Research Article

Finite Element Study to Compare Stress Distribution and Displacement in the Palatal Implant in Lingual Orthodontics in Four Different Combinations of Palatal Implant and Lever Arm

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ABSTRACT

Introduction: The choice of orthodontic appliance depends upon the patients age, profession and availability of them. Lingual orthodontic appliances are preferred over labial by patients because of its invisibility. The aim of this research is to compare the Von Mises stress distribution and displacement of palatal implants in the lingual orthodontic system among four different combinations of palatal implant and lever arm.

Materials and Method: Four Finite element models were constructed for the bilaterally extracted first premolar maxillary arch. In all these models 0.018" slot lingual brackets were placed at the center of the clinical crown. A similar retraction force (150gm) was applied with the help of NiTi closed coil spring for all the models but the length of the lever arm vary as well as the palatal implant position also varies in these models. Finite element analysis was then performed to compare the Von Mises stress distribution, and displacement of the palatal implant using ANSYS 12.1 software.

Result: In this study, displacement was the same (0.0005 mm) for all four models. Highest amount von mises stress was observed in Model 3 (3.4798 MPa) as a comparison to Model 1 (2.5442 MPa), Model 2 (2.5018 MPa), and Model 4 (3.3854 MPa). The stress value for the palatal implant was within the acceptable fatigue limit of the titanium of 193 MPa therefore all four models combination was safe for the clinical application.

Conclusion: Double palatal implant systems were more effective in comparison to the single palatal implant system in lingual orthodontics. In this study, we found that the displacement of the palatal implants was not affected by the length of the lever-arm and the amount of stress was decreased when we increase the length of the lever-arm.

KEYWORDS: En-masse retraction, Finite element analysis, lingual orthodontics, Palatal implants, Von Mises stress

INTRODUCTION

Aesthetic concerns of the patient during fixed orthodontic treatment make lingual orthodontic treatment more popular than the labial orthodontic treatment. Lingual orthodontics required sound knowledge of biomechanics and anatomy.[1] The palatal tipping of the incisors is one of the common problems during the en-masse retraction of anterior. For achieving translation movement of the anterior it is mandatory to pass retraction force through the center of the resistance but it's quite difficult in lingual orthodontics to apply the force from the center of resistance due to palatal contour. To solve this problem long lever-arm was used which was contoured according to the palatal contour. This contouring of lever-arm reduces its effective length and helps to pass force through the center of the resistance.[2-5]

The introduction of inter-radicular mini-implant in labial orthodontics brings a revolutionary change to solve the problem like anchorage management. Similarly in lingual orthodontics, the introduction of the palatal implant made the mechanics easy as well as helps to solve the problem regarding palatal tipping and vertical bowing of the arch.[6-8] Palatal implant also reduces the chances of damaging the roots, periodontium, and also reduces the risk of implant fracture due to the larger dimension of the inter-radicular mini implant.[9]

According to Ludwig et al[10], the anterior palate, area around mid palatal raphae, and alveolus area between the second premolar and first molar is a more suitable insertion site for the placement of the palatal implant. The thickness of the palatal mucosa and quality of the palatal bone is also one of the deciding factors for the length and diameter of the palatal implant. Retraction force applied to the palatal implant generates stress at the implant which produces some amount of implant displacement. If this stress and displacement were above the optimum limit then it may cause implant fracture and implant failure.[11-14]

In this study, we used four different finite element models of the maxillary arch with a different combination of the single and double palatal implant positioned at the mid palatal raphae and near to the mid palatal raphae along with 12 mm and 15 mm long contoured leverarm. Finite element methods were used to assess and compare the stress distribution and the displacement in the palatal implant.

