Original Article

Initial Displacement of Teeth as an Indicator of Ideal Force System for En Masse Retraction Using Mini Implant—A FEM Study

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ABSTRACT

Objectives: To evaluate the initial displacement of maxillary anterior teeth under different forces of en masse retraction. To find out the ideal force system for en masse retraction using initial displacement.

Material and Methods: ADENTASCAN was converted into three dimensional Finite Element Model (FEM) of maxilla using HyperMesh software. Two models were constructed having different implant angulations i.e., 45 and 60 degrees. Each model was applied 150, 200, 250 and 300 gm of load. The results were analyzed using ANSYS software.

Results: The maximum initial displacement of 0.095 mm was observed in lateral incisor under 300 gm of load with 45 degrees of implant placement, followed by central incisor and the least displacement was observed in canine.

Conclusion: The amount of initial tooth displacement can predict the favorable force system required for en masse retraction of anterior teeth which according to our study is 300 gm of retraction force at 60 degrees of implant placement.

Key words: FEM, Ideal force system, Initial displacement, Orthodontic tooth movement.

INTRODUCTION

In 1999, P.L. Soenen et al postulated that the initial tooth displacements, as measured by speckle interferometry, are a good predictor of long-term displacements due to bone remodeling. The teeth start to move immediately after force application and this initial displacement is movement of teeth within the socket before the boneremodeling begins.[1]

From a mechanical point of view, alteration in the stress strain distribution in the surrounding alveolar bone and within the periodontal ligament (PDL) is the first reaction to the application of an Orthodontic load. This leads to an intra-alveolar displacement of the tooth followed by bending of the surrounding alveolar bone, provided the forces used are large enough.[2] Van Driel et al. suggested that the very rapid initial change in the position of the tooth might be facilitated by the rapid relocation of fluid in the periodontal space, which is possibly due to the high porosity of the PDL.[3]

Different methods have been used to measure the initial tooth displacement. Strain gaugeswere used by Gould and Picton in 1962 and by Picton in 1963. A two dimensional model was usedby Haack and Weinstein in 1963. In 1962 in vivo measurement was tried by Hofman and Diemer.The strain gaugetechnique was applied extensively on dryhuman skulls by Lanyon and Smith in 1970; Sugimuraet al. in 1983, 1984 and by Ichikawa et al.in 1984. Thistechnique has been used in vivo by Kannan in 1982,as well as on autopsy material by Pedersen et al. in 1991.Double exposure holography was used toregister orthodontic tooth movement by Burstoneet al. in 1978 and by Burstone and Pryputniewicz in 1980,1982.[1] Laser Measuring technique are non invasive and the displaced object is not touched by the measuring device (non- destructive testing), which have an important advantage over the previously described methods.

Speckle interferometry was introduced by Goldin et al. in 1980, in an attempt to measure larger displacements,and investigations using this techniquehave been carried out by Kleutghen et al. in1982; Dermaut et al. in 1986 and De Clerck et al. in 1990.[1]

For practical reasons, initial displacements afterforce application cannot be measured in eachpatient and to do so we need to find out the stress and strain levels in the periodontium. A valid model with sensitive measuring technique that can read every minute change is therefore essential to measure the initial displacement. The finite element method (FEM) is one such technique used to analyze structural stressand strain values. This method was used in engineering since long time. This method uses the computer to solve large numbers of equations to calculate stress-strain values on the basis of the physical properties of structures being analyzed.[4]

The FE method was introduced into dental biomechanicalresearch by Farah et al.[5] in 1973. Since then FEMhas been extensively usedin orthodontics. Middleton et al.[6] in 1990 used it to analyze the three dimensional orthodontic tooth movement.Puente et al.[7] in 1996 measured initial stress during various tooth movements using FEM.Tanne et al.[8] in 1998 evaluated the biomechanical response to orthodontic forces by FEM analyses.Reimann et al.[9] in 2007 studied the position of Centre of resistance of incisors using a three dimensional FEM model.YingliQian et al.[10] in 2008 did the numerical simulation of tooth movement using FEM.Tominaga et al.[11] in 2012 studied the role of play in sliding mechanics using this technology. Junning Chen et al.[12] in 2014 studied the remodeling in orthodontic tooth movement using FEM.

Therefore, in the present study we designed a FEM model of maxilla to measure the precise initial displacement of the maxillary anterior teeth during en mass retraction using a mini implant placed at two different angulations and under four different retraction forces.

MATERIAL AND METHODS

The fabrication of FE Model is a very complex process. Various steps involved in fabrication of the Finite Element model are as following:

Construction of Geometric Model

A DENTASCAN of human maxilla was used for the fabrication of geometric model.The DENTASCAN images were saved as BMP format (Bitmap Image File) data and exported to 3D image processing and editing software MIMICS (Materialize Interactive Medical Image Control System) version 8.11. The MIMICS software converted the DENTASCAN images into thegeometric model of the maxilla which was saved as STL (Stereolithography) format. After this the maxillary first pre molar was removed from the geometric model of maxilla to generate extraction space.

