EVALUATION OF CENTER OF RESISTANCE OF MAXILLARY ANTERIOR SEGMENT WHEN RETRACTING WITH LINGUAL APPLIANCE, SLIDING MECHANICS AND PALATAL MINI-SCREW IMPLANTS - A FINITE ELEMENT STUDY

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CHENNAI

DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation titled **"EVALUATION OF CENTER OF RESISTANCE OF MAXILLARY ANTERIOR SEGMENT WHEN RETRACTING WITH LINGUAL APPLIANCE, SLIDING MECHANICS AND PALATAL MINI-SCREW IMPLANTS - A FINITE ELEMENT STUDY"** is a bonafide and genuine research work carried out by me under the guidance of **Dr.Kavitha S Iyer, M.D.S.,** Reader, Department of Orthodontics and Dentofacial Orthopedics, Ragas Dental College and Hospital, Chennai.

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PLAGIARISM CERTIFICATE

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On verification with the urkund.com website for the purpose of plagiarism check, the uploaded thesis file from introduction to conclusion contains **3 percentage** of plagiarism, as per the report generated and enclosed in Annexure – II.

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CERTIFICATE

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This dissertation is submitted to **THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY,** in partial fulfillment for the degree **of MASTER OF DENTAL SURGERY in BRANCH V** - Orthodontics and Dentofacial Orthopedics. It has not been submitted (partially or fully) for the award of any other degree or diploma.

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ABSTRACT

Aim:

To evaluate the center of resistance of maxillary anterior segment in second bicuspid extraction cases when retracted using lingual appliance with sliding mechanics using palatal mini-screw implants (MSI) , different position and length of power arm using finite element method(FEM).

Materials and Methods:

A three dimensional finite element model was constructed using CBCT and intra oral laser scan data of the patient. The lingual appliance was modeled along with the lingual arch wire and second bicuspids were extracted from the model.

The study was divided into four groups according to the condition of different retraction mechanics, each differing in position of the power arm and mini-screw implants (MSI). In the group A and C power arm were placed between the lateral incisor and canine on both sides and in group B and D power arm were placed between central incisor and lateral incisor on both sides. Two different length of the power arm (10mm and 13mm) were used in both the positions. In the group A and B, MSIs were placed at four heights, 4mm, 6mm, 8mm and 10mm in the interdental palatal slope mesial to the first molar measuring from the cervical region. In group C and D, MSIs were

placed in the mid palatal region at two different levels 12mm and 24mm behind the distal most portion of the incisive papilla.

A retraction force of 200 gm per side from the hook, towards the direction of the mini-implant position was applied and tooth displacement was studied in Y-axis (anterior-posterior) direction and the Z-axis to the (coronal-apical or vertical) direction by probing points marked at the crown and root of the reference teeth.

Descriptive statistics and two dimensional line graphs were used to represent the type of tooth movement in each reference tooth in all the groups.

Results:

The results of our study in Y-axis showed decreased torque loss in group C when 13mm power arm placed between lateral incisor and canine with MSI placed at 12mm behind the incisive papilla on the mid-palatal area. Group B showed bodily retraction of anterior segment with 13mm power arm placed between central and lateral incisor with MSI placed 8-10mm in the posterior palatal slope mesial to the first molar but the central incisor showed severe torque loss. Group A and D showed loss of torque of anterior segment in all the retraction conditions of which group D showed comparatively less torque loss when MSI placed 12 mm behind the incisive papilla with 13mm length of power arm. When mid-palatal MSI is compared with MSI placed in the posterior palatal slope with power arm placed between the lateral incisor and canine, more desired tooth movement is seen in sagittal and vertical plane with the mid-palatal MSIs. When the results of group B and group D were compared, group D showed a more controlled crown tipping during retraction with power arm placed between central and lateral incisor.

Conclusion:

Based on the findings of this study we concluded the following,

1. Incisor retraction was effective with minimal torque loss in the group in which the MSI was placed 12mm from the incisive papilla in the maxillary midline.
2. Between the two lengths of power arm that were evaluated, the length of the power arm that was 13mm seem to have a bodily tooth movement.
3. Similarly, the group in which the power arm located between the canine and lateral incisor exhibited greater bodily retraction.

Based on FEM analysis it is logical to conclude that when lingual appliances, a sliding mechanics with the power arm length of 13 mm located between the maxillary lateral incisor and canine and origin of force at MSI placed 12mm from the incisive papilla on the mid-palatal suture region could be the best combination for maximum bodily retraction with minimal torque loss.

However the clinicians should be aware of the inherent limitation of the FEM study and use his clinical acumen when extrapolating these findings in clinical situations.

Key words:

CENTRE OF RESISTANCE, MINI-SCREW IMPLANTS, MID-PALATAL IMPLANTS,

Introduction

INTRODUCTION

In the recent years lingual orthodontics has gained popularity due the increase in the number of adults seeking orthodontic treatment and high aesthetic demand.

The treatment planning as well as biomechanical considerations will vary from labial to lingual orthodontics. Knowledge concerning the location of the center of resistance of maxillary anterior teeth would contribute to a successful treatment result and a possibly reduced treatment time. Efficient orthodontic tooth movement depends on an appreciation of the relationship between a line of action of the force and the center of resistance of a tooth. In retraction, force passing through center of resistance results in bodily tooth movement and a force which does not pass through the center of resistance produces a moment that tends to rotate the tooth.[34]

Even though, in lingual orthodontics, retraction can be done with sliding as well as loop mechanics, most clinicians prefer sliding mechanics due to patients comfort. Lever-arm or power-arm mechanics is used to achieve bodily translation by keeping the line of force closer to the center of resistance of anterior teeth. A retraction force parallel to the occlusal plane which is applied through the center of resistance of the anterior teeth will bodily retract the anterior segment of teeth.[8]

Temporary anchorage devices (TADs) or Mini-screw implants (MSIs) are used to provide absolute skeletal anchorage and good control over tooth movement in all the three planes. Especially MSIs has an additional advantage in achieving good torque control and absolute intrusion which helps to reduce the vertical bowing effect during retraction in lingual orthodontics.

The position of mini-screw implant (MSI) and the length of the power arm which contributes to the retraction system play a major role in determining the type of tooth movement, tipping or bodily movement. So it is important to determine the position of the MSIs and the position of the power arm and its length which greatly influences the retraction by providing the optimal line of force.

Also, the change in position of force application from labial to lingual orthodontics changes treatment planning. The force applied in lingual orthodontics is placed close to the center of resistance which makes retraction of anterior teeth easier. The anchorage loss in lingual orthodontics is comparatively very less due to the distobuccal rotation of the distal root of first molar resulting in cortical anchorage. This in turn reduces the space requirement during retraction. Therefore the cases requiring first premolar extractions can be treated by extracting second premolars. Another advantage of extracting second premolar in lingual orthodontics is that, the extraction space is presented posteriorly.

Therefore we decided to compare the retraction mechanics in lingual orthodontics to find the optimal position of the mini-screw implants(MSI), the position and length of the power arm for effective enmasse retraction of the anterior segment in second bicuspid extraction cases which is previously not dealt in the literature so far.

This study was designed to locate the center of resistance of maxillary dentition by identifying the optimal position of the MSI and the ideal length and position of the power arm by using finite element method. The FEM analysis model was constructed from second premolar extraction case.

Aim of the Study:

To estimate the optimal line of action of force through center of resistance for bodily retraction of maxillary anterior segment in a maxillary second premolar extraction case treated with lingual appliance. This can be achieved by finding

1. The optimal position of the palatal mini-screw implants for retraction.

2. The ideal position and length of the power arm for retraction.

Review of Literature

REVIEW OF LITERATURE

- **Lingual treatment mechanics**
- **Center of resistance**
- **Palatal mini-implants**

LINGUAL TREATMENT MECHANICS

Lee, Park and kyung[29] (2001) used micro-implant anchorage for lingual treatment of a skeletal class II malocclusion. A 19 year old female patient of skeletal class II with severe overjet (10mm) and anterior openbite of -2mm was treated with lingual appliance and micro-implant (1.2 mm in diameter, 10 mm in length) placed in the palatal alveolar bone between the maxillary first and second molar in a 30˚ to 40˚ angle to the bone surface to avoid root contact. Nickel titanium coil springs were stretched between the micro-implant and the hooks on the anterior part of the archwire. Class I canine was achieved seven months after micro-implant placement. Normal overjet and overbite was achieved. This demonstrated that micro-implants can provide reliable, absolute anchorage for lingual orthodontics.

Kim et al.[19] (2004) used a C-lingual retractor to treat severe class II anterior deep bite malocclusion in a 24 year old female patient. The C-lingual retractor had 3 components – 1. Mesh part soldered lever arm, 2.Wire with bent hook and 3.auxillary hook soldered for intrusion. The position of the bent hook follows the line of action of force and passes through the center of resistance. Extraction of upper first premolars and intrusion and retraction of upper six anterior teeth was done using an intra-arch anchorage unit, transpalatal arches in first and second molar bands. Double niti closed coiled springs were used for retraction and a high pull head gear was used for anchorage reinforcement during en masse retraction. Normal overjet and overbite was achieved in 14 months of treatment time, by intruding and retracting the maxillary 6 anterior teeth using a C-lingual retractor. Study concluded that C-lingiual retractor as an alternative method for segmental orthodontics and can be an effective tool for closing extraction space in various vertical dimensions.

Kawakami et al.[17] (2004) presented a case of bimaxillary protrusion treated with second premolar extraction using screw-type implants as an anchorage for lingual orthodontic mechanics. A 22 year old woman with convex profile and bialveolar protrusion with class I molar with moderately crowded anterior teeth was treated with extraction of upper and lower second premolars following lingual orthodontic treatment with maxillary and mandibular micro-implants for absolute anchorage. Titanium screws (1.5 mm in diameter , 15mm in length) were implanted in the upper and lower alveolar bones in the interseptal areas of the molars to avoid root damage. Force was applied with an elastic thread using ligation of the titanium screws. After 12 months of retraction, all implant screws were removed. Results showed good occlusion and her facial profile improved with retraction of upper and lower lips. This report concluded that lingual orthodontics is an excellent system for invisible treatment in an adult patient and that implant anchorage with titanium screws can be used for efficient anchorage maintenance with anterior retraction procedures.

Hong et al.[10] **(2005)** suggested a lever arm and mini-implant system for anterior torque control during retraction in lingual orthodontic treatment. Torque control of the anterior teeth during space closure is the most difficult problems in lingual orthodontic treatment. The torque control is achieved by using lever-arm mechanics to obtain the desired line of action of the force with respect to center of resistance. Using cephalograms, the force application and line of action are planned for obtaining desired force and designing optimal lever-arm and mini-implant system. By adjusting the length of the lever-arm and the position of the mini-implant, the desired line of action of the retraction force with respect to the center of resistance of the anterior segment is established.

For determining the length of the lever-arm and the position of the mini-implant , the center of resistance of the unit to be moved is set as a basic point. **Vandenbulcke et al** [48] have concluded that the center of resistance for 6 anterior teeth was located at 7 mm apical to the interproximal bone level between the central incisors, when measured perpendicular to the occlusal plane. Using this point, the length of the lever-arm and the position of the mini-implant are determined for different clinical situations during retraction.

Hyun sang Park[11] **(2006)** designed a miniscrew assisted transpalatal arch for use in lingual orthodontics. An .036” round stainless steel wire soldered to the first molar bands and an .028” round stainless steel connecting wire and soldered brass hooks to the TPA for application of the retraction force. And this connecting wire is directly bonded to the palatal implant. Force is given by closed coil springs or elastic chain attached to the lever arms which are connected to the lingual archwire. Author concludes that miniscrew behind the TPA provides a better biomechanical point of retraction force application than when anchorage is supported extra orally.

Hee-Moon Kyung[29] (2006) explains the use of micro-implants in lingual orthodontic treatment. He advocates at least 6mm of the screw portion into the bone for maxillary micro-implants. Following are the general guiding rules and his recommendations. palatal mucosal thickness of 6mm, use a 12mm screw; midpalatal thinner mucosa, use a 6 to 7 mm screw; buccal alveolar region and attached gingiva, use 7-8mm mini-implants; adult patients with thick dense cortical bone use a 7mm screw; young patients; less dense cortical bone, use a 8 mm screw; labial aspect of maxillary incisors, good quality bone and not subjected to occlusal forces, use a 6mm screw. The diameter of the screw shanks can vary from 1.2 to 2.0mm. Screw diameter can be varied depending on the site of placement. Maxillary buccal or labial regions, 1.3 to 1.5 mm thickness screw; Palatal interdental regions, 1.4 to 1.6 mm thickness screws; Midpalatal regions, depending on bone density 1.6 to 2 mm thickness screws are recommended.

Chung et al.[6] (2008) describes the treatment of class II malocclusion with severe anterior protrusion and a high mandibular plane angle for a women patient aged 25 years, treated by combining lingual retractor and a palatal plate. In lingual enmasse retraction of maxillary anterior teeth, torque and anchor control are the most impotant factors. The treatment plan consisted of extracting both first maxillary first premolars and retraction of 6 anterior teeth in the maxilla. A c-lingual retactor was used combines with a palatal c-plate with horizontal arm and 1.5 x 5mm miniscrews were used and enmasse retraction was performedand treatment was completed. This appliance reduces periodontal damage and discomfort in the maxillary posterior dentition. The concluded that c-plate and c-retractor combined approach can be used for maximum anchorage requirement cases and this method can be effective for intrusive retraction of anterior teeth.

Tamamura et al.[45] (2009) reports the successful treatment method of scissors-bite correction using miniscrew anchorage and a lingual multi-bracket appliance. A female patient, 17 years old with Angle Class I malocclusion with bimaxillary protrusion and incisor crowding and also showed a scissorsbite of the second molar on the right side. Miniscrews were inserted into the palatal region of the upper second molar to reinforce the anchorage, and a lingual multi-bracket appliance was placed into the maxilla. Miniscrews inserted palatally were used to correct the scissors-bite in the first 3 months; afterward, they were used to retract the six anterior teeth. The total active treatment period was 26 months. Because of the bite-plane effect, the upper and lower molars were separated in occlusion, and the scissors-bite was corrected effectively within a short time. Author concluded that combined use of palatal miniscrew anchorage and lingual multi-bracket appliances enhances efficiency of molar scissors-bite correction.

Sung et al.[43] (2010) designed effective enmasse retraction with orthodontic mini-implant anchorage using finite element analysis. The design of an appliance for correcting a bialveolar protrusion by using orthodontic mini-implant anchorage and sliding mechanics must take into account the position and height of the miniimplant, the height of the anterior retraction hook and compensating curve, and midline vertical traction.

Mo et al.[32] (2011) evaluate the factors that affect effective torque control during en-masse anterior retraction by using intrusion overlay archwire and partially osseointegrated C-implants as the exclusive sources of anchorage without posterior bonded or banded attachments. Base models were constructed from a dental study model. No brackets or bands were placed on the posterior maxillary dentition during retraction. Different heights of the anterior retraction hooks to the working segment archwire and different intrusion forces with an overlay archwire placed in the 0.8-mm diameter hole of the C-implant were applied to generate torque on the anterior segment of the teeth. The amount of tooth displacement after finite element analysis was exaggerated 70 times and compared with tooth axis graphs of the central and lateral incisors and the canine. Results showed that the height of the anterior retraction hook and the amount of intrusion force had a combined effect on the labial crown torque applied to the incisors during en-masse retraction. The difference of anterior retraction hook length highly affected the torque control and also induced a tendency for canine extrusion. They concluded that with a 70-g intrusion force and a 1-mm high hook, the maxillary central incisors displaced lingually in a controlled tipping pattern. Increasing the hook height to 4 mm produced almost bodily movement, and, in the 10-mm group, root retraction was produced ahead of the crowns. As intrusion force increased, the amount of coronal retraction decreased, and root retraction increased. Higher intrusion forces and longer retraction hooks also caused increased incisor intrusion and canine extrusion.

Kim at al.[18] **(2011)** analysed lingual en masse retraction combining a C-lingual retractor and a palatal plate. Pretreatment cephalometric radiographs with those taken after en masse retraction of the six anterior teeth were acquired and the sample consisted of 35 non growing patients with an average age of 22.9 years. The average retraction period was 10 months and a total of 35 C-palatal plates were used as the only source of anchorage for maxillary anterior retraction with the C-lingual retractor, thereby eliminating the need for bonded or banded anchor teeth. The cephalometric radiographs were analyzed for differences between pretreatment and postretraction variables. Results showed significant incisor and canine retraction was achieved in all patients, and the upper posterior teeth did not show significant mesial drifting during the retraction period. According to the length of the lever arm of the C-retractor, tooth movement showed different directions. The analysis confirmed that the system produced excellent and efficient retraction with good control of torque and desired intrusion of the anterior segment, and there was no significant effect on the upper posterior buccal dentition, which had no attachments whatsoever during the retraction.

Park et al.[35] **(2012)** reported esthetic orthodontic treatment with a double J retractor and temporary anchorage devices for managing a Class II malocclusion in an adult. The patient, a woman aged 24 years 2 months, had crowding and a convex profile. She was treated with maxillary first premolar extractions, a double J retractor, and temporary skeletal anchorage devices in the maxillary arch and used bonding pads instead of mesh brackets, which were common with earlier lingual retractors. The anterior lever arm hooks were bent in the wire approximately 20 mm from the pad so. Three temporary skeletal anchorage devices were placed (OSAS, Tuttlingen, Germany). Two (diameter, 1.6 mm; length, 8.0 mm) were placed palatally between the maxillary first and second molars, and 1 temporary anchorage device (diameter, 1.6 mm; length, 7.0 mm) was placed in the midpalate. Elastic chains or superelastic closed-coil springs were stretched from the anterior hooks to the temporary skeletal anchorage device. Posttreatment records after 2 years showed excellent results with good occlusion and long-term stability. They concluded that The double J retractor is an esthetic, effective, and simplified option for closing spaces caused by tooth extractions. It uses a single point force, so by controlling the magnitude and direction of the force, it is easy to prevent unwanted tooth movements. Since it can easily retract the maxillary anterior dentition in the various vertical dimensions, it could be an effective alternative in appropriate situations for patients who are reluctant to use conventional fixed appliances.

Mo et al.[33] **(2013)** evaluated the factors that affect torque control during anterior retraction when utilizing the C-retractor with a palatal miniplate as an exclusive source of anchorage without posterior appliances. The C-retractor was modeled using a 3-dimensional beam element (0.9-mm-diameter stainless-steel wire) attached to mesh bonding pads. Various vertical heights and 2 attachment positions for the lingual anterior retraction hooks (LARHs) were evaluated. A force of 200 g was applied from each side hook of the miniplate to the splinted segment of 6 or 8 anterior teeth. Results showed during anterior retraction, an increase in the LARH vertical height increased the amount of lingual root torque and intrusion of the incisors. In particular, with increasing vertical height, the tooth displacement pattern changed from controlled tipping to bodily displacement and then to lingual root displacement. The effects were enhanced when the LARH was located between the central and lateral incisors, as compared to when the LARH was located between the lateral incisors and canines. Study concluded that LARH can be placed between the central and lateral incisors or between the lateral incisors and canines. Placement distal to the central incisors was considered preferable because the treatment effects were better. If the LARH is distal to the lateral incisors, a vertically higher hook is necessary to achieve bodily displacement.

Kwon et al.[25] (2014) introduces a lingual bonded retraction system (Kinematics of Lingual Bar on Non-Paralleling Technique, KILBON) for efficient sliding mechanics combined with vertical control of the anterior and posterior teeth, which is suitable for Class II hyperdivergent patients. Patient with hyperdivergent class II malocclusion were treated with the KILBON system and temporary skeletal anchorage devices on the palate in the paramedian area. Results showed that a large amount of intrusion and retraction of the anterior teeth and simultaneous intrusion of the posterior segment were achieved in short treatment time. Concomitant counterclockwise rotation of the mandible improved the esthetic profile. Periodontal support without dehiscence or bone loss was confirmed on anterior region in spite of large amount of retraction. This report presented a lingual retraction system that provides simple and effective vertical and sagittal control of both anterior and posterior teeth.

Lambardo et al.[52] (2014) compared displacements and stress after en masse retraction of mandibular dentition with lingual and labial orthodontics using three-dimensional finite element models. A 3D FEM of each lower tooth was constructed and located as appropriate to Roth's prescription. The 0.018-in. GAC Roth Ovation labial and Ormco 7th Generation lingual brackets were virtually bonded to the lower teeth and threaded with 0.018 × 0.025- and 0.016 × 0.022-in. SS labial and lingual mushroom archwires. En masse retraction was simulated by applying 300 g of distal force from the canine to the second premolar on the 0.016 × 0.022-in. SS labial and lingual archwires. The type of finite element used in the analysis was an eight-noded brick element. The Algor program was used to calculate the strains and displacements at each nodal point. Results showed lingual tipping and extrusion of the anterior dentition occurred with both archwires. At the premolars and first molars, intrusion, lingual movements, and lingual tipping were seen with the labial archwire, while intrusion was accompanied by labial movements, mesial tipping, and buccal rotation with lingual mechanics.

Lingual and labial mechanics provoke very different stress patterns and consequently tooth movements. Specifically, considering a first premolar extraction case treated by lingual orthodontics, more tipping and less extrusion occurred at the lower incisors and less lingual tipping and more distal tipping and extrusion at the canines. Furthermore, at the second premolars, transverse, vertical, and sagittal displacements were less pronounced and rotational movement was greater. At the lower first molar, rotational movement was more prominent with the lingual technique, while mesial tipping was greater with the labial technique, whereas at the second premolar, rotational movement was greater with lingual mechanics, while labial mechanics produced greater mesial tipping.

Seo et al.[41] (2015) evaluated and compared the effects of two appliances on the en masse retraction of the anterior teeth anchored by temporary skeletal anchorage devices (TSADs). The sample comprised 46 non growing hyperdivergent adult patients who planned to undergo upper first premolar extraction using lingual retractors. They were divided into three groups, based on the lingual appliance used: the C-lingual retractor (CLR) group and two antero-posterior lingual retractor (APLR) groups. The APLR group was divided by the posterior tube angulation; posterior tube parallel to the occlusal plane and distally tipped tube. A retrospective clinical investigation of the skeletal, dental, and soft tissue relationships was performed using lateral cephalometric radiographs obtained pretreatment and post en masse retraction of the anterior teeth. Results showed that all groups achieved significant incisor and canine retraction. The upper posterior teeth did not drift significantly during the retraction period. The APLR group had less angulation change in the anterior dentition, compared to the CLR group.

By changing the tube angulation in the APLR, the intrusive force significantly increased in the distally tipped tube of group 3 patients and remarkably reduced the occlusalplane angle. They concluded that compared to the CLR, the APLR provides better anterior torque control and canine tipping while achieving bodily translation. Furthermore, changing the tube angulation will affect the amount of incisor intrusion, even in patients with similar palatal vault depth, without the need for additional TSADs.

