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Dr. Ruchira Shreevats
Post Graduate Student, Department of Orthodontics, Rajiv Gandhi University, Bangalore, Karnataka, India

Dr. Prashanth CS
Professor, Department of Orthodontics, Rajiv Gandhi University, Bangalore, Karnataka, India

Dr. Amarnath BC
Professor, Department of Orthodontics, Rajiv Gandhi University, Bangalore, Karnataka, India

Dr. Akshai Shetty
Professor, Department of Orthodontics, Rajiv Gandhi University, Bangalore, Karnataka, India

Correspondence
Dr. Ruchira Shreevats
Post Graduate Student, Department of Orthodontics, Rajiv Gandhi University, Bangalore, Karnataka, India

An fem study on anterior tooth movement, in sliding mechanics with varying bracket slot and archwire dimension with and without alveolar bone loss

Dr. Ruchira Shreevats, Dr. Prashanth CS, Dr. Amarnath BC and Dr. Akshai Shetty

Abstract
The design of an appliance for en-masse anterior tooth retraction using mini implants as anchorage with varying anterior retraction hook and varying alveolar bone height situations in adult patients for bodily tooth movements using Finite element analysis (FEA) to determine the best combination of above factors. A mini implant of diameter 1.2mm and length 8mm was placed in between the maxillary 2nd premolar and 1st molar root with working wires as 0.019X.025 inch stainless steel wire in 0.022inch slot and 0.017x0.025inch stainless steel wire in 0.018 inch slot & anterior retraction hook (ARH) soldered between lateral incisor and canine with varying alveolar bone height situations of 100%, 75% and 50% along with the varying retraction hook uptil 10mm. Conclusion is that bodily tooth movement differs with varying retraction hook on both base archwires with varying alveolar bone height.

Keywords: Mini implant, anterior retraction hook, finite element analysis (FEA)

1. Introduction

Controlled anterior tooth movement is one of the key requirements for success of any orthodontic treatment. Two major types of space closure employed by orthodontists are sliding mechanics and Loop mechanics [8]. Sliding mechanics for space closure is used by a large number of Orthodontists worldwide. This involves the actual sliding of brackets and tubes along the archwire [2, 1]. Power arms are usually combined with Sliding mechanics for obtaining controlled anterior tooth movement.

The size of bracket slots and arch wire dimensions are the known factors affecting the type of anterior tooth movement in Sliding mechanics. Optimal loading conditions for controlled tooth movement of anterior teeth in sliding mechanics combined with power arms are not fully understood. Few studies in FEM have been reported for en-masse retraction using sliding mechanics [6]. The power arms attached to the arch wire enables one to achieve controlled movement of the anterior teeth. That is, the force system for the desired type of tooth movement such as lingual crown tipping, lingual root tipping, or bodily movement can be easily carried out by varying the positions and the heights of the power arm attached to the arch wires in Sliding mechanics [5].

Unintended anterior movement of molars results in anchor loss in Sliding mechanics during space closure. By introducing micro-screw implants into the armamentarium of the Sliding mechanics it is possible to obtain a controlled, effective and predictable en-masse retraction of anterior teeth with no room for anchor loss [9]. Present day orthodontists have a large percentage of adult patients with reduced alveolar bone support in comparison to adolescent patients. The biomechanical implications of this reduction in alveolar bone support in adults needs to be studied for designing effective force system to obtain controlled anterior tooth movement.

The effect of these varying parameters was investigated using Finite Element Methodology (FEM). The reaction of teeth to sliding mechanics was analyzed by using Finite Element Analysis (FEA) [9]. With 3-dimensional (3D) computer models, various conditions were simulated by varying the simulation parameters. The initial reactions of the teeth, periodontal ligament (PDL), and alveolar bone can be evaluated qualitatively and quantitatively.

The purpose of this study was to assess the effects of two commonly used arch wire & bracket slot combinations in Sliding mechanics with varying heights of the power arms on the arch wire between lateral incisor and canine brackets at three different alveolar bone height situations, (at 100%, 75% and 50%) to obtain controlled anterior tooth movement during space closure by means of a 3D FEM study.

