THREE DIMENSIONAL EVALUATION OF STRESS DISTRIBUTION AND DISPLACEMENT BY MINISCREW IMPLANTS ASSISTED PALATAL EXPANDER - A FINITE ELEMENT STUDY

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DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation titled **"THREE DIMENSIONAL EVALUATION OF STRESS DISTRIBUTION AND DISPLACEMENT BY MINISCREW IMPLANTS ASSISTED PALATAL EXPANDER - A FINITE ELEMENT STUDY"** is a bonafide and genuine research work carried out by me under the guidance of **Dr. M.K. ANAND, M.D.S.,** Professor, Department of Orthodontics and Dentofacial Orthopaedics, Ragas Dental College and Hospital, Chennai.

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CERTIFICATE

This is to certify that this dissertation titled **"THREE DIMENSIONAL EVALUATION OF STRESS DISTRIBUTION AND DISPLACEMENT BY MINISCREW IMPLANTS ASSISTED PALATAL EXPANDER - A FINITE ELEMENT STUDY"** is a bonafied record of work done by **Dr. K.T. Sharanya Dhevi** under my guidance during her postgraduate study period 2013-2016.

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

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CONTENTS

Introduction

Introduction

Rapid maxillary expansion (RME) is a well-established method to correct transverse maxillary deficiency and arch-length discrepancy. During expansion, the force of the appliance counteracts the existing anatomical resistance from the dentoalveolus, mid-palatal suture, zygomaxillary buttress, and circumaxillary sutures.[8,29,39,41,52,98,106] This was first introduced as early as 1860 by **Angell**. In adults, nonsurgical palatal expansion can result in dentoalveolar tipping that might consequently cause detrimental periodontal effects such as bony dehiscence. Therefore, skeletal orthopedic expansion is essential to prevent such effects and to establish proper posterior occlusion**. (Capelozza Filho et al., 1996; Chang et al., 1997; Garib et al., 2005; Koudstaal et al., 2009; Gurel et al., 2010; Baysal et al., 2011).**[21,23,38,45,66]

In adult patients, who are skeletally matured, conventional RME is known to have a limited effect on the opening of mid-palatal suture because of reduction in elasticity of bone and the increasing resistance from interdigitated mid-palatal and lateral maxillary sutures (**Kokich et al**).[50,65,109] With increasing age, surgically assisted rapid maxillary expansion (SARME) has been an accepted modality for adult patients, but this method produces minimal horizontal translation and was mainly a lateral rotation of the 2 maxillary halves associated with a large amount of relapse during the post retention period demonstrated by **Byloff and Mossaz.**[20] To overcome these surgical complications and to achieve better skeletal expansion, bone-borne palatal expanders were used.

In recent years, bone anchored rapid palatal expanders were developed with the advantage of directly anchoring the appliance to the palatal bone and many of them could achieve sufficient skeletal expansion without producing dental ill-effects.[47] Currently, temporary anchorage devices (TADs) have been applied to correct the transverse problem. **Tausche et al,**[109] reported that a miniscrew implant assisted rapid palatal expander (MARPE) is a viable expansion technique, that prevents the buccal tipping of posterior dentoalveolar segment.[91]

The treatment effects of RME, have been extensively studied through various methods, including analysis of photoelastic models **(Chaconas and Caputo:1982, Lima et al., 2011)**[22] Strain gauges (**Tanne et al., 1985**)[106] and laser speckle interferometry (**Pavlin and Vukicevic, 1984).**[33] Unfortunately these techniques are limited in their ability to measure internal displacements and strain-stress levels in a complicated structure such as craniofacial skeleton. On the other hand the 3 dimensional finite element analysis method **(FEM), (Iseri et al., 1998; Jafari et al., 2003; Yu et al., 2007; Han et al., 2009; Lee et al., 2009; Boryor et al., 2010**)[4,8,46,48,112] has been successfully applied to the mechanical study of stress and strains and makes it practicable to elucidate biomechanical components such as displacements in living structures from various external forces (**Tanne et al**).[107] The most important advantage of this model is the ability to test an unlimited number of force applications once an adequate FEM model is created.[111] Finite element analysis is useful for simulating stress distribution and displacement patterns in the craniofacial structures when transverse forces are applied to palatal vault and maxillary teeth due to different orthodontic appliances. Inspite of inherent pitfalls, FEM is definitely a viable tool to integrate findings with treatment planning.

In the recent past with the increase in the number of adult cases seeking orthodontic treatment, reducing the side effects of RME is of prime importance. To increase the skeletal effect, reduce the periodontal degradation, customizing the design of RME is essential. Hence this study has been carried out to assess the efficiency of various HYBRID designs of RME.

Aim of the study

The aim of the study is to assess the stress distribution and displacement of the maxilla and teeth in an average and constricted arch width models according to different designs of RME using miniscrew implants on a 3D FE model of the skull.

Objectives:

1. To analyse the stress distribution in the mid-palatal suture area at 3 points:
    a. Distal to canine.
    b. Between first premolar and second premolar.
    c. Between second premolar and first molar.
2. To analyse the stress distribution in the cross section at the level of first premolar and first molar regions.
3. To analyse the stress distribution around the circumaxillary sutures.
4. To analyse the amount of displacement of alveolar bone reference points at canine and first molars respectively.
5. To analyse the amount of displacement of dental reference points at canine and first molars respectively.

Review of Literature

REVIEW OF LITERATURE

Rapid maxillary expansion

Hass et al (1961)[9] A real maxillary deficiency is characterized by compression of the maxilla with constriction of the buccal tooth movements. Teeth may be upright over the base, but most often inclined buccally or labially as the maxillae move apart. As a result of expansion force lateral bending of alveolar process followed by gradual opening of mid-palatal suture followed by separation of central incisors takes place. In addition there is mechanical widening of nasal cavity laterally and the palatine process moves inferiorly. The suture opening is greatest at the anterior and least near the apex of nasal cavity.

Issacson et al (1964)[93] described the design, construction and calibration of force measuring system which was developed to accurately measure the force produced by rapid expansion techniques. Single activation of expansion appliance produced 3 to 10 pounds of force. Total expansion becomes physiologically stable in a shorter treatment time with expansion procedures carried out at lower forces with slower activation. Major resistance to rapid maxillary expansion apparently was not the mid-palatal suture but the remainder of the maxillary articulations.

Zimring et al (1965)[57] investigated the force present during the retention phase of treatment and the duration it has to be maintained. The rate of activation in young patients were twice daily for first four to five days followed by once a day and for older individuals two activation per day for first two days, one activation daily for next five to seven days and one activation every day to complete the treatment. The retention of the rapid maxillary expansion is not depend on the presence of bone in the opened mid palatal suture but rather on the creation of a stable relationship at the articulation of maxilla and the other bones of the facial skeleton.

Starnbach et al (1966)[51] determined the tipping or bodily movement of the buccal segments, rotational movement of palatal processes and reactions at the facial sutures by rapid palatal expansion appliance. The tooth movement was predominantly bodily rather than tipping. The facial sutures nasal, maxillary-zygomatic and zygomaticotemporal showed evidence of cellular activity, the nasal suture showed the most.

Moss et al (1968)[55] The other indications of rapid expansion of the maxilla are bilateral or severe unilateral crossbite in class I cases, narrowness of the maxillary arch and nasal stenosis. There is an immediate improvement of the nasal airway and correction of the crossbite with rapid expansion. It has been suggested by Derichsweiler (1953) and Krebs (1958) that the forces applied to the maxillary arch cause disruption of the suture and a tilting of the maxillary fragments outward with a resultant downward movement of the palatal shelves.

Donald J. Timms (1980)[30] examined the effects of R.M.E. on the basal bone posterior to the application of the force, showed that only the maxillae but also the palatine bones moved apart, with the pterygoid processes of the sphenoid bone splaying outward, at least as far as their inferior portions are concerned. The relationship of the basal movement to the dental expansion was not close, and increasing age may be a factor in progressively reducing basal movement.

Melson et al (1982)[15] The change in morphology of the palatomaxillary region that takes place during the postnatal period indicates that the area is responding to a heavy functional demand for a mutual displacement of the bones involved in the area-the maxilla, the palatine bone, and the sphenoid bone. The heavy interdigitation can be expected to exhibit a pronounced resistance to vertical and horizontal displacement of the maxilla, except in the early stages of postnatal development. Finally, it is suggested that the area may serve as a “hinge” around which a posterior rotation often occurs due to treatment with inter maxillary appliances or during the application of extra oral forces.

Samir E. Bishara et al (1987)[98] The effects of expansion on facial structures, dentition, and periodontium are reviewed. Patients who have lateral discrepancies that result in either unilateral or bilateral posterior cross bites are candidates for RME. The constriction may be skeletal (narrow maxillary base or wide mandible), dental, or a combination of both skeletal and dental constriction. The magnitude of the discrepancy between the maxillary and mandibular first molar and premolar widths; if the discrepancy is 4 mm or more, the severity of the crossbite, and the initial angulation of the molars and premolars should be considered prior to RME. In buccally inclined maxillary molars conventional expansion tips them further into the buccal musculature; and in case of the lingually inclined mandibular molars, the buccal movement increases the need to widen the upper arch. The pressure applied acts as an orthopedic force that opens the mid-palatal suture.

Warren Hamula et al (1998)[114] Jackscrews have been used to open the mid-palatal suture since 1860. The Haas-type rapid palatal expander, with a midline jackscrew embedded in acrylic pads, is currently used by many orthodontists. Drawbacks include the possibility of tissue inflammation beneath the acrylic and the difficulty of oral hygiene. The Hyrax jackscrew uses four wire extensions soldered to bands and thus does not require acrylic palatal support. Bonded acrylic splint expanders have several advantages over other RPE devices, no band fitting required. It has easy in-house lab fabrication. No acrylic coverage of the palatal soft tissue. Occlusal coverage is given to intrude the posterior teeth in open-bite cases.

Stanley Braun et al (2000)[101] examined the biomechanics involved in the motion of the palatal halves, and to suggest improvements in the design of the appliances commonly used in rapid maxillary sutural expansion. The center of rotation is thus constrained to be at the frontonasal suture the fringe (micro-stress) patterns on the zygoma are fundamentally translatory, implying a primary shearing stress in the zygomatico temporal sutures, and primary compression and shearing stresses in the zygomatico maxillary and zygomatico frontal sutures. If less tipping were desired and a more linear opening of the maxillary suture antero-posteriorly, the fabricated structure joining the sutural opening mechanism to the teeth would have to be more rigid. The center of rotation to migrate superiorly in the frontal view, reducing the degree of tipping, and in the occlusal view, the center of rotation would migrate further posteriorly, resulting in a more linear separation of the mid palatal suture. The sutural expansion designs that use an acrylic interface with the teeth are far less stiff than those constructed solely of soldered stainless steel wire which allow for a greater degree of maxillary half tipping in the frontal and occlusal planes during mid-palatal sutural expansion.

Chung et al (2004)[27] examined the maxillary and mandibular responses to rapid palatal expansion in all 3 dimensions. There was a slight forward and downward movement of maxilla, induced by RPE treatment. The mandible moved downward and backward, and the anterior facial height increased significantly after RPE.

Doruk et al (2004)[31] evaluated and compared the sagittal, transverse, and vertical effects of rapid maxillary expansion (RME) and fan-type RME on dento facial structures. The fan-type RME appliance separated the mid-palatal suture like the conventional RME appliances. In addition, the action of the appliances showed more results:

- Inter-molar width showed a slight expansion with fan-type RME when compared with the conventional RME.
- There were no differences for inter-canine width between the groups.

- Opening of the mid-palatal suture is more parallel in RME than in fan-type RME when viewed from the coronal and frontal plane.
- The changes achieved in dento facial structures with a conventional RME were more stable than that achieved with the fan-type RME.
- The maxilla moved downward and forward in both groups.
- Both groups I and II demonstrated significant increase in vertical dimension. However, the fan-type RME avoided expanding and tipping the posterior teeth, which causes increase in vertical facial height.
- The upper incisors were tipped palatally in group II and tipped buccally in group I.
- Nasal cavity width increased more in group II than in group I.

Oliveira et al (2004)[83] used a 3-dimensional surface laser scanning technique and computerized cast analysis to assess the morphologic changes of the palate by 2 kinds of expanders: tissue-borne Haas; and tooth-borne Hyrax. Haas appliances achieved expansion with a greater component of orthopedic movement (greater interpalatal gain), whereas Hyrax appliances achieved expansion by dentoalveolar expansion (greater interpalatal angulation after treatment). Molar crown tipping was not significant in the Haas group but was significant in the left side for the Hyrax group.

Davidovitch et al (2005)[29] compared the skeletal and dental effects of conventional 4-band and 2-band (attached to the first permanent molars only) RPE devices.

- The greater the skeletal resistance, the smaller the sutural response but the greater the dental response to RPE therapy.
- Both appliances displayed a typical “V”- shaped suture expansion whereas the dental arch expansion showed a “reverse V” pattern. The inverse skeletal and dental responses are related to a progressive antero-posterior increase in skeletal resistance limiting mid-palatal suture expansion posteriorly while effecting greater dental expansion in the same region.
- Four-band RPE is indicated when severe anterior crowding is accompanied by a tapered arch form, and 2-band RPE is recommended in the mixed dentition when mild crowding occurs with posterior constriction.

Holberg et al (2006)[26] examined the distribution pattern and the level of the stresses induced at the cranial bases of juveniles and adults using a Finite Element Method. He conclude that:

- Rapid palatal suture expansion leads to moderate stresses at the cranial base in children and adolescents so that serious complications are unlikely in the area of the juvenile cranial base.
- During adulthood, lateral bending of the pterygoid process during a rapid palatal suture expansion leads to a marked development of stress, particularly in the area of the sphenoid.
- The lower the patient’s bone elasticity during a rapid palatal suture expansion, the more important are protective measures for protecting the cranial base.

- The pterygomaxillary connection should be completely severed on both sides in adults who are undergoing a surgically assisted palatal suture expansion.

Wayel deeb et al (2010)[116] examined and detected the increases in transversal nasal width and the changes in nasal area and volume from bone-borne SARME with the Dresdon Distractor by using CT. The bone-borne DD has proved to be effective for preventing the negative side effects associated with tooth-borne RME such as extrusion, loss of pulp vitality, root resorption, bony dehiscence, and buccal tipping of the anchor teeth. With the bone-borne method the expansion force leads to immediate opening of the palatal suture without the tipping side effects. Despite high resistance from the basal cranium to the expansion forces, nasal volume increases especially in the anterior area of the nasal floor. This is due to the v-shaped opening of the palatal suture in the horizontal and frontal planes.

Christie et al (2010)[62] examined the maxillary response on the transverse dimensions to rapid palatal expansion by using cone-beam computed tomography. There was an increased nasal width, related to the jackscrew opening, occurred at the levels of the first permanent molars and the second deciduous molars. Significant increases in basal bone of the maxilla at the levels of the first permanent molars, and the second deciduous molars, first deciduous molars, and deciduous canines. Significant openings in the mid-palatal sutures were observed. After RPE, significant increases in the transverse dimensions of the nasal cavity, the maxillary basal bone, and the mid-palatal suture opening occurred, with the greatest increase in the mid-palatal suture followed by basal bone and nasal cavity. The mid-palatal suture opened in a parallel fashion.

