpa, V=0.3 and cancellous bone with E=1300 Mpa, V=0.3 was modeled (Figure 4).[11]

The dimension of maxilla was taken from CT scan of a patient with the consideration of magnification factor. The maxilla was approximately 11 mm in width bucco-lingually, 13 mm in height infero-superiorly and 6.5 mm in length in the mesio-distal direction. Implant inserted was at an angle of 45 degrees. After completing the fabrication of CAD model, meshing of implant and bone complex was done with 67660 hexahedral element and 67934 nodes (Figure 5 to Figure 10). Level of osseointegration hypothesized were complete osseointegration and partial osseointegration (Figure 11,12). A force of 2 Newton was applied perpendicular to the mini-implant to simulate the clinical scenario (Figure 13).

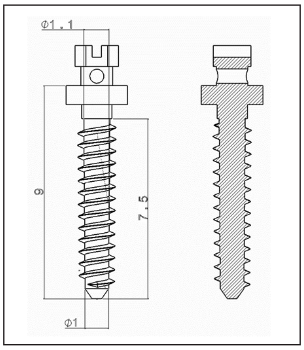

Figure 1: Dimension of implant

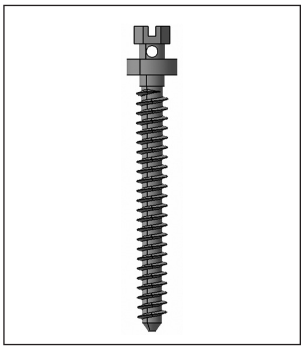

Figure 2: CAD model of implant

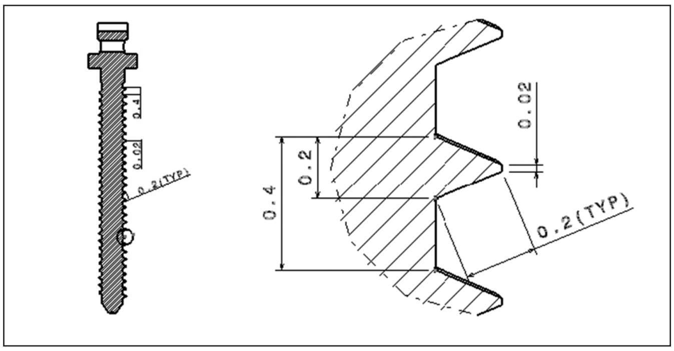

Figure 3: Dimension of thread of implant

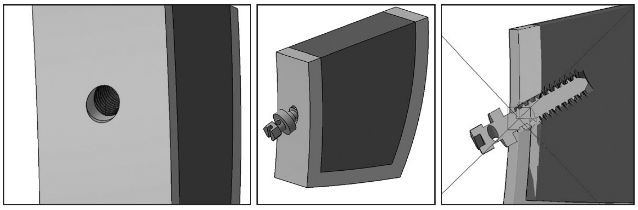

Figure 4: A. CAD model of bone B. CAD model of implant-bone complex C. Transection view of CAD model of implant and bone complex

