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Evaluation Of Displacements Of Mandibular Teeth During Enmasse Distalisation With Varied Heights Of Buccal Shelf Screws And Retraction Hooks-A Finite Element Method Study

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Abstract:
Background: *To quantify the linear measurements of displacements occurring in mandibular teeth during enmasse distalization at various heights of buccal shelf screws and retraction hooks.*
Materials and Methods. *A finite element method was used for modeling mandibular teeth. The brackets, buccal tubes, retraction hooks and buccal shelf screws were designed by using 3D experience. In the mandibular model, buccal shelf screws were positioned at heights of 3 mm, 5 mm, and 8 mm below the cemento-enamel junction, and the retraction hooks at heights of 2 mm and 6 mm were placed between the lateral incisor and the canine. A bilateral force of 200 grams was applied through E chain connecting the retraction hooks to the implant heads. Three mandibular models (M1, M2, M3) were created and the displacements under various conditions were analyzed using ANSYS software.*
Results: *During mandibular distalization, the displacement of mandibular teeth was found to be gradually reduced as the heights of buccal shelf screws and retraction hooks were increased.*
Key Word: *Distalization, Buccal shelf screws, retraction hooks.*

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I. Introduction

En-masse distalization is a nonextraction orthodontic technique used to correct molar relationships such as Class II or Class III and reduce crowding, without causing arch expansion or interdental reduction. Treatment strategies vary between growing and non-growing patients; growth modification with orthopedic or functional appliances is feasible in younger patients, while adults typically require camouflage or surgical approaches. The advent of temporary anchorage devices like miniscrews has transformed orthodontics by providing reliable absolute anchorage for complex tooth movements, including molar distalization. Traditional intraoral appliances such as the Pendulum and Distal Jet have been used, but their limitations include anchorage loss, incisor flaring, and molar tipping, which miniscrews help to address. However, miniscrews pose risks like root damage during placement, leading to the increased use of extra-alveolar mini implants. The position and height of miniscrews and retraction hooks are crucial for achieving the desired tooth movement, particularly ensuring the force vector passes through the center of resistance for bodily movement. Accurate placement requires clinical judgment to optimize force application and minimize tipping. Establishing guidelines for the optimal heights of miniscrews and hooks, based on the movement type and the center of resistance, is essential. The finite element method (FEM) has become a valuable tool for simulating stress distribution and displacement patterns during orthodontic tooth movement. While many studies have evaluated displacement patterns at different miniscrew heights, few have quantitatively measured the linear displacements of mandibular teeth during en-masse distalization with varied heights of buccal shelf screws and retraction hooks. This study aims to use FEM to quantify the linear displacements of mandibular teeth during en-masse distalization at different heights of buccal shelf screws and retraction hooks.

II. Material And Methods

This study incorporates three-dimensional computer simulation and has obtained prior ethical approval from the Institutional Ethics Committee. It was conducted in the Department of Orthodontics at PSM College of Dental Science and Research in Thrissur, in collaboration with the CAD Lab in the Department of Mechanical Engineering at Manipal Institute of Technology.

Procedure methodology

Construction of 3Dmodel of the skull

A Cone Beam Computed Tomography (CBCT) image of patient's skull with full component of teeth was acquired in DICOM (Digital Imaging and Communications in Medicine) format with slice thickness 300 µm. Three dimensional geometrical construction of finite element model of mandibular dentition with their periodontal structures was done. Periodontal ligament was modeled of a thickness of 0.25 mm. The alveolar bone followed the cementoenamel junction gingivally and extended 1 mm beyond the apices. In the axial plane, the CT scan images of the mandibular dentition were taken. These data were exported to 3D image processing and editing software – MIMICS (version 18.0).

Modeling Of Orthodontic System

The format of images were transformed into STL files using reverse engineering techniques in the PG CAD lab of Aeronautical and Automobile Engineering at MIT, Manipal. The stereo lithographic (STL) format was employed for the models obtained from MIMICS.To develop the surface and solid features of the geometric model, Dassault Systems 3D was utilized to upload the model into the 3D Experience. Individual surface models of mandible were generated. To create precise outlines, the models were smoothed and improved. A continuous surface model was created by healing and joining the discontinuous surfaces. A solid model was then created based on the surface model.

