# EFFECTIVE EN-MASSE RETRACTION OF MAXILLARY DENTITION WITH TUBEROSITY MINI-IMPLANT ANCHORAGE: A FINITE ELEMENT ANALYSIS

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# CERTIFICATE

This is to certify that this dissertation titled **"EFFECTIVE EN-MASSE RETRACTION OF MAXILLARY DENTITION WITH TUBEROSITY MINI-IMPLANT ANCHORAGE: A FINITE ELEMENT ANALYSIS"** is a bonafide record of work done by **DR. N.MANIKANDAN** under my guidance during his postgraduate study period between 2010–2013.

This dissertation is submitted to **THE TAMIL NADU Dr. M.G.R. MEDICAL UNIVERSITY**, in partial fulfillment for the degree of **Master of Dental Surgery in Branch V – Orthodontics and Dentofacial Orthopedics**. It has not been submitted (partially or fully) for the award of any other degree or diploma.

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# CONTENTS

ABSTRACT

In the end of 90’s the adoption of mini-implants as anchorage allowed a paradigm change influencing even the way of thinking orthodontic mechanics. Currently, mini-screw implants or temporary anchorage devices TADs are considered versatile as it can be used clinically as an absolute source of anchorage. Recently, there has been revitalization for the en masse retraction of maxillary dentition which has various advantages over molar distalization followed by anterior retraction. Thus the entire maxillary dentition when distalized as a single unit with mini-implants as a source of anchorage using sliding mechanics would serve as a viable option in overcoming the adverse effects of distalizing appliances and provides better patient comfort. Since Modern medical imaging, modeling, and finite element (FE) analysis solutions can provide powerful tools for optimizing 3-dimensional morphology from radiographic scans and determining stress and deflection distributions for complex anatomic geometries is possible, thus the reactions of teeth and their supporting tissues on application of orthodontic forces would warrant to predict the clinical situation efficiently.

Therefore the aim of the present study was to investigate effectiveness of 19 x 25-in stainless steel archwire with retraction hooks of various heights placed in a 0.022 x 0.028-in slot for en-masse retraction of maxillary dentition using tuberosity implants by finite element method.

**Keywords**: En- masse retraction; Absolute anchorage; Tuberosity implant, FEM.

# INTRODUCTION

Facial and smile attractiveness play a key role in social interaction.[84] An esthetic smile is comprised of proper tooth alignment, inclination and symmetric dental arch.

Opinions to extract or not to extract have changed remarkably over the years. The major consideration in this decision relates to management of crowding/protrusion and the possibility of camouflaging skeletal problems.

Anchorage control plays a pivotal role in the effective management in orthodontic patients for obtaining both structural and facial esthetics.[51] Conventionally head gear and Intermaxillary elastics have been used when anchorage conservation has been a challenge in orthodontics.[73] However due to the reported disadvantage of this methods and difficulty in obtaining patient compliance, the advent of mini implants for group distal movements of entire maxillary teeth may be required in certain situations without the need for premolar extractions.

Difficult tooth movement which includes molar distalization and en-masse retraction of the entire maxillary arch in cases of mild to moderate arch length discrepancies with implants placed in the tuberosity region have gained importance in recent past. Mini-implants placed in maxillary tuberosity region propose bio-mechanical advantage to treat certain malocclusion. Inspite of compromised bone quality, good results can be achieved if proper protocol is followed in terms of both miniscrew placement and biomechanics.[73]

Literature search on such treatment methodology using mini implants on the tuberosity region for en-masse retraction of the whole dentition is scant. Thus before clinical implication on patients a situation that would simulate the maxillary dento-alveolar structures - invitro for the purpose of studying the effectiveness of such modality would serve as a proper guide to be relied upon invivo studies.

In the last decade the application of a well proven predictive technique, originally used in structural analysis, the Finite element method (FEM) has revolutionized dental biomechanical research.[86] Thus a model derived from the CT of a human with maxilla and whole dentition intact with the cranial base was taken and implants were placed in the tuberosity region to simulate treatment mechanics.

**Therefore the aim of the present study was to investigate effectiveness of 19 x 25-in stainless steel archwire with retraction hooks of various heights placed in a 0.022 x 0.028-in slot for en-masse retraction of maxillary dentition using tuberosity implants by finite element method.**

# REVIEW OF LITERATURE

Literature has been reviewed under the following headings:

I. FEM STUDIES IN ORTHODONTICS

II. IMPLANTS USED IN RETRACTION, MOLAR DISTALIZATION

## I. FEM STUDIES IN ORTHODONTICS:-

**Moss et al (1985)**[55]used finite element for the development of a new and potentially clinically useful method for describing craniofacial growth. In practice, the FEM permits analysis of the skull at a scale significantly finer than previously possible, by considering cranial structures consisting of a relatively large number of contiguous finite elements.

**Tanne et al (1987)**[74] investigated the stress levels induced in the periodontal tissue by orthodontic forces using the three-dimensional finite element method and concluded that during tipping movement, stresses non-uniformly varied with a large difference from the cervix to the apex of the root.

**Tanne et al (1989)**[36] investigated the biomechanical effect of protractive maxillary orthopaedic forces on the craniofacial complex by using three dimensional finite element method (FEM). An anteriorly directed 1.0kg force was applied on the buccal surfaces of the maxillary first molars is both horizontal direction and a 30° obliquely downward directions to the functional occlusal plane. Results showed only downward protraction force produced uniform stress distribution.

**Haskell et al. (1990)**[6] employed finite element analysis with ANSYS (version 4.3) to modify and refine the designs of maxillary and mandibular springs for space closure management. Elgiloy retraction spring model in the edgewise mode were developed so that the effects of three different pre-activation bends could be refined by computer analysis. sixty-four analyses were performed for each spring, with each three-angle bends varied from 0° to 45° in 15° increments. The employment of this computer method promises to simplify the design and development of complex interacting orthodontic systems.

**Anderson et al. (1991)**[1] studied material parameters and stress profiles within periodontal ligaments with the use of finite element model. Levels and profiles of initial stress in the periodontal ligament after application of various force systems were studied. Two finite element models based on sections of human autopsy material were developed to simulate one full and one partial mandible.

Results showed that there was a marked variation in the stress distribution from cervix to apex when tipping were applied. Bodily movement of the tooth produced a uniform stress distribution; root movement produced stress patternsopposite to those observed during tipping; and masticatory forcealone produced stress pattern almost identical to those achieved by masticatory force in combination with orthodontic forces.

**Tanne et al (1991)**[74] investigated the nature of initial tooth displacements associated with varying root lengths and alveolar bone heights. The results showed that moment-to-force values at the bracket level for translation of a tooth decreased with shorter root length and increased with lower alveolar bone height. In addition, apico-gingival levels of the center of resistance shifted more gingivally to the cervix, or the alveolar crest with a shorter root.

However, the relative distances of the centers of rotation from the alveolar crest in comparison with the alveolar bone heights were constant at 0.4 mm, with variations in the root length and alveolar bone height. Because this study showed that root length and alveolar bone height affect the patterns of initial tooth displacements both in the center of resistance and the centers of rotation and also in the amount of displacement, forces applied during orthodontic treatment should take into consideration the anatomic variations in the root length and alveolar bone height so as to produce optimal and desired tooth movement.

**McGuinness et al (1992)**[52] conducted a finite element analysis (FEA) to determine the stress induced in the periodontal ligament in 3 dimensions when a maxillary canine tooth is subjected to and orthodontic force similar to that produced by an edgewise appliance. The findings suggested that even with the perfect edgewise mechanics it would be difficult to obtain canine movement by pure translation or bodily movement.

**Cobo et al (1993)**[16] determined the stress that appears in tooth, periodontal ligament and alveolar bone, when a labiolingual force of 100 gm is applied in a labiolingual direction in a midpoint of the crown of an inferior digitalized canine, and its changes depending on the degree of loss of the supporting bone. After applying the labiolingual force in the canine, a progressive increase of the stress in the labial and lingual zones of the tooth, periodontal membrane and alveolar bone was observed when the alveolar bone was reducing. In the mesial and distal zones, no compensating forces appeared which could provoke a tooth rotation during the tipping movements.

**Tanne et al. (1987)**[73] investigated stress distribution in maxillary complex using FEM model. A posteriorly directed force of 1.0kg was applied to the maxillary first molars in the directions parallel and 30° inferior to the occlusal plane. Results showed that the maxillary complex exhibits postero-inferior displacement with clockwise rotation from the horizontal headgear force. This becomes more prominent as the direction of force becomes more inferior.

**Rinaldi (1995)**[76] used finite element method instead of conventional bench studies to the new spring (space closure) design. Results showed that this spring mechanism has eliminated a significant portion of the geometric non-linearity by using force application devices (activators) such as elastics or coil springs as the means of activation. By selecting the right activator it may be possible to close the entire extraction site.

**Puente et al (1996)**[63] analyzed the distribution of the stress on dental and periodontal structures when a simple tipping dental movement or torque movement is produced. A tridimensional computer model based on finite element techniques was used for this purpose. The model of the lower canine was constructed on the average anatomical morphology and 396 isoparametric elements were considered. The three principal stresses (maximum, minimum and intermediate) and Von Mises stress were determined at the root, alveolar bone and periodontal ligament (PDL). It was observed how the distribution of stress is not the same for the three structures studied. In all loading cases for bucco-lingually directed forces, the three principal stresses were very similar in the PDL. The dental apex and bony alveolar crest zones are the areas that suffer the greatest stress when these kind of movements are produced.

**Bobak et al. (1997)**[84] and his co-workers studied the effects of transpalatal arch (TPA) on periodontal stresses of molars that were subjected to typical retraction forces, with the use of FEM. A finite element model, consisting of two maxillary first molars, their associated periodontal ligaments, alveolar bone segments and a TPA was constructed.

Results showed that the presence of TPA has no effect on molar tipping and decrease the molar rotations and affects periodontal stress magnitudes by less than 1%. The final results suggest an inability of the TPA to modify orthodontic anchorage through modification of periodontal stresses.

**Chen et al (1999)**[11] conducted a coordinated histomorphometric and 3D FEA to investigate the mechanical environment of cortical bone adjacent to the threads of a retromolar endosseous implant, used for orthodontic anchorage to mesially translate mandibular molars in response to normal functional loading. A 3D model of the mandible and the retromolar implant with the surrounding cortical bone were modeled. A strong stress pattern change was found immediately around the implant, which was reflected by a moderate change of stresses between the threads and a significant increase in stress at the tips of the threads.

**Rudolph et al (2001)**[65] conducted a study to determine the types of orthodontic forces that cause high stress at the root apex. The material properties of enamel, dentin, PDL, and bone and 5 different load systems (tipping, intrusion, extrusion, bodily movement, and rotational force) were tested. The finite element analysis showed that purely intrusive, extrusive, and rotational forces had stresses concentrated at the apex of the root. The principal stress from a tipping force was located at the alveolar crest. For bodily movement, stress was distributed throughout the PDL; however, it was concentrated more at the alveolar crest. They conclude that intrusive, extrusive, and rotational forces produce more stress at the apex. Bodily movement and tipping forces concentrate forces at the alveolar crest, not at the apex.

**Va´squez M et al (2001)**[54] conducted a 3-D FEA to evaluate the initial stress differences between sliding and sectional mechanics with an endosseous implant as anchorage. A mathematical model was constructed that used the finite element method, which simulated an endosseous implant and an upper canine with its periodontal ligament and cortical and cancellous bone. Levels of initial stress were measured during 2 types of canine retraction mechanics (friction and frictionless). The lower magnitude and more uniform stresses in the implant and its cortical bone were found to have a moment-force ratio (M/F) of 6.1:1, whereas the canine and its supporting structures exerted a M/F ratio of 10.3:1. On the basis of these results, they concluded that when the anchor unit is an endosseous implant, it was better to use a precalibrated retraction system without friction (T-loop) where a low load-deflection curve would be generated. Overall, the area with the highest stress was the cervical margin of the osseointegrated implant and its cortical bone. These stresses are of such low magnitude that they are unable to produce a permanent failure of the implant.

**Gallas et al. (2005)**[20] performed a FE model of an endosseous implant and its surrounding osseous structure and found out that the highest stress when the implant is used for orthodontic anchorage was located in the cervical margin.

**Kojimaa et al (2005)**[41] discussed a method that allowed the simulation of more complex tooth movements. A 3-dimensional finite element method was used to simulate the orthodontic tooth movement (retraction) of a maxillary canine by sliding mechanics and any associated movement of the anchor teeth. Absorption and apposition of the alveolar bone were produced in proportion to the stress of the periodontal ligament. The canine tipped during the initial unsteady state and then moved bodily during the steady state. It became upright when the orthodontic force was removed. The anchor teeth moved in the steady state and tipped in the mesial direction. The decrease in applied force by friction was about 70%. The tipping of the canine decreased when the wire size was increased or when the applied force was decreased. They suggested that this method might enable one to estimate various tooth movements clinically.

**Kojimaa et al (2006)**[42] developed a comprehensive mechanical, 3-dimensional, numerical model for predicting tooth movement. Tooth movements produced by wire bending were simulated numerically. The teeth moved as a result of bone remodeling, which occurs in proportion to stress in the periodontal ligament. With an off-center bend, a tooth near the bending position was subjected to a large moment and tipped more noticeably than the other teeth. Also, a tooth far from the bending position moved slightly in the mesial or the distal direction. With the center V-bend, when the second molar was added as an anchor tooth, the tipping angle and the intrusion of the canine increased, and movement of the first molar was prevented. When a wire with an inverse curve of spee was placed in the mandibular arch, the calculated tendency of vertical tooth movements was the same as the measured result. In these tooth movements, the initial force system changed as the teeth moved. Tooth movement was influenced by the size of the root surface area. Concluded, that tooth movements produced by wire bending could be estimated.

**Kojima et al (2006)**[41] studied the combined effect of friction and an archwire's flexural rigidity on canine movement in sliding mechanics, and to explain how to select a suitable archwire and force level for efficient bodily movement. As the frictional force decreased, both the net force acting on and the moving speed of the canine increased. The elastic deformation of the archwire increased, and the moving pattern of the canine changed from bodily movement to tipping, although there was no clearance between the archwire and the bracket slot. When a light wire was used, wire deformation increased, and the canine experienced greater tipping.

