Original Article

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Quick Response Code:
Website:
www.jorthodsci.org
DOI:
10.4103/jos.jos_77_22

Factorial analysis of variables affecting bone stress adjacent to mini-implants used for molar distalization by direct anchorage—A finite element study

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Abstract

OBJECTIVE: The aim of this study was to investigate the stresses on mini-implant, cortical bone, and cancellous bone for maxillary molar distalization using an orthodontic implant in a finite element model for different angulations and depths of insertion.

METHODS: A three-dimensional finite element method was used to simulate overall orthodontic tooth movements by using ANSYS software. The maxillary bone and the molars were reproduced using CT scan images and conversion of the same into STL file was done. Finite element model was generated and the effect of forces was studied on the model for different depths and angulations of mini-implant insertions. The distalization force was exerted by an open-coil spring and the direct skeletal anchorage was provided by a mini-implant. Mini-implants were placed in depths of 5 mm, 7 mm, and 9 mm inside the bone and insertion angles of 30°, 60°, and 90°. Stresses on mini-implant and extent of stress on the surrounding bone were assessed by the software.

RESULTS: 1. Least stress was found when the mini-implant was inserted at an angle of 30°, as it is nearer to the stronger cortical bone. 2. As the length of the mini-implant increases, accompanied by the increase in the depth of insertion, a decrease in stress in the mini-implant, cortical bone, and cancellous bone was noticed.

CONCLUSION: An increase in the insertion angle from 30° to 90° increases the stresses on both the implant and the cortical bone. A higher depth of thread in the bone helps in reducing the stress on the implant, cortical bone, and cancellous bone. This helps in improving the primary stability of the mini-implant and its life.

Keywords:
Angulations of the mini-implant, depth of min implant, FEM, orthodontic mini-implant

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Submitted: 25-Aug-2022
Revised: 25-Oct-2022
Accepted: 10-Nov-2022
Published: 18-Mar-2023

Introduction

Anchorage during orthodontic treatment is a major challenge for an orthodontist. Traditionally, the principles of mechanics in orthodontic treatment are based on the anchorage provided by the surrounding dental units from which reactive forces may result in anchorage loss.[1]

Orthodontic implants have become broadly accepted as alternatives to extraoral devices in patients who either have insufficient dental support suitable for orthodontic anchorage or are not compliant with wearing extraoral devices.[2] Compared with traditional anchorage reinforcements such as transpalatal arches and extraoral appliances, mini-implants are advantageous because of their smaller size, convenient insertion and

How to cite this article: Kovuru V, Aileni KR, Mallepally JP, Kumar KS, Sursala S, Pramod V. Factorial analysis of variables affecting bone stress adjacent to mini-implants used for molar distalization by direct anchorage—A finite element study. J Orthodont Sci 2023;12:18.

removal procedures, relatively low cost, and the fact that immediate orthodontic loading is possible.

A practical issue with the mini-implants would be its loosening, which can compromise the success of the procedure. The failure rate of mini-implant for orthodontic anchorage is reportedly up to 30%. Research studies have investigated biological and mechanical factors, other than infection, that might be related to the failure of mini-implants. These factors include orthodontic force level, site of implantation, cortical bone thickness, and patient-dependent oral conditions. Although a mini-implant is used as a temporary anchorage device, its primary stability is crucial to the long-term success of the associated treatment. Because of limited interdental space, the mini-implant can be close to the root, and orthodontic forces can be transmitted directly to the alveolar bone via the mini-implant. Moreover, the development of a stress field incorporating the alveolar bone around the mini-implant is reportedly correlated with mini-implant failure.[3]

Some relevant factors that may affect the primary stability of orthodontic mini-implants (OMIs) are bone quality, implant design, insertion method, cortical bone thickness, and insertion angle. Studies have reported that mini-implants that are inclined in the bone surface provide greater contact with the cortical bone, resulting in increased mechanical retention and stability of the implant.[4,5]

The finite element method is a computational system for continuum mechanics that estimates the deformation (fully detailed changes of the position of all component particles) that are expected to result from a specified pattern of stresses (forces) upon a mechanical system.

The aim of this study was therefore to investigate the stresses on mini-implant, cortical bone, and cancellous bone for maxillary molar distalization using an orthodontic implant in a finite element model for different angulations and depths of insertion.