CENTER OF RESISTANCE

Matsui et al.[30] (2000) stressed the importance of locating the center of resistance to control tooth movement. The center of resistance for anterior arch segment was determined using photoelastic model of anterior 4 maxillary teeth, which was interconnected firmly with 6mm space between the lateral incisors and canines. A wide variety of load conditions that generated the more uniform stresses in the supporting alveolar bone simulant to determine the center of resistance. The CR was specified from the forces that produced more uniform stresses around the teeth. The center of resistance for the 4 tooth segment was located within the mid-sagittal plane, approximately 6mm apical and 4mm posterior to a line perpendicular to the occlusal plane from the labial alveolar crest of the central incisor.

Yoshida et al.[53] (2001) did a study which designed to locate the center of resistance in human subjects, of two, four or six unit consolidated teeth during retraction. Retraction force was applied and the initial displacements of these units were separately measured using magnets. Then location of center of resistance for each unit was determined by calculating the angle of rotation from the displacements measured. the center of resistance of two and four unit was located 4.3 $\pm$ 0.3 mm apical to the palatal bone level and for six tooth unit it was approximately 0.8 mm more incisal. The results revealed that the centers of resistance of two and four incisor units were approximately at the same position, and for the six teeth unit it was observed to be more incisal. This also indicated that the palatal alveolar bone height level may be an indicator of the center of resistance of anterior segment than the labial alveolar bone height level.

Sia et al.[42] (2007) determined the center of resistance and the relationship between height of retraction force on power arm (length) and movement of anterior teeth (degree of rotation) during sliding mechanics retraction. 3 human subjects with maxillary protrusion were selected, initial tooth displacements of maxillary right central incisor under sliding mechanics with various heights of retraction forces were measured in vivo using a 2-point 3-dimentional displacement magnetic sensor device. By calculating the angle of rotation from the displacements measured, the location of the center of resistance was determined. The results concluded that the location of the center of resistance of the maxillary central incisor was shown to be approximately 0.77 of the root length from the apex. During anterior tooth retraction with sliding mechanics, controlled crown-lingual tipping and controlled crown labial movement can be achieved by attaching a powerarm length that is lower or higher than the level of center of resistance, respectively. Bodily translation movement (lingual movement) can be achieved by attaching a power-arm length that lies on the same level of the center of resistance.

Jang et al.[12] (2010) located the center of resistance of six maxillary anterior teeth retracted by the Double J Retractor (DJR) and the optimal position of palatal miniscrewswas assessed. The three-dimensional (3D) finite element model included 12 teeth with two first premolars extracted. The DJR was modeled as a 3D beam element. The miniscrew was sagittally placed between the second premolar and the first molar, and the vertical position of the miniscrew was established at five conditions: 6, 7, 8, 9, and 10 mm apically from the cervical line of the first molar. The length of the retraction lever arm was determined according to the position of the miniscrew, for the direction of retraction force to be parallel to the maxillary occlusal plane. The 3D finite element method was used to determine the location of the center of resistance of the maxillary anterior teeth by visualizing the tooth displacement and stress distribution. Results showed that as the miniscrew was located apically, the stress spread out to the root apex and the adjacent alveolar bone and at the 8-mm level of miniscrews, a bodily-like parallel retraction could be obtained with DJR. They concluded that the center of resistance of the six maxillary anterior teeth retracted by DJR with palatal miniscrews was estimated to be 12.2 mm apically from the incisal edge of the central incisor.

Jiang et al.[14] (2016) developed a method to quickly estimate the location of center of resistance in mesial-distal and buccal-lingual directions from the tooth's image. The maxillary cone-beam computed tomography scans of 18 patients were used. Finite elementmodels of the canines and their surrounding tissues were built based on their CBCT scans to calculate the locations of CR. Root length, centroid of the contact surface (CCS), and centroid of projection of the contact surface (CPCS) were also obtained from the images. The CCS and CPCS locations were projected on the tooth's long axis, which were represented as percentages of the root length measured from the root's apex. Results showed that the average location of CR calculated using the FE method was 60.2% measured from the root's apex in the MD direction and 58.4% in the BL direction. The location of the CCS was 60.9%. The difference in CR was 0.7% in the MD direction and 2.5% in the BL direction. The location of CPCS was 60.2% in the MD direction and 59.1% in the BL direction, which resulted in a 0.1% and 0.8% difference with the reference CR, respectively. The average difference of CR in the MD and BL directions was small but statistically significant. They concluded that the locations of the CRs in the MD and BL directions are small but statistically different. The locations of the CRs of a human canine in the MD and BL directions can be estimated by finding the CPCSs in the two directions.

Sushil et al.[44] (2016) determined the center of resistance and center of rotation by applying a force of 1 N in upper central incisor tooth with an alveolar bone height of 13, 12, 10.5, 8, 6.5, and 5 mm using FEM and to compare center of resistance and center of rotation in all the six models with various alveolar bone heights. Results demonstrated for normal alveolar bone height, the CRes was at 7 mm apical to the point of force application. For 1 mm alveolar bone loss, the CRes was at 9.9 mm.For 2.5 mm alveolar bone loss, the CRes was at 10.3 mm. For 5 mm alveolar bone loss, the CRes was at 11.55 mm. For 6.5 mm alveolar bone loss, the CRes was at 12.35 mm.For 8 mm alveolar bone loss, the CRes was at 13.18 mm.

The study showed that the orthodontic forces should be kept as light as possible with decrease in alveolar bone height. The reduced supporting PDL area and volume result in ever higher amounts of displacements in supporting structures of affected teeth for a given level of force and moment magnitude. Applied force and moment magnitudes must be reduced in proportion to maintain physiologically tolerable movements with minimal damage to these supporting structures.

PALATAL IMPLANTS

Schlegel et al.[40] (2002) described the anatomic characters the mid-palatal region by performing trephine bur biopsies from donors whose age ranges from 12 to 53 years. This study showed that complete ossification of the mid-palatal suture is uncommon before the age of 23 years. The mean distance between the ossified borders of the mid-palatal suture was found to be 0.03 mm and implants in this region without complete osseous fusion can still osseointegrate since the typical implant diameter of 0.4 cm commonly used.

Poggio et al.[37] (2006) provided a guide for mini-screw positioning in the maxilla and mandible using volumetric tomographic images. This study showed that In maxilla, the greatest amount of mesio-distal bone was on the palatal side between the second premolar and the first molarand the greatest thickness of bone in the bucco-palatal dimension was between the first and second molars and the least was found in the tuberosity. In the mandible, the greatest mesiodistal bone was between 1st and 2nd premolar and the least amount of bone was between the 1st premolar and the canine. In the bucco-lingual dimension, the greatest thickness was between 1st and 2nd molars and the least amount of bone was between first premolar and the canine.

King et al.[21] (2007) analyzed the CBCT data for measuring vertical bone volume and defining regions that are most likely to support mini-implants in the paramedian palatal region. CBCT data of 183 orthodontic patients were measured for bone volume in the paramedian palate. The results of this study confirm the paramedian palatal region in adolescents as a site for placing orthodontic mini- implants. The site 4 mm distal and 3 mm lateral to the incisive foramen was identified as the best location in the paramedian palatal area.

Kim et al.[20] (2010) investigated the success rate of midpalatal miniscrews examining total of 210 miniscrews in the midpalatal suture area. The overall success rate was found to be 90.80% and no significant associations among success rate and sex were found. The factors influencing the clinical success of orthodontic miniscrews were found to be patient's age, operator's skill, placement of the miniscrew in the midpalatal suture.

Ludwig et al.[3] (2011) described anatomical guidelines for miniscrew insertion in palatal sites. The author said that the cortical bone is thicker in the palate than at interradicular insertion sites, and favorable attached gingiva is available which ensures high success. The anterior palate appears to be one of the best sites for orthodontic miniscrews. The palatal alveolus between the roots of the second premolar and first molar may be considered as an alternative miniscrew location.

Han et al. (2012)[9] evaluated the palatal bone density in adults and adolescents using cone beam computerized tomography scans of 60 adolescents and 60 adults. They found that adults have more cortical and cancellous bone densities than adolescents. Gender comparison revealed that females had greater cortical bone densities than males.

Jayakumar et al.[13] **(2012)** assessed the palatal bone thickness in an ethnic Indian population using CT. CT data of 60 patients (30 male and 30 female) in two different age-groups (15–24 years; 25–35 years) were included for the study. The measurement points were taken in the anterior region of the palate at 4mm, 8mm, and 12 mm and also in the posterior region of the palate at 24 mm and 28 mm from inferior border of the incisive foramen at the midline. Also, lateral to the midline, the measurements were made on the right side of each CT at 0mm, 3mm, and 6 mm. The authors say mid-palatal suture area is a high-density bone structure with sufficient bone height, making it a noble location for orthodontic mini implant placement. It was shown that the bone density at the mid palatal suture area at 12mm behind the incisive foramen is 7.31 ± 3.26 mm in 15-24 age grouped individuals and bone density is 6.19 ± 2.87 mm in 25-35 age grouped individuals. The bone density at the mid palatal suture area at 24mm behind the incisive foramen is 6.96 ± 3.15 mm in 15-24 age grouped individuals and bone density is 6.74 ± 3.24mm in 25-35 age grouped individuals.

Winsauer et al.[51] (2014) in a systematic review examined the available measurements of vertical palatal bone height and concluded that the anterior paramedian palate in the area 3 mm behind the incisive foramen and 3 to 9 mm lateral to the midpalatal suture provides sufficient vertical bone height and in the area up to 12 mm behind the incisive foramen and 9 to 12 mm lateral to the midpalatal suture provides adequate vertical bone height for safe placement of temporary anchorage devices.

Materials and Methods

This in-vitro study was carried out in the Department of Orthodontics and dentofacial Orthopaedics, Ragas Dental College and Hospital, Chennai. The study protocol was approved by the Institutional review board of the institutional research ethics committee.

This FEM study was designed to find ideal retraction protocol for maxillary dentition in lingual orthodontics for a bimaxillary protrusion case treated with second premolar extraction. Ideal retraction protocol was identified from,

a) optimal position of palatal MSI
b) power arm position
c) Ideal power arm length.

The finite element model was constructed from CBCT of a female adult patient with class I bimaxillary protrusion and mild crowding in lower arch, who had opted for lingual orthodontic treatment, requiring second premolar extraction.

The patient was selected with inclusion and exclusion criteria as follows;

Inclusion Criteria:

- Adult patient with class I bimaxillary protrusion

- Patient requiring second premolar extraction in lingual orthodontic treatment.
- Patient with complete complement of dentition.

Exclusion Criteria:

- Patient whose growth has not been completed.
- Patient requiring extractions other than second premolars.
- Patient with any systemic disease and under medication, long term use of antibiotics, anti-inflammatory drugs and syndromic patients.
- Patient with active periodontal disease.
- Patient with history of previous orthodontic treatment.

Construction of the finite element model

We levelled and aligned the dental arches using customized 3D lingual bracket system (Berininov Advanced Orthodontics, Ernakulam, Kerala, India). The levelling and aligning was carried out before taking CBCT in order to obtain alignment to carry out the sliding mechanics during retraction. In this study we have included the first premolar also into anterior segment for enmasse retraction. The changes in the posterior segment were insignificant when using MSIs. Thus this study was limited to the displacement of anterior segment.

The CBCT of the patient was taken before second premolar extraction to avoid void area during data extraction for construction of the finite element model.

The cone beam computed tomography of the patient was taken using Digital Kodak 9500 cone beam tomography scan, France and the scan time ranged from 8.9 to 20 seconds with a resolution of 0.25 to 0.30 mm. The CBCT was taken with a mouth prop placed between the maxillary and mandibular dentition. The CBCT images were stored in DICOM format.

The data extraction from CBCT was done using 3D slicer (version 4.7) along with seg3D software (version 2.1). Later software called Control was used to refine the data.

Defining the lingual appliance from the CBCT data was not possible due to the streak metal artefacts present in the imaging by CBCT. Therefore we planned to obtain tooth crown outlines from pre-treatment 3-dimensional laser scan of the patient models which was performed using R700 scanner (3 shape, Asia). The individual crowns were separated from the 3-dimentional laser scan data and stitched to their respective roots from the data extracted from CBCT using Geomagic software (3D systems, North Carolina, United States).

The berininov 3D lingual system (Berininov Advanced Orthodontics, Ernakulam, Kerala, India) was modelled and positioned over the crowns of the teeth of the FEM model which was constructed.

The finite element model was contructed using tetrahedron solid elements with a total of 173,548 elements and 49,921 nodes. The material properties of the elements were based on the values of Young's modulus and Poisson's ratio according to previous studies as shown in table 1. This finite element model included 12 maxillary teeth except second premolars, with periodontal ligament, alveolar bone and the palatal bone. Figure 1a shows the base model constructed and figure 1b shows the mesh pattern of the base model.

The finite element analysis was performed using ANSYS 15.0 (Swanson analysis system, Canonsburg, USA). The design of the retraction system and mini-screw implant(MSI) position were made using the software Mimics 17.0(Materialise NV, Leuven, Belgium) and 3-Matic medical software 9.0 (Materialise, Leuven, Belgium).

Retraction system

The retraction system consists of a stainless steel retraction hooks (0.8 mm diameter round wire) and mini-screw implants (MSI) placed on the palatal area with 16X22 stainless steel base wire placed into the slots of the lingual brackets from second molar to second molar in the FEM model.

According to the length of the power-arm and position of palatal mini-screw implant (MSI) the analysis was divided into four groups (Group A, B, C and D):

Group A: MSI in the posterior palatal slope with power arm between lateral incisors and canines.

Two MSIs were placed over the palatal slopes between second premolar and first molar area on either side, in 4 heights (4mm, 6mm, 8mm, and 10mm) from the cervical margin of posterior teeth. The reference line to place MSI was a perpendicular line drawn from cervical margin of the posterior teeth. (Figure 3)

The power arm (0.8mm stainless steel round wire) was attached to the lingual arch wire by node sharing, in between the lateral incisor and the canine on the both sides. Power arm was contoured close to the palate and the hook was designed to engage elastic chain. (Figure 2a)

The length of the power arm was 10mm and 13mm. The power arm with length 10mm was used for retraction with MSIs placed 4mm and 6mm from the alveolar crest between second premolar and first molar area and the length of the power arm was increased as when the position of MSI moved apically to 8mm and 10mm so that the retraction force acting was kept as parallel as possible to the occlusal plane. (Figure 4)

Group B: MSI in the posterior palatal slope with power arm between lateral incisors and central incisors (figure 2b)

A retraction system and conditions similar to the group A was used with the power arm placed between the central and the lateral incisor. (Figure 5)

Group C: MSI in the mid-palatal suture area with power arm between lateral incisors and canines (figure 2c)

A single MSI was placed in the mid-palatal suture region at two heights (12mm and 24 mm) antero-posteriorly measured from the distal part of the incisive papillae. (Figure 6)

Two individual power arms were attached to the lingual archwire between the lateral incisor and canine on both sides which were contoured to the palate to engage the elastic chain for retraction. (Figure 6)

The power arm was made in two different lengths (10mm and 13mm) to compare the retraction conditions with two mid-palatal mini-implant positions. (Figure 2c)

Group D: MSI in the mid-palatal suture area with power arm between lateral incisors and central incisors (figure 2d)

A retraction system and conditions similar to the group C was used with the power arm placed between the central and the lateral incisor. (Figure 7)

Force application

A retraction force of 200 gm per side from the hook, towards the direction of the MSI position was applied.

Tooth displacement

The tooth displacement values at both the crown incisal midpoint and root apex of the anterior segment (#11, #12, #13 and #14) were measured for all the groups with various retraction conditions mentioned above.

The midpoint of the incisal edges of the incisors, point at the cusp tip of the canines and the point at the buccal cusp tip of the first premolar were marked as IE (Incisal edge and cusp tips) and all the corresponding root tips were marked as RA (root apex) and probed for their displacement values in Y-axis (sagittal) and Z-axes (vertical). The IE and RA values after retraction showed the displacement of each tooth at the incisal and apical level, taken zero as the value of IE and RA prior to retraction.

We assigned the x axis to the median-lateral direction (transverse), the y axis to the anterior-posterior (sagittal) direction, and the z axis to the coronal-apical (vertical) direction.

We assumed no movement of posterior teeth since they do not receive any direct force which was applied to the lingual bracket system.

With this we have measured the tooth displacement values which were presented as descriptive statistics and two dimensional line graphs.

Figures

FIGURE 1 : BASE MODEL

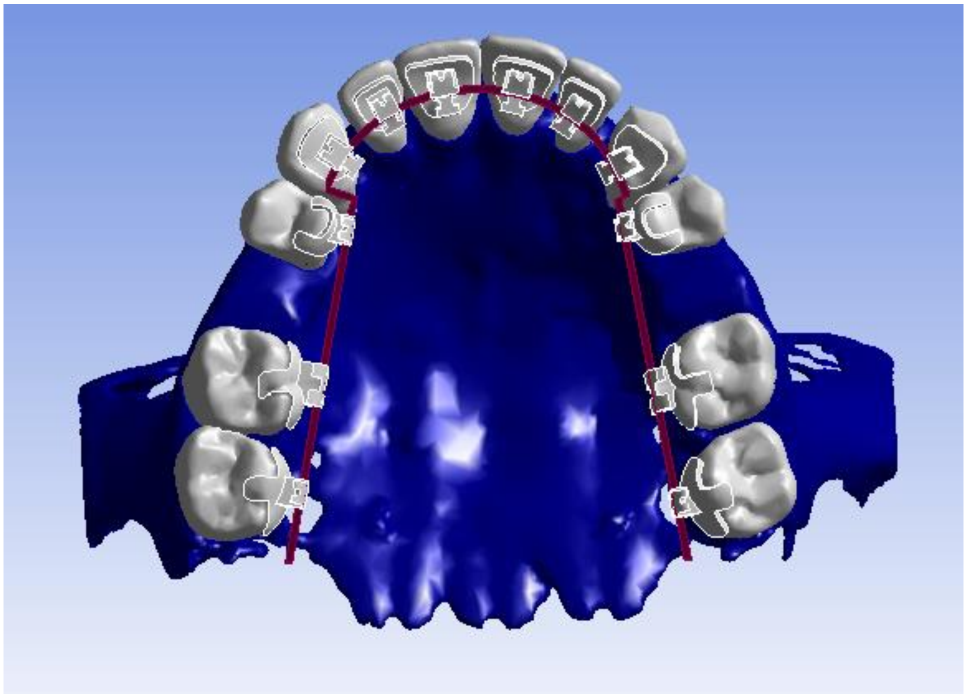


FIGURE 2: MESHED BASE MODEL

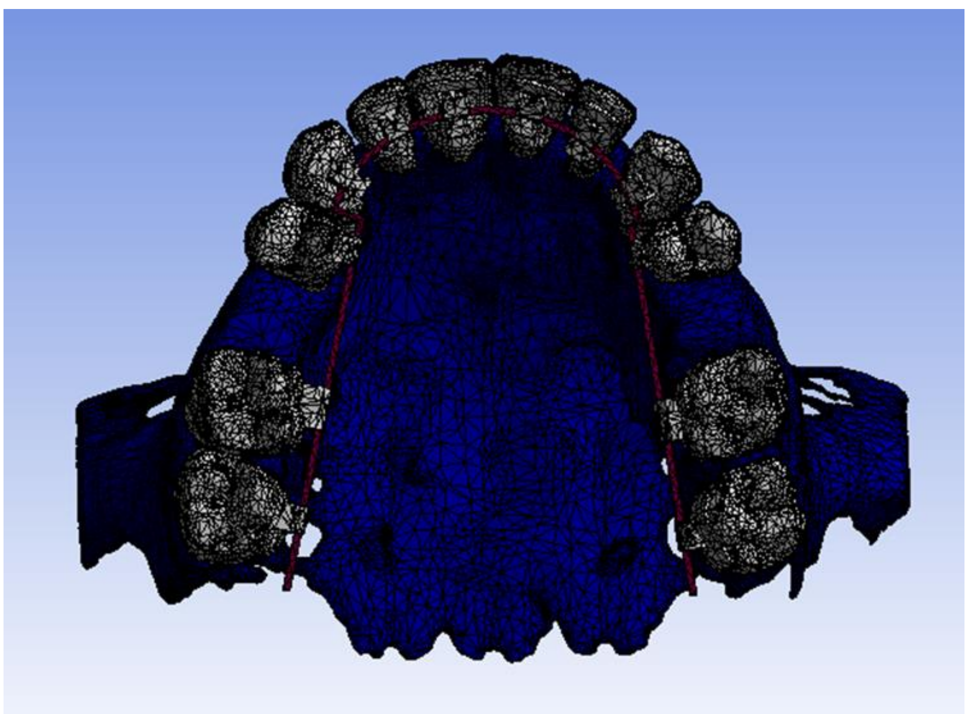
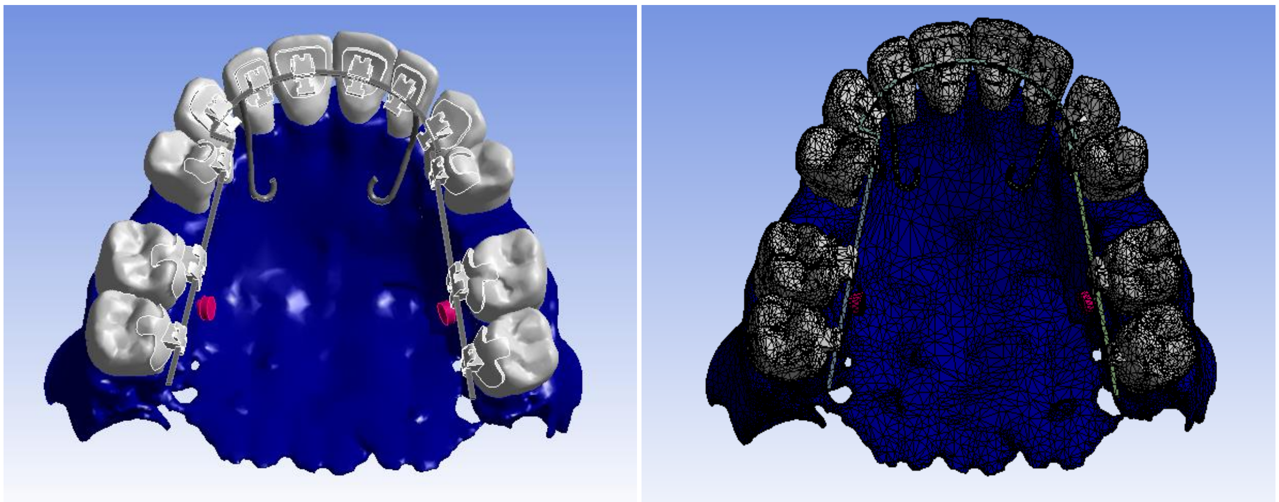
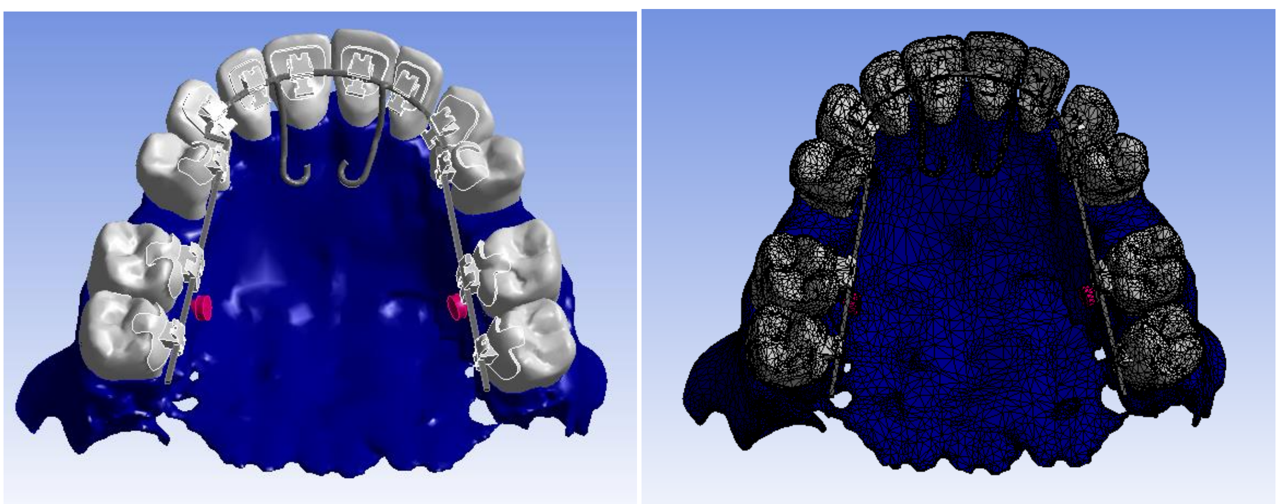