A 3D Finite Element Methodology (FEM) was also used in this study to simulate an en-masse anterior teeth retraction in sliding mechanics using 0.017×0.025 SS & 0.019×0.025 SS arch wires in 0.018 and 0.022 inch slot MBT prescription respectively. The degree of labiolingual tipping of the maxillary central incisor was calculated when the retraction force (150 grams) was applied to different heights of a power arm (1-10mm at 1mm incremental intervals) constructed mesial to the canine in between lateral incisor and canine brackets bilaterally [6].

2. Materials and Methodology

2.1 Source of data

Computed Tomography scanned image of maxilla from skull was used for constructing a 3D geometric model using MIMICS software 8.11version. Dental model parameters were taken from Major M. Ash, Stanley J. Nelson Wheeler's Dental Anatomy, Physiology, and Occlusion. 2009, 8th edition

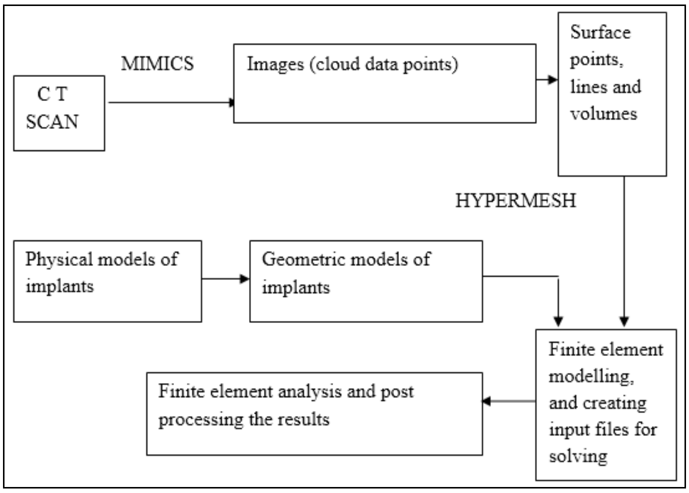


Fig 1: Flow chart for the methodology

2.2 Steps involved in the Finite Element Analysis are

2.2.1 Generation of 3-D Geometric Model Using Mimics

A mathematical model, which represented the biological properties of the alveolar bone and the mini implant was constructed. This was represented in terms of points (grids), lines, surfaces (patterns) and volumes (hyperpatches). CT-scan data of the skull was processed using MIMICS 8.11 software; here the dicom images of the CT-scan were selected and converted into Binary STL format, only region of interest of the study (maxilla in this study) was selected. Further this was converted into geometric model consisting of surfaces and lines. Once the surface model was obtained, it was exported to Finite Element Modeling tool using HYPERMESH software version 10.0. (Fig: 1)

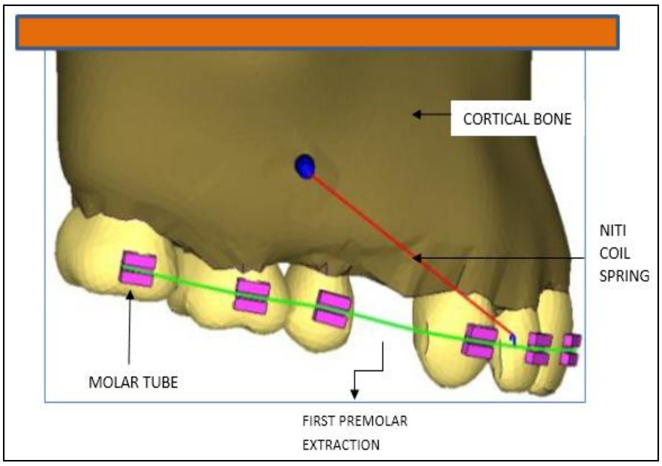


Fig 2: 3D geometric model simulating the cortical bone, teeth, brackets, 1st premolar extraction space and the Ni Ti coil spring used for retraction

2.2.2 Conversion of 3-D Geometric Model into Finite Element Model/Discretization

In this study, the geometric model was converted into Finite element model by using software called HYPERMESH software version 10.0. The model of the maxillary dentition with bilateral first premolar extraction was simulated and converted into a finite element model i. e. discretization. Discretization may simply be described as the process in which the given body is subdivided into an equivalent number of finite elements. This is done by connection of nodes and elements, which forms the finite element mesh. Thickness of the periodontal ligament was considered to be uniform (0.25 mm). The alveolar bone crest was constructed to follow the curve of the Cemento-Enamel Junction.

