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Original Research Article

A Comparative evaluation of stress distribution in bone and mini-implant during en-masse retraction of anterior teeth in maxilla using forces from anchorage units (mini-implants and molar hook) to both canine hook and arch wire hook. An FEM study

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ABSTRACT

Introduction: The study aimed to compare and evaluate the stress that was distributed around mini-implant, molar hook and anterior dentition during its en-masse retraction from both canine hook and arch-wire hook.

Materials and Methods: Four FEM models of maxilla were created to carry out en-masse retraction of the anterior teeth using forces from mini-implant and molar hook to both arch-wire hook and canine hook. The force of 200 grams was applied with Ni-Ti closed coil spring in all four models to carry out anterior teeth retraction. Stress distribution were then analyzed.

Results: The mini-implant group showed higher stresses on the implant when compared to the molar hook group. The molar hook groups showed more stress on the dentition than that of the mini-implant group. The models where the arch-wire hook used for retraction showed less stress values on the bone, teeth, dentition, PDL when compared with that of the canine hook.

Conclusion: The arch-wire hook can be considered a better option than the canine hook. When forces were applied to the arch-wire hook lesser stresses were seen on bone, teeth, dentition, and PDL. The implant-supported group showed lesser stress values on teeth when compared with that of the molar hook group.

1. Introduction

In orthodontic treatment space closure is considered as a crucial step, which needs sound knowledge of biomechanics to eliminate the possible side effects of the treatment. To analyze anchorage needs and various modalities of treatment, an understanding of biomechanical principles of space closure is important.[1] It is performed using friction and frictionless mechanics. Friction mechanics, which is also referred to as sliding mechanics, is a simple technique of space closure in which elastics, coil springs etc are used to deliver force such that orthodontic arch-wire slides within the bracket. Frictionless mechanics use a loop to generate forces for space closure.[2] With both friction and frictionless mechanics, space closure is performed by either en-masse or two step retraction. Planning anchorage has an important role in orthodontic treatment. Inadequate anchorage can lead to improper correction of

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anteroposterior malocclusions.[3] Mini-implants are utilized in orthodontics for anchorage in sliding mechanics. It is impossible to find precise stresses around mini-implants in patients, so finite element analysis gives a method to measure external applied loads and their responses on the 3-dimensional structures. The finite element method (FEM) helps to study the stresses by generating three-dimensional models of structures that are evaluated for their responses to applied forces.[4] Shape and dimensions of the models are reproduced in all three dimensions of space, and the material properties of the structures can be incorporated to make the model closely resemble a practical situation. Several studies have been done to compare various methods of retraction and anchorage. However, very few FEM studies throw light on the common sources used for retraction (i.e the arch-wire hook and canine hook) and the difference in stress on the anterior teeth and anchor units when these different sources of anchorage and retraction are used. Thus, this study planned to evaluate stresses around mini-implant, molar hook, and the anterior teeth during en-masse retraction from both canine hook and arch-wire hook.

2. Materials and Methods

The FEM models used in the study are -maxilla with dentition, periodontal ligament, alveolar bone, pre-adjusted edgewise appliance (022" x 028") (3M), 019" x 025" stainless steel arch-wire with an arch-wire hook. (G&H orthodontics)nickel-Titanium closed coil spring, titanium mini-implants (1.6mm x 6mm)-AbsoAnchor.

The Software used are:

1. Geomagic modeling software
2. Altair Hypermeshver 12
3. Altair Optistructver 12
4. Altair Hyperviewver 12

The Hardware with A personal computer of HP company with an i5 processor and 8 GB ram was used in the study.