FIGURE 3: MODELS OF ALL GROUPS SHOWING DIFFERENT POSITIONS OF THE POWER ARM AND MINI-IMPLANT

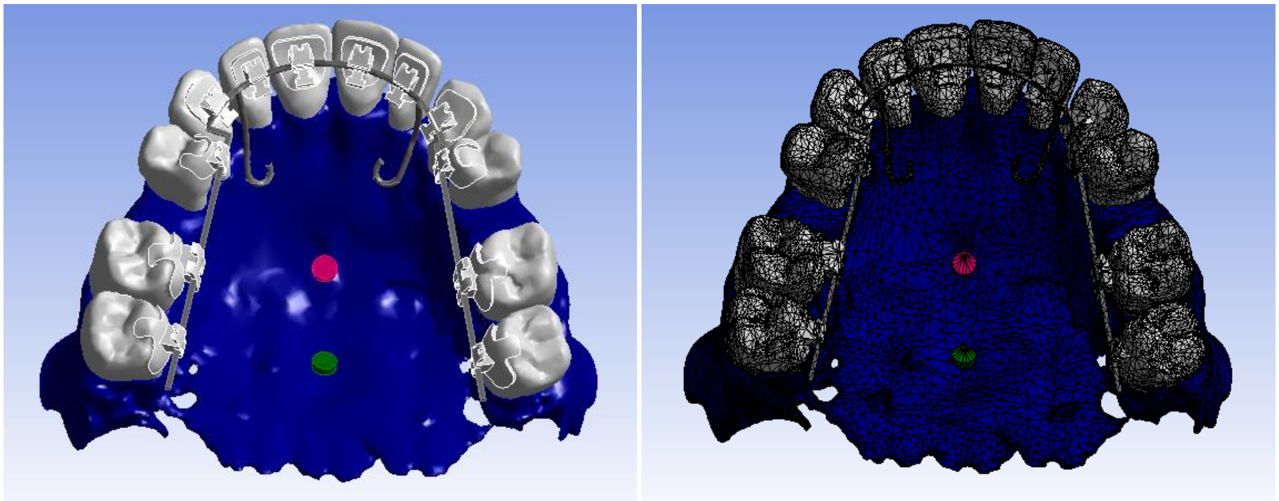
3a.GROUP A – power arm between lateral incisor and canine and MSI in the palatal slope



3b.GROUP B – power arm between central incisor and lateral incisor and MSI in palatal slope



3c.GROUP C - power arm between lateral incisor and canine and MSI in mid-palatal region



3d.GROUP D - power arm between central incisor and lateral incisor and MSI in the mid-palatal region

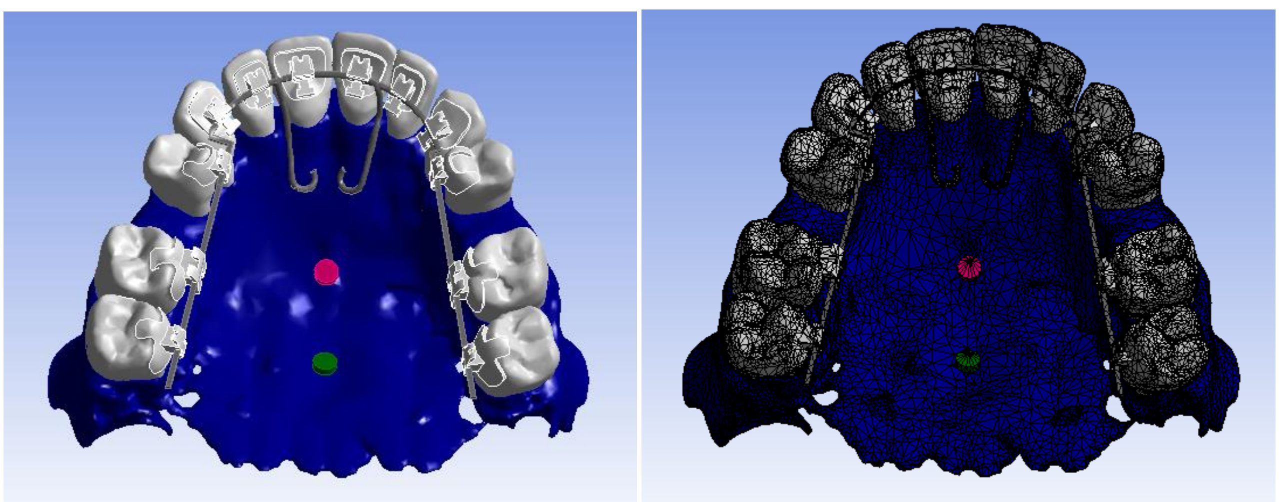


FIGURE 4: DIFFERENT LENGHTS OF THE POWER ARM

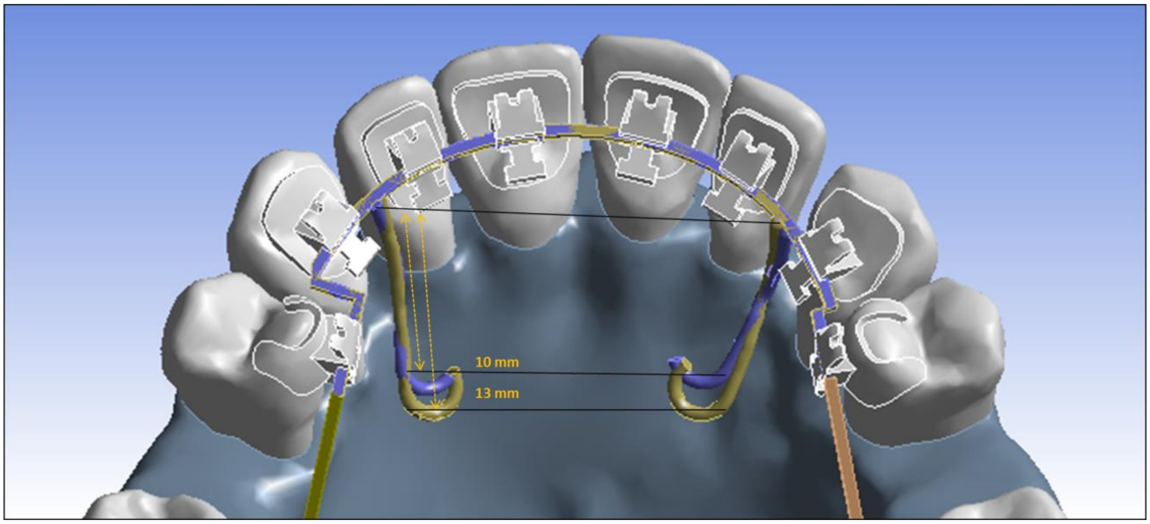


FIGURE 5: DIFFERENT HEIGHTS OF MINI-IMPLANT POSITIONED AT THE SLOPES OF THE PALATE

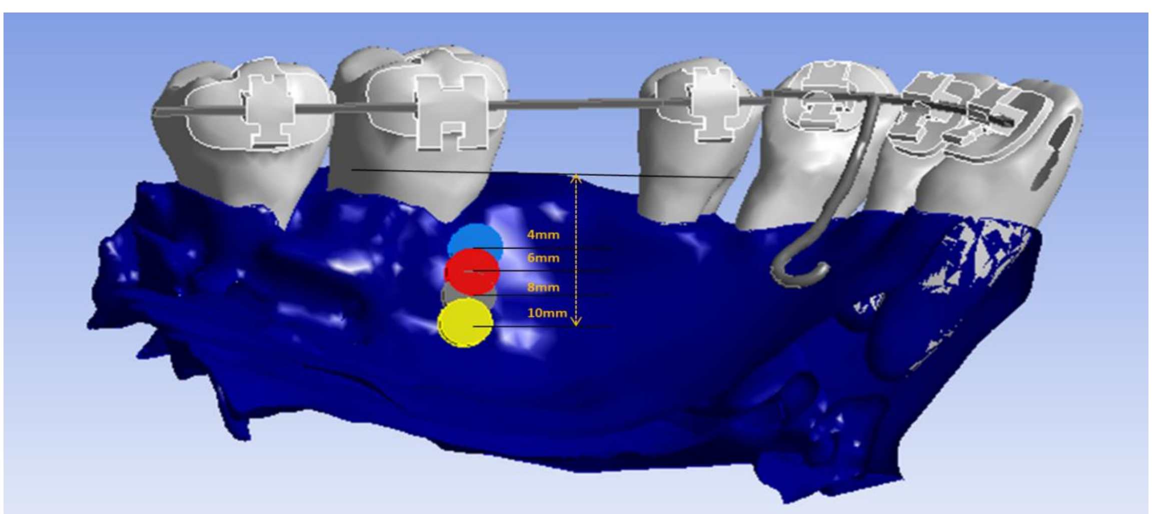


FIGURE 6: DIFFERENT HEIGHTS OF MINI-IMPLANT POSITIONED AT THE MIDPALATAL REGION

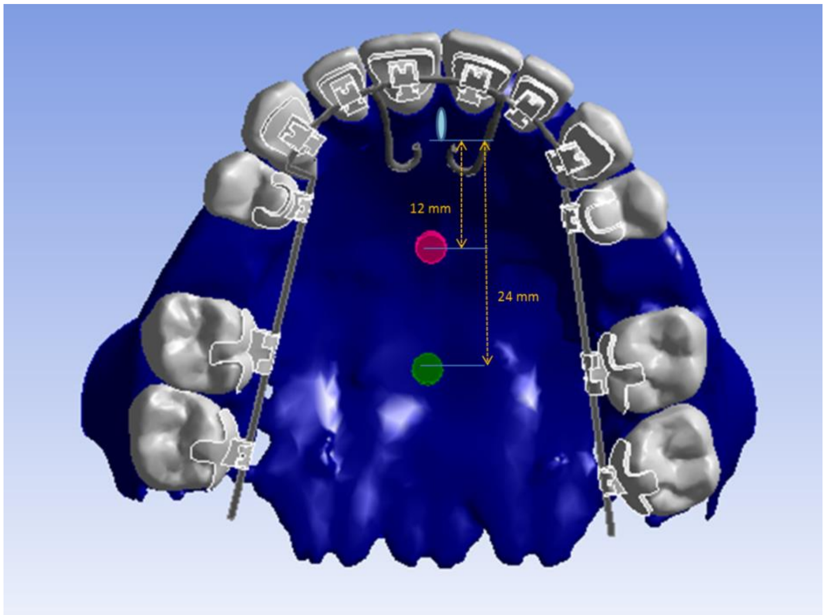


FIGURE 7a: REFERENCE POINTS MARKED AT THE INCISAL EDGES AND CUSPTIP OF THE REFERENCE TEETH (IE)

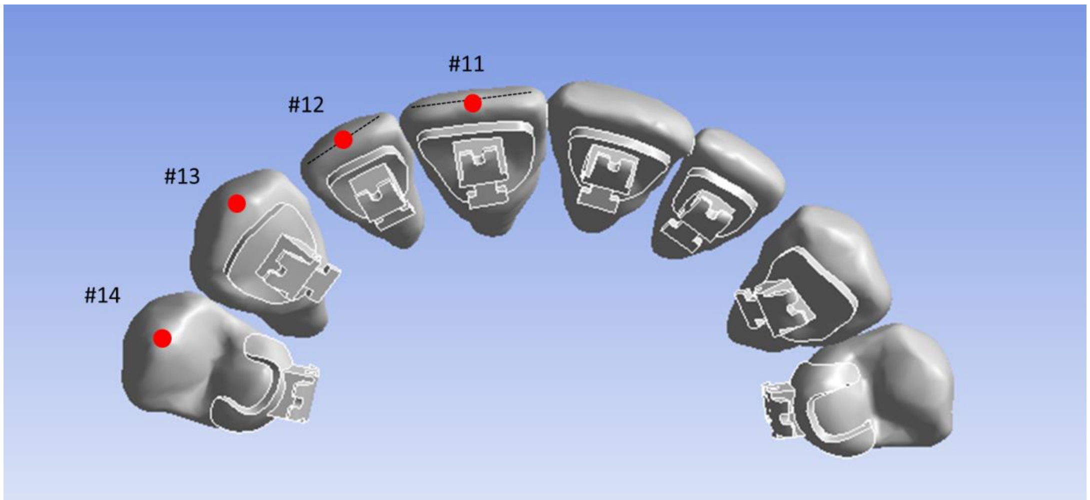


FIGURE 7b: REFERENCE POINTS MARKED AT THE ROOT APEX (RA)