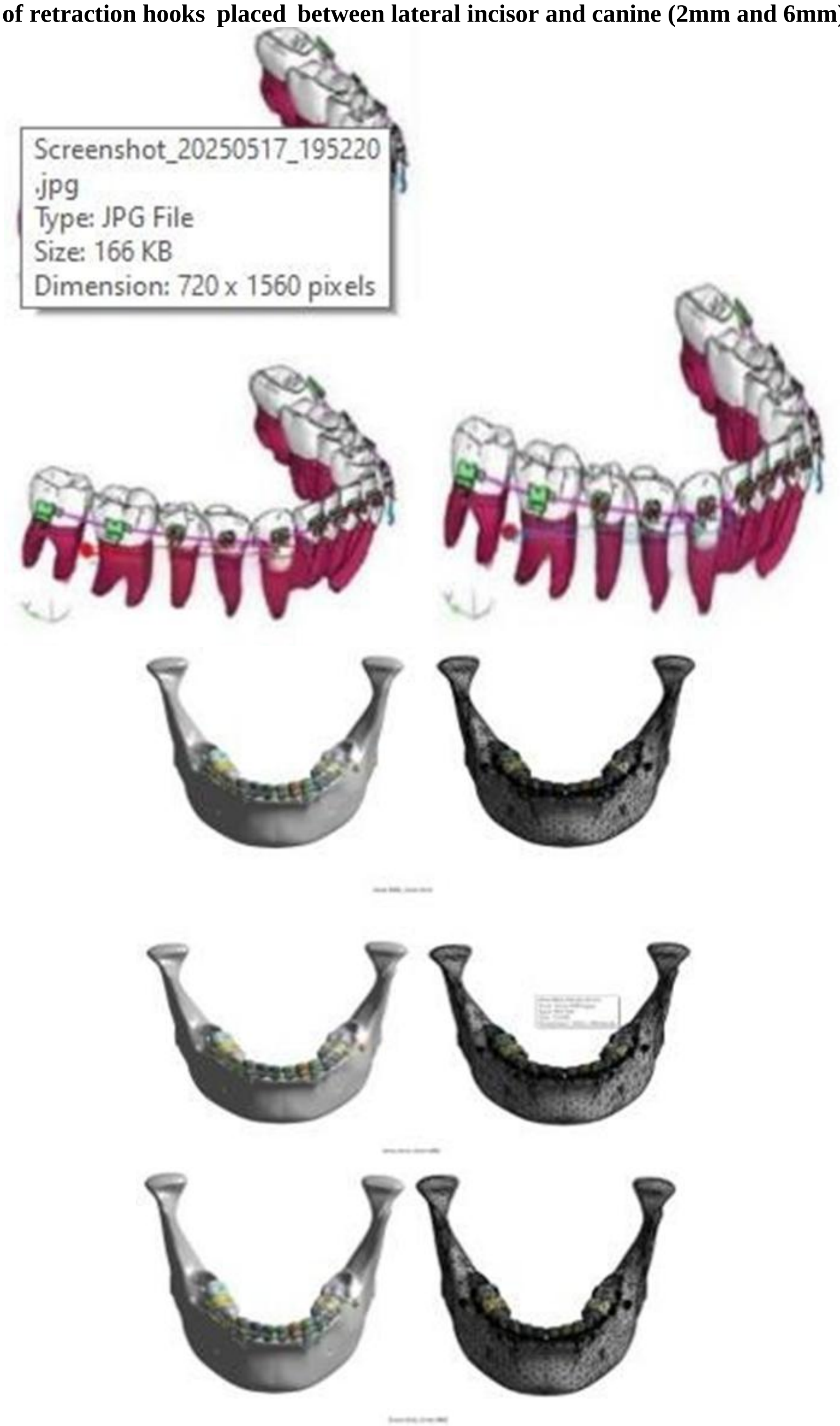
A three-dimensional model was developed that includes the mandible with complete dentition excluding third molars, the mandibular buccal shelf region, and a periodontal ligament with a thickness of 0.25 mm. It also features standard 0.022-inch slot preadjusted edgewise brackets with MBT prescription, buccal tubes, and two buccal shelf screws measuring 10 mm in length and 2 mm in diameter.Once the mandibular model were generated, all teeth were set up with metal brackets of MBT prescription with 0.022 x 0.028 inch slot and aligned with 0.019 × 0.025″ stainless steel wire. Brackets were attached to the crown so that the facial axis point was at the center of the bracket slot. The 0.019 × 0.025″ SS arch wire and retraction hooks using rigid (0.036-inch) SS wire, were modelled by 3D CAD modelling software with the help of 3D drawings, to minimize deflection when distalization force was applied. For the model to be used for enmasse distalization, the third molars were removed from the mandibular models on both sides.The buccal shelf screws (2 × 10 mm) and the miniscrews were made up of Stainless Steel.The brackets, buccal tubes and buccal shelf screws were designed by using 3D experience.

