



SATHYABAMA INSTITUTE OF SCIENCE & TECHNOLOGY

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Jeppiar Nagar, Chennai



Distalization of Total Maxillary Arch Using Infrazygomatic Screw with Varied Power Arm Length and It's Associated Biomechanical Variations - A Finite Element Study -

**By
Dr. A. JYOSTHNA**

Dissertation submitted to
Sathyabama Institute of Science & Technology
(Deemed to be University), Chennai, Tamil Nadu

In partial fulfillment of the requirements for the degree of
Master of Dental Surgery
In the specialty of
Orthodontics and Dentofacial Orthopedics

Under the guidance of
Prof. Dr. Shahul Hameed Faizee
Head of the Department
Department of Orthodontics and Dentofacial Orthopedics
Sathyabama Dental College and Hospital
Jeppiaar Nagar, Chennai-600119, Tamil Nadu
2019 – 2022

CERTIFICATE BY THE GUIDE

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A Dissertation submitted to the **Sathyabama Institute of Science & Technology (Deemed to be University)** Chennai, Tamil Nadu, in partial fulfillment of the requirements for the degree of **Master of Dental Surgery in the Specialty of Orthodontics & Dentofacial Orthopedics**.

Co- guide

Guide

Dr. Navaneetha Nambi, M.D.S

Reader

Department of Orthodontics and
Dentofacial Orthopedics

Sathyabama Dental College & Hospital,
Chennai

Dr. Shahul Hameed Faizee, M.D.S

Professor and Head

Department of Orthodontics and
Dentofacial Orthopedics

Sathyabama Dental College &
Hospital, Chennai

Date:

Place: Chennai

**ENDORSED BY THE HEAD OF THE INSTITUTION
AND HEAD OF THE DEPARTMENT**

This is to certify that the dissertation titled "**Distalization of Total Maxillary Arch Using Infrazygomatic Screw with Varied Power Arm Length and It's Associated Biomechanical Variations - A Finite Element Study -**" is the bonafide record of work done by **Dr. A. JYOSTHNA**, under the guidance of **Dr. Shahul Hameed Faizee, M.D.S**, Professor and Head, Department of Orthodontics and Dentofacial Orthopedics, Sathyabama Dental College & Hospital, Chennai, Tamil Nadu.

Head of the Department

Dean

Dr. Shahul Hameed Faizee, M.D.S

Department of Orthodontics and
Dentofacial Orthopedics

Sathyabama Dental College &
Hospital, Chennai

Dr. B.Thayumanavan, M.D.S

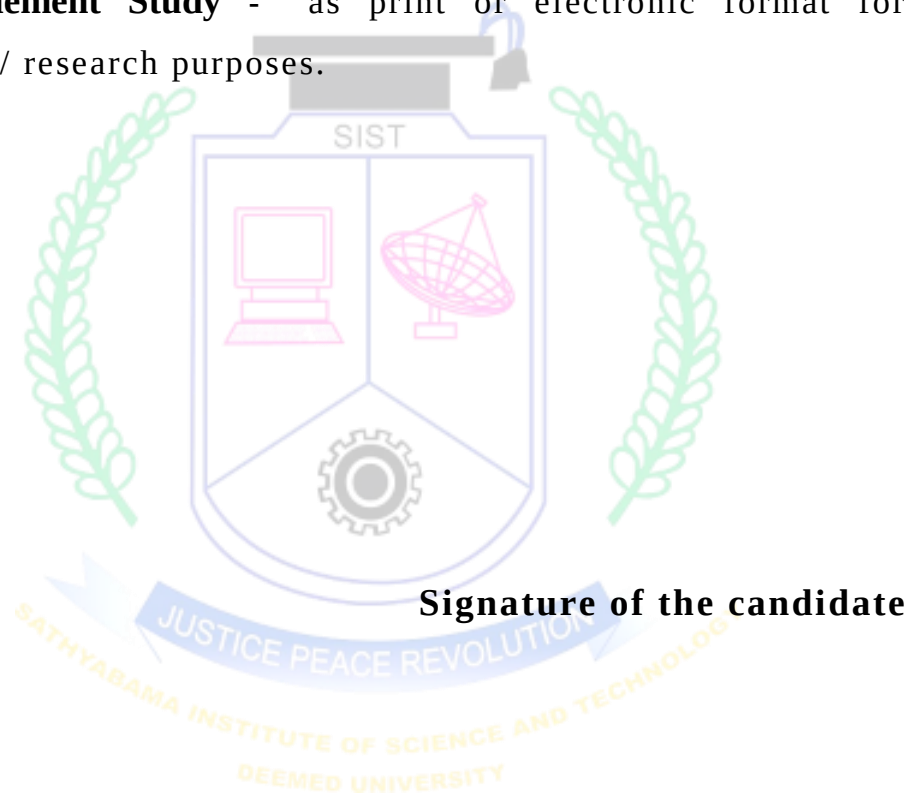
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26th March 2021

Ref: 180/IRB-IBSEC/SIST Dated 26th March 2021

To,

Dr. A. Jyosthna

Post Graduate

Department of Orthodontics and Dentofacial Orthopedics,

Sathyabama Dental College & Hospital

Chennai - 119

Dr. A. Wilson Aruni, PhD, FAMPV
Pro Vice Chancellor,
**Chair Person, Institutional
Biosafety & Ethical Committee
(IBEC), SIST**

Dr. B. Thayumanavan, MDS
Dean, Sathyabama Dental College
**Secretary & Convener
Institutional Review Board &
Institutional Biosafety & Ethical
Committee (IBEC), SIST**

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Dr. Thayumanavan
Secretary & Convener
IBEC, SIST

Dr. A. Wilson Aruni
Deputy Chair Person
IBEC, SIST

DECLARATION OF PLAGIARISM CHECK

From,

A. Jyosthna

III year Post Graduate student

Department of Orthodontics and Dentofacial Orthopedics

Sathyabama Dental College and Hospital

Chennai

To,

The Head of the Department

Department of Orthodontics and Dentofacial Orthopedics

Sathyabama Dental College and Hospital

Chennai

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INTRODUCTION

Class II malocclusion is a craniofacial anomaly described by **Angle** in 1899 as “the relationship of the jaws were abnormal, in which all the mandibular teeth are relatively distal to the maxillary teeth of more than one-half the width of the cusp”¹. It is one of the most common developmental disorder with a prevalence ranging from 15% to 30% in most populations². This type of malocclusion exists because of the maxillary excess or mandibular deficiency or combination of both. The typical features are convex profile, incompetent lips, class II molar and canine relationship, increased overjet and overbite.

The treatment modalities differ from growing to non-growing individuals. In growing patients, the growth modification can be done using orthopaedic appliances or functional appliances³. In non-growing patients the treatment options include camouflage or surgical correction⁴. This decision should be made by a prudent differential diagnosis considering the face, skeletal pattern, and dentition^{5,6}.

Modern orthodontic viewpoints have been directed towards conservative regimen approach and current trends in orthodontics have shifted towards non-extraction therapy. The maxillary molar distalization mechanics have become increasingly popular for the treatment of class II malocclusion where extraction or mesialization of mandibular dentition is considered as undesirable⁷. Distalization is indicated when there is a minimal arch length discrepancy, class II molar relationship and low mandibular plane angle^{8,9}.

Many conventional appliances have been developed to distalize the maxillary molars which include headgear^{10,11}, distal jet^{12,13}, jones jig¹⁴, and

pendulum appliances^{15,16}. However, the major drawbacks of these modalities include patient compliance and anchor loss like flaring of incisors, increase in overjet, mesial movement of pre-molars, tipping of molars leading to unsatisfactory treatment results¹⁷.

Absolute anchorage systems have conquered the world of orthodontics over the past two decades with its ability to convert borderline surgical cases into non-surgical and extraction cases into non-extraction cases¹⁸. But the major constraint during the placement of TADs is that it poses a risk of injuring the root while inserting in the dento-alveolar area¹⁹.

More recently an apt balance was achieved with the advent of the Orthodontic Bone Screws²⁰. These bone screws had an extra-radicular site of placement in the infra-zygomatic crest of the maxilla and the buccal shelf area of the mandible, incisive fossa, canine fossa, premaxillary region, midpalatal region, symphysis, anterior external oblique ridge and retromolar area with significantly less failure rates than regular mini-implants but also doesn't require extensive surgical intervention for their placement^{21,22}.

Infra-zygomatic crest has been an obvious choice for miniscrew insertion due to the thickness of the cortical plate and its position which lies higher and lateral to the molar region²³. **Lin**²⁴ preferred bone screws to be placed in between the 1st and 2nd molar region, whereas **Liou**²⁵ opined a more anterior placement, closer to the mesiobuccal root of the 1st molar and orienting at 55° - 70° towards the tooth and 2 mm above the mucogingival junction in the alveolar mucosa.

Finite Element Analysis (FEA) dates back to 1943 when **R. Courant**²⁶ first developed this technique. It was applied in dentistry and termed by **Clough** in 1960²⁷. It was introduced in implant dentistry in 1976 by **Weinstein. Moss** in

1985²⁸ utilised FEM to document the growth model. Finite element method (FEM) or Finite Element Analysis (FEA) is a contemporary research tool for an orthodontist and it has been used for the creation of models based on the information of human anatomy and experimentation of the force models, type of reaction, and bone stress levels during retraction and distalization using various treatment mechanics. FEM has become a powerful technique in orthodontics because of its versatility in calculating stress distributions within complex structures.

The adverse effects associated with distalization using skeletal anchorage devices is anchor loss like lingual tipping of incisors, distal tipping of molars and tendency of occlusal plane changes by extrusion of the anterior segment and intrusion of the posterior segment leading to either steepening or flattening of the occlusal plane²⁹.

To achieve the desired biomechanical tooth movement during distalization of the maxillary dentition, the height of the power arm and centre of resistance of the maxillary dentition play a crucial role. The increase in the power arm height has been reported to reduce the tendency of tipping and leading to more bodily movement³⁰. For instance, in open bite cases the shorter power arm will bring the extrusion of the incisors and clockwise rotation of the maxillary dentition, whereas in deep bite cases the longer power arm will bring the intrusion of the anteriors and anticlockwise rotation of the maxillary dentition³¹.