**Ulusoya et al (2008)**[77] evaluated the effects of the Class II activator and the Class II activator high-pull headgear (HG) combination on the mandible with 3-dimensional (3D) finite element stress analysis. To investigate the effects of the Class II activator, a 3D model of the lower part of this appliance was constructed and fixed on the mandibular model. The Class II activator high-pull headgear model was established as described, and an extraoral traction force of 350 g was directed from the middle of the Class II activator to the top of the mandibular condyle. The stress regions were studied with the finite element method. The regions near the muscle attachment areas were affected the most. The inner part of the coronoid process and the gonial area had the maximum stress values. Therefore, both functional appliances can cause morphologic changes on the mandible by activating the masticatory muscles to change the growth direction.

**Holberg et al (2008)**[28] analyzed the strains induced in the sutures of the midface and the cranial base by headgear therapy involving orthopedic forces. A finite element model of the viscerocranium and the neurocranium was used. The magnitude and the distribution of the measured strains depended on the level and the direction of the acting force. Overall, the strain values measured at the sutures of the midface and the cranial base were moderate. The measured peak values at a load of 5 N per side were usually just below 20µ strain irrespective of the force direction. A characteristic distribution of strain values appeared on the anatomical structures of the midface and the cranial base for each vector direction. The measurements based on the finite element method provided a good overview of the approximate magnitudes of sutural strains with orthopedic headgear therapy. The signal arriving in the sutures is apparently well below threshold, since the maximum measured strains in most sutures were about 100 fold lower than the minimal effective strain. A skeletal effect of the orthopedic headgear due to a mechanical effect on sutural growth cannot be confirmed from these results. They concluded that the good clinical efficacy of headgear therapy with orthopedic forces is apparently based mainly on dentoalveolar effects, whereas the skeletal effect due to inhibition of sutural growth is somewhat questionable.

**Provatidis et al (2008)**[62] did a finite element model (FEM) of a dry human skull with the RME appliance cemented in place in order to evaluate these effects on the overall craniofacial complex with different suture ossification. The behaviour of the FEM was compared with the findings of a clinical study and to an in vitro experiment of the same dry skull. It was found that the maxillolacrymal, the frontomaxillary, the nasomaxillary, the transverse midpalatal sutures, and the suture between the maxilla and pterygoid process of the sphenoid bone did not influence the outcome of RME, while the zygomatico-maxillary suture influenced the response of the craniofacial complex to the expansion forces. Moreover, the sagittal suture at the level of the frontal part of the midpalatal suture plays an important role in the degree and manner of maxillary separation.

**Gautam et al (2009)**[23] evaluated biomechanically the displacement patterns of the facial bones in response to different headgear loading by using a higher-resolution finite element method model than used in previous studies. Different headgear forces were simulated by applying 1 kg of posteriorly directed force in the first molar region to simulate cervical-pull, straight-pull, and high-pull headgear. The distal displacement of the maxilla was the greatest with the straight-pull headgear followed by the cervical-pull headgear. The high-pull headgear had better control in the vertical dimensions. The center of rotation varied with the direction of headgear forces for both the maxilla and the zygomatic complex. A potential for chondrogenic and osteogenic modeling exists for the articular fossa and the articular eminence with headgear loading.

**Teasoo kim et al (2010)**[75] used the finite element method to examine the optimum conditions for parallel translation of the anterior teeth under a retraction force. He concluded that the position of the power arm was moved from the incisor to the premolars, the length of the power arm became longer for parallel translation.

**Kojimaa et al (2010)**[88] calculated the long-term tooth movements in en-masse sliding mechanics. Long-term tooth movements in en-masse sliding mechanics were simulated with the finite element method. Tipping of the anterior teeth occurred immediately after application of retraction forces. The force system then changed so that the teeth moved almost bodily, and friction occurred at the bracket-wire interface. Irrespective of the amount of friction, the ratio of movement distances between the posterior and anterior teeth was almost the same. By increasing the applied force or decreasing the frictional coefficient, the teeth moved rapidly, but the tipping angle of the anterior teeth increased because of the elastic deflection of the archwire. Finite element simulation clarified the tooth movement and the force system in en-masse sliding mechanics.

**Yukio kojima (2012)**[87] clarified the relationship between force direction and movement pattern in the extraction space closure with miniscrew sliding mechanics. He concluded that the rotation of the entire dentition was decreased when the power arm was lengthened. The posterior teeth were effective for preventing rotation of the anterior teeth. in cases of the high-position miniscrew, bodily tooth movement was almost achieved. The vertical component of the force produced intrusion or extrusion of the entire dentition.

**Jasmine et al (2012)**[33] evaluated the stress patterns in bone and micro-implant immediately after loading with different insertion angulations of the micro-implant using finite element method. They concluded that the comparison of the maximum von Mises stress in the microimplant showed that, as the insertion angle increased from 30° to 90°, stress decreased. The comparison of the maximum von Mises stress in the cortical bone showed that, as the insertion angle increased from 30° to 90°, stress decreased. The comparison of the maximum von Mises stress in the cancellous bone showed that, as the insertion angle increased from 30° to 90°, little stress was transmitted to the cancellous bone. Microimplants should be placed as perpendicular to the bone as possible for better stability.

## II. IMPLANTS USED IN RETRACTION, MOLAR DISTALIZATION:

**Kim CN (2003)**[38] The purpose of this study was to investigate the micro-implant height and anterior hook height to prevent maxillary six anterior teeth from lingual tipping and extruding during space closure. Bracket was .022" x .028" slot size and attached to tooth surface. Wire was .019" x .025" stainless steel and .032" x .032" stainless steel hook was attached to wire between lateral incisor and canine. The heights of them were 4, 6, 8, 10mm starting from wire. They analyzed initial displacement of teeth by various force application points, applying force of 150gm to each micro-implant and anterior hook. The conclusions of this study are as follows: 1. when the micro-implant height was 4mm and the anterior hook height was 5mm and below, anterior teeth were tipped lingually. When the anterior hook height was 6mm and above, anterior teeth were tipped labially. 2. When the micro-implant height was 6mm and the anterior hook height was 5mm and below, the anterior teeth were tipped lingually. When the anterior hook height was 6mm and above, the anterior teeth were tipped labially. But lingual tipping of anterior teeth decreased and labial tipping increased when the micro-implant height was 6mm, compared with 4mm micro-implant height. 3. When the micro-implant height was 8mm and the anterior hook height was 2mm, the anterior teeth were tipped lingually. When the anterior hook height was 3mm and above, labial tipping movement of the anterior teeth increased proportionally.4. When the micro-implant height was 10mm and the anterior hook height was 2mm and above, labial tipping of the anterior teeth increased proportionally. 5. As the anterior hook height increased, anterior teeth were tipped more labially. But extrusion occurred on canine and premolar area because of the increase of wire distortion. 6. Movement of the posterior teeth was tipped distally during maxillary six anterior teeth retraction using micro-implant because of the friction between bracket and wire.

**Park, Kwon, Sung (2004)**[58] retracted the maxillary and mandibular posterior teeth with microscrew implants (1.2mm in diameter and six to 10 mm long) that were placed into the alveolar bone and used as anchorage. The retraction proceeded without adverse reciprocal effects on the, reactive part of the conventional mechanics, such as premolar extrusion and flaring of the incisors. The anterior crowding was resolved without any deleterious effect on the facial profile.

**Gelgor et al (2004)**[25] investigated (1) the efficiency of intraosseous screws for anchorage in maxillary molar distalization and (2) the sagittal and vertical skeletal, dental, and soft tissue changes after maxillary molar distalization using intraosseous s crew-supported anchorage. Subjects with skeletal Class I, dental Class II malocclusion participated in the study. An anchorage unit was prepared for molar d distalization by placing an intraosseous screw behind the incisive canal at a safe distance from the midpalatal suture following the palatal anatomy. The screws were p laced and immediately loaded to distalize upper first molars or the second molars when they were present. The average distalization time to achieve an overcorrected Class I molar relationship was 4.6 months. The skeletal and dental changes were measured on cephalograms and dental casts obtained before and after the distalization. In the cephalograms, the upper first molars were tipped 8.8° and moved 3.9 mm distally on average. On the dental casts, the mean distalization was five mm. The upper molars were rotated ciistopalatally. Mild protrusion (mean 0.5 mm) of the upper central incisors was also recorded. However, there was no change in overjet, overbite, or mandibular plane angle measurements. In conclusion, immediately loaded intraosseous screw-supported anchorage unit was successful in achieving sufficient molar distalization without major anchorage loss.

**Park, Lee, Kwon (2005)**[59] quantified the treatment effects of distalization of the maxillary and mandibular molars using microscrew implants. The success rate and clinical considerations in the use of the microscrew implants were also evaluated. The maxillary first premolar and first molar, showed significant distal movement, with no significant distal movement of the anterior teeth. The mandibular first premolar and first and second molars showed significant distal movement, but no significant movement of the mandibular incisor was observed. The microscrew implant success rate was 90% over a mean application period of 12.3 6 5.7 months. The results might support the use of the microscrew implants as an anchorage for group distal movement of the teeth.

**Buchter A (2005)**[7] The purpose of this study was to determine the clinical and biomechanical outcome of two different titanium mini-implant systems activated with different load regimens. A total of 200 mini-implants (102 Abso Anchor and 98 Dual Top) were placed in the mandible of eight Göttinger minipigs. Two implants each were immediately loaded in opposite direction by various forces (100, 300 or 500 cN) through tension coils. Additionally, three different distances between the neck of the implant and the bone rim (1, 2 and 3 mm) were used. Clinical implant loosing was only present when load exceeded 900 cN mm. No movement of implants through the bone was found in the experimental groups, for any applied loads .They concluded that the dual Top implants revealed a slightly higher removal torque compared with Absoanchor implants. Based on the results of this study, immediate loading of mini-implants can be performed without loss of stability when the load-related biomechanics do not exceed an upper limit of TM at the bone rim.

**Sugawara J et al (2006)**[68] investigated the amount of distal movement of the maxillary first molars, the type of movement, the difference between actual and predicted amounts of distalization, and the relationship between the amount of distalization and age. Twenty-five non growing patients (22 female, 3 male) successfully treated with the skeletal anchorage system (SAS) were the subjects in this study. The amount and the type of distalization, the difference between predicted and resulting amounts of distalization, and the relationship between the patient's age and the amount of distalization were analyzed with wide-opening cephalometric radiographs. The average amount of distalization of the maxillary first molars was 3.78 mm at the crown level and 3.20 mm at the root level. The amount of distalization at the crown level was significantly correlated with the average value of treatment goals (3.60mm).The maxillary molars were predictably distalized in accordance with the individualized treatment goals without regard to patient age and extraction of the third or second molars. They concluded that SAS is a viable noncompliance modality to move maxillary molars for distally correcting maxillary protrusions and malocclusions characterized by maxillary incisor crowding.

**Kircelli et al (2006)**[40] designed the bone-anchored pendulum appliance (BAPA). A conventional pendulum appliance was modified to obtain anchorage from an intraosseous screw instead of the premolars. The aim of this study was to evaluate the stability of the anchoring screw, distalization of the maxillary molars, and the movement of teeth anterior to maxillary first molars. The study group comprised 10 patients (mean age 13.5+/-1.8years) with Class II molar relationship. A conventional pendulum appliance was modified to obtain anchorage from an intraosseous screw instead of the premolars. The screw was placed in the anterior paramedian region of the median palatal suture. Skeletal and dental changes were measured on cephalograms, and dental casts were obtained before and after distalization. A super Class I molar relationship was achieved in a mean period of 7.0 +/- 1.8 months. The maxillary first molars distalized an average of 6.4 +/- 1.3 mm in the region of the dental crown by tipping distally an average of 10.9 degrees +/- 2.8 degrees. Also, the maxillary second premolar and first premolar moved distally an average of 5.4 +/-1.3 mm and 3.8 +/- 1.1mm, respectively. The premolars tipped significantly distally. No anterior incisor movement was detected. The BAPA was found to be an effective, minimally invasive, and compliance-free intraoral distalization appliance for achieving both molar and premolar distalization without any anchorage loss.

**Sheau Soon Sia (2006)**[67] conducted a study To determine the location of centre of resistance and the relationship between height of retraction force on power arm (power-arm length) and movement of anterior teeth (degree of rotation) during sliding mechanics retraction .The results suggested that different heights of retraction forces could affect the direction of anterior tooth movement. They concluded that the higher the retraction force was applied, the lower the degree of rotation (crown-lingual tipping) would be. The tooth rotation was in the opposite direction (from crown-lingual to crown-labial) if the height of the force was raised above the level of the centre of resistance .During anterior tooth retraction with sliding mechanics, controlled crown-lingual tipping, bodily translation movement, and controlled crown-labial movement could be achieved by attaching a power-arm length that was lower, equivalent, or higher than the level of the centre of resistance, respectively. The power-arm length could be the most easily modifiable clinical factor in determining the direction of anterior tooth movement during retraction with sliding mechanics.

**Y.-C. Tseng (2006)**[10] the aim of this study was to explore the use of mini-implants for skeletal anchorage, and to assess their stability and the causes of failure. Forty-five mini-implant were used in orthodontic treatment. The diameter of the implants was 2 mm, and their lengths were 8, 10, 12 and 14 mm. The drill procedure was directly through the cortical bone without any incision or flap operation. Two weeks later, a force of 100–200 g was applied by an elastometric chain or NiTi coil spring. The average placement time of a mini-implant was about 10–15 min. Four mini-implants loosened after orthodontic force loading. The overall success rate was 91.1%. The location of the implant was the significant factor related to failure. In conclusion, the mini-implants are easy to insert for skeletal anchorage and could be successful in the control of tooth movement.

**Chung.K.R (2007)**[13] this article describes the orthodontic treatment of a 14.5-year-old girl with severe bidentoalveolar protrusion. Specially designed sandblasted, large-grit, acid-etched (SLA) orthodontic microimplants (C-implants, C-implant Co, Seoul, Korea) were placed in the alveolar bone in all 4 quadrants to provide anchorage for en-masse retraction without the help of banded or bonded molars. The osseointegration potential of these microimplants allows them to resist rotational force moments and control 3-dimensional movements of the anterior teeth during retraction. Facial aesthetics improved for the patient, fullness of the upper and lower lips was reduced, and the interdental relationship was corrected. Biomechanical considerations, efficacy, and potential complications of the treatment technique are discussed.