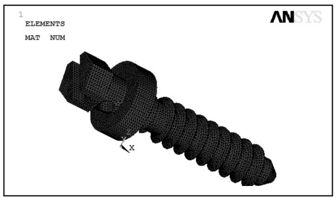

Figure 5: Meshed structure of implant

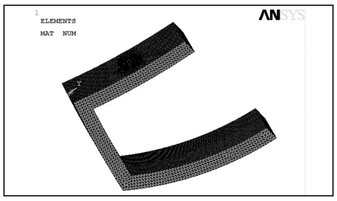

Figure 6: Meshed structure of cortical bone

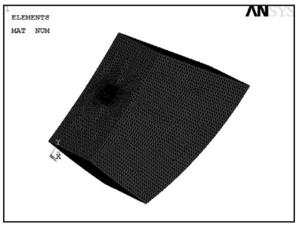

Figure 7: Meshed structure of cancellous bone

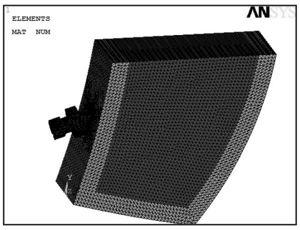

Figure 8: Meshed structure of implant-bone complex

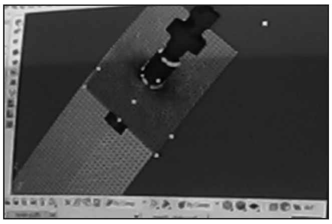

Figure 9: Node placement

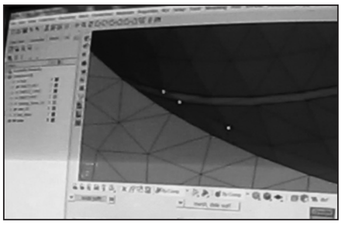

Figure 10: Close view of node placement

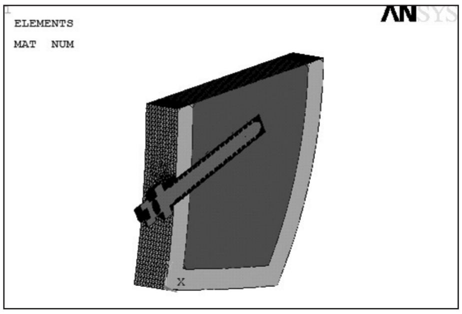

Figure 11: Complete osseointegration

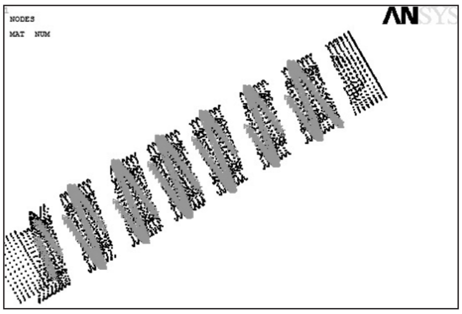

Figure 12: Partial osseiointegration

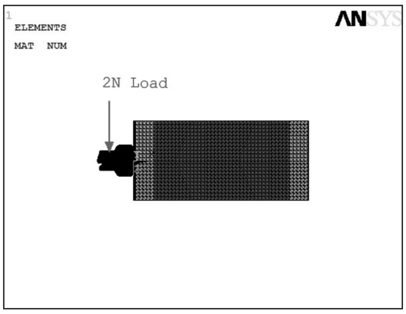

Figure 13: Application of 2N horizontal force

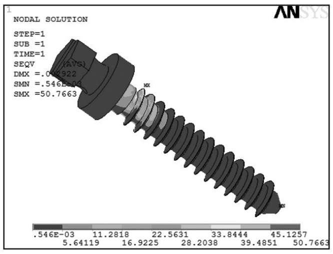

Figure 14: A. stress development in implant in complete osseointegration

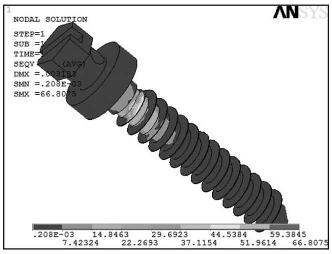

Figure 15: A. stress development in implant in partial osseointegration

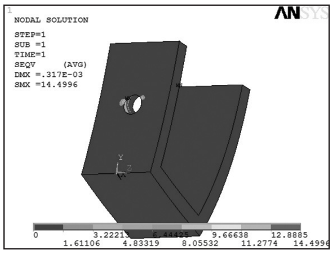

Figure 16: Stress development in cortical bone in complete osseointegration

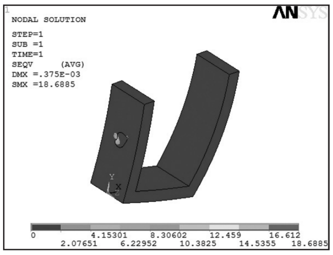

Figure 17: Stress development in cortical bone in partial osseointegration

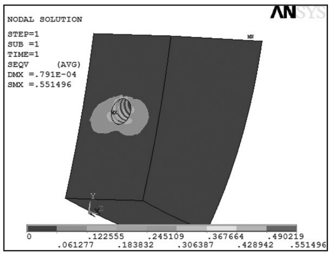

Figure 18: Stress development in cancellous bone in complete osseointegration

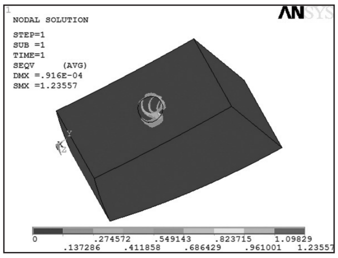

Figure 19: Stress development in cancellous bone in partial osseointegration

RESULT

FEM analysis showed that high values of maximum Von Mises stress arose within the screw and principally at the neck in both complete and partial osseointegration (Figure 14,15). In case of cortical and cancellous bone, stress development closer to the implant was higher and gradually decreased as the distance increased (Figure 16 to 19).

In all continuums, maximum Von Mises stress was more in partial osseointegration than in complete osseointegration (Table 1). For cancellous bone, the pattern of stress development appeared to be more sensitive to the level of osseointegration than in cortical bone and implant.

DISCUSSION

In the present study, analysis of stress distribution was carried out in complete and partial osseointegration of 9mm mini-implant inserted in maxilla utilizing 3D fininte element analysis. The maximum stress developed in implant were 50.76 MPa and 62 MPa in complete and partial osseiointegration respectively. Since the yield strength of Titanium miniscrew is 880 MPa,[14] the maximum Von Mises stress developed on implant was significantly smaller. So miniscrew is safe in both complete and partial osseointegration.