Model design and forces

The FEM model was designed according to the study done by Lu *et al*.[6] The distalization force was exerted by open-coil spring and the direct skeletal anchorage was provided by a mini-implant. Brackets were placed on all teeth except the second premolar. A 0.019 × 0.025-inch SS arch wire was engaged. To distalize the first molar, 150 g of force was applied by open-coil spring between the first premolar and the first molar. To prevent labial movement of anterior teeth, a force of 150 g was applied between a virtual position of a mini-implant (8 mm apical to arch wire and 2 mm lateral to the alveolar bone surface) and a 0.8-mm SS retraction hook attached to the arch wire between the lateral incisor and canine [Figures 1 and 2]. The implants were placed in the interdental space between the second premolar and the first molar in the maxilla as suggested by Chen *et al*.[7] and Ishii *et al*.[8]

Materials and Methods

In this study, the CT scan (DICOM format data) of the maxilla and the maxillary dentition in the axial plane was taken. The cut sections were taken starting from 1 mm from the apex and moving incisally at a thickness of 1 mm. The processing was done using MIMICS (Materialize's Interactive Medical Image Control System) software and then maxilla was exported to STL (Stereolithography) format. This STL format is imported into rapid form software to create the surface data. Surface data are converted to IGES (Initial Graphic Exchange Specification) and is exported to HYPER MESH. Approved by ethical committe & form uploaded Date of approval 05-12-2017.

Steps involved in the finite element model

1. Construction of the geometric model
2. Conversion of the geometric model to a finite element model
3. Material property of the data representation
4. Defining the boundary condition
5. Loading configuration
6. Interpretation of results.

Utilizing a mock approach, the mini-implant was placed between the root of the second premolar and first molar teeth into the bone model. The suitable site of arch wire placement was assumed in measuring the position of the implant. Three different angles of implant insertions were considered: 30°, 60°, and 90°. Three different depths of insertion 5 mm, 7 mm, and 9 mm were considered. The area of the simulation was

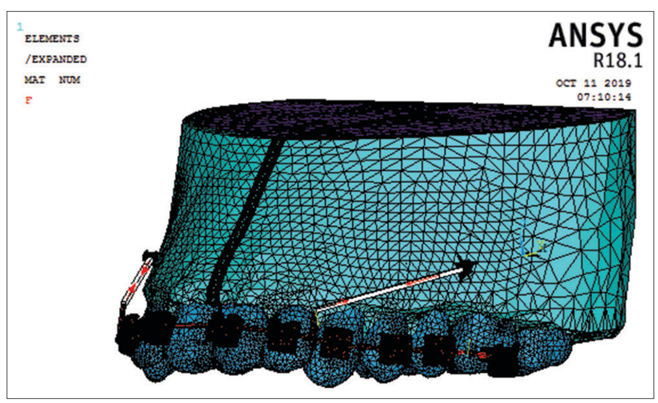

Figure 1: Boundary conditions for the problem

the interdental region between the maxillary second premolar and first permanent molar. The placement of the mini-screw was 5 mm gingival from the intercrestal bone level between the two teeth [Figure 3].