**Gelgor, Karaman, and Buyukyilmaz (2007)**[24] compared the effects of 2 distalization systems supported by intraosseous screws for maxillary molar distalization. Subjects were divided into group I and group 2. An anchorage unit was prepared by placing an intraosseous screw in the premaxillary area of each subject. To increase the anchorage in group 2, we used an acrylic plate resembling the Nance button around the screw. The screws were placed and immediately loaded to distalize the maxillary first molars or second molars when they were present. Skeletal and dental changes were measured on cephalograms, and dental casts were obtained before and after distalization. The average distalization times were 4.6 months for group 1 and 5.4 months for group 2. On the cephalograms, the maxillary first molars were tipped 9.05° in group 1 and .0.75° in group 2. The mean distal movements were 3.95 mm in group 1 and 3.88 mm in group 2. On the dental casts, the mean distalization amounts were 4.85 mm for group 1 and 3.70 mm for group 2. In group1, the maxillary molars was rotated distopalatally to a moderate degree, but this was not significant in group 2. Mild protrusion of the maxillary central incisors was also recorded for group 1 but not for group 2. However, there were no changes in overjet, overbite and mandibular plane angle measurements for either group. Immediately loaded intraosseous screw-supported anchorage units were successful for molar distalization in both groups. In groups 2, side effects such as molar tipping and rotation were smaller, but distalization times were longer and hygiene was poorer.

**Cornelis MA, De Clerck HJ (2007)**[17] evaluated the effects of maxillary molar distalization in patients treated with a miniplate skeletal anchorage system. Thirty-one miniplates were placed on the infrazygomatic crests of 17 nongrowing patients consecutively selected for Class II treatment with skeletal anchorage. Three weeks after surgery, a 150-g force was applied to distalize the molars. No appliances were placed in the mandible. Models made before treatment and after molar distalization were scanned. Linear measurements were made on the digitized casts. Molar movement was measured on the superimposed maxillary arches before and after distalization, coregistered on the untreated mandibular models. A molar hyper Class I relationship was reached in all patients 7.0 +/- 2.0 months after miniplate loading. The maxillary molars were moved distally a mean distance of 3.27 +/- 1.75 mm. In patients without contact between the maxillary and the mandibular incisors, overjet decreased by 0.99 +/- 1.32 mm. Intermolar width increased by 2.78 +/- 1.38 mm. Maxillary molar distalization with miniplates for skeletal anchorage is an efficient, noncompliance-dependent, and predictable treatment modality for patients with Class II molar relationship.

**Barlow M (2008)**[4] reviewed recent literature to determine strength of clinical evidence concerning the influence of various factors on the efficiency (rate of tooth movement) of closing extraction spaces using sliding mechanics .Of these ten trials on rate of closure, two compared arch wire variables, seven compared material variables used to apply force, and one examined bracket variables. Other articles which were not prospective clinical trials on sliding mechanics, but containing relevant information were examined and included as background information. The results of clinical research support laboratory results that nickel-titanium coil spring produce a more consistent force and a faster rate of closure when compared with active ligatures as a method of force delivery to close extraction space along a continuous arch wire; however, elastomeric chain produces similar rates of closure when compared with nickel-titanium springs. Clinical and laboratory research suggest little advantage of 200 g nickel-titanium springs over 150 g springs. More clinical research is needed in this area.

**Kokitsawat S (2008)**[43] conducted a study to measure the clinical effects associated with miniscrew anchorage used to retract the upper anterior teeth, specifically the positional changes associated with the miniscrews, the upper anterior teeth and the first upper molar. After orthodontic alignment, miniscrews were inserted in the maxillary zygomatic buttresses as anchorage for en masse retraction of the upper anterior teeth. Following premolar extractions, nickel-titanium closed coil springs, stretched between the miniscrews and upper archwire, were used for retraction. Three-dimensional changes in the upper anterior teeth, the upper first molars and the heads of the miniscrews were measured on study models taken before a 300 g force was applied and seven months later, or when retraction was completed if less than seven months. They concluded that miniscrews provide satisfactory anchorage for retraction of the upper anterior segment, but do not remain absolutely stationary under orthodontic loads. Because of coincidental mesial movement of the upper molars, there must be sufficient clearance mesial to the molars to avoid the molar roots contacting the miniscrews.

**Hoste S (2008)**[29] The aims of this review are twofold, firstly, to give an overview of the general and local risk factors when using temporary anchorage devices (TADs) and the prerequisites for placement and, secondly, to illustrate the orthodontic indications of various TADs. They concluded that temporary anchorage devices have a place in modern orthodontics. Careful treatment planning involving radiographic examination is essential. Consultation with an oral surgeon is advisable if a soft tissue flap is required. Excellent patient compliance, particularly avoidance of inflammation around the implant, is an important consideration for successful use of TADs.

**Justen E (2008)**[34] conducted a study to evaluate clinical success and longevity of mini-screws during orthodontic treatment and to assess the patient's opinion. Fifty mini-screws were inserted in the mandible and maxilla of 21 patients with a flapless technique under local anaesthesia. Thirty-three mini-screws (64%) remained stable sufficiently long enough to obtain the effect during the orthodontic movement. The survival was comparable in mandible or maxilla, and not related to the orthodontic forces applied or time of activation of the load. The results do suggest that a waiting period of 1 week before loading improves success, and mini-screws inserted into the anterior region score better also compared to the posterior region. Initial periodontal parameters, which are very important in prognosis of orthodontic treatment, are not influencing the success rate in the examined group. They concluded that the mini-screw implant is an easy and an inexpensive method for temporary anchorage of orthodontic appliances.

**Garfinkle (2008)**[22] conducted a study to determine the success rate , positional stability , and patient evaluation of orthodontic mini-implants(OMI).13 patients were selected .The right and left arch was randomly selected for immediate loading up to 250g of direct force .The contra lateral side was loaded 3-5 weeks later. They found that the combined success rate of loaded OMIs was significantly higher than that of unloaded OMIs. They concluded that OMIs are a predictable, effective and well tolerated anchorage source for adolescents. The orthodontic forces can be applied immediately to OMIs.

**Badris T (2008)**[3] conducted a study to measure and compare the rates of canine retraction with titanium microimplant anchorage and conventional molar anchorage.12 patients were selected. After the levelling and aligning, titanium microimplants 1.2mm in diameter and 9mm in length were placed between the roots of the second premolar and 1$^{st}$ molar in the maxilla and mandible. A brass wire guide and a peri-apical radiograph were used to determine the implant position. After 15 days the implants and the molars were loaded with closed coil springs with a force of 100g for canine retraction. They concluded that the canine retraction proceeds at a faster rate when titanium microimplants were used as anchorage.

**Mimura H**. **(2008)**[52] conducted a study to describe the treatment of severe bimaxillary protrusion with the aid of miniscrews and to discuss the complications encountered during treatment. Following extraction of the four first premolars, miniscrews were placed bilaterally in both jaws to permit maximum retraction of the anterior teeth, and intrusion of the posterior and upper anterior teeth. The mandible rotated forward and upward, the face height reduced and the facial aesthetics improved. During treatment an irregular ridge of bone developed labial to the upper incisors, bone was deposited in the incisive fossae and the apices of the upper incisors were resorbed. They concluded that absolute anchorage provided by miniscrews may become an effective alternative to orthognathic surgery for treatment of severe bimaxillary protrusion. During extensive retraction, the teeth may contact structures not normally encountered during conventional orthodontic treatment.

**Madhur Upadhyay (2008)**[50] conducted a randomized controlled trial to quantify the treatment effects of en-masse retraction of anterior teeth with mini-implants as anchor units in bialveolar dental protrusion patients undergoing extraction of all 4 first premolars. A total of 40 patients were randomly assigned either to group 1 (G1), anterior space closure with mini-implants as anchor units, or group 2 (G2), anterior space closure with conventional methods of anchorage (without mini-implants).Anchorage loss, in both the horizontal and vertical directions, was noted in G2, whereas G1 showed distalization (anchorage gain) and intrusion of molars. They concluded that Mini-implants provided absolute anchorage to allow greater skeletal, dental, and aesthetic changes in patients requiring maximum anterior retraction, when compared with other conventional methods of space closure. The treatment changes were favourable. However, no differences in the mean retraction time were noted between the 2 groups.

**Tae-Woo-Kim (2008)**[39] in their study have used miniscrews for anterior retraction with sliding mechanics. They have found that using conventional anchorage causes the molar to move forward by 3.6-3.8mm and also causes the anterior and posterior segments to rotate around the centre of rotation causing bowing of the archwire. They have suggested that the use of miniscrews produces a force which is not reciprocal hence avoiding the bowing effect .They have also recommended the use of short hooks(2-3mm) on the archwire in open bite cases and long hooks(10mm) for translator movement of anterior teeth.

**Lim and Hong (2008)**[47] described the use of the lever-arm and mini-implant system for controlled distal movement of maxillary molars. Two patients were treated with this system. They concluded that mini implants are needed to control the point of force application in the posterior area with no anchorage loss. When the length of the lever arm and the position of the mini implant are adjusted, the desired line of action of the distal force is determined with respect to the center of resistance of maxillary molars. The lever-arm and mini-implant system is useful not only for absolute anchorage, but also for three-dimensional control during distal movement of the upper molars.

**Papadopoulos (2008)**[57] described the orthodontic treatment of case of a Class II malocclusion, a deep bite, and increased overjet. Initially, an intraoral miniscrew implant supported distalization system (MISDS) was used to distalize the maxillary first molars. Temporary stationary anchorage was provided by 2 miniscrew implants that were placed paramedian in the anterior region of the palate. After distalization, the system was modified slightly by a chair-side procedure and then used to provide the desired stationary anchorage for subsequent anterior tooth retraction in conjunction with conventional full fixed orthodontic appliances. After 18 months of treatment, a Class I molar relationship was achieved, and the deep bite, overjet, posterior intercuspation, and facial esthetics were improved. Biomechanical considerations, clinical efficacy, and the advantages and potential complications of MISDS treatment are discussed. The case report illustrated the use of MISDS to distalize the maxillary molars and retract the anterior teeth, providing noncompliance, nonextraction, and efficient approach for the orthodontic treatment of patients with Class II malocclusion, which is initially invisible.

**Eddie Hsiang-Hua Lai (2009)**[46] conducted a retrospective study on dental models to compare the orthodontic outcomes of maxillary dentoalveolar protrusion treated with headgear, miniscrews, or miniplates for maximum anchorage. The 40 subjects were divided into 3 groups according to the type of anchorage used. The 3D analysis of serial dental models demonstrated that, compared with headgear, skeletal anchorage achieved better results in the treatment of maxillary dentoalveolar protrusion. Greater retraction of the maxillary anterior teeth, less anchorage loss of the maxillary posterior teeth, and the possibility of maxillary molar intrusion all facilitated correction of the Class II malocclusion, especially for patients with a hyperdivergent face.

**Upadhyay M (2009)**[50] conducted a study to examine the skeletal, dental, and soft tissue treatment effects of retraction of maxillary anterior teeth with mini-implant anchorage in non-growing Class II division 1 female patients. Twenty-three patients (overjet > or =7 mm) were selected on the basis of predefined selection criteria. Treatment mechanics consisted of retraction of anterior teeth by placing mini-implants in the interdental bone between the roots of the maxillary first molar and second premolar. The upper anterior teeth showed significant retraction (5.18 +/- 2.74 mm) and intrusion (1.32 +/- 1.08 mm). The upper first molar also showed some distal movement and intrusion, but this was not significant. They concluded that mini-implants provided absolute anchorage to bring about significant dental and soft tissue changes in moderate to severe Class II division 1 patients and can be considered as possible alternatives to orthognathic surgery in select cases.

**Kuroda S (2009)**[45] in this study, they compared treatment outcomes of patients with severe skeletal Class II malocclusion treated using miniscrew anchorage (n = 11) or traditional orthodontic mechanics of headgear and transpalatal arch (n = 11). Both treatment methods, miniscrew anchorage and headgear, achieved acceptable results as indicated by the reduction of overjet and the improvement of facial profile. However, incisor retraction with miniscrew anchorage did not require patient cooperation to reinforce the anchorage and provided more significant improvement of the facial profile than traditional anchorage mechanics (headgear combined with transpalatal arch). They concluded that orthodontic treatment with miniscrew anchorage is simpler and more useful than that with traditional anchorage mechanics for patients with Class II malocclusion.

**Yamada et al (2009)**[85] quantified the treatment effects of interradicular miniscrew anchorage and confirmed the validity of the clinical usage of interradicular miniscrews in the distal movement of maxillary molars in nonextraction treatment. Maxillary molars were moved to the distal using miniscrews placed in the interradicular space between the second premolar and the first molar at an oblique angle of 20 to 30 degrees to the long axis of the proximal tooth. The teeth were evaluated as to how the molars were moved to the distal with the use of lateral cephalograms and dental casts. Maxillary molars were moved to the distal by 2.8 mm with distal tipping of 4.8 degrees and intruded by 0.6 mm. Maxillary incisors were moved to the distal by 2.7 mm with palatal tipping of 4.3 degrees. Molar extrusion and/or consequent mandibular rotation was not observed in any patient. It was concluded that miniscrews placed in the maxillary interradicular space provide successful molar distal movement of 2.8 mm without patient compliance and with no undesirable side effects such as incisor proclination, clockwise mandibular rotation, or root resorption.

**Sia S (2009)**[68] This study was designed to determine the optimum vertical height of the retraction force on the power arm that is required for efficient anterior tooth retraction during space closure with sliding mechanics. Three adults (1 man, 2 women) with Angle Class II Division 1 malocclusions were selected for this study. In each subject, the maxillary right central incisor was the target tooth. The tooth's motion trajectories on the midsagittal plane were studied. The location of the centre of rotation of the target tooth varied according to the different heights of the retraction forces. Controlled anterior tooth movement (ie, lingual-crown tipping, lingual-root movement) can be predicted, simulated, or even manipulated by different heights of retraction forces on the power arm in the sliding mechanics force system. A power arm length of 3 to 5 mm is estimated to produce controlled lingual-crown tipping (with the apex as the centre of rotation) for efficient anterior tooth retraction during sliding space closure in adults with Angle Class II Division 1 malocclusion. They concluded that knowing and applying the correct height of retraction force on the power arm is the key to efficient anterior tooth retraction.