The need of the hour is to have proper guidelines regarding the required length of the power arm depending on the type of tooth movement and its relation to the centre of resistance of the maxillary dentition. Literature on such treatment methodology using infrazygomatic screws and variable power arm lengths for

distalization of the whole maxillary dentition from a biomechanical point of view is relatively scant.

Hence, the aim of the present study was to investigate the effect of distalization of total maxillary arch using infrazygomatic screw with varied power arm length and its associated biomechanical variations by Finite element method.

REVIEW OF LITERATURE

Literature has been reviewed under the following headings:

- I. CLASS II MALOCCLUSION**
- II. DISTALIZATION FOR CLASS II CORRECTION**
- III. TEMPORARY SKELETAL ANCHORAGE DEVICES USED FOR DISTALIZATION**
- IV. FINITE ELEMENT METHOD**

CLASS II MALOCCLUSION:

Edward Angle et al (1899)³² published his ‘Classification of Malocclusion’. He described Class I molar relation as, the mesiobuccal cusp of upper first permanent molar occludes with mesiobuccal groove of the lower first permanent molar. The distobuccal cusp of upper first permanent molar occludes with the mesiobuccal groove of the lower first permanent molar in the Class II and, in a Class III molar relation, the lower first permanent molar lies mesial to upper first permanent molar by a premolar width or a cuspal width.

Graber and Swain et al (1972)³³ pointed out that Angle’s classification failed to distinguish between malocclusions with anteroposterior relationships, which require different treatment plans.

Salzmann et al (1977)³⁴ showed that Class II malocclusion is the second in frequency, distribution, and prevalence among Angle’s malocclusion classes. However, it is the most frequently encountered and treated malocclusion in orthodontic practice. And also he studied prevalence for American whites and blacks and found to be 34% and 18% respectively.

Moyers et al (1980)³⁵ classified Class II malocclusion into six horizontal types and five vertical types describing possible dental and skeletal features of Class II malocclusion out of which two such interesting types being associated with retrognathic maxilla.

Rinchuse and Rinchuse et al (1989)³⁶ found Angle's classification limited because it is a system of discrete classes. They further mentioned that Angle was not clear about the description and definition of his classes and his writings were equivocal, leading to the possibility of one class overlapping into another and it only addresses the sagittal dental dimension and does not address the vertical and transverse dental dimensions; it also lacks a consideration of the face.

Katz MI et al (1992)³⁷ revisited Angle's classification. The original classification had Class II as a full premolar width distoclusion and Class III as a full premolar width mesiocclusion. Assuming an average premolar width of 7.5 mm, this range was far too wide, and so in 1907, Angle revised his definition, making Class II more than half a cusp distoclusion and Class III more than half a cusp mesiocclusion. That modification reduced the range from 14 mm to a 7 mm range.

DISTALIZATION FOR CLASS II CORRECTION:

Gianelly et al (1991)³⁸ used Japanese NiTi superelastic coils to move the molars distally. These NiTi springs exerts 100 gm of force, when compressed against the maxillary first molars and moved the molars distally 1 to 1.5 mm/month. Anchorage was obtained with a modified Nance appliance cemented onto the first premolars in conjunction with a fixed appliance.

Hilgers et al (1992)³⁹ introduced pendulum appliance, it uses the palate as an anchorage unit to distalize the first molars. It contains acrylic plate that is retained

in place either by clasps to the first premolars. Distalization arms or springs are consists of a closed helix and a U-loop. The purpose of the closed helix is to allow for activation of the distalization arms. The U loops are incorporated mesial to the molars to allow for adjustment of the axial inclination during distalization. Typically, an initial activation of 60° to 70° (around the width of one molar) will generate 250g of force per side.

Kurol et al (1992)⁴⁰ analyzed the clinical and the dentofacial effects of using repelling SmCo5 magnets for distalization of maxillary first and second molars. The magnets were attached buccally in the premolar and first molar area to a fixed orthodontic appliance. When the magnets were activated, the molars could move freely distally. The mean molar crown movement was 4.2 mm, and the maxillary first molars tipped distally and rotated distobuccally by 8.0 and 8.5 degrees, respectively.

Bondemark et al (2000)⁴¹ evaluated cephalometrically the dental and skeletal treatment effects of a new lingual intra-arch Ni-Ti coil appliance for molar distalization. The mean amount of distal molar movement was 2.5 mm (SD 0.69) in the lingual coil group and 2.6 mm (SD 0.51) in the magnet group. A significantly higher degree of distal molar tipping was found in the magnet group, –8.8 degrees, compared with –2.2 degrees for the lingual coil group. Due to anchorage loss, the maxillary incisors moved forwards, and the overjet was increased by an average of 1.2 mm in the lingual coil group and 1.7 mm in the magnet group. The benefits of the new Ni-Ti appliance were due to the design preventing molar tipping and its single activation.

Ferguson et al (2005)⁴² determined the skeletal, dental, and soft tissue effects of three molar distalization appliances, two of which do not depend upon patient

compliance (i.e., distal jet and Greenfield molar distalizing appliance) and one that does (i.e., sagittal appliance combined with cervical headgear); Pretreatment to transition evaluation showed significant distal movement of the first molars for the distal jet (3.4 mm), the Greenfield molar distalizing appliance (3.9 mm), and the sagittal appliance with headgear (2.1 mm). Distal tipping of the first molar was seen in all samples, but significantly more so in the Greenfield molar distalizing appliance (6.5 degrees +/- 6.6) and the sagittal appliance with headgear (13.5 degrees +/- 8.1) than in the distal jet (3.2 degrees +/- 2.8).

Antonarakis et al (2008)¹⁷ evaluate quantitatively the dental effects of noncompliant intramaxillary appliances in Class II malocclusion. A literature search was carried out identifying thirteen prospective or retrospective clinical studies and only appliances with conventional anchorage designs were considered. Maxillary first molars showed distal crown movement and tipping greater than the mesial crown movement and tipping shown by incisors and premolars. Vertical movements of incisors and premolars were in general extrusive, but molars were intrusive or extrusive.

Ramesh Sabhlok et al (2018)⁴³ listed the limitations with Conventional Molar distalization Appliances. They are, group distalization is almost impossible, undesirable counteraction that is anchorage Loss (Flare out of incisors, overjet increases, mesial movement of Pre-molar, tipping of molars, mandibular clockwise rotation, complicated devices are required, poor oral hygiene, discomfort for patients and need patients cooperation if removable appliances, headgear and or intermaxillary elastics are combined.

TEMPORARY SKELETAL ANCHORAGE DEVICES USED FOR DISTALIZATION:

Park et al (2004)⁴⁴ retracted the maxillary and mandibular posterior teeth with micro-screw implants 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)⁴⁵ investigated the efficiency of intraosseous screws for anchorage in maxillary molar distalization and the sagittal and vertical skeletal, dental, and soft tissue changes after maxillary molar distalization using intraosseous screw-supported anchorage. The average distalization time to achieve an overcorrected Class I molar relationship was 4.6 months. 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 5 mm. However, there was no change in overjet, overbite, or mandibular plane angle measurements.

Kwon et al (2005)⁴⁶ quantified the treatment effects of distalization of the maxillary and mandibular molars using micro-screw implants. The success rate and clinical considerations in the use of the micro-screw 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.

Buchter A et al (2005)⁴⁷ determined the clinical and biomechanical outcome of two different mini-implant systems activated with different load regimens. 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.

Sugawara J et al (2006)⁴⁸ 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 using skeletal anchorage. The average amount of distalization of the maxillary first molars was 3.78mm.

Kircelli et al (2006)⁴⁹ designed the bone-anchored pendulum appliance. A conventional pendulum appliance was modified to obtain anchorage from an intraosseous screw instead of the premolars to study the stability of the anchoring screw, distalization of the maxillary molars, and the movement of teeth anterior to maxillary first molars. 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.

Sheau Soon Sia et al (2006)⁵⁰ conducted a study to determine the location of centre of resistance and the relationship between height of retraction force on power arm and movement of anterior teeth during sliding mechanics retraction. 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.

Gelgor et al (2007)⁵¹ compared the effects of two distalization systems supported by intraosseous screws for maxillary molar distalization. On the cephalograms, the maxillary first molars were tipped 9.05° in group 1 and $.0.75^{\circ}$ 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 group 1, the maxillary molars were 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.

Cornelis MA et al (2007)⁵² evaluated the effects of maxillary molar distalization in patients treated with a mini-plate skeletal anchorage system. 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 mini-plates for skeletal anchorage is an efficient, noncompliance-dependent, and predictable treatment modality for patients with Class II molar relationship.

Garfinkle et al (2008)⁵³ conducted a study to determine the success rate, positional stability, and patient evaluation of orthodontic mini-implants (OMI). They concluded that OMIs are a predictable, effective and well tolerated anchorage source for adolescents. The orthodontic forces can be applied immediately to OMIs.

Tae-Woo-Kim et al (2008)⁵⁴ in their study have used mini-screws 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 mini-screws 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 et al (2008)⁵⁵ described the use of the lever-arm and mini-implant system for controlled distal movement of maxillary molars. 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.

Papadopoulos et al (2008)⁵⁶ used the mini-screw implant supported distalization system to distalize the maxillary first molars. After 18 months of treatment, a Class I molar relationship was achieved, and the deep bite, overjet, posterior intercuspation, and facial esthetics were improved.

Upadhyay M et al (2009)⁵⁷ 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. 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.

Yamada et al (2009)⁵⁸ quantified the treatment effects of inter-radicular mini-screw anchorage in the distal movement of maxillary molars in nonextraction treatment. 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 were not observed in any patient.

Chung et al (2010)⁵⁹ illustrated a new treatment system combining segmented wire and Osseo integrated mini-implants for molar distalization without complex appliances. Study showed 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 osteo-integrated mini-implant (C-implant) was a simple and effective treatment choice in distalization treatment.

Fudalej P et al (2011)⁶⁰ performed a systematic review of studies pertaining to the distalization of teeth with appliances reinforced with temporary skeletal anchorage devices. 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.

Eduardo yugo Suzuki et al (2013)⁶¹ described the clinical application of the indirect Palatal mini-screw Anchorage and Distalization Appliance (iPanda) and the dental and skeletal effects obtained with this innovative appliance. The iPanda was anchored on a pair of midpalatal mini-screw implants to deliver the distalizing force to the maxillary first molars. This study demonstrated that the innovative iPanda is effective to bodily distalize the maxillary molars into a Class I molar relationship and to provide maximum anchorage.