Using ANSYS software version 12.1, the arch wire was modeled with a cross section of 0.019X0.025-in SS and 0.017X0.025 in SS wire in 0.022 inch and 0.018 inch bracket slots respectively. The power arm/anterior retraction hook (ARH) was set between the lateral incisor bracket and the canine bracket bilaterally. Mini implants of diameter 1.2 mm were used in the study placed 8mm above the alveolar crest at 40° to occlusal plane in between the maxillary 2nd premolar and 1st molar root, in the thick alveolar cortical plate, on both sides. This model of maxilla was fixed in all directions and discretized in X, Y and Z axis. (Fig 2).

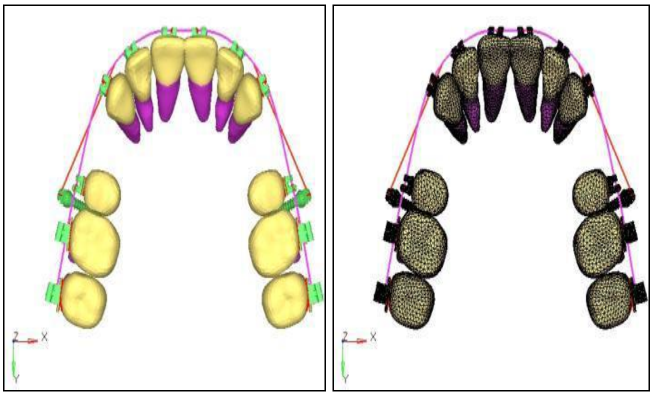


Fig 3: Conversion of 3D model to FE model

2.2.3 Assigning Material Properties

The assignment of proper material properties to a finite element model is necessary to simulate the behavior of the object studied. The different structures involved in this study were teeth, alveolar bone, periodontal ligament and stainless steel. To simplify the model and reduce the time for analysis, the same properties were given to the arch wires, power arms, and brackets. Other materials such as teeth, alveolar bone, and PDL were taken as homogenous and isotropic for the same reason. The material properties assigned were the Young's Modulus (or modulus of elasticity) and the Poisson's Ratio and they were assumed to be isotropic and homogenous. (Fig: 3), (Table: 1)

Table 1: Material parameters of tooth, pdl, alveolar bone, archwire, power arm and bracket

Material	Young's modulus (MPa)	Poisson's ratio
Tooth	2,000	0.30
Pdl	0.05	0.30
Alveolar bone	2,000	0.30
Archwire/power arm/ bracket	2,00,000	0.30

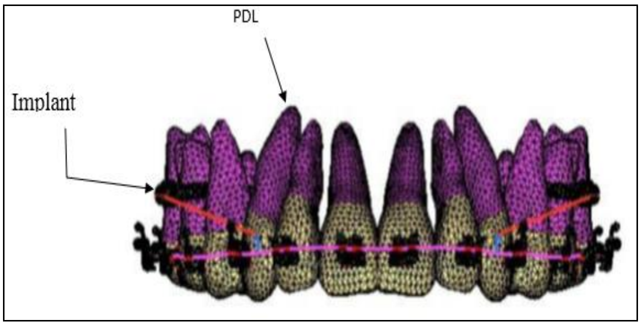


Fig 4: FE model simulating implant assisted retraction setup during sliding mechanics.

2.2.4 Boundary Conditions

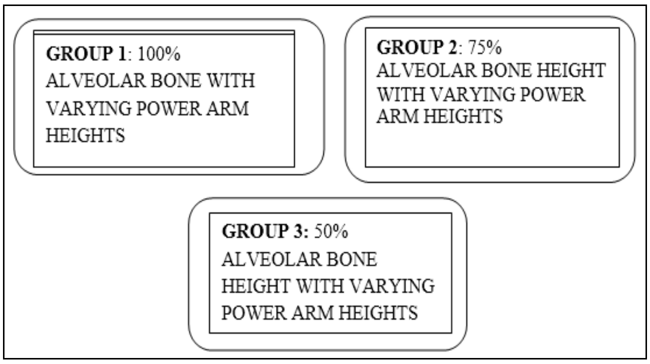
The boundary conditions were defined to simulate how the model was constrained and to prevent it from free body motion. The nodes attached to the area of outer surface of bone were fixed in all directions to avoid free movement of the tooth. The amounts of tooth movement were calculated at each nodal point using HYPERMESH and ANSYS software's for generating models.