**Chung et al (2010)**[14] illustrated a new treatment system combining segmented wire and Osseo integrated mini-implants for molar distalization without complex appliances. The procedures, advantages, efficacy, and indications for this method are discussed. Two patients whose treatment plans included distal molar movement and orthodontic mini-implant treatment were recruited. One patient required 1 molar to be up righted, and the other needed molar distalization to regain space lost for the missing maxillary right second premolar. C-implants (diameter, 1.8 mm; length, 8.5 mm) were placed and, after 4 weeks of healing, were used as direct anchorage and indirect anchorage simultaneously for correcting the asymmetric Class II molar relationship. Few orthodontic attachments were necessary, and the teeth moved rapidly to the planned positions without detrimental effects on the occlusion. The combination of segmented arch wires, minimum bonded attachments, and a partially osteointegrated mini-implant (C-implant) was a simple and effective treatment choice in distalization treatment.

**Chung et al (2010)**[14] described the concept of relocating orthodontic mini- implants during dental distalization to provide unrestricted distal movement of the full maxillary dentition. The patient was an 18-year old Korean woman with a full-step Class II Division malocclusion and mandibular deficiency. Mini-implants were initially placed bilaterally between the maxillary second premolar and the first molar. Sliding jigs were used to distalize the maxillary first and second molars. After the maxillary molars were distalized to a Class I molar relationship, the mini-implants were removed and immediately relocated distally to provide space for retraction of the anterior teeth. The occlusion was completed with Class I molar and canine relationships with optimal overjet and overbite. The 2-year posttreatment records showed a stable treatment with retention.

**Oh Y-H et al (2011)**[56] quantify the treatment effects of microimplant-aided mechanics on group distal retraction of the posterior teeth. The pretreatment and posttreatment cephalometric radiographs and dental casts of 23 patients (mean age, 22.1 ± 5.17 years), treated with distalization of the posterior teeth against microimplant anchorage and without extraction of the premolars or other teeth except the third molars, were used. The soft-tissue, skeletal, and dental measurements in the vertical and anteroposterior dimensions were analyzed. The changes in interpremolar and intermolar widths and rotations of the molars were analyzed with dental casts. The upper and lower lips were repositioned distally. The Frankfort horizontal to mandibular plane angle was decreased in the adult group. The maxillary posterior teeth were distalized by 1.4 to 2.0 mm with approximately 3.5° of distal tipping, and the mandibular posterior teeth were also distalized by 1.to2.5mm with approximately 6.6° to 8.3° of distal tipping. The maxillary posterior teeth showed intrusion by 1mm. There were increases in arch widths at the premolars and molars. The overall success of microimplants was 89.7%; a well-experienced clinician had a higher success rate (98%) than did novices in this sample. The mean treatment time was 20±4.9months. They concluded that with microimplant- aided sliding mechanics, clinicians can distalize all posterior teeth together with less distal tipping and the technique seems effective and efficient to treat patients who have mild arch length discrepancy without extraction.

**Fudalej P (2011)**[19] Our objective was to perform a systematic review of studies pertaining to the distalization of teeth with appliances reinforced with temporary skeletal anchorage devices. PubMed, Embase, Cochrane

Central Register of Controlled Trials, Web of Knowledge, Ovid and Scopus were searched until the second week of August 2010 to identify all articles reporting on the use of orthodontic implants or miniplates in distalization of teeth. The quality of the relevant studies was ranked on an 11-point scale, from low to high quality. Twelve relevant articles were identified. The distal movement of the maxillary molars was from 3.3 to 6.4 mm; the concomitant molar distal tipping was from 0.80° to 12.20°. The maxillary incisors remained stable during molar distalization. The assessment of study quality showed that 8 studies were of low and 4 of medium quality. They concluded that molar distalizers reinforced with the temporary skeletal anchorage devices seem to effectively move molars distally without unwanted mesial incisor tipping and because of the lack of high-quality studies, however, the findings of this study should be interpreted with caution.

**Choi YJ et al (2011)**[12] was of the view that in nongrowing patients with skeletal Class II malocclusion, premolar extraction or maxillary molar distalization can be used as camouflage treatment. Orthodontic miniscrew implants are widely used for this purpose because they do not produce undesirable reciprocal effects and do not depend on the patient's cooperation. This article reports on maxillary molar distalization by using miniscrew implants to correct a Class II problem. The main considerations of molar distalization treatment with miniscrew implants were discussed.

# MATERIALS ANS METHODS

Computerized Tomography (CT) image acquisition in DICOM (Digital Imaging Communications in Medicine) format was taken for an 18 yr old male patient with class II malocclusion. (GE Healthcare Technologies - Lightspeed VCT, Bharat Scans, Chennai.).

Three dimensional finite element models were created for the following components after scanning them with computed tomography with the slice thickness of 1.5mm.

1. The maxilla with full dentition except for the third molars along with the cranial base.(Fig. I a)
2. Absoanchor miniimplant (Dentos, Taegu, Korea) with the size specification of 1.5mm diameter and 8mm length. (Fig. I b)
3. A standard pre adjusted edgewise bracket, Ovation Roth prescription with the slot size of 0.022"X 0.028". ( Dentsply-GAC USA) (Fig. I c)
4. A stainless steel (SS) archwire of specification 0.019X 0.025 inch, (GAC- USA)
5. (Fig. I d)
6. Nickel titanium tension coil spring with hooks, 12mm in length (GAC, Japan) (Fig. I e)

**MAXILLA WITH CRANIAL BASE**

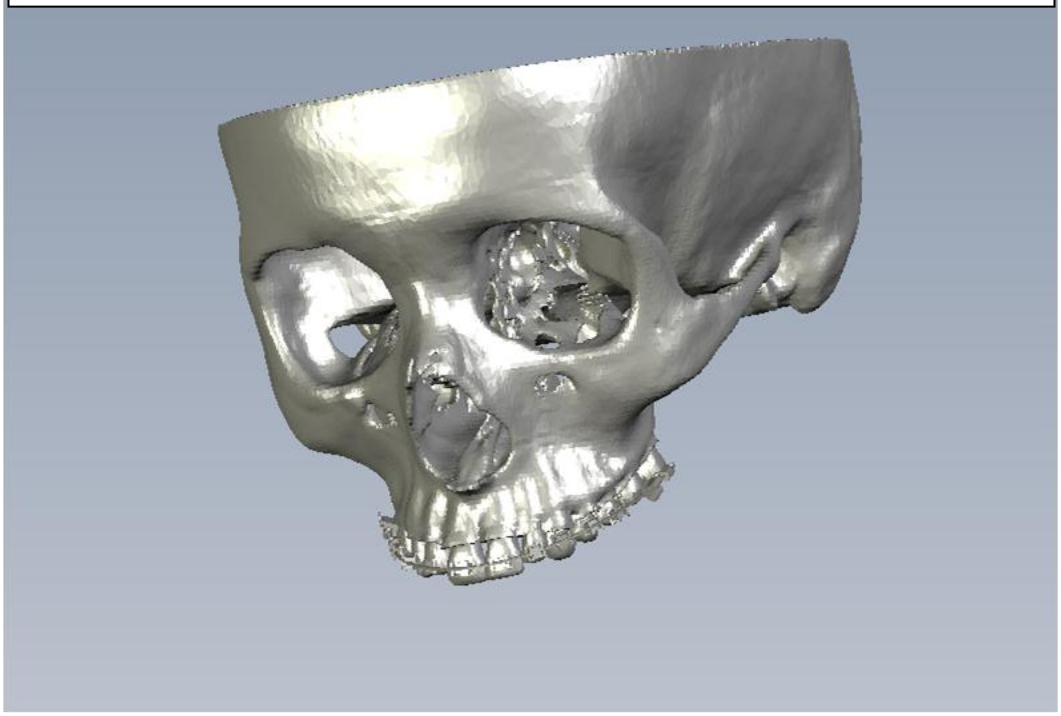


Fig. I a

**MINIIMPLANT**

Diameter-1.5mm ; Length-8mm

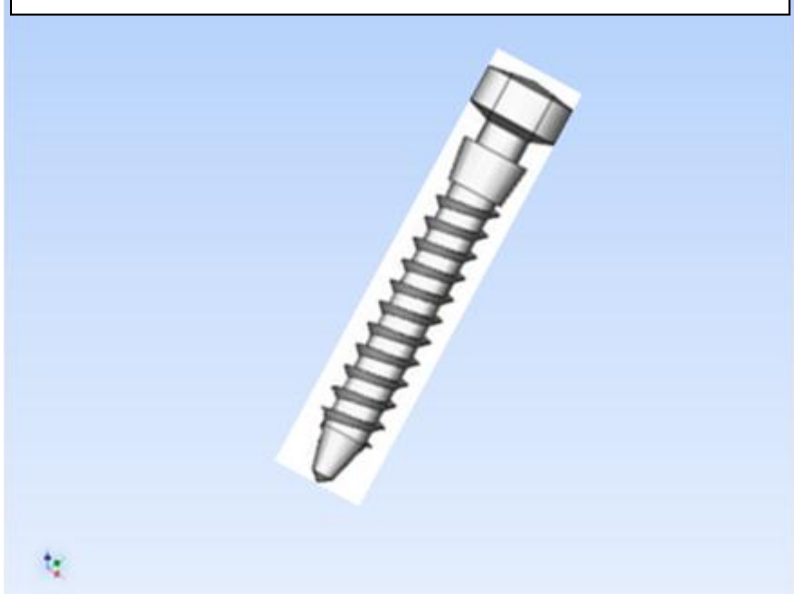


Fig. I b

**0.022'x 0.028'- ROTH PRESCRIPTION BRACKET**

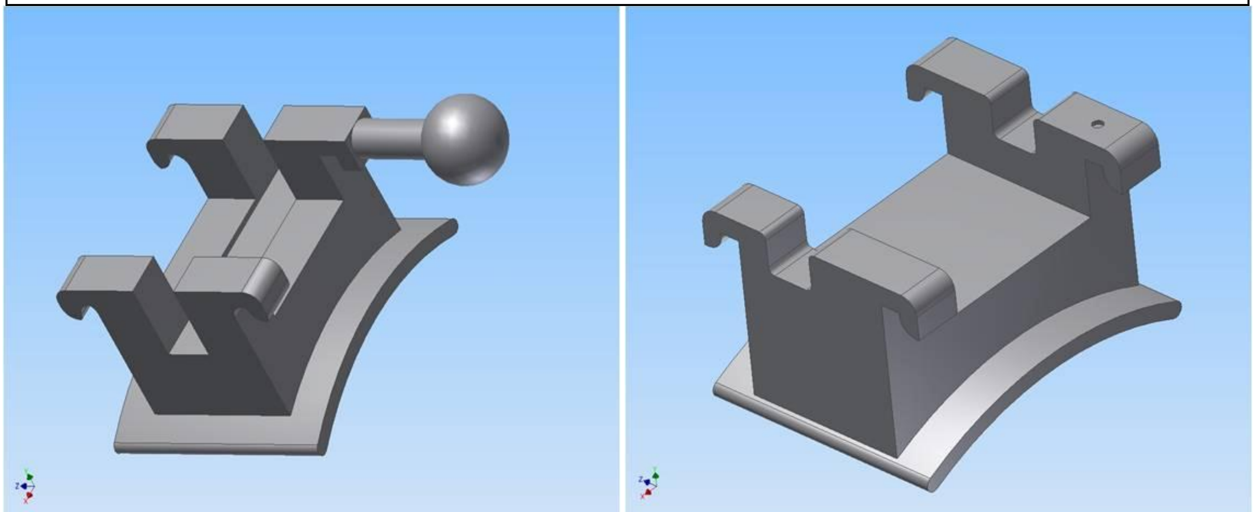


Fig. I c

**ARCHWIRE**

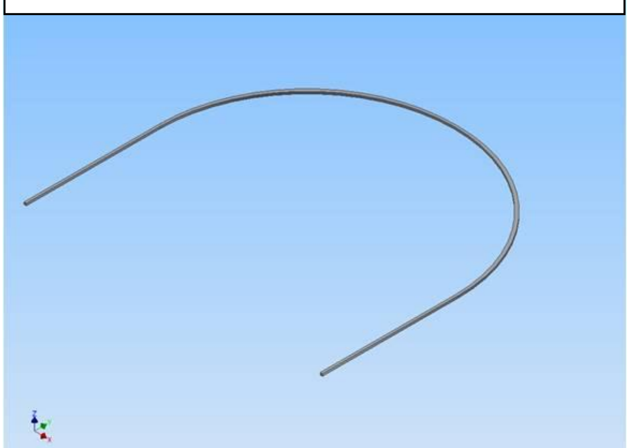


Fig. I d

**NiTi CLOSED COIL SPRING**

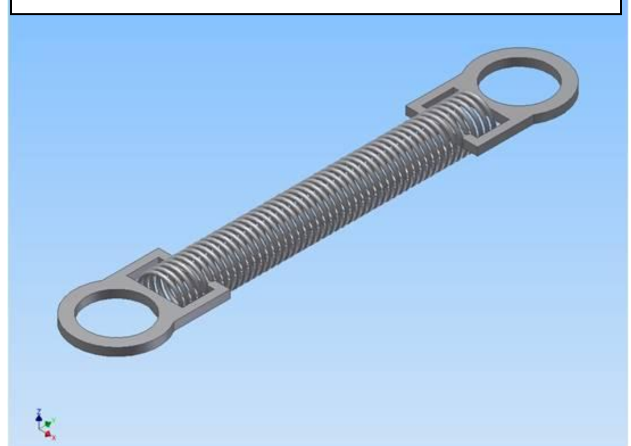


Fig. I e

**MODELING**:

The images were obtained in a **Dicom** (Digital imaging and communication in medicine) data format. The modeling was done using a software called **3-matic** which is a unique software which combines CAD tools with preprocessing (meshing) capabilities. Additionally it is extremely suitable for free form 3D data such as anatomical data resulting from the segmentation of medical images.

The 0.022x 0.028 inch roth prescription bracket was attached to the crown so that the facial axis point was at the center of the bracket slot. The mini implant was inserted at **45º** angulation to the bone surface, **12mm** above from the functional occlusal plane and **7mm** distal to the maxillary second molar in the tuberosity region.