After that buccal shelf screws were placed at the area of buccal shelf region on both the sides of mandibular model and the point of insertion is inter-dentally between the first and second molars at different heights of 3, 5 and 8 mm below the cemento enamel junction.The retraction hooks of different heights (2mm and 6mm) were placed between lateral incisor and canine on either side of mandibular models (figure 3).The constructed 0.019 × 0.025" SS archwire was inserted into bracket slot and extended till the distal part of the second molar. A force of 200 gram is applied bilaterally with the help of E chain between the retraction hooks and the head of the implant on either sides of mandibular models.FEM Models are depicted in Table :1. Incisal edges of mandibular anteriors were used as land marks for the assessment of displacement.

Table1: MANDIBLE

Models	Buccal shelf screw Height (mm)	Hooks height(mm)
M1	3	2
		6
M2	5	2
		6
M3	8	2
		6

Figure 3: buccal shelf screws were stimulated at 3mm,5mm and 8mm respectively with different lengths of retraction hooks placed between lateral incisor and canine (2mm and 6mm)



Creation Of Mesh Model

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 that given these elements were not overlapping but are connected only at the key points, which are known as nodes. The joining of elements at the nodes and eliminating duplicate nodes is termed as'Meshing'. The total number of nodes and elements established in mandible are 2320140. Interfaces between different structures were considered bonded to avoid relative movement throughout all model interfaces.

Application of Material Properties & Boundary/Loading Conditions

When the meshing and contacts are defined, the next process is to setup boundary condition and it was established at the condylar region. After creating the 3D model, it was transformed into a Finite Element (FE) model using ANSYS software (2024 R2). The preprocessing stage involved cleaning up the geometry, generating the mesh, assigning material properties, and applying loads and boundary conditions. Material design was conducted using ANSYS software from Dassault Systems.

In this study, all materials were considered to be isotropic, linear-elastic, and homogeneous. Properties of materials applied, such as Young's modulus and Poisson's ratio, were obtained from the literature and depicted in (table 3).

Table no: 3 : Material properties of various components used in this study

	Young's Modulus	Poisson's ratio
Teeth	1.96×10^4	0.31
PDL	0.667	0.45
Stainless steel	190,000	0.31
Cancellous bone	1.37×10^3	0.30
Cortical bone	1.37×10^4	0.26

Static Structural Analysis Of Orthodontic System

In the mandibular model, three different models were developed, M1, M2, and M3 (Table:1). The force of 200 grams were applied through e-chain to all the models.

Model 1 (M1): Composed of mandibular teeth bonded with bracket of MBT prescription in a 0.022 x 0.028-inch slot and 19 x 25 SS wire was inserted. Buccal shelf screws were placed 3mm below the cemento enamel junction and retraction hooks (2 and 6 mm) were placed (Figure 3).

Model 2(M2): It resembles Model 1 but buccal shelf screws were positioned 5mm below the cementoenamel junction.

Model 3(M3): As similar to Model 1 but buccal shelf screws were placed 8mm below the cemento enamel junction.