A CT scan was obtained in STL format. This STL format was converted to a CAD model using the software. Each tooth 3D model was designed from the standard measurements of Wheeler, and teeth were arranged in their anatomic position with tip and torque values of MBT.[5] The maxillary dentition was arranged according to the normal arch forms of MBT. A 3D model of the periodontal ligament with a thickness of 0.25 mm designed to fit outside the root.[6] A 3D model of the alveolar bone was constructed into which the teeth and PDL were made to fit. The 3D models of pre-adjusted edgewise brackets of slot size 022" x 028" were placed on the crowns and the point of the facial axis was set at in the middle of bracket slot. The 3D model of arch wire (019" x 025") was constructed according to the MBT normal arch forms. The boundary condition of these models was specified after finite element model construction so that all model movements were confined. A 3D model of titanium mini-implant was inserted at an angle of 45° in the first 2 models, where the implant was placed 8mm from the crest of the alveolar bone placed in between the roots of first molar and second premolar in the maxillary arch.[7]

Table 1: The total number of nodes and elements used for the study were as follows

Model	No. of nodes	No. of elements
Total maxillary teeth	105714	522566
Bracket	8500	30990
Bone	148986	749379
PDL	111782	183943
Titanium mini-implant	2801	10821
Arch-Wire	2223	980
NiTi Coil Spring	5320	13473

A retraction force of 200 gm was applied with the help of nickel titanium closed coil spring which was stretched from the arch-wire hook to titanium mini-implant and from canine bracket hook to mini-implant.[8] The height of the arch-wire hook used in the study was 6mm. In the other two groups, the retraction was carried out using nickel titanium closed coil spring stretched from the arch-wire hook to the molar hook and from the canine hook to the molar hook respectively.

Table 2: The properties of the materials and various components in the study

Materials	Young's modulus (mpa)	Poisson's ratio
Teeth	20,000	0.30
Periodontal ligament	0.05	0.30
Alveolar bone	2000	0.30
Titanium mini-implant	110,000	0.35

3. Results and their Interpretation

The stress was measured around the mini-implant, molar hook, canine hook, arch-wire hook, anterior teeth, PDL, and bone during retraction of anterior teeth from:

1. Figure 1: Implant to Arch-Wire Hook
2. Figure 2: Implant to Canine Hook
3. Figure 3: Molar hook to arch-wire hook
4. Figure 4: Molar hook to canine hook.

The stress values thereby obtained were studied and compared and subjected to analysis. An orthodontic force of 200gm was applied for retracting the anterior teeth in all 4 Figure.

Table 3: Stress distribution patterns at variouslocations (in Mpa)

Figure	**Von, Mises stress in Mpa** **Max. Stress in complete model**	**Max. stress in Bone**	**Max. stress in Teeth**	**Max. stress in PDL**	**Max. stress at TAD Location**
Figure 1	15.57	10.95	0.94	0.0207	10.95
Figure 2	15.43	11.23	0.9	0.0226	11.23
Figure 3	1.1	0.234	1.1	0.0164	N/A
Figure 4	1.16	0.256	1.16	0.0170	N/A