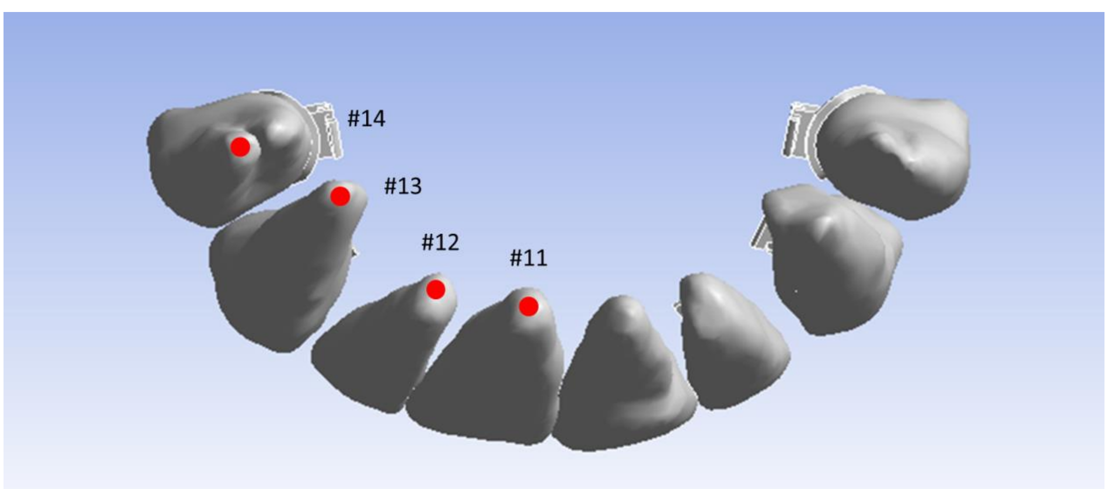


FIGURE 8a: GROUP A , TOOTH DEFORMATION IN Y-AXIS

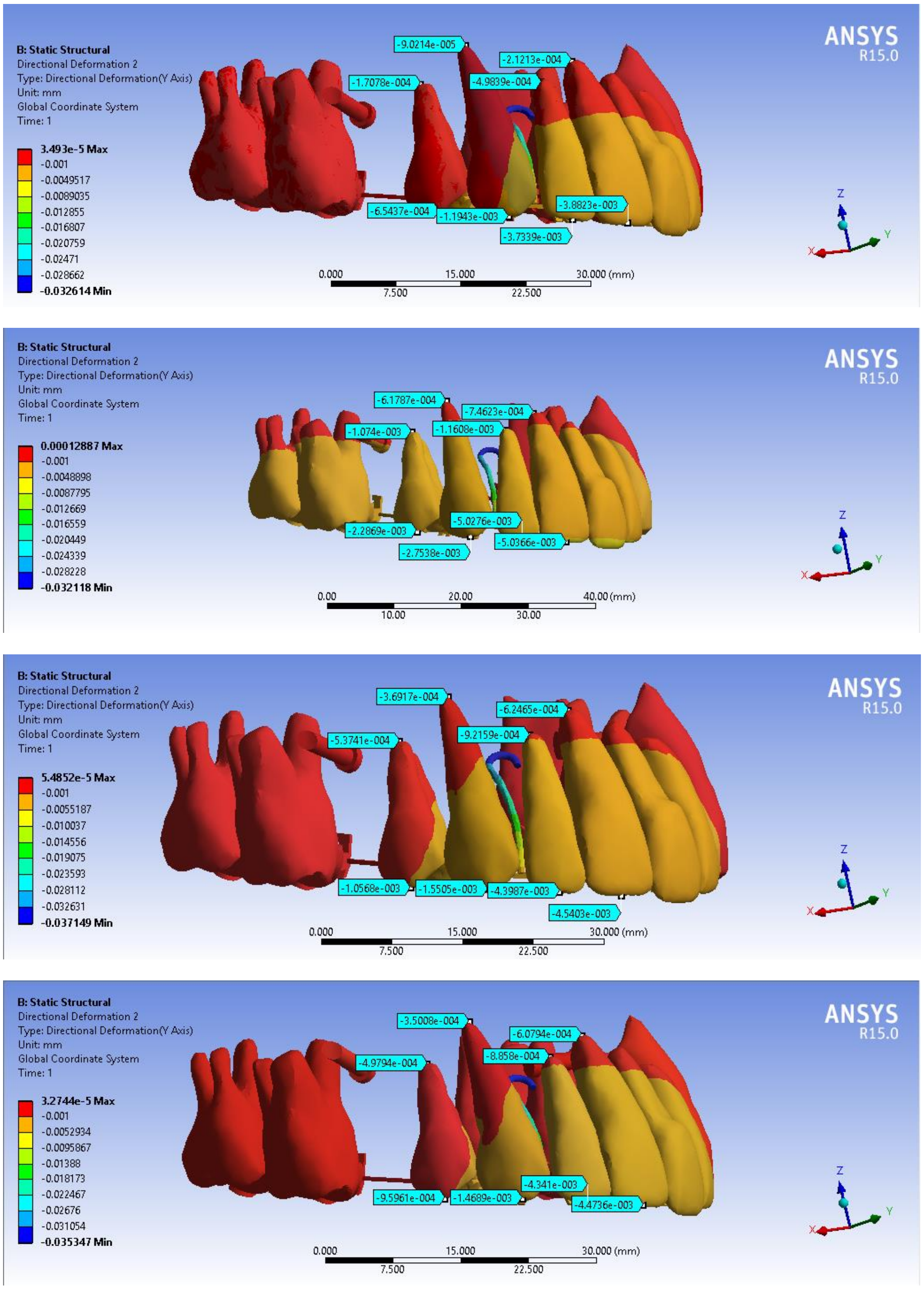


FIGURE 8b: GROUP A , TOOTH DEFORMATION IN Z-AXIS

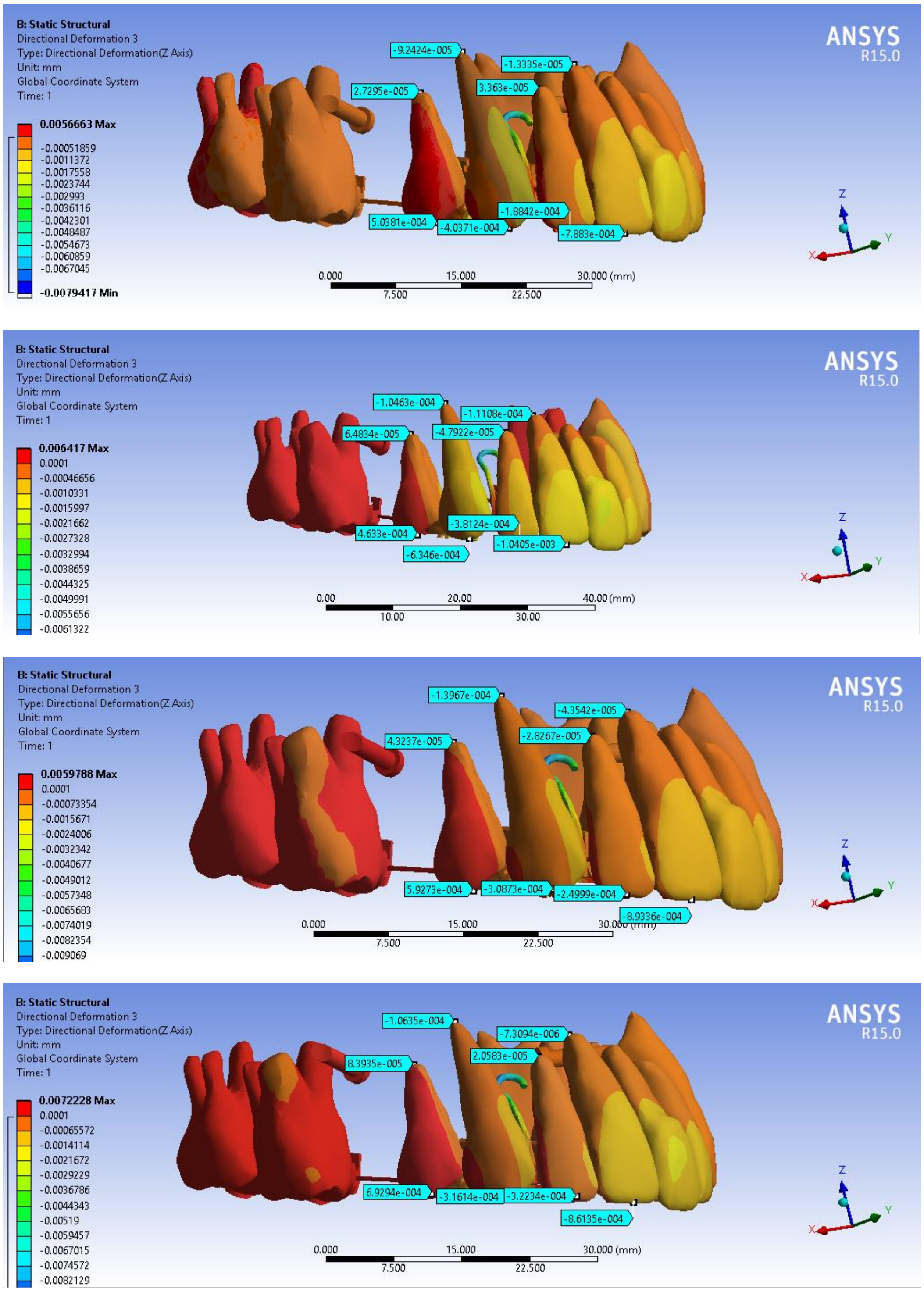


FIGURE 9a: GROUP B , TOOTH DEFORMATION IN Y-AXIS

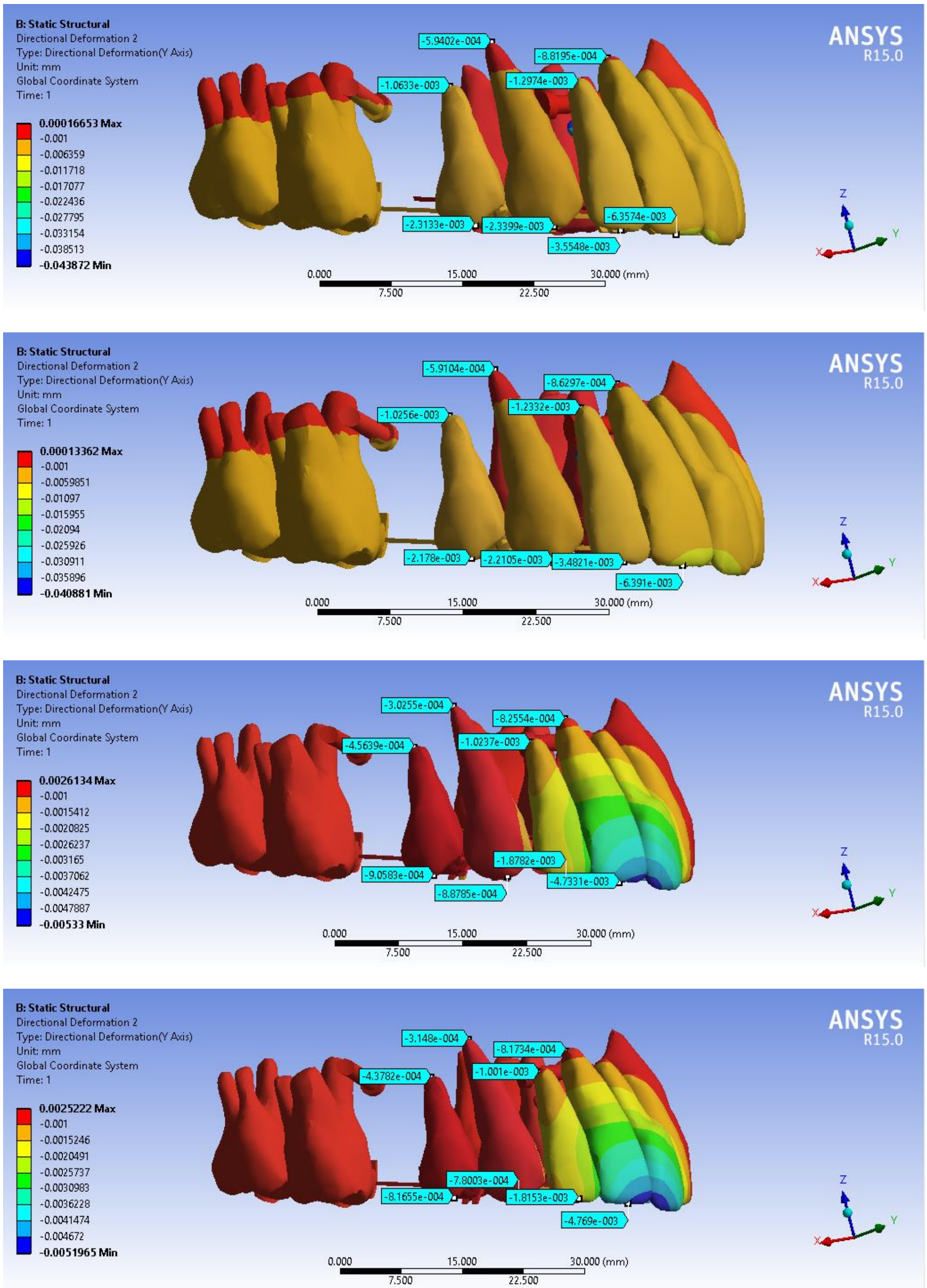


FIGURE 9b: GROUP B , TOOTH DEFORMATION IN Z-AXIS

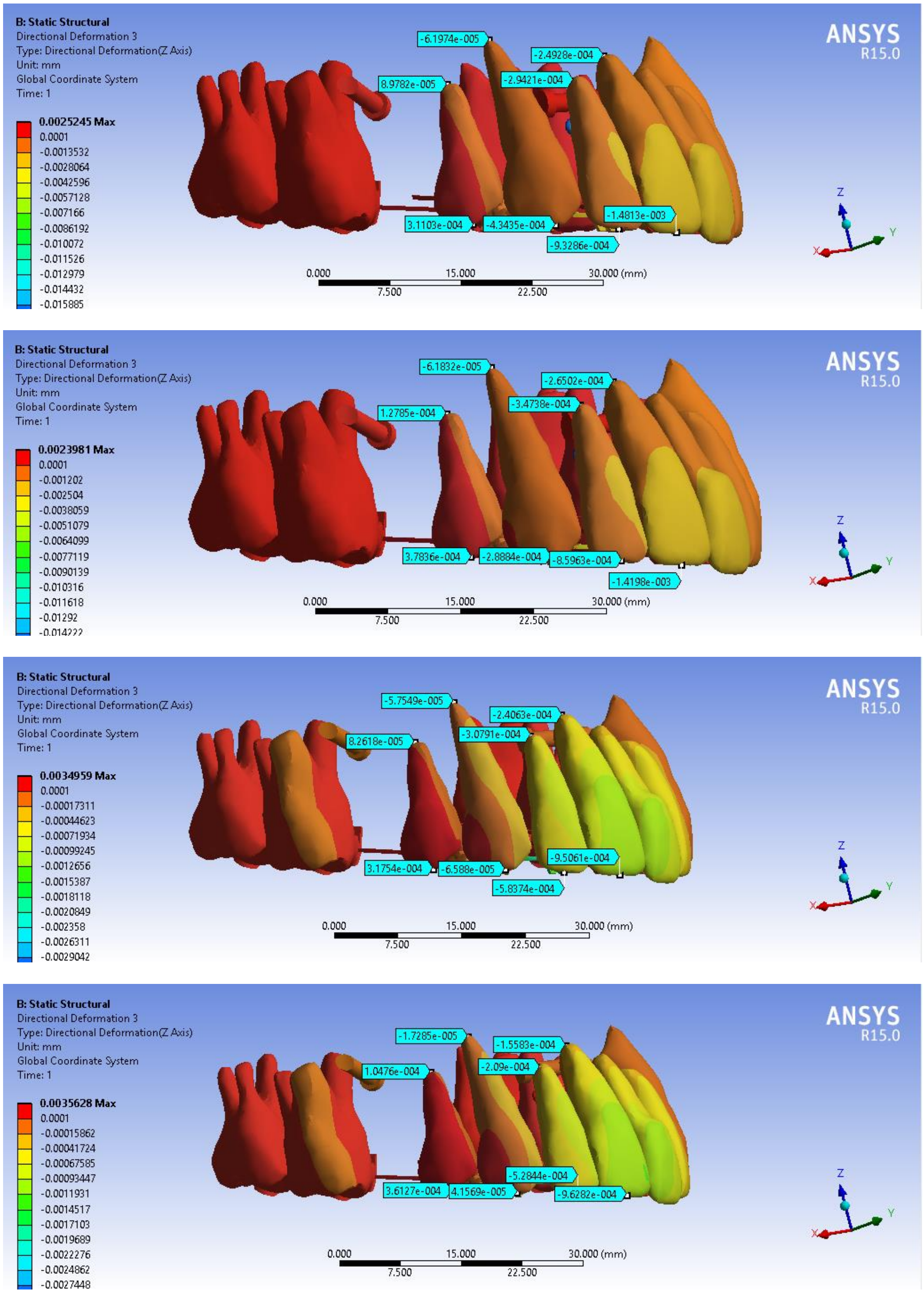


FIGURE 10a: GROUP C , TOOTH DEFORMATION IN Y-AXIS

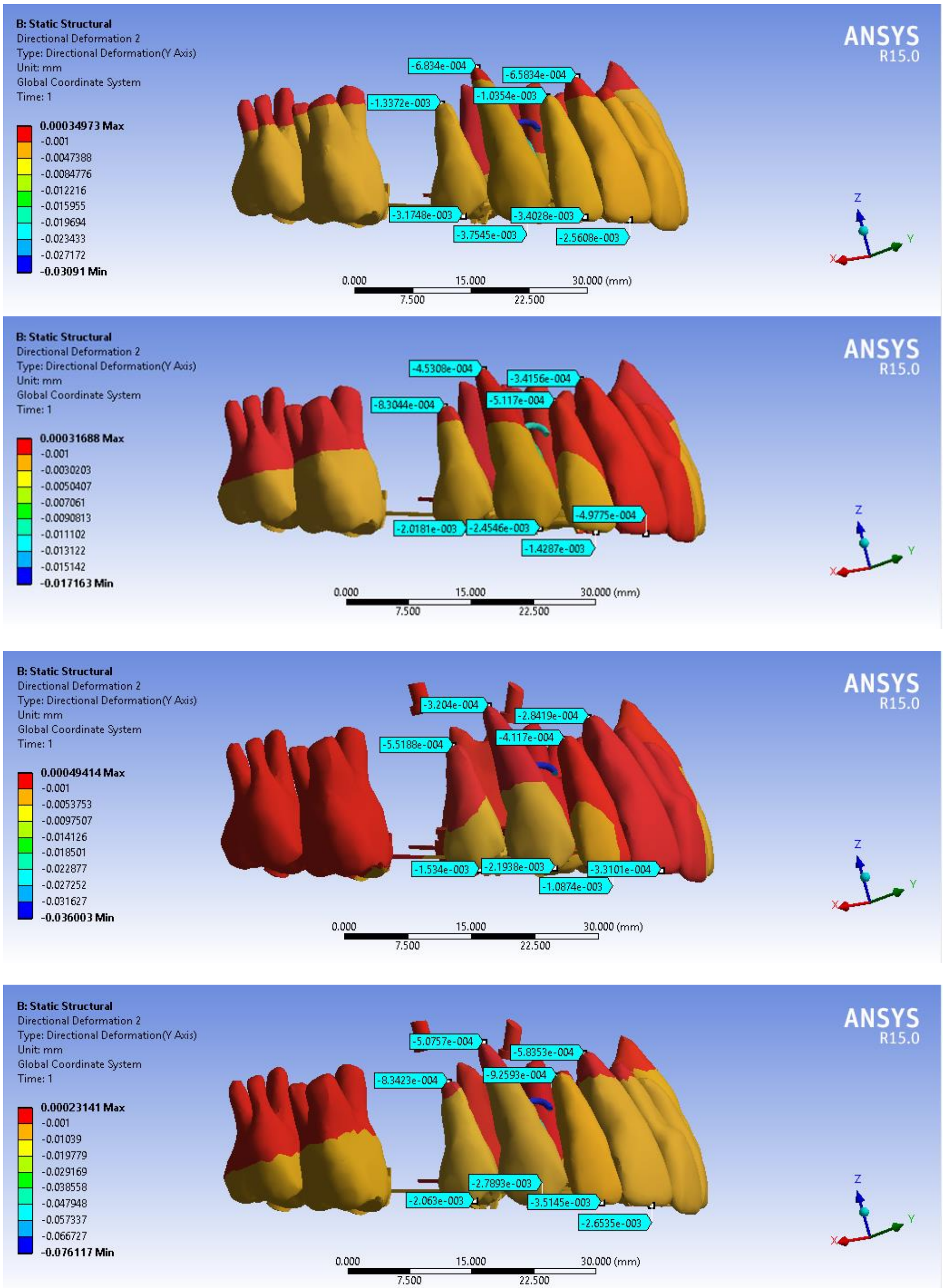


FIGURE 10b: GROUP C, TOOTH DEFORMATION IN Z-AXIS

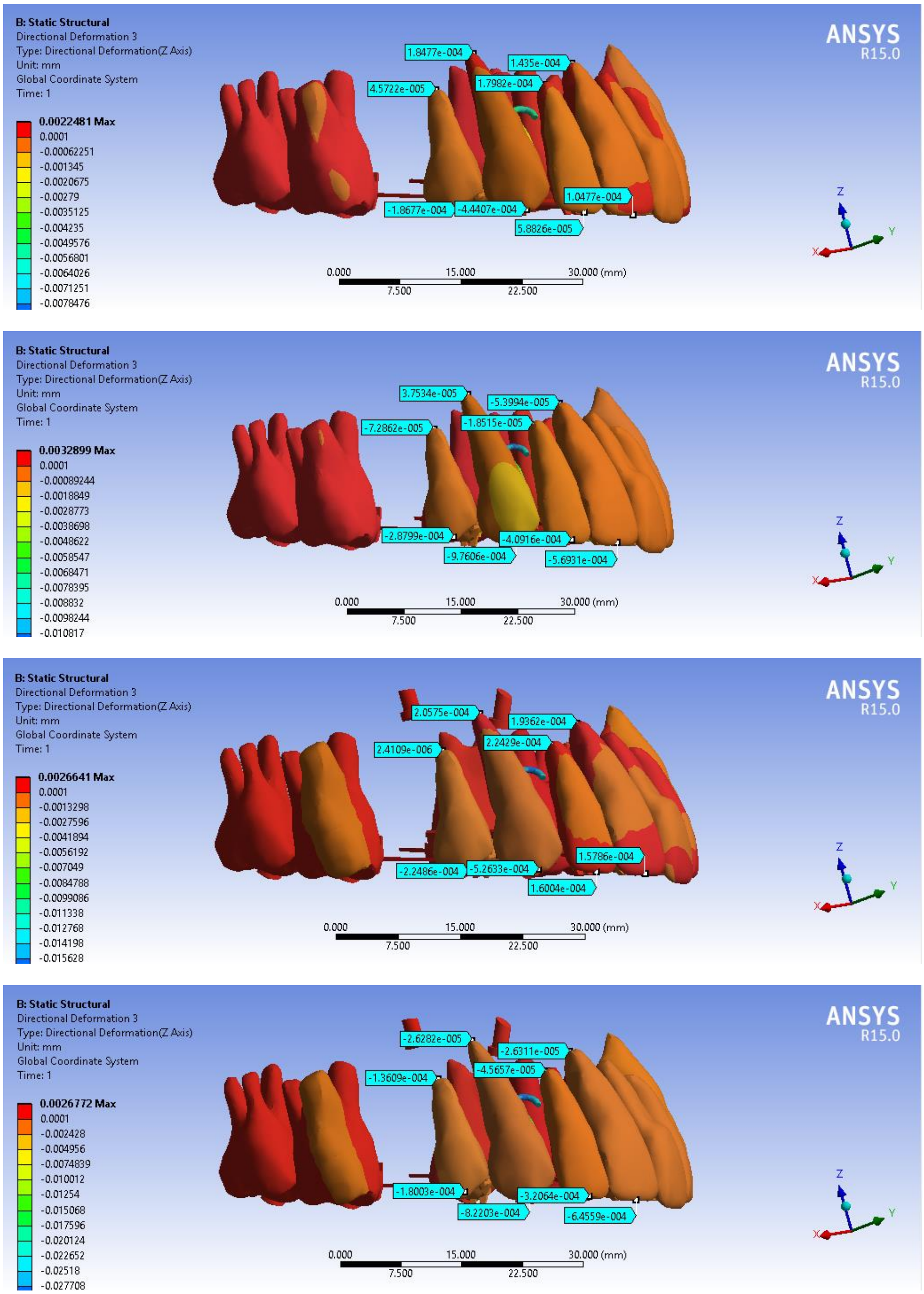


FIGURE 11a: GROUP D , TOOTH DEFORMATION IN Y-AXIS

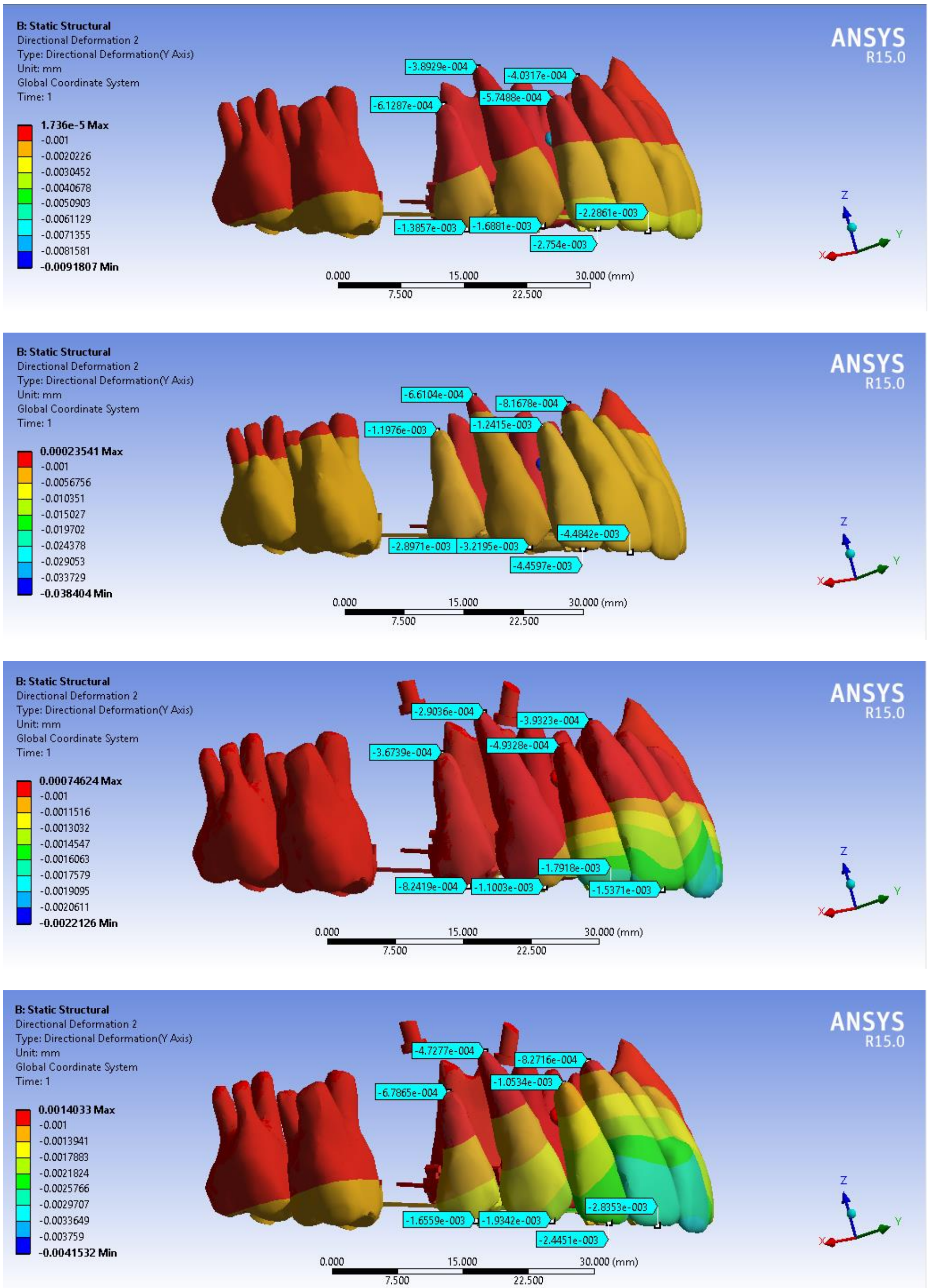
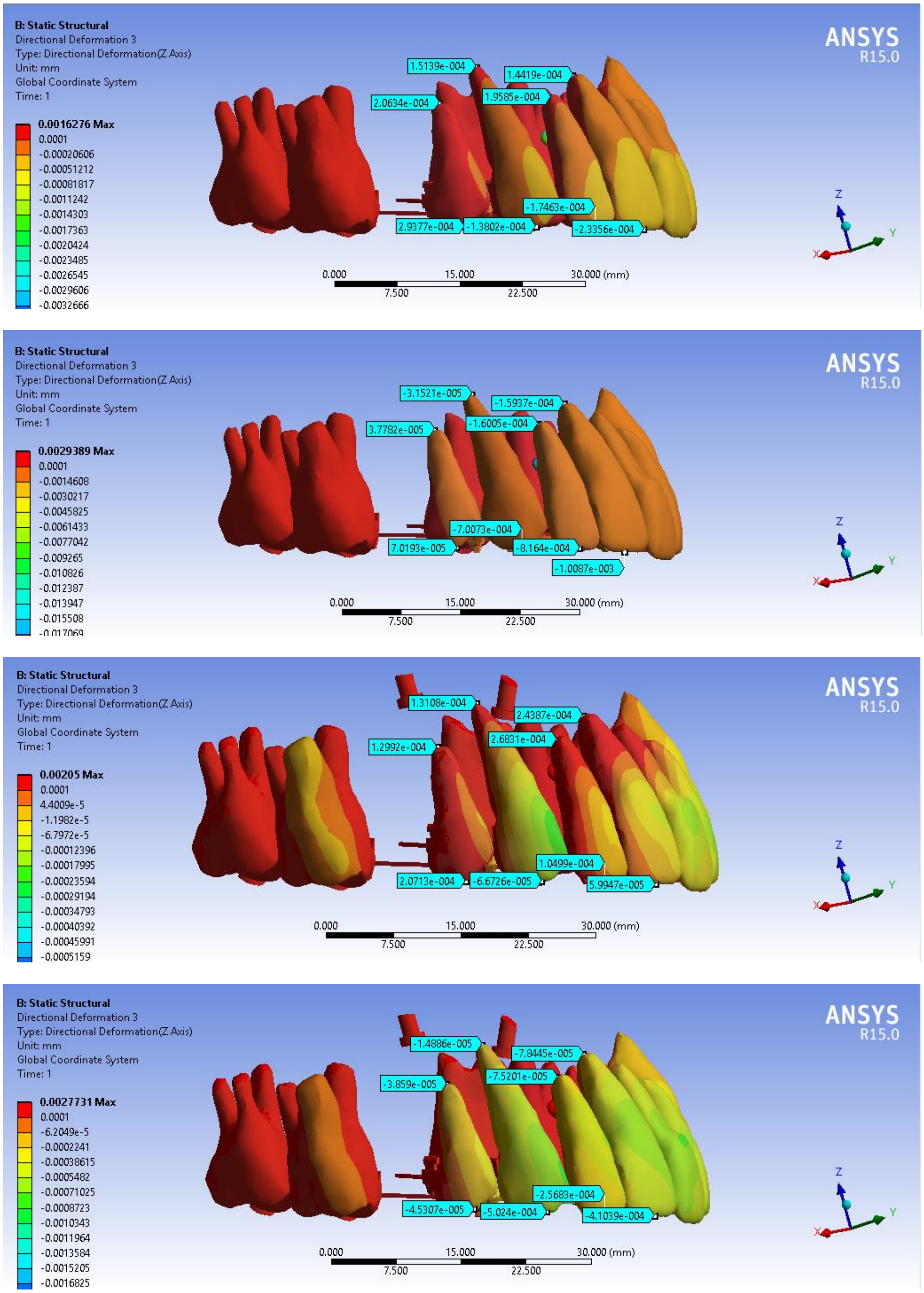


FIGURE 11.b: GROUP D , TOOTH DEFORMATION IN Z-AXIS



Results

RESULTS

This in-vitro study was performed to find an optimal position of palatal mini-screw implants, ideal position of the power arm and its length, by locating the centre of resistance of maxillary dentition in second bicuspid extraction cases retracted by 3D lingual bracket system using finite element study.