**Construction of archwire:**

The 0.019x 0.025 inch stainless steel archwire with retraction hooks of different sizes were attached at a distance constructed distal to the canine on either side placed gingivally. The constructed archwire was engaged into bracket slot and extended till the distal part of the second molar buccal tube, without cinching.

Thus three different retraction hooks were constructed.

- 0.019x 0.025 inch SS archwire with 2mm retraction hook.
- 0.019x 0.025 inch SS archwire with 5mm retraction hook.
- 0.019x 0.025 inch SS archwire with 8mm retraction hook.

Nickel titanium closed coil spring was stretched across the mini implant and the retraction hook on either side to simulating a force delivery of **270-300 grams** for en-masse retraction of maxillary dentition.

All the modeled images are then assembled together in the assembly model. Once the assemblage is completed it is then exported to an analysis package. The export is through a bidirectionally understandable translator called **IEGS (Initial graphics exchange specification).**

**FINITE ELEMENT ANALYSIS:**

There are several FEA packages like Ansys, Cosmos, Nastran etc., but for the system of large difference in material properties and stiffness, Ansys will be a suitable software. **Ansys** is a finite element analysis (FEA) code widely used in the computer aided engineering (CAE) field. This software allows to construct computer models of structures, apply operating loads and other design criteria and study physical responses such as stress levels, displacement, M/F ratio etc.,

The constructed modeled images of maxillary arch with the skull base and dentition, brackets, archwire, mini implant, Niti closed coil spring were imported to Ansys classic software and relevant material properties were assigned. The material properties required are poisons ratio and young’s modulus of each component as given in the table below.

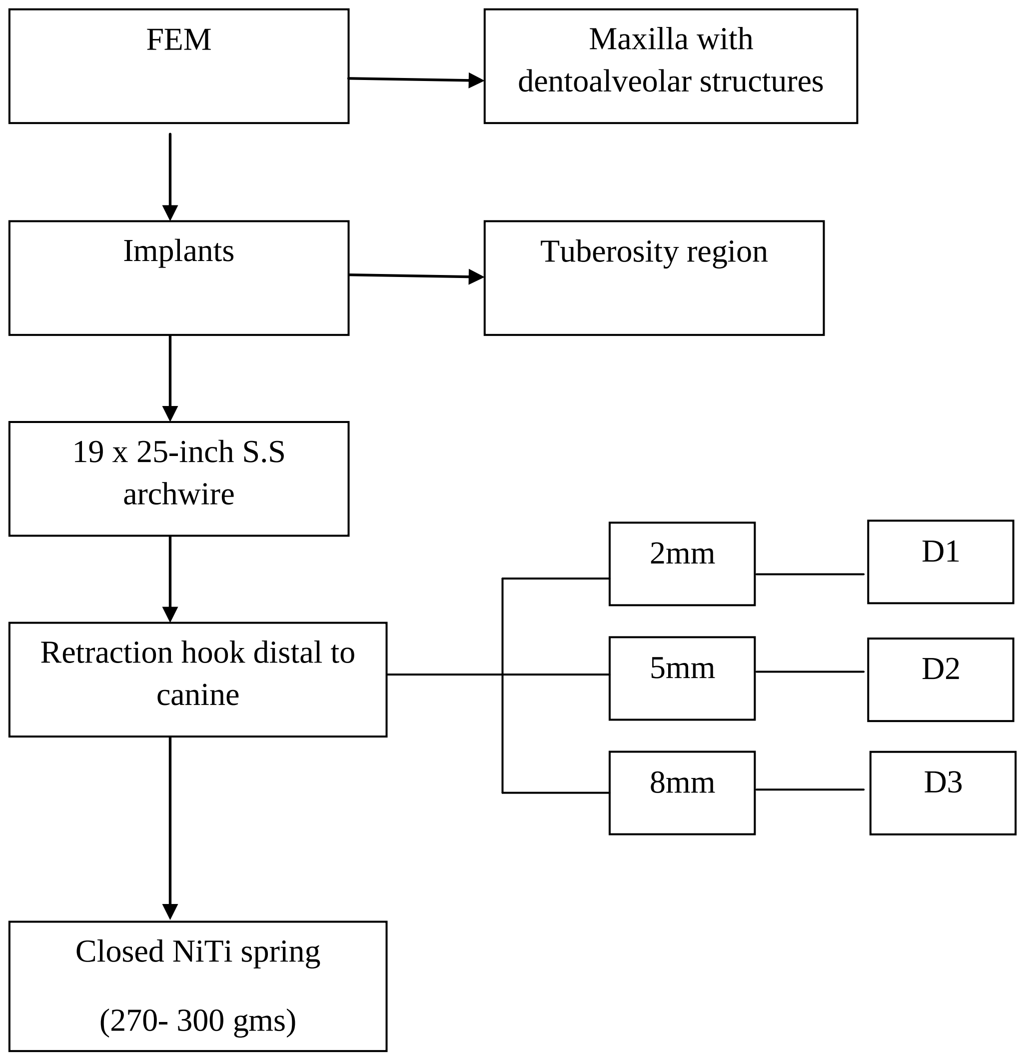
Material properties of various components used in this study:

| MATERIALS | Young's modulus (MPa) | Poisson's ratio |
|---|---|---|
| Tooth | 20,000 | 0.30 |
| Alveolus with maxilla | 13,800 | 0.30 |
| Periodontal ligament | 0.059 | 0.49 |
| Closed coil spring | 110,000 | 0.35 |
| Bracket | 180,000 | 0.30 |
| Mini implant | 110,000 | 0.35 |

Once the images were imported the software can do an automatic meshing with defined material properties, so the models were converted to elements and is essential that these elements are not overlapping but are connected only at the key points, which are termed as nodes. The joining of elements at the nodes and eliminating duplicate nodes is termed as **'Meshing'**. Thus the type of element used is **mid noded tetrahedron** and the total number of **elements and nodes** established in this study are **90791** and **255468** respectively. Once meshing and contacts are defined the next process is to define **boundary conditions**. The nodes present in the periphery of the skull and maxillary tuberosity implant were marked as boundary condition. Once the loads are defined then the problem is solved and the results can be reviewed.

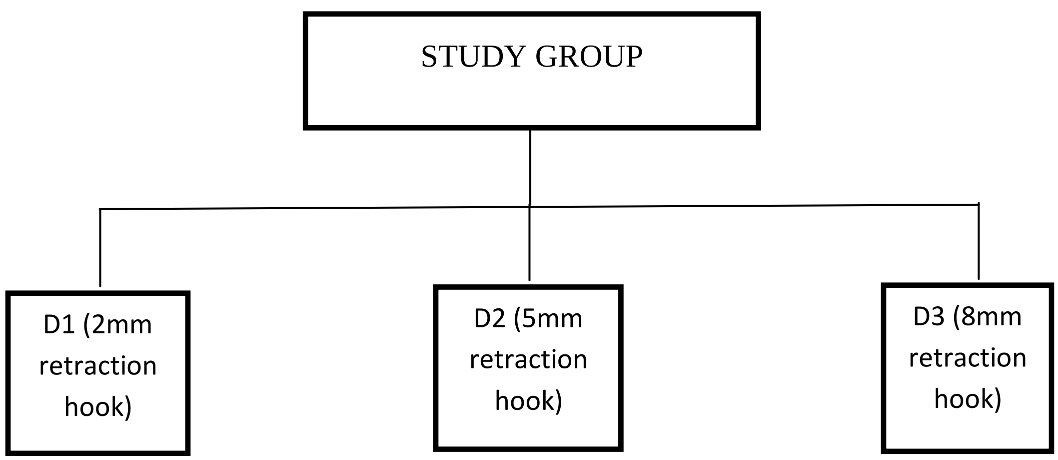
As the three dimensional finite element model of maxilla with dentition and the archwire were obtained, the force distribution, moment to force ratio and the displacement pattern was analysed for 19 x 25-in stainless steel archwire with retraction hook heights of 2mm, 5mm and 8mm. The retraction force was applied bilaterally to the center of mini implant through the closed coil spring to the retraction hook.

# FLOW CHART


FEM
Maxilla with dentoalveolar structures
Implants
Tuberosity region
19 x 25-inch S.S archwire
Retraction hook distal to canine
2mm
5mm
8mm
D1
D2
D3
Closed NiTi spring
(270- 300 gms)

## STATISTICAL ANALYSIS

All statistical analysis was performed by using **SPSS software package** (SPSS for windows XP, version 17.0, Chicago). To evaluate the significance of the individual parameters such as the force and displacement, a one way ANOVA test with 95% confidence interval was performed. Pearson correlation co-efficient test was done for assessing the measure of correlation between the two variables, namely forces acting at the bracket level to the displacement of the tooth. A **P-value** less than or equal to **0.05** was taken as significant.



# RESULTS

Oneway ANOVA presented with 95% confidence interval.

**Force acting on bracket compared between 2mm, 5mm and 8mm retraction hook**

Table 1

| | Group | Mean | Std. deviation | Sig |
|---|---|---|---|---|
| Forces | D1 | 201.1429gms | 57.92935 | 0.657 |
| | D2 | 191.1429gms | 50.46262 | |
| | D3 | 175.7143gms | 45.93370 | |

Results showed that:

- No significant difference between forces acting on bracket were found with 2mm, 5mm and 8mm retraction hook with implant placed in tuberosity region.
- 2mm retraction hook showed an average force level of 201.14.
- 5mm retraction hook showed an average force level of 191.14.
- 8mm retraction hook showed an average force level of 175.71.
- Though there was no significant difference of force acting at the bracket level was found, as the retraction hook height was increased, the forces acting at the bracket level was found to be decreased.

Oneway ANOVA presented with 95% confidence interval.

**Displacement of crown with different retraction hook:**

Table 2

| | Group | Mean | Std. deviation | Sig |
|---|---|---|---|---|
| Displacement on crown | D1 | .317866mm | .3658115 | 0.001 |
| | D2 | .195025mm | .1658357 | |
| | D3 | .026568mm | .0222894 | |

Results showed that:

- Significant difference was found in the crown displacement when compared between three groups.
- The displacement of crown was more in D1 group and least in D3 group.
- The order of increase in crown displacement was found to increase as the retraction hook height decreased.

Oneway ANOVA presented with 95% confidence interval

**Displacement of root with different retraction hook:**

Table 3

| | Group | Mean | Std. deviation | Sig |
|---|---|---|---|---|
| Displacement on root | D1 | .494811mm | .2857225 | 0.216 |
| | D2 | .473220mm | .2727314 | |
| | D3 | .618143mm | .2982533 | |

Results showed that:

- There was no significant difference found in the root displacement between three groups.
- Though there was no significant difference, the displacement of root was more in the D3 group when compared with other two groups.

**Displacement of tooth with different retraction hook:**

Table 4

| | Group | Mean | Std. deviation | Sig |
|---|---|---|---|---|
| Displacement on tooth | D1 | .812677mm | .4381408 | 0.242 |
| | D2 | .668245mm | .2861981 | |
| | D3 | .644711mm | .2913671 | |

Results showed that:

- There was no significant difference found in the total tooth displacement between three groups.
- The order of increase in tooth displacement was found to increase as the retraction hook height decreased.

**Moment: Force**

Table 5

| Group | Moment : Force |
|---|---|
| D1(2mm ARH) | 7.6 : 1 |
| D2(5mm ARH) | 9.9 : 1 |
| D3(8mm ARH) | 11.8 : 1 |

**Comparison of moment: force with different retraction hook height:**

- The moment/force ratio was found to be high in the D3 group
- The moment/force ratio was found to be less in the D1 group
- The order of increase in moment/force ratio was found to increase as the retraction hook height increased.

Table 6

Correlations-D1 group

| Forces acting on | | Displacement of crown |
|---|---|---|
| 2mm retraction hook | Pearson correlation | .081 |
| | Sig.(2-tailed) | .863 |

| Forces acting on | | Displacement of root |
|---|---|---|
| 2mm retraction hook | Pearson correlation | .523 |
| | Sig.(2-tailed) | .132 |

| Forces acting on | | Displacement of tooth |
|---|---|---|
| 2mm retraction hook | Pearson correlation | .374 |
| | Sig.(2-tailed) | .409 |

Correlations-D2 group

Table 7

| Forces acting on | | Displacement of crown |
|---|---|---|
| 5mm retraction hook | Pearson correlation | -.598 |
| | Sig.(2-tailed) | .156 |

| Forces acting on | | Displacement of root |
|---|---|---|
| 5mm retraction hook | Pearson correlation | .597 |
| | Sig.(2-tailed) | .157 |

| Forces acting on | | Displacement of tooth |
|---|---|---|
| 5mm retraction hook | Pearson correlation | .151 |
| | Sig.(2-tailed) | .746 |

Table 8

Correlations-D3 group

| Forces acting on | | Displacement of crown |
|---|---|---|
| 8mm retraction hook | Pearson correlation | -.031 |
| | Sig.(2-tailed) | .947 |

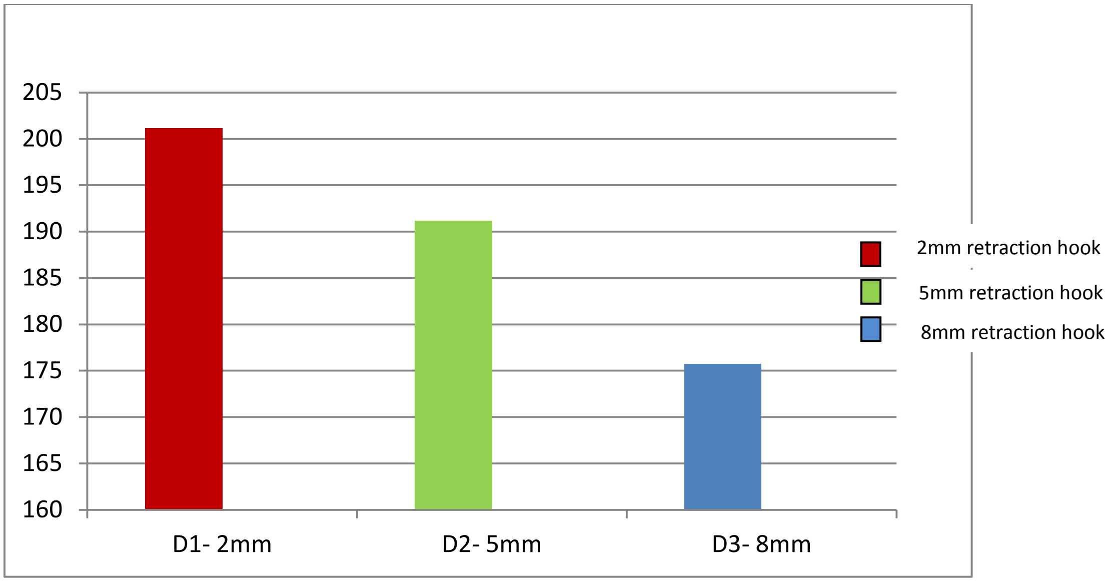
| Forces acting on | | Displacement of root |
|---|---|---|
| 8mm retraction hook | Pearson correlation | .580 |
| | Sig.(2-tailed) | .173 |

| Forces acting on | | Displacement of tooth |
|---|---|---|
| 8mm retraction hook | Pearson correlation | .582 |
| | Sig.(2-tailed) | .170 |