Analysis Of Results In Orthodontic System

Once the loads were defined, programs were run using ANYSYS software and the results have been tabulated. Anterior segment of mandibular teeth were used as landmark for the assessment of displacement. A standard coordinate system was established with the y-axis corresponding to the bucco lingual direction. +y value was defined as the posterior direction. The linear measurements of displacements of mandibular anterior teeth from the initial to final position were calculated.

III. Result

In the present study, FEM interpretation was done to assess the displacements in anteroposterior plane along the Yaxis during mandibular distalization. A positive value (+Y) indicates posterior displacement and a negative value (-y) indicates anterior displacement . The extent of displacement was determined using a series of colour arrows. Displacement of mandibular teeth in Anteroposterior plane:

In **Model 1 (M1),** buccal shelf screws were positioned 3mm below the cemento enamel junction, and the distalization force of 200 grams were applied to retraction hooks (2mm and 6mm).The maximum displacement of the mandibular teeth observed was 5.30E -05 mm when utilizing the combination of 3mm buccal shelf screw and 2mm retraction hooks(Figure: 4).

For the **Model 2 (M 2),** buccal shelf screws were placed 5 mm below the cemento enamel junction and 200 grams of force were applied to the retraction hooks of heights 2mm and 6mm. The displacements of mandibular teeth was maximum of 2.66 E -05 mm observed in combination of 5 mm buccal shelf screws and 2 mm retraction hooks(Figure: 4).

In the case of **Model 3 (M3),** buccal shelf screws were positioned 8mm below the cemento enamel junction and distalization force of 200 grams were applied to the retraction hooks of 2mm and 8mm. The maximum displacement of mandibular teeth was 2.31 E -05mm and it was seen in the combination of 8mm buccal shelf screws with 2mm retraction hooks (Figure: 4). During enmasse distalization, the displacement of mandibular teeth was found to be reduced as the heights of buccal shelf screws and retraction hooks were increased. Comparison of displacements of mandibular teeth were illustrated in Table 4,Graph 1.

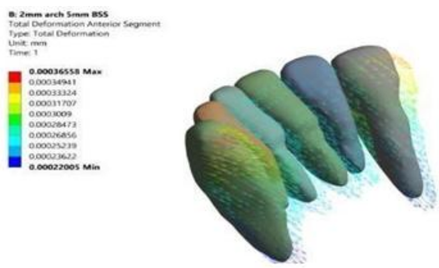
Table no 4: Displacements of mandibular teeth

BUCCAL SHELF SCREW POSITION(MM)	Y-axis	Y-axis
	2mm	6mm
3	5.30E-05	2.36E-05
5	2.66E-05	1.72E-05
8	2.31E-05	1.53E-05

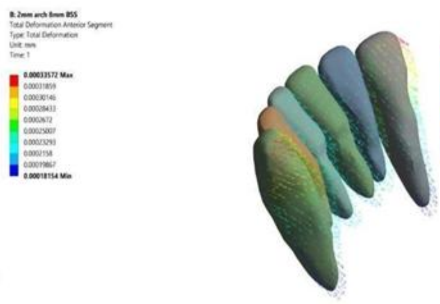
Figures 4: Mandibular Models
Displacement of Mandibular Anterior teeth with Buccal shelf screws

