Evaluation of Optimal Implant Positions and Height of Retraction Hook for Intrusive and Bodily Movement of Anterior Teeth in Sliding Mechanics: A FEM Study

Shrinivas S Ashekar, Rahul S Deshpande, Pravin Shetty, Sandip Lele, Shailesh S Patil

ABSTRACT

Introduction: The design of an appliance for retraction of six anterior teeth using orthodontic mini-implant (OMI) anchorage and sliding mechanics must take into account the position and height of the mini-implant and the height of the anterior retraction hook. We used finite element analysis to examine effective en masse retraction with orthodontic mini-implant anchorage and sought to identify a better combination of the above factors.

Materials and methods: Base models were constructed from measurements given in Wheeler’s dental anatomy book. The center of resistance for the six anterior teeth in the base model was calculated. The working archwires were assumed to be 0.019" × 0.025" in stainless steel. The amount of tooth displacement after finite element analysis was measured.

Results and conclusions: In low OMI (6 mm) anterior showed tipping movement. Mid-implant condition (8 mm) showed more of bodily movement during retraction as the force passes near or through the CRs of all the six anterior teeth. In high OMI (10 mm) and 0 mm ARH condition, all the six anterior teeth showed intrusion with retraction.

Keywords: Mini-implants, Anterior retraction hook, Sliding mechanics, Finite element method (FEM).

INTRODUCTION

It has become more practical to use implants for anchorage in orthodontic patients thanks in part to smaller and more versatile implant designs. Orthodontic mini-implant (OMI) expand the horizons of orthodontic treatment because they allow treatment to proceed successfully with virtually no anchorage loss and minimal patient cooperation (Figs 1A to C). However, they are typically used as auxiliaries to the posterior anchor teeth during en masse retraction with sliding mechanics.1-3 Extraction of four premolars is commonly believed necessary for the proper management of some malocclusions. The 7 mm of space gained in each quadrant is used in one or more of three ways: relief of crowding, retraction of incisors, or mesial movement of molars. Anchorage control is the term used to describe the manoeuvres followed by the orthodontist, according to the treatment plan, to ensure the correct use of space in an extraction case.4 To obtain a rigid anchorage, dental implants and bone screws have been reported as orthodontic and orthopedic anchors. Some new types of implants have been designed to provide anchorage for orthodontic tooth movements. Recently, as a result of advances in biocompatible medical materials, osteointegrated titanium implants have been developed and used in bone screws and miniplates for rigid fixation in orthodontics. This application leads to the hypothesis that a titanium miniplate might also be used as a source of stationary anchorage for tooth movements.5 The reaction of teeth to sliding mechanics can be analyzed by using finite element analysis (FEA). Various conditions can be simulated by varying the simulation parameters. The initial reactions of the teeth, periodontal ligament (PDL), and alveolar bone can be evaluated qualitatively and quantitatively.6 In this study, the FEA was for an effective en masse retraction design with orthodontic mini-implant anchorage. The effect of position, and height of the OMI, height of the ARH was examined and an effort was made to identify a better combination of these factors.

MATERIALS AND METHODS

The standard values for construction of central incisor (11), lateral incisor (12), canine (13), second premolar (15) and first molar (16) were taken from Wheeler’s dental anatomy, physiology and occlusion (8th edition).7 The long axes were considered according to this model. The thickness of PDL was considered to be uniform (0.25 mm). The alveolar bone...
crest was constructed to follow the curve of the cement-enamel junction (Fig. 2).

Using ANSYS version 13, the archwire was modeled by beam 4 elements with a cross section of 0.019” × 0.025” SS wire. The ARH (0.05” SS wire) was set between the lateral incisor bracket and the canine bracket bilaterally. The height of the anterior retraction hook and the position of the mini-implant is considered from the main archwire. Free axial rotation movement of the archwire in the brackets was allowed, while friction between the archwire and brackets along the axial direction was ignored.

In the system studied, the Y-axis was the mid-sagittal line of the dental arch on the occlusal view, and the Z-axis was perpendicular to the Y-axis. The total numbers of nodes (or total numbers of elements) comprising the model were 49039 (249796) for the base model. For the discretization of the teeth, the PDL, and the alveolar bone, 4-node tetrahedron element (ANSYS solid185) were used, and material properties in the models were assumed to be isotropic and homogeneous8 (Table 1).

The position of the mini-implants was assumed to be 8 mm (low OMI traction) or 10 mm (high OMI traction). Retraction force vectors of 150 gm from the anterior retraction hook (0, 5 and 8 mm) to low or high mini-implant traction were resolved into components along the X, Y and Z axes and applied to the anterior retraction hook.

The study involved three different implant positions, in between second premolar and first permanent molar, and three different heights of anterior retraction hook for force application. The position of orthodontic mini-implant (OMI) and the anterior retraction hook (ARH) were measured from the main archwire. In low mini-implant traction, the implant was placed at the height of the 6 mm from the archwire. In medium traction, it was placed at 8 mm and, in high condition, it was placed at 10 mm from the main archwire. The ARH was placed in between lateral incisor and canine. Three different heights were considered as 0 mm, i.e. directly to main archwire, and others are 5 and 8 mm respectively, from the main archwire. Effects of force application from the different height of anterior retraction hook are calculated with finite element method.