2.2.5 Application of Forces

A mini implant model of diameter 1.2mm and length 8mm was incorporated in between the maxillary 2nd premolar and 1st molar root, in the thick alveolar cortical plate area of the 3D FEM model, on both sides. A retraction force of 150gms was applied bilaterally on to the power arms/anterior retraction hooks with varying heights (from 1mm to 10mm with 1mm incremental increase) from the mini implants.

2.2.6 Execution of Analysis and Interpretation of Results

The arch wire 0.017X0.025 inch SS and 0.019X0.025 inch SS in 0.018 inch and 0.022 inch bracket slots were used for all the three groups. Three 3D models were constructed as per the above mentioned Groups, with different alveolar bone heights. The orthodontic mini implant of 1.2mm diameter was inserted at 8mm height from alveolar crest, in the buccal region of the posterior teeth i.e. between maxillary second premolar and first molar. In each group, simulated en masse retraction force on six anterior teeth was applied on a 0.017x0.025 inch stainless steel wire in 0.018 inch slot and in 0.019X0.025 inch stainless steel wire in 0.022 inch slots respectively A horizontal retraction force of 150 grams was applied on both the sides to each power arm / ARH between canine and lateral incisor brackets With the varying heights of a power arm from 1-10mm at 1mm intervals (1, 2, 3, 4, 5, 6, 7, 8, 9 and 10mm heights). Friction between the arch wire and brackets along the axial direction was ignored. Under these conditions, 3D finite element analysis was performed by using a 3D finite element program using ANSYS software.



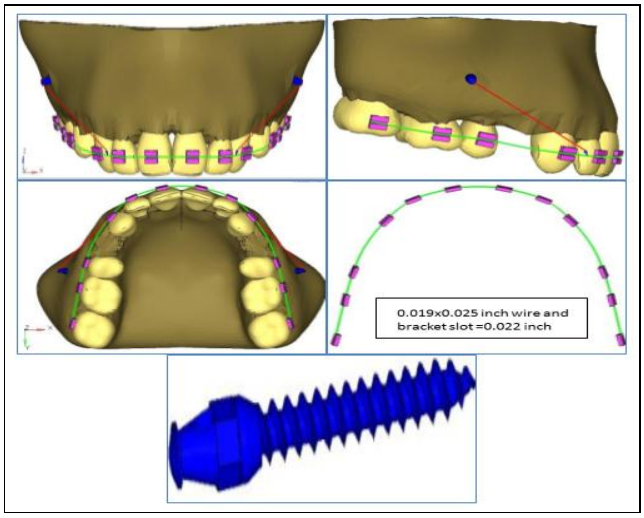


Fig 5: Normal 100% Bone Implant positioned at 8mm from the crest, 1.2mm diameter and 40deg to occlusal plane. Hook is 1mm

3. Results

3D base models were prepared, FEA analysis were performed. The results demonstrated, the amount of tipping and bodily movement achieved in the anterior teeth, using different combinations of alveolar bone heights and varied anterior retraction hook heights incrementally increased by 1mm. Tooth movement obtained with maximum displacements were presented in colour coded bands w. r. t global coordinate system represented by positive and negative signs. Colour coded portions signifies the area of the tooth being displaced. The positive and the negative signs represent different type of tooth displacement in different planes, X, Y and Z axis representing-Mesio-distal, Labio-lingual, and Intrusive-extrusive tooth movement.

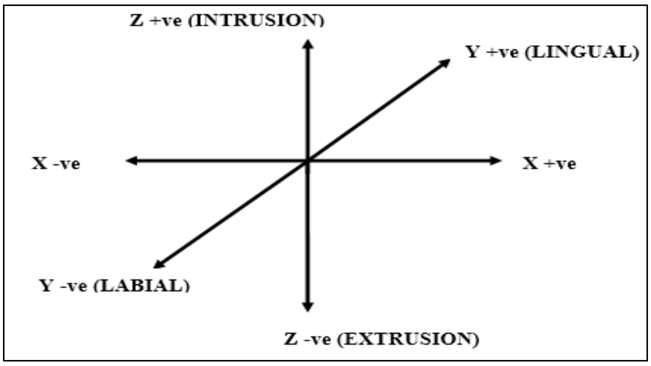


Fig 6: Represents type of tooth displacement with positive and negative signs.