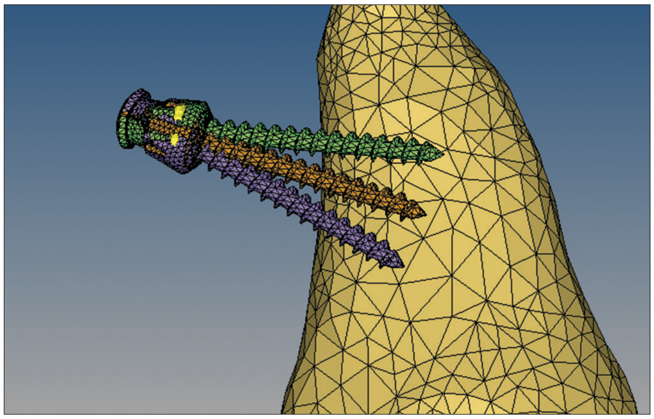

Figure 2: Arranged implants in 90-, 60-, and 30-degree orientation

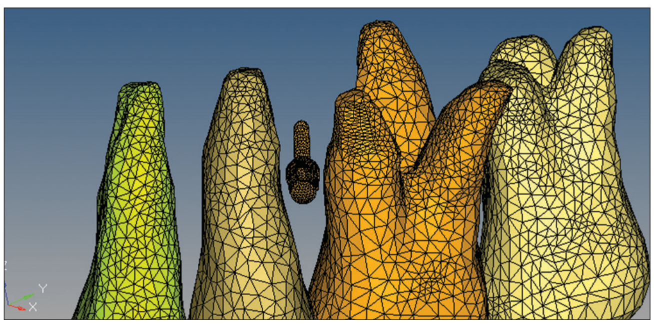

Figure 3: Position of the mini-implant in relation to the teeth

Results

The analysis was done to check the Von Mises stresses on the implant, cortical bone, and cancellous bone while performing direct distalization of the maxillary first molar with a force of 150 gm/side. The Von Mises stresses on the implant, cortical bone, and cancellous bone for different angulations and depths were calculated and the results were tabulated.

Stress values for different angulations of insertion of mini-implant

The different inclinations of implant insertions give a significant influence on the stress distribution and its magnitude within bones and implant. Within all implant inclinations, the pattern of stress seemed to be approximately similar to each other [Figures 4-6,10].

The stress was more concentrated at the neck and first thread of the implant in the mesial direction [Table 1]. The results obtained were; for a depth of 5 mm insertion the stress on the implant was found to be 1.02294 MPa, for a depth of 7 mm insertion the stress on the implant was found to be 0.67637 MPa, and for a depth of 9 mm insertion the stress on the implant was least at 0.512657 MPa. With the increase in the length of the mini-implant and the subsequent increase in depth of insertion, the Von Mises stress values reduced gradually [Table 2]. For a depth of 5 mm insertion the stress on the cortical bone is 0.101577 MPa, for a depth of 7 mm the stress was 0.071402 MPa, and for a depth of 9 mm insertion the stress on the

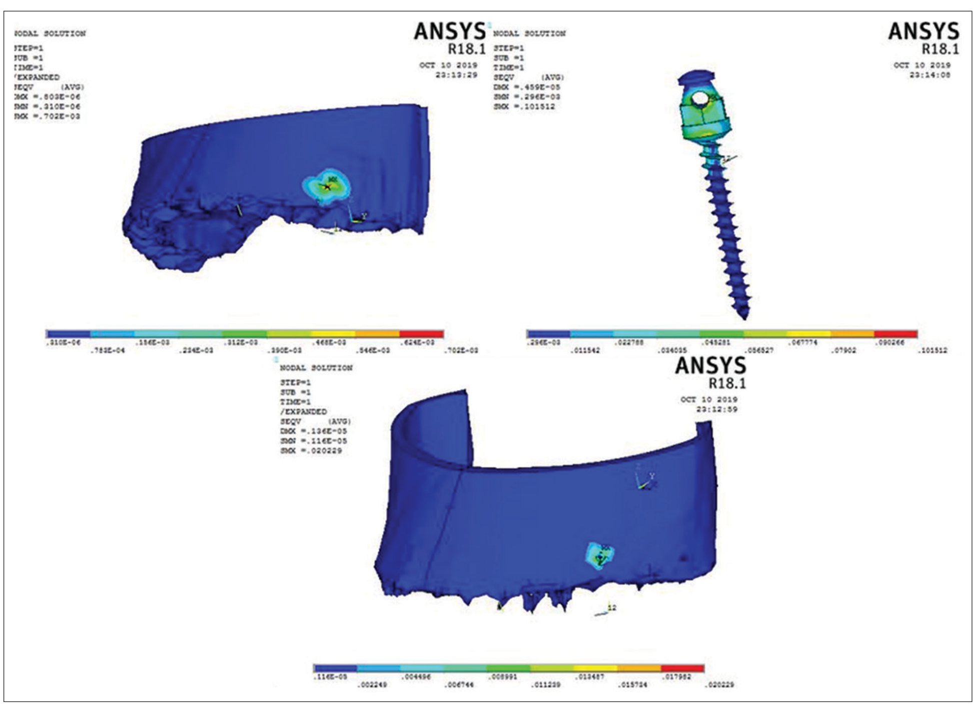

Figure 4: Implant insertion angle of 30° (8 mm)