Kee-joon lee et al (2010)[63] showed the treatment effects and stability of the miniscrew implants assisted rapid palatal expansion in a patient with severe maxillary constriction and mandibular prognathism. There are greater chances of bony dehiscence by using tooth-borne expanders. MARPE is a simple modification of the conventional RPE appliance; the main difference is the incorporation of several miniscrews to ensure expansion of the underlying basal bone and maintain the separated bones during the consolidation period. Dentoalveolar expansion also occurred with SARPE, and the amount of expansion at the maxillary basal bone was not as much as the dentoalveolar expansion. Tooth-and-bone-borne appliance required a simple procedure for miniscrews placement and definitely did not need an osteotomy, implying that an effective replacement of SARPE with MARPE in young adults.

Gurel et al (2010)[44] evaluated the long-term changes in maxillary arch widths, overjet, and overbite in patients who were treated with rapid maxillary expansion (RME) followed by edgewise appliances. A significant amount of relapse occurred in maxillary arch widths at the post retention assessment, the greatest being in inter canine width. RME significantly decreased overbite and increased overjet, and a statistically significant decrease was observed in both overbite and overjet at the post retention assessment.

Ghonemia et al(2011)[1] examined the effects of orthopedic forces on the cranial and circumaxillary sutures in adolescents treated with RME by using low dose multiplanar CT scans. Cranial sutures respond differently to the external orthopaedic forces according to their anatomic location and the degree of interdigitation. All cranial and circumaxillary sutures measured in this study showed significant increases in width except for the frontozygomatic, zygomaticomaxillary, zygomaticotemporal, and pterygomaxillary sutures, showing that these areas are affected by the generated forces. The nonsignificant difference in the width of the pterygomaxillary suture indicates its rigid interdigitation and high resistance to expansion. The lack of significant differences in the widths of the other craniofacial sutures might be explained also by their increased interdigitation and rigidity.

Sun et al (2011)[103] characterized their mechanical strain during acute expansion. Alveolar bone strain increased linearly with expander activation during post activation intervals. Compressive strain at anchor-tooth alveolar bone locations was directed occlusally and apically, related to tooth tipping, and significantly higher than that at non anchor tooth locations. With expander activation, suture strains increased monotonically and tended to plateau. Suture strain magnitude was generally similar to physiologic strains. The dominant strain polarity was compression at the maxillary-zygomatic and zygomatic-temporal sutures, but there was tension at the maxillary premaxillary suture.

Primozic et al (2013)[56] quantified longitudinal palatal changes in children treated for maxillary constriction associated with functional crossbite. There was an increased palatal surface area and volume as a result of the acrylic splint expander. An increase in palatal volume after treatment is a good indicator to assess the re-establishment of normal growth for maxillary constriction in deciduous dentition.

Yosuke et al (2014)[118] examined the effects of palate depth, modifications of the arm shape, and anchor screw placement in the mid-palatal area on rapid maxillary expansion (RME) using finite element (FE) analysis. He analysed that:

- As the palate deepens, the arm strain increases and the effect of RME decreases.
- Modified arm shapes, such as a larger diameter arm, arms connected by a diagonal wire, a straight arm, and a shorter arm, promoted expansion of the maxillary dental arch.
- Anchor screws increased the effect of RME, and generated more and closer bodily movement of the tooth together with parallel mid-palatal suture expansion. By contrast, in the design without arms, the tooth displacement decreased; therefore, the arms are necessary for effective RME when placing anchor screws near the suture

Kim et al (2015)[73] evaluated and compared, in late adolescence, the immediate skeletal and dental effects after RME with bone-borne or tooth-borne type expanders using high-resolution CBCT.

- In late-adolescent patients, bone-borne expanders produced greater transverse skeletal expansion when compared to tooth-borne hyrax expanders.
- In the bone-borne expander group there was less alveolar bending, less dental tipping, and less vertical alveolar bone loss at the first premolar.
- Dental expansion at the root apices in the C expander group was similar to that of the banded teeth of the hyrax group but greater than that of the nonbanded teeth.
- The bone-borne expander used without surgical assistance can be an effective treatment modality for maxillary skeletal deficiency in late adolescents.

FEM studies

Tanne et al (1987)[61] investigated the stress levels induced in the periodontal tissue by orthodontic forces using three dimensional finite element method. Principal fibers were determined at the root, alveolar bone and periodontal ligament. In all loading cases for bucco-lingually directed forces, three principal stresses in the PDL were very similar. At the surface of root and alveolar bone, large bending stresses acting almost parallel to the root were generally observed. The pattern & magnitude of stresses in periodontium from a given magnitude of force were markedly different, depending on the centre of rotation of tooth.

Kazuotanne et al (1989)[60] investigated the biomechanical effect of protractive maxillary orthopaedic forces on the craniofacial complex by use of the three-dimensional finite element method. The pattern of displacements, in a parallel protraction, the nasomaxillary bones experienced a forward repositioning, while the posterior region of the craniofacial complex slightly displaced in a backward direction. A downward protraction force produced a forward displacement of the entire complex in almost an equal fashion. In both loading cases, high stress levels were observed at the nasomaxillary complex and its surrounding structures.

Haluk lseri et al (1998)[45] evaluated the biomechanical effect of rapid maxillary expansion on the craniofacial complex by using a three-dimensional finite element model of the craniofacial skeleton. RME produces an expansion force at the intermaxillary suture, also high forces on various structures in the craniofacial complex. Rapid displacement or deformation of the facial bones results in a marked amount of relapse in the long term, while relatively slower expansion of the maxilla would probably produce less tissue resistance in the nasomaxillary structures, hence slow maxillary expansion followed by RME, immediately after the separation of the mid-palatal suture, would stimulate the adaptation processes in the nasomaxillary structures, and also would result in reduction of relapse in the post retention period.

Verrue et al (2001)[113] created a 3D subject-specific FEM of the craniofacial skeleton in an attempt to test and evaluate the effect of extra-oral force systems on this model. The calculated initial displacement of the FEM of the same animal was compared with the initial bone displacement in vivo. The results of this study show that the creation of a FEM of the craniofacial complex automates the 3D division in elements in combination with an accurate and more precise integration of sutures and sutural elastic properties to obtain an improved model.

Toms et al (2003)[102] determined the importance of using nonlinear mechanical properties and non-uniform geometric data in computer predictions of periodontal ligament stresses and tooth movements. Prediction of the maximum and minimum principal stresses and Von-Mises stresses in the PDL were determined for extrusive and tipping forces. The results indicated that the finite element models predicted substantially different stresses in the PDL for extrusive loading than did the uniform thickness model. In addition, incorporation of nonlinear mechanical properties for the PDL resulted in dramatic increases in the stresses at the apex and cervical margin as compared with the linear models.

.**Jafari et al (2003**)[4] evaluated the pattern of stress accumulation, dissipation and displacement of various craniofacial structure after RME. Pyramidal displacement of maxilla away from the midline was evident from the frontal view. The base of the pyramid was located on the oral side and the apex faced the nasal bone. Viewed occlusally, the two halves of the maxillary dentoalveolar complex, basal maxilla, and the lateral walls of the nasal cavity separated more widely, anteriorly.

Hansen et al (2007)[46] evaluated 3-dimensional changes in dental, alveolar, and skeletal structures caused by a bone-borne implant-supported rapid maxillary expansion device. In transverse dimension, a V-shaped opening of the suture and the dentition was shown, with the greatest amount of opening anteriorly directed. Expansion caused tipping of teeth and alveolar processes. There was no significant transverse increase in the posterior nasal spine. Changes at the zygomaticomaxillary point were also insignificant. The amount of dental tipping was less in comparison with studies using traditional tooth-borne RME. Screw expansion was transmitted to the alveolar bone at a higher rate in comparison with transmission to teeth.

Hyung et al (2007)[53] To clarify the effect of mid-palatal suture opening and the displacement and stress of the craniofacial bones following maxillary protraction for the treatment of skeletal Class III malocclusions, a 3D FEM was made to reassemble the craniofacial bone at the sutures.When a protraction force of 500 g was applied 20 degrees inferior to the occlusal plane passing through the first premolar with RPE, the amount of displacement and stress at the maxilla, zygomatic arch, and circumaxillary sutures were compared based on whether the mid-palatal suture was open or not and analysed.

The results were as follows:

1. There was less compressive and greater tensile stress to the circumaxillary suture area of the maxilla and zygomatic arch when the mid-palatal suture was opened. The greatest stress was found in the area of the zygomaticomaxillary suture.
2. There was a decrease in the upward – forward rotation of the maxilla and zygomatic arch and also a greater amount of displacement in all frontal, vertical, and lateral directions, when the mid-palatal suture was opened, compared to when there was no opening of the mid-palatal suture.
3. When the mid-palatal suture was opened, the frontal and lateral displacement increased gradually from the upper to the lower part and from the posterior to the anterior part of the maxilla, parallel to the zygomaticomaxillary suture line.
4. Opening the mid-palatal suture using a RPE appliance and directing the protraction force inferiorly from the occlusal plane, passing through the maxillary centre of resistance and also through the apical portion of the first premolar, maxillary protraction that is similar to normal downward and forward growth of the maxilla can be effectively achieved.

Pawan gautam et al (2007)[89] evaluated stress distribution along craniofacial sutures and displacement of various craniofacial structures with rapid maxillary expansion therapy. The distant structures of the craniofacial skeleton-zygomatic bone, temporal bone, and frontal bone-were affected by transverse orthopedic forces. RME facilitates expansion of the maxilla in both the molar and the canine regions. It also causes downward and forward displacement of the maxilla.

Provatidis.C.G.(2008)[90] systematically investigate RME by means of a FEM. The role of the sutural network of the craniofacial complex and the degree of its ossification on the maxillary segment separation during RME were studied and the results of the finite element analysis (FEA) were compared with the clinical findings of a previous study and an experimental in vitro application of the method. Moreover, the way that the maxillary halves move away from each other (orthopaedic effect) as well as the stress – strain field within the PDL and anchor teeth (orthodontic effect) were analysed.

1. The pyramidal shape of expansion is a result of the different degrees of resistance that the mid-palatal suture of the maxilla encounters along its length. An important role is the frontal part of the mid-palatal suture, especially at the level of the trans-septal fibres.
2. FEA of models that consider the mid-palatal suture as unossified and the in-vitro experiment of the dry human skull both suggest that the maxillary halves in reaction to the expansion forces of the jackscrew device of RME appliance separate in a pyramidal manner with the base being at the incisor area and the apex being in the posterior region of

the maxillae. In the vertical dimension, maximum opening occurs at the level of the dentition and decreases in an upward direction.

3. The frontomaxillary, nasomaxillary, the transverse palatal sutures, and the suture between the maxilla and the pterygoid process of the sphenoid bone do not influence the outcome of RME. On the contrary, the zygomatico-maxillary sutures at the level of the zygomatic arch influence the response of the craniofacial complex to the expansion forces. The sutures that separate the maxillary halves from each other must be unossified in order for maxillary expansion to occur.
4. The results show that the maximum displacements are observed in the area of the maxillae below the hard palate and from the central incisors to the second premolars.
5. The most significant positive contribution of the FEM is the ability to predict events at sites at which measurements are impossible in living humans. In future studies, larger FE meshes and more measuring points for detailed comparison with clinical findings would be even more beneficial.

Haofu lee et al (2009)[47] developed a method for constructing a 3-dimensional finite-element model of the maxilla to yield an anatomically accurate model of the maxilla and its surrounding structures. From this model, three models were generated: solid, fused and patent. The fused model expressed a stress pattern similar to that of the solid model, except for the decreased first principal stress concentration in the incisive foramen area. The anterior nasal spine and the central incisors moved downward and backward in both solid and fused models but moved primarily downward with a slight backward movement of the anterior nasal spine in the patent model.

Pawan Gautam et al (2009)[88] compared the stress patterns along the various craniofacial sutures with maxillary protraction with and without expansion. The overall stresses after maxillary protraction with maxillary expansion were significantly higher than with a facemask alone. After maxillary protraction the sutures associated with maximum von-mises stress were the sphenozygomatic followed by zygomaticomaxillary and zygomaticotemporal sutures. High stresses generated in various craniofacial sutures after maxillary protraction with expansion are responsible for disrupting the circumaxillary sutural system and presumably facilitating the orthopedic effect of the facemask.

Pawan Gautam et aL (2009)[89] evaluated biomechanically 2 treatment modalities maxillary protraction alone and in combination with maxillary expansion by comparing the displacement of various craniofacial structures. Forward displacement of the nasomaxillary complex with upward and forward rotation was observed with maxillary protraction. A tendency for anterior maxillary constriction after maxillary protraction was evident. The amounts of displacement in the frontal, vertical, and lateral directions with mid-palatal suture opening were greater compared with no opening of the mid-palatal suture. Maxillary protraction combined with maxillary expansion appears to be a superior treatment modality for the treatment of maxillary retrognathism than maxillary protraction alone.

Boryor et al (2010)[18] This study compares the strain measured on the zygomatic process of the skull with the results of a finite element model generated. An increasing transversal force was applied on the alveolar process (teeth) until rupture. Strain on the zygomatic process, maxilla displacement and the expanding forces were registered. The results of this study show linear material behaviour of the skull before rupture. The highest stress during the experiments and FE simulation was observed on the alveolar process.

Lagravere et al (2010)[74] compared the transverse, vertical, and antero-posterior skeletal and dental changes in adolescents receiving expansion treatment with tooth-borne and bone-anchored expanders. Immediate and long-term changes were measured on cone-beam computed tomography images. Immediately after expansion, the subjects in the tooth-borne expander group had significantly more expansion at the crown level of the maxillary first premolars. Dental crown expansion was greater than apical expansion and skeletal expansion with both appliances. Both treatment groups had significant long-term expansion at the level of the maxillary first molar crown and root apex, first premolar crown and root, alveolus in the first molar and premolar regions, and central incisor root. Both expanders showed similar results. The greatest changes were seen in the transverse dimension; changes in the vertical and antero-posterior dimensions were negligible. Dental expansion was also greater than skeletal expansion.

Miniscrew Implant assisted rapid palatal expansion

Asscherickx et al (2010)[59] Anchorage control is a challenge in orthodontics. Implants can be used to provide absolute anchorage. This study evaluated the success rates of palatal minisrew implants used for various anchorage purposes. Three implants failed during the waiting period before orthodontic loading, within 3 months after placement. During the orthodontic loading period, no implants were lost. No statistically significant correlations were found between success rate and sex, age, primary stability, placement site (median or paramedian), implant size, or palatal depth. Pain perception after surgery was acceptable. The success rate of the palatal miniscrew implants in this study was 91% palatal implants are a reliable method of providing absolute anchorage control in a variety of patients for different indications. They can be loaded both directly and indirectly.

Farnsworth (2011)[33] MSIs are commonly placed into the maxillary and mandibular buccal alveolar bones to improve anchorage. They have also been placed in the palatal alveolar bone and the para median palate. Wilmes et al found that cortical bone thickness has a strong effect on the primary stability of MSIs. Cortical bones at commonly used MSI placement sites in the maxilla and the mandible are significantly thicker in adults than in adolescents. There are no sex differences in cortical bone thickness at sites commonly used for MSI placement. There are differences in cortical bone thickness both between and within regions in the maxilla and the mandible.

Suzuki et al (2011)[3] used miniscrews to provide absolute anchorage during orthodontic treatment. By changing the optimum design or shape of the miniscrew, it might reduce its size and lessen the chance of root contact. In addition, miniscrews are placed at several angles, and orthodontic forces are applied in various directions. Finite element analysis helps to investigate changes in stress distribution at the supporting bone and miniscrew by changing the angle and the shape of the miniscrew and the direction of force.

