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ORIGINAL RESEARCH

EN MASSE RETRACTION OF ANTERIOR TEETH- TOOTH DISPLACEMENT USING VARIOUS MINI-IMPLANT MATERIALS: A FINITE ELEMENT ANALYSIS

Sneha Devarakonda[1], Aravind Kumar Subramanian[2]
[1]Department of Orthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India
[2]Professor and Head of the Department, Department of Orthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India.
***Corresponding Author:** Dr. Aravind Kumar Subramanian , Professor and Head of the Department, Department of Orthodontics, Saveetha Dental College and Hospitals, SIMATS, Chennai, India. aravindkumar@saveetha.com
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ABSTRACT

Background: Orthodontic mini implants are conventionally made from materials such as Titanium, Stainless steel Cobalt-Chromium alloys, ect. This study was conducted to evaluate the displacement of anterior teeth when using three different mini-implant materials for direct anchorage in a Finite Element Model.

Methods and Materials: A Cone beam computed tomography (CBCT) of maxillary arch was used to generate a 3 Dimensional model. The position of the mini-implant was planned between the roots of the second premolar and molar to provide anchorage for anterior retraction. The force levels were simulated at 250g per side. Three Finite element models were generated for the use of different mini implant materials- I: Titanium (Ti6Al4V), II: Stainless steel, III: Magnesium alloy (WE43 alloy).

Results: In the sagittal and vertical plane, the greatest anterior tooth movement was seen using Magnesium, followed by Titanium, and least with Stainless steel. In case of posterior teeth, all three groups presented in the same range of minimal movement, in sagittal and vertical planes.

Conclusion: The simulation of retraction of anterior teeth using Finite Element Modelling allows a standardized simulation of biomechanical outcomes. Further clinical and invitro studies can correlate the findings of this simulation.

Keywords: Finite Element Analysis, Orthodontic mini implants, Retraction, Stainless steel, Titanium.

INTRODUCTION

The concept of ‘anchorage’ in orthodontics was first popularized by Edward H Angle.[1] In clinical orthodontics, anchorage is defined as the resistance which the dentofacial structures offer to change in form or position under an applied force. [2] The greatest limitation to orthodontic tooth movement using dentoalveolar anchorage was the tendency of the anchor units to undergo displacement as a result of the applied forces, according to Creekmore and Eklund. [3]

Skeletal anchorage devices have been in use since 1945, when vitallium screws were made by Gainsforth and Higley to provide anchorage for orthodontic traction in dogs. [4] Titanium based screws and plates were introduced by Costa in 1998, for surgical fixation devices. [5] With respect to mini implants for orthodontic anchorage, Kanomi et al., first reported their clinical use[6]. Since their evolution, skeletal anchorage systems have allowed efficient anchorage augmentation for various orthodontic scenarios.

Therapeutic extraction of premolars is commonly used to relieve crowding, followed by retraction of anterior teeth in cases of dental proclination. Anchorage augmentation is essential in such cases to avoid a reciprocal force on the posterior segment, when dentoalveolar components are used as the sources of anchorage [7]. With use of mini implants for anterior retraction, the force is not directly applied on the posterior dental unit and the posterior teeth show lesser tendency for undesired orthodontic anchor loss. In addition, the point and direction of force application can be varied with the placement of the mini implant.[8]

Finite Element Analysis (FEA) breaks down complex structures, like teeth and jaws, into simpler ‘elements’ like PDL, alveolar bone, tooth structure, etc., to allow simulation of the applied forces and predict the possible

behavior of these elements under an applied force, thermal changes, pressure, etc. [9]

Finite Element Models can also be used for a non-invasive and accurate simulation of the biomechanical forces for an orthodontic loading system. The aim of this study was to compare and evaluate the retraction of anterior teeth using three different mini-implant materials when used for direct anchorage in a Finite Element Model.

MATERIALS AND METHODS

Finite Element Modelling was performed under the following steps, in accordance with a study by Ali et al.,:

1. Geometric Modeling
2. Representation of element properties
3. Loading and evaluation of stress distribution [10]

1. Geometric modeling:

Any patient undergoing orthodontic treatment with 0.022" x 0.028" prescription pre-adjusted edgewise appliance, with extraction of upper 1st premolars was eligible for modelling the maxillary elements. A Cone Beam Computed Tomography (CBCT) was recorded at the end of the leveling and aligning stage, on a 0.019" x 0.025" Stainless Steel arch wire, and a 3-dimensional maxillary bone model was generated. Stereolithography model (STL) of an orthodontic mini implant measuring 1.3mm diameter and 8mm in length was used for this study.[11] Geometric modeling of the components was done using Analysis system software (ANSYS). The number of nodes generated is summarized in Figure 1.

Node and Element Details for Model Setup		
Name	**No. of Nodes**	**No. of Elements**
Maxila Bone	381492	1757991
Teeth	239084	1102363
PDL	35337	69559
Bracket & Wire	146038	106566
Screw	155772	731490
Total	957723	3767969

Figure 1a. Various elements and nodes used for Geometric modeling on ANSYS.

