A Three-dimensional Finite Element Analysis – Comparison of Intrusion or Extrusion of Maxillary Anteriors during En masse Retraction with Retraction Hook Mesial and Distal to Canine at 15 mm Height

Anas Khan[1]*, Amitabh Kallury[1], Chetan Jayade[2], Rajesh Balani[1], Chandrika Dubey[1], Nimisha Chaturvedi[1]

[1]Department of Orthodontics and Dentofacial Orthopedics, People's Dental Academy, Bhopal, Madhya Pradesh, India.
[2]Center for Orthodontic Research and Education, Hubli, Karnataka, India.

Abstract

Intrusion is a common orthodontic tooth movement which is employed in the cases of deep bite where anteriors are intruded for correction, or in anterior open bite where posteriors are intruded to close the bite for correction. The article discusses the biomechanics of Intrusion and extrusion in Orthodontic treatment during enmasse retraction at different positions of crimpable hooks. The finite element method (FEM) is basically a numerical method of analyzing stresses and deformations in the structures of any given geometry. The duration of orthodontic treatment can influence root resorption and gingival recession by increasing the risk of plaque accumulation over the long term. Knowing the centre of resistance can be beneficial in biomechanics, such as predicting tooth movement, proper force direction and decreasing side effects leading to potential reduction of treatment duration. Reduced treatment duration and elimination of unfavourable appearance of spacing distal to lateral incisors following canine retraction are the benefits that makes en masse retraction more favourable. Conclusion: When the crimpable hook was placed in the mesial position (between the lateral incisor and canine), the rotation of the anterior teeth segment increased, while the movement in the vertical plane decreased.

Keywords: Displacement, En masse retraction, Extrusion, Finite element method, Intrusion.

Introduction

In orthodontic treatment, intrusion movement of maxillary incisors is often necessary. Therefore, the objective of this investigation is to evaluate the initial distribution patterns and magnitude of compressive stress in the periodontal ligament (PDL) in a simulation of orthodontic retraction of maxillary incisors, considering the points of force application.

Malocclusion can occur in three planes of space, that is, sagittal, transverse, and vertical plane. Extraction space closure is particularly interesting aspect of orthodontic treatment with respect to the principles of biomechanics due to the large movement of distances involved.[1] As per Newton's third law, for every action, there is equal and opposite reaction. Similarly, during space closure when forces are applied, there are favorable as well as unfavorable movements occur on the teeth. The actions and reactions of the forces and moments must, therefore, be studied so as to reduce empiricism in the orthodontic treatment.

Thus, the aim of the present finite element method (FEM) was to evaluate the von Mises stress in the PDL and alveolar bone and study the displacement of the maxillary anterior teeth in vertical plane during en masse retraction and retraction hooks.

The finite element method (FEM) is basically a numerical method of analyzing stresses and deformations in the

Access this article online

Website:
www.jrad.co.in

DOI:
https://doi.org/10.53064/jrad.2022.13.6.295

Address for correspondence: Dr. Anas Khan,
Department of Orthodontics and Dentofacial Orthopedics,
People's Dental Academy, Bhopal, Madhya Pradesh, India.
Email: khananas661@gmail.com

Received: Dec, 01, 2022; **Accepted:** Dec, 20, 2022; **Published:** Dec, 28, 2022

How to cite this article: Khan A, Kallury A, Jayade C, Balani R, Dubey C, Chaturvedi N. A Three-Dimensional Finite Element Analysis – Comparison of Intrusion or Extrusion of Maxillary Anteriors During En masse Retraction with Retraction Hook Mesial and Distal to Canine at 15 mm Height. J Res Adv Dent 2022;13(6):46-49.

structures of any given geometry.[2] It has revolutionized dental biomechanical research.[5] Basically, the object to be studied is graphically simulated in a computer, which defines the geometry of the body being studied. It is divided into a number of subunits termed elements. These are connected at a finite number of points called nodes.[4] The elements are prescribed the appropriate material properties of the structure that they represent. It is a mathematical model of the likely physical response of that object to load; large volumes of information about stresses, strains, and displacements being obtained through the continuum defined.[6]

FEM makes it possible to analytically apply various force systems at any point and in any direction and also quantitatively assess the distribution of such forces through the wire and related structures.[4]

Objectives

The objectives of this study were as follows:

1. Tooth displacement at sagittal plane
2. Tooth displacement at vertical plane
3. Von Mises stresses at apical and cervical region of anteriors.