Kun Chen et al (2015)⁶² studied Class III malocclusion treated with distalization of the mandibular dentition with mini-screw anchorage. The treatment included extractions of the mandibular second molars, fixed appliance therapy, and mini-

screw aided mandibular arch distalization. The patient's facial profile was greatly improved. The mandibular third molars erupted into the second molar spaces, with acceptable intercuspation with the maxillary dentition.

EH Sung et al (2015)⁶³ observed stress distribution and displacement patterns of the entire maxillary arch with regard to distalizing force vectors applied from interdental mini-screws. A single distalizing force at the archwire level induced lingual inclination of the anterior segment, and slight intrusive distal tipping of the posterior segment. In contrast, force at the high level of the retraction hook resulted in lingual root movement of the anterior segment, and extrusive distal translation of the posterior segment. Rotation of the occlusal plane was dependent on the relationship between the line of force and the possible center of resistance of the entire arch.

Haibo Liu et al (2016)⁶⁴ assessed the anatomic structure of the buccal alveolar bone in the infrazygomatic crest region with cone-beam computed tomography to locate safe zones for mini-screws in maxillary dentition distalization. They found that buccal alveolar bone was thicker in the U6-U7 region than in the U6 and U5-U6 regions. The buccal alveolar bone thickness tended to get thicker from the alveolar crest to the sinus floor. The thickest buccal alveolar bone of 4.07 mm was observed at the plane of 11 mm of the U6-U7 region. The percentages for the height of bone from the crest edge to the sinus floor were smaller than 10 mm at the regions of U5-U6, U6, and U6-U7: 38%, 52%, and 43%, respectively. The inter-radicular space was smallest in the U6 region and largest in the U5-U6 region.

Sung Youn Jo et al (2018)⁶⁵ compared the skeletal, dental, and soft-tissue treatment effects of nonextraction therapy using the modified C-palatal plate

(MCP) to those of premolar extraction (PE) treatment in adult patients with Class II malocclusion. The MCP group showed 4.0 mm of distalization and 1.3 mm of intrusion with 2.9° distal tipping of the maxillary first molars and they conclude MCP is an effective distalization appliance in the maxillary arch. The amount of incisor retraction, however, was significantly higher in the PE group. Therefore, four PE may be recommended when greater improvement of incisor position and soft-tissue profile is required.

Till Edward bechtold et al (2020)⁶⁶ investigated treatment stability of mini-screw anchored maxillary distalization in Class II malocclusion. Total arch distalization therapy led to 4.2 mm of distal movement of U6 without distal crown tipping and 3.3° of occlusal plane steepening. They conclude, in Class II treatment, mini-screw anchored maxillary total arch distalization can provide stable distal movement of the maxillary first molars and central incisors.

Swapna sreenivasaagan et al (2020)⁶⁷ compared infrazygomatic crest mini-implants with inter-radicular mini-implants for both Enmasse retraction of anterior teeth and Enmasse distalization of the upper dentition using finite element method. They concluded maximum distalization was achieved when the infrazygomatic crest mini-implants were placed at 70 degrees. The infrazygomatic crest mini-implants were more effective in en masse distalization of the maxillary dentition. If both intrusion and retraction are indicated infrazygomatic mini-implants are a better choice than inter-radicular mini-implants.

Alex Hung Kuo et al (2020)⁶⁸ evaluated the long-term skeletodental effects, the volume of maxillary tuberosity, and airway space changes after maxillary molar distalization using modified C-palatal plate in adolescents with Class II malocclusion. They conclude that after the long-term observation period, sagittal

skeletal and dental relationships were maintained. The vertical skeletal dimension did not change during treatment and was stable at the long-term follow-up. The volume of the maxillary tuberosity showed no significant change during long-term retention.

Camontip sujaritwanid et al (2021)⁶⁹ compared the stress distribution and displacement patterns of the one versus two maxillary molars distalization with iPanda and to evaluate the biomechanical effect of distalization on the iPanda using the finite element method. They showed, for one molar, the stress was concentrated at the furcation and along the distal surface in all roots with a large amount of distalization and distobuccal crown tipping. For two molars, the stress in the first molar was ten times higher than in the second molar with a great tendency for buccal tipping and a minimal amount of distalization. Moreover, the stress concentration on the distal mini-screw was six times higher than in the mesial mini-screw with an extrusive and intrusive vector, respectively.

Mohamed Bayome et al (2021)⁷⁰ conducted a systematic review to assess the treatment effects of buccally versus palatally placed temporary skeletal anchorage devices (TSADs) on maxillary first molars during distalization. The first molar distalization was 2.75 mm when buccal inter-radicular TSADs were used, but 4.07 and 4.17mm with palatal and infrazgomatic TSADs. The palatal appliances were associated with 11.17° of distal tipping of the first molar while infrazygomatic and buccal inter-radicular TSADs resulted in 3.99° and 1.70° of tipping, respectively.

FINITE ELEMENT STUDIES:

Clough et al (1960)²⁷ coined the term 'Finite element method' and widely used method for numerically solving differential equations arising in engineering and mathematical modelling. FEM is a general numerical method for solving differential equations in two or three space variables.

Moss et al (1985)²⁸ 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.

Anderson et al (1991)⁷¹ studied stress profiles within periodontal ligaments after application of various force systems were studied with the use of finite element model. Results showed the stress distribution from cervix to apex when tipping were applied and uniform stress during bodily movement and root movement produced stress patterns opposite to those observed during tipping.

Tanne et al (1991)⁷² 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.

McGuinness et al (1992)⁷³ 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 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)⁷⁴ determined the stress that appears in tooth, periodontal ligament and alveolar bone, when a labiolingual force of 100gm is applied to the crown of a 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.

Tanne et al (1995)⁷⁵ 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 posteroinferior displacement with clockwise rotation from the horizontal headgear force.

Bobak et al (1997)⁷⁶ studied the effects of transpalatal arch on periodontal stresses of molars that were subjected to typical retraction forces, with the use of FEM. 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%.

Rudolph et al (2001)⁷⁷ conducted a study to determine the types of orthodontic forces that cause high stress at the root apex. The material properties of enamel, dentin, periodontal ligament, and bone and five different load systems 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.

Gallas et al (2005)⁷⁸ performed a FE model of an endo-osseous 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)⁷⁹ conducted a FEA study to simulate the retraction of a maxillary canine by sliding mechanics and any associated movement of the anchor teeth. 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.

Ulusoya et al (2008)⁸⁰ evaluated the effects of the Class II activator and the Class II activator high-pull headgear (HG) combination with an extraoral traction force of 350 g on the mandible using finite element stress analysis. 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.

Gautam et al (2009)⁸¹ evaluated biomechanically the displacement patterns of the facial bones in response to different headgear loading by using a finite element method model. 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.

Teasoo kim et al (2010)⁸² 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)⁸³ calculated the long-term tooth movements in en-masse sliding mechanics using 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.

Yukio kojima et al (2012)⁸⁴ clarified the relationship between force direction and movement pattern in the extraction space closure with mini-screw 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 mini-screw, bodily tooth movement was almost achieved. The vertical component of the force produced intrusion or extrusion of the entire dentition.

Jasmine et al (2012)⁸⁵ 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 cortical bone showed that, as the insertion angle increased from 30° to 90°, stress decreased.

Yingjuan et al (2014)⁸⁶ investigated the effect of different length and diameters on the stability of mini implant by Finite element analysis. The Maximum equivalent stress in maxilla and Maximum displacement of mini implant decreased as length and diameter increased. They concluded that from the biomechanical point of view, the choice of the length should not be more than 9mm. When Composite force is loaded using the mini implant, diameter exceeding 1.2 mm are optimal design for mini implant.

YingJuan et al (2015)⁸⁷ compared the stress on the bone surrounding a micro-implant after application of a single force of 200gm using Finite element models. They concluded that the larger force led to greater instability of the micro-implant and the effect was most pronounced at an implant diameter of 1.2 mm. The use of implant diameters of 1.6 mm and 2.0 mm produced no significant difference in implant stability.

Chang Liu et al (2015)⁸⁸ evaluated the effects of maxillary protraction using labiolingual arches and implant-type protraction devices using FEM. They showed labiolingual arch caused less stimulatory growth on the maxilla, whereas the implant caused greater stimulatory growth on the maxilla. Protraction with the labiolingual arch is more suitable for early skeletal Class III patients at a younger age; protraction with an implant is applicable to skeletal Class III patients in the late mixed dentition or early permanent dentition.

Sung Hwan Choi et al (2016)⁸⁹ analyzed stress distributions in the roots, periodontal ligaments, and bones around cylindrical and tapered mini-screws inserted at different angles using a finite element analysis. The mini-screws were inserted at 30°, 60°, and 90° angles with respect to the bone surface. A simulated horizontal orthodontic force of 2 N was applied to the mini-screw heads. They showed very little stress was transmitted to the roots, PDLs, and cancellous bone. During cylindrical mini-screw insertion, the maximum Von-Mises stress increased as insertion angle decreased. Tapered mini-screws exhibited greater maximum Von-Mises stress than cylindrical mini-screws.

Jong Moon Chae et al (2018)⁹⁰ analysed and clarified the mechanics of tooth movement patterns for total distalization of the mandibular dentition based on force angulation. The whole dentition was rotated clockwise or counter-clockwise when the line of action of the force passed below or above the center of resistance. Elastic deflection of the archwire induced a lingual tipping of the anterior teeth. It became larger when increasing the magnitude of angulation. The archwire could be rotated within the clearance gap between the archwire and the bracket slot, and thereby the teeth tipped.

Tarulatha Revanappa Shyagali et al (2019)⁹¹ evaluated and analyzed the distribution of stresses on the palatal micro-implants and the cortical bone at the micro-implant site with optimal orthodontic retraction force in lingual orthodontics using the finite element model. They concluded that 6 mm micro-implant can be the choice for the implant-supported lingual orthodontic retraction as it produced minimal stresses on the cortical bone, and the initial stress displacements produced on the micro-implant were also minimal.