The geometric model of brackets, implant, archwire and nickel titanium spring were fabricated using Reverse-Engineering process. This process measures the physical dimensions of the original object and replicates it into a 3D model. The titanium implant of diameter of 1.5 mm and length 9 mm was designed. The stainless steel archwire of 0.019 × 0.025inch dimension with a retraction hook between maxillary lateral incisor and canine was used. Stainless steel brackets of 0.022 slot size and MBT prescription were used. A Nickel Titanium closed coil spring was designed to apply retraction force on the anterior teeth.

Now the geometric models of brackets along with archwirewereimposedon the geometric model of maxillary teeth. The geometric model of implant was assembled between the roots of maxillary second premolar and maxillary first molar and a nickel titanium closed coil spring was attached from retraction hook to the implant head **(Figure 1)**. The implant was placed at two different angulations i.e., 45 degrees and 60 degrees to the buccal surface of the alveolus, hence two geometric models were fabricated.

Construction Finite Element Model from Geometric Model

These geometric models were imported into HyperMesh software version 9.0 and converted into finite element model. **(Figure 2)**. Two finite element models were generated, in which all the parameters were kept same except the angulations of the implant i.e., 45 degrees and 60 degrees.

Assigning Material Properties

The finite element models were assigned the material properties. All materials used in this study were assumed to have homogeneous, isotropic, and linearly elastic behavior, so that they can simulate the behavior of the structures under consideration[13-15] **(Table 1)**.

Defining the Boundary Conditions

Nodes and elements for 3-D FE models were defined. The model with 45 degrees implant angulation consisted of 256801elements and 59206 nodes, whereas the FE model with 60 degrees of implant angulation consisted of 256825 elements and 59218 nodes.

Application of Forces

After defining the boundary conditions, four different loads were applied to each model in the Y plane of the co ordina-

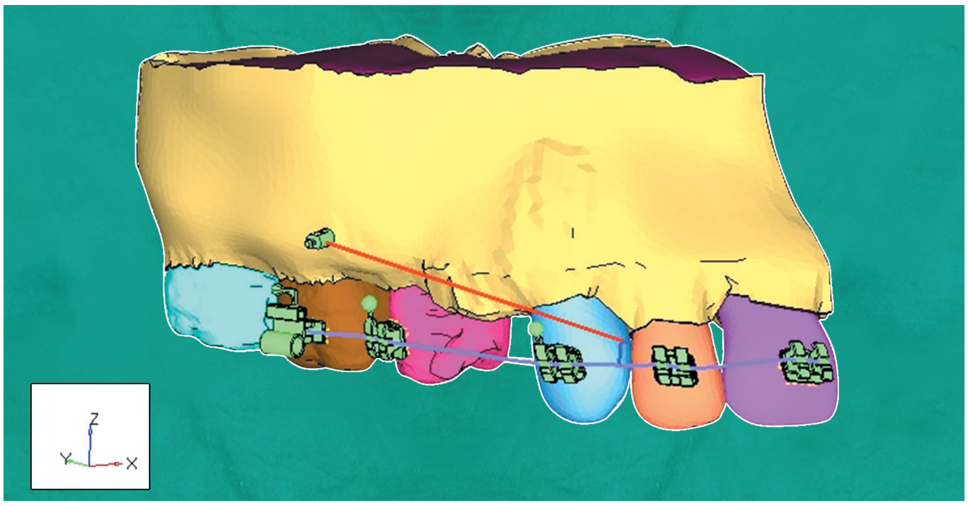

Figure 1 Three dimensional geometric model of maxilla with brackets, mini implant, archwire and spring attached

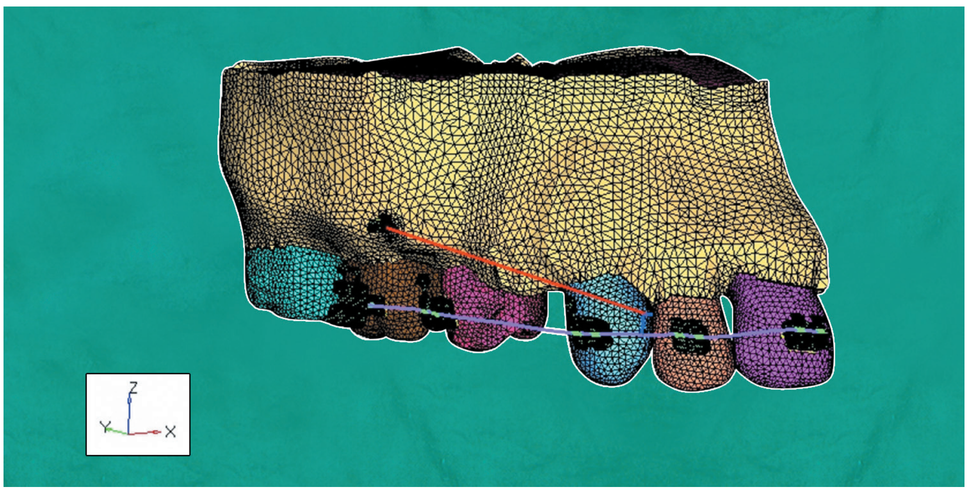

Figure 2 The finite element model (FEM) of maxilla fabricated from the 3D geometric model