The results were based on the tooth displacement values mainly in two planes of movement, the sagittal (Y-axis) and vertical (Z-axis), using mathematically simulated finite element model constructed from CBCT of a patient.

The analysis was split into 4 groups, each with the following parameters

a) Two different power arm heights,

b) Position of the power arm and

c) Position of the mini-screw implants.

The groups A and B had 4 different locations of MSI placed in the slopes of the posterior palate and the groups C and D had 2 different locations of the MSI placed in the mid-palatal region. The power-arms were placed between the lateral incisors and canines in groups A and C and between the central and lateral incisors in the groups B and D.

A 200 gram of retraction force was applied for retraction in each of the sides, through the hook of the power arm towards the MSI position. Reference points at root apex (RA) and incisal edge (IE) of the anterior segment (#11, #12, #13 and #14) were probed for displacement values in Y-axis (sagittal) and in Z-axis (vertical). These measurements were transferred to descriptive statistics (Tables 2, 3, 4, 5) and graphically determined the tooth displacement in all the groups (figure 11-14). Two dimensional line graphs were used to represent the type of tooth movement in each tooth of all the groups. The point 1 in the graph represents point at the root apex (RA) and the point 2 represents the point at the incisal edge (IE) of the respective retracted tooth. Tooth displacement in each group were analysed separately for the Y-axis (sagittal) (Figures 8a, 9a, 10a, 11a) and Z-axis (vertical) (Figures 8b, 9b, 10b, 11b). The groups A with C and B with D graphs were superimposed and compared to analyse the difference in tooth displacement between MSI placed on posterior palatal slopes and mid-palatal region, keeping the position of power arm constant. (Figure 15 and 16)

The results were discussed under the following headings:

1. **Tooth displacement pattern on the Y-axis (sagittal plane).**

2. **Tooth displacement pattern on the Z-axis (vertical plane).**

1. TOOTH DISPLACEMENT PATTERN ON THE Y-AXIS.

Central incisor(#11)

The central incisor(#11) showed uncontrolled and palatal crown tipping in both 10mm and 13mm lengths of the power arm placed in both the positions with all the positions of the MSI except at 1 condition. The central incisors resulted a bodily retraction in group C with both the lengths of the power arm placed between the lateral incisor and the canine with the MSI placed 12mm from the incisive papilla, in the anterior mid-palatal region. (#11 in Figure 14a)

The maximum palatal crown tipping of #11 was observed in group A and B when retracted using 10mm power arm at both positions with 4 mm and 6 mm heights of the MSIs placed in the slopes of the posterior palatal. And this effect seems to reduce when the power arm height and the MSI height are increased to 13mm and 8-10mm respectively. (#11 in Figure 12a and 13a)

The comparison between groups shows that #11 results in more desired movement in group C and D when mid-palatal implants are placed 12mm behind the incisive papilla in the anterior palate. #11 showed bodily movement in both lengths of the power arm when placed between the lateral incisors and the canine and a lesser degree of crown tipping was seen when the power arm placed between the central incisor and the lateral incisor. The degree of the torque loss in #11 is reduced when MSI is placed in the mid-palatal region and is more desired in the anterior mid-palatal region with both the lengths and positions of the power arm. (#11 in Figure 16a)

Lateral incisor (#12)

The lateral incisor (#12) resulted in uncontrolled and palatal crown tipping in group A with both 10mm and 13mm lengths of the power arm when placed between the lateral incisors and canines and in all the 4 heights of MSI over slopes of the posterior palate in group A (#12 in Figure 12a). The degree of the lingual tipping is reduced in group B when the power arm is placed between central incisor and lateral incisor in group B when compared to group A. When the length of power arm is compared in group B a more of bodily movement is seen with 13 mm length with 8-10mm heights of MSI positions in the posterior palatal slope. (#12 in Figure 13a)

The comparison between groups shows that #12 results in more desired tooth movement in group C and D when mid-palatal implants are placed 12mm behind the incisive papilla in the anterior mid-palatal area. #12 showed bodily movement in both lengths of the power arm when placed between the lateral incisors and the canine and a controlled crown tipping when the power arm placed between the central incisor and the lateral incisor when MSI is placed in the anterior mid-palatal region. (#12 in Figure 16a)

The maximum palatal crown tipping of #12 was observed in group A (with both 10mm and 13mm lengths of the power arm placed between the lateral incisors and canines along with MSI over slopes of the posterior palate) followed by group D while using 10mm power arm between the lateral incisor and the central incisor with MSI placed 24mm behind the incisive papilla in the posterior mid-palatal region. (#12 in Figure 12a and 15a)

Canine (#13)

The canine (#13) showed more bodily movement in group B with the MSI placed in the slopes of the posterior palate (8mm and 10mm) with 13mm power arm length placed between the central incisor and the lateral incisor. (#13 in Figure 13a)

Comparatively less tipping was seen in group C and group D when MSI placed in the anterior mid-palatal region with both 10 mm and 13 mm power arm lengths placed between the lateral incisor and canine, central incisor and lateral incisor respectively. When compared between group C and D, the degree of tipping was reduced in group C with anterior mid-palatal MSI placed 12mm behind the incisive papilla along with 10 and 13mm lengths of the power arm when placed between central and lateral incisor. (#13 in Figure 14a and 15a)

The maximum palatal crown tipping of #13 was observed in group C and group D when we used power arm length of 10mm in both positions between the lateral incisor and canine and between central incisor and lateral incisor with MSI placed 24mm behind the incisive papilla. (#13 in Figure 14a and 15a)

First premolar (#14)

Mild distal crown tipping was seen in most of the retraction conditions in all the groups for first premolars. The degree of crown tipping was reduced in group C and group D, when MSI placed 12 mm behind the incisive papilla over the mid-palatal region with 13 mm power arm placed in both the positions. (#14 in Figure 14a and 15a)

A similar mild distal crown tipping of #14 was observed in group A and group B when 8mm and 10mm MSI placed in the slopes of the posterior palate with 13mm power arm placed in both the positions. (#14 in Figure 12a and 13a)

The greatest degree of distal crown tipping of #14 was observed in group C and group D when 10mm length of the power arm in both the positions with MSI placed 24mm behind the incisive papilla. (#14 in Figure 17a)

2. Tooth displacement pattern on the Z-axis.

The results of tooth displacement in z-axis or the vertical plane were represented in positive values for intrusion and negative values for extrusion.

Central incisor (#11)

The central incisor (#11) showed extrusion of the crown with MSI placed at all 4 heights at the slopes of the posterior palate with both the positions and lengths of the power arm in group A and B. The degree of extrusion of #11 was more with MSI placed in the posterior palatal slope with the power arm lengths 4mm and 6mm. The degree of extrusion was higher when power arm placed between the central and lateral incisor than between the lateral incisor and the canine. (#11 in Figure 12b and 13b)

The central incisors showed mild intrusion during retraction when MSI placed in the anterior mid-palatal area 12mm behind the incisive papilla with both the lengths of the power arm placed between the lateral incisor and canine. (#11 in Figure 14b)

#11 showed neither intrusion nor extrusion during retraction when retracted using 10mm power arm placed between the central incisor and lateral incisor with MSI placed anterior mid-palatal region 12mm behind the incisive papilla. (#11 in Figure 15b)

Comparison of the groups shows that the degree of extrusion was more in group B when the 10mm power arm positioned between central incisors and the lateral incisors with MSI at 4mm and 6mm on the slopes of the posterior palate. Extrusion was also more in combination with 10 mm power arm between central and lateral incisors when MSI is placed at the posterior palatal slope area. (#11 in Figure 17b)

Lateral incisors (#12)

The lateral incisors (#12) showed mild extrusion in group A and B with both the lengths and both positions of the power arm with MSI placed in all four heights on the posterior palatal slope. The degree of the extrusion was lesser when 13mm power arm placed between the lateral incisor and the canine with MSI placed 8mm and 10mm on the slopes of the posterior palate. (#12 in Figure 12b)

The #12 showed mild intrusion with both lengths of the power arm placed between the lateral incisor and the canine with MSI at the anterior palatal region and when 13mm power arm placed between the central incisor and lateral incisor with MSI placed at 12mm behind the incisive papilla. (#12 in Figure 14b and 15b)

#12 showed neither intrusion nor extrusion in group D during retraction when retracted using 10mm power arm placed between the central incisor and lateral incisor with MSI placed in the anterior mid-palatal region 12mm behind the incisive papilla. (#12 in Figure 15b)

#12 showed extrusion when MSI is placed 24mm behind the incisive papilla with both the lengths of the power arm placed at both positions. (#12 in Figure 14b and 15b)

Canines (#13)

The canines (#13) showed extrusion with both the lengths of the power arm placed at both positions with MSI placed 24mm behind the incisive papilla. (#13 in Figure 14b and 15b)

The degree of extrusion was reduced with both the lengths of the power arm placed at both positions with MSI placed in the posterior palatal slope. (#13 in Figure 12b and 13b)

#13 showed neither intrusion nor extrusion in group C and D during retraction when retracted using both the lengths of the power arm placed in both positions with MSI placed in the anterior palatal region 12mm behind the incisive papilla. This condition also resulted with 13mm power arm placed between the central incisor and lateral incisor with MSI placed 8mm and 10mm on the posterior palatal slopes. (#13 in Figure 14b, 15b and 13b)

First premolar (#14)

The first premolar (#14) showed extrusion in group A and B with both the lengths of the power arm at both positions with MSI placed in all four heights in the slopes of the posterior palate. The degree of extrusion was reduced with both the lengths of the power arm placed between central incisor and lateral incisor with MSI placed in all four heights in the slopes of the posterior palate. (#14 in Figure 12b and 13b)

#14 exhibited mild extrusion in group D when retracted with both the lengths of the power arm when placed between the lateral incisor and central incisor with MSI placed 12mm and 24mm behind the incisive papilla in the mid-palatal region. (#14 in Figure 15b)

#14 showed mild intrusion in group D when retracted with both the lengths of the power arm when placed between the central and lateral incisor with MSI placed 12 mm behind the incisive papilla in the anterior mid-palatal region. (#14 in Figure 14b)

#14 showed neither intrusion nor extrusion in group D during retraction when retracted using both the lengths of the power arm placed between central and lateral incisor with MSI placed 24mm behind the incisive papilla. (#14 in Figure 15b)

Collectively, the results in **Y-axis** (antero-posterior) showed that, the incisors showed lesser crown tipping with mid-palatal MSI in group C and D, and a bodily movement was seen with both the lengths of the power arm placed between the lateral incisor and canine with MSI at 12mm behind the incisive papilla. The canine and premolar showed a lesser degree of crown tipping than the incisors in all conditions. They nearly showed bodily movement with13 mm power arm placed between central incisor and lateral incisor with either anterior mid-palatal implant or with 8-10 mm on slopes of posterior palate.

The results in the **Z-axis** (vertical) for the anterior teeth showed extrusion with MSI placed in the posterior palatal slope with both the lengths of the power arm placed in both positions. The canine showed neither intrusion nor extrusion when retracted using 13mm power arm placed between the central and lateral incisor with MSI 8-10mm in the posterior palatal slope.

Anterior teeth showed intrusion when retracted with mid-palatal MSI 12mm behind the incisive papilla. The degree of intrusion was lesser in canines than in incisors. When retracted with posterior mid-palatal implants (24mm), the anterior teeth experiences extrusion. The degree of extrusion was less with 13mm power arm placed between central and lateral incisor.

The first premolars showed intrusion with MSI placed in the posterior palatal slope and the degree of intrusion was lesser with power arm placed between central and lateral incisor. Whereas it showed extrusion with power arm between the central and lateral incisor with MSI placed in anterior mid-palatal area. Neither intrusion nor extrusion with MSI placed in the posterior mid-palatal region.

TABLE 1: THE MECHANICAL PROPERTIES OF THE MATERIALS USED FOR EACH TISSUE TYPE IN THE STUDY

	Young's Modulus (Mpa)	Poisson's Ratio
Periodontal ligament	5.0E-02	0.49
Alveolar bone	2.0E+03	0.30
Tooth	2.0E+04	0.30
Stainless Steel	2.0E+05	0.30

TABLE 2: RETRACTION CONDITION RELATIVE TO Y AXIS (ANTERO-POSTERIOR) AND Z AXIS (VERTICAL) IN GROUP A

Tooth	Length of the lever arm (mm)	Vertical Height of Implant (mm)		Y axis	Z axis
#11	10	4	RA	-2.12E-04	-1.33E-05
			IE	-3.88E-03	-7.88E-04
		6	RA	-7.46E-04	-1.11E-04
			IE	-5.04E-03	-1.04E-03
	13	8	RA	-6.25E-04	-4.35E-05
			IE	-4.54E-03	-8.93E-04
		10	RA	-6.08E-04	-7.31E-06
			IE	-4.47E-03	-8.61E-04
#12	10	4	RA	-4.98E-04	3.36E-05
			IE	-3.73E-03	-1.88E-04
		6	RA	-1.16E-03	-4.79E-05
			IE	-5.03E-03	-3.81E-04
	13	8	RA	-9.22E-04	-2.83E-05
			IE	-4.40E-03	-2.50E-04
		10	RA	-8.86E-04	2.06E-05
			IE	-4.34E-03	-3.22E-04
#13	10	4	RA	-9.02E-05	-9.24E-05
			IE	-1.19E-03	-4.04E-04
		6	RA	-6.18E-04	-1.05E-04
			IE	-2.75E-03	-6.35E-04
	13	8	RA	-3.69E-04	-1.40E-04
			IE	-1.55E-03	-3.09E-04
		10	RA	-3.50E-04	-1.06E-04
			IE	-1.47E-03	-3.16E-04
#14	10	4	RA	-1.71E-04	2.73E-05
			IE	-6.54E-04	5.04E-04
		6	RA	-1.07E-03	6.48E-05
			IE	-2.29E-03	4.63E-04
	13	8	RA	-5.37E-04	4.32E-05
			IE	-1.06E-03	5.93E-04
		10	RA	-4.98E-04	8.39E-05
			IE	-9.60E-04	6.93E-04

In Y axis, positive values mean tooth procline and negative values mean retraction.
In Z axis, positive values mean tooth intrusion and negative values mean tooth extrusion.
RA – Root Apex, IE – Incisal Edge

TABLE 3: RETRACTION CONDITION RELATIVE TO Y AXIS (ANTERO-POSTERIOR) AND Z AXIS (VERTICAL) IN GROUP B

Tooth	Length of the lever arm (mm)	Vertical Height of Implant (mm)		Y axis	Z axis
#11	10	4	RA	-8.82E-04	-2.49E-04
			IE	-6.36E-03	-1.48E-03
		6	RA	-8.63E-04	-2.65E-04
			IE	-6.39E-03	-1.42E-03
	13	8	RA	-8.26E-04	-2.41E-04
			IE	-4.73E-03	-9.51E-04
		10	RA	-8.17E-04	-1.56E-04
			IE	-4.77E-03	-9.63E-04
#12	10	4	RA	-1.30E-03	-2.94E-04
			IE	-3.55E-03	-9.33E-04
		6	RA	-1.23E-03	-3.47E-04
			IE	-3.48E-03	-8.60E-04
	13	8	RA	-1.02E-03	-3.08E-04
			IE	-1.88E-03	-5.84E-04
		10	RA	-1.00E-03	-2.09E-04
			IE	-1.82E-03	-5.28E-04
#13	10	4	RA	-5.94E-04	-6.20E-05
			IE	-2.34E-03	-4.34E-04
		6	RA	-5.91E-04	-6.18E-05
			IE	-2.21E-03	-2.89E-04
	13	8	RA	-3.03E-04	-5.75E-05
			IE	-8.88E-04	-6.59E-05
		10	RA	-3.15E-04	-1.73E-05
			IE	-7.80E-04	4.16E-05
#14	10	4	RA	-1.06E-03	8.98E-05
			IE	-2.31E-03	3.11E-04
		6	RA	-1.03E-03	1.28E-04
			IE	-2.18E-03	3.78E-04
	13	8	RA	-4.56E-04	8.26E-05
			IE	-9.06E-04	3.18E-04
		10	RA	-4.38E-04	1.05E-04
			IE	-8.17E-04	3.61E-04

In Y axis, positive values mean tooth procline and negative values mean retraction.
In Z axis, positive values mean tooth intrusion and negative values mean tooth extrusion.
RA – Root Apex, IE – Incisal Edge

TABLE 4: RETRACTION CONDITION RELATIVE TO Y AXIS (ANTERO-POSTERIOR) AND Z AXIS (VERTICAL) IN GROUP C

Tooth	Length of the lever arm (mm)	Mid palatal height of the mini screw (mm)		Y axis	Z axis
#11	10	12	RA	-3.42E-04	1.44E-04
			IE	-4.98E-04	1.05E-04
		24	RA	-6.58E-04	-5.40E-05
			IE	-2.56E-03	-5.69E-04
	13	12	RA	-2.84E-04	1.94E-04
			IE	-3.31E-04	1.58E-04
		24	RA	-5.84E-04	-2.63E-05
			IE	-2.65E-03	-4.57E-05
#12	10	12	RA	-5.12E-04	1.80E-04
			IE	-1.43E-03	5.88E-05
		24	RA	-1.04E-03	-1.85E-05
			IE	-3.40E-03	-4.09E-04
	13	12	RA	-4.12E-04	2.24E-04
			IE	-1.09E-03	1.60E-04
		24	RA	-9.26E-04	-4.57E-05
			IE	-3.51E-03	-3.21E-04
#13	10	12	RA	-4.53E-04	1.85E-04
			IE	-2.45E-03	-4.44E-04
		24	RA	-6.83E-04	3.75E-05
			IE	-3.75E-03	-9.76E-04
	13	12	RA	-3.20E-04	2.06E-04
			IE	-2.19E-03	-5.26E-04
		24	RA	-5.08E-04	-2.63E-05
			IE	-2.79E-03	-8.22E-04
#14	10	12	RA	-8.30E-04	4.57E-05
			IE	-2.02E-03	-1.87E-04
		24	RA	-1.34E-03	-7.29E-05
			IE	-3.17E-03	-2.88E-04
	13	12	RA	-5.52E-04	2.41E-06
			IE	-1.53E-03	-2.25E-04
		24	RA	-8.34E-04	-1.36E-04
			IE	-2.06E-03	-1.80E-04

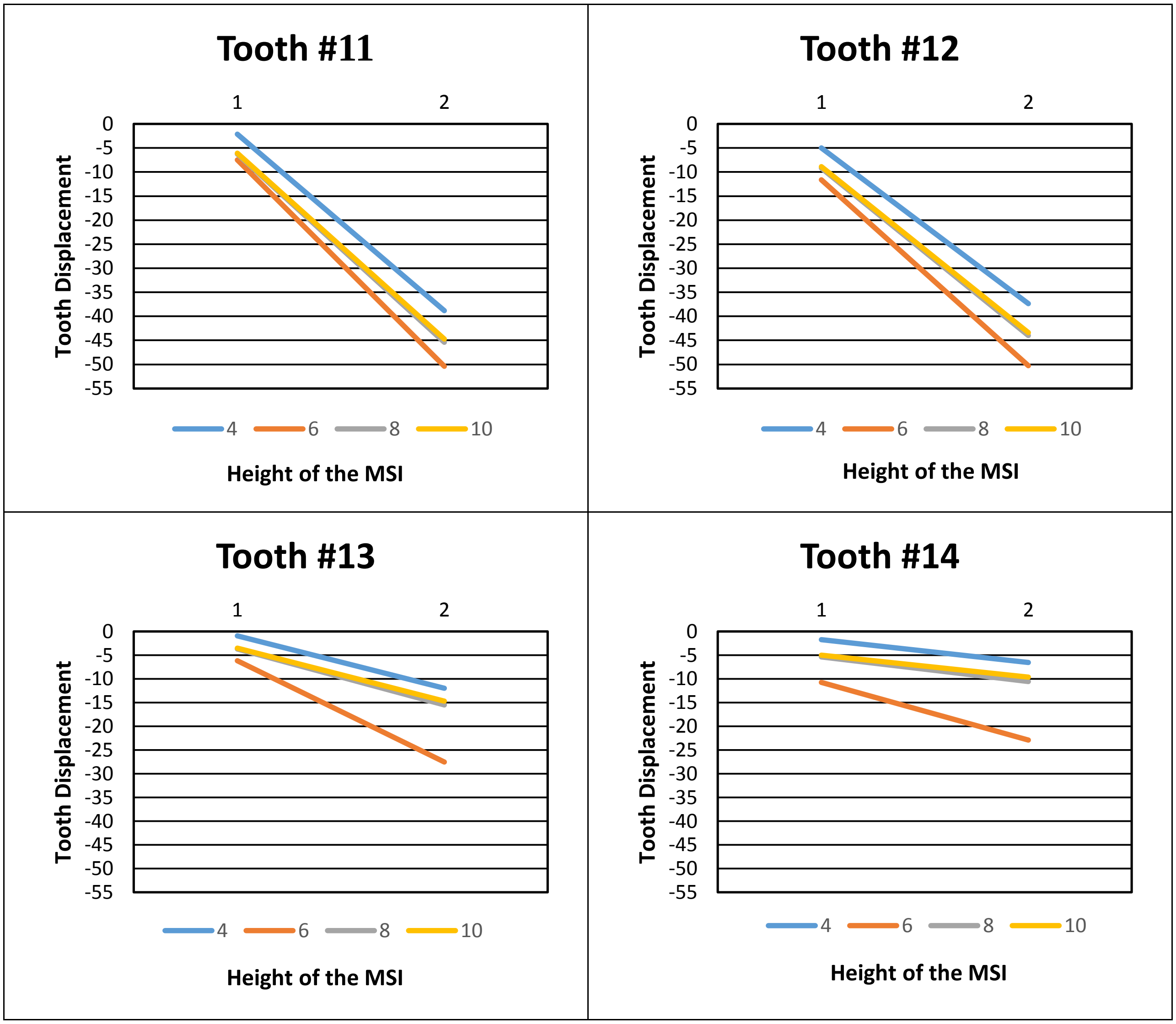
In Y axis, positive values mean tooth procline and negative values mean retraction.
In Z axis, positive values mean tooth intrusion and negative values mean tooth extrusion.
RA – Root Apex, IE – Incisal Edge