MATERIALS AND METHOD:

In this study model, the CT scan (SIEMENS, DICOM, Syngo CT 2006 C2 format) images of maxilla with maxillary dentition were taken in the axial plane and saved as DICOM format. This data was exported to 3D image processing and editing software - MIMICS 8.11version (Materialises Interactive Medical Image Control System), with the help of RapidForm2004 software geometric model, was constructed consisting of only surface data. Lingual Brackets (slot size 0.018", Ormco 7th generation), segmented arch wire (0.016 x 0.022" SS), titanium palatal-implants (2 mm x 10 mm, SK Surgical), Ni-Ti closed coil springs and lever arms (12 mm and 15mm) were virtually modelled using the Reverse engineering technique (figure 1). The amount of retraction force was 150 gm used in all four models.[15]

Lever-arms were placed between central and lateral incisors in all four models. In a single palatal implant system, a single palatal implant was placed at the mid palatal raphae between the first and second molar region. In the double palatal implant system, two palatal implants were placed at 5mm away from mid palatal raphae between the first and second molar region. Three dimensional surface to surface sliding contacts between the bracket and wire of coefficient of friction 0.1 was used. The "Hypermesh 13.0" software was used for the conversion of the geometric model to the finite element model. This finite model was used for the analysis of stress distribution and the displacement in the palatal implant (Figure 2).The study was approved by the Institutional ethical committee meeting held on 30th November 2016 (approval no.- TDN1605001) and written informed consent was obtained from the participants before their enrollment.

RESULT:

Finite element analysis was performed for all the four models with the help of ANSYS 12.1 software. For Model 1 magnitude of displacement in the palatal implant was a maximum 0.0005mm at the implant head region and a minimum 0.0002mm at the implant tip region. The amount of von mises stress was a maximum of 2.5442 MPa at the mid-region of the palatal implant and a minimum of 0.0001 MPa at the implant head & tip region (Figure 3, 4 & 5 and Table 1). In case of Model 2, magnitude of displacement in the palatal implant was a maximum 0.0005mm at the implant head region and a minimum 0.0002mm at the implant tip region. The amount of von mises stress was a maximum of 2.5018 MPa at the mid-region of the palatal implant and a minimum of 0.0001 MPa at the implant head & tip region (Figure 4, 5 & 6 and Table 1). Where as for Model 3 magnitude of displacement in palatal implants was a maximum 0.0005mm at the implant head region and a minimum 0.0001mm at the implant tip region. The Amount of von mises stress was a maximum of 3.4798

MPa at the mid-region of the implant and a minimum of 0.0000 MPa at the implant head and tip region (Figure 4, 5 & 7 and Table 1). In the last model i.e Model 4 magnitude of displacement in palatal implants was a maximum 0.0005mm at the implant head region and a minimum 0.0001mm at the implant tip region. The amount of von mises stress was a maximum of 3.3854 MPa at the mid-region of the implant and a minimum of 0.0001 MPa at the implant head and tip region (Figure 4, 5 & 8 and Table 1).

Table 1. Displacement and Von mises stress distribution in the palatal implant for MODEL 1, 2, 3, and 4

	MODEL 1	MODEL 2	MODEL 3	MODEL 4
Von mises stress	2.5442	2.5018	3.4798	3.3854
Displacement	0.0005	0.0005	0.0005	0.0005

Legends:

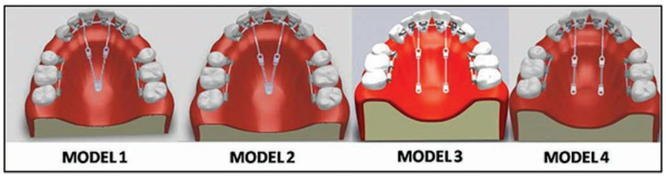

Figure 1: Finite element models a) MODEL 1, b) MODEL 2, c) MODEL 3, and d) MODEL 4.

Figure 2: Palatal Implant (2 mm X 10 mm) was used in Model 1, 2, 3, and 4.

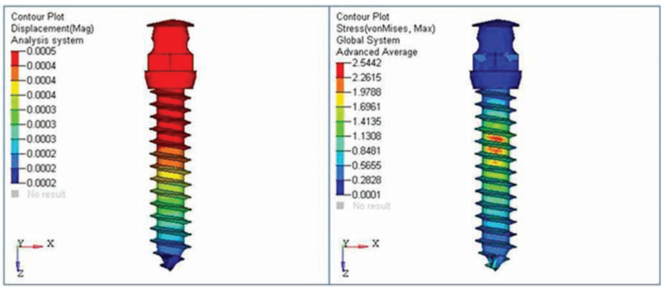

Figure 3: In the palatal implant for MODEL 1; a)Displacement, b) Von mises stress distribution.