Table1

Material properties required in FEM model[13-15]

Materials	*Elastic modulus E (G Pa)*	*Poisson's ratio v*
Trabecular/soft bone	1.5	0.30
Cortical/hard bone	14.7	0.30
Tooth	20.7	0.30
PDL	6.89×10^{-5}	0.45
Titanium mini implant	114	0.34
Bracket & wire(stainless steel)	179	0.30
Nickel titanium	36	0.33

tion system. The loads applied were 150 gm, 200 gm, 250 gm and 300 gm.

Execution of Analysis and Interpretation of Results

The FE models were then imported to ANSYS (Analysis System) software version 12.1 toanalyze the initial displacement in response to applied loads. The displacement was calculated by change in the position of nodes and internodes when retraction forces were applied.

RESULTS

The maximum initial displacement of 0.09 5 mm was observed in lateral incisor under 300 gm of load with 45 degrees of implant placement whereas with 60 degrees the displacement was 0.09 2 mm with same load. The central incisor underwent maximum initial displacement of 0.057 mm under 300 gm of load and 45 degrees of implant placement and for 60 degrees it was 0.055 mm. The maximum initial displacement of canine was 0.038 mm under 45 degrees implant angulation and 0.037 mm under 60 degrees angulation.

The lowest initial displacement of 0.012 mm was observed in canine teeth under 150 gm of load at 60 degrees of implant angulation. The central incisor measured 0.018 mm as least initial displacement under 150 gm load and 60 degrees implant angulation. The minimum displacement of lateral incisor was 0.031 mm under 150 gm load and 60 degrees implant angulation **(Tables 2 and 3)**.

DISCUSSION

In this study we found out that under all the loads applied for en masse retraction the maximum initial displacement was seen on the lateral incisor tooth followed by central incisor and the minimum initial displacement was seen on canine. This pattern of tooth movement suggests that the maximum initial stresses were transmitted to PDL of lateral incisor followed by central incisor and least stresses were transmitted to canine due to which the lateral incisor underwent the maximum initial displacement. This finding is in agreement to a study done by Reimann[9] et al in which the strain in the PDL of the lateral incisors was significantly higher than at the central incisor, therefore it was assumed that the lateral incisors might initially move faster than the central incisors due to a higher bone remodeling rate.

This assumption of higher remodeling rate is further supported by Melsen,[16] he concluded that the load exerted by stretched PDL fibers will most likely lead to delivery of strain values which will lead to remodeling and thus tooth movement will take place. Hence higher the stretch value of PDL faster will be the tooth movement.

We observed that the initial displacement was highest for lateral incisor, this is similar to a study conducted by Young et al.[17] in which 300 gm of load was applied to anterior teeth using class II elastics and the maximum displacement was produced on lateral incisor tooth followed by central incisor and then remaining teeth.

The mini implant was placed at two different angulations of 45 degrees and 60 degrees, on comparing the amount of

Table 2

Initial Displacement of various teeth at 45 degrees of implant angulation

Load	*Displacement*		
	Lateral incisor	*Central incisor*	*Canine*
150 gm	0.032 mm	0.019 mm	0.013 mm
200 gm	0.063 mm	0.038 mm	0.025 mm
250 gm	0.079 mm	0.048 mm	0.032 mm
300 gm	0.095 mm	0.057 mm	0.038 mm

Table 3

Initial Displacement of various teeth at 60 degrees of implant angulation

Load	*Displacement*		
	Lateral incisor	*Central incisor*	*Canine*
150 gm	0.031 mm	0.018 mm	0.012 mm
200 gm	0.061 mm	0.037 mm	0.024 mm
250 gm	0.076 mm	0.046 mm	0.031 mm
300 gm	0.092 mm	0.055 mm	0.037 mm

initial tooth displacement it was slightly more for 45 degrees but the difference was not significant enough. The most favorable angulations for implant placement as reco mmended by recent studies[18-20] are 60 to 70 degrees. Although the initial displacement was slightly more with 45 degrees but considering the stability of mini implant we reco mmend the placement of implant at 60 degrees.

CONCLUSION

Higher the bone remodeling rate, higher will be the rate of initial tooth displacement and hence speedier will be the space closure. Therefore, we suggest that the amount of initial tooth displacement can predict the favorable force system required for en masse retraction of anterior teeth which according to our study is 300 gm of retraction force at 60 degrees of implant placement. The type of tooth movements that will be produced by this force system needs to be evaluated further.

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