At 100% alveolar bone height 17x25 archwire in.018 slot produced bodily tooth movement at 10mm of power arm height (Fig 6) and 19x25 archwire in.022 slot produced bodily tooth movement at 8mm of power arm height (Fig 7)

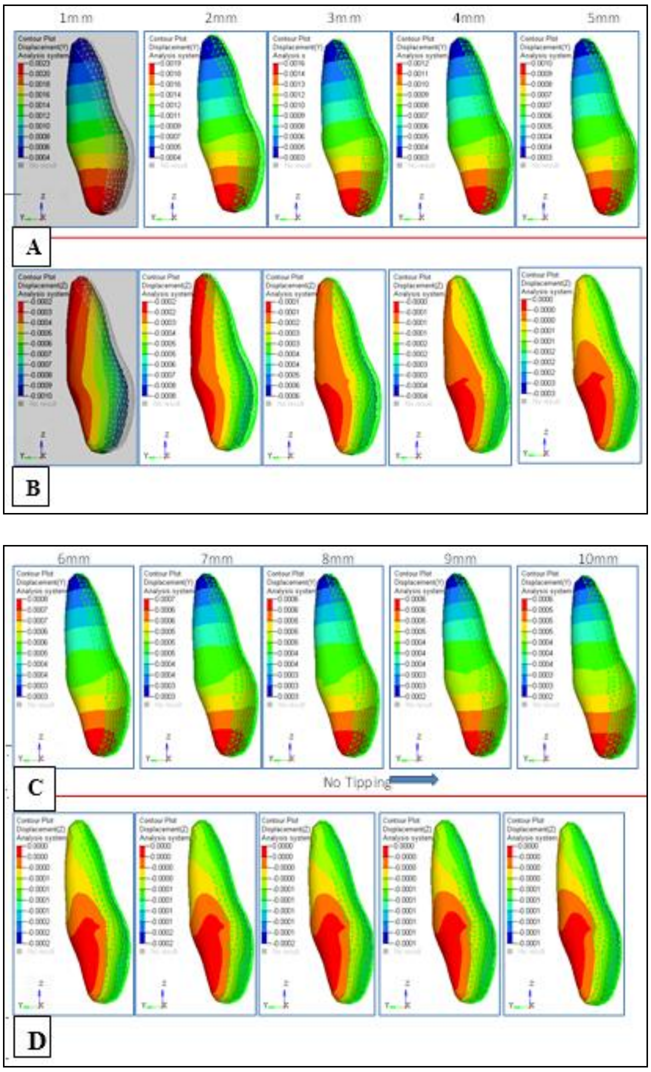


FIG 6: A To D: 17x25 Archwire In 0.018 Slot With Varying Anterior Retraction Hook (Arh) From 1mm To 10mm In Y And Z Axis (100% Alveolar Bone Height)