Manreet sidhu et al (2020)⁹² evaluated the stress pattern in cortical and cancellous bones, periodontal ligament, and in the implant itself when a mini-implant (MI) is inserted in the inter-radicular space. Finite element study was conducted with MI insertion at 30°, 45°, 60°, 75°, and 90° angulations. At these angulations, horizontal forces of 150, 200, and 250 g were applied to the middle of the MI head. They concluded highest Von-Mises stress values were detected in the MI itself, followed by cortical bone, cancellous bone, and periodontal ligament. The Von-Mises stress values in cortical bone were highest at 30° angulation and lowest at 90° angulation.

Bingran Du et al (2020)⁹³ measured the bone depth and thickness of different insertion paths for safe placement of infrazygomatic crest miniscrews between the first (U6) and second maxillary molars (U7) by FEM. The results showed maximum bone depth was present at 13 mm insertion sites with a gingival tipping angle of 50° and a distal tipping angle of 30°. Maximum bone thickness was present at 17 mm insertion site with a gingival tipping angle of 70° and a distal tipping angle of 30°.

Arathi Murugesan et al (2020)⁹⁴ compared the infrazygomatic crest thickness (IZC) above the mesiobuccal root of the first and second maxillary molar in different vertical skeletal patterns. Significant difference in IZC bone thickness above the first molar region was noted between high angle and average angle groups and high angle and low angle. Above the second molar region, a significant difference was seen between high angle and average angle groups. Significant difference in bone thickness was also observed among the first molar and second molar region in all the three groups.

Hala Sadek Alosman et al (2021)⁹⁵ evaluated the displacement and stress distribution in the maxillary dentition associated with the use of two different unilateral distalization appliances: Unilateral zygoma gear appliance (UZG) and asymmetric headgear (AHG) using finite element analysis. They concluded with the UZG, the first molar showed greater root distalization than the crown in the model with the third molar, whereas the model without the third molar showed distalization and distal tipping of the first molar. With the AHG, the first molar showed a large amount of distal tipping in the model without a third molar. However, this tipping was less than that in the model with third molars.

Jun Kawamura et al (2021)⁹⁶ analyzed and clarify tooth movement during mesialization of the whole maxillary dentition with various force angulations. With all FAs, the central incisors and molars tipped labially and mesially, respectively. The tipping angles gradually decreased as the FAs shifted from -30° to 30° . The molars tipped lingually with FAs of -30° and -15° , whereas they tipped buccally with FAs of 0° , 15° , and 30° . The molars tended to rotate mesiolingually more as the angle of force increased toward an FA of 30° . The occlusal plane rotated counterclockwise with FAs of -30° , -15° , and 0° , whereas it rotated clockwise with FAs of 15° and 30° .

MATERIALS AND METHODS

This is an In-Silico (computer simulation) study executed in the Department of Orthodontics, Sathyabama Dental College, Chennai. Approval to conduct this study was obtained from the Institutional Review Board of the Sathyabama Institute of Science and Technology:

Ref No: Sathyabama Dental College and Hospital/IHEC/Study no. 180

A Cone Beam Computerized Tomographic (CBCT) image (Figure 1) with the slice thickness of 300µm was acquired in DICOM (Digital Imaging Communications in Medicine) format of a patient's skull with full component of teeth.

Three Dimensional model was created for following components:

- 1) The maxilla with full dentition except third molars.
- 2) Infrazygomatic crest and maxillary tuberosity.
- 3) The periodontal ligament with thickness of 0.2mm.
- 4) A standard conventional preadjusted edgewise brackets of 0.022 slot MBT prescription and buccal tubes.
- 5) Two IZC screw with 12mm in length and 2mm in diameter.
- 6) 19×25 Stainless Steel archwire
- 7) Power arms of varying lengths of 4mm, 8mm and 12mm.

MODELLING PROCEDURE:

The CBCT scan of the skull (Figure 2) was taken and the crosssections were converted into a three-dimensional mathematical model using the software MIMICS (Materialise Interactive Medical Image Control System), exported to Geomagic Studio, and modified by Solidworks and 3-matic research. The

Infrazygomatic crest screw (IZC) was obtained from Fav Anchor (Skeletal Anchorage system, India). It is made up of Stainless Steel and 12×2 mm in length and diameter respectively. Using model scanner (Figure 3), the Brackets, Buccal tubes and IZC screw (Figure 4a, 4b, 4c) were scanned and converted into standard tessellation language (.STL) file using reverse engineering technique in Ramz Dental Lab, Thiruvannamiyur, Chennai. The 0.019 x 0.025 inch stainless steel (SS) archwire and retraction hook using a rigid (0.036-in) SS wire was modelled using 3D CAD modelling software with the help of 2D drawings, in order to reduce the deflection when distalization force was applied.

The IZC were placed above the buccal groove of the first molar and 13mm above the cemento enamel junction at 70° angulation to the bone surface, from the level of the occlusal plane.

The 0.022 x 0.028 inch MBT prescription brackets were attached to the crown so that the facial axis point was at the center of the bracket slot (Figure 5). Three different power arms were constructed on the archwire and placed between the lateral incisor and canine on either side (Figure 6, Table 1):

1. 0.019 × 0.025” SS archwire with 4mm retraction hook (Model 1)
2. 0.019 × 0.025” SS archwire with 8mm retraction hook (Model 2)
3. 0.019 × 0.025” SS archwire with 12mm retraction hook (Model 3)

The constructed archwire was inserted into bracket slot and extended till the distal part of the second molar. A force of 350 grams is applied between the power-arm and the head of the implant on either side for en-masse distalization of maxillary dentition²⁴. This model was fixed in all directions and discretized in X, Y and Z axes.

BASIC STEPS IN FINITE ELEMENT ANALYSIS

1. Pre-processing.
2. Conversion of geometric model into finite element model.
3. Assembly/Material Property data representation.
4. Defining the boundary conditions.
5. Loading Configuration.
6. Processing.
7. Post-processing

Once the 3D model was created, it was converted into FE Model using Hypermesh software (2021 Altair Engineering Inc., version 10.0). Preprocessing includes geometrical clean up, meshing, assigning material properties, applying Loads & boundary conditions. ABAQUS software (Dassault Systems) was used for material designing. The properties of the materials used in this study were depicted in Young's modulus and Poisson's ratio. [Table 2]

Once the images were imported, the software did an automatic meshing with defined material properties, so the models were converted to elements and care was taken that these elements were 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'. The total number of elements and nodes established in this study were 428222 and 1798668 respectively [Figure 7a, 7b, Table 3]. Once meshing and contacts are defined the next process is to define boundary conditions. The nodes present in the lower border of the infraorbital region superiorly and mastoid process posteriorly were marked as boundary condition (Figure 8), so that the maxillary alveolar bone remained

absolutely still when the force was applied. Once the loads were defined, programs were run using ANSYS software and the results have been tabulated.

The midpoints of central incisor edge, mesiobuccal cusp tip of first molar, central incisor root apex and mesiobuccal root of first molar were used as landmarks for the assessment of displacement. The rotation of occlusal plane changes was calculated by connecting the midpoint of the central incisal edge and the mesiobuccal cusp of the first molar and angle was measured by pre and post FEM simulated models using 3D-matic software. A standard coordinate system was constructed with the x-axis corresponding to the transverse direction, the y-axis to the sagittal direction, and the z-axis to the vertical direction.

TABLES

Model	Hook Height
Model 1	4mm
Model 2	8mm
Model 3	12mm

Table 1: FEM Model Details

MATERIALS	Young's Modulus (MPa)	Poisson's Ratio
Teeth	20000	0.3
Periodontal ligament	5	0.3
Alveolus with maxilla	2000	0.3
Bracket	200000	0.3
Wire and Hook	200000	0.3
Infrazygomatic screw	200000	0.3

Table 2: Material Properties of Various Components used in This Study

Components	Node and Element Details	
	No. of Nodes	No. of Elements
Maxillary Alveolar Bone	165294	672562
Periodontal Ligament	5410	10448
Teeth	49102	208714
Infrazygomatic Screw	7250	27970
Arch Wire & Retraction Hook	7442	4086
Preadjusted edgewise Appliance Brackets	116710	531420
Buccal Tube	77014	343168

Table 3: Nodes and Elements Count

FIGURES



Figure 1: CBCT Machine (Sirona Dentsply)