TABLE 5: RETRACTION CONDITION RELATIVE TO Y AXIS (ANTERO-POSTERIOR) AND Z AXIS (VERTICAL) IN GROUP D

Tooth	Length of the lever arm (mm)	Mid palatal height of the mini screw (mm)		Y axis	Z axis
#11	10	12	RA	-4.03E-04	1.44E-04
			IE	-2.29E-03	-2.34E-04
		24	RA	-8.17E-04	-1.59E-04
			IE	-4.48E-03	-1.01E-03
	13	12	RA	-3.93E-04	2.44E-04
			IE	-1.54E-03	5.99E-05
		24	RA	-8.27E-04	-7.84E-05
			IE	-2.84E-03	-4.10E-04
#12	10	12	RA	-5.75E-04	1.96E-04
			IE	-2.75E-03	-1.75E-04
		24	RA	-1.24E-03	-1.60E-04
			IE	-4.46E-03	-8.16E-04
	13	12	RA	-4.93E-04	2.68E-04
			IE	-1.79E-03	1.05E-04
		24	RA	-1.05E-03	-7.52E-05
			IE	-2.45E-03	-2.57E-04
#13	10	12	RA	-3.89E-04	1.51E-04
			IE	-1.69E-03	-1.38E-04
		24	RA	-6.61E-04	-3.15E-05
			IE	-3.22E-03	-7.01E-04
	13	12	RA	-2.90E-04	1.31E-04
			IE	-1.10E-03	-6.67E-05
		24	RA	-4.73E-04	-1.49E-05
			IE	-1.93E-03	-5.02E-04
#14	10	12	RA	-6.13E-04	2.06E-04
			IE	-1.39E-03	2.94E-04
		24	RA	-1.20E-03	3.78E-05
			IE	-2.90E-03	7.02E-05
	13	12	RA	-3.67E-04	1.30E-04
			IE	-8.24E-04	2.07E-04
		24	RA	-6.79E-04	-3.86E-05
			IE	-1.66E-03	-4.53E-05

In Y axis, positive values mean tooth procline and negative values mean retraction.
In Z axis, positive values mean tooth intrusion and negative values mean tooth extrusion.
RA – Root Apex, IE – Incisal Edge

