Torque Loss in En-Masse Retraction of Maxillary Anterior Teeth Using Miniimplants with Force Vectors at Different Levels: 3D FEM Study

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ABSTRACT

Objective: This FEM study was conducted to quantify the amount of torque loss in maxillary anterior teeth by applying force vectors from different levels to the anterior retraction hook at various heights and comparing with that of molar anchorage system.

Materials and Methods: Five 3D FEM models were constructed with force vectors at different levels: HOT- High Orthodontic Traction (13.5mm from archwire) to ARH_1 – Anterior Retraction Hook (5mm), HOT to ARH_2 (8mm), LOT- Low Orthodontic Traction (8 mm) to ARH_1, LOT to ARH_2 and from conventional molar hook to ARH_1. Mini-implants were placed buccally between the roots of second premolar and first molar. Torque loss was calculated by measuring the displacement of the teeth at crown tip and root apex in two planes i.e. sagittal and vertical using Y and Z axis respectively

in all the five models. The results were statistically analyzed by using Kruskal Wallis ANOVA and Mann-Whitney U-test.

Results: HOT to ARH_1 showed that the anterior teeth moved bodily (p =0.5127), followed by molar hook - ARH_1 (p=0.0495*) which showed mild uncontrolled tipping. Whereas the HOT-ARH_2, LOT - ARH_1, and LOT - ARH_2 models exhibited uncontrolled tipping with maximum torque loss in LOT - ARH_1 (p=0.0001*).

Conclusion: It can be concluded that bodily movement with very minimal torque loss was observed in HOT-ARH_1 model whereas the maximum torque loss was recorded in LOT-ARH_2 model. Conventional molar anchorage group showed uncontrolled tipping with some amount of extrusion and anchor loss of posteriors.

INTRODUCTION

Torque in general means the tendency of force to rotate an object about an axis, whereas torque in orthodontics is represented by third order relationship of rectangular arch wire in rectangular bracket slot. Torque which is faciolingual control over root position is of vital importance for optimal esthetics, function and stability of the orthodontic treatment outcome [1]. During space closure with en masse retraction it is very critical and important to maintain torque, for which the point of force application plays a vital roleand also anchorage control is crucial in the success of orthodontic treatment outcome. To overcome the problems of conventional anchorage, nowadays mini-implants are commonly used for the purpose of anchorage [2].The first successful orthodontic implant which was used for intrusion was placed by Creekmore and Eklund [3] in 1983, but it was Kanomi [4] in 1997 who described a mini-implant specifically designed for orthodontics use. With the evolution of mini-implants as an anchorage device, there has been a paradigm shift also in the field of biomechanics of space closure [5,6].

Orthodontic research has undergone many changes in the last two decades. In order to find out the mechanical changes taking place within a biological system numerous studies such asphotoelasticstrain gauge [7], laser holographic interference techniques [8] and finite element methods [9] have been attempted. The finite element method (FEM) was developed in 1940 for use in civil and aerospace engineering. This tool was introduced to orthodontics in 1972 by Yettram et al., [10] since then number of studies have been carried out using this method. This method makes it possible to apply various force systems analytically at any point or in any direction. It also quantitatively assesses the

distribution of such forces through the wire & related structures. Since, the physiology of tooth movement and treatment mechanics with implants differs from conventional mechanics.

The objectives of the study were to quantify the amount of torque loss during en masse retraction using mini-implants with force vectors at different levels through a three dimensional finite element analysis and compared to torque loss in the maxillary anterior during en masse retraction with conventional molar anchorage.

MATERIALS AND METHODS

Construction of the finite element model involved the following steps:construction of the geometric model, conversion of the geometric model to a finite element model, material property data representation, defining the boundary condition, loading configuration and interpretation of results for deformation.

A geometric model of maxilla with the dentition was constructed using a CT scan (SIEMENS, DICOM, Syngo CT 2006 C2 format). The cut section was taken from 1mm from the apex to the occlusal surface. The processing was carried out using MIMICS (Materialise's interactive medical imaging control system; Materilise HQ, Technologiclean, Belgiaum) software, and then the maxilla was exported to STL (Stereolithography) format. This STL format is imported into RAPIDFORM (Geomagic, Asia Pacific) software to create the surface data. The surface data was converted to IGES (Initial graphic exchange specification) which was exported to HYPERMESH (HyperWorks CAE Software, Altair Engineering, Michigan).The geometric models of the maxillary central incisor, maxillary lateral incisor, maxillary canine, maxillary second premolar & maxillary first molar were constructed using ANSYS software

(Canonsburg, Pa). The first premolar was not constructed in order to simulate retraction in 1st premolar extraction cases. These teeth were then arranged into the maxillary archform.