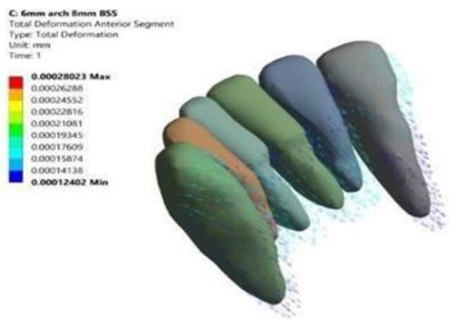
MODEL 1

MODEL 2

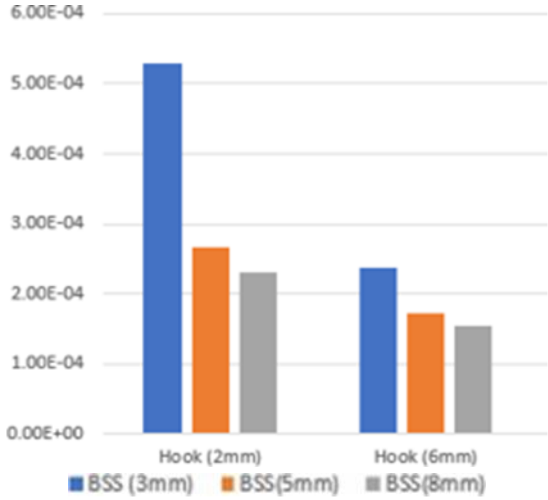


MODEL 3





Graph 1: Comparison of displacements of mandibular anterior teeth in Y direction with varied heights of retraction hooks



IV. Discussion

Distalization is a conventional orthodontic method used to create space by moving the posterior teeth in a distal direction. It has been effectively used for several years to treat mild to moderate Class I, Class II, and Class III malocclusions. This method can be categorized based on the dental arch involved, the site of appliance placement, removable or fixed, as well as extraoral or intraoral. The choice of treatment approach depends on several factors, including the clinician's priorities, the severity of the malocclusion, the patient's age and their compliance.

Distalization helps to achieve satisfactory results for the patient, since many patients are reluctant to consent to the surgical option because of increased risk and treatment financial cost. It is the most advisable treatment option for patients who aim to avoid premolar extractions and complicated orthognathic surgery, with long recovery time. Combining regional acceleratory phenomenon and a mini-implant anchorage system may help in achieving satisfactory results with a shorter treatment time.[9,10,11,12] In order to facilitate the distalization of mandibular arch, third molar extraction is almost invariably mandatory. Extraction of mandibular third molars just prior to distalization may create a regional acceleratory phenomenon and help to speed up tooth movements. Antonarakis and Kiliaridis et al[13], have published a systematic review examining 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 minimize these side effects, temporary anchorage devices were introduced to facilitate enmasse distalization as well as to accelerate the orthodontic treatment.Micro-implants and extra-radicular bone screws have revolutionized contemporary orthodontic treatment mechanics by introducing the concept of absolute anchorage [14]. Absolute anchorage have significantly broadened the scope of orthodontics, providing a wider variety of nonsurgical, non- extraction, and noncompliant treatment options.

Sugawara et al[15] highlighted the effectiveness of orthodontic bone screws for mandibular molar distalization without causing undesired movement of incisors. The distalization techniques with these extraradicular bone screws aimed to achieve goal of clinical excellence which enhances patient outcomes and expands the capabilities of orthodontic practice.Treatment strategies for mandibular distalization that involve analyzing displacements and stress distributions can be effectively evaluated using the finite element method (FEM).The FEM is a potent tool which enables quantitative visualization of an object in all three dimensions.

Even though several FEM studies have been conducted to evaluate the displacements of mandibular teeth using miniscrews and retraction hooks at varied heights , few studies have quantified the linear measurements of displacements during enmasse distalisation with varied heights of mini implants and retraction hooks.In the present study, FEM is used to quantify the linear measurements of displacements occurring in mandibular teeth during enmasse distalisation at various heights of buccal shelf screws and retraction hooks.

Mini screws positioned in the buccal shelf area produce a retraction force system that aids in the distalization of the mandibular arch. Each particular case requires the appropriate application of force regarding the direction and anchoring point. Therefore, two key factors must be considered when examining effective force design, which enables various types of tooth movements. These factors include the heights of retraction hooks in the anterior area and height modifications in extra-alveolar mini-implants insertion.