Singh et al (2012)[100] analyzed the stress distribution and displacement patterns that develop in an orthodontic miniscrew implant and its surrounding osseous structures for 2 implant materials under horizontal and torsional loading, with no ossseointegration. Stress distribution was not significantly different between the 2 types of implant material. Increased stress values were located at the necks of the implants and the surrounding cortical bone. Bending of the titanium miniscrew was observed in the neck region under horizontal traction. The differences between the values of stress and displacement we obtained for the 2 types of miniscrew were too small to be clinically significant. Optimization of the miniscrew implant composed of the titanium alloy might be achieved by increasing the bulk (quantity) of the material in the neck region. The miniscrew implant can be immediately loaded and used for group movement of teeth.

Ludwig et al (2013)[16] assessed the ability of a new viscoelastic finite element method model to accurately simulate rapid palatal expansion with a miniscrew-supported hybrid hyrax appliance. The resulting finite element method model was a suitable approximation of the clinical situation and adequately simulated the forced expansion of the mid-palatal suture. The newly developed model provided a suitable simulation of the clinical effects of the hybrid hyrax appliance, which proved to be a suitable device for rapid palatal expansion.

Araugio et al (2013) [91] evaluated the influence of the expansion screw height of a hyrax expander on the degree of dental inclination during rapid maxillary expansion by using the finite element method. When the screw was simulated below the maxillary first molars center of resistance, buccal tipping of the crowns and lingual tipping of the roots were registered. This tendency decreased when the screw was simulated at the same level as the maxillary first molars' center of resistance. When the screw was simulated above the maxillary first molars' center of resistance, the tipping tendency was inverted, with the crowns displaying lingual tipping and the roots displaying buccal tipping. From an orthopedic perspective, the ideal screw position might be slightly above the maxillary first molars' center of resistance; this would generate less dental tipping.

Lee et al (2014)[52] analyzed stress distribution and displacement of the craniofacial structures resulting from bone-borne rapid maxillary expanders with and without surgical assistance using finite element analysis. Alveolar bone at the posterior region in the nonsurgical bone-borne type showed more transverse displacement than movement in the anterior area. However, the surgical types demonstrated slightly more expansion at the anterior area than at posterior areas. Nevertheless, in all types, the mid-palatal suture showed more opening anteriorly. The nonsurgical bone-borne type showed the highest stresses along the mid-palatal suture and the maxillofacial landmarks. Bone-borne rapid maxillary expanders with mid-palatal suture separation in surgical type showed lower stresses than did nonsurgical type. The 3 surgical models showed similar amounts of stress and displacement along the teeth, the mid-palatal suture, and the craniofacial sutures. Therefore, when using a bone-borne rapid maxillary expander in an adult, it is recommended to assist it with mid-palatal suture separation, which requires a minimal surgical intervention.

kim et al (2014)[99] analyzed stress distribution and displacement of the maxilla and teeth according to different designs of bone-borne palatal expanders using miniscrew implants. A three dimensional finite-element model of the craniofacial bones and maxillary teeth was obtained. Four designs of rapid maxillary expanders: one with miniscrew implants placed lateral to mid-palatal suture, the second at the palatal slope, the third as in type 1 with additional conventional hyrax arms, and the fourth surgically assisted tooth-borne expander were added to the FE models. Expanders were activated transversely. All types exhibited downward displacement and more horizontal movement in the posterior area. Type 2 had the least stress concentrations around the anchorage and showed alveolar expansion without buccal inclination of the dentition.

MacGinnis et al(2014)[75] analysed the use finite element method (FEM) to determine the stress distribution and displacement within the craniofacial complex when simulated conventional and miniscrew implant-assisted rapid palatal expansion (MARPE) expansion forces are applied to the maxilla. The simulated stress distribution produced within the palate and maxillary buttresses in addition to the displacement and rotation of the maxilla could then be analyzed to determine if miniscrew implants aid in skeletal expansion. The conclusions are as follows:

- In comparison to the conventional expansion, stress distribution from the MARPE showed less propagation to the buttresses and adjacent locations in the maxillary complex.
- By placing expansion forces closer to the maxilla's center of resistance, less tipping occurs with a more lateral translation of the complex. MARPE can be beneficial in patients with sutures that are fused. Lastly, MARPE is also beneficial in young dolichofacial patients by helping to prevent bone bending and dental tipping.

Surgically assisted rapid palatal expansion (SARPE):

Berger et al (1998)[17] examined and compared the dental and skeletal changes over time for both orthopedic maxillary expansion and surgically assisted palatal expansion. Clinically, there is no difference in the stability of surgically assisted rapid palatal expansion and nonsurgical orthopedic expansion. In this study, there was a significant difference in the amount of expansion between groups for inter-canine and inter-molar width as well as inter alveolar distance. Both the orthopedic and the surgical groups showed stable results.

Byloff et al (2004)[20] Over recent years, SARPE has proved to be clinically effective and stable for the correction of maxillo-mandibular transverse discrepancies. However, this study has demonstrated that real skeletal expansion through translation is only minimal. Tipping produced by the force exerted on the teeth by the palatal expander is also due to the lateral rotation of the two maxillary halves. This suggests that the total relapse in tipping observed was not only dental but also skeletal. New techniques using osseointegrated implants as anchorage, or expanders fixed directly to the maxillary bones, as described **by Mommaerts (1999) and Matteini and Mommaerts (2001),** should improve the skeletal component of the expansion and could demonstrate more overall stability.

Lagravere et al (2006)[68] evaluated skeletal and dental changes after surgically assisted rapid maxillary expansion (SARME). Expansion was greater at the molars and diminished progressively to the anterior part of the dental arch in all the evaluation periods. Vertical and sagittal skeletal changes were nil or not clinically significant. The nasal portion of the maxillary complex showed an increase in dimensions thereby improving nasal patency. An overall dental relapse of 0.5–1 mm is reported after 1 year of orthodontic treatment.

Christof Holberg et al (2007)[25] investigated the stresses in the mid-face and at the cranial base during surgically assisted rapid maxillary expansion, to determine whether surgically assisted separation of the maxilla from the cranial base can be considered justified and necessary. The cranial base should be protected from excessive stresses during rapid maxillary expansion in adult patients to prevent undesirable side effects. An effective means to reduce stress near the cranial base is the surgical separation of the pterygo maxillary junction; this should be done in addition to conventional surgical measures in adults before rapid maxillary expansion.

Suri et al (2008)[104] SARPE is a widely used procedure for the correction of MTD in skeletally mature patients. However, there is sparse information on many issues pertaining to SARPE. There are still no conclusive ways to identify the optimal equilibrium between extensive surgeries for adequate mobilization versus a conservative procedure with minimal complications. Advances in imaging techniques have added another dimension to the evaluation of bone density and surgical manipulation. These can assist in achieving greater precision and help standardize surgical techniques and orthodontic treatment protocols.

Sylvain Chamberland (2008)[105] assessed the amount of dental and skeletal expansion and stability following surgically assisted rapid maxillary expansion.

- Skeletal expansion with SARPE is about half the total inter-molar expansion at the maximum expansion point. From that point, dental relapse occurs but the skeletal expansion is stable, so that at the end of treatment about two-thirds of the net expansion is skeletal.

- The transverse stability of SARPE is not significantly greater than segmental Le-Fort I osteotomy, bringing into question the routine use of two-stage surgery as a way to improve transverse stability in patients requiring widening and A–P or vertical repositioning of the maxilla.
- Relapse in the amount of arch width increase produced by SARPE is comparable to relapse with the other expansion procedures.
- With SARPE, the relapse is almost entirely dental, so that at the end of treatment there is a net skeletal expansion of 67% of the total change. With nonsurgical expansion in growing patients, the expectation is that 50% of the total change will be skeletal.

Kim et al(2009)[111] evaluated the displacement of the maxilla according to different surgical techniques for SARME and to analyze stress distributions using 3-dimensional FEM. SARME is a useful method of treatment to increase the transverse dimension of the maxilla in skeletally mature individuals. The surgical technique for SARME involving a mid-palatal split was described in 1938 (**Brown, 1938**) and later, a Le Fort I type of osteotomy with a segmental split of the maxilla was presented

Steinhauser (1972), Kennedy et al (1976) popularized the use of an osteotomy of the zygomaticomaxillary buttress as the major factor in overcoming resistance to maxillary expansion. A combination of Le Fort I and paramedian osteotomy with pterygomaxillary separation is an effective measure in achieving more displacement and less stress in the maxilla during SARME. Pterygomaxillary separation appears to be helpful in increasing the amount of expansion.

Gauthier (2011)[35] evaluated the periodontal effects of SARPE by means of a complete clinical evaluation and cone-beam computerized tomography (CBCT) evaluation**.** Forces delivered by the expander produce areas of compression in the periodontal ligament, which could lead to alveolar bone resorption and possible changes in the attachment level. SARPE seems to have little detrimental effects on the periodontium clinically. However, radiographic data demonstrated some statistically significant changes:

- A significant decrease in the buccal alveolar bone thickness on most teeth, with the most clinically important changes on the distal aspect of the first molars.
- A significant increase in the palatal alveolar bone thickness on most teeth.
- These changes could eventually have a clinically significant impact on the periodontium.

Magnusson et al (2012)[6] evaluated transverse skeletal changes after surgically assisted rapid maxillary expansion. The changes were registered by using a 3-dimensional computerized tomography technique based on superimposition on the anterior base of the skull. Surgically assisted rapid maxillary expansion had a significant transverse skeletal treatment effect, significantly greater posteriorly than anteriorly. The expansion was parallel anteriorly, but posteriorly there was significant transverse tipping. Although there was no statistically significant difference between the changes at the corresponding landmarks, the range of standard deviations was marked. The results showed that, for registering transverse skeletal changes after surgically assisted rapid maxillary expansion 3-dimensional superimposition is a reliable method, circumventing projection and measurement errors. Surgically assisted rapid maxillary expansion had a significant but non-uniform skeletal treatment effect. Despite careful surgical separation, pronounced posterior tipping occurred. No correlation was found between the severity of tipping and the patient's age.

Nada et al (2012)[82] evaluated the long-term skeletal outcome following tooth-borne and bone-borne SARME using CBCT imaging. Surgically assisted rapid maxillary expansion (SARME) using tooth-borne or bone-borne distractors are used for correcting substantial transverse maxillary deficiency in adult patients. When conventional tooth-anchored devices are used, the mechanical stresses are applied via the teeth. Consequently, applying the expansion force directly to the bone via bone-borne expanders was introduced to provide more skeletal expansion, less undesired tooth movement. Comparing bone-borne and tooth-borne expansion, bone-borne devices led to significantly more transverse skeletal overall expansion, with a maximum in the premolar region and converging to the molars. The amount of dental expansion increased from the canines to the molars with bone-borne distraction, whereas it tended to be more parallel along the arch with tooth-borne expansion.

Gabriela et al (2014) [36] Surgically assisted rapid palatal expansion (SARPE) is the procedure of choice for treatment of adults with transverse maxillary deficiency greater than 7 mm. There is no consensus about the dentoskeletal effect of an orthodontic retainer on the outcome of SARPE. Our objective was to assess the effectiveness of an orthodontic retainer on dentoskeletal stability. SARPE were divided into 2 groups—no retention and retention and assessed. Both groups exhibited a small relapse in the bone measurements (cervical area and WALA ridge), indicating that a transpalatal arch is unnecessary. Furthermore, a possible strategy to prevent tooth relapse (measurement on cusps) might be either to start orthodontic treatment immediately after removing the hyrax device or to leave the hyrax for longer than 6 months. The analysis of relapse in both groups suggests that the use of a transpalatal arch as a retaining device does not improve dento-osseous stability.

Singaraju GS et al (2015)[41] analyzed the displacement pattern and stress distribution during surgically assisted rapid maxillary expansion (RME) with three different types of RME devices by constructing a finite element model. According to the type of RME device, 3 groups were simulated on this mesh model. The experimental groups were as follows; Group I (tooth-borne appliance), Group II (bone-borne appliance), and Group III (hybrid appliance). A Le fort I osteotomy with bilateral pterygomaxillary disjunction and mid-palatal split osteotomy cuts were incorporated in all the groups.Tooth borne appliance has more rotational tendencies. The bone-borne and the hybrid appliance exhibited similar stress patterns for the dissipation of the forces produced by RME appliances. The pivoting effect or the rotational tendencies is least with the hybrid appliances. This can be utilized for patients with vertical maxillary excess and backward rotation of the mandible.

Materials and Methods

MATERIALS AND METHODS

1. CONSTRUCTION OF FE MODEL:

The 3D finite element models of an average maxillary arch width (Group-A, Patient name: Monisha) and constricted maxillary arch width (Group-B, Patient name: Punitha) were generated by following methods.

A.COMPUTED TOMOGRAPHY:

Three-dimensional Finite element model of craniofacial bones and maxillary teeth were generated based on computed tomography scan data obtained from two patients of different maxillary arch widths. Image slices were taken at 1mm thickness and 0.5 mm intervals for the entire skull, from chin to vertex.

B. SOFTWARES USED:

a) Mimic Software: The scanned images were then converted to STL file format using **MIMIC. (Fig 1)**
b) Assembling the traced image & creation of geometric model using the modelling software Creo parametric version 2.0**. (Fig 2)**
c) Meshing the Geometric model: The complete model from **CREO PARAMETRIC** software was imported into the HYPER MESH software as an assembly and all the independent parts like, teeth, cancellous and compact bone, was meshed with tetrahedral element types. **(Fig 3)**

d) Construction of an FE model: The FE model of the craniofacial bones and maxillary teeth was generated. This model was divided, the maxilla including the teeth and alveolar bone.

e) ANSYS: The finite element model was imported into ANSYS version 15.0 software

2) MATERIAL PROPERTIES:

The material properties were assigned to various structures such as tooth, periodontal ligament, cancellous and compact bone **(Table-1).**[62] This model was divided, the maxilla including the teeth and alveolar bone into 1 mm tetrahedrons and rest of the skull excluding the maxilla into 5 mm tetrahedrons. The difference in the elements and nodes (**Tables- 2&3)** between four types was because of different conditions caused by miniscrew implants, and expanders. The teeth, alveolar bone, and the periodontal ligament were considered to be homogenous and isotropic. The thickness of the cortical bone was determined according to the study by **Farnsworth et al**[34] ; the thickness of the periodontal ligament was 0.2 mm **(Kronfeld),**[68] and the thicknesses of the maxillofacial and mid-palatal sutures were 0.5 mm **(Fricke-Zech et al).**[35]

3. BOUNDARY CONDITION AND REFERENCE POINTS:

Foramen magnum was completely fixed and used as the origin point **(Fig-4).** 3D co-ordinates were X, antero-posterior direction plane; Y, transverse direction; and Z, vertical direction **(Fig-7D).** The midpoints of the buccal and lingual alveolar ridge of each tooth were used as reference points to evaluate alveolar bone displacement. Positive values indicate forward, outward, and upward displacements on the X, Y, and Z planes, respectively. The models were sectioned at canines and first molar by YZ plane and reference points were placed to assess teeth displacement. **(Fig-7,8)**

4) APPLIANCE DESIGN: In this study leone expansion screw of 9mm and miniscrew implant (DENTOS miniscrew implants) of type short head with 2mm of diameter and 6 mm length were used. 4 designs of rapid maxillary expanders used:

TYPE1: 4 Miniscrew implants placed 3 mm lateral to mid-palatal suture and connected to the expander. **(Fig 5-A)**

TYPE2: 4 Miniscrew implants placed beneath the alveolar ridge at palatal slope: two between the canines and first premolars and two between the second premolars and first molars. Miniscrew implants were connected to the expander through an acrylic resin cover**. (Fig -5B)**

TYPE3: 2 Miniscrew implants placed 3mm lateral to mid-palatal suture between the canines and first premolars and connected to the expander with conventional hyrax arms soldered on the first molar. **(Fig- 5C)**

TYPE4: Conventional tooth-borne appliance assisted by perforations at the mid-palatal suture using miniscrew implants of size 2x6 mm at 3 points from the incisive papilla to the last molar**. (Fig- 5D)**

1. Perforation at the mid-palatal suture distal to canine.
2. Perforation at the mid-palatal suture between first and second premolar.