These different implant positions and different heights of ARH give three models for the study. In the first model, orthodontic mini-implant was at the position of 6 mm and the point of force application are at 0, 5 and 8 mm respectively. In the second model, the OMI was at the height of 8 mm and point of force application are at 0, 5 and 8 mm respectively on the retraction hook. In the last model, the implant height was at 10 mm from the archwire and the point of force application were same as above on the anterior retraction hook.

RESULT

In the first model, implant was at 6 mm, when the force was applied at 0 mm ARH and 0.019” × 0.025” SS as the main archwire, central incisor, lateral incisor and canine were tipped lingually by en masse retraction. The maximum force was distributed on lateral incisor, as the point of force application was on the archwire in between lateral incisor and canine. The canine showed slight extrusion and lingual tipping compared to the central and lateral incisor. 0.019” × 0.025” SS wire is stiffer thus shows less labial tipping of the incisors. When the force was applied at 5 mm ARH, lingual tipping of the central and lateral incisor reduced. Central incisors showed more tipping than lateral incisors and canines. The central incisors showed maximum amount of force distribution. In the third condition, when force was applied to 8 mm retraction hook, central incisor, lateral incisor and canine tipped lingually and show extrusion. Canine showed more distal tipping. In the second model, where implant is at 8 mm, the force was applied

<table>
<thead>
<tr>
<th>Material properties</th>
<th>Young’s modulus (×10⁶)</th>
<th>Poisson’s ratio</th>
</tr>
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<tr>
<td>Teeth</td>
<td>2</td>
<td>0.3</td>
</tr>
<tr>
<td>Periodontal ligament</td>
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<td>0.3</td>
</tr>
<tr>
<td>Alveolar bone</td>
<td>2 × 10⁵</td>
<td>0.3</td>
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<tr>
<td>Stainless steel</td>
<td>2 × 10⁻⁷</td>
<td>0.3</td>
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Fig. 1A to C: Various OMI placements: (A) low OMI traction; (B) high OMI traction. Arrows indicate moments generated by force components; (C) combination of anterior and vertical traction
Evaluation of Optimal Implant Positions and Height of Retraction Hook for Intrusive and Bodily Movement of Anterior Teeth

JIOS
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481

to 0 mm retraction hook from the implant. Central incisor, lateral incisor and canine tipped lingually and show some amount of intrusion. Lateral incisor and canine tipped lingually. In second condition, the force was applied 8 mm OMI to 5 mm ARH, central incisor show extrusion and lateral incisor show bodily movement. Canines showed maximum bodily movement. The third condition was also checked in while force is applied from 8 mm OMI to 5 mm ARH. Here OMI and ARH are at the same height (Fig. 3).

In the last model, the OMI was at 10 mm from archwire. The force is applied from OMI to three different heights of ARH. In first situation when force is applied from 10 mm OMI to 0 mm ARH (Fig. 4), central incisor, lateral incisor and canine show en masse retraction with intrusion. When the force was applied from 10 mm OMI to 5 mm ARH, central incisor and lateral incisor show lingual tipping and intrusion. Canines showed bodily movement in distal direction. In the last condition, the OMI was at 10 mm and force was applied to 8 mm ARH, central incisor showed lingual tipping while lateral incisor and canine showed bodily movement in distal direction without any significant intrusion.

DISCUSSION

Extraction of premolars and maximum en masse retraction are indicated in many patients with protrusion of lips or bidentoalveolar proclination or in Class II div. 1 with increased overjet to achieve a harmonious profile and esthetics. If torque is not maintained during the retraction of the teeth, however, the incisor will procline and amount of retraction will increased. The tendency toward lingual crown or lingual root movement of the anterior teeth is determined by the direction of the retraction force and notably by the rotational effects derived from the relation of the line of action of the retraction force relative to the center of resistance.9,10 The correct design of the anterior retraction hook and orthodontic mini-implant position was chosen after careful analysis of clinical situations. To maintain or control the inclination of the incisors, we can built additional torque in the archwire or use high torque brackets. Reinforcement of incisor torque might cause incisor extrusion or posterior anchorage loss. Hence, the orthodontic mini-implant can be an efficient tool not only in solving anchorage problem but also in controlling anterior torque by varying implant positions.11 If orthodontic mini-implants were positioned apically to the crown at proximal root spaces between premolar and first permanent molar, they can generate intrusive force vector.

The purpose of this study was to determine the force systems which bring about the intrusion with retraction and the bodily movement of anterior segment during retraction. For en masse retraction with low orthodontic mini-implant (6 mm) system and 0 mm anterior retraction hook condition, the ARH between lateral incisor and canine was the point of force application. The intrusive component was applied anteriorly to the center of resistance for the six anterior teeth and was expected to induce a counter clockwise moment that would balance the distal tipping of incisors. The optimum combination of position of OMI that can generate more intrusive force and the length of ARH that makes the application of the force through center of resistance was necessary to control inclination.