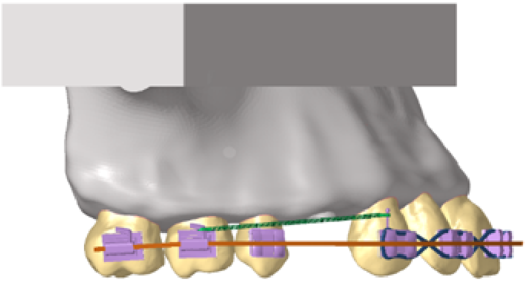

Figure 1: En-masse retraction from mini-implant to arch wire hook

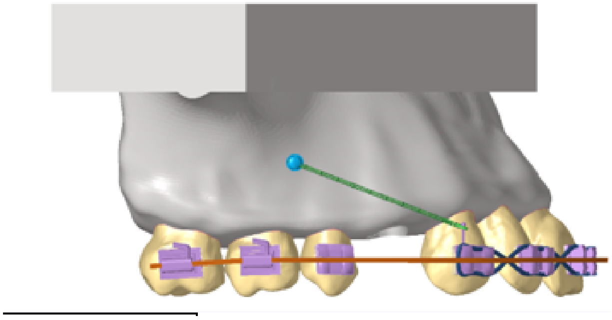

Figure 2: En-masse retraction from mini-implant to canine hook

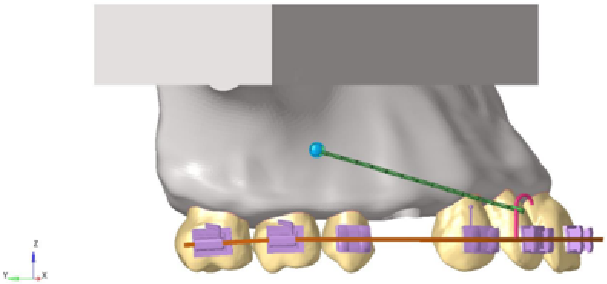

Figure 3: L 3- En-masse retraction from molar hook to arch wire hook

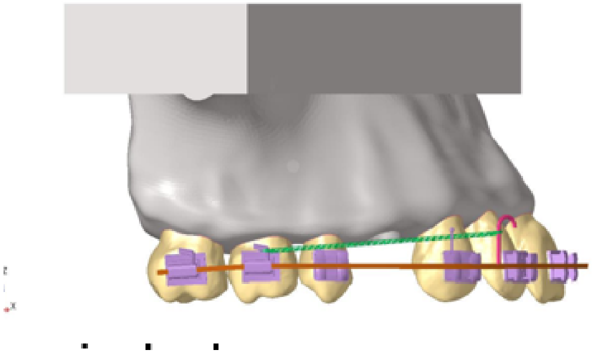

Figure 4: En-masse retraction from molar hook to canine hook

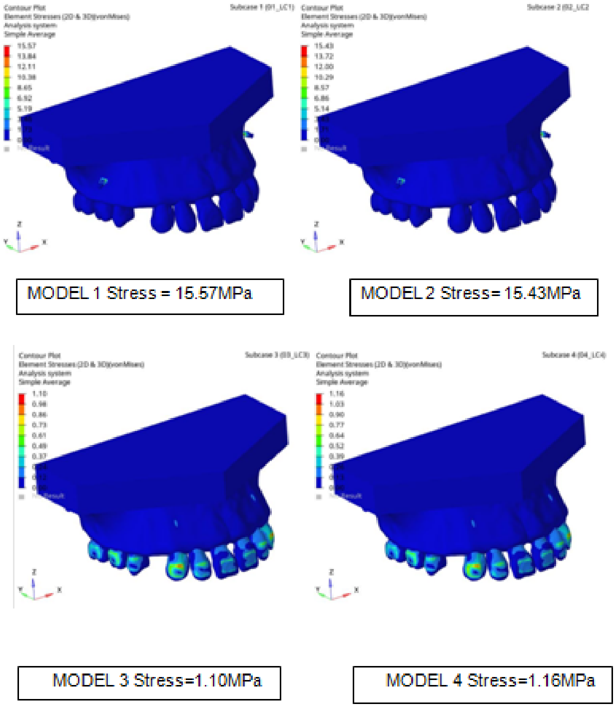

Figure 5: Maximum stress in complete model

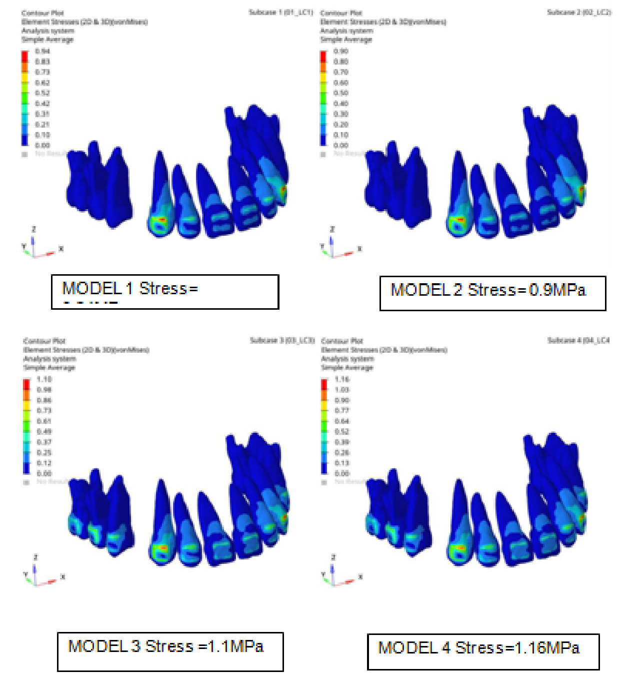

Figure 6: Stress distribution pattern on dentition

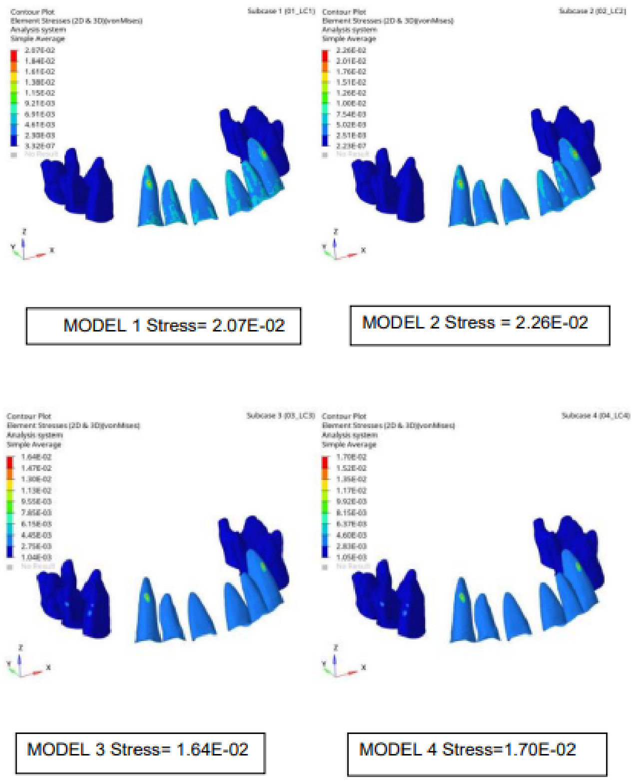

Figure 7: Stress distribution pattern on PDL

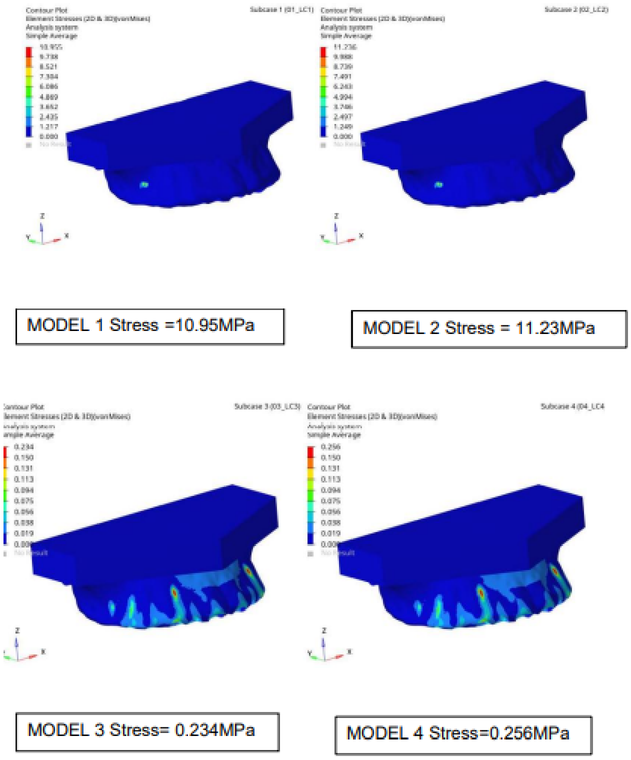

Figure 8: Stress distribution pattern on maxillary jaw

4. Discussion

The total number of elements used in the study was *1,512,152* and nodes were *3,85,326.* The study was performed to determine the efficacy of arch wire hook versus canine hook for en-masse retraction of the anterior teeth using forces from the mini-implant and molar hook in four different models. When the force was applied to the arch wire hook in Figures 1 and 3, maximum overall stress was seen in Figure 1 where mini-implant was used. Lesser stress on the dentition and PDL were observed when compared to the group where the canine hook was used. The maximum stress in the bone adjacent to the mini-implant was seen in Figure 1 when compared with model 3 because the anchorage was directly taken from the bone. Similarly, when force was applied from the canine hook to the implant and molar hook it was observed that Figure 2 received higher stress on the implant whereas Figure 4 showed higher stress on the dentition. When the overall stress was compared between Figures 1 and 3 with that of Figures 2 and 4, the models where the arch wire hook was used showed lesser stress values on the bone, teeth, and PDL when compared with the models teeth, and PDL when compared with the models where the canine hook was used. Thereby decreasing the deleterious reactions like root resorption and their effects on pattern of tooth movement like tipping in the dentition. When the stress values were compared between the TADs group and the molar hook group, it was seen that the mini-implant showed higher stress values on the implant itself and