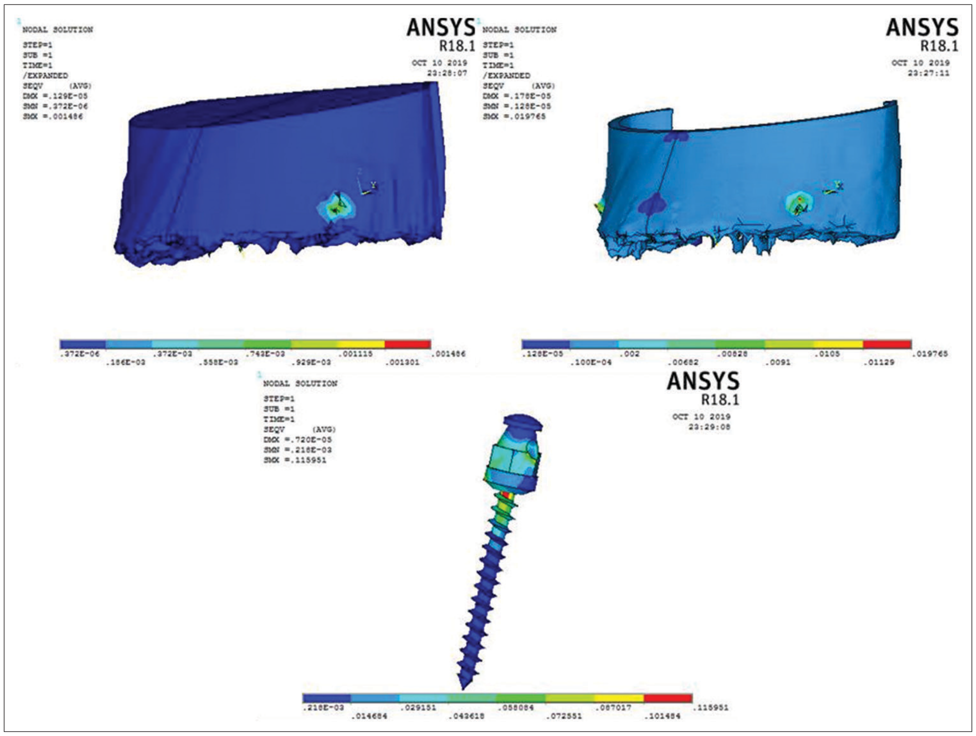

Figure 5: Implant insertion angle of 60° (8 mm)

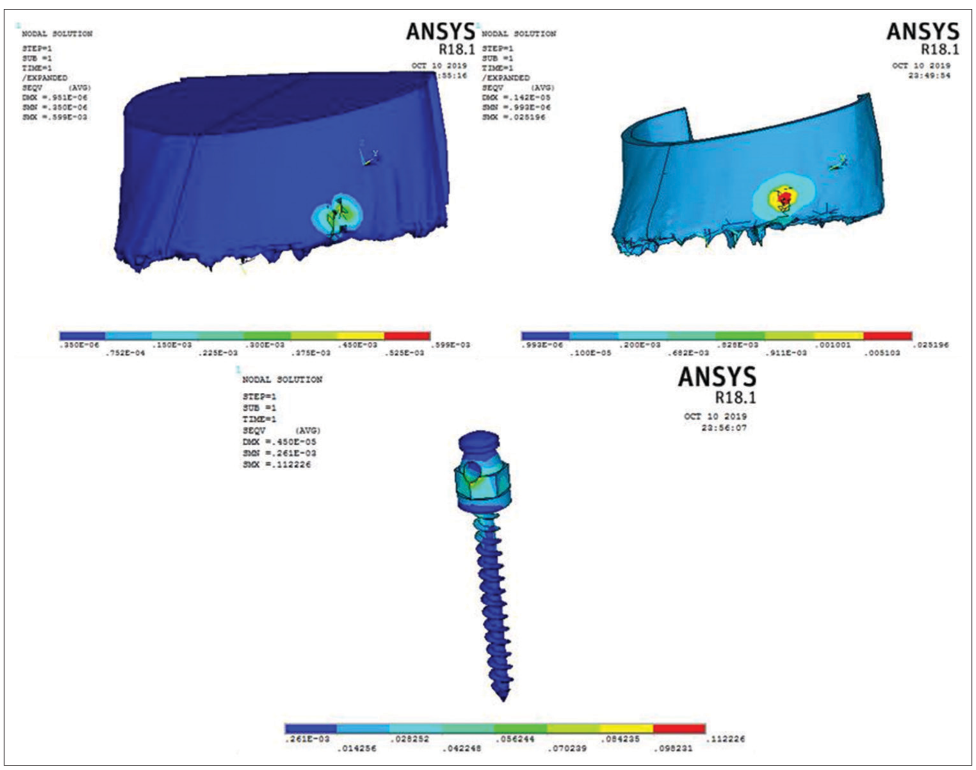

Figure 6: Implant insertion angle of 90° (8 mm)