3. Perforation at the mid-palatal suture between second premolar and first molar.

5) EXPANSION AND ANALYSIS: Expansion force of 45 newtons (N) were applied **(Fig-6).** Expanders were activated transversely for 0.5 mm in Y direction and were unfixed in X and Z directions to prevent interference with the resultant movement. Von- Mises stress distribution and displacement at the maxillofacial region were evaluated.

SCHEMATIC REPRESENTATION OF THE STUDY

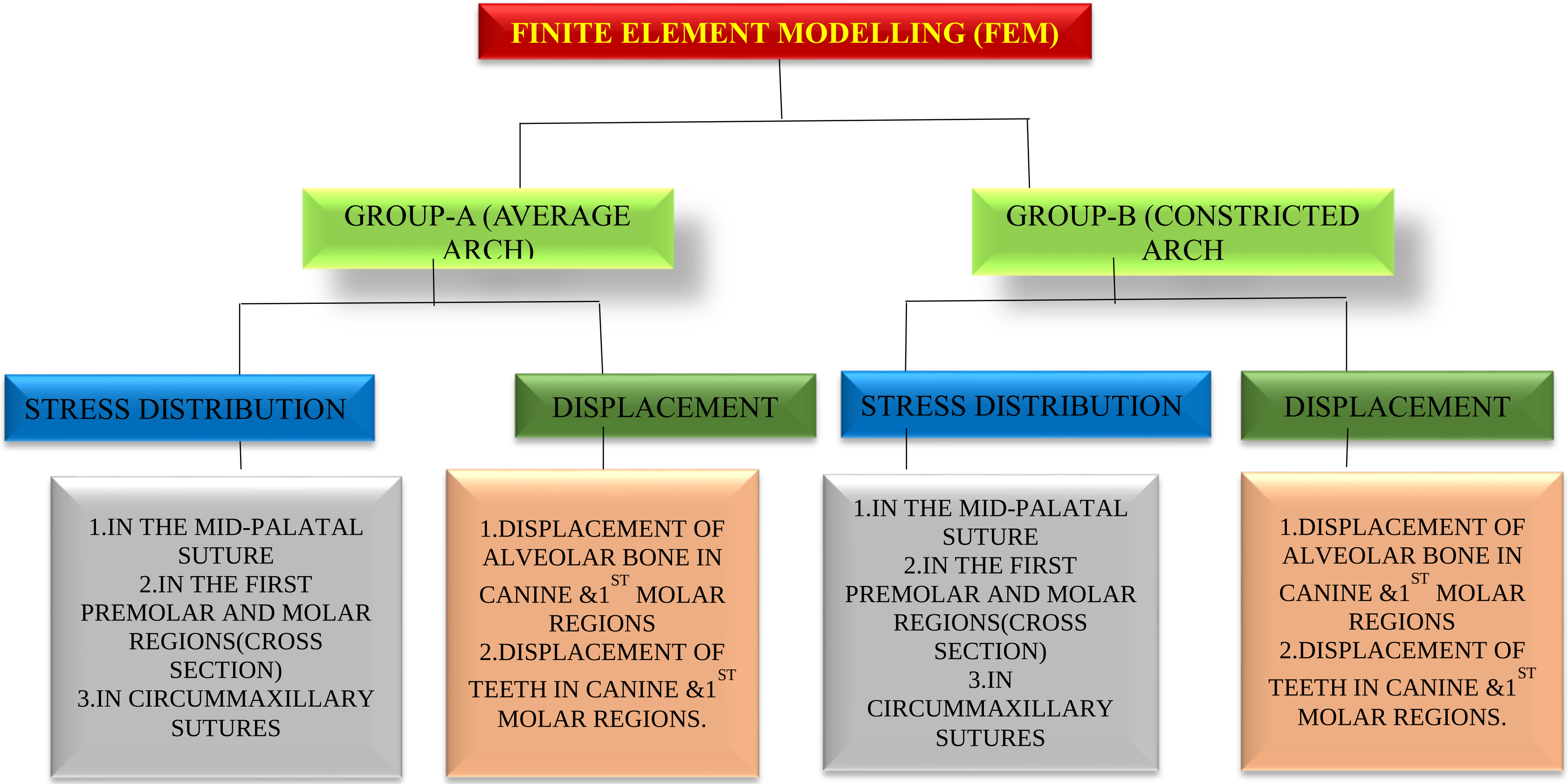


FIGURE 1: – STL MODEL IN MIMICS

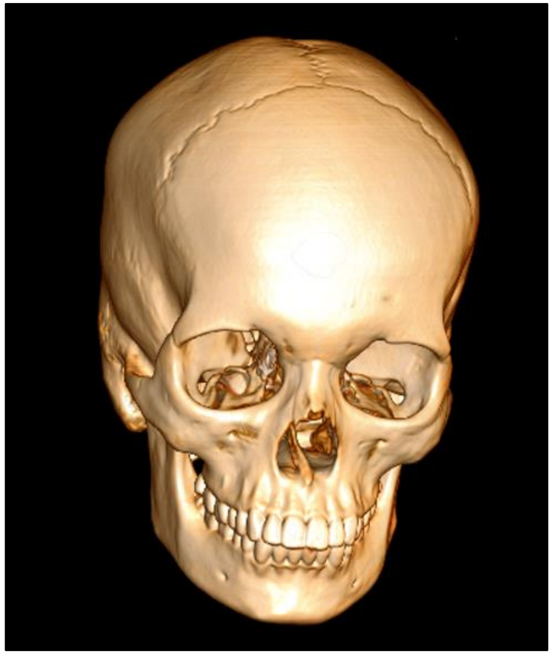


FIGURE 2 : GEOMETRIC MODEL-CREO PARAMETRIC VERSION 2.0

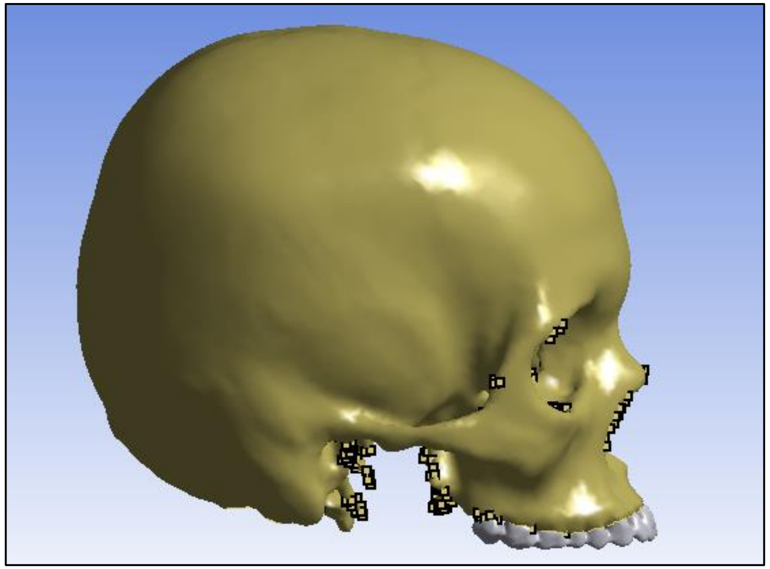


FIGURE 3 : MESHED GEOMETRIC MODEL

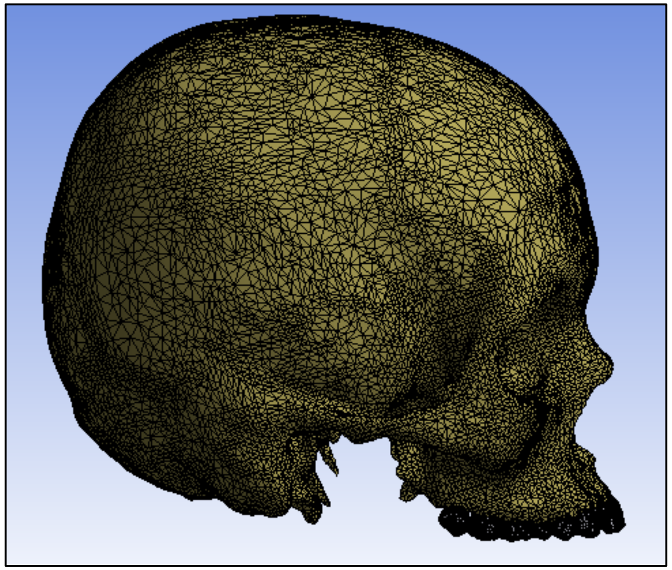
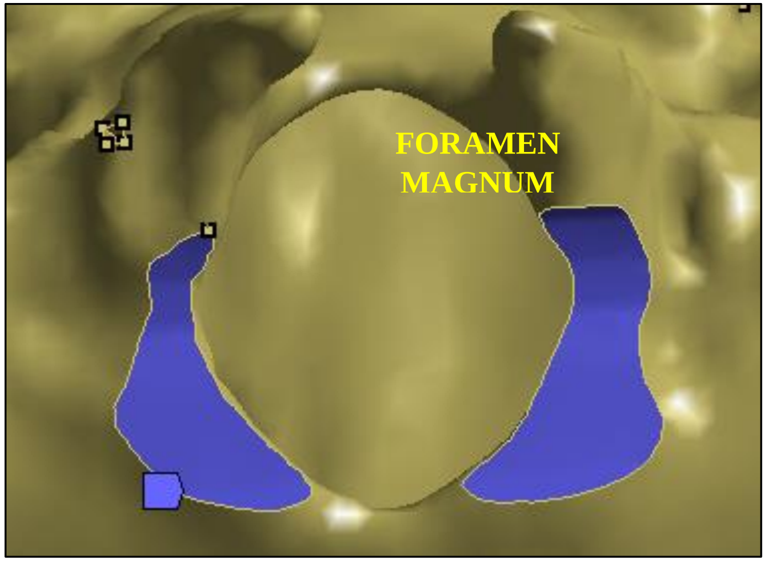


FIGURE 4: BOUNDARY CONDITION



FIGURES5 : DESIGNS OF THE RME TYPES - GROUP-A(AVERAGE ARCH) AND GROUP-B(CONSTRICTED ARCH)- (A)MINICREW IMPLANTS PLACED 3 mm LATERAL TO MID-PALATAL SUTURE (TYPE 1); (B) BONE-BORNE EXPANDER WITH MINISCREW IMPLANTS PLACED AT THE PALATAL SLOPE (TYPE 2)

GROUP-A **GROUP-B**

(A) **(A)**

(B) **(B)**

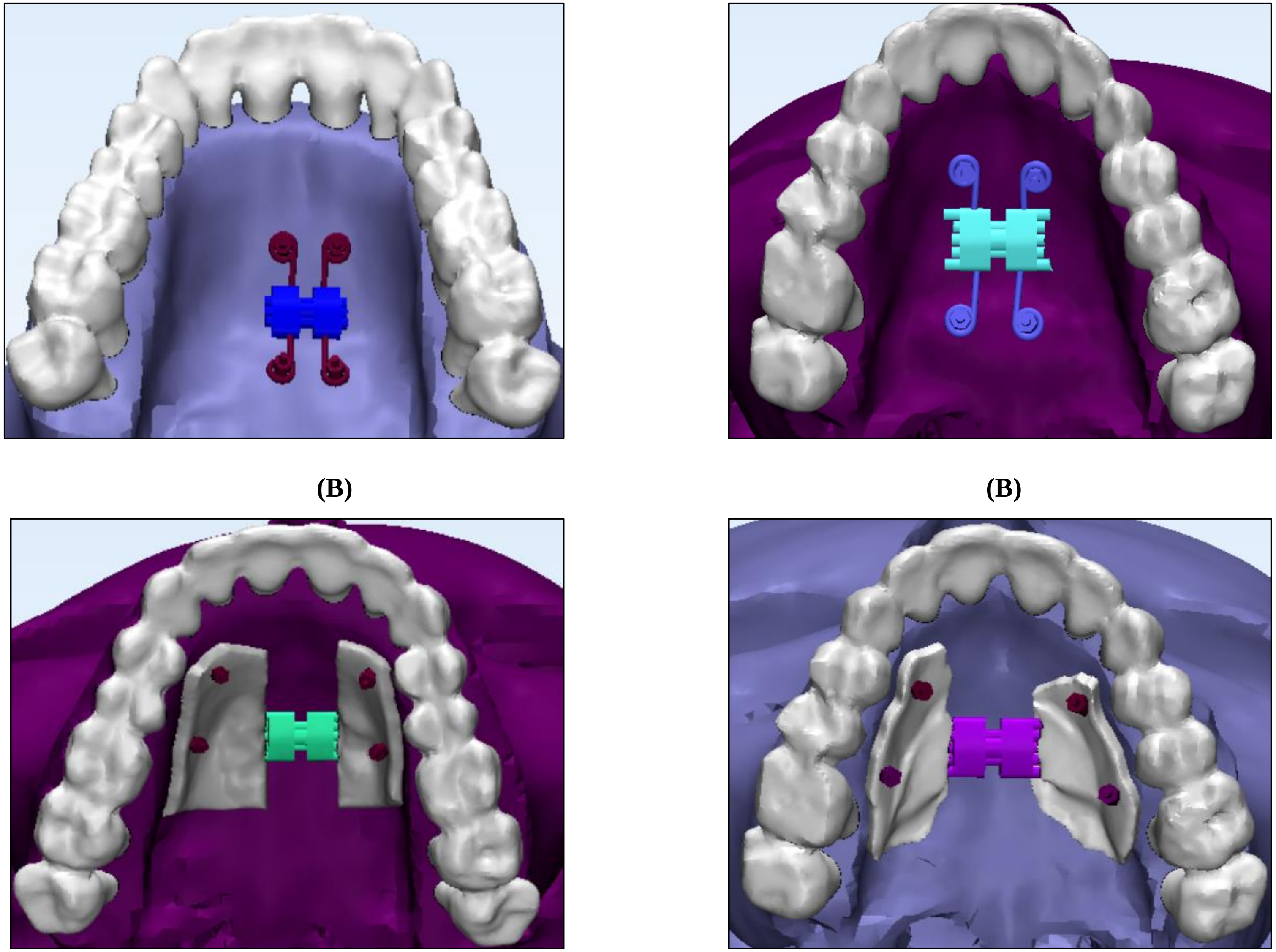
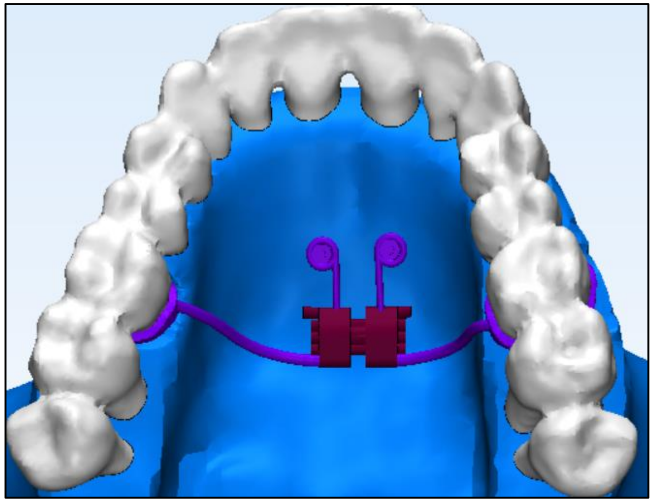
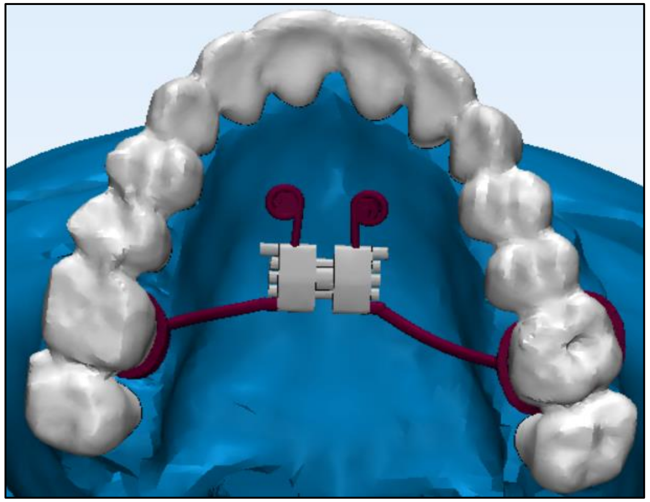