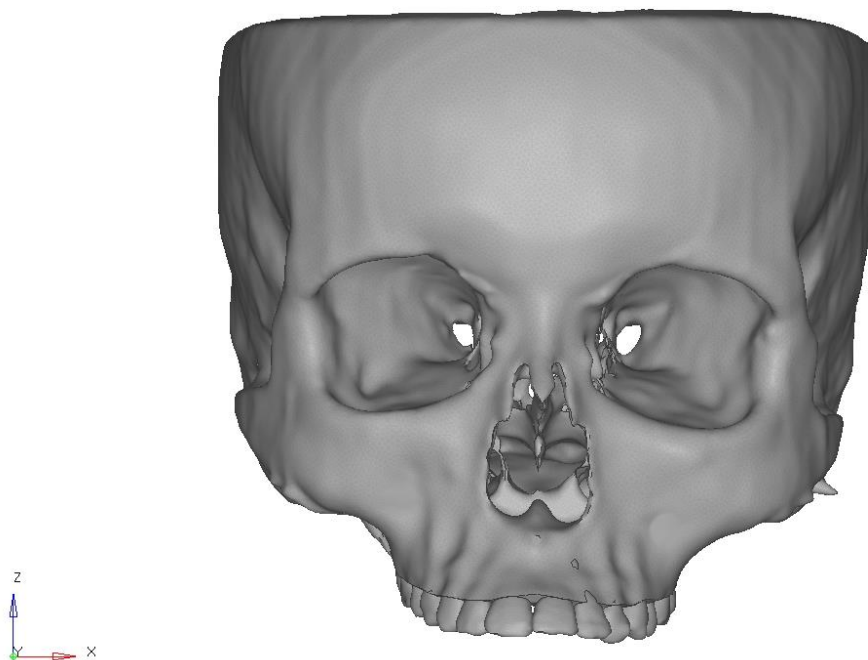


Figure 2: CBCT Skull Model



Figure 3: Model Scanner with Bracket

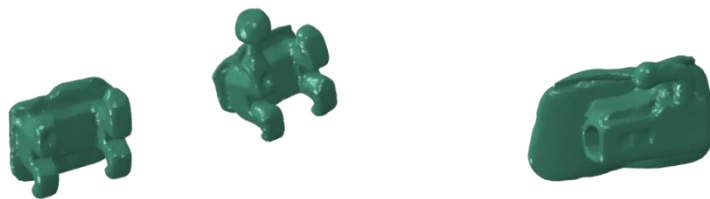


Figure 4a: Scanned Brackets Figure 4b: Scanned Buccal Tubes



Figure 4c: Scanned Infrazygomatic screw

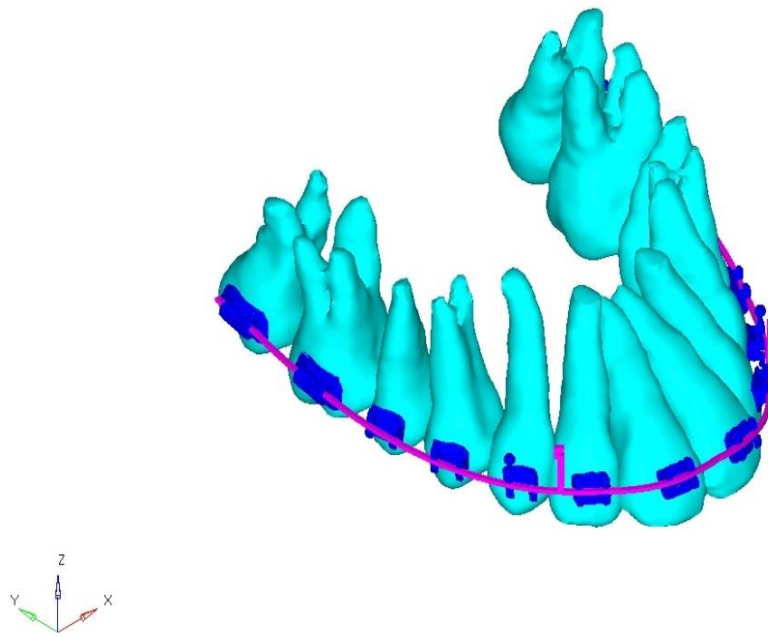


Figure 5: Teeth, Brackets and Archwire with Retraction Hook Assembly

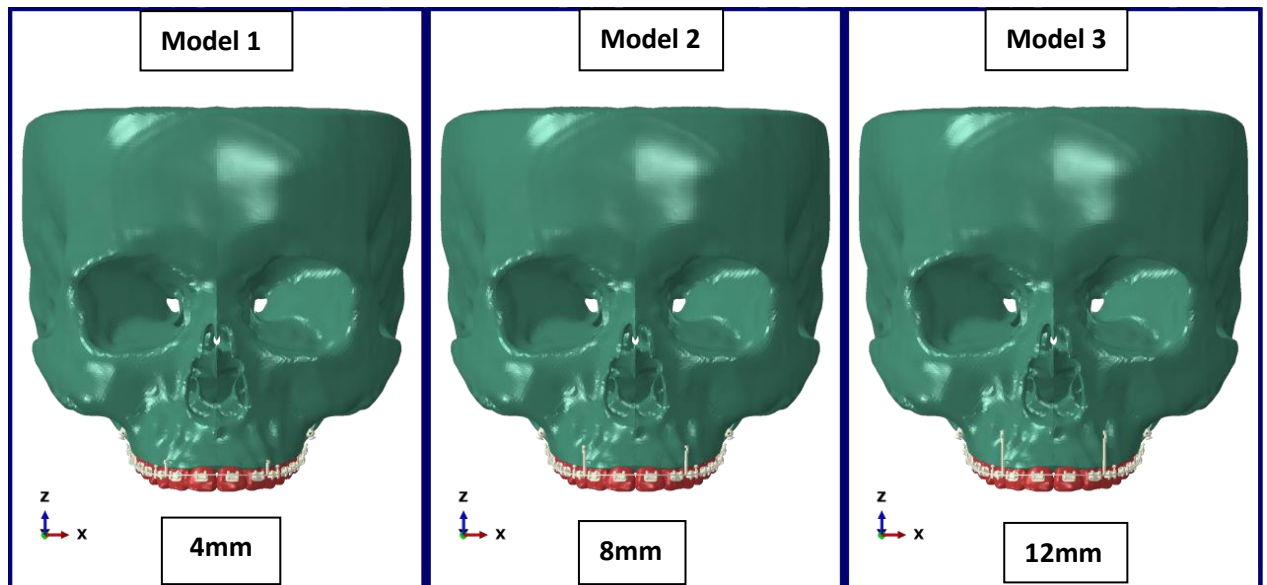
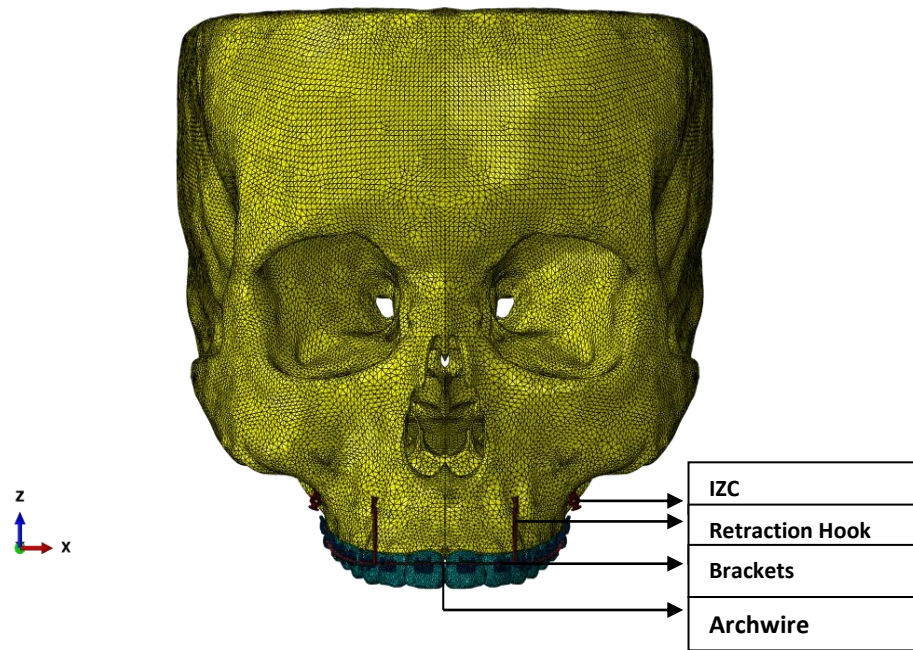
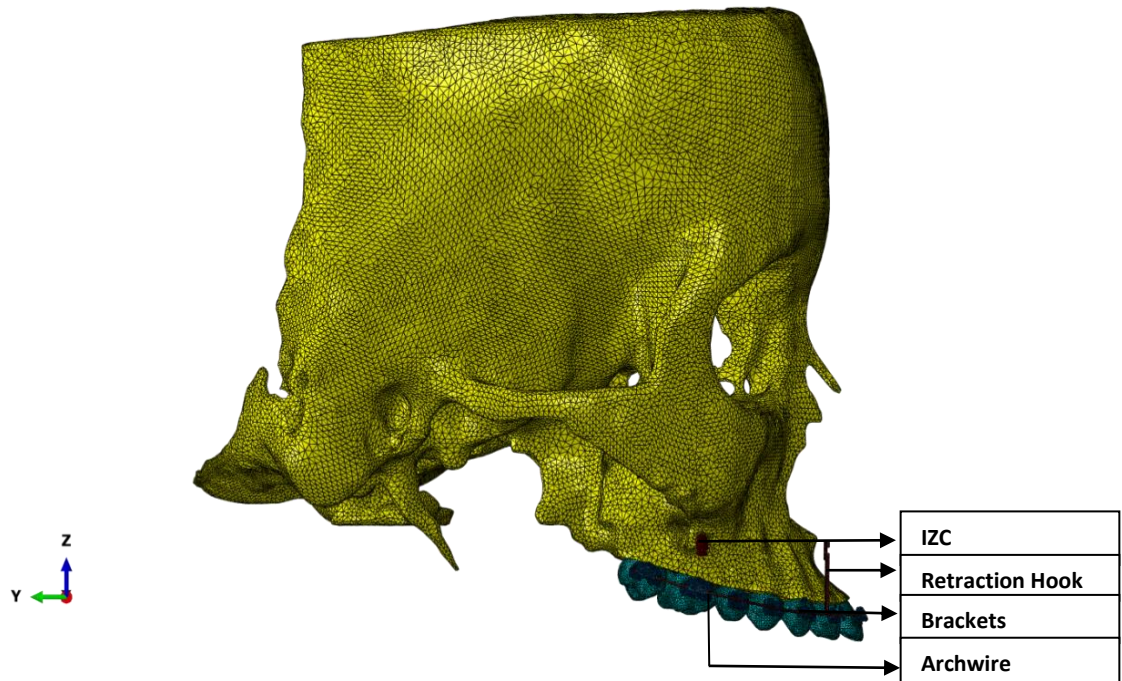