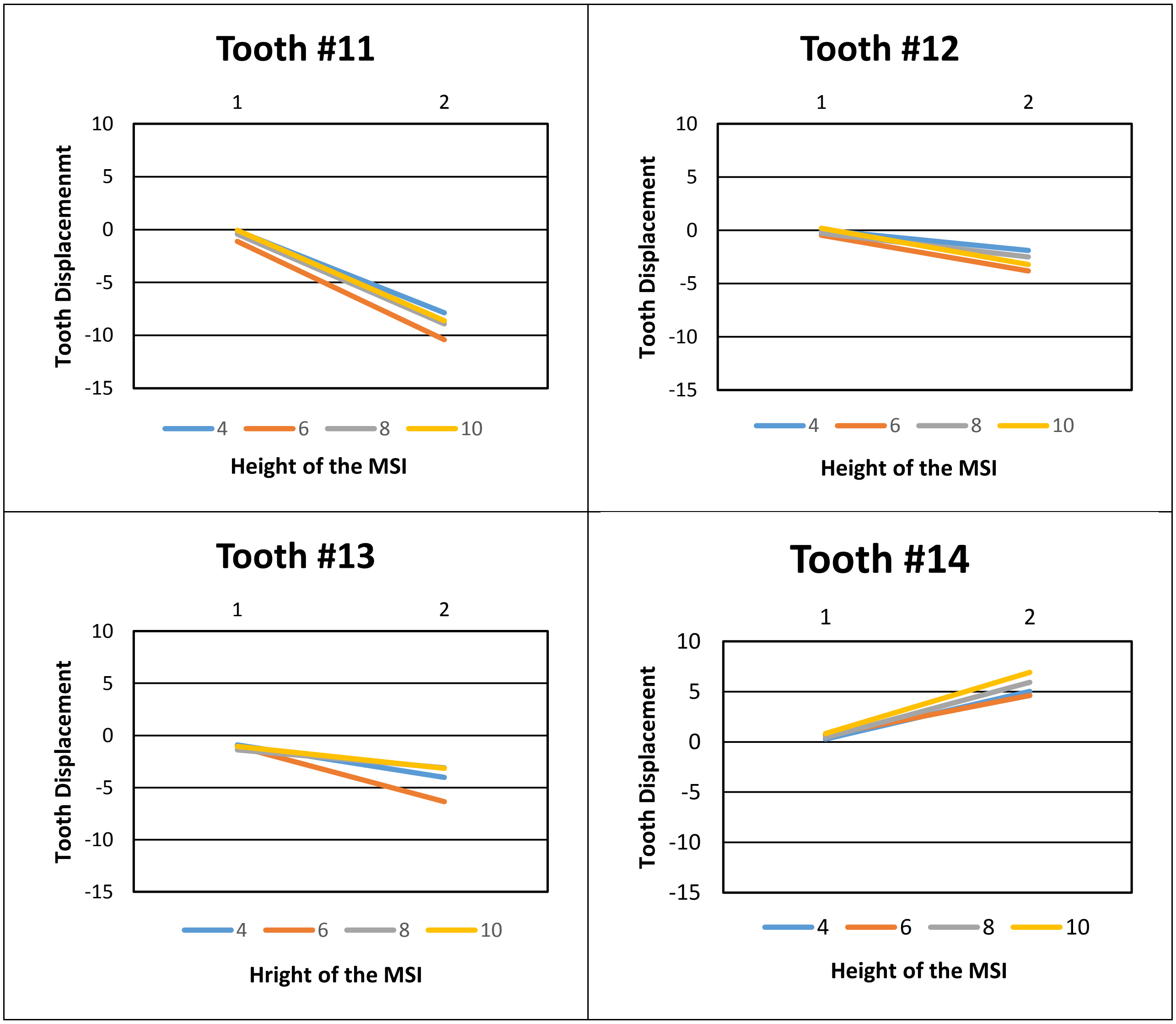
FIGURE 12a: COMPARISON OF THE EFFECTS IN Y AXIS (ANTERO-POSTERIOR) IN GROUP A



1 – Root Apex; 2 – Incisal Edge

<All points in the graph are expressed in E-04 or 10^{-4}>

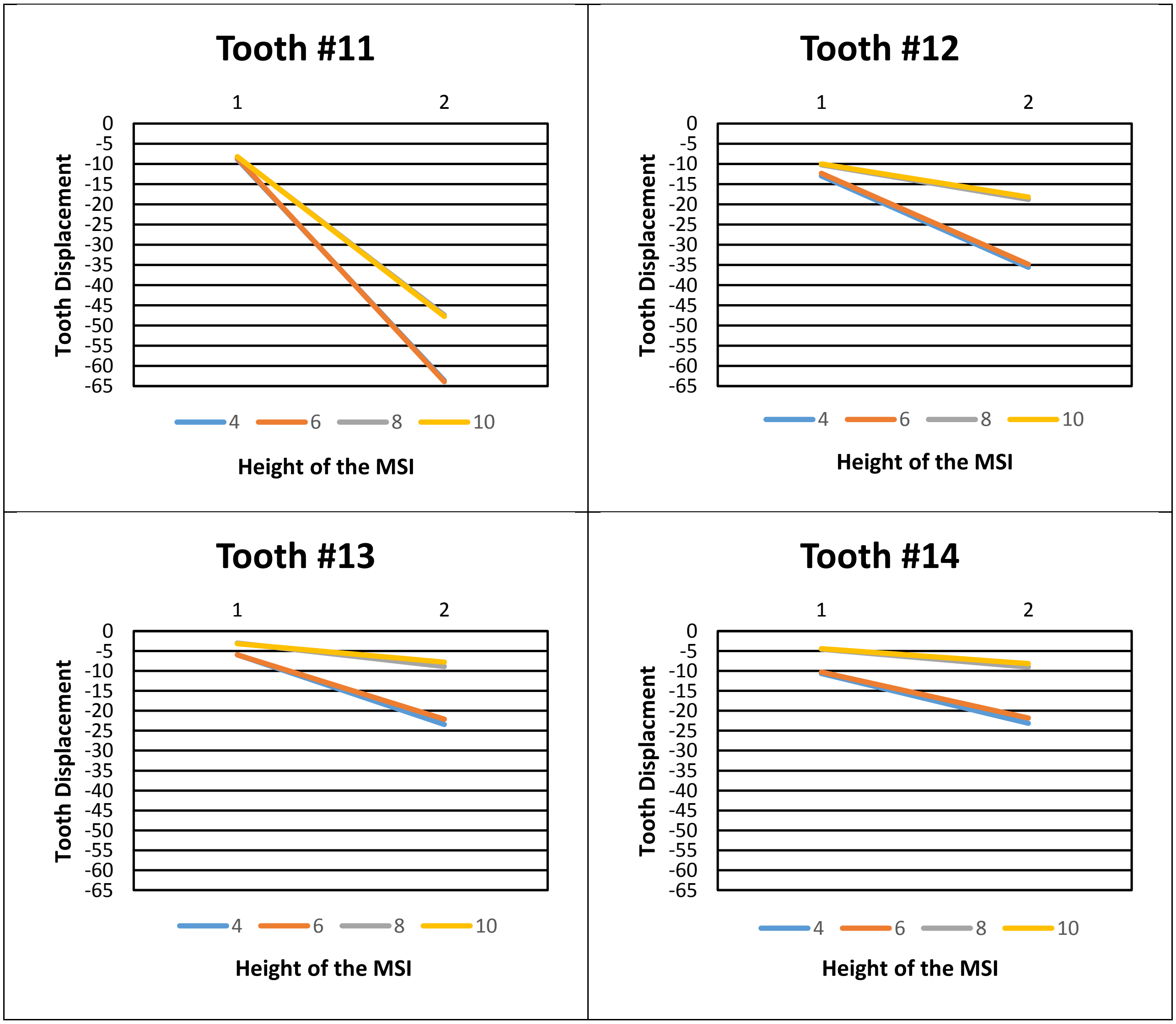
FIGURE 12b: COMPARISON OF THE EFFECTS IN Z AXIS (VERTICAL) IN GROUP A



1 – Root Apex; 2 – Incisal Edge

<All points in the graph are expressed in E-04 or 10^{-4}>

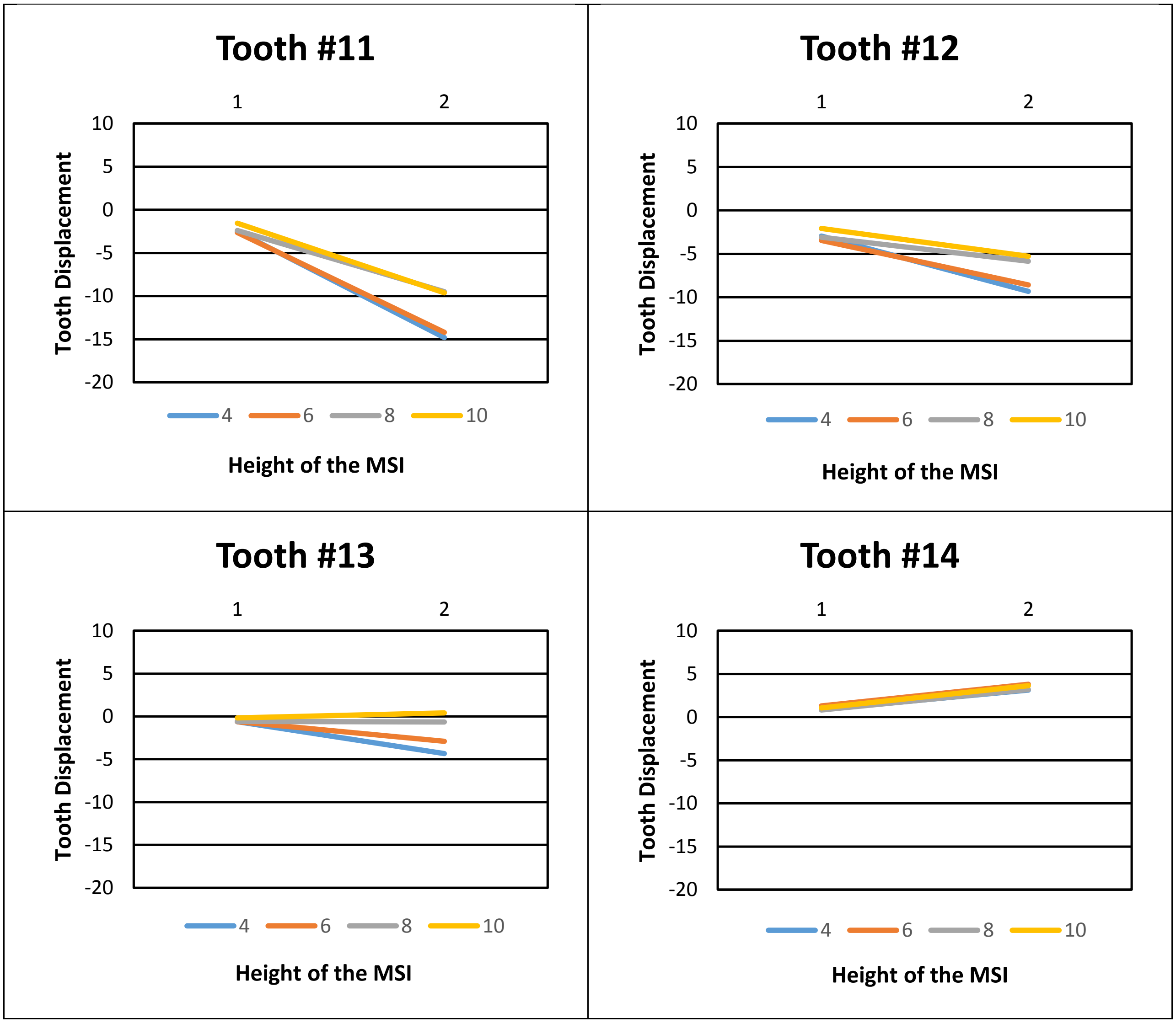
FIGURE 13a: COMPARISON OF THE EFFECTS IN Y AXIS (ANTERO-POSTERIOR) IN GROUP B



1 – Root Apex; 2 – Incisal Edge

<All points in the graph are expressed in E-04 or 10^{-4}>

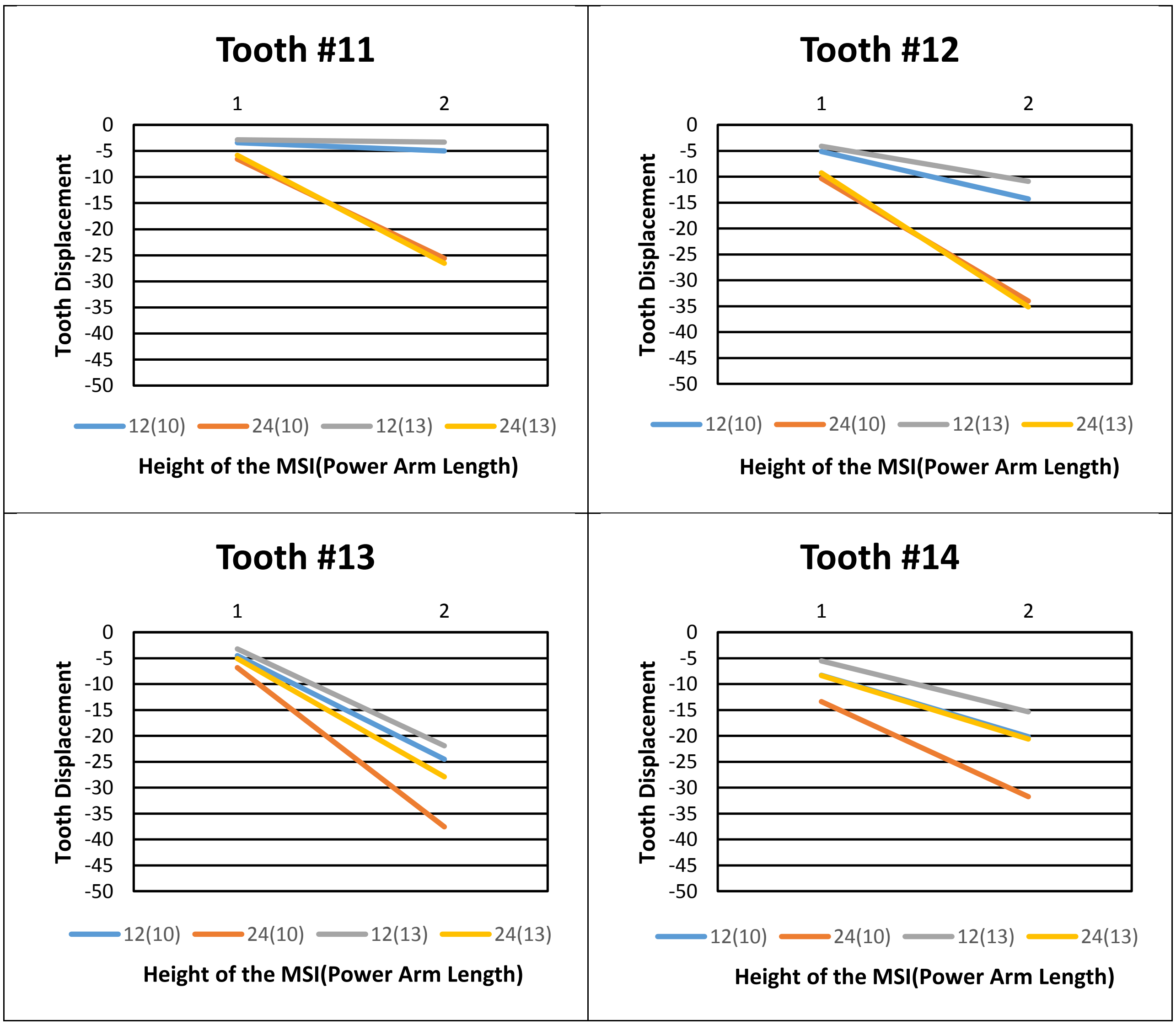
FIGURE 13b: COMPARISON OF THE EFFECTS IN Z AXIS (VERTICAL) IN GROUP B



1 – Root Apex; 2 – Incisal Edge

<All points in the graph are expressed in E-04 or 10^{-4}>

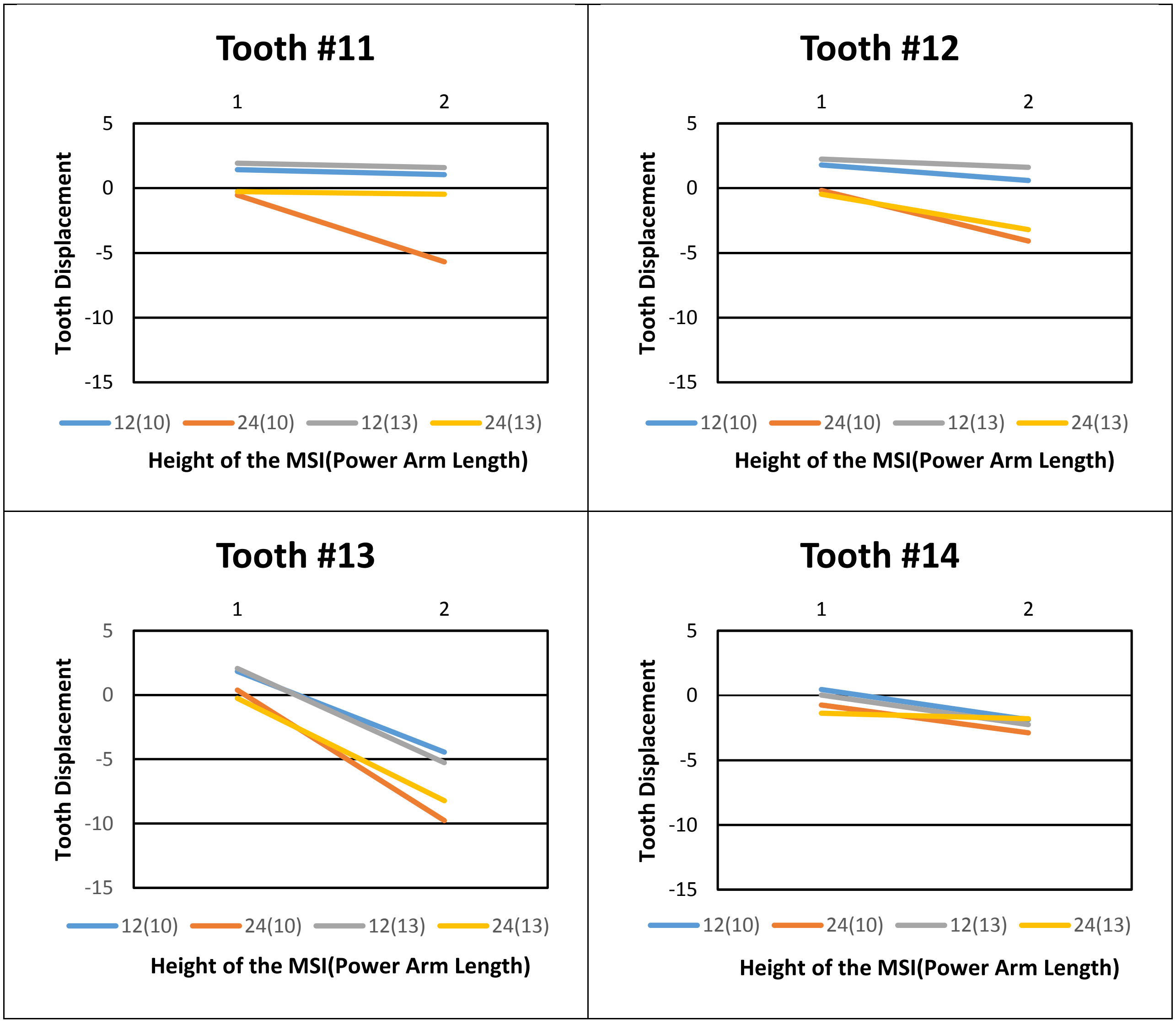
FIGURE 14a: COMPARISON OF THE EFFECTS IN Y AXIS (ANTERO-POSTERIOR) IN GROUP C



1 – Root Apex; 2 – Incisal Edge

<All points in the graph are expressed in E-04 or 10^{-4}>

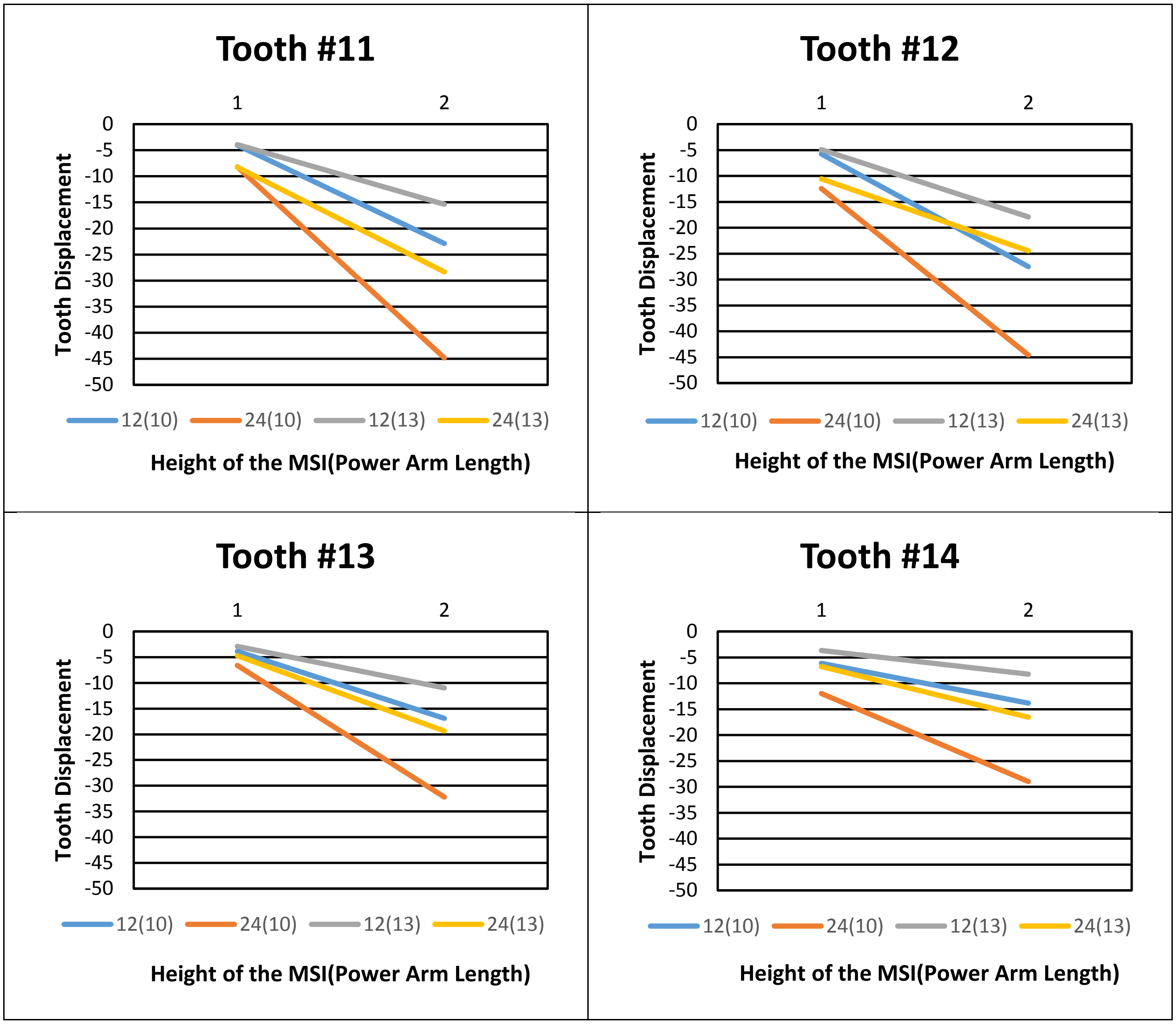
FIGURE 14b: COMPARISON OF THE EFFECTS IN Z AXIS (VERTICAL) IN GROUP C



1 – Root Apex; 2 – Incisal Edge

<All points in the graph are expressed in E-04 or 10^{-4}>

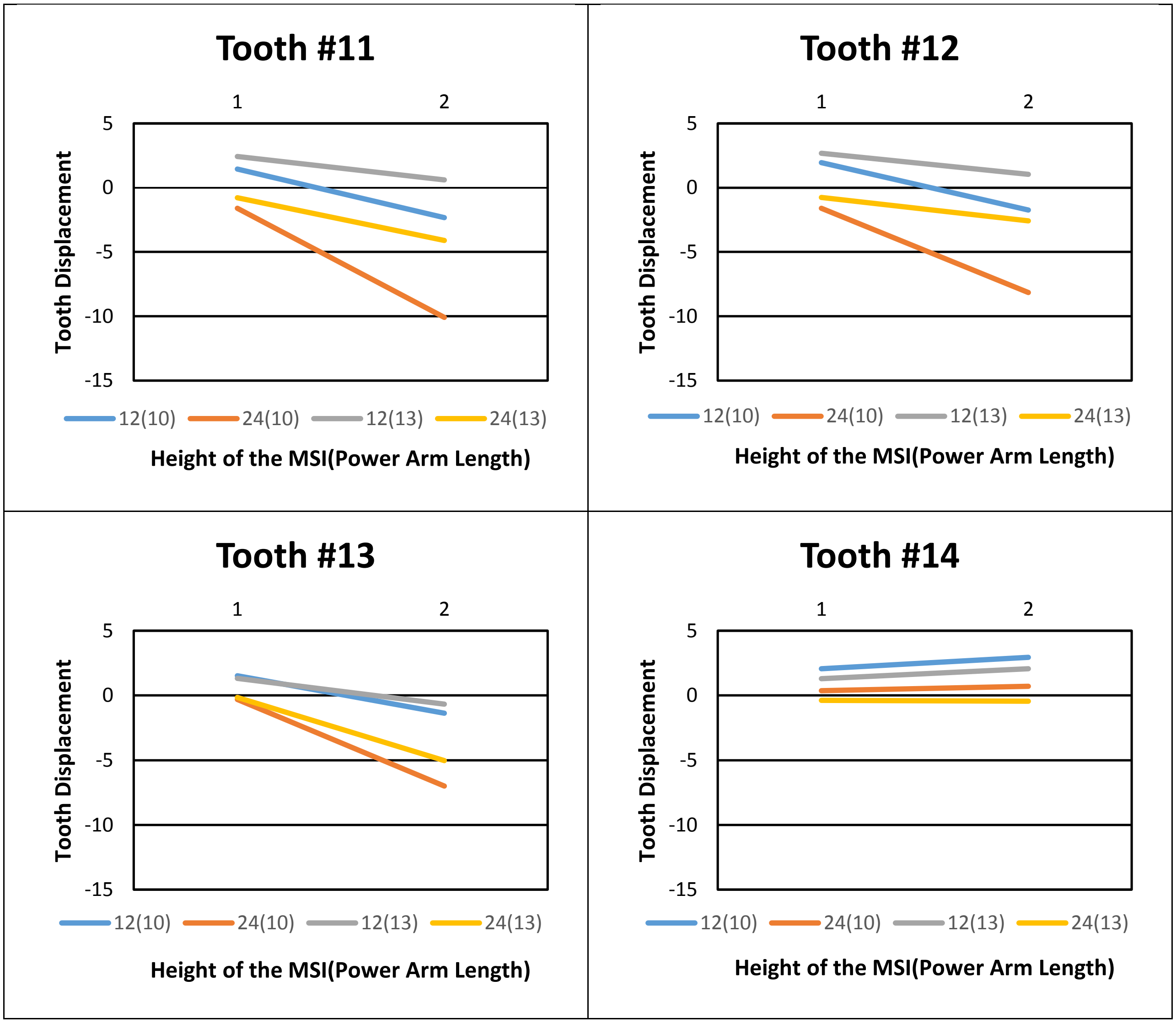
FIGURE 15a: COMPARISON OF THE EFFECTS IN Y AXIS (ANTERO-POSTERIOR) IN GROUP D



1 – Root Apex; 2 – Incisal Edge

<All points in the graph are expressed in E-04 or 10^{-4}>

FIGURE 15b: COMPARISON OF THE EFFECTS IN Z AXIS (VERTICAL) IN GROUP D



1 – Root Apex; 2 – Incisal Edge

<All points in the graph are expressed in E-04 or 10^{-4}>

FIGURE 16a: COMPARISON OF GROUP A AND GROUP C (POWER ARM PLACED BETWEEN LATERAL INCISOR AND CANINE) CONDITIONS AND SUPERIMPOSITION OF TOOTH DISPLACEMENT IN Y AXIS

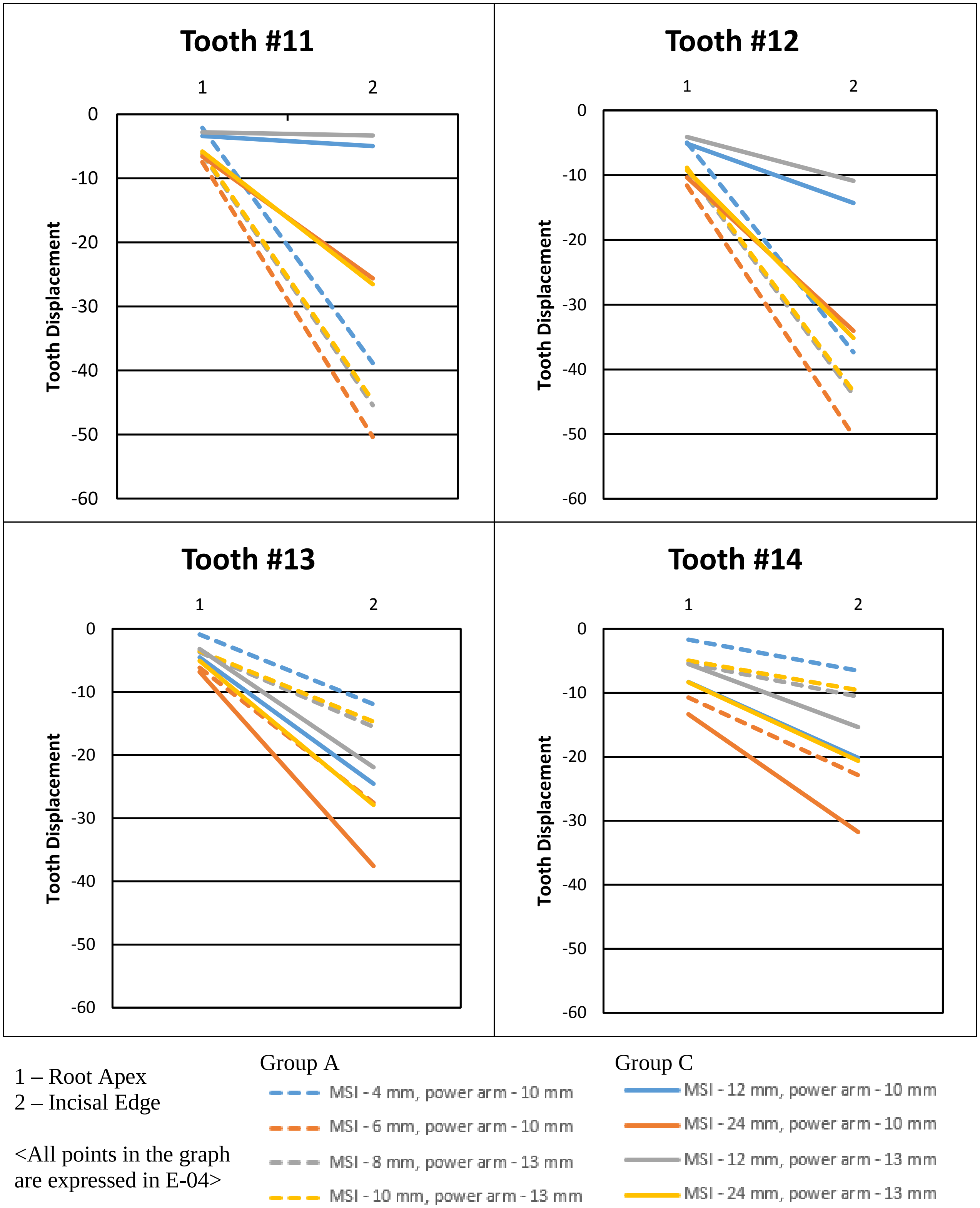
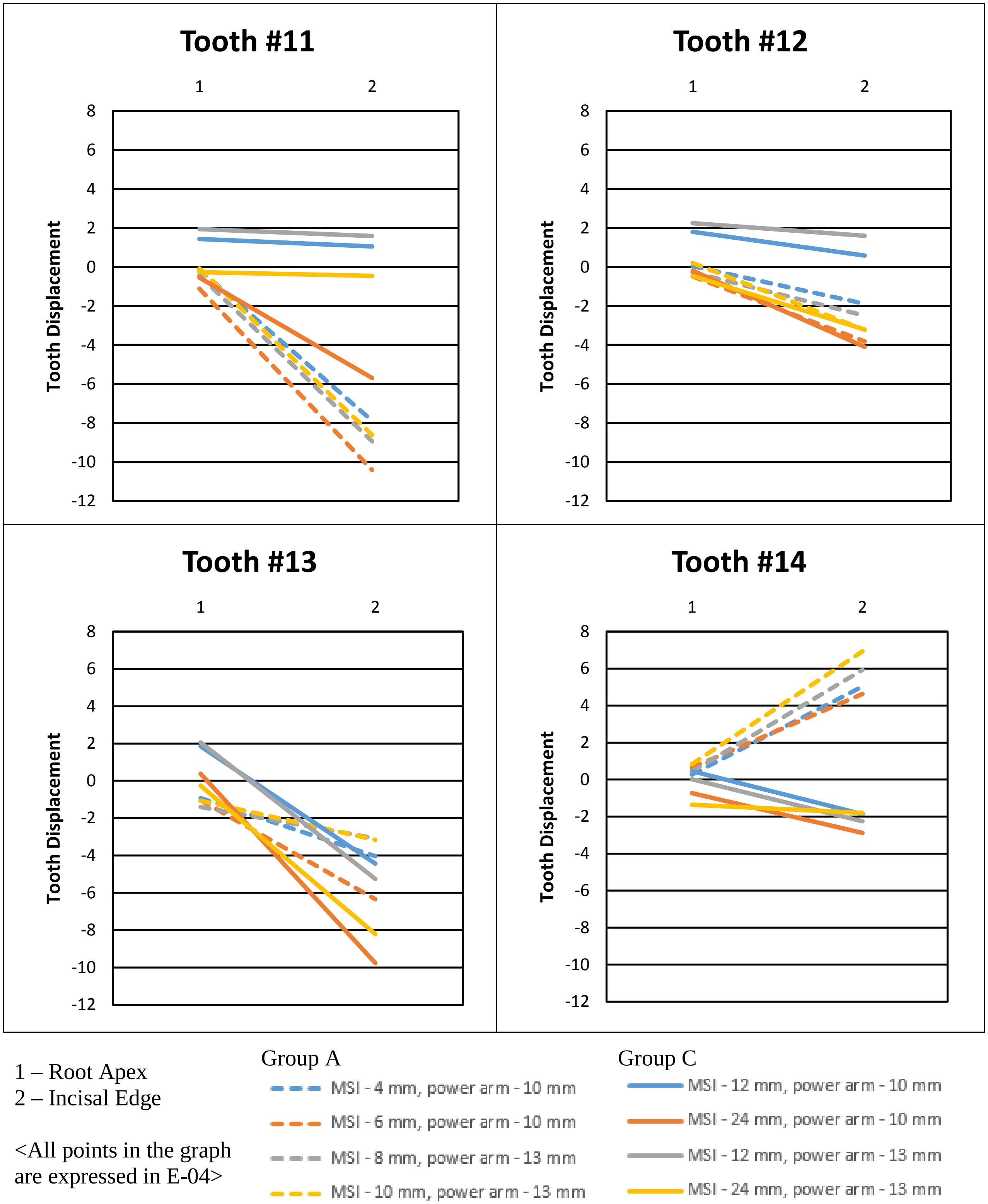


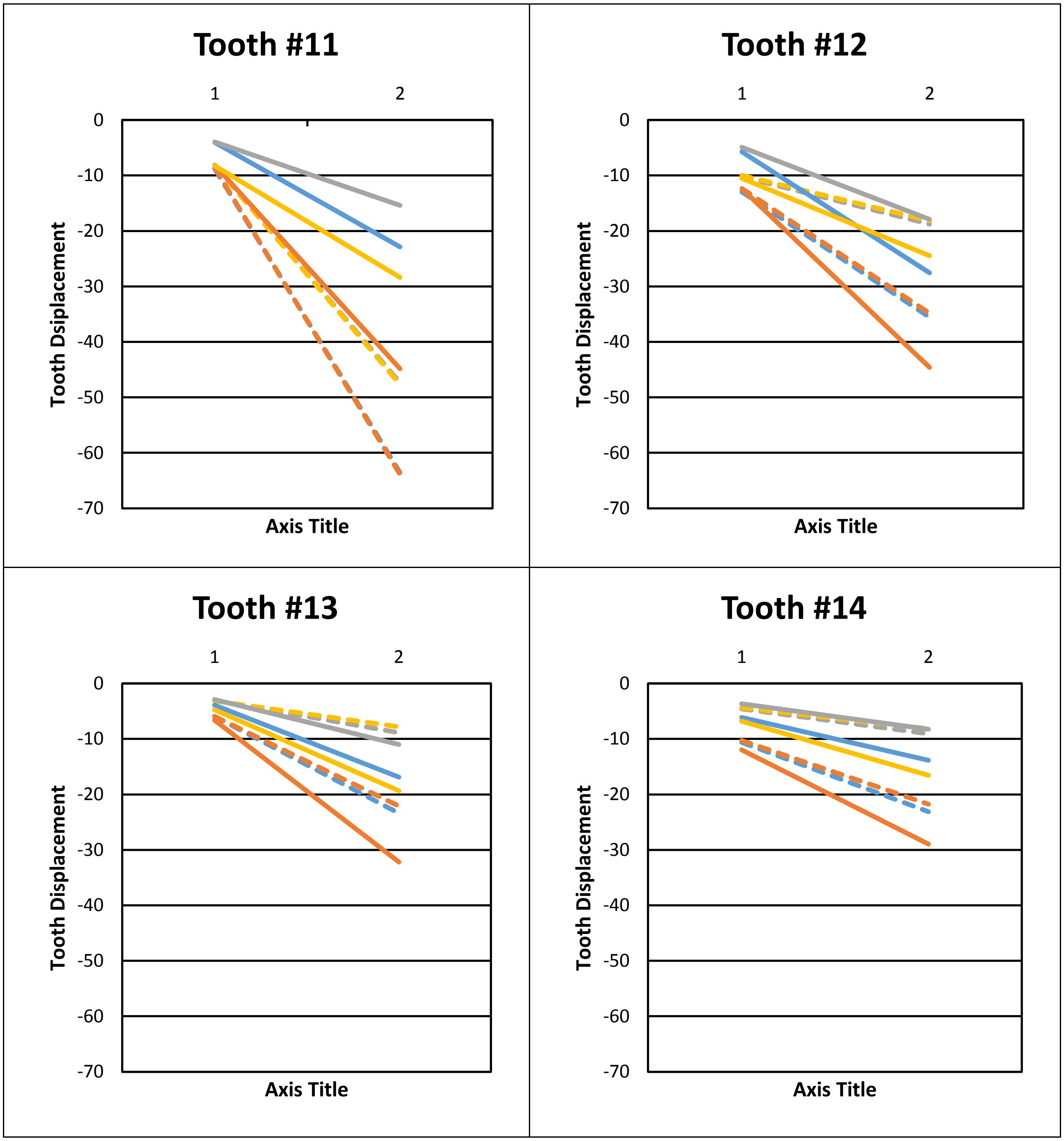
FIGURE 16b: COMPARISON OF GROUP A AND GROUP C (POWER ARM PLACED BETWEEN LATERAL INCISOR AND CANINE) CONDITIONS AND SUPERIMPOSITION OF TOOTH DISPLACEMENT IN Z AXIS



1 – Root Apex
2 – Incisal Edge

<All points in the graph are expressed in E-04>

FIGURE 17a: COMPARISON OF GROUP B AND GROUP D (POWER ARM PLACED BETWEEN CENTRAL INCISOR AND LATERAL INCISOR) CONDITIONS AND SUPERIMPOSITION OF TOOTH DISPLACEMENT IN Y AXIS



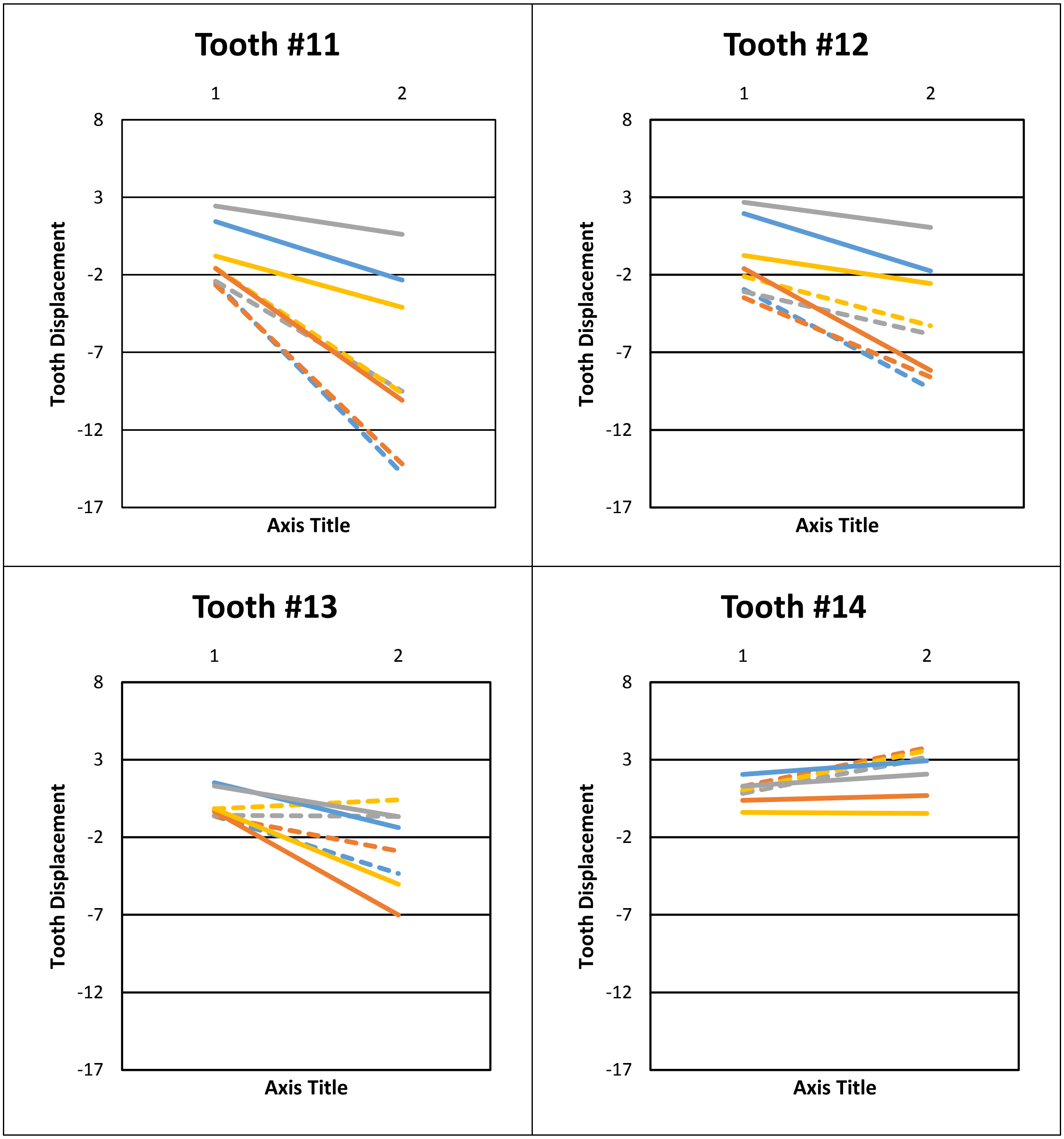
1 – Root Apex
2 – Incisal Edge

<All points in the graph are expressed in E-04>

Group B
- MSI - 4 mm, power arm - 10 mm
- MSI - 6 mm, power arm - 10 mm
- MSI - 8 mm, power arm - 13 mm
- MSI - 10 mm, power arm - 13 mm

Group D
- MSI - 12 mm, power arm - 10 mm
- MSI - 24 mm, power arm - 10 mm
- MSI - 12 mm, power arm - 13 mm
- MSI - 24 mm, power arm - 13 mm

FIGURE 17b: COMPARISON OF GROUP B AND GROUP D (POWER ARM PLACED BETWEEN CENTRAL INCISOR AND LATERAL INCISOR) CONDITIONS AND SUPERIMPOSITION OF TOOTH DISPLACEMENT IN Z AXIS



1 – Root Apex
2 – Incisal Edge

<All points in the graph are expressed in E-04>

Group B
- MSI - 4 mm, power arm - 10 mm
- MSI - 6 mm, power arm - 10 mm
- MSI - 8 mm, power arm - 13 mm
- MSI - 10 mm, power arm - 13 mm

Group D
- MSI - 12 mm, power arm - 10 mm
- MSI - 24 mm, power arm - 10 mm
- MSI - 12 mm, power arm - 13 mm
- MSI - 24 mm, power arm - 13 mm

Discussion

DISCUSSION

With more number of adults seeking orthodontic treatment, there is an increase demand for employing lingual appliance which are virtually invisible. Aligners and lingual appliances offer a solution since they are less conspicious. The main drawback of aligners is its high cost and dilemma about the biomechanics to achieve bodily tooth movement and the inability of the operater to control the force vector. Thus lingual appliance is a viable option that offers the advantage of being invisible and better operator control.