MATERIAL PROPERTY DATA REPRESENTATION

The different structures involved in this study include alveolar bone, PDL tooth, bracket, archwire and power arm. Each structure had a specific material property. The material properties used in this study was derived by Chang et al., [11] . The Young's modulus (kg/mm²) of tooth, PDL, alveolar bone, bracket and arch wire were 2.0×10^3, 6.8×10^{-2}, 1.4×10^3, 21.4×10^3, 21.4×10^3 respectively.

In all the models anterior en-masse retraction was performed with force vectors from two different levels of mini-implants; high orthodontic traction (HOT: 13.5 mm from archwire), low orthodontic traction (LOT: 8 mm from archwire) and the conventional molar hook to two different levels of anterior retraction hook (ARH) which were placed between the lateral incisor and canine (ARH_1 and ARH_2 with 5 and 8 mm form the archwire respectively). The models were divided into five groups: 1: HOT to ARH_1; 2: HOT to ARH_2; 3: LOT to ARH_1; 4:LOT to ARH_2; 5: From conventional molar hook (3mm from archwire) to the ARH_1. [Table/Fig-1].

Mini implants were placed buccally between the roots of second premolar and first molar. A retraction force of 150gm/side was applied bilaterally similar to that mentioned in Mo SS et al., [12] study. The analysis was carried out and deformation/movement was calculated and represented in Y and Z axis. The amount of torque loss of anterior teeth were correlated by measuring the parameters from COGS analysis (Cephalometric analysis for Orthognathic Surgery) 1: UI – NF angle (measured valueof 110⁰) before loading, 2: UI-NF distance (linear perpendicular distance measured from the crown tip of maxillary central incisor to the nasal floor(measured as 24.35mm) [Table/Fig-2].
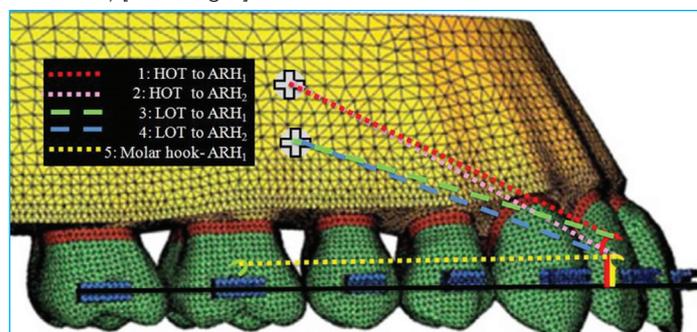
[Table/Fig-1]: FEM model showing different force applications
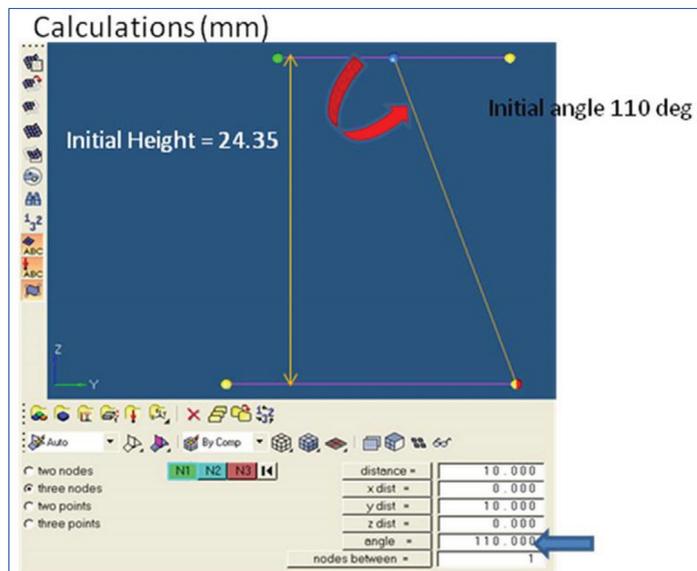
[Table/Fig-2]: Torque measurement of maxillary anterior teeth in FEM model