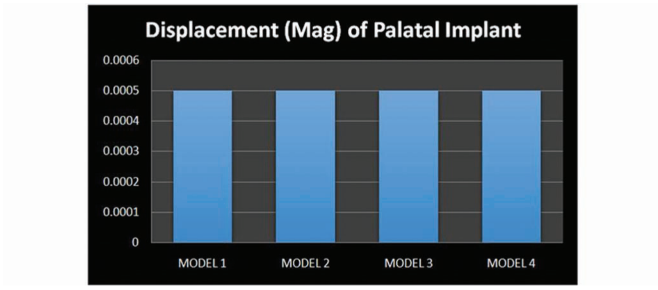

Figure 4: Displacement of Palatal Implant for MODEL 1, 2, 3 & 4.

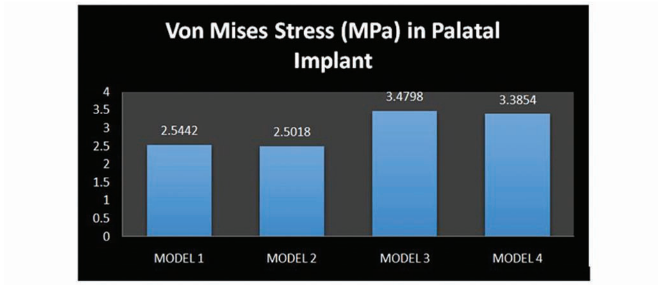

Figure 5: Von mises stress distribution in Palatal Implant for MODEL 1, 2, 3 & 4.

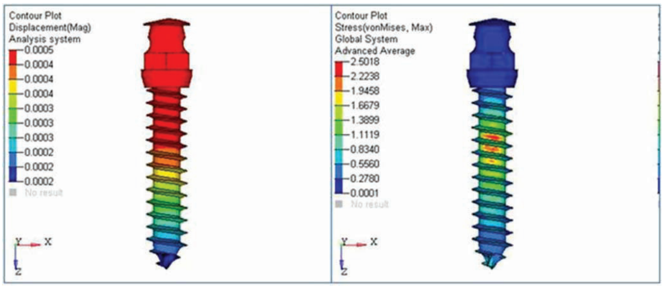

Figure 6: In the palatal implant for MODEL 2; a) Displacement, b) Von mises stress distribution.

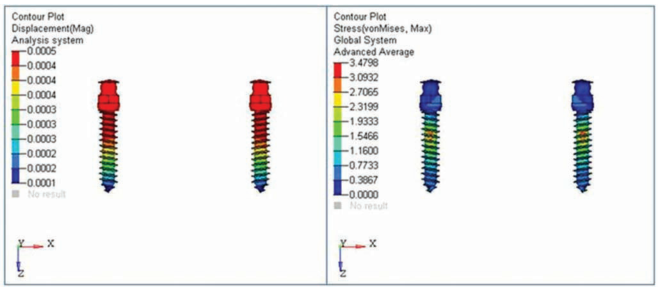

Figure 7: In the palatal implant for MODEL 3; a) Displacement, b) Von mises stress distribution.

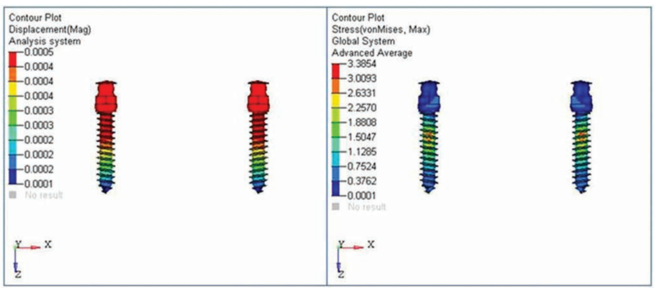

Figure 8 a, b: In the palatal implant for MODEL 4; a) Displacement, b) Von mises stress distribution.