The points of force application were selected based on simulated clinical situations and considering points which the clinician usually would choose. Thus, the points of force application were:

- Model 1:M1: Retraction hook mesial to canine (height 15 mm)
- Model 2:D1: Retraction hook distal to canine (height 15 mm).

Materials and Methods

In this study, the following materials were used:

1. Cone-beam computerized tomography (CBCT) scan (Acteon X-MIND PRIME 3D, Aceton India Pvt. Ltd., Maxilla
2. 3D finite element models simulating:
    a. All maxillary teeth except first premolar with surrounding periodontal ligament and alveolar bone.[3]
3. HyperMesh software (version 11, Altair Engineering, Inc, USA). HyperMesh software is a multi-disciplinary finite element pre-processor software which imports STL file format of CBCT/CAD-CAM images and processes these images to form meshed finite element models that can be used for various problem solving[4]
4. ANSYS software (version 18.1, ANSYS Inc, Southpointe, Pittsburg, USA). ANSYS is a software which analyzes the meshed finite element models and numerically solves various wide variety of mechanical problems such as displacement of teeth when load is applied, stress distribution around the PDL, and strain energy.[4]

A CBCT scan projection of a maxilla with extracted first premolar will be obtained. These computed tomography scans (slice thickness 1 mm, pixel size 0.42 mm) will serve as the pattern for construction of the mathematical model. Processing will be performed using Autocad 2017. The DICOM file (digital imaging and communications in medicine) will be generated through CBCT evaluation and will be imported to Autocad 2017 software for semi-automatic edge detection, followed by meshing of surface elements using hypermesh software to construct 3D analytical model of maxillary dentition by thresholding the growing region and calculating 3D operations. With the help of software, for FEA analysis, we will be using ANSYS 2019 to find out stress and strain deformation due to different levels of applied forces.[3,4]

Table 1: Number of elements and nodes in the models

Group	Number of elements	Number of nodes
Conventional group	548,528	792,724

Table 2: Number of elements and nodes of individual components of the models

Model	Elements	Nodes
Maxillary central incisor	20666	32622
Maxillary lateral incisor	10670	17798
Maxillary canine	13050	21760
Maxillary second premolar	10208	17134
Maxillary first molar	28544	46600
Maxillary second molar	23812	38586
Cancellous bone	227730	335444
Cortical bone	35956	67438
Brackets	147130	255998
Arch wire/hook	1026	2054
Complete model	548528	792724

Table 3: Mechanical properties of the material used in modeling

Model	Poisson’s ratio	Young’s modulus
Teeth	2×10^4	0.68
PDL	0.68	0.49
Alveolar bone	2×10^3	0.30
Bracket	2.1×10^5	0.30
Arch wire/hook	2.1×10^5	0.30

Construction of geometric model

The geometric models of the maxillary central incisor, lateral incisor, canine, second premolar, first molar, and second molar will be constructed using the dimensions and morphology found in Wheeler’s text book. First premolar will not be constructed to simulate retraction in 1st premolar extraction cases. These teeth will then be arranged in ovoid arch form. To establish mesiodistal angulations and labiolingual inclination of the teeth, the maxillary dentition will be arranged according to MBT norms.[3]

To establish the natural anatomy, PDL will be constructed with an average thickness of 0.25 mm around the roots of all the teeth. Next alveolar bone will be constructed; PDL and the teeth will be fitted into the bone.

Bracket with slot size 0.022” × 0.028” will be made and attached to the crowns such that the facial axis point was coinciding with the center of the bracket slot (base point and slot point).[4]

Stainless steel arch wire of dimension 0.019” × 0.025” will be designed.