RESULTS

Displacement of the teeth at crown tip and root apex was calculated in two planes i.e. sagittal and vertical plane using the Y and Z axis respectively. The Y axis showed displacement of the crown tip and root apex inthe sagittal plane [Table/Fig-3], Z axis showed displacement of teeth in the vertical plane [Table/Fig-4], Positive value indicated posterior movement in Y axis and upward movement in Z axis. Negative value indicated anterior movement in Y axis and downward movement in Z axis. All the results were expressed in millimetres [Table/Fig-5,6]. The results of the FEM were correlated to the two parameters: UI-NF angle and a linear perpendicular distance measured from the crown tip of maxillary central incisor to the nasal floor [Table/Fig-7]. To find the CR of the six anterior teeth, a 200-g retraction or intrusion force was applied in a superior or posterior direction from the midpoint of the labial splinting wire at 0.5-mm intervals. After simulation, the initial tooth displacement was magnified 400 times Sung SJ et al., [13]. The CR was estimated from the point of force application that resulted in bodily movement of the six anterior teeth in the base model.

When the force was applied from HOT to ARH_1 (group 1) in the arch wire, the anterior teeth moved bodily in the direction of force application with the crown tip displaced an average of 0.005815 mm lingually and the root apex also moved in the same direction by 0.005272 mm. There was no statistically significance between the displacements of the crown apex and root tip (p-value 0.5127) exhibiting minimal or no toque loss in the anterior teeth. The
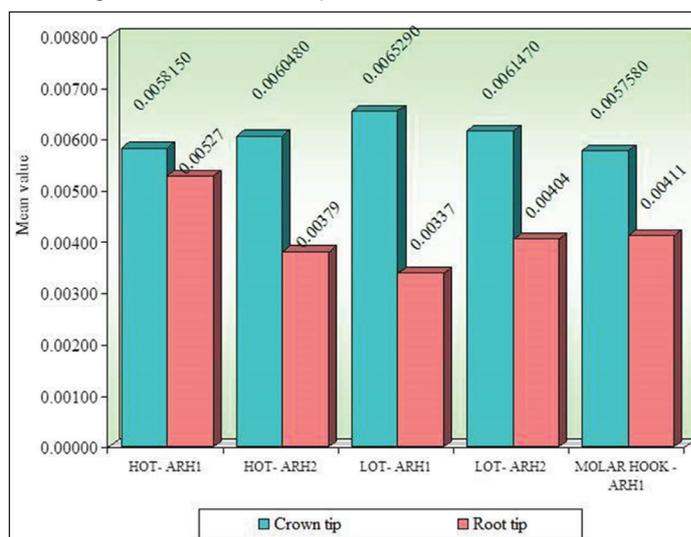
[Table/Fig-3]: Comparison of crown tip and root tip groups with respect to displacement in Y axis in five groups by Mann-Whitney U test
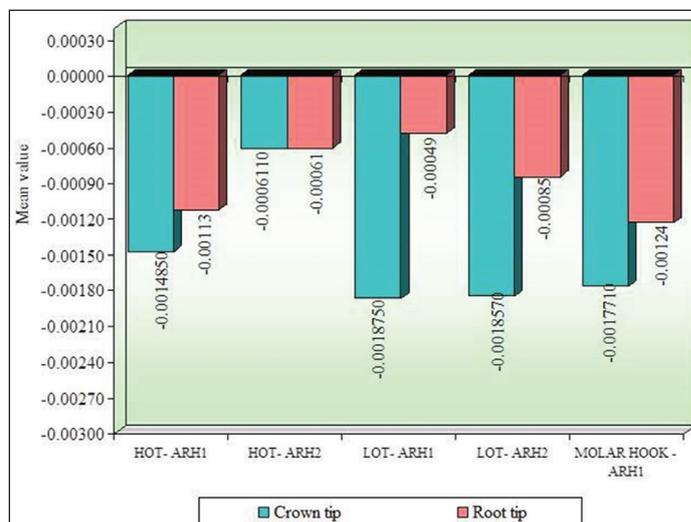
[Table/Fig-4]: Comparison of crown tip and root tip groups with respect to displacement in Z axis in five groups by Mann-Whitney U test