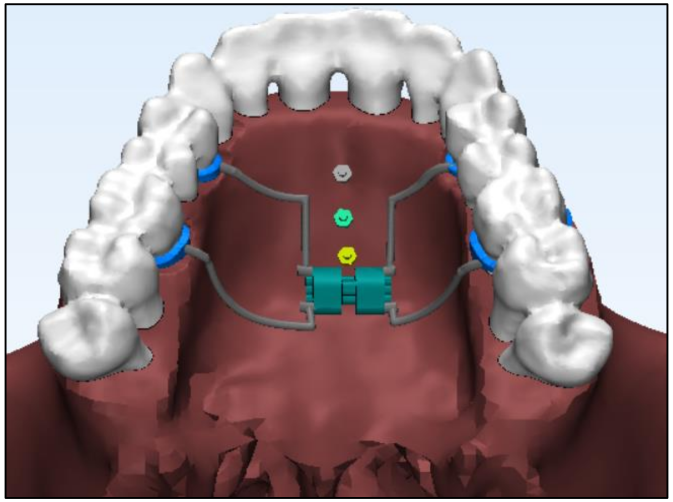
FIGURE 5 : DESIGNS OF THE RME TYPES - GROUP-A(AVERAGE ARCH) AND GROUP-B(CONSTRICTED ARCH)- (C) COMBINED EXPANDER WITH ADDITIONAL CONVENTIONAL HYRAX ARMS ON THE FIRST MOLAR (TYPE 3); (D) TOOTH-BORNE EXPANDER WITH PERFORATIONS USING MINISCREW IMPLANTS IN MID-PALATAL SUTURE (TYPE 4).



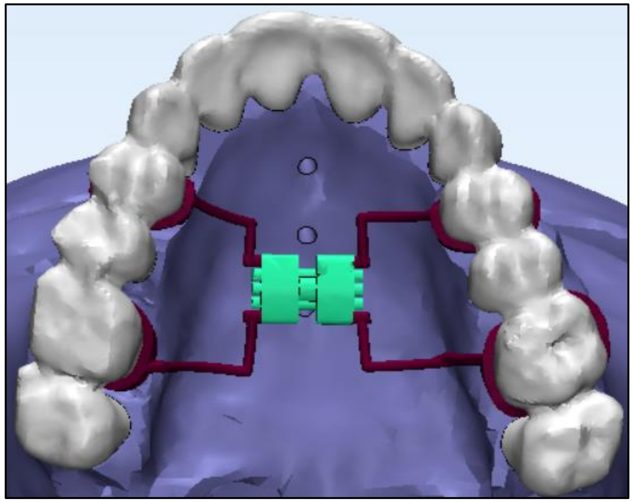
(C)



(C)

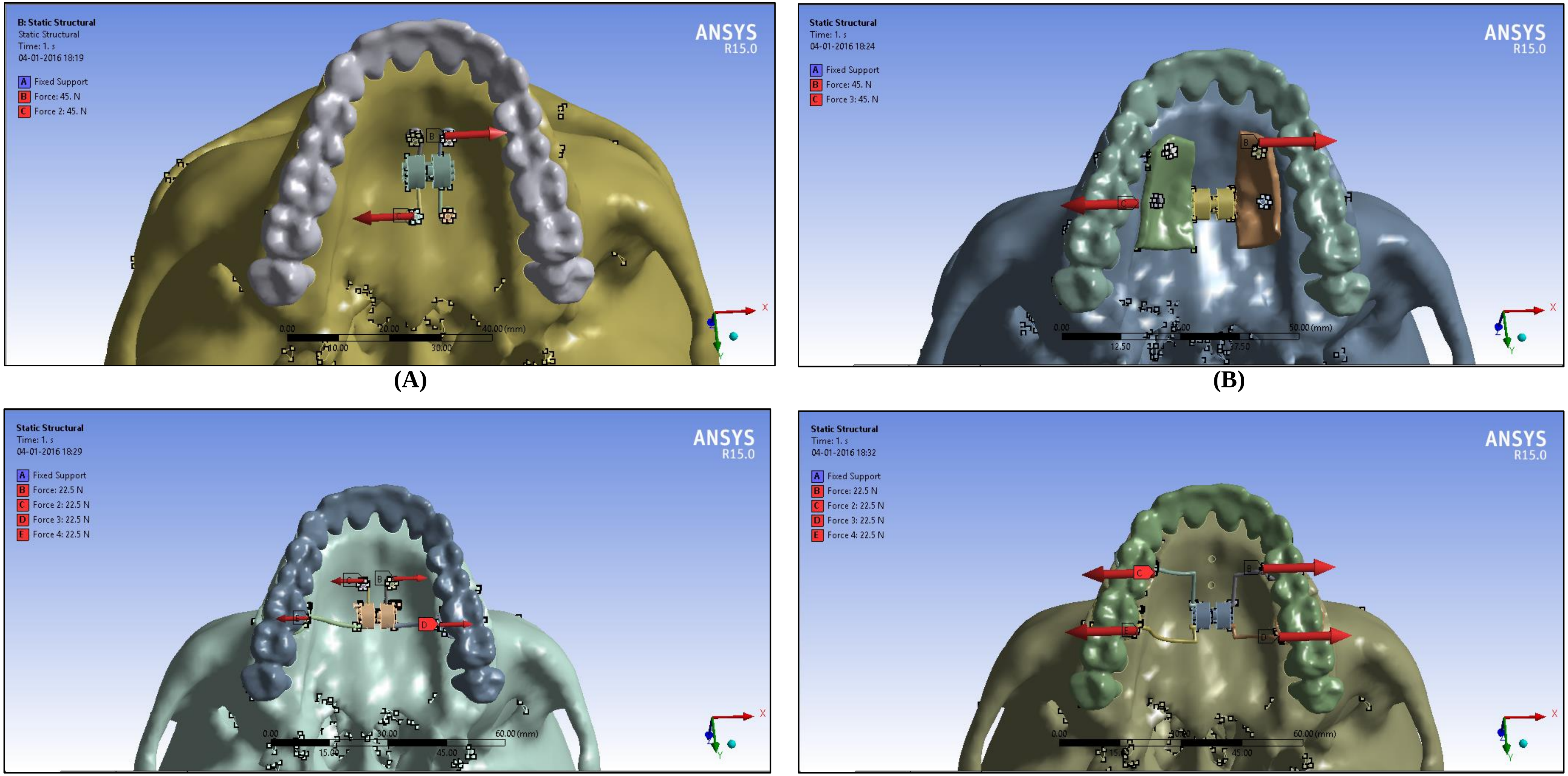


(D)



(D)

FIGURE 6 : APPLICATION OF EXPANSION FORCES IN (A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4



(A) (B)

(C) (D)

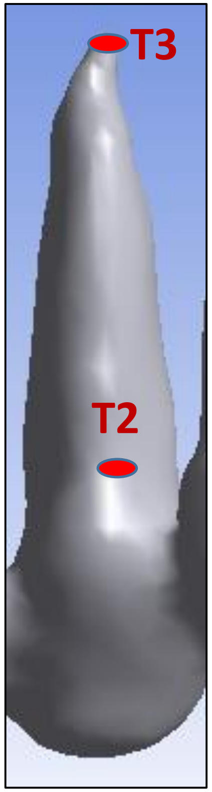
FIGURE 7 (A),(B),(C),(D) SCHEMATIC REPRESENTATION OF THE LANDMARKS FOR CANINE REFERENCE POINTS AND 3D COORDINATES(D)

BUCCAL VIEW

7(A)

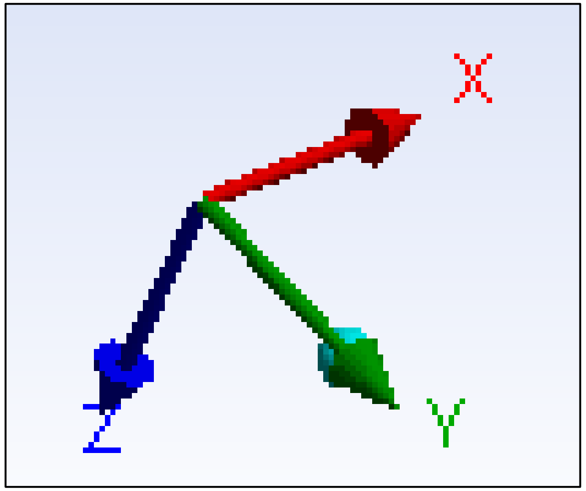
LINGUAL VIEW

7 (B)



SOCKET VIEW

7(C)



7(D)

FIGURE 8 (A),(B),(C)SCHEMATIC REPRESENTATION OF THE LANDMARKS FOR FIRST MOLAR REFERENCE POINTS

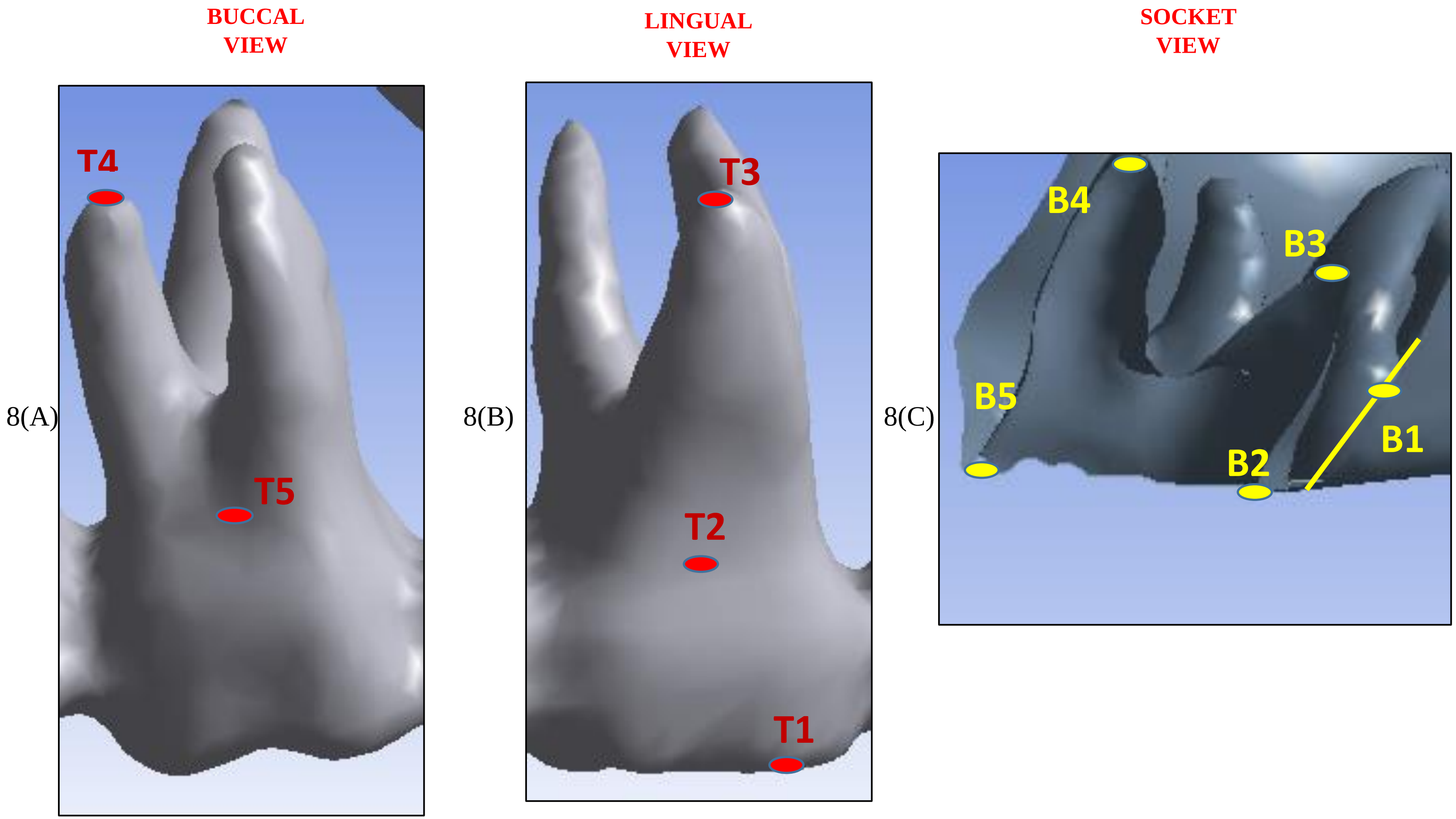


FIGURE 9 : LANDMARKS FOR CIRCUMAXILLARYSUTURES.A-(1)NASOFRONTAL SUTURE,(2)FRONTOMAXILLARY SUTURE,(3)NASOMAXILLARY SUTURE,(4)ZYGOMATICOTEMPORAL SUTURE,B-(5)ZZYGOMATIC ARCH,(6)FRONTOZYGOMATIC SUTURE,(7)ZYGOMATICOMAXILLARY SUTURE,C-(8)MEDIAL PTERYGOID PLATE,(9)LATERAL PTERYGOID PLATE,(10)PTERYGOID HAMULUS