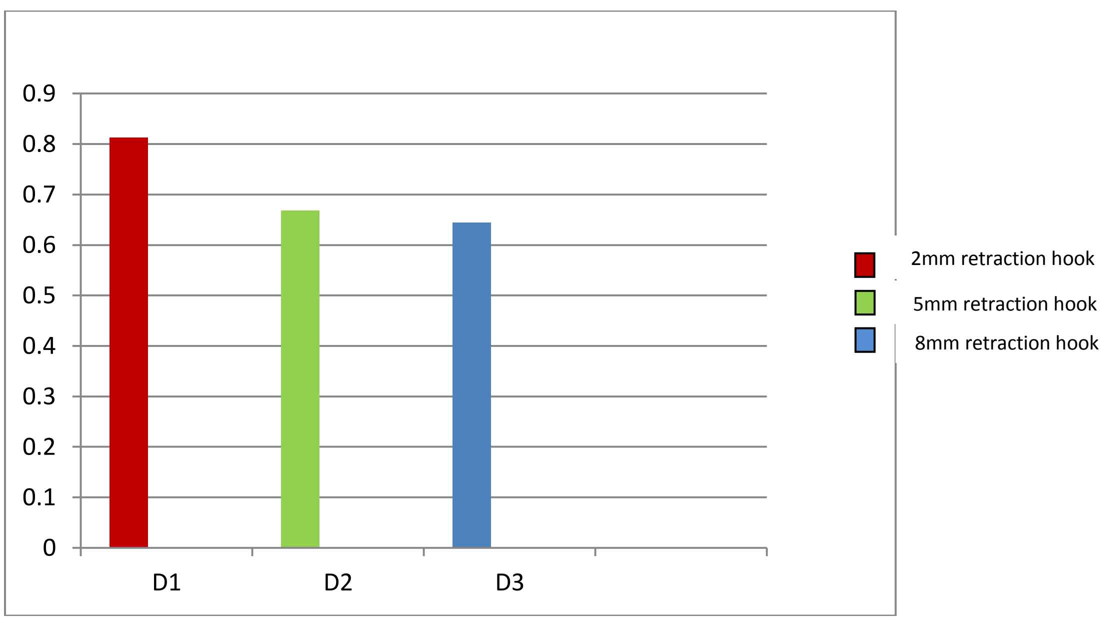
**Inference**

- In D1 group the correlation between displacement of crown and forces showed positive correlation.
- In D2 and D3 group the correlation between displacement of crown and forces showed negative correlation.
- In all groups the correlation between displacement of root and forces showed positive correlation.

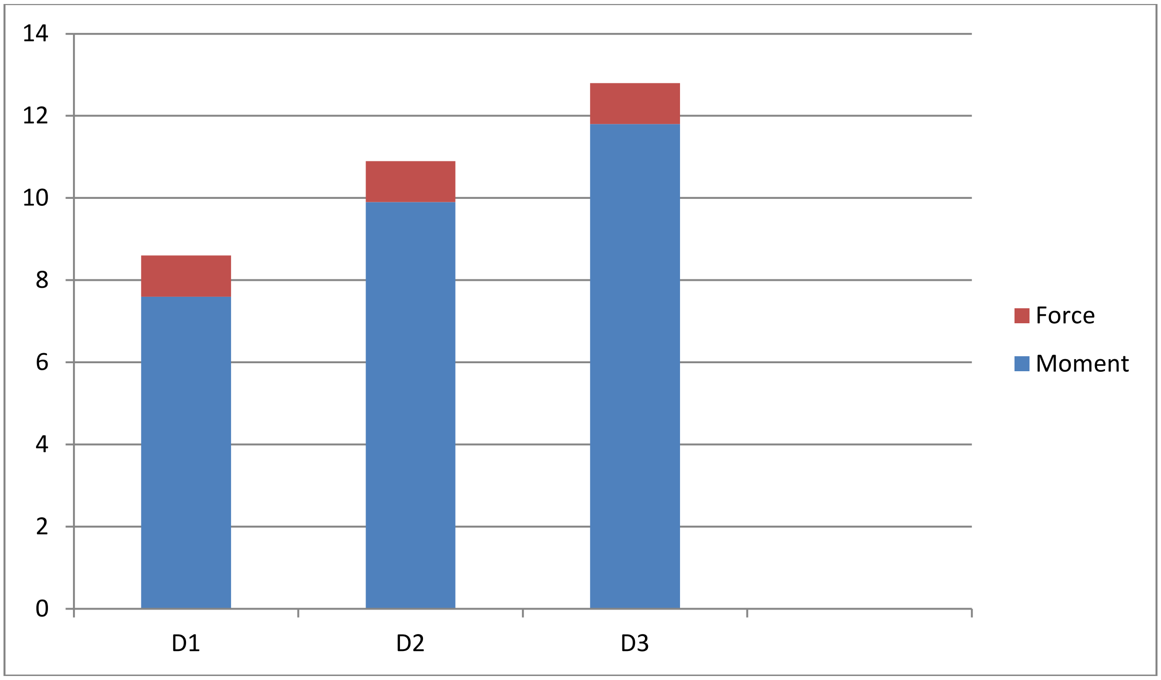
**Force acting on 2mm, 5mm and 8mm retraction hook**

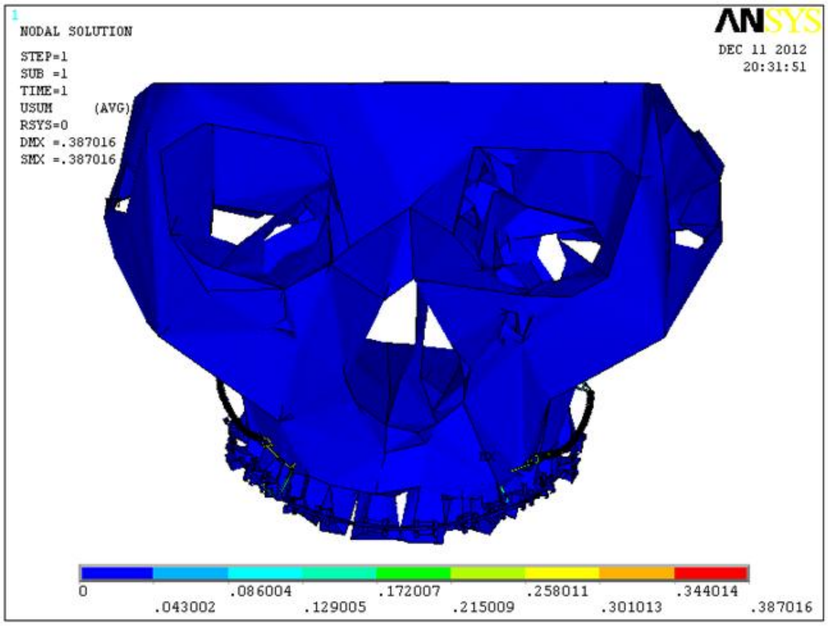



**Displacement of tooth with different retraction hook:**



**Moment: Force**





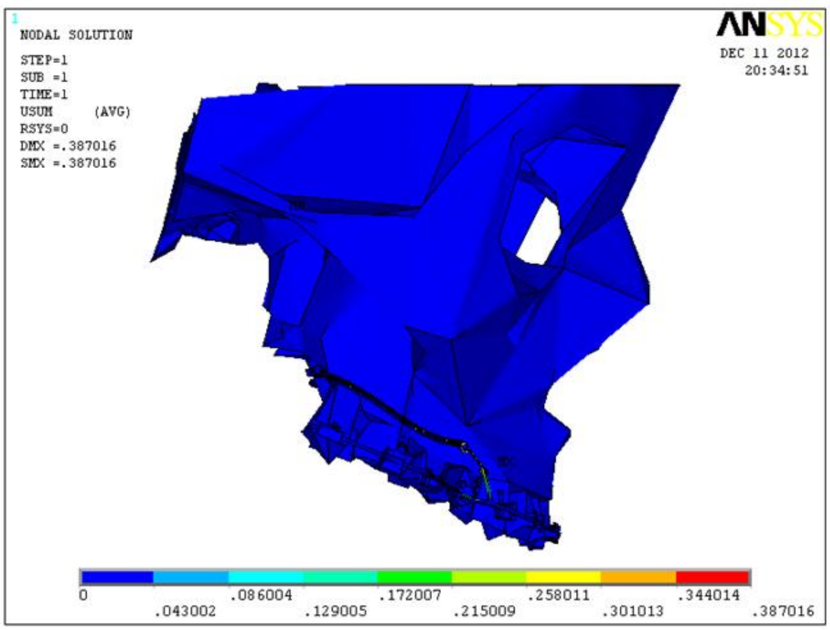
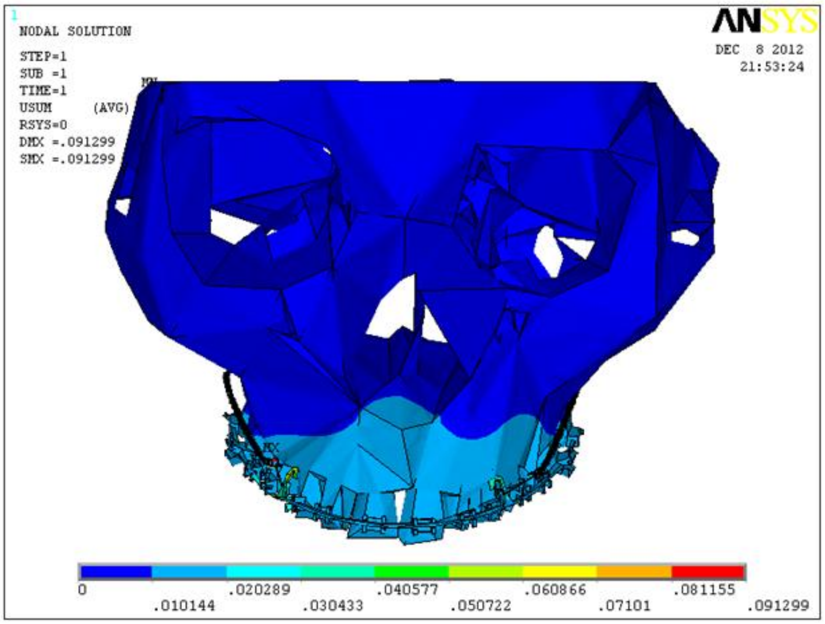




Fig. II

Constructed FEM model showing no displacement of dentition with 250 grams of force for en-masse retracion