Figure 6: FEM Model with Retraction Hooks Attached to Archwire



**Figure 7a: CAD Model with Brackets, Archwire, Retraction Hook and IZC
(Frontal View)**



**Figure 7b: CAD Model with Brackets, Archwire, Retraction Hook and IZC
(Lateral View)**

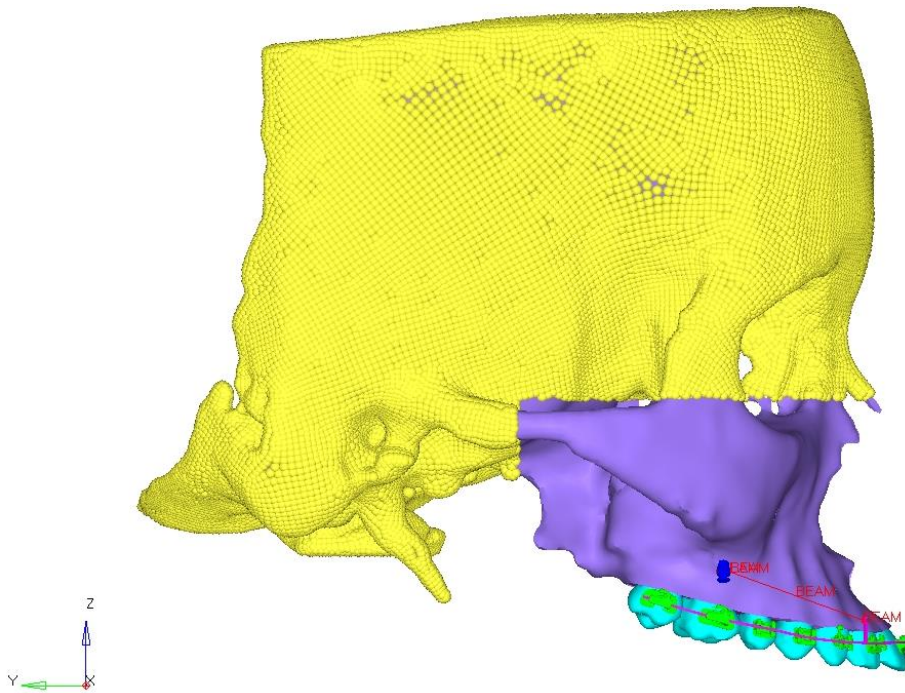


Figure 8a: Boundary Condition – Lateral View

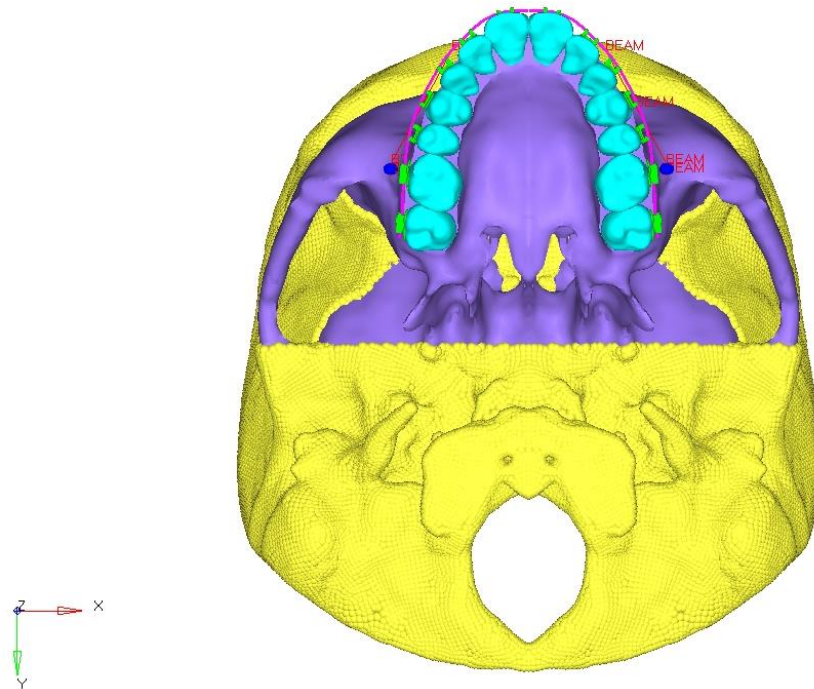


Figure 8b: Boundary Condition – Occlusal View

RESULTS

In the present study, FEM interpretation was done for Y and Z axes. Y axis signifies displacement in anteroposterior plane, [a positive value (+Y) indicates posterior displacement and a negative value (-Y) indicates anterior displacement], wherein, Z axis represents displacement in vertical plane, [a positive value (+Z) indicates intrusion and a negative value (-Z) indicates extrusion]. The extent of displacement was determined using a series of colour bands.

Table 1: FEM Model Details

Model	Hook Height
Model 1	4mm
Model 2	8mm
Model 3	12mm

Displacement of maxillary teeth in Anteroposterior plane:

The displacement of crown in posterior direction of Central Incisor Edge (CIE) was maximum in Model 1 (1.612mm), followed by Model 2 (1.567mm) and least in Model 3 (1.513mm). Similarly, the displacement of Mesio Buccal Cusp of First Molar (MBC6) in posterior direction was maximum in Model 1 (1.415mm), followed by Model 2 (1.394mm) and least in Model 3 (1.370mm).

In contrast, the displacement of the apex of Central Incisor Root (CIR) in posterior direction was maximum in Model 3 (1.226mm), followed by Model 2 (1.221mm) and least in Model 1 (1.218mm). Similarly, the displacement of Mesio Buccal Root of First Molar (MBR6) in posterior direction was maximum in Model 3 (1.190mm), followed by Model 2 (1.178mm) and least in Model 1 (1.169mm).

Table 4 and Figure 9 depict the displacement in Y axis for all 3 models.

Displacement		Varying Power arm Length		
		4mm	8mm	12mm
Y axis (mm) CROWN	CIE	1.612e ⁻⁰³	1.567e ⁻⁰³	1.513e ⁻⁰³
	MBC6	1.415e ⁻⁰³	1.394e ⁻⁰³	1.370e ⁻⁰³
Y axis (mm) ROOT	CIR	1.218e ⁻⁰³	1.221e ⁻⁰³	1.226e ⁻⁰³
	MBR6	1.169e ⁻⁰³	1.178e ⁻⁰³	1.190e ⁻⁰³

Table 4: Displacement of Maxillary Teeth in Anteroposterior Plane – Y Axis

Displacement of maxillary teeth in Vertical plane:

The maximum amount of extrusion of central incisor edge was in Model 1 (-7.536mm), followed by Model 2 (-5.504mm) and least in Model 3 (-5.154mm). Similarly, the maximum amount of intrusion of mesiobuccal cusp of first molar was in Model 1 (1.717mm), followed by Model 2 (1.606mm) and least in Model 3 (1.584mm).

Table 5 and Figure 10 depict the displacement in Z axis for all 3 models.

Displacement		Varying Power arm Length		
		4mm	8mm	12mm
Z (mm)	CIE	-7.536e ⁻⁰⁴	-5.504e ⁻⁰⁴	-5.154e ⁻⁰⁴
	MBC6	1.717e ⁻⁰⁴	1.606e ⁻⁰⁴	1.5814e ⁻⁰⁴

Table 5: Displacement of Maxillary Teeth in Vertical Plane – Z Axis

Changes in Occlusal Plane angle:

The rotation of occlusal plane changes was measured by a tangent line drawn between central incisor edge and mesiobuccal cusp of first molar. The angle is measured using 3D matic software by superimposition of before and after simulation of FEM models and keeping the reference point at lower border of infraorbital ridge. This angle at intersection denotes the occlusal plane change. The maximum degree of clockwise rotation of the maxillary occlusal plane was in Model 1 (2.31°) followed by Model 2 (1.80°) and minimal rotation in Model 3 (1.19°).

Table 6 and Figure 11 illustrate the change in occlusal plane in all three models.

Model	Occlusal plane change (°)
4mm	2.31
8mm	1.80
12mm	1.19

Table 6: Change in Occlusal Plane Angle

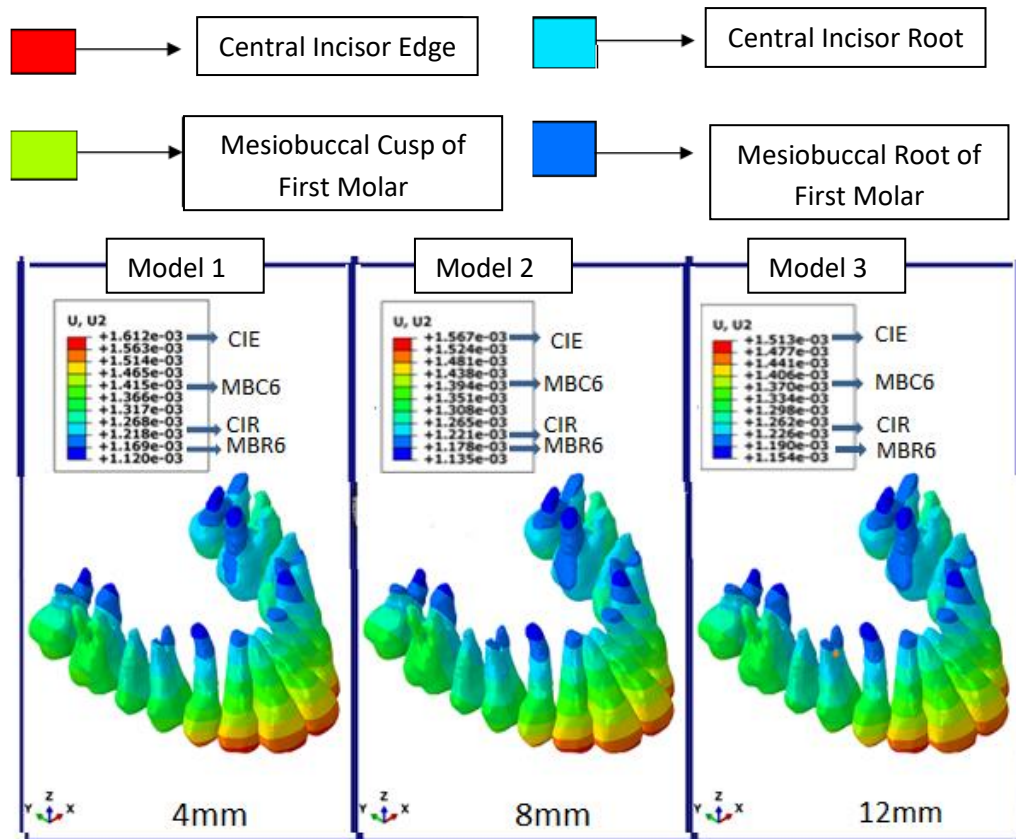


Figure 9: Displacement of Maxillary Teeth in Anteroposterior Plane [Y Axis]