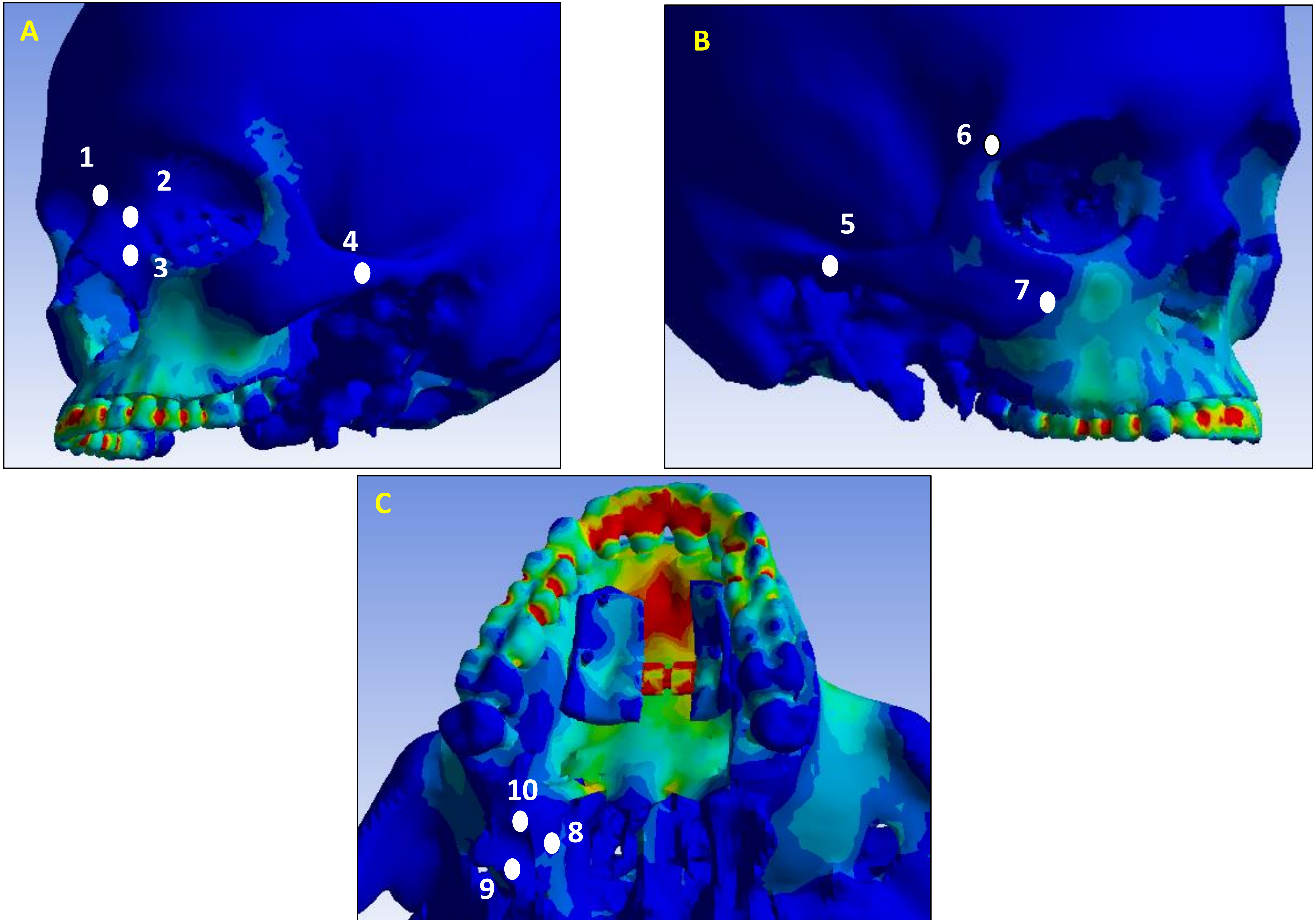
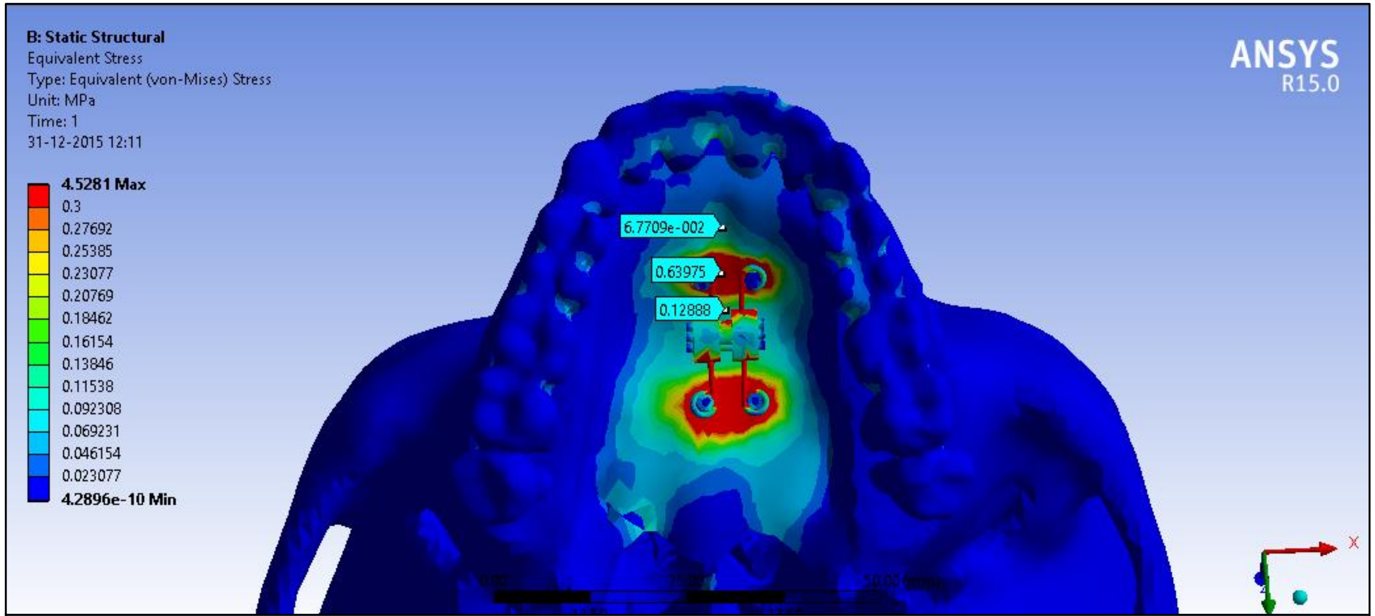
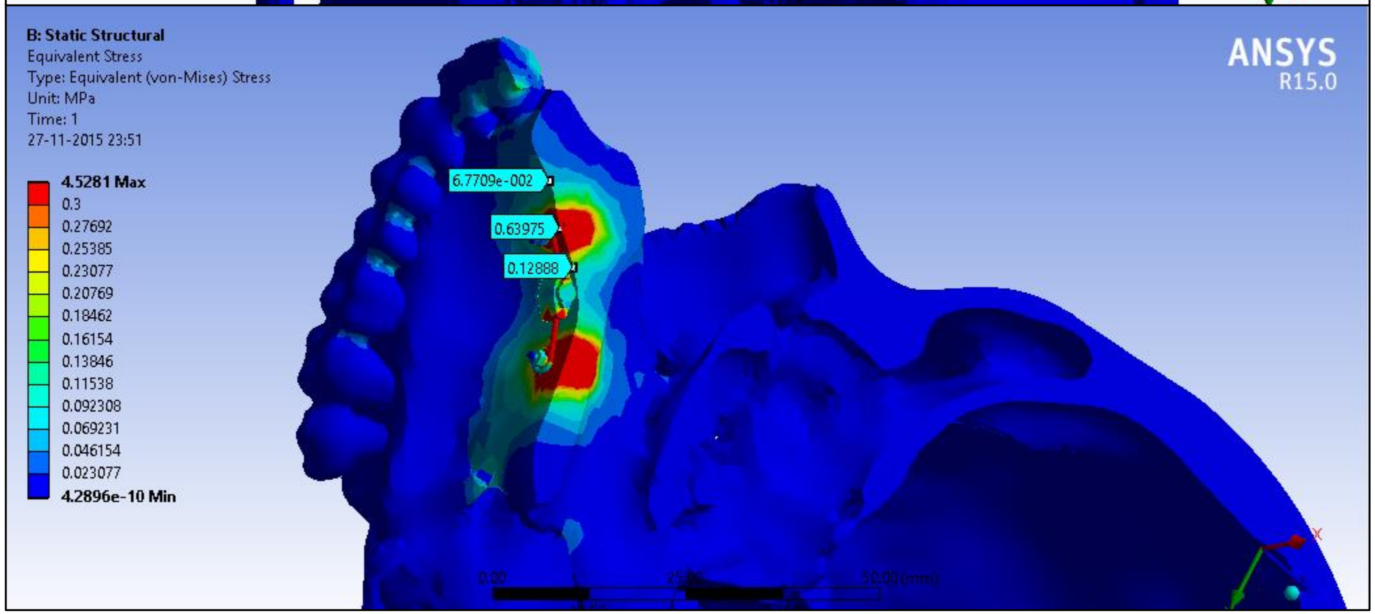