A significant section of the population in this part of the country has bidental proclination and class II malocclusion which often warrants extraction.[1]

Retraction of anterior segment with ideal biomechanics to achieve tip and torque control has been formulated through years of researches and documented for labial orthodontics. The practice of lingual appliance was challenging due to its need for expensive lab procedures, high material cost coupled with complex biomechanics, with little or no literature evidences. With the increasing demand for lingual orthodontics in the past few years understanding the ideal biomechanical considerations have become mandatory. Though lingual appliances have been used from the early 1970's, the innovations from 1st generation to 7th generation lingual bracket by Dr. Craven kurz has been the motivation for several innovations such as the 2D and the customised lingual brackets (3D) and self-ligating brackets in lingual orthodontics. Nevertheless the efficient control of the anterior torque and intrusion during retraction continues to be a challenge.

To overcome the torque loss while retraction in lingual orthodontics several authors like Sung-seo Mo et al[33] and Jang et al[12], have suggested various biomechanical considerations from their clinical and research findings. But still there is no concrete scientific evidence available as reference for a successful retraction protocol in lingual orthodontics. Thereby, we have decided to find the ideal retraction protocol with various biomechanical considerations.

Efficient orthodontic retraction depends on an appreciation of the association between a line of action of the force and the centre of resistance of a tooth. Force passing through the centre of resistance results in bodily tooth movement and the force which does not pass through the centre of resistance produces a moment that tends to rotate the tooth.[34]

Knowledge concerning the location of the centre of resistance of maxillary anterior teeth would contribute to a successful treatment result and possibly reduce treatment time.

By definition, the centre of resistance is found at a point where a single force produces pure translation. Centre of resistance of a single tooth with normal periodontal tissues, exists two third of the distance from the alveolar crest to the apex. In case of a multi-rooted tooth, the center of resistance is located near the furcation.[8] Few authors like Burstone[5] reported that center of resistance was located at 33% of the distance of the root length apical to the alveolar crest in individuals with normal periodontal apparatus. Burstone and Pryputniewicz[4] found that the center of resistance was at a point one-third of the distance from the alveolar crest to the apex. Tanne et al[47] used a finite element method to determine displacements of teeth with various root length and alveolar bone height conditions and concluded that the location of the CR shifted apically as the alveolar bone height was reduced.

Dermaut and Bulcke used the laser reflection technique and holographic interferometry in testing 2 types of segmented arches on a macerated human skull. When the anterior six teeth were incorporated in the sectional wire, the center of resistance was located more towards distal side of the canines and the center of resistance of the four incisors was situated approximately distal to the lateral incisors. Bulcke et al have concluded that the center of resistance for the 6 anterior teeth was located at 7.0 mm apical to the interproximal bone level between the central incisors, measured perpendicular to the occlusal plane.[48]

The effect of bracket position and location of the point of force application on tooth movement differs in lingual orthodontics from labial orthodontics. For the same amount of retraction and intrusion forces applied to the incisor teeth, the line of force tend to differ between labial and lingual appliance. The resultant force in the lingual system shifts further lingual to the centre of resistance of the incisors compared with the labial system. Thus the net force in the lingual system will produce a larger moment which results in greater amount of torque loss compared to labial system.[39] Anterior torque control is achieved either by directly applying a moment and force to a lingual bracket or by using lever-arm mechanics to obtain the desired line of action of force with respect to the center of resistance.[36]

The direct application of torque is possible by incorporating it to the base of the bracket as well as using bends in the archwire. Even though we can avoid torque loss to an extent by adding excess torque to the bracket base, the complete expression of torque is practically impossible due to the lesser interbracket distance and decreased archwire size used in lingual retraction. So, the lever arm or power arm mechanics parallel to the occlusal plane and close to the centre of resistance will be a better option to maintain torque of anterior teeth during retraction. This is not possible by attaching the retraction force from the lever arm to the posterior teeth since the resultant force vector won't be parallel to the occlusal surface. Therefore the MSI (mini-screw implants) assisted retraction has been adopted in lingual mechanics to avoid torque loss by keeping the force vector parallel to the occlusal plane as far as possible.

Mini-screw implants (MSI) are bone-borne and provide excellent control over tooth movement in the three planes of movement. Effective enmasse retraction with improved facial esthetics, good torque control and effective intrusion can be accomplished using MSI in lingual orthodontics.

The aim of the study was to elucidate the ideal force vector that would be generated for bodily retraction of the incisors. The variable that influence the force vector namely the location of the appliance, the location of the power arm in the anterior segment, the length of the power arm and the optimal design from the point of origin of the force to the point of application were estimated using finite element method (FEM).

The finite element analysis (FEA) or finite element method (FEM) is an engineering resource used to evaluate stress and deformation in complex structures, and it has been extensively applied in biomedical research. The FEM principle is based on the division of a complex structure into smaller sections called elements in which physical properties, such as the modulus of elasticity, are applied to indicate the object response against an external stimulus such as an orthodontic force. With FEM, it is possible to anticipate the tissue responses to orthodontic forces applied which in turn will give a clear picture of the results from the applied forces.

In the past few years MSIs have been used extensively in orthodontics especially for retraction. In lingual orthodontics the possible sites for MSI are mid-palatal region and slopes of posterior palate. Even though the palate has become a popular site for placement of MSIs because of its easy access, presence of rich keratinized tissue, and low risk potential for root injury, the stability is questionable due to the porous maxillary bone structure. According to the classification of Misch, the maxilla is mostly composed of porous bone corresponding to D3 or D4, whereas the midpalatal area has dense cortical bone corresponding to D1 or D2.4 Also Schlegel gave similar conclusion that the midpalatal suture area is composed of dense cortical bone, and this site has been determined as the best anchorage site in maxilla.[40]

The computed tomography study by Jayakumar et al[13] quantitatively assessed the palatal bone thickness in an ethnic Indian population and concluded that there are significant variations in the thickness of the palatal bone at different sites, at different ages, and between genders. It was shown that the bone density at the mid palatal suture area at 12mm behind the incisive foramen is 7.31 ± 3.26 mm in 15-24 age grouped individuals and bone density is 6.19 ± 2.87 mm in 25-35 age grouped individuals. The bone density at the mid palatal suture area at 24mm behind the incisive foramen is 6.96 ± 3.15 mm in 15-24 age grouped individuals and bone density is 6.74 ± 3.24mm in 25-35 age grouped individuals. He concluded saying that mid-palatal suture area is a high-density bone structure with sufficient bone height, making it a preferred location for orthodontic mini implant placement[9]

Similarly Kim et al investigated the success rate of midpalatal miniscrews with a total of 210 miniscrews in the midpalatal suture area and concluded that overall success rates of midpalatal miniscrews were 88.20% for the total number of patients and 90.80% for the total number of miniscrews under an initial load of 500 to 800 g per miniscrew. He also concluded that midpalatal miniscrews can serve as absolute orthodontic anchorage for various types of tooth movements with high success rates.[54]

Yun et al also reported that a uniform soft tissue thickness of one mm is present in the midpalatal area from 4 mm posterior to the incisive papilla. Therefore, the soft tissue in the midpalatal area is optimal for miniscrew implantation.[55]

The posterior palate has also been described as a suitable location for miniscrew applications. Another alternative is the palatal alveolus between the maxillary first molar and second premolar, where the favorable position of the first molar's palatal root and the buccal angulation of the second premolar provide excellent access for direct insertion of miniscrew. This location offers the largest interradicular space, a sufficiently wide cortical plate and moderately thick attached gingiva.[3]

Poggio et al assessed CT of 21 subjects and found that the interradicular bone width between the second premolar and first molar is 5mm, located 4-6mm apical to the alveolar crestal margin. Measuring from the interproximal contact point of first molar and second premolar, they found optimal bone thickness of 8-9mm apically. The author concluded that MSI placed in this area can be useful in supporting posterior intrusion, en masse protraction, space closure, retraction, and molar distalization. The largest amount of maxillary interradicular bone in the mesiodistal direction, buccally and palatally, is between the second premolar and first molar.[37]

The sliding mechanics had an advantage of being simple, while retraction using different loop mechanics is very effective but requires a lot of skill from the orthodontist. Though wire friction and uncontrolled retraction force are the main disadvantages of sliding mechanics, it is widely preferred by orthodontists to avoid more complex wire bending in lingual orthodontics.

During en masse retraction, vertical bowing at the premolar region is the main challenge in maxilla. Since the net force vector is placed lingual to the center of resistance of the teeth, it causes lingual tipping of incisors and vertical bowing effect in the premolar region. Therefore, the retraction force should be minimal, and greater torqueing force is necessary while retracting anterior teeth in lingual orthodontics. So the retraction force used in our study for the anterior segment (8 teeth) was 200 gram per side, which was endorsed by the work of chung at al[6] and Mo et al[33].

The use of lever-arm mechanics makes it possible to achieve bodily translation during anterior retraction with lingual orthodontics. A retraction force parallel to the occlusal plane and applied through the center of resistance of the anterior teeth will bodily retract the anterior segment.

Anterior torque control during retraction is difficult to achieve with lingual orthodontic treatment. The mini-implant, in conjunction with the lever-arm, is useful not only for absolute anchorage but also for anterior torque control during retraction. By adjusting the length of the lever-arm and the position of the mini-implant, the desired line of action of the retraction force with respect to the center of resistance of the anterior segment is established.[39]

Considering these criteria we have constructed a finite element model (FEM) of maxilla of 32 year old female patient with bimaxillary proclination who opted for lingual orthodontic treatment for aesthetics. All the pretreatment records were obtained and the crown was utilised for construction of FEM data.

Previous studies like Mo et al[33], had taken the data from a dental study model to construct the FEM model which will neither mimic the quality nor the height of the bone and periodontium. To overcome these drawbacks we have contructed the finite element model from patient's CBCT and pre-treatment study models.

The lingual appliance showed streak metal artefacts in the CBCT which didn't give clear bracket morphology during data extraction. Therefore we separated the root outlines from the CBCT data and stitched it to their respective crown outlines from the data obtained from the 3dimentional laser scanned model. The model comprised of tetrahedron solid elements with the total 173,548 elements and 49,921 nodes. The material properties of the elements were based on the values of Young's modulus and Poison's ratio as given by Tanne et al[46] and Poppe et al[38].

Three dimensional lingual bracket system was constructed with scanned pre-treatment model using R700 scanner (3 shape, Asia). With this customized bracket system, levelling and aligning of the maxillary dentition was done. The CBCT was taken after levelling and aligning to mimic the ideal biomechanical consideration for retraction.

The change in the position of force application from labial to lingual orthodontics changes treatment planning. Application of force in lingual orthodontics is placed close to the center of resistance and thus increases lingual inclination of anterior teeth and force application lingual to the center of resistance in molars, inclines the crown lingually and root bucally which in turn provides cortical anchorage in molars. And the archwire in lingual orthodontics is bent posteriorly outwards in the transverse plane which gives a distobuccal rotation to the molar and thereby moving the root towards the cortical bone. This increases the anchorage value in lingual orthodontics and also changes the treatment plan by reducing the space requirement during retraction. Therefore cases requiring first premolar extraction in labial orthodontics can be treated with second premolar extraction in lingual orthodontics.

The extraction of second premolar was done after taking CBCT to omit void area during data extraction from CBCT. Also clinically, when bimaxillary proclination cases are treated with lingual orthodontics, the extraction procedure is often carried out after initial leveling and aligning of the dental arches, to avoid the torque loss and to provide aesthetics. This also helps in accelerated tooth movement during retraction due to the RAP phenomenon.

To this constructed FEM model of maxilla, customized 3D lingual bracket system (Berininov Advanced Orthodontics, Ernakulam, Kerala, India) were attached with node sharing. A 16x22 stainless steel archwire was constructed separately and placed at the bracket slots.

At this level, the constructed FEM model had

a) Maxillary dentition from second molar to second molar except second premolars.

b) Alveolar and palatal bone of maxilla.

c) 3 dimentional lingual appliance with 16x22 stainless steel archwire.

The FEM model was constructed with four different retraction conditions according to the position of the power arm and placement of the palatal MSIs (Figure 2).

Group A - power arm placed between lateral incisor and canine and MSI in the palatal slope. (Figure 2a)

Group B - power arm placed between central incisor and lateral incisor and MSI in palatal slope. (Figure 2)

Group C - power arm placed between lateral incisor and canine and MSI in mid-palatal region. (Figure 2c)

Group D - power arm placed between central incisor and lateral incisor and MSI in the mid-palatal region. (Figure 2d)

Two lengths of the power arm have been used in all the groups (10mm and 13mm) (Figure 4). The MSI in the posterior palatal slope (group A and B) was placed between the first molar and second premolar area, at 4 different heights (4mm, 6mm,8mm,10mm) measuring from the cervical margin of the posterior teeth (Figure 5).

The MSI placed in the mid-palatal region was placed at 2 different heights measuring from the distal most portion of the incisive papilla (12mm – anterior mid-palatal MSI and 24mm- posterior mid-palatal MSI) (Figure 6). The palatal miniscrew was placed mesial to the first molar to avoid the greater palatine foramen and the porous trabecular D4 bone found in the posterior maxilla.[2]

200 gram of retraction force was applied in all the groups from the retraction hook towards the respective MSI on both sides. Tooth displacement after retraction was measured in sagittal and vertical planes to estimate the center of reistance of maxillary anterior segment for analysing the tooth

movement during retraction. The measurement were taken using two reference points, one at the incial edge (IE) and other at the root apex(RA) of each tooth of one segment. Figure 7a shows the points taken for measurement at the incisal edges and cusp tips (IE) and Figure 7b shows the corresponding root apex points (RA) taken for measurement of tooth displacement.

The measured values for group A, B, C and D in the sagittal plane (Y-axis) is shown in the FIGURES 8a,9a,10a,11a respectively and the measured values for the groups in vertical plane (Z-axis) is shown in the figures 8b, 9b, 10b and 11b. The measured values were then shown as descriptive statistics in tables 2, 3, 4 and 5. Two dimensional line graphs were used to graphically represent the tooth displacement in Y-axis (sagittal) and Z-axis (vertical) for all the groups.

The results of our study in Y-axis showed a similar to that of previous FEM studies of Mo et al which showed a decreased torque loss in group C. The retraction protocol here was 13mm power arm placed between lateral incisor and canine with MSI placed at 12mm behind the incisive papilla on the mid-palatal area. But this was contradictory to the study by Jang et al[12] in which the power arm was placed between central and lateral incisor. Group C showed true intrusion of central and lateral incisor with 13mm power arm with MSI placed at 12mm behind the incisive papilla over the mid-palatal area. This finding was similar to Mo et al[33] study.

Group B showed bodily retraction of anterior segment with 13mm power arm placed between central and lateral incisor with MSI placed 8-10mm in the posterior palatal slope mesial to the first molar. This was similar to the results of study done by Mo et al[33]. But the central incisor showed severe torque loss in this group which was not seen in study done by Mo et al[33]. This can be due to difference in the force application to the tooth through vertical alteration of bracket positioning. In this study the point of application of force was kept at much closer level to the cervical margin compared to the normal position of lingual bracket system. So this may not be an ideal retraction protocol using sliding mechanics with lingual appliance. Group B showed extrusion of all anterior and intrusion of first premolar.

Group A and D showed loss of torque of anterior segment in all the retraction conditions of which group D showed comparatively less torque loss when MSI placed 12 mm behind the incisive papilla with 13mm length of power arm. The vertical plane in group A showed extrusion for all anterior teeth and intrusion for the premolars. This is due to the inherent bowing effect of sliding mechanics. But group D showed intrusion of both anterior teeth and first premolar when 13mm power arm was used with MSI placed at 12mm behind the incisive papilla on the mid-palatal area.

When mid-palatal MSI is compared with MSI placed in the posterior palatal slope with power arm placed between the lateral incisor and canine, more desired tooth movement is seen in sagittal and vertical plane with the mid-palatal MSIs. We could not find any literature to support this comparison.

When the results of group B and group D were compared, group D showed a more controlled crown tipping during retraction with power arm placed between central and lateral incisor. This finding was similar to results of the study done by Mo et al[33]. The vertical plane also showed intrusion in group D when compared to group B.

Based on our FEM study the ideal retraction mechanics in lingual appliance would be to engage a 16 x 22 SS wire with a power arm of 13mm placed between the maxillary lateral incisor and canine and a force of 200gm origin from a MSI placed at 12mm from the incisive papilla over the midline. This combination produces maximum bodily retraction with minimum torque loss and negligible vertical side effects.

Summary and Conclusion

SUMMARY AND CONCLUSION

This in vitro finite element study was performed with 3D lingual bracket system to find an optimal position of palatal mini-screw implants and the ideal position of power arm and its length, by locating the centre of resistance of maxillary dentition in second bicuspid extraction cases during retraction.

A three dimensional finite element model was constructed using CBCT and intra oral laser scan data of the patient. The study was divided into four groups according to the condition of different retraction mechanics, each differing in position and lenth of the power arm and mini-screw implants (MSI). In group A and C power arm were placed between the lateral incisor and canine on both sides and in group B and D power arm were placed between central incisor and lateral incisor on both sides. Two different length of the power arm (10mm and 13mm) were used in both the positions. In group A and B, MSIs were placed at four heights, 4mm, 6mm, 8mm and 10mm in posterior interdental palatal slope mesial to the first molar measuring from the cervical region. In group C and D, MSIs were placed in the mid palatal region at two different levels 12mm and 24mm behind the distal most portion of the incisive papilla. A retraction force of 200 gm per side from the hook, towards the direction of the mini-implant position was applied and tooth displacement was studied in Y-axis (anterior-posterior or sagital) and the Z-axis to the (coronal-apical or vertical) by probing points marked at the crown and root of right side maxillary anterior segment. Descriptive statistics and two dimensional line graphs were used to represent the type of tooth movement for each reference tooth in all the groups.

Based on the findings of this study we concluded the following,

1) The position of MSI to achieve translation in sagittal and vertical plane during retraction was achieved when placed it 12mm behind the incisive papilla over the mid-palatal area.

2) 13mm power arm produced bodily tooth movement in sagittal and vertical plane with anterior mid-palatal MSI.

3) The power arm placed between the canine and the lateral incisor showed maximum bodily movement in both sagittal and vertical planes.

Hence, the ideal line of force to achieve bodily movement in second premolar extraction case with lingual appliance, would be 13mm power arm placed between lateral incisor and canine with MSI placed at 12mm behind the incisive papilla over the mid-palatal area.

Therefore, in lingual orthodontics, the power arm length should be extended beyond the center of resistance to achieve bodily retraction due to the anatomical curvature of the palate. Since in lingual orthodontics, the curvature of the anterior palate coupled with rugae does not allow to place a vertical power arm one has to incorporate more length to it, to make it as close to the center of resistance. So, when selecting a patient for lingual orthodontic treatment with maxillary proclination, one should have an ample depth of the anterior palate to achive bodily retraction.

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Annexures

Annexure – I

RAGAS DENTAL COLLEGE & HOSPITAL

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Date: 18.12.2017
Place: Chennai

From
The Institutional Review Board,
Ragas Dental College and Hospital,
Uthandi,
Chennai – 600 119.

The dissertation topic titled **"LOCATING THE CENTER OF RESISTANCE OF MAXILLARY TEETH RETRACTED USING SLIDING MECHANICS IN LINGUAL APPLIANCE AND TO FIND THE OPTIMAL POSITION OF PALATAL MINI SCREWS – A FINITE ELEMENT ANALYSIS."** submitted by **Dr. GOPINAATH KANDHAN.**, has been approved by the Institutional Review Board of Ragas Dental College and Hospital.

Dr. N.S. Azhagarasan M.D.S,
Member secretary,
Institution Ethics Board,
Ragas Dental College & Hospital
Uthandi,
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Annexure – II

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