Groups	Group	Mean	SD	p-value
HOT- ARH_1	Crown tip	0.005815	0.000000	0.5127
	Root tip	0.005272	0.000848	
HOT- ARH_2	Crown tip	0.006048	0.000000	0.005*
	Root tip	0.003790	0.002129	
LOT- ARH_1	Crown tip	0.006529	0.000000	0.0001*
	Root tip	0.003367	0.002195	
LOT- ARH_2	Crown tip	0.006147	0.000000	0.003*
	Root tip	0.004038	0.002128	
Molar hook - ARH_1	Crown tip	0.005758	0.000000	0.0495*
	Root tip	0.004106	0.001891	

[Table/Fig-5]: Comparison of crown tip and root tip groups with respect to displacement in Y axis in five groups
*p<0.05

Groups	Group	Mean	SD	p-value
HOT- ARH_1	Crown tip	-0.001485	0.000277	0.1250
	Root tip	-0.001132	0.000580	
HOT- ARH_2	Crown tip	-0.001857	0.002117	0.0005*
	Root tip	-0.000611	0.000701	
LOT- ARH_1	Crown tip	-0.001875	0.000000	0.0001*
	Root tip	-0.000489	0.000739	
LOT- ARH_2	Crown tip	-0.001677	0.000000	0.0005*
	Root tip	-0.000851	0.000462	
Molar hook - ARH_1	Crown tip	-0.001771	0.000000	0.0495*
	Root tip	-0.001241	0.000468	

[Table/Fig- 6]: Comparison of crown tip and root tip groups with respect to displacement in Z axis in five groups
*p<0.05

Models	HOT- ARH_1	HOT- ARH_2	LOT- ARH_1	LOT- ARH_2	Molar hook-ARH_1
UI- PP Angle (110°)	109.943°	109.884°	109.856°	109.796°	109.931°
U1- PP ▢ distance (24.35mm)	24.352mm	24.367mm	24.3589mm	24.392mm	24.392mm

[Table/Fig-7]: Measurement of angle of central incisor and linear distance from PP

clockwise rotation of the anterior segment leads to extrusion of incisors that was correlated with the displacement observed in the Z axis i.e. the vertical plane which showed the extrusion of the anterior teeth. The above findings can also be correlated with the negligible decrease in the UI-PP angle (109.943°) and the linear perpendicular measurement from incisal tip of central incisor to the palatal plane (24.352 mm).

In group 2 (HOT - ARH_2), there was uncontrolled tipping (p-value 0.005*) which was observed as there was more of crown movement (0.006048 mm) than of a root apex (0.003790 mm) in the direction of force application. The clockwise rotation of the anterior segment results in extrusion of crown tip by 0.001857 mm and root apex by 0.000611mm. These findings were correlated with the decrease in the UI-PP angle (109.884°) and the linear perpendicular measurement from incisal tip of central incisor to the palatal plane (24.367mm).

LOT to ARH_1 (group 3) results showed uncontrolled tipping, with 0.006529 mm of crown movement and 0.003367 mm of root apex in the direction of force application. The difference in the crown and root movements exhibited a p-value of 0.0001* which has statistically high significance. In this group, bite deepening was also observed because of extrusion of anterior teeth. (crown: 0.001875mm; root: 0.000489mm and p=0.0001*). Decrease in the UI-PP angle (109.856°) and the linear perpendicular measurement from incisal tip of central incisor to the palatal plane (24.589 mm) confirms the uncontrolled tipping. Group 4 (LOT - ARH_2) also exhibited the uncontrolled tipping, but the degree of tipping was less than that

of LOT - ARH_1 group but similar to that of HOT - ARH_2. The crown moved lingually by 0.006147 mm and the root by 0.004038 mm (p = 0.003*)

Conventional molar anchorage FEM model (group5) showed more of crown movement(0.005758mm) than of a root apex (0.004106 mm) in the sagittal plane which results in minimal torque loss of anterior teeth (p=0.0495*). There was almost a bodily movement (but when compared to the HOT-ARH_1 it showed slightly more torque loss, though the amount was very less. These findings can also be correlated with the negligible decrease in UI-PP angle (109.931°) to the long axis of central incisor and the linear perpendicular measurement from incisal tip of central incisor to the palatal plane (24.392 mm).