2. Representation of element properties

The average thickness of the Periodontal Ligament (PDL) was set at 0.25mm. The apico-gingival height of the maxillary alveolar bone was averaged at 14mm. The element properties are summarized in Figure 2.

3. Loading and evaluation of stress distribution:

Following the generation of 3D maxillary and mini-implant models, the implant placement was simulated at a height of 9mm from the arch wire between the 2nd maxillary premolar and 1st permanent molar. Retraction hooks were positioned at a height of 4mm from the arch wire, between the lateral incisor and maxillary canine. Retraction of the anterior segment was simulated using a NiTi coil spring from the anterior hook to the mini-implant with an average force of 250g/ side. (Figure 3) Evaluation of en masse retraction was performed using three different orthodontic mini-implant materials:

I: Titanium alloy (Ti6Al4V)

II: Stainless steel

III: Magnesium alloy (WE43 alloy)

Table of Material Properties		
Name	**Young's Modulus (Mpa)**	**Poisson's Ratio**
Maxila Bone	2000	0.3
Teeth	20000	0.3
PDL	5	0.3
Bracket & Wire	200000	0.3
TI Screw	110000	0.31
SS Screw	190000	0.265
MG Screw	44200	0.27

Figure 2. Coating of Mg alloy with Chitosan-Bioactive Glass at 0.10V, 0.05A.

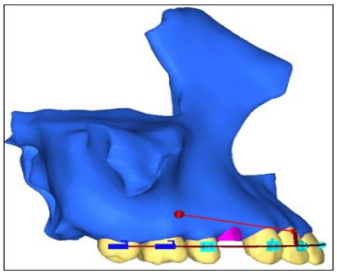

Figure 3. Simulation of mini-implant placement and loading for anterior retraction.

RESULTS

Based on the abovementioned properties of the elements, three Finite Element Models were generated to simulate the en masse retraction of anterior teeth using: Titanium, Stainless steel, and Magnesium mini-implants. (Figure 4a-d) Results were represented in Y and Z axis, where Y and Z axis represented movements in the sagittal and vertical plane respectively. Positive value indicated distal movement in Y axis and the upward movement in Z axis. The negative value indicated mesial movement in Y axis and downward movement in Z axis.

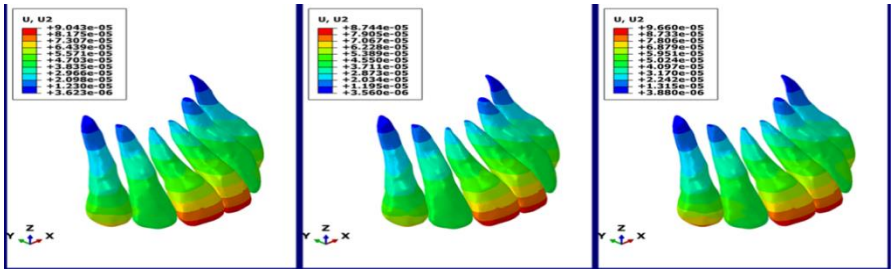

Figure 4a. Simulation of anterior teeth retraction in the sagittal plane using three mini-implant materials. (Titanium, Stainless steel, Magnesium)

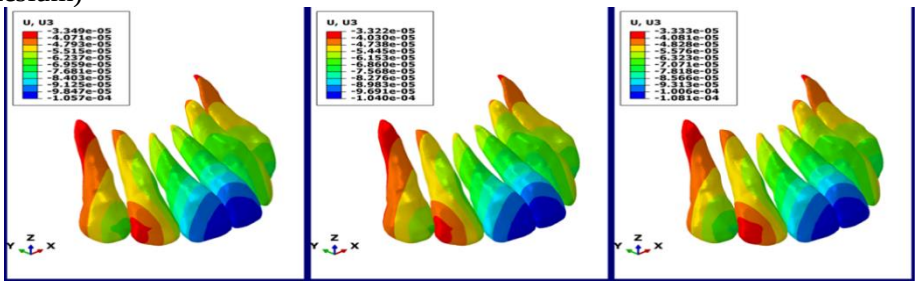

Figure 4b. Simulation of anterior teeth retraction in the vertical plane using three mini-implant materials. (Titanium, Stainless steel, Magnesium)

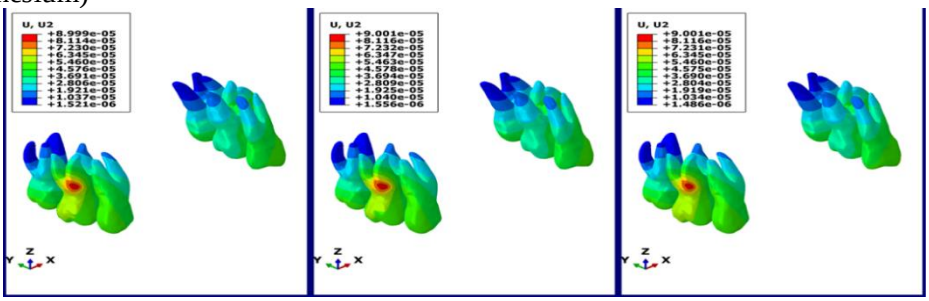

Figure 4c. Simulation of posterior teeth retraction in the sagittal plane using three mini-implant materials. (Titanium, Stainless steel, Magnesium)