DISCUSSION:

According to Newton's third law of motion "For every action, there is an equal and opposite reaction". Similarly, owing to this law it is very difficult to move only the tooth or teeth that you want to move without moving the anchorage unit. The concept of reciprocal anchorage has been altered dramatically with the development of mini-implants but its reactionary force can affect the implant stability and may lead to implant fracture. Hence, we have to consider all biological conditions like bone quality and quantity as well as implant properties like diameter, length, material, placement angulations. In this study, we had opted 150 gm force magnitude for retraction of anterior that is within the optimal limit of force magnitude suggested by Alrbata et al[16] for the fulfillment of the biomechanical demands and stability requirements. Alrbata et al found in his study that the optimum force magnitude onto the orthodontic implant should not be more than 3.75N - 4.5N, considering the quality of bone.

Our study displayed the presence of stress values for the palatal implants in Model 1 (2.5442 MPa), Model 2 (2.5018 MPa), Model 3 (3.4798 MPa), and Model 4 (3.3854 MPa) and these values were well within the acceptable fatigue limit of titanium of 193 MPa.[17] According to the studies performed by Melo Pithon et al[18], the torsional strength values were observed to increaseas the implant diameters were increased. Moreover, reducing the size also reduces the mechanical strength of the implant, thus impacting the maximum torsional strength negatively and therefore causing its deformation and fracture. A study done by Lemieux et al[19] concluded that while selecting the mini-implant length, the clinician should critically cognize that, while what may benefit the anchorage could also cause a risk in its placement. Miyawaki et al[20] and Seon et al[21] reported that the success of an implant was significantly impacted by its diameter rather than any other parameters. The implant diameter dictates the placement as well as its removal, therefore deducing its stability. Barros et al[22] through his study disclosed that as the diameterof the mini-implant is increased it significantly influenced the placement torque and fracture torque as such that it progressively decreased the fracture risk.

Melsen[23] suggested that the depth and quality of the bone,angle of placement, the thickness of trans-mucosa, and adjacent vital structures should dictate the ultimate length of the mini-implant to be used. Short screws commonly dislodge especially in regions having thick soft tissues, such as the palatal mucosa, and use of the implant lengths more than 6 mm has been suggested by many well-known authors.[24] Vijayalakshmi[25] et al found in her study that the areas with the highest stress and strain to be around the neck of the implant and the surrounding bone at the cervical margin. The implant neck should be long enough not to impinge and irritate the soft tissues, moreover provide sufficient length for any form of attachments.

During implant selection, one should be confident that the neck of the implant is strong and steady, as maximum stress gets concentrated at the neck of the implant. If not strong in this region, it may compromise the implant integrity. To solve this problem we chose a 2 mm diameter palatal implant which was steady enough to withstand the force.

The parameter of this finite study are based on clinical conditions. Finite models have various limitations in comparison to biological tissue so it is not possible to achieve the identical stress around the palatal implant in vivo.[26-28] With the help of this study, the following clinical implications could be derived:

First, the amount of displacement was the same for all the four models, so in these positions, implant stability was not the problem for en-masse retraction of anterior in lingual orthodontics. Second, Von mises stress was highest in Model 3 but within the optimal limit, so all the four model conditions were safe for the clinical practice. Lastly, the long lever arm system is more effective for the en-masse retraction in lingual orthodontics.

CONCLUSION:

Maximum displacement was found at the implant head region for all four Models where as a minimum displacement was found at the implant tip region for all four Models. The maximum displacement of the implant remained the same for all four Models which denotes that the displacement of the palatal implant was not affected by the length of the lever-arm. The Von mises Stresses were marginally higher in 12 mm long lever-arm models in comparison to 15 mm long lever-arm models but well within the optimum limit. It was also noted that they were highest in Model 3. Moreover, Von mises stress was highest in the mid-region and minimum at the head & tip of the implant.

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