DISCUSSION

One of the major challenges faced by the orthodontists is to understand and predict the complexities involved in the response of teeth to the forces and the moments. The force application close to the centre of resistance (CR) can be achieved by modifying the heights of force application source (mini-implants at different heights) and the position of anterior retraction hook (Chang Y et al., [11]). The finite element analysis was selected for this study because of its advantages like, it is a non-invasive technique, the object of interest can be studied in three dimensions, the actual physical properties of the materials involved can be simulated and the tooth, alveolar bone and the PDL can be simulated when the material properties of these structures are assigned, it is nearest that one possibly can get in simulating the oral environment in-vitro, the actual displacement of the tooth can be visualized, the actual stress experienced at any given point can be measured, the model can be magnified infinitely [12,14].

During en-masse retraction, adjustment of the anterior retraction hook length is recommended to control the torque loss from lingual tipping of the anterior teeth [15].The torque loss was calculated by measuring the difference between the initial displacement of crown tip and root apex, if both the crown tip and root apex moved equally it showed the translation i.e. the bodily movement. According to Melsen et al., [16] the CR was located 13.5 mm posteriorly and 9 mm superiorly from the centre of the archwire. If the force passes through the CR bodily movement is observed where as if it passes below the CR uncontrolled tipping is observed.The force application close to the CR can be achieved by modifying the height of anterior retraction hook. Mini implants were used at different heights to quantify the torque control from different levels of force vectors.

In this study, enmasse retraction of all the six teeth was attempted; therefore the force applied was 150gms per side. The forces was provided by a pre-stretched elastic chain, extending from two different locations of implants, which were placed between the roots of maxillary second premolar and molar to the two different levels of ARH between lateral incisors and canines. In this view a model of six maxillary anterior teeth was developed with defined material properties. The model was analysed to calculate torque when force was applied from two different level of implant to the two different levels of ARH and from molar hook to the ARH.The results of the FEM were correlated to the parameters like, UI-PP and linear perpendicular distance was measured from the crown tip of maxillary central incisor to the palatal plane.

The results of our study revealed that HOT to ARH_1 (group 1) model showed least amount of torque loss, as the force was applied more close to the centre of resistance. Where as in all other groups (HOT - ARH_2, LOT - ARH_1, LOT - ARH_2, and molar hook- ARH_1) the anterior teeth exhibited various amount of uncontrolled tipping. This tipping was more in LOT - ARH_1 model. Though the torque loss was comparatively very less in conventional anchorage group (group 5) but the problems encountered with the molar anchorage is the anchor loss which is quite difficult to avoid and requires

lot of preparation, whereas the mini implants provides absolute anchorage. In all the models there was clockwise rotation of the anterior segment leads to extrusion of incisors, which is more in LOT- ARH$_1$ group and least in HOT to ARH$_1$.

Tipping can be prevented by applying lingual root torque to the archwire [15] or to increase archwire hook length to the level of centre of resistance [17]. The position of the mini implant should also be at the same level so that theforce passes through the centre of resistance and bodily movement occurs [18]. Melsen and colleagues (1990) recommended that the archwire hook extend 10mm from the main archwire. If the maxillary force passes close to the centre of resistance, this could eliminatethe need for applying lingual root torque to the archwire to prevent lingual tipping. Elimination of the unnecessary requirement of applying lingual root torque on themaxillary anterior teeth makes treatment mechanics simpler Jeong HS et al., [19]. The only factors clinicians should keep in mind are the direction of the force and the response of the teeth to the force [20]. The limitations of this study were: although the FEM is a wonderful tool, it cannot represent the human skull perfectly; the result of this study is only valid with patients exhibiting similar bone density, root lengths, root angulations, crown sizes etc; placing implants 13.5mm above the archwire is not always possible in clinical situations.

CONCLUSION

The conclusions drawn from this study were, the maximum to minimum torque loss was observed in the following order LOT to ARH 1 , LOT to ARH 2 , HOT to ARH 2 , Molar hook to ARH 1 and HOT to ARH 1 respectively.

When implant was placed at HOT there was less torque loss when compare to that of the LOT. Extrusion was observed in all the models.

HOT to ARH 1 model showed translation (bodily movement) else all the models showed various degrees of uncontrolled tipping.

Anchor loss in posteriors was observed in molar anchorage group,whereas mini implants provided absolute anchorage in all other groups.

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