FIGURE-10: VON- MISES STRESS DISTRIBUTION IN THE MID-PALATAL SUTURE - TYPE1

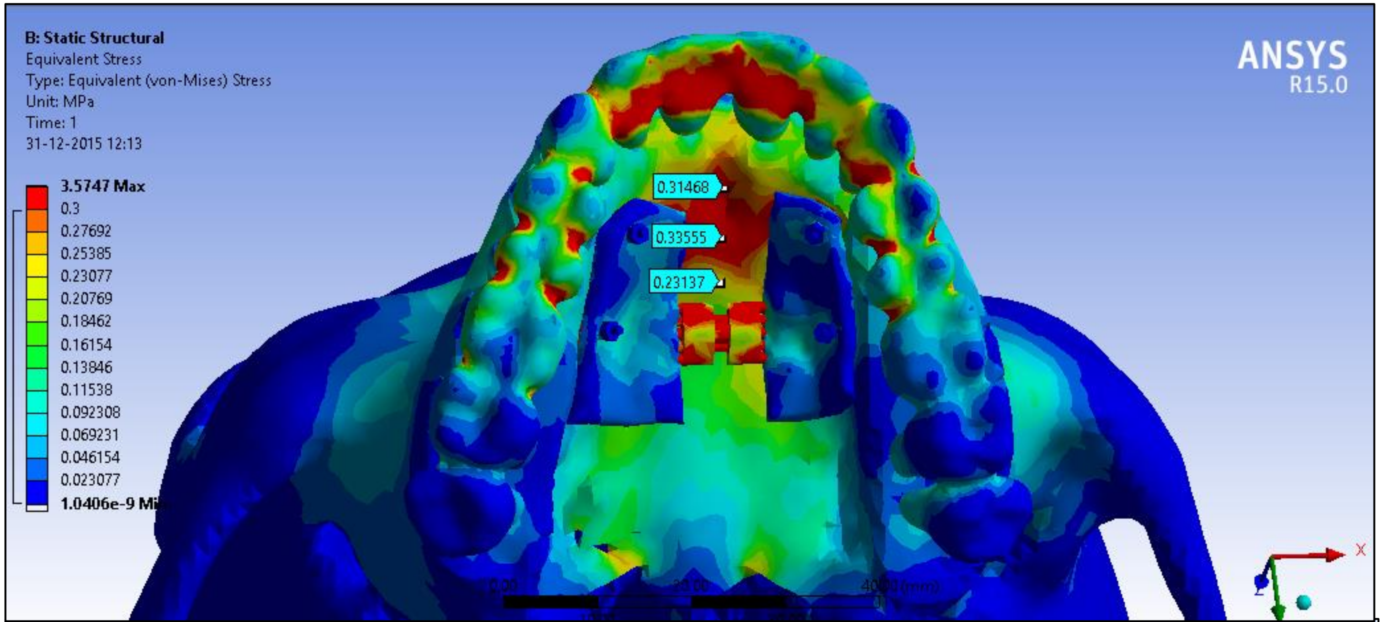


OCCLUSAL VIEW

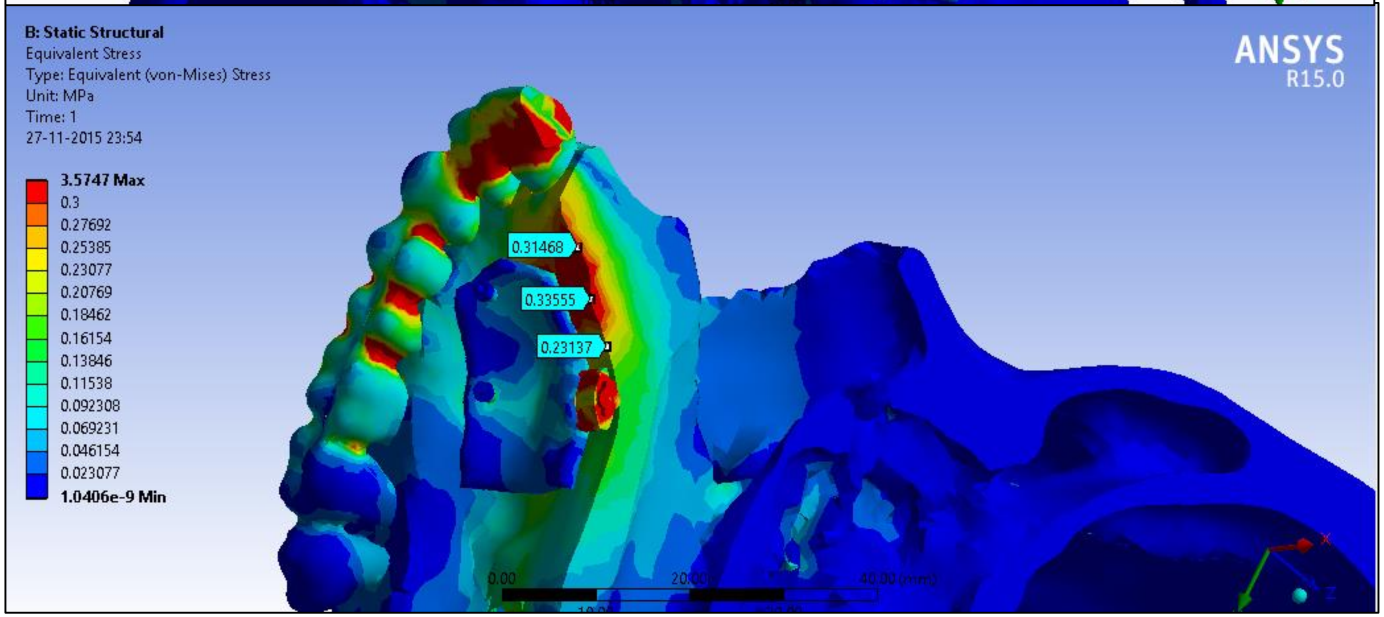


CROSS SECTION VIEW

FIGURE-11 :VON-MISES STRESS DISTRIBUTION IN THE MID-PALATAL SUTURE – TYPE2

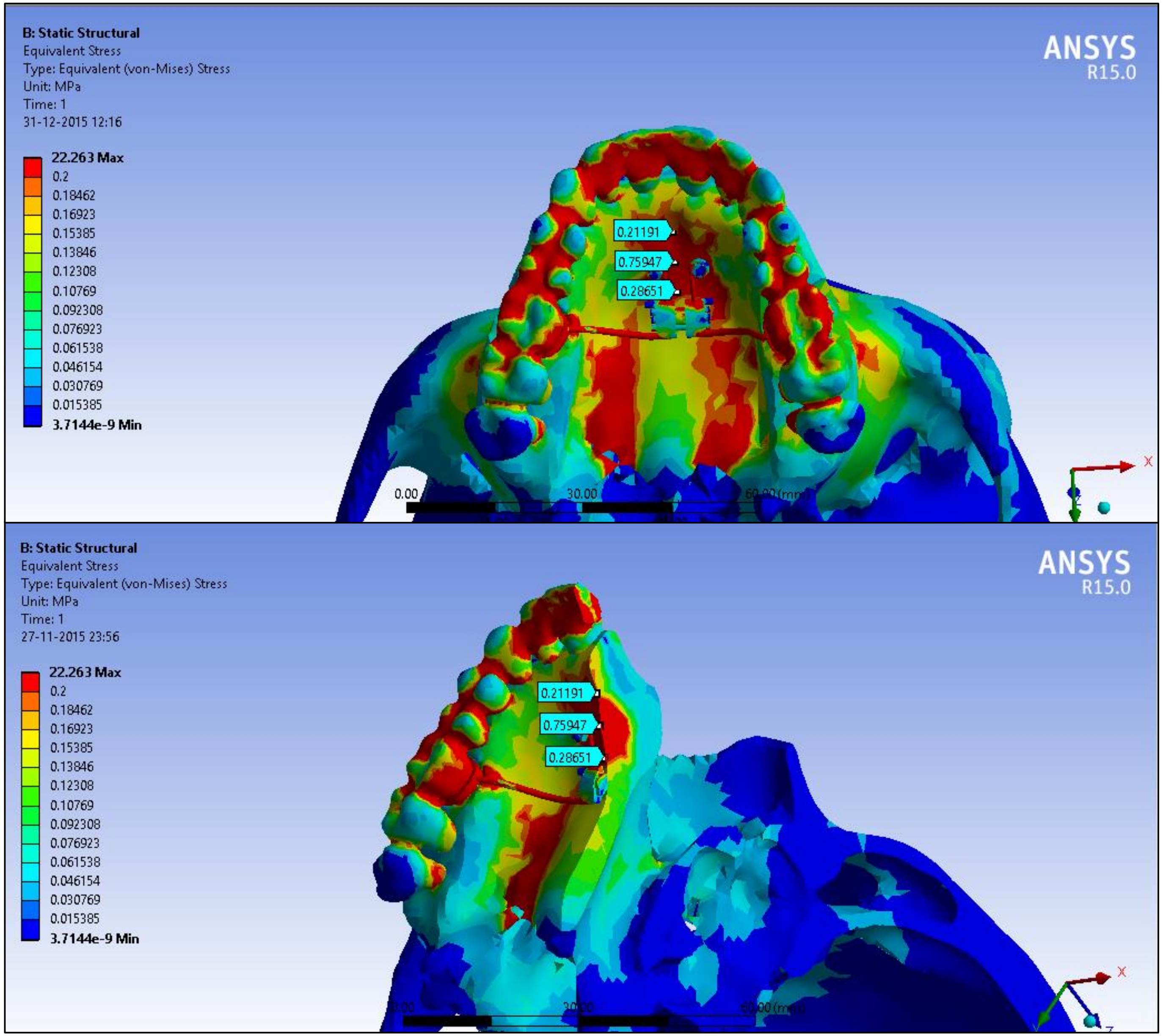


OCCLUSAL VIEW



CROSS SECTION VIEW

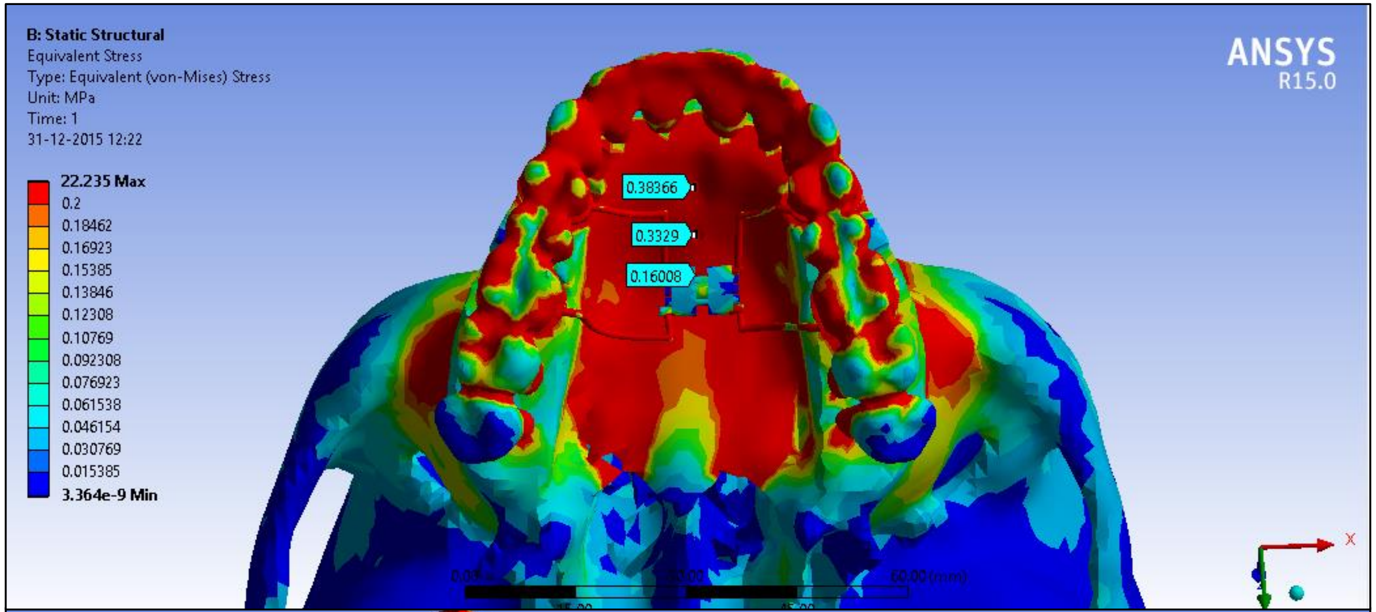
FIGURE-12 :VON-MISES STRESS DISTRIBUTION IN THE MID-PALATAL SUTURE - TYPE3



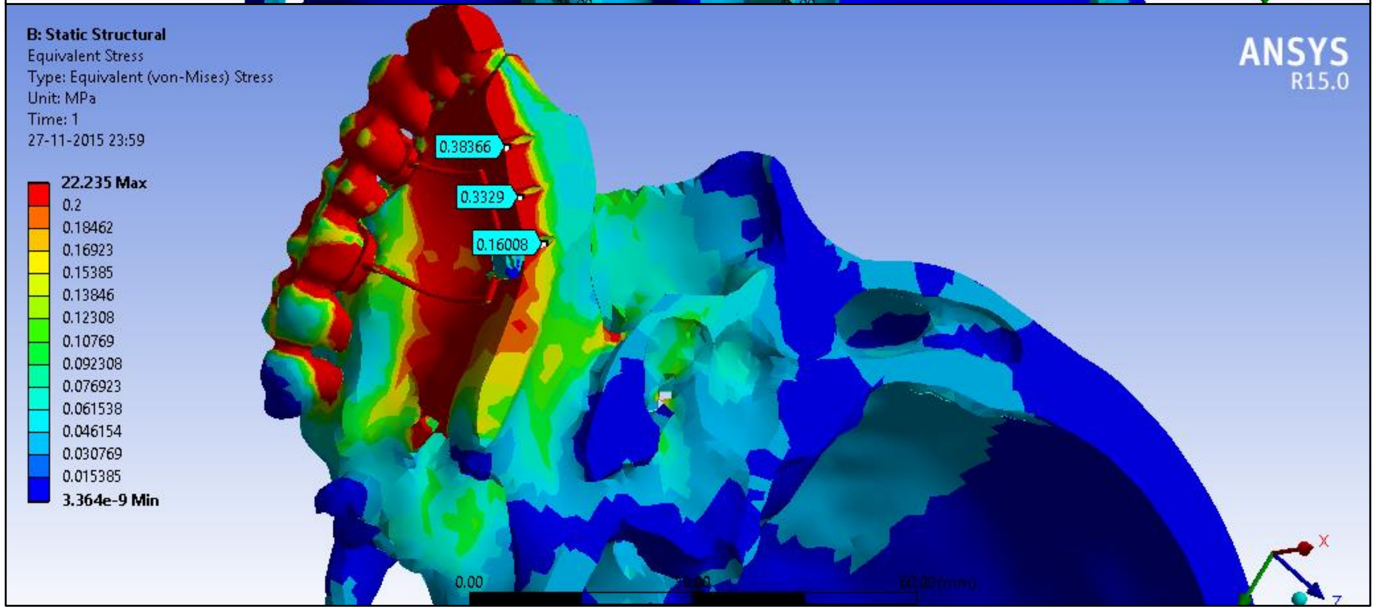
OCCLUSAL VIEW

CROSS SECTION VIEW

FIGURE-13 :VON-MISES STRESS DISTRIBUTION IN THE MID-PALATAL SUTURE -TYPE4



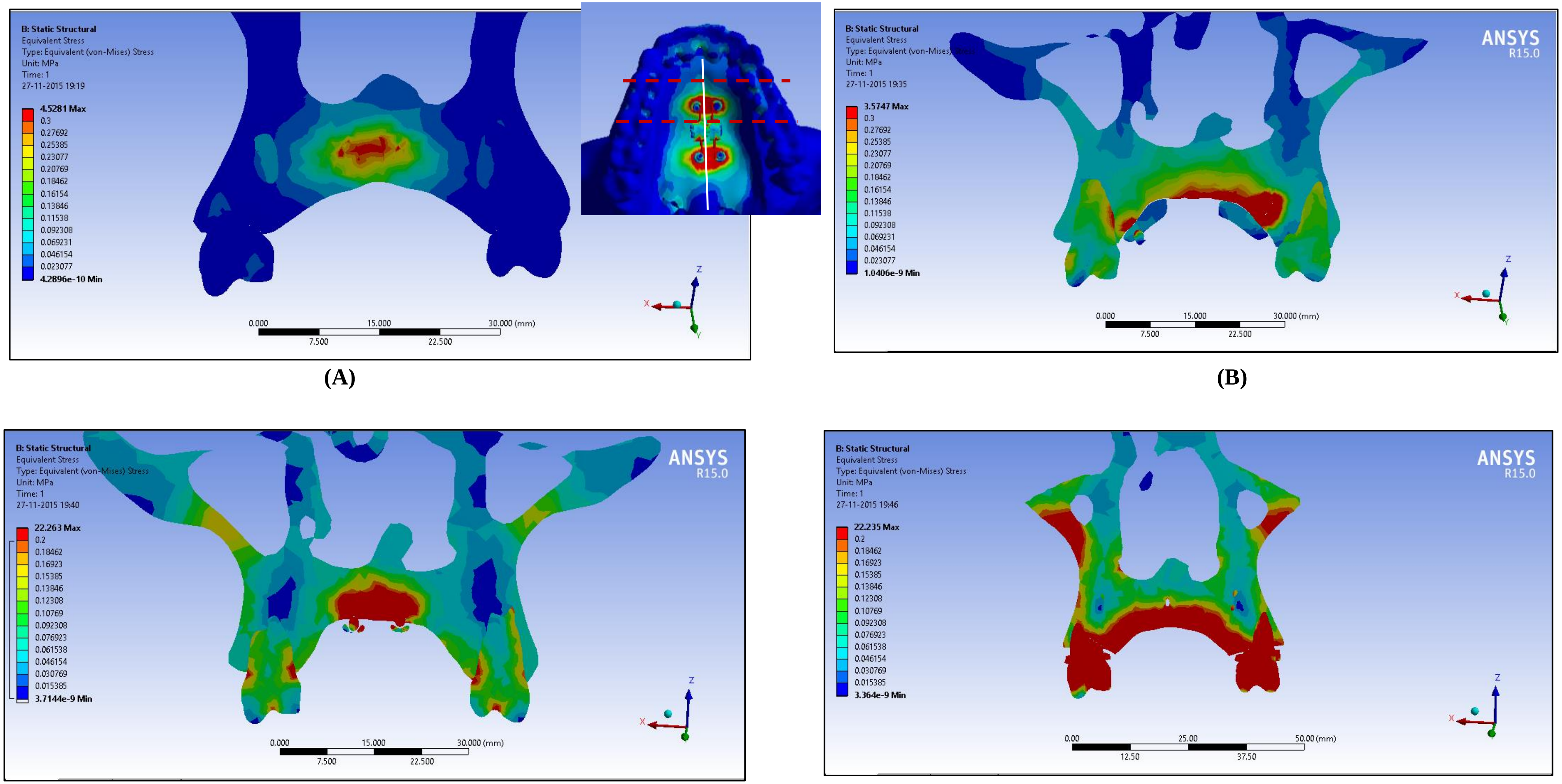
OCCLUSAL VIEW



CROSS SECTION VIEW

FIGURE-14 :VON-MISES STRESS DISTRIBUTION IN CROSS SECTION IN FIRST PREMOLAR REGION

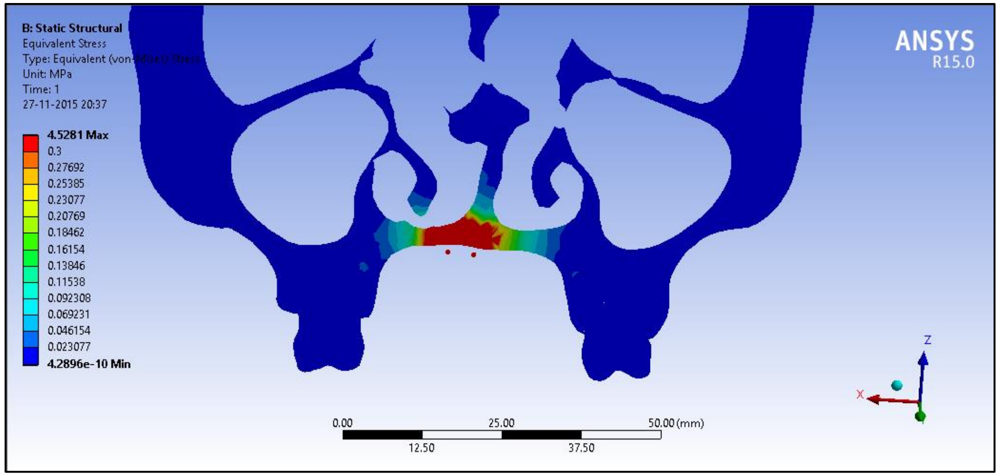
(A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4



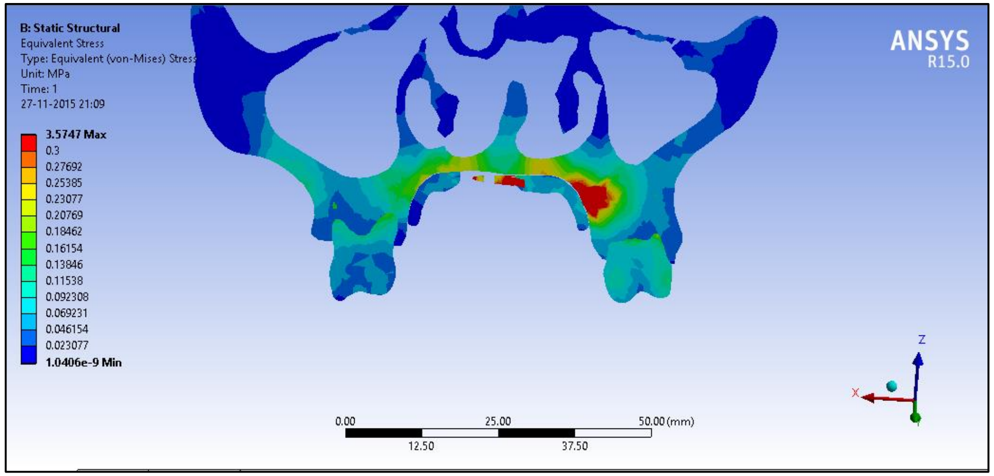
(C) (D)