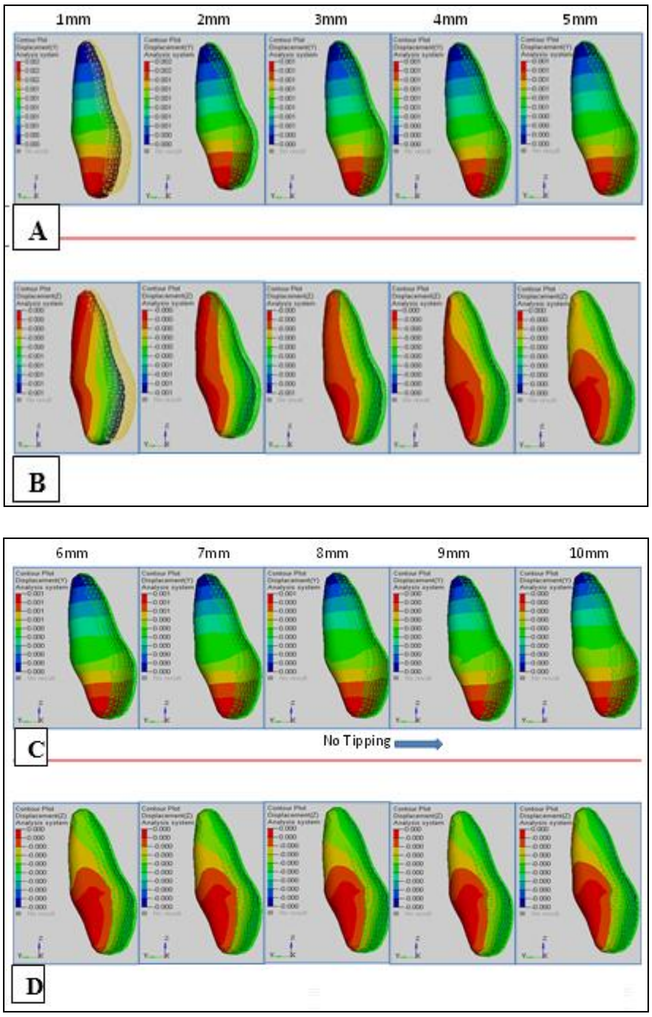


FIG 7: A To D: 19x25 Archwire in 0.022 Slot With Varying Anterior Retraction Hook (Arh) from 1mm to 10mm In Y and Z Axis (100% alveolar bone height)

3.1 Result Summary for 100% bone height situation
- For 0.019X0.025 wire, No tipping is observed from 8mm Hook onwards
- Centre of resistance will be at 8mm (Hook height)
- No significant difference between 0.019X0.025 and 0.017X0.025 wire
- 0.017X0.025 wire case has little more tipping compared to 0.019X0.025 wire case
- However for both cases, for 100% bone the CR is around 8mm

3.2 Result Summary for 75% bone height situation
- For 0.019X0.025 wire, No tipping is observed from 10 mm Hook onwards
- Centre of resistance will be at 10 mm (Hook height)
- No significant difference between 0.019X0.025 and 0.017X0.025 wire
- 0.017X0.025 wire case has little more tipping compared to 0.019X0.025 wire case
- However for both cases, for 75% bone the CR is around 10 mm

3.3 Result Summary for 50% bone height situations
- For 0.019X0.025 wire, No tipping is observed from 14 mm Hook onwards
- Centre of resistance will be at 14 mm (Hook height)
- No significant difference between 0.019X0.025 and

0.017X0.025 wire

- 0.017X0.025 wire case has little more tipping compared to 0.019X0.025 wire case
- However for both cases, for 75% bone the CR is around 14 mm

4. Discussion

Sliding mechanics is the most commonly used mechanics for space closure. Use of miniscrew for reinforcement of orthodontic anchorage has become increasingly popular in recent years, especially for the space closure in maximum anchorage cases [41]. The orthodontic mini implants can be useful not only as a skeletal anchorage, but also for torque control during retraction. To bring about a bodily tooth movement, the resultant force must pass as close to centre of resistance as possible, which in case of maxilla is between the roots of premolars [45].

Tooth movement are determined by the relationship between a line of action of a force and the location of the centre of resistance of a tooth. The idea of placing mini implants at these heights 8mm was to make the force vector pass as close to the centre of resistance as possible to bring about a bodily retraction. Mini implant heights were chosen to be 8 mm because implant placement in the premolar-molar region more apical to this height is critical because of 2 reasons: risk of perforation of maxillary sinus and placement in the movable alveolar mucosa. Also there is a risk in placing the implant more coronal to this height because of the root proximity of premolar and molar and can result in perforation of PDL or root damage [47].

The finite element method (FEM) is a highly precise technique used to analyze structural changes. Finite element analysis has been used in dentistry to investigate a wide range of topics, such as the structure of teeth [48], biomaterials and restorations [49], dental implants [50], and root canals [51].

In present study FEM was used to compare the effects of two commonly used arch-wire & bracket slot combinations in sliding mechanics 0.017x0.025 in 0.018-in slot and 0.019 x 0.025 in 0.022- in slot with varying heights of the power arm at different alveolar bone height situations (at 100%, 75% and 50%) to obtain the controlled anterior tooth movement during space closure.