It is not always feasible to adjust the heights of mini-implants due to various factors that influence the selection of the optimal location. However, considering the required force direction for each case, it is understood that the type of anterior retraction hooks or power arm, specifically its height and placement will significantly affect the type of tooth movement. Adjustments to the geometry of force through various heights of miniscrews and retraction hooks in the anterior region of mandibular arch can influence incisor torque control and also determines the vertical force component.[16]

There were different opinions on the significance of lengths of retraction hooks. Some authors argue that the height of the power arm is more critical, while others emphasize that the position of the attachment is more important. To address this issue, the present study simulated three different heights of miniscrews and two different heights of retraction hooks in the mandibular models in which buccal shelf screws were positioned at the heights of 3, 5 and 8 mm below the cemento enamel junction along with retraction hooks of 2mm and 6mm.This study provided insights into the optimal combinations of these components.Identifying the ideal placement of orthodontic mini-implants and anterior retraction hooks are essential for maximizing distalization and preventing any undesired labial or lingual inclination of the teeth.

As the height of the anterior retraction hooks increases, the line of force can move closer to the center of resistance of mandibular dentitions. This reduces the vertical force component ,which is caused by the height difference between the retraction hooks and miniscrews, thereby facilitating bodily movement of the tooth without uncontrolled tipping. Ultimately, optimizing these parameters can enhance orthodontic treatment outcomes and improve treatment efficiency.

In 2013, Ashekar et al[17]assessed the optimal positioning of retraction hooks and miniscrews in the maxillary arch during enmasse retraction. He utilized retraction hooks of lengths 0, 5, and 8 mm, along with 6, 8, and 10 mm miniscrews. He concluded that the optimal length of the retraction hooks varied based on the placement of the mini implants. Specifically, for the 6 mm implant position, he preferred to use 5 mm hooks to achieve bodily movement. The study recommended that in order to achieve optimal posterior displacement, it's essential for the force vector to pass near the center of resistance rather than passing through it . To achieve this, the implant and the anterior retraction hooks can be positioned nearly at the same height, thereby minimizing the vertical force components that may arise from any height difference between the retraction hook and the miniscrews.Most previous studies[17] conducted on whole arch distalization have utilized loading forces ranging from 200 to 300 grams. Among these, a force magnitude of 200 grams was chosen , as it was found to minimize the side effects such as root resorption and periodontitis.

Therefore, for this study, force magnitude of 200 grams were selected.

Suzuki et al[18]. studied power arm lengths of 0, 5, and 10 mm, finding that increasing length reduced incisor extrusion and promoted bodily movement. They used finite element analysis to assess stress patterns and observed that longer power arms helped to achieve bocily movement. Zohreh Hedayati and Mehrdad Shomali[19] in 2016 identified that 9mm hook height minimized rotation of anterior dentition and achieved bodily retraction during enmasse retraction. Namburi et al[20]. examined mini-implants of 7, 10, 13, and 12 mm heights, finding that 10 mm implants best facilitated bodily movement. Low level implants caused tipping, while higher ones resulted in intrusion.

In the current study during enmasse distalization, the displacement of mandibular teeth was found to be gradually reduced as the heights of buccal shelf screws and retraction hooks were increased.Understanding the center of resistance of the mandibular arch is essential for controlled distalization, with Lee et al. estimating its position near the mesial root of the first molar, approximately 13.5 mm below and 25 mm behind the incisal edge. By understanding the location of center of resistance , it is possible to control mandibular distalization by directing the line of action between the buccal shelf screws and retraction hooks in relation to the centers of resistance of mandibular arch.Limitations of finite element analysis highlight the need for long-term studies, such as randomized controlled trials, to better understand biological responses and develop clear biomechanical guidelines for implant-supported distalization using temporary anchorage devices.

V. Conclusion

The study concluded that during enmasse distalization, the displacement of mandibular teeth was found to be gradually reduced as the heights of buccal shelf screws and retraction hooks were increased.

The selection of hook length for whole arch distalization should be based on the patient's malocclusion and treatment goals, with short hooks facilitating anterior crown tipping and posterior intrusion to reduce open bites, and long hooks promoting palatal root movement and posterior rotation for deep overbites. Careful planning of miniscrew placement and power arm heights is crucial to achieve desired tooth movements, with proper biomechanics and case selection enhancing treatment success. Ultimately, individualized treatment planning ensures optimal outcomes by appropriate hook selection, miniscrew positioning, and biomechanics with each patient's specific needs.

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