transferred some amount of stress to their adjacent bone. But in Figures 3 and 4 where the force was applied from the molar hook, the maximum effect of stress was seen on the teeth. (Table 3) This could be because the anchorage was directly taken from teeth with the help of a molar hook, whereas in the TADs group anchorage was taken directly from bone thereby reducing the deleterious effect on the dentition. The TADs group showed less stress regarding their effect on the dentition when compared to the molar hook group.Consolaro et al[9] also stated that a bodily pattern of tooth movement achieved after the anterior teeth retraction provides an extended amount of tension in the bone and periodontal ligament, thereby limiting the possibility of cell death and hyalinization of the extracellular matrix, thus preventing their side effects, such as root resorption. From the assessment of the above parameters, it can be said that the implant group showed lesser stresses on teeth thereby reducing the deleterious effects of heavy stresses on teeth.

When the stress was evaluated after the application of force from implant to arch wire hook (Figure 1), it was found that higher stress was found at the neck region of the implant. When an implant was placed at 45° angulationin Figures 1 and 2, it was seen that the anterior region of the implant showed less stress in bone when compared to the posterior region of bone. The pattern of the stress was mostly present on the head and neck region of the implant. The cortical bone has a high modulus of elasticity can withstand higher loads and offers higher resistance to deformation. The results were similar to the study conducted by Jasmine et al[10] where they stated that the higher stress seen on the implant is due to the higher resistance offered by the entrance of an implant into the cortical as well as the cancellous bone. it was seen that the implant received the highest stress when compared with cortical bone and alveolar bone. It was similar to the findings done by Shivani Singh et al[11] and Ashish Handa et al[12] where maximum stresses were produced in the neck of the implants and maximum stresses were located at the neck region of the implant and near the bone junction. Kojima et al[13] in their study stated that retraction of anterior teeth in en-masse method when forces are