Teeth, PDL, alveolar bone, Brackets, and arch wire will be considered as isoparamertic and homogenous. Brackets and arch wire will be given the properties of stainless steel. The different structures involved in this study will have a specific material property.[4]

Results

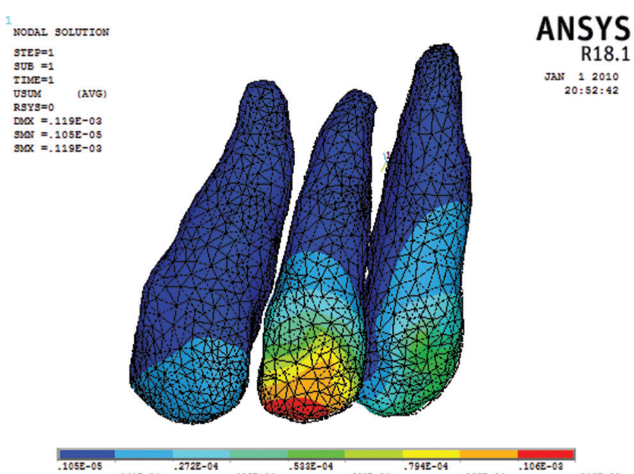
The models were tested in the ANSYS software (version18.1, ANSYS Inc, Southpointe, Pittusburg, USA). Force of 150 g was applied during the process for en masse retraction of maxillary anterior teeth. Tooth displacement in the maxillary anteriors and von Mises stresses in the PDL in cervical and apical parts were assessed and compared. The results obtained were as follows:

Tooth displacement

Model 1: M1: Retraction hook mesial to canine.

In the vertical plane (Z-axis), M1 showed intrusion of central incisors and lateral incisors by 0.0000159 mm and 0.0000864 mm, respectively, and canine intrusion of 0.000000363 mm.

In the sagittal plane (Y axis), MODEL M1 showed distal displacement of both the crown and the root of central incisor by 0.00000731 mm and 0.00000416 mm. Lateral incisor showed distal displacement of both the crown and the root by 0.00000302 mm and 0.00000865 mm, respectively. Canine showed distal displacement of both the crown and the root by 0.0000276 mm and 0.00000105 mm, respectively.

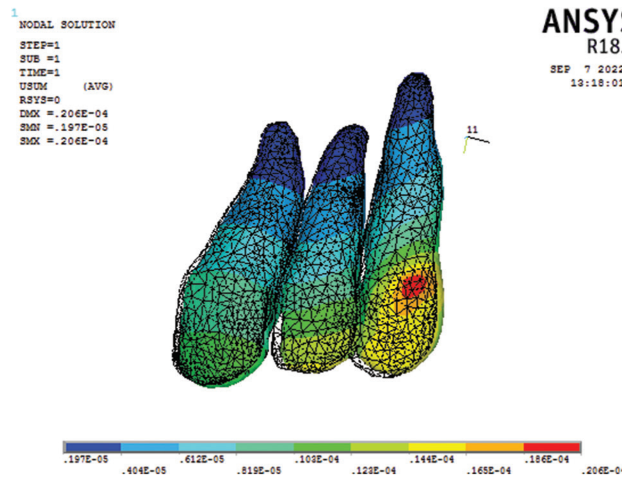


Anterior displacement at 15 mm from mesial hook

Model 2: D1: Retraction hook distal to canine.

In the vertical plane (Z axis), D1 showed neither any intrusion nor extrusion of central incisors and intrusion of lateral incisors and canines by 0.00000559 mm and 0.00000732 mm, respectively.

In the sagittal plane (Y axis), MODEL D1 showed distal displacement of both the crown and the root of central incisor by 0.00000817 mm and 0.0000011 mm. Lateral incisor showed distal displacement of both the crown and the root by 0.00000948 mm and 0.00000228 mm, respectively. Canine showed distal displacement of both the crown and the root by 0.00000996 mm and 0.00000245 mm, respectively.



Anterior displacement at 15 mm from distal hook

Discussion

One of the major challenges faced by the orthodontists is to understand and predict the complexities involved in the response of the teeth to the forces and the moments. Many methods have been used to study the relationship between force systems and distribution of stress/strain on tooth and its surrounding tissues. Some of the methods are FEM, laser holographic techniques, and mathematical models representing the *in vivo* situation and photoelastic studies. Each of these techniques have inherent advantages and disadvantages. The 3D FEM used in the present study provides the freedom to simulate orthodontic force applied clinically and to analyze the response of the dentition to the force in three-dimensional space. The point of force application, magnitude, and direction of force may easily be varied to simulate the clinical situation.