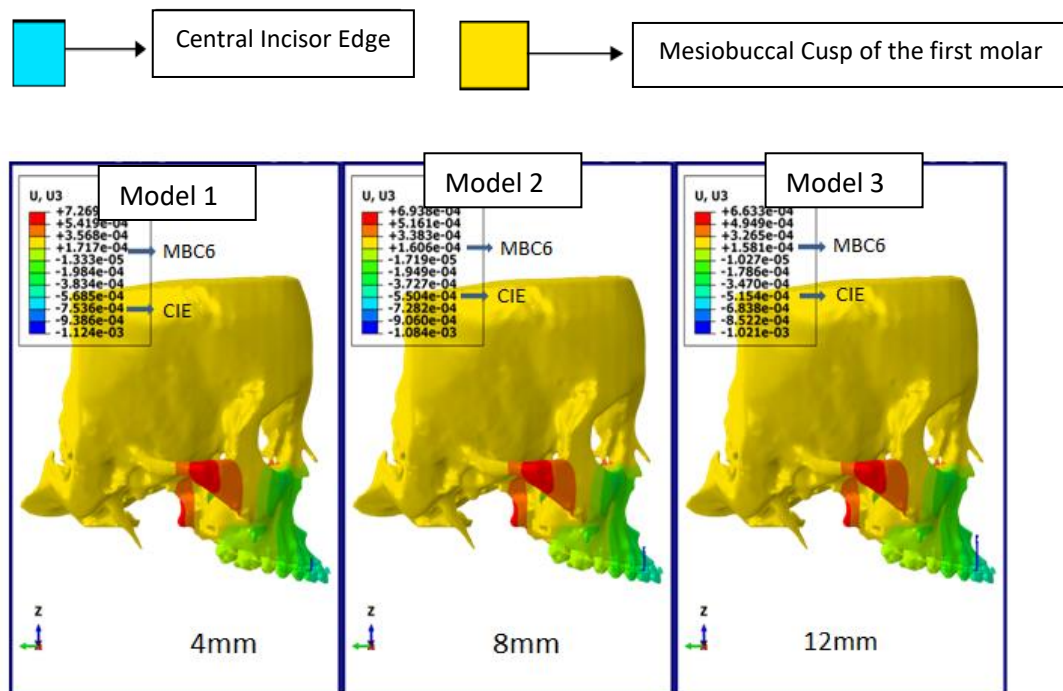


Figure 10: Displacement of Maxillary Teeth in Vertical Plane [Z Axis]

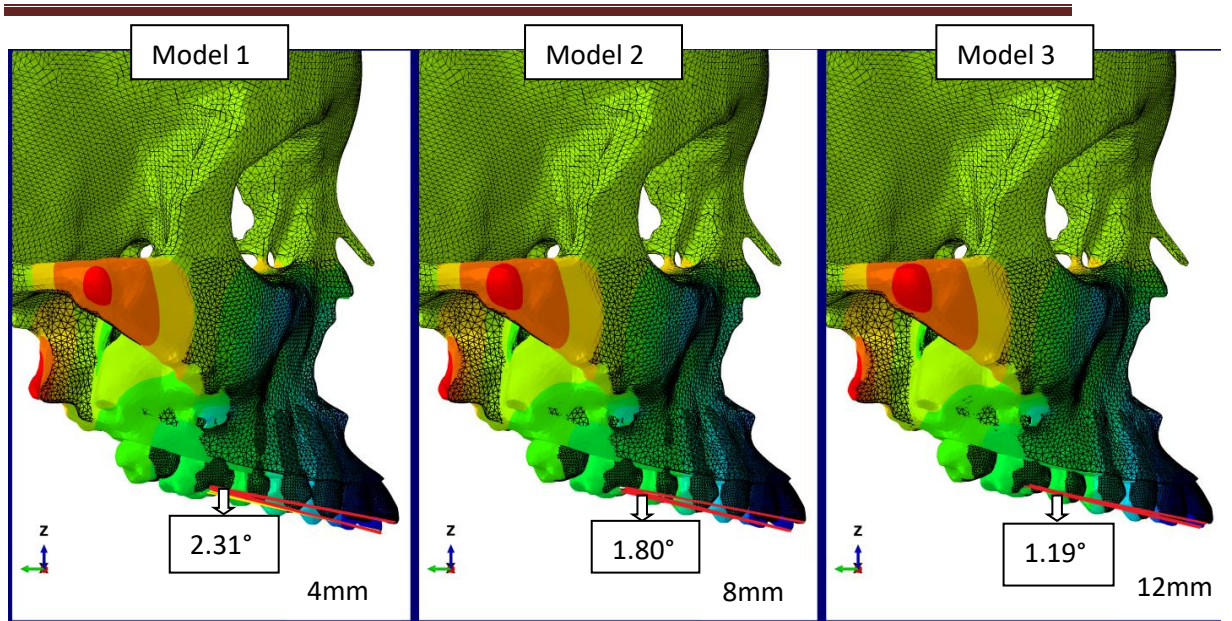


Figure 11: Change in Occlusal Plane Angle

DISCUSSION

Distalization is a conservative method that is utilized in orthodontics to gain space by moving the posterior teeth distally⁹⁷. For more than 100 years, this method has been successfully used in orthodontics to treat many cases, most notably are cases with class II malocclusion. Distalization can be classified based on the arch involved, site of placement, removable or fixed and extraoral or intraoral appliances⁹⁸. The selection of treatment modality varies depending on the clinician's priorities, nature of anomaly, patient age and compliance^{99,100}.

One of the traditional method to achieve distalization is the incorporation of extraoral appliances like headgears^{101,102}. These appliances are commonly utilized either for anchorage or distalization of the molars to correct the molar relation. However, the success of these appliances is mainly dependent on the patient compliance¹⁰³. Therefore, alternate treatment modalities such as pendulum and distal jet were introduced because they required only minimal patient cooperation^{12,13,16,104}.

Ravera et al¹⁰⁵ have shown the possibility of obtaining Class II correction in non-growing subjects with a sequential maxillary molar distalisation using conventional appliances. But unfortunately, some reciprocal anchorage loss occurred during distalization with these conventional methods.

Antonarakis and Kiliaridis et al¹⁷ conducted a systematic review on the effects of conventional tooth-borne distalizers and found that anchorage loss ranges from 24% to 55% and most of the appliances were associated with mesial movement and tipping of incisors and premolars. To reduce these shortcomings,

temporary skeletal anchorage devices were introduced to achieve maxillary total arch distalization and accelerate orthodontic treatment^{106,107}.

Micro-implants and extra-radicular bone screws have brought about a renaissance to the field of contemporary orthodontic treatment mechanics. With its concept of absolute anchorage, they have expanded the scope of orthodontics, providing a wider range of nonsurgical, nonextraction, and noncompliant treatment options⁴⁶. **Sugawara et al**¹⁰⁷ introduced the use of orthodontic bone screws for maxillary and mandibular molar distalization without causing undesired movement of incisors. The distalization techniques with these extra-radicular bone screws when used judiciously could help in overcoming newer challenges and go beyond boundaries in achieving the ultimate goal of – “Clinical Excellence¹⁰⁸.”

Chris Chang et al⁶⁰ enumerated numerous advantages in choosing extra-alveolar sites, like less risk of root damage, more bone at the site of placement, adequate anchorage for enmasse distalization and low failure rates. The infrazygomatic crest (IZC) is one among the extra-alveolar sites which has thick pillar of cortical bone which is palpable and runs along the curvature between the alveolar and zygomatic processes of the maxilla.

Studies of **Kanomi and Schnelle et al**¹⁰⁹ concluded that IZC region lies above the maxillary first molar in younger subjects and between the first molar and second molar in adults. In patients with Class II Division 1 malocclusion with mild skeletal maxillary excess, IZC serve as a suitable treatment option for distalization of total maxillary arch. **Wu et al**¹¹⁰ reported 4.3mm incisor retraction and 3.1mm molar distalization with IZC in 20 adult patients. **Melsen and Verna et al**¹¹¹ stated that infra-zygomatic region can be successfully used to provide

skeletal anchorage for maxillary canine retraction, anterior retraction, en-masse distalization and intrusion of the maxillary posterior teeth.

The experimental methods that have been utilized for the interpretation of force systems and the resultant displacement patterns include the photoelasticity method¹¹², laser holography method¹¹³, the strain gauge¹¹⁴, displacement gauge¹¹⁵, and finite element method (FEM)^{85,90,96}. The FEM is a potent tool, as it enables quantitative visualization of an object in three dimensions.

Many studies have been conducted to correct class II malocclusions with various treatment modalities that use both conventional and skeletal anchorage devices, but only few studies have attempted to predict the tooth movement patterns using bone screws from a biomechanical standpoint. Therefore, the aim of this study was to simulate the effect of distalization of total maxillary arch using infrazygomatic screw with varied power arm length and its associated biomechanical variations.

In the present study, finite element model (FEM) was created for simulating the orthodontic tooth movement during total maxillary arch distalization. Finite element analyses (FEA) optimize 3-dimensional (3D) morphology from radiographic scans and determine stress and displacements within complex anatomic geometries. The article to be studied is graphically simulated in a computer in the form of a mesh. Using Geomagic® FreeForm® (3D Systems, Rock Hill, SC, USA) software, the mesh was divided by a process called as discretization into a number of subunits termed elements. These are connected at a finite number of points known as nodes. The result of FEM is

based upon the nature of the modelling and for that reason, in our study, the process of modelling was done with utmost importance.

The Modelling was done using software called MIMICS 8.11 (Materialise, Ann Arbor, MI). The converted .STL file was corrected using 3D CAD Modelling Software. MIMICS software offers design modification, design simplification, 3D texturing, remeshing, forward engineering on an STL level. After modelling it was 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 was suitable software and this enables organizations to confidently predict how their products will operate in the real world^{88,89}.

3D FEM model for skull was created using CBCT to simulate the actual clinical situation. The material properties (Young's modulus and Poison's ratio) were designated for the teeth, bracket, bone, periodontal ligament (PDL) and arch wire according to the study by **Song et al**¹¹⁶. The teeth and the alveolar bone were presumed to be rigid bodies, whereas, the PDL was assumed to be a linear elastic film of 0.2mm thickness.

The 3D model of brackets (MBT prescription - 0.022×0.028 slot) and buccal tubes were created using model scanner and obtained in .STL file and converted into FEM model and these brackets were attached to the crown, whereas 0.019×0.025 " stainless steel (SS) and retraction hook of 0.036" SS were modelled using 3D CAD modelling software with the help of 2D drawings. Both the brackets and wires were also considered as rigid bodies.