implant was found to be 0.054146 MPa. The values of Von Mises stress in the cortical bone also decreased gradually as the depth of insertion of the mini-implant increased. For a depth of 5 mm insertion the stress on the cancellous bone was found to be 0.002199 MPa, for a depth of 7 mm insertion the stress was found to be 0.001572 MPa, and for a depth of 9 mm insertion the stress was found to be 0.001276 MPa. The values of Von Mises stress in the cancellous bone also decreased gradually as the depth of the mini-implant increased [Figures 7-9,11].

This clearly shows that with the increase in length of the mini-implant inside the bone, the stability of the implant increases with reduced stress.

Discussion

Mini-implant failure and loosening rates for orthodontic tooth movement range from 6.9 to 28.0%, and their success depends on several factors including the magnitude and direction of the applied force; operator experience; insertion site; quality of cortical bone; surface contact area in cortical bone; length, depth, diameter, thread configuration, the shape of the mini-implant; and patient's age.[9]

The study conducted shows that the stress is concentrated at the neck of the mini-implant with Maximum stress of 0.000702 MPa observed at the implant cancellous interface. The maximum stress is localized due to implant and cancellous geometrical interface due to stress concentration. The least stress in the mini-implant is noted for 30° inclination as it is nearer to the stronger cortical bone, ensuring maximum support available for load transfer. Laursen *et al*.[10] in their study found a similar finding that changing the insertion angle from 90° to 45° increased the cortical bone-to-implant contact by an average of 47% and ensured increased primary stability of the mini-implant. Kravitz *et al*. said that the major problem associated with angulated insertion is that it does not allow complete insertion of the OMI threads into the bone, leading to a larger lever arm formed off-the-bone, negatively contributing to primary and secondary stability, as well as increasing the possibility of forming niches where food may accumulate.[11] For all the different depths of insertion, there was greater cortical bone deformation when compared to the cancellous bone. But the greatest strain was located on the mini-implant. Tension on the mini-implant was located in its cervical region. It was noticed that as the depth of the implant increased, the Von Mises stress values decreased on all the parameters assessed. This indicated that the greater the implant length and the accompanied depth, the greater is its primary stability. Chiatzigianni *et al*. found a similar result in their study and concluded that both increased diameter and length

Table 1: Results to find effect of inclination on the stress generation

Implant orientation (Angle)	Implant stress (MPa)	Cortical stress (MPa)	Cancellous stress (MPa)
30°	0.101512	0.020229	0.000702
60°	0.115951	0.019765	0.001486
90°	0.112226	0.025196	0.000599

Table 2: Results to find the effect of depth of implant in the bone

Implant length-Depth of thread inside the bone	Implant stress (MPa)	Cortical stress (MPa)	Cancellous stress (MPa)
6-5 mm depth	1.02294	0.101577	0.002199
8-7 mm depth	0.67637	0.071402	0.001572
10-9 mm depth	0.512657	0.054146	0.001276