En-masse retraction of anteriors: Hook placed mesial to canine (15 mm) - M1

In the vertical plane (Z axis), M1 showed intrusion of central incisors and lateral incisors by 0.0000159 mm and 0.0000864 mm, respectively, and canine intrusion of 0.000000363 mm**.**

En-masse retraction of anteriors: Hook placed distal to canine (15 mm) - D1

In the vertical plane (Z axis), D1 showed no intrusion or extrusion of central incisors and intrusion of lateral incisors

Total displacement at mesial and distal								
Strain energy in upper anterior teeth for mesial and distal group (10^{-6})								
	Displacement at crown			Total	Displacement at root			Total
	CI	LI	C	CI+LI+C	CI	LI	C	CI+LI+C
M80	0.00000731 mm	0.00000302 mm	0.0000276 mm	0.00003719 mm	0.00000416 mm	0.00000865 mm	0.00000105 mm	0.00001386 mm
D80	0.00000817 mm	0.00000948 mm	0.00000996 mm	0.00002761 mm	0.0000011 mm	0.00000228 mm	0.00000245 mm	0.00000484

Strain energy in the upper anterior teeth for mesial and distal group (10^{-6})	
Model	15 mm
Mesial	6.42
Distal	0.833

and canines by 0.00000559 mm and 0.00000732 mm, respectively.

Comparison of en-masse retraction of anteriors from hooks placed mesial and distal to canine at 15 mm. (M1 vs. D1)

In the vertical plane there is more intrusion seen in incisors from mesial crimpable hook and more intrusion in canine from distal crimpable hook.

Strain energy from mesial crimpable hook observed is 6.42 and from distal crimpable hook, it is 0.833 mm.

Summary and Conclusion

Maxillary anterior en masse retraction with maxillary first premolar extraction in Class I bimaxillary cases was evaluated by FEM.

More intrusion was seen from mesial hook in incisors and less in canine as compared to distal hook.

When the crimpable hook was placed in the mesial position (between the lateral incisor and canine), the rotation of the anterior teeth segment increased, while the movement in the vertical plane decreased.

When the crimpable hook was placed in the distal position (between the canine and second premolar), the rotation of the anterior teeth segment increased, while the movement in the vertical plane decreased.

As the point of force application moves apically amount of extrusion is slightly reduced and amount of intrusion is slightly increased.

Mesial and distal hook at 15 mm showed extrusion at centrals and laterals while intrusion at canine.

Von Mises stress in the PDL of upper anterior teeth were more in cervical region and less in apical region. The highest magnitude of von Mises stress is highest at cervical region of maxillary canine (from mesial crimpable hook) and less at apical region of maxillary central incisor (from distal crimpable hook).

Strain energy in the upper anterior teeth for mesial crimpable hook was found to be greater than distal crimpable hook.

The further direction of FEM studies should involve the tissue reactions, more accurate simulation of loading and approximation of material behaviors as well as variations in geometries of PDL, bone and teeth in three-dimensional finite element analysis.

References

1. Saga AY, Maruo H, Argenta MA, Maruo IT, Tanaka OM. Orthodontic intrusion of maxillary incisors: A 3D finite element method study. Dental Press J Orthod 2016;21:75-82.
2. McGuinness NJ, Wilson AN, Jones ML, Middleton J. A stress analysis of the periodontal ligament under various orthodontic loadings. Eur J Orthod 1991;13:231-42.
3. Khlef HN, Hajeer MY, Ajaj MA, Heshmeh O. En-masse retraction of upper anterior teeth in adult patients with maxillary or bimaxillary dentoalveolar protrusion: A systematic review and meta-analysis. J Contemp Dent Pract 2019;20:113-27.
4. Hedayati Z, Shomali M. Maxillary anterior en masse retraction using different antero-posterior position of mini screw: A 3D finite element study. Prog Orthod 2016;17:31.
5. Chetan S, Keluskar KM, Vasisht VN, Revankar S. En-masse retraction of the maxillary anterior teeth by applying force from four different levels-a finite element study. J Clin Diagn Res 2014;8:ZC26-30.
6. Sung SJ, Jang GW, Chun YS, Moon YS. Effective en-masse retraction design with orthodontic mini-implant Anchorage: A finite element analysis. Am J Orthod Dentofacial Orthop 2010;137:648-57.