applied away from the COR of both anterior and posterior dentition produce tipping and rotation of the whole dentition. They stated that a bodily type of tooth movement is obtained by placing an implant near the COR of the posterior dentition. This pattern of tooth movement is also achieved by using an appropriate anterior retraction hook height by placing it near the COR of the anterior dentition. From the above-mentioned study, we can say that Figure 1 where retraction was carried out from mini-implant to the arch wire hook can help in achieving bodily tooth movement without the loss of anchorage, can be achieved.

Domingos et al[14] found that stress was concentrated on the canine region. Lee et al[15] in their study stated that an absolute anchorage tends to decrease the stress on the posterior aspect of the teeth and concentrates on the roots of the anterior teeth as well. The results obtained in the study were also similar such that the implant groups showed the least amount of stresses on the posterior teeth whereas the overall dentition was affected with higher stress when the force was applied from arch wire hook and canine to that of the molar hook instead of mini-implant.

5. Conclusion

It can be concluded that:

1. Among the implant-supported group, Figure 1 where en-masse retraction was carried out using Ni-Ti coil spring-applied force from arch wire hook to implant showed better results when compared to Figure 2 where en-masse retraction was carried out from the implant to the canine hook owing to better stress distribution.
2. When both mini-implant group and conventional group taken as an anchorage units, the arch wire hook showed better results when compared with the canine hook for the retraction. Thereby, it can be safely concluded with substantial evidence from finite element modelling that retraction by applying force to arch wire hooks is better than using canine hooks for retraction.
3. The conventional anchorage groups (Figures 3 and 4) showed higher stress distribution on overall dentition that directly affects heavy forces on teeth and can lead to the tipping of the teeth.
4. Using TADs for anchorage has a definite advantage over taking conventional anchorage from molar hooks.

6. Source of Funding

None.

7. Conflict of Interest

None.

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