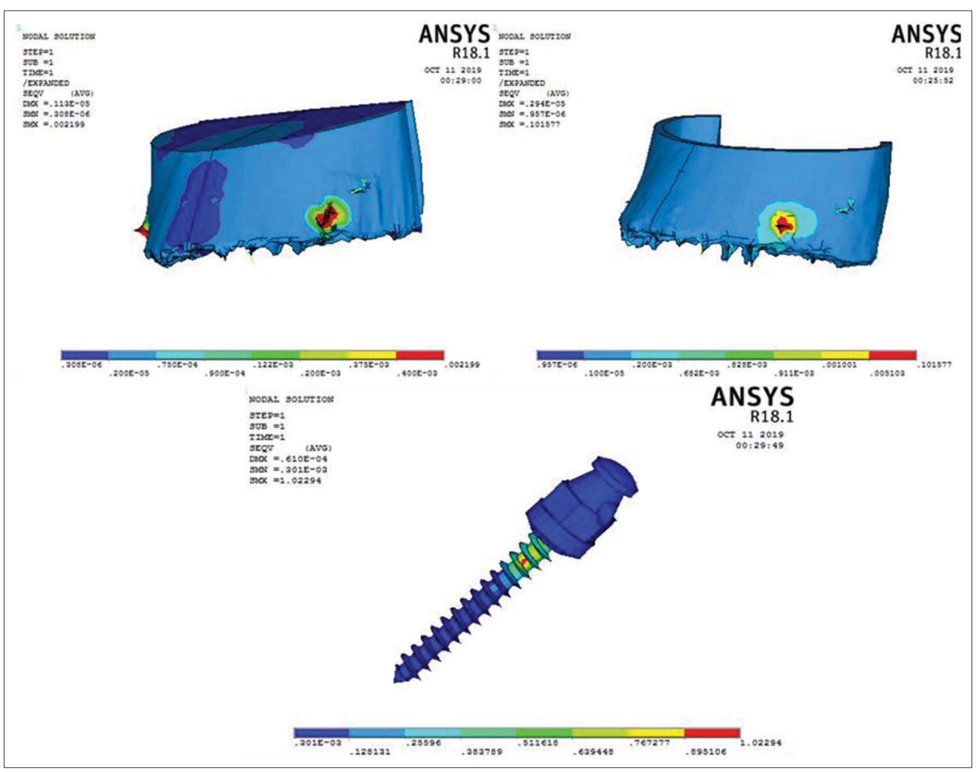

Figure 7: 5 mm—Depth into the bone

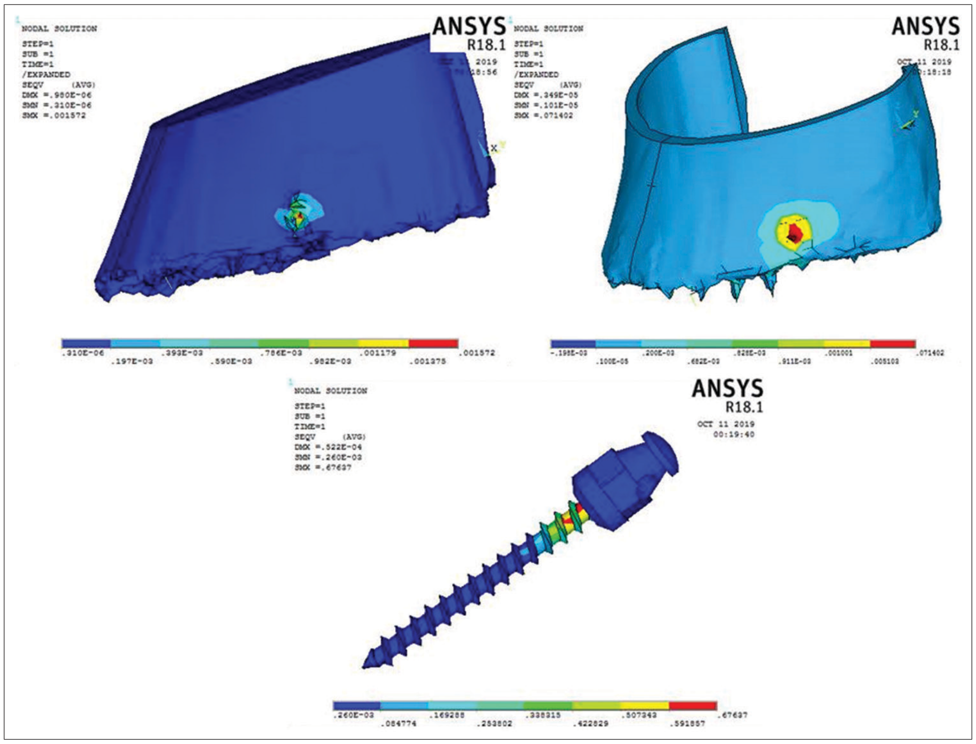

Figure 8: 7 mm—Depth into the bone

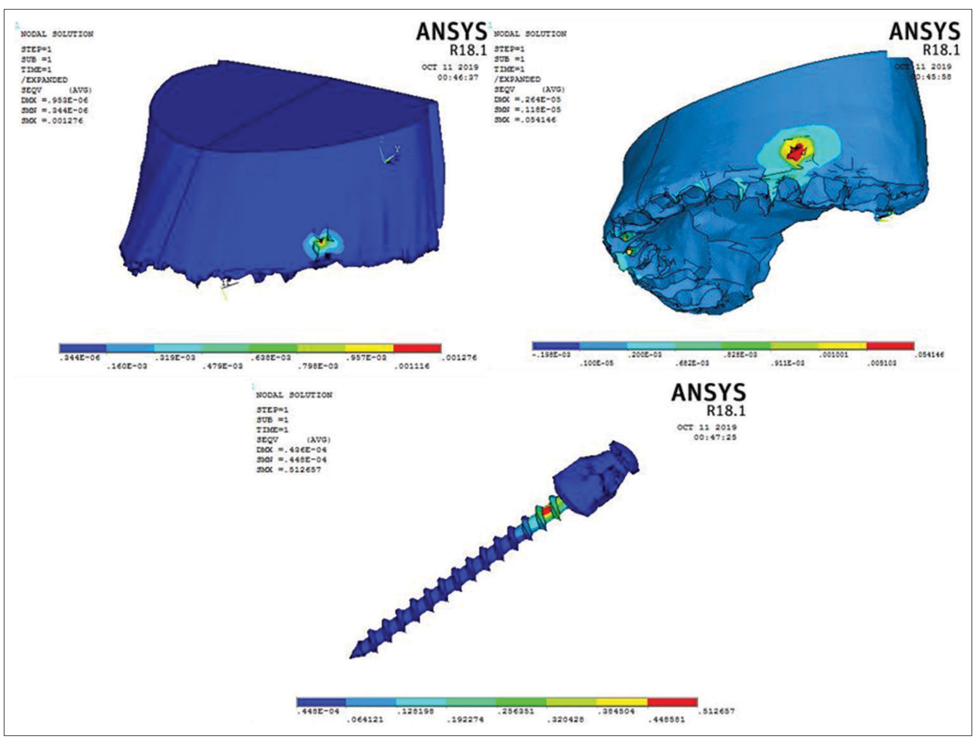

Figure 9: 9 mm—Depth into the bone

of the orthodontic mini-implant resulted in decreased mini-screw mobility.[12] Lin *et al*. compared exposure length, insertion angle, and direction of the force on cortical bone stresses. The results showed that exposure length has the highest influence (82.38%) followed by insertion angle (6.03%). It was found that the orthodontic stress was mainly borne by the cortical bone.[13]