**STRESS DISTRIBUTION IN D1 GROUP (2mm retraction hook)**



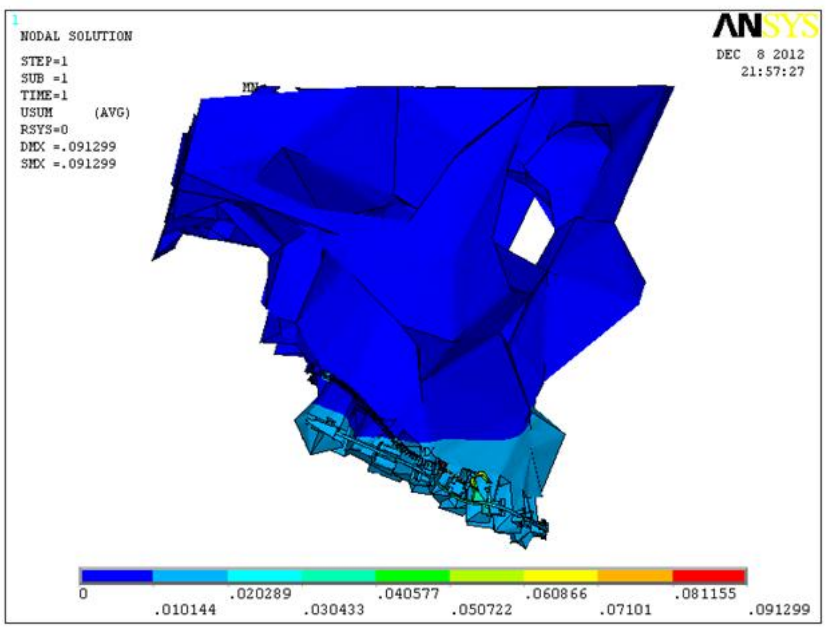




Fig. III

**STRESS DISTRIBUTION IN D2 GROUP (5mm retraction hook)**

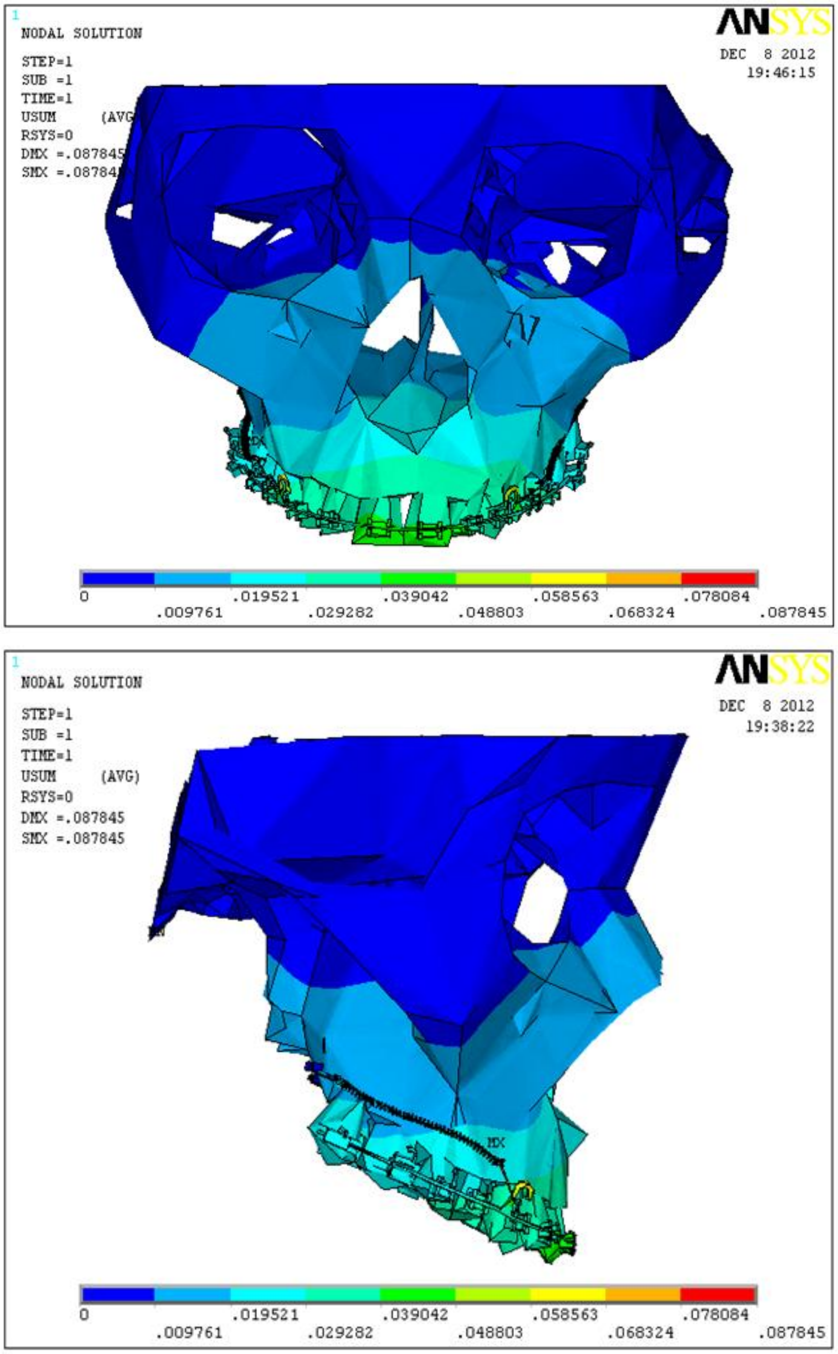
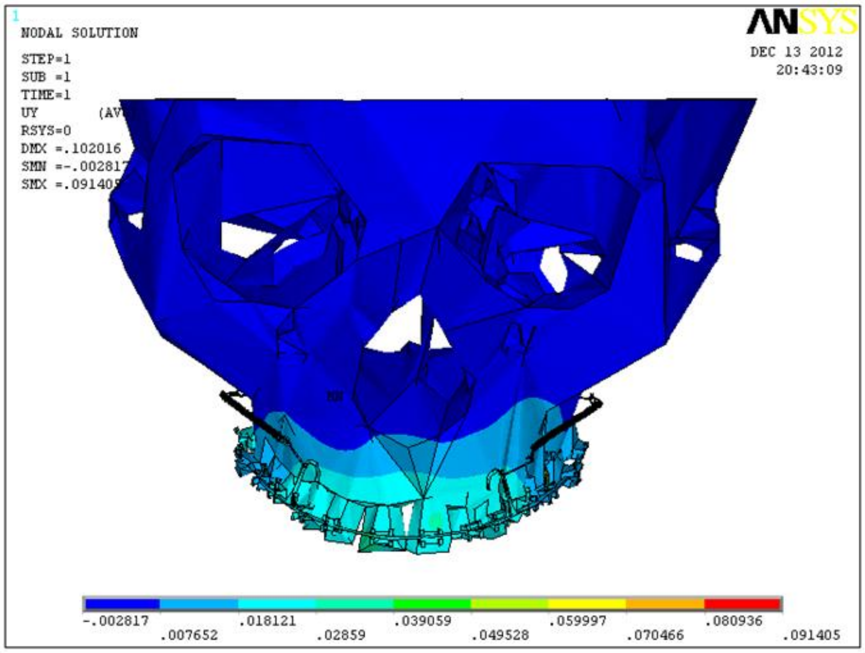



Fig. IV

**STRESS DISTRIBUTION IN D3 GROUP ( 8mm retraction hook)**



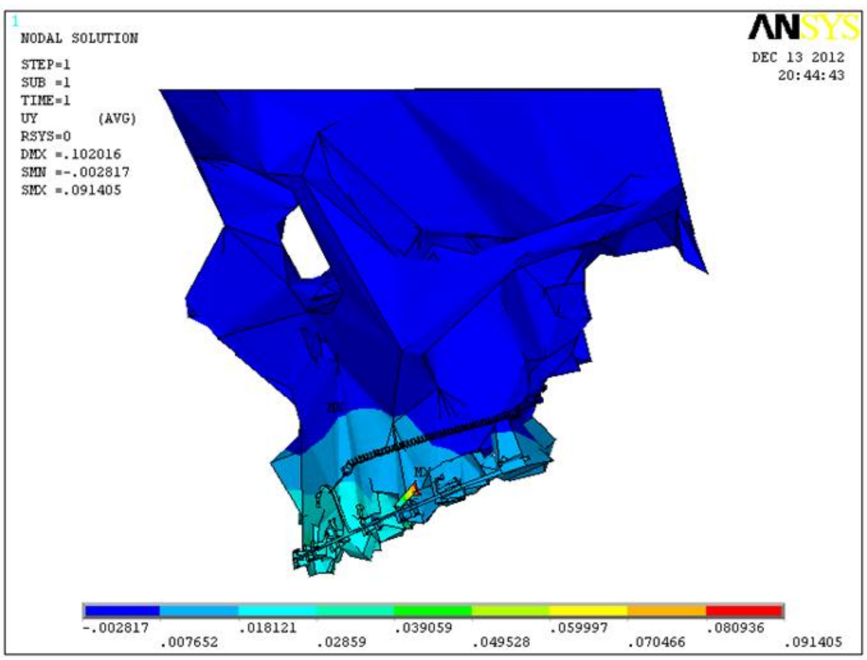




Fig. V

# DISCUSSION

For much of the past century, orthodontic theory and practice was based on the Angle orthodontic ideal. This ideal assumed that nature intended for all adults to have 16 teeth, perfectly aligned in each dental arch, and interlocking in ideal occlusion. Angle preached that, when this occurred, the face would be in perfect harmony and balance.

The major reasons to extract teeth is to provide space to align the remaining teeth in presence of severe crowding and to allow teeth to be moved so that protrusion can be reduced or skeletal class II or class III problems can be camouflaged. In recent years there has been a tendency to return "non extraction" orthodontics and one of the methods that are gaining popularity is molar distalization, to convert extraction to non extraction treatment approach. With this in mind, several authors have shown that orthodontic treatment which involves the holding back or attempted posterior movement of the permanent molars may actually reduce posterior arch space, in turn, resulting in the impaction of the third molars.[65]

The alternatives to extraction in treating borderline crowding or proclination cases are expansion, proximal stripping and distalization of whole dentition. Expansion of arches can be accompanished in only selected cases and show relapse tendencies.[5,81] Proximal stripping of the teeth involves removal of healthy and protective tooth material leading to chances of increased sensitivity.[63] Posterior movement of dentition has been an area of special interest since the beginning of $21^{st}$ century. The objective is to move dentition distally, create space to relieve crowding or proclination and correct the molar relation.

There are numerous methods to move teeth distally; some techniques require a patient's active compliance, whereas others do not. Among these active compliance appliances most traditional techniques included are extraoral traction,[26] the cetlin removable plate,[9] and Wilson arches.[84] However, all these distalizing appliances rely partially or totally on patient cooperation, without which treatment success could be endangered and treatment duration increases. Since patient's cooperation during orthodontic treatment is frequently problematic, the appliance that eliminate the need for compliance are usually deemed superior to those demanding cooperation.

Keeping these drawbacks in mind, during last few decades, many appliances and techniques that reduce or minimize the need for patient compliance have been introduced.[57] They are therefore aptly termed non-compliance molar distalization appliances. Using these modalities, the treatment procedures are better controlled by the orthodontist and therefore predictable results can be achieved. Various intraoral methods, though being, clinician controlled and patient friendly compared to extra-oral methods have emerged with their own share of drawbacks. **Antonarakis and kiliaridis** systematically reviewed the effects of noncompliance tooth-borne distalizers and found that most noncompliant appliances were associated with mesial movement and tipping of incisors and premolars.[2]

One of the limiting factor in the posterior region is the strong muscular pressure being exerted by the buccinator, masseter, temporalis and pterygoid muscles. When adequate space does not already exist in the upper arch and distal forces are applied to the first molars, the second molars are often driven disto-buccally, with the third molars becoming deeply impacted. This occurs essentially because there is simply not enough tuberosity growth to accommodate all these teeth in the arch. Thus an efficient treatment modality that would entirely distalize the complete dentition into the remodeled third molar space would combat the disadvantages faced with other treatment modalities.[65]

Recently, there has been a revitalization of the En Masse Retraction of maxillary dentition which has various advantages over molar distalization followed by anterior retraction. Thus the entire maxillary dentition is distalized as a single unit in this mechanics there by overcoming the adverse effects of distalizing appliances and providing better patient comfort.

The importance of anchorage in orthodontic tooth movement is highly significant. Currently, mini-screw implants or temporary anchorage devices TADs have been proposed to be used clinically as temporary stationary anchorage for orthodontic tooth movement, because of their ability to provide absolute anchorage.[10] With their increase in popularity, many reports have dealt with various clinical situations, such as en-masse retraction of anterior or posterior teeth, retraction of the whole dentition, molar distalization etc.

Mini-implants provide reliable three-dimensional anchorage, leading to predictable treatment outcomes and less reliance on patient cooperation. Because mini-implants may be immediately loaded, they require adequate primary stability followed by a consolidation period of secondary stabilization. Hence, primary stability is regarded as the key indicator of success and varies according to several patient, mini-implant design, and clinical technique factors.[48]

In orthodontics, many attempts have been made to model the reactions of teeth and their supporting tissues on application of orthodontic forces. Therefore, biomechanical analysis for the applied orthodontic tools should be carried out before the procedure. Previous studies have used the photoelasticity method, the strain gauge method, laser holography. The use of digital radiography can overcome some problems of image distortions resulting from magnification or image noise and reflections, but stress and strain distributions under orthodontic force application cannot be determined. Modern medical imaging, modeling, and finite element (FE) analysis solutions can provide powerful tools for optimizing 3-dimensional (3D) morphology from radiographic scans and determining stress and deflection distributions for complex anatomic geometries such as bone.[31] This is the numerical form of analysis that allows stresses and displacements to be identified. The object to be studied is graphically simulated in a computer in the form of a mesh, which defines the geometry of the body being studied. This mesh is divided by a process called discretization, into a number of sub units termed elements. These are connected at a finite number of points called nodes. The results of FEM will be based upon the nature of the modeling systems and for that reason, the procedure for modeling is most important. Thus it can be effectively used as a reliable tool and further would warrant results that can be carried out in clinical situation efficiently.

Three dimensional finite element models were created for the maxilla and other components after scanning them with computed tomography. FEM models were created from CT scan due to its advantage over CBCT. There are a number of drawbacks of CBCT technology over that of CT scans, such as increased susceptibility to movement artifacts and to the lack of appropriate bone density determination.

The Hounsfield scale is used to measure radiodensity and, in reference to medical-grade CT scans, can provide an accurate absolute density for the type of tissue depicted. The radiodensity, measured in Hounsfield Units is inaccurate in CBCT scans because different areas in the scan appear with different greyscale values depending on their relative positions in the organ being scanned, despite possessing identical densities, because the image value of a voxel of an organ depends on the position in the image volume.[18] HU measured from the same anatomical area with both CBCT and CT scanners are not identical and are thus unreliable for determination of site-specific, radiographically-identified bone density for purposes such as the placement of dental implants, as there is "no good data to relate the CBCT HU values to bone quality”.

Initially the modeling was done using software called 3-matic. The basic design most commonly starts with the use of a CAD package or scanned data. However, the closer we get to the actual production, the more one needs a flexible tool to make design modifications on the STL level. This is where 3-matic comes into play. 3-matic offers design modification, design simplification, 3D texturing, remeshing, forward engineering, and much more, and all on an STL level. 3-matic bundles the most powerful STL functions in the industry.

After modeling it is exported to an analysis package. There are several FEA packages like Ansys, Cosmos, Diffpack, Lusas, Nastran, SAP2000, visual FEA etc., but for the system of large difference in material properties and stiffness, Ansys will be a suitable software. ANSYS software enables organizations to confidently predict how their products will operate in the real world.

**Hyo-Sang Park et al**[32] evaluated the density of the alveolar and basal bones of the maxilla and the mandible using sixty-three sets of computed tomographic (CT) images. The density of the cancellous bone of the maxilla ranged approximately between 280 and 500 HU except for the lowest density of the tuberosity area (151 HU).

**Paola Maria Poggio et al**[60], used volumetric tomographic images of 25 maxillae and 25 mandibles and assessed the mesiodistal and the buccolingual distances measured at 2, 5, 8, and 11 mm from the alveolar crest. In the maxilla, the greatest amount of mesiodistal bone was on the palatal side between the second premolar and the first molar. The least amount of bone was in the tuberosity. The greatest thickness of bone in the buccopalatal dimension was between the first and second molars, whereas the least was found in the tuberosity.

Several sites have been proposed for the placement of miniscrew implants for en-masse retraction of maxillary dentition. Most frequently recommended sites were the mid palatine area, the alveolar bone between the maxillary second premolars and first molars[71]. Although being a preferred implant site, interradicular placement of orthodontic miniscrews risks trauma to the periodontal ligament or the dental root. Potential complications of root injury include loss of tooth vitality, osteosclerosis, and dentoalveolar ankylosis[17].