Similarly maximum Von Mises stress developed in cortical bone were 14.49 MPa and 18.68 Mpa in complete and partial osseointegration respectively which were also less sensitive because the yield strength of cortical bone is 122 Mpa.[12] Although maximum Von Mises stress in partial osseointegration (1.23MPa) was very high than in complete osseointegration (0.551MPa), it was smaller than yield strength of cancellous bone (2MPa).[12] The results for cancellous bone is sensitive because Von Mises stress was 0.55 Mpa and 1.23 Mpa in complete and partial osseointegration respectively. But that value was also not so significant beacause it is well below the level of yield strength of cancellous bone which is 2 Mpa. The FE predictions in the present investigation were in good

Table 1: Von Mises stress in complete and partial osseointegration

Stress	Level of Ossienintegration	Cortical bone Mpa	Cancellous bone Mpa	Implant Mpa
Von Mises	Complete	14.49	0.551	50.76
	Partial	18.68	1.23	66.80
Total	208.377	49.000	-	-

agreement with the results of Gracco *et al*[6] who found that more stress was developed in partial osseointegration than in complete osseointegration but was well below the level of yield strength of the material.

The present study has some limitations. Firstly, homogeneous and isotropic material was hypothesized. In reality they are neither homogeneous nor isotropic. Secondly, the finite element model represents a static situation at the moment of load application and not an actual clinical situation. In reality, the loading of the structure is more dynamic and cyclic. The diameter of the implant thread and of the bone hole were made identical so that the stress component due to insertion could be neglected.[13]

CONCLUSION

In partial osseointegration stress developed was higher but well below the yield strength of respected continuum. So the partial osseointegration is a good compromise between the necessity of reducing mobility of implant and the necessity for easier screw removal.

Acknowledgement:

Authors would like to thank Mr Nagbhusan (Engineer), Tejshbi Institute of Engineering, Bengaluru, India for technical support.

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