They also found that the primary stability of mini-implants is positively correlated with the quality and thickness

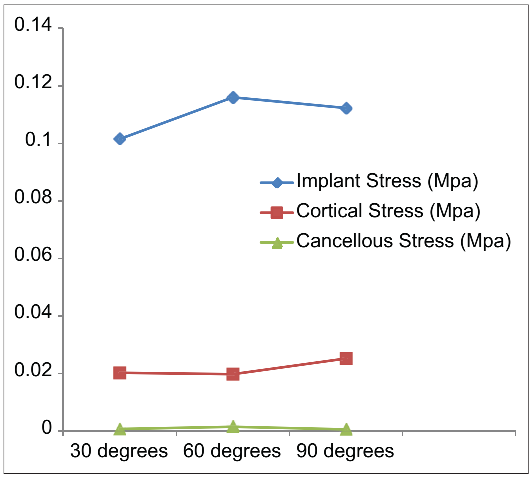

Figure 10: Graphical representation showing the effect of inclination on the stress generation

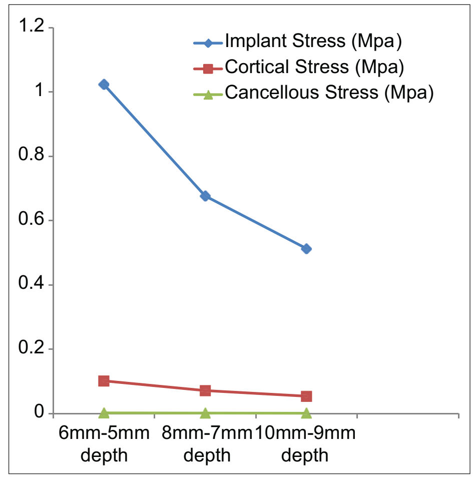

Figure 11: Graphical representation showing the effect of depth of implant on the bone

of the cortical bone at the insertion site. The study parameters assessed were positively correlated with the factors which increased the contact area with the cortical and increased depth of OMI in the cancellous bone. The closer the screw head is to the attached mucosa, the less destructive will be the applied load.[14,15]