Initially, it was needed to investigate the center of resistance for the six anterior teeth in the base model to apply the force close to the center of resistance. The center of resistance varies among patients, depending upon root length, alveolar bone support and number of teeth.15 The teeth in this FE model were reproduced from the standard values given in Wheeler’s dental anatomy 8th edition. The location of center of resistance in the base model varied depending on the material properties of the PDL and alveolar bone. Pederson et al reported that the center of resistance of six anterior teeth was located on a line 3 mm behind the distal surface of canine in a study of human autopsy material. Melsen et al13 deduced the center of resistance for six anterior teeth from other studies. Their estimated center of resistance was half way between the midpoint of the four incisor’s CR and the canine’s CR. The center of resistance for this model is located 13.5 mm posteriorly and 9 mm superiorly from the CR of archwire, similar to the estimate of Melsen et al.

When height of ARH is increased, the line of action of force should be closer to the CR of six anterior teeth.14 The vertical force component generated by the vertical difference between the ARH and the OMI, however, will be decreased.
Clinically deflection of ARH by a retraction force might cause gingival impingement, hence the ARH of 0.05” SS was modeled to minimize the deflection. In sliding mechanics, the dimension of main archwire can vary according to the bracket slot size. Generally 0.019” × 0.025” SS wire is recommended for a 0.022” slot. In a combination of a main wire and 0.05” SS ARH, the bending moments are highest at the joint of the relatively flexible main archwire. Deformation of the main archwire will induce labial tipping of lateral incisor and lingual tipping of canine. Even though the line of action of force was applied close to the CR for the six anterior teeth with an 5 mm ARH, the central and lateral incisor were not bodily retracted, shows that the maximum PDL compressive stress was distributed on the lingual root apices of central and lateral incisors. This movement showed retraction and simultaneous intrusion. The high PDL tensile strength was on the labiobuccal third of canine because of extrusion and lingual tipping.15

To produce a more vertical intrusion force component, the orthodontic mini-implant can be placed at the level of 10 mm from main archwire and in between the second premolar and first permanent molar. Although the line of action of force from 5 mm ARH to high mini-implant (10 mm), passing under the CR for the six anterior teeth, lingual tipping of the incisors and canine were reduced. The lingual tipping of incisor and canine is more in 0 and 5 mm ARH condition when force was applied from 10 mm OMI position. In 8 mm ARH the lingual tipping of all six anterior teeth is reduced when force was applied from 10 mm implant position. Labial tipping of incisors did not occurred in high mini-implant condition.

To produce more amount of retraction, the force vector must pass through or near the CR of all six anterior teeth. For this the implant and the ARH16 can be placed at the same height so the vertical force component will be minimal. The reason for this that the vertical force component generated by the vertical difference between the ARH and the OMI, however, will be decreased. The line of action of force from 8 mm ARH to medium orthodontic mini-implant (8 mm) passed closer to CR of six anterior teeth, the lingual tipping of incisors was reduced but the central incisor showed the maximum tipping as compared to lateral incisor and canine show bodily retraction. But, in this condition, there was no or minimum intrusion of six anterior teeth. In 8 mm ARH and high OMI (10 mm) condition, the line of action of force passed through the CR for the six anterior teeth, central incisor, lateral incisor and canine showed bodily movement and less of tipping.

The design of the en masse retraction for bodily movement of all six anterior teeth should be such that the line of action of force must pass through the CR of anterior segment, and for the intrusion with retraction of anterior segment vertical component of force vector should be considered.

CONCLUSION

1. In low orthodontic mini-implant (6 mm) traction, when force was applied from OMI to 0 mm ARH condition, tipping and slight amount of intrusion of six anterior teeth was seen. When force was applied to 5 mm ARH the tipping was reduced as compared to 0 mm ARH condition and when retraction force was applied to 8 mm ARH causes slight tipping and extrusion of all six anteriors.

2. In mid-orthodontic mini-implant (8 mm) traction, when retraction force was applied to 0 mm ARH, lingual tipping of anterior segment with intrusion was noticed. When force was applied to 5 mm ARH, tipping and intrusion of six anterior teeth reduced compared to 0 mm ARH condition. But when force was applied to 8 mm ARH all the six anterior teeth showed bodily type of movement.

3. In high orthodontic mini-implant traction (10 mm), when force was applied to 0 mm ARH showed intrusion with retraction of all six anterior teeth. The intrusion was more as compared to 0 mm ARH and 8 mm OMI traction. When retraction force was applied to 5 mm ARH, intrusion was reduced as compared to 0 mm ARH condition and when force was applied to 8 mm ARH, less amount of intrusion but some counter clockwise movement of anterior teeth was noticed.

REFERENCES