- It was being observed that, Bodily Tooth movement in an 100% alveolar bone height situations with 0.019x0.025 inch wire and 0.017x0.025 inch SS wire in 0.022 and 0.018 inch bracket slot was obtained when the anterior retraction hook is at 8mm and 10mm respectively.

Observations during this case with 1mm ARH was:

In X-direction, we see teeth movement by 0.003 mm

In Y-direction: root apex is having displacement of 0mm (dark blue colour) and crown tip is having highest displacement of 0.002 mm (red colour). Teeth is moving inside

In Z-direction, we see teeth retraction by 0.001 mm.

Tooth displacement reduces in both root apex and in the clinical crown region with the increase in height of anterior retraction hook, thus obtaining the approximate centre of resistance with the individual archwire and obtaining bodily tooth movement.

With the increase in number of adult patients seeking orthodontic treatment, associated with varied amounts of bone support, necessitates the observation of tooth displacements with varying alveolar bone height situations. It was observed that the moment/force ratio (at the bracket level) required to produce bodily movement increases in association with alveolar bone loss. Bone loss causes center of resistance movement toward the apex. Greater amounts of displacements of incisal edge and apex were observed with increased alveolar bone loss for a constant applied force.

- Bodily Tooth movement in an 75% alveolar bone height situations with 0.019 x 0.025 inch wire and 0.017 x 0.025 inch SS wire in 0.022 and 0.018 inch bracket slot was obtained when the anterior retraction hook is at 10mm respectively.

Observations during this case with 1mm ARH was:

In X-direction, we see teeth movement by 0.006mm

In Y-direction: root apex is having displacement of 0mm (dark blue colour) and crown tip is having highest displacement of 0.006mm (red colour).Teeth is moving inside

In Z-direction, we see teeth retraction by 0.002 mm.

Tooth displacement reduces in the clinical crown region with the increase in height of anterior retraction hook, thus obtaining the approximate centre of resistance at 10mm as with bone loss centre of resistance of the tooth moves towards the apex and thus obtaining en-masse tooth movement for both the archwires (0.019x0.025 inch SS in 0.022 “slot and 0.017x0.025 inch SS wire in 0.018” slot).

With further reduction in alveolar bone loss, the centre of resistance moved towards the apex with greater amounts of displacements of incisal edge and apex for a constant applied force.

- Bodily Tooth movement in an 50% alveolar bone height situations with 0.019x0.025 inch wire and 0.017x0.025 inch SS wire in 0.022 and 0.018 inch bracket slot was obtained when the anterior retraction hook is at 14mm respectively.

Observations during this case with 1mm ARH was:

In X-direction, we see teeth movement by 0.008mm

In Y-direction: root apex is having displacement of 0mm (dark blue colour) and crown tip is having highest displacement of 0.010mm (red colour). Teeth is moving inside

In Z-direction, we see teeth retraction by 0.003 mm.

Tooth displacement in 50% alveolar bone loss cases further reduces with the increase in height of anterior retraction hook, thus obtaining the centre of resistance at 14mm for an end-masse tooth movement for both the arch wires.

In the light of above mentioned observations, it can be concluded that there will be greater moment generated when retraction forces are applied more coronal to the centre of resistance resulting in tipping type of tooth movement with intrusion of anterior teeth. When bodily type of tooth movement is required the retraction force should be applied as apical as possible using high retraction hooks placed on the arch wire.

However, these results are right only for the initial movement, which is produced by elastic deformation of the PDL. This is a limitation of this FEM study. Long-term orthodontic movement might not be the same as the initial movement. Especially when many teeth are connected with an arch wire, the force system varies with tooth movement.

5. Conclusion

It has been concluded that there had been no significant difference with respect to-0.018 in and 0.022 in bracket slots with their respective retraction wires in both 100% and 75% bone loss cases, except the fact that lingual root torquing is more in 0.018 in slot than in 0.022 in slot which is not much of significance.

And as in cases of 50% bone loss and more, use of 14mm of power arm in order to produce bodily tooth movement is not feasible clinically; therefore various other methods can be used:

1. Giving curve of spee in arch wire
2. Giving torque in the arch wire
3. Giving anchor bends posteriorly in the arch wire
4. Use high torque brackets

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