Sang-Jin sung et al¹¹⁷ conducted a finite element analysis for en-masse retraction using mini-implant. He used a combination of 0.019 x 0.025” S.S archwire in a 0.022 x 0.028 MBT slot and 0.016 x 0.022” S.S archwire in a 0.018 x 0.022 MBT slot. On comparison, the 0.016 x 0.022” S.S archwire showed more tipping of teeth than 0.019 x 0.025” S.S archwire. He recommended 0.022 x 0.028 MBT slot brackets and retraction using 0.019 x 0.025” S.S archwire.

In this study, IZC was modelled using model scanner and .STL file was converted into FEM model. The IZC was placed above the mesiobuccal groove of the first molar in the muco-gingival junction which is 13mm above the functional occlusal plane and angulated at 70 degrees inferior to the horizontal plane. After assessing the CBCT of the skull, the maximum cortical bone thickness was present above the mesiobuccal groove of the first molar, hence the IZC was placed above the mesiobuccal groove of the first molar.

In sliding mechanics, power arms are used on the archwire as force application points to achieve retraction. Force vector can be controlled either by changing mini-implant insertion height or power arm height¹¹⁸. In our study, three retraction hooks of varying height were simulated: 4mm, 8mm and 12mm and placed on the arch wire on either side between the lateral incisors and canines in each model. 4mm was designated as model 1, 8mm as model 2 and 12mm as model 3. This was considered in accordance with **Masayoshi Suzuki et al¹¹⁹**, they conducted a FEM study for enmasse retraction of the maxillary dentition using implant anchorage by means of 0mm, 5mm and 10mm power arms.

In this present study, 350 gms of force were delivered per side for the distalization of total maxillary arch. The force is given from the head of the IZC to power arm. **Almeida et al¹²⁰** recommended a force magnitude of 340 to 450 gms

for mini-implants placed in the IZC area and **Lin et al**²⁴ suggested 10–12 Oz (284–360 g) of distalizing force. It is worth mentioning that such force magnitude enables enmasse distalization of the entire arch.

In our study, 350gms of force was applied to all three FEM Models. In the Ansys software, the run command was given to initiate the analysis. Consecutively, after the analysis the displacement in anteroposterior plane and vertical plane has been obtained. The results revealed, all the teeth moved posteriorly in anteroposterior plane, but the amount of displacement in anterior teeth is more and gradually decreased towards the posterior teeth. The displacement of the crown in posterior direction of Central Incisal Edge (CIE) was maximum in Model 1 (1.612mm), followed by Model 2 (1.567mm) and least in Model 3 (1.513mm). Similarly, the displacement of Mesiobuccal Cusp of First Molar (MBC6) in posterior direction was maximum in Model 1 (1.415mm), followed by Model 2 (1.394mm) and least in Model 3 (1.370mm) [Figure 9, Table 4]. This is attributed to the fact that the line of force is passed below the CRes of the maxillary dentition, so that the tendency for tipping is increased in model 1 compared to model 3.

The results of our study were consistent with **Suzuki et al**¹¹⁹, in which the results revealed, in anteroposterior plane, all the teeth moved posteriorly. Nevertheless, the anterior teeth moved the most and this movement progressively decreased the amount of displacement toward the posterior teeth.

In the present study, the displacement of apex of the Central Incisal Root (CIR) in posterior direction was maximum in Model 3 (1.226mm), followed by Model 2 (1.221mm) and least in Model 1 (1.218mm). Similarly, the

displacement of Mesio Buccal Root of First Molar (MBR6) in posterior direction was maximum in Model 3 (1.190mm), followed by Model 2 (1.178mm) and least in Model 1 (1.169mm) [Figure 9, Table 4]. This is due to the fact that the line of force is passed almost at or near to the CRes of the maxillary dentition and so the tendency for translation is increased in model 3 compared to model 1.

The findings of our study were in accordance with **Sung et al**¹²¹, they investigated the displacement pattern of the entire maxillary arch, with regard to various distalizing force vectors applied by interdental miniscrews and the results showed when distalizing force applied at the archwire level, it induced lingual crown inclination of the anterior segment, and in contrast, applying force from a retraction hook at a higher level resulted in more lingual root movement of the anterior segment.

In another study by **Tominaga et al**¹²², the authors estimated that a power arm height of 5.5mm produced bodily movement as well as caused less arch wire deformation. When the power arm height was increased by more than 5.5mm, the anterior segment of the arch wire was deformed, causing lingual root movement.

The results of the present study, in vertical plane, displayed the maximum amount of extrusion of CIE in Model 1 (-7.536mm), followed by Model 2 (-5.504mm) and least in Model 3 (-5.154mm). Similarly, the maximum amount of intrusion of MBC6 was in Model 1 (1.717mm), followed by Model 2 (1.606mm) and least in Model 3 (1.584mm) [Figure 10 and Table 5]. Since, the extrusion of the anterior segment and intrusion of the posterior segment, the occlusal plane was rotated clockwise.

The rotation of occlusal plane changes was measured by a tangent line drawn between central incisor edge and mesiobuccal cusp of first molar. The angle is measured using 3D matic software by superimposing the occlusal plane on before and after simulation of FEM models and keeping the reference point at lower border of infraorbital ridge. This angle at intersection denotes the occlusal plane change. It was observed that the maximum degree of clockwise rotation of the maxillary occlusal plane was in Model 1 (2.31°) followed by Model 2 (1.80°) and minimal rotation in Model 3 (1.19°) [Figure 11 and Table 6]. This is because, the line of force is passed below the CRes of the maxillary dentition and lead to clockwise rotation of the maxillary plane.

This results were consistent with **Almeida et al**¹²⁰ in which they disclosed, that if the line of force passes below the maxillary CRes, it generates intrusive force in the molars and extrusive force in the incisors leading to clockwise rotation of the occlusal plane (OP), whereas, if the line of force passes above the maxillary CRes, it generates extrusive force in the molars and intrusive force in the incisors leading to counterclockwise rotation of the occlusal plane (OP). Hence, incisor extrusion must be expected when force passes below the CRes, which may be favorable for patients with open bite, on the contrary it is unfavorable for deep bite correction and gummy smile¹²³.

Likewise, the results were in agreement with the study conducted by **Jun Kawamura et al**⁹⁷, in which they studied to see the changes in occlusal plane during distalization of total maxillary dentition using distalization force of 300gms applied to the archwire at five different angulations(-30°, -15°, 0°, 15°, 30°). They concluded that the force angulations which passes below the CRes leads to

clockwise rotation of the occlusal plane, while the force angulations which passes at the CRes leads to minimal or no rotation of the occlusal plane.

Our results were also in accordance with **Yukio kojima et al¹²⁴**, they stated that when the line of action of force was passed to short power arm which is below the CRes of the maxilla, the entire dentition rotated in clockwise direction and when increasing the length of the power arm near to the centre of resistance, the rotation of the entire dentition decreased.

Jeong et al¹²⁵ reported that the center of resistance of the full maxillary dentition was 11.0 mm apical and 26.5 mm posterior to the incisal edge of the upper central incisor. Knowing the location of the centre of resistance (CRes) of the whole maxillary dentition is important when moving the whole dentition as one rigid body. Total arch distalization can be controlled by directing the line of action generated between the IZC and the power arm relative to the CRes of the maxillary arch.

Total distalization of the maxillary dentition without extraction of the maxillary premolars for Class II malocclusion correction has become commonly available with the development of temporary skeletal anchorage devices. Inter-radicular screws have anatomic limitations and are unable to distalize the maxillary dentition more than 3 mm. Henceforth, in Class II treatment, mini-screw placed in extra-radicular site can provide stable distal movement of the maxillary first molars and central incisors during total maxillary arch distalization.

The results of our study exhibited, in anteroposterior plane, the tipping of central incisor edge and mesiobuccal cusp of the first molar is maximum in model

1 and least in model 3, whereas, the central incisor root movement and mesiobuccal root of the first molar is greatest in model 3 and least in model 1. In vertical plane, the extrusion of central incisor edge and intrusion of mesiobuccal cusp of the first molar was maximum in model 1 and minimum in model 3, which indicates more clockwise rotation while using model 1. The substance drawn from our study states that, the desired biomechanical effect can be achieved by altering the retraction hook height in accordance with the required treatment objective, for instance, in open bite cases the usage of shorter power arm shall prove more beneficial and aid in clockwise rotation of the occlusal plane.

The present FEM study, poses few limitations namely, the displacement pattern alone for entire maxillary arch was assessed, whereas, the stress distribution due to the displacing force in the teeth, periodontal ligament and bone surrounding the IZC were not assessed. The other confinements in this study were, that the result may not reflect exact clinical outcomes, which are influenced by the cumulative effects of bone reactions and rebounding of the archwire, and the thickness of the periodontal ligament was assumed to be uniform (0.2 mm), whereas in reality, it can vary at the mid root level. There are other factors that were not taken into considerations are alveolar bone height, occlusal force, and soft tissue pressure from perioral muscles. Nonetheless, when supplemented with clinical, cytological, and biochemical research, the findings of this study may be effectively applied to clinical situation.

Thus, future clinical studies are warranted to compare the long term effects of skeletal, dental and soft tissue changes and treatment stability followed by total arch distalization with Infrazygomatic screw and varied power arm length.

SUMMARY AND CONCLUSION

This present insilico study was carried out to investigate the effect of distalization of total maxillary arch using infrazygomatic screw with varied power arm length and its associated biomechanical variations.

The CBCT of the skull was taken and Finite element analysis was done using Ansys software. Brackets, Buccal tubes and Infrazygomatic screws were scanned and converted into FEM model. Three different retraction hooks with varying length were modelled: 4mm, 8mm and 12mm in 0.019 x 0.025 inch stainless steel archwire.

The following conclusions were drawn from the present study:

1. In anteroposterior plane, the amount of crown movement in posterior direction was maximum in 4mm hook height, followed by 8mm hook height and least in 12mm hook height. The amount of root movement in posterior direction was maximum in 12mm hook height, followed by 8mm hook height and least in 4mm hook height.
2. In vertical plane, the extrusion of incisors and intrusion of molars was maximum in 4mm hook height, followed by 8mm hook height and least in 12mm hook height.
3. Rotation of the maxillary occlusal plane in clockwise direction is more in 4mm hook height and minimal in 12mm hook height.

To conclude from the results of our study, the desired biomechanical outcome can be achieved judiciously by altering the length of the power arm in relation to the centre of resistance of the maxillary dentition during total maxillary arch distalization using infrazygomatic screw.

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