Conclusions

1. As the angle of insertion increases from 30° to 90°, the stresses on both the implant and the cortical bone increased.
2. Depth of insertion has a significant effect on the stresses generated.
3. As the length of the mini-implant increases accompanied by the increase in the depth of insertion, the stresses in the mini-implant, cortical bone, and cancellous bone decrease.
4. A higher depth of thread in the bone helps in reducing implant stress, cortical stress, and cancellous stress. Finally, this helps in improving the life and stability of the implant.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Singh S, Mogra S, Shetty VS, Shetty S, Philip P. Three-dimensional finite element analysis of strength, stability, and stress distribution in orthodontic anchorage: A conical, self drilling miniscrew implant system. Am J Orthod Dentofacial Orthop 2012;141:327-36.
2. Elias CN, de Oliveira Ruellas AC, Fernandes DJ. Orthodontic implants: Concepts for the orthodontic practitioner. Int J Dent 2012;2012:549761.
3. Lin TS, Tsai FD, Chen CY, Lin LW. Factorial analysis of variables affecting bone stress adjacent to the orthodontic anchorage mini-implant with finite element analysis. Am J Orthod Dentofacial Orthop 2013;143:182-9.
4. Gracco A, Cirignaco A, Cozzani M, Boccaccio A, Pappalettere C, Vitale G. Numerical/experimental analysis of the stress field around miniscrews for orthodontic anchorage. Eur J Orthod 2009;31:12-20.
5. Deguchi T, Nasu M, Murakami K, Yabuuchi T, Kamioka H, Takano-Yamamoto T. Quantitative evaluation of cortical bone thickness with computed tomographic scanning for orthodontic implants. Am J Orthod Dentofacial Orthop 2006;129:721.e7-12.
6. Lu Y-J, Chang S-H, Ye J-T, Ye Y-S, Yu Y-S. Finite element analysis of bone stress around micro-implants of different diameters and lengths with application of a single or composite torque force. PLoS One 2015;10:e0144744.
7. Chen Y, Kyung HM, Zhao WT, Yu WJ. Critical factors for the success of orthodontic mini-implants: A systematic review. Am J Orthod Dentofacial Orthop 2009;135:284-91.
8. Ishii T, Nojima K, Nishii Y, Takaki T, Yamaguchi H. Evaluation of the implantation position of mini-screws for orthodontic treatment in the maxillary molar area by a micro CT. Bull Tokyo Dent Coll 2004;45:165-72.
9. Miyawaki S, Koyama I, Inoue M, Mishima K, Sugahara T, Takano-Yamamoto T. Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage. Am J Orthod Dentofacial Orthop 2003;124:373-8.
10. Laursen MG, Melsen B, Cattaneo PM. An evaluation of insertion sites for mini-implants A micro-CT study of human autopsy material. Angle Orthod 2013;83:222-9.
11. Kravitz ND, Kusnoto B. Risks and complications of orthodontic miniscrews. Am J Orthod Dentofacial Orthop 2007;131:S43-51.
12. Chatzigianni A, Keilig L, Reimann S, Eliades T, Bourauel C. Effect of mini-implant length and diameter on primary stability under loading with two force levels. Eur J Orthod 2011;33:381-7.
13. Mohammed HI, Al-Sheakli II. Comparing the primary stability of three different orthodontic mini-Implants with various dimensions on artificial bone. Int J Med Res Health Sci 2018;7:128-34.
14. Mohamed RN, Basha S, Al-Thomali Y. Maxillary molar distalization with miniscrew-supported appliances in class II malocclusion: A systematic review. Angle Orthod 2018;88:494-502.
15. Araujo-Monsalvo VM, González-Aréas MG, Martínez-Coria E, Flores-Cuamatzi E, Araujo-Monsalvo B, Domínguez-Hernández VM. Effect of insertion angle on the stability of orthodontic mini-implants in a rabbit tibia model: A finite element analysis. Cir Cir 2019;87:190-5.