Bone density is another important criteria, that affects the primary stability of a Mini implant. **Gapsky et al**[21] classified Bone density into 4 groups (D1, D2, D3, and D4) based on Hounsfield units (HU). D1 (>1250 HU) is dense cortical bone primarily found in the anterior mandible and the maxillary midpalatal area. D2 (850-1250 HU) is thick (2 mm), porous cortical bone with coarse trabeculae primarily found in the anterior maxilla and the posterior mandible. D3 (350–850 HU) is thin (1 mm), porous cortical bone with fine trabeculae primarily found in the posterior maxilla with some in the posterior mandible. D4 (150–350 HU) is fine trabecular bone primarily found in the posterior maxilla and the tuberosity region.

Maxillary tuberosities seem to mainly consist of marrow spaces, adipose tissue, and a low vital bone profile. Females demonstrate a statistically significant lower amount of vital bone than males. Histomorphometric analysis demonstrated a mean percentage of vital bone of 24.23% +/- 5.2%. The cortical bone density in the maxilla is approximately 810 Hounsfield units (HU) and 940 HU at the alveolar bone. The maxillary tuberosity shows 443 HU at the buccal region and 615 HU at the palatal alveolar bone region.[21]

Mini-implant design features (eg, body diameter and shape) have reported to affect primary stability, with insertion torque reported to be higher for tapered than for cylindrical mini-implants.[48] The insertion technique, such as the insertion angle and predrilling, may also influence primary stability.[48] **Jasmine et al** suggested that Mini-implants inserted at 60° to 70° to the bone surface have been shown to exhibit greater primary stability than those inserted at 90°.[19] In the current study mini-implantwere inserted at an 45° angulation to the bone surface, 7mm distal to second molar and 12mm above from the functional occlusal plane

The placement of miniscrew implants in the maxillary tuberosity would provide an advantage over the other sites by negating the effect of root damage while placement and efficiently providing anchorage for desired treatment outcome. To avoid root contact and to ensure stability after placement, some authors recommends that regular screws (i.e., about 1.5 mm in diameter) should be used in a region with sufficient cortical bone thickness and bone quality; however, in a region with fragile bone, wide screws (i.e., 2 mm in diameter) was preferred. **Sung and colleagues**[71] recommend using a relatively long miniscrew with a diameter of 1.3- 1.5mm in areas with predominance of cancellous bone and low bone density, such as the maxillary tuberosity. Also, other studies by Park et al, Kuroda et al have also shown higher success rates by increasing the length of the MSIs with the same diameter, but the differences were not statistically significant. Thus mini-implant with the dimension of 1.5mm diameter and 8mm length was selected in the present study.

**Sang-Jin sung et al**[66] conducted a finite element analysis for en-masse retraction of anterior using mini-implant. He used a combination of 19 x 25-in S.S. archwire in a 0.022 x 0.028-in slot and 16 x 22-in S.S. archwire in a 0.018 x 0.022-in slot. On comparison the 16 x 22-in S.S. archwire showed more tipping of teeth than 19 x 25-in S.S. archwire. Accordingly, in this study 19 x 25 stainless steel archwire in an 0.022 x 0.028-in slot was designed for en-masse retraction of entire dentition.

Even though the bone quality in the tuberosity area is not ideal as in other potential sites, good results can be achieved if proper protocol is followed in terms of both mini-screw placement and biomechanics.[70] The mini-implants placed in the maxillary tuberosity region have several advantages over mini implants placed in the other region: there is a less chance for root contact during placement of mini implant and there is no interference with root or any other anatomic structures during tooth movement and we don’t need to reposition mini implants as needed during molar distalization or en-masse retraction using mini implants placed in other locations.

To the best of our knowledge, finite element analysis to investigate the en-masse retraction of maxillary dentition using tuberosity implant is very scant. Even though the bone quality in the tuberosity is not as ideal as in other potential sites maxillary tuberosity appears to be a biomechanically feasible location for miniscrew placement when en-masse retraction of the upper dentition is desired.

Thus in our study an finite element model was created that would simulate the maxillary dentition along with the cranial base where en-masse retraction of the entire dentition using mini implants as a source of anchorage to demonstrate certain fact and outcome of using such mechanotherapy was carried out.

**V.Dixon**[78] proposed that, to obtain orthodontic tooth movement, fine control of force exerted by the orthodontic appliances is required. Several common methods are used to obtain such force: these are elastic modules, elastic chain and NiTi springs. However, the potential disadvantage of elastic chain or active modules is the significant force delay over time. NiTi springs have the reported advantage of giving significantly quicker and more consistent rates of space closure.

**Heinz Tripolt** suggested that to apply optimal forces, it is highly recommended to use NiTi coils instead of stainless steel coils due to the super-elastic properties within the NiTi alloy. The forces provided by the stainless steel coils are so much higher than the NiTi coils, mainly in the beginning of the coil activation. However, they decrease gradually and progressively, which may incite the clinician to either change or reactivate the stainless steel coil more frequently.

In our study we used a NiTi closed coil spring to produce force for en-masse retraction of maxillary dentition. In an usual clinical scenario mini implant placed in the tuberosity region to the anterior retraction hook would be of a longer distance and cumbersome if shorter Niti coil spring was used to exert force. Thus a 12mm NiTi coil was chosen to produce efficient and constant force delivery.

In sliding mechanics, hooks are used on the archwire as force application points to achieve anterior retraction. Force vector can be controlled by changing mini-implant insertion height and/or anterior region support height, thereby raising a number of different force action line alternatives.

Force action lines will be employed and determine the vertical effect that the force vector will exert upon the anterior teeth, and such retraction force vectors are referred as high, medium and low installation.[8] In the present study three anterior retraction hooks were decided for simulation, such as 2mm, 5mm and 8mm to study the effect produced by these force action line.

In this study we placed mini-implant in tuberosity region for en-masse retraction with hook placed distal to canine. For en-masse distalization of maxillary arch using sliding mechanics, retraction hooks are placed distal to canine instead of mesial to canine. If a hook placed mesial to canine would cause interference with the soft tissue overlying the canine prominence and thereby dissipation of some of the force generated by the coil spring. The hook placed distal to canine have straight path of force application and it is relatively closer to the center of resistance of maxillary dentition.

For “en-masse” retraction of anterior teeth, force levels of 150grams to 300grams is prescribed for each side and this amount of force is sufficient to close 0.5mm to 1.0mm space per month while allowing adequate control over the tooth movement. Moreover **Deguchi, Favero and Kyung** suggested that on an average the mini-implants can sustain forces of about 200grams to 400grams of force.[8] There are no studies available in literature describing the amount of force required for the en-masse retraction of the maxillary dentition. In the constructed FEM model a retraction force of 250 grams was initially desired for en-masse retraction of the whole dentition, but there was no displacement of dentition (fig.II). The reason could possibly be because the force level was insufficient to retract the entire dentition hence there was no displacement. Thus the retraction force levels was increased further and considerable amount of displacement was found when it ranged between 270-300 grams of force was delivered.

Thus the study aimed to evaluate the force levels acting on the bracket, Displacement of dentition in relation to the applied force and further to assess the moment to force ratio with the combination of hook height variation, namely 2mm, 5mm and 8mm, using FEM

There are hardly any previous literature that documented about the force exerted at the bracket level during retraction. For the statistical evaluation of the study, the various retraction hooks were divided into D1-representing 2mm retraction hook; D2- representing 5mm retraction hook; D3-representing 8mm retraction hook to evaluate the forces acting on the bracket and displacement of tooth using one way ANOVA test with 95% confidence interval was performed.

Forces acting at the bracket level did not show any variation when compared between the three groups. Marginal variation in the order of force levels was found to decrease starting from D1>D2>D3. Maximum force level in the 2mm retraction hook group delivered force levels of 201.14grams, followed by 5mm retraction hook delivered force of 191.14grams and the 8mm retraction hook delivered force levels of 175.71grams. As the retraction hook height increased force acting at the bracket level decreased. (Ref. Table 1)

In this study the displacement of crown was found to be significantly varying when compared between all three retraction hook heights. So, the displacement of crown was more in D1 (2mm retraction hook) group and least in the D3 (8mm retraction hook) group. The order of increase in crown displacement was found to increase as the retraction hook height decreased. (Ref. Table 2)

When compared the displacement of root between various retraction hook height, there was no statistically significant difference found. Still the displacement of root was more in the D3 (8mm retraction hook) group when compared with the other two groups. D2 (5mm retraction hook) group showed the minimal displacement of root in all three groups. (Ref. Table 3)

When compared the total tooth displacement between various retraction hook heights, there was no statistically significant difference found. The displacement of tooth was more in D1 (2mm retraction hook) group and least in the D3 (8mm retraction hook) group. The order of increase in tooth displacement was found to increase as the retraction hook height decreased. (Ref. Table 4)

**SheauSoon Sia et al**[67] stated that by changing the power arm length higher or lower than the level of center of resistance and also added that bodily translation can be achieved by attaching a power arm length that lies at the same level of center of resistance. **Yukio kojima et al**[86] stated that when the line of action of force passed below the center of resistance of the anterior and posterior teeth and when increasing the length of the power arm the rotation of the entire dentition decreased.

**Miki and Hirato**[27] stated that center of resistance of maxillary dentition was located between the first and second premolars anteroposteriorly and between the lower margin of orbitale and the distal apex of the firsty molar vertically in the sagittal plane. **Bulcke, Burstone & Sachdeva**[32] using laser reflection technique found out that center of resistance for two incisors was located 3.5mm apical to interproximal level, for 4 anterior 5mm apical to interproximal level, and for 6 anterior 7mm apical to interproximal level. In our study the center of resistance for entire maxillary dentition was present between 1$^{st}$ and 2$^{nd}$ premolar approximately 27.5mm in horizontal direction(X axis) and 10.7mm in the vertical direction (Y axis) from the central incisor tip.

**Sang-jin sung et al**[66] conducted an FEM study and his results concluded that the retraction force vector applied above center of resistance, bodily movement did not occur.

**Kim et al**[38] in a previous FEM study proposed that when the length of the power arm was 4.987mm when located between the lateral incisor and the canine, or 8.218 mm when located between the canine and the first premolar, parallel translation of anterior teeth en-masse was generated. The retraction force was applied at an angle of 23° or 45° if the power arm was located between the lateral incisor and the canine or between the canine and the first premolar.

In our study the force vector was calculated with occlusal plane as the reference line. A constructed occlusal plane perpendicular and the line drawn from the mini-implant to the different levels of retraction hook gave the degree of force vector. For the 2mm, 5mm and 8mm retraction hook the force vector was found to be 13°, 9° and 5° respectively to the occlusal plane. Since the maximum angle of retraction force hardly exceeded 13° the situation could not be exactly correlated with the previous study. Still the 2mm retraction hook showed maximum crown movement and total tooth displacement when compared between the other two groups.

Moment to force ratio (M/F) applied at the bracket whose value determines the position of the center of rotation during the orthodontic movement as stated by **Burstone**. The Moment:Force ratio were compared between the groups to find the nature of tooth movement. It was found to be high in the 8mm retraction hook height group and decreased gradually when hook height decreased. Clinically this situation can be correlated to say that increase in retraction hook height increased Moment:Force ratio. (Ref. Table 5)

Pearson correlation co-efficient test was utilized for assessing the measure of correlation between the two variables, namely forces acting at the bracket level to the displacement of the tooth. In the 2mm retraction hook group the correlation between the displacement of crown and forces acting at the bracket showed positive correlation. Whereas in the 5mm and 8mm retraction hook groups showed a negative correlation for the same. In all the groups the correlation between the displacement of root and forces acting at the bracket showed positive correlation. Among the groups correlated D1 group alone showed a positive correlation at the crown and the root displacement but the displacement of root movement was statistically insignificant. (Ref. Table 6, 7, 8)

Thus with summation of all such resultant tooth movement, we can forecast the behavior of tooth movement by considering the vector of orthodontic force in an arrangement against the CR of the entire dental arch. Counterclockwise rotation of the maxillary dental arch is expected as the force vector passes superior to the CR, clockwise rotation is observed when the force vector passes inferior to the CR.

Other than the advantages En-masse retraction would inadvertently bring about some extrusion and tipping movements and in order to counteract such unwanted sequelae compensatory curves in the archwire can be given or an implant placed in the anterior nasal spine region to intrude the anterior region during the retraction phase can effectively serve as another viable option. Thus further studies with such Mini-implant placement in the anterior nasal spine region would be of future interest.

Mini-implants can contribute significantly to the retraction phase. Orthodontists, however, should acquaint themselves with the peculiarities of using mini-implants in this treatment stage. If used appropriately, mini-implants can be more efficient than traditional anchorage methods besides making treatments more predictable.

Though an finite element method can preclude and serve as an tested act invitro to be used in a patient invivo, it also suffers from certain limitations. The limitation of this study using FEM analysis simulation routines has the inability to directly predict long-term tooth movement quantitatively simulates them. Until the physiologic and biomechanical processes of orthodontic tooth movement are fully understood and represented mathematically in a patient-specific model, this aspect must still be left up to the common clinical practice of experienced orthodontists.

## SUMMARY AND CONCLUSION

The present invitro study using Finite element analysis was carried out to investigate the effectiveness of 19 x 25-inch stainless steel archwire with retraction hooks of various heights placed in a 0.022 x 0.028-inch slot for en-masse retraction of maxillary dentition using tuberosity implants was studied.

The following conclusions were drawn from the present study:

1. The optimal force level for en-masse retraction of the entire dentition in the maxilla ranged between 270-300 grams of force.
2. As the retraction hook height was increased the forces acting at the bracket level decreased.
3. Significant amount of crown displacement occurred as the retraction hook height decreased relating that maximum displacement occurred in the 2mm retraction hook height group.
4. 8mm retraction hook showed maximum root displacement among the three groups.
5. As the retraction hook height decreased the tooth displacement increased.
6. Increase in the hook height was directly proportional to the increase in Moment to force ratio.

Based on this study the maxillary tuberosity appears to be a feasible location for miniscrew placement and when en-masse retraction of the upper dentition is required. The appropriate vector of force can be directed by varying the retraction hook height which would bring about the desired tooth movement.

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