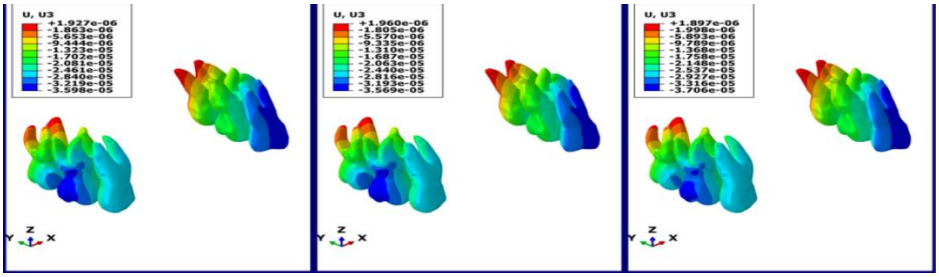

Figure 4d. Simulation of posterior teeth retraction in the vertical plane using three mini-implant materials. (Titanium, Stainless steel, Magnesium)

DISPLACEMENT OF POSTERIOR TEETH:

The posterior teeth were simulated as anchor units and the displacement in these segments was also evaluated to assess potential for anchor loss.

In the **sagittal** plane, the **posterior** teeth showed similar displacements, with Magnesium and Stainless steel causing 90.01µm movement, and Titanium causing 89.99µm movement.

In the **vertical** plane, **posterior** tooth movement was greatest with Magnesium (-37.06µm), followed by Titanium (-35.98µm), and least in Stainless Steel (-35.69µm).

DISCUSSION

Mini implants have revolutionized the field of orthodontics with their versatility in clinical application, ease of use, and non dependance on patient compliance, while optimizing anchorage control.[12,13] These devices, which offer absolute anchorage, are mainly mechanically retained by the surrounding bone and are retrieved after their period of intended use.[14] An understanding of the surface stresses produced on a mini-implant and in the local peri-implant bony tissue is required for ideal biomechanical placement and planning the application of force from the orthodontic mini implant can be optimized to reduce clinical loss of anchorage. [15]

Finite element analysis has become a popular method of simulation to predict the behaviour of various biomechanical models under various forces. Evaluating the available numerical and experimental data on orthodontic mini implants, Chatzigianni et al. suggested that Finite Element Studies offer a possible alternative to experimental procedures in simulation and prediction of clinical scenarios.[16] Lin et al., studied the association between the mini implant-bone interface and suggested a positive correlation between the length of exposed orthodontic implants and the resultant stress on their surfaces.[17] Lee et al., demonstrated that a greater mini implant diameter and taper suggested a higher microdamage to the local cortical bone. [18]

This study compared the bone stresses using three different implant materials- Titanium, Stainless steel, and Magnesium- of which Titanium and Stainless steel are used for the commercial manufacture of orthodontic implants. [19] With use of these conventional mini implant materials, studies have reported a mismatch in the mechanical properties between that of human cortical bone and the implant material- resulting in a stress shielding effect of bone. This reduces the load stimulation of the local peri-implant bone, producing a more porous and compromised architecture of newly formed bone.[20] Magnesium (WE43 alloy) based fixation devices are being studied extensively in mandibular fracture

fixation for their superior biocompatibility and characteristic resorptive properties when placed in biologically active tissue. [21] In addition, Magnesium has a Young's Modulus similar to that of human adult cortical bone (cortical bone ~25 GPa, Magnesium ~44 GPa, Titanium ~110 GPa) - making it the material of choice in this Finite Element Analysis. [22]

The results of our study demonstrate a greater bone stress with use of Magnesium based orthodontic implants, followed by Stainless steel, and Titanium. This correlates with the 'stress shielding effect' and mismatch between the material properties of non resorbable conventional implants and human bone. Conversely, a higher implant surface stress was observed in Titanium, followed by Stainless steel and least in Magnesium. Clinically, these factors can play a role in determining the fracture of various implant materials during insertion and implant retrieval procedures.[23]

CONCLUSION

The results of our study provide a simulation for the biomechanical outcomes using different orthodontic implant materials. Further in vitro evaluation of the material properties should be tested for various implant designs to correlate the outcomes. Clinical evaluation of commercially available Stainless steel and Titanium is essential to establish a reference for newer mini implant materials like Magnesium.

DECLARATIONS

No funding was received from any financially supporting body.

Consent for publication

Informed consent was obtained from every participant for documentation and examination.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was granted by the Institutional Human Ethical Committee

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