FIGURE-15 :VON-MISES STRESS DISTRIBUTION IN CROSS SECTION IN FIRST MOLAR REGION

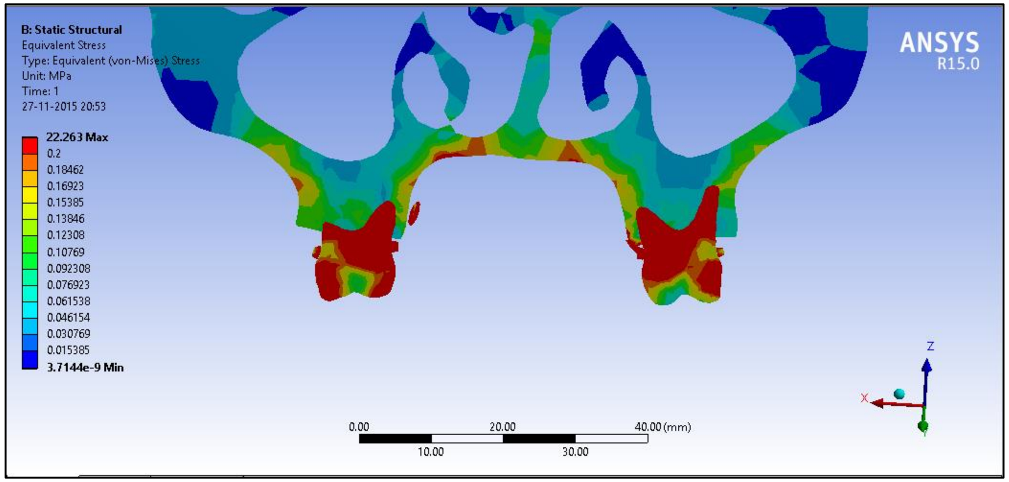
(A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4



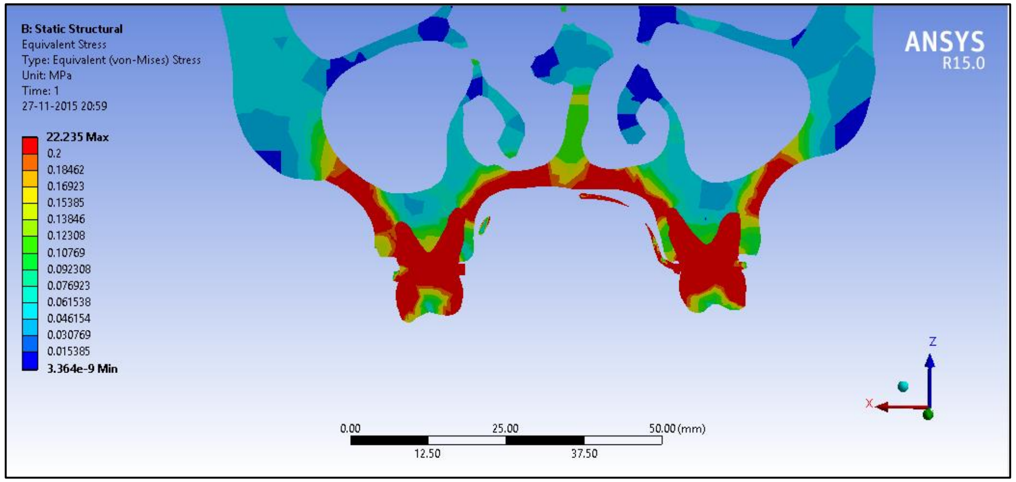
(A)



(B)



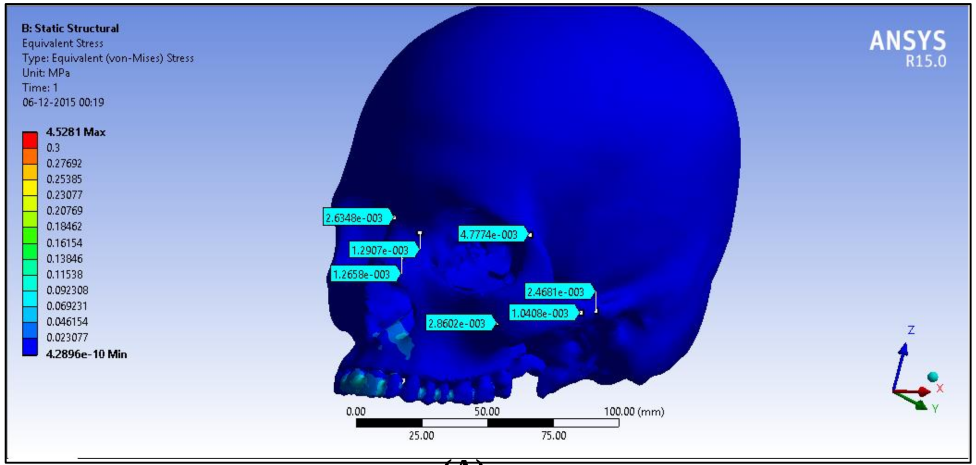
(C)



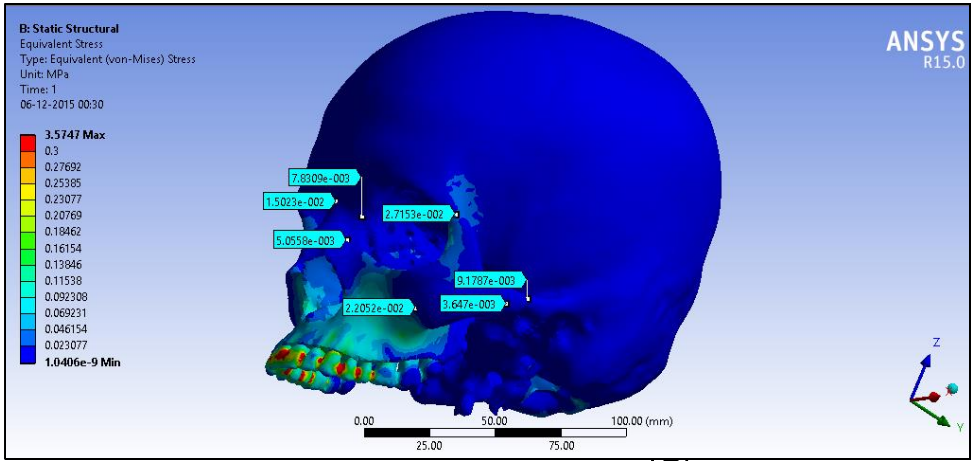
(D)

FIGURE-16 :VON-MISES STRESS DISTRIBUTION IN CIRCUMMAXILLARY SUTURES

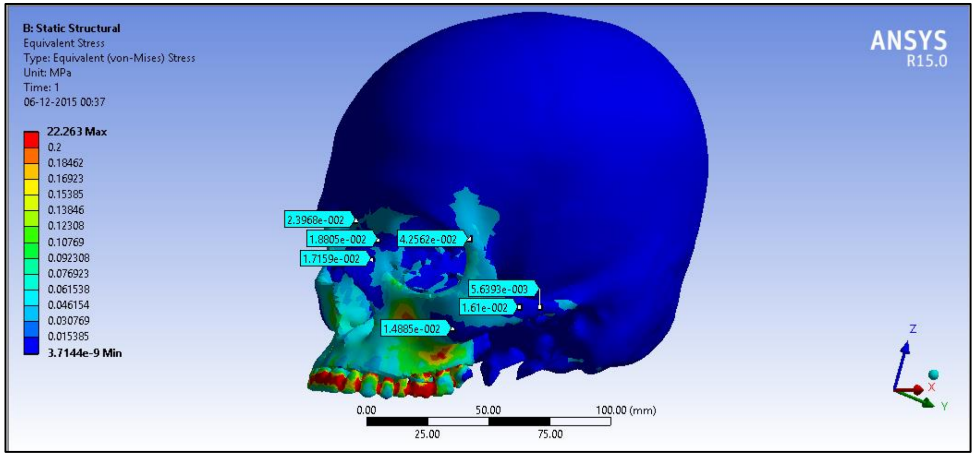
(A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4



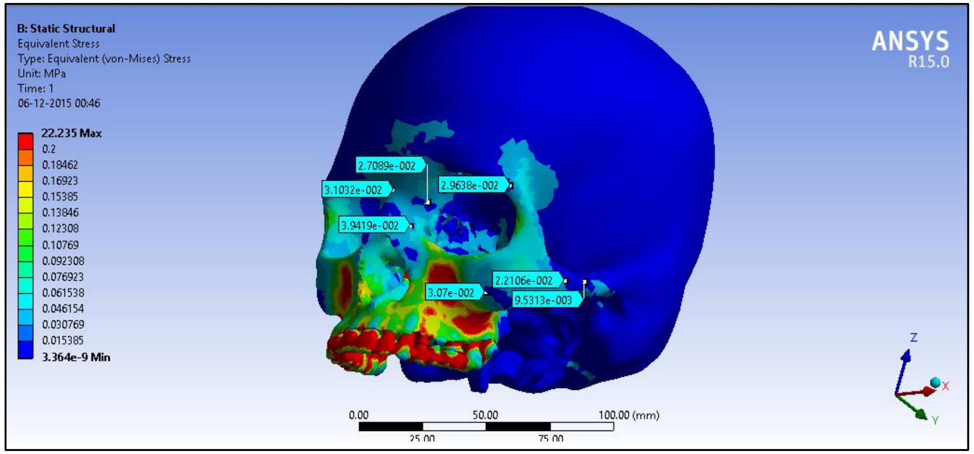
(A)



(B)



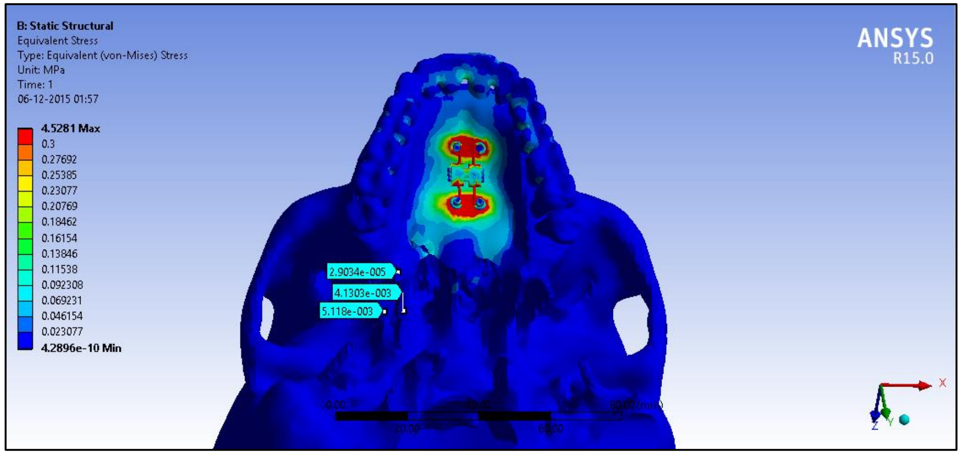
(C)



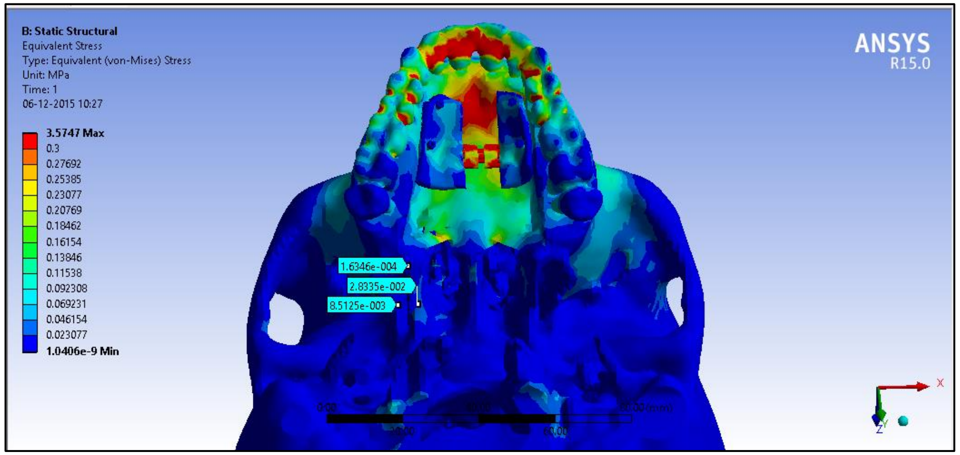
(D)

FIGURE 17:VON-MISES STRESS DISTRIBUTION IN THE PTERYGOID PLATES

(A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4



(A)



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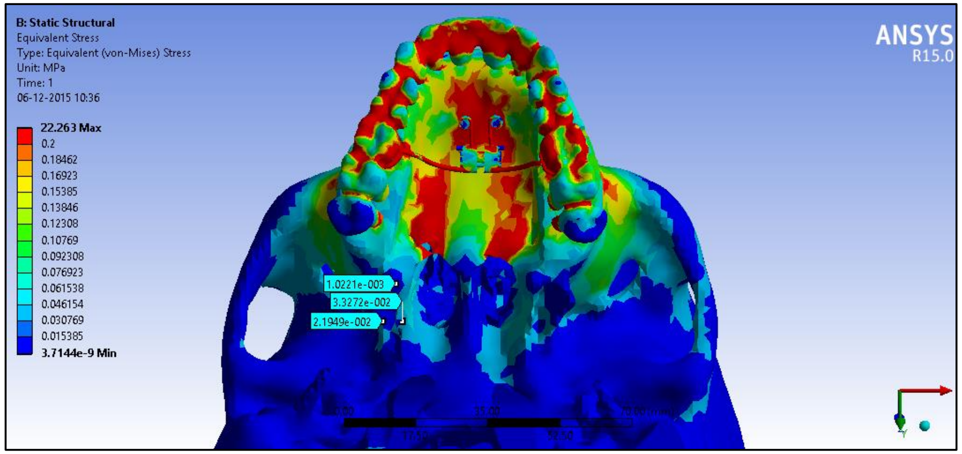

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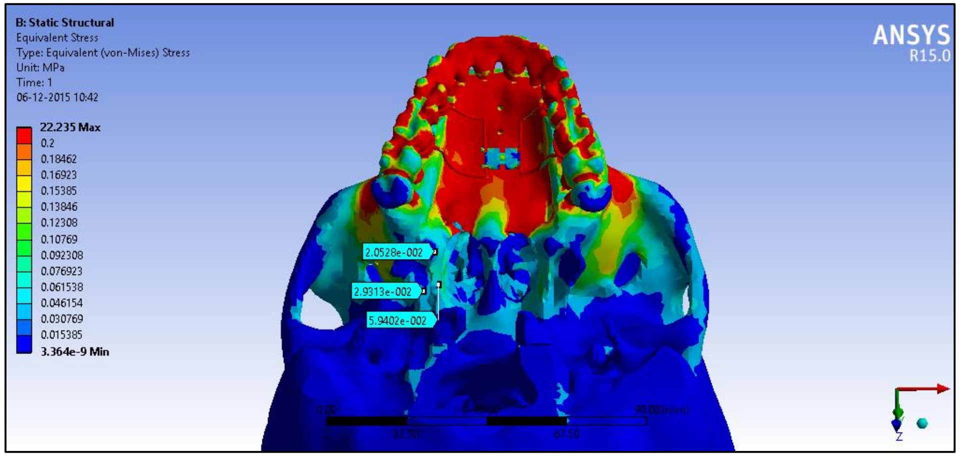


(D)

FIGURE-18 :ROTATIONAL MOVEMENT OF THE ALVEOLAR BONE IN FIRST PREMOLAR AREA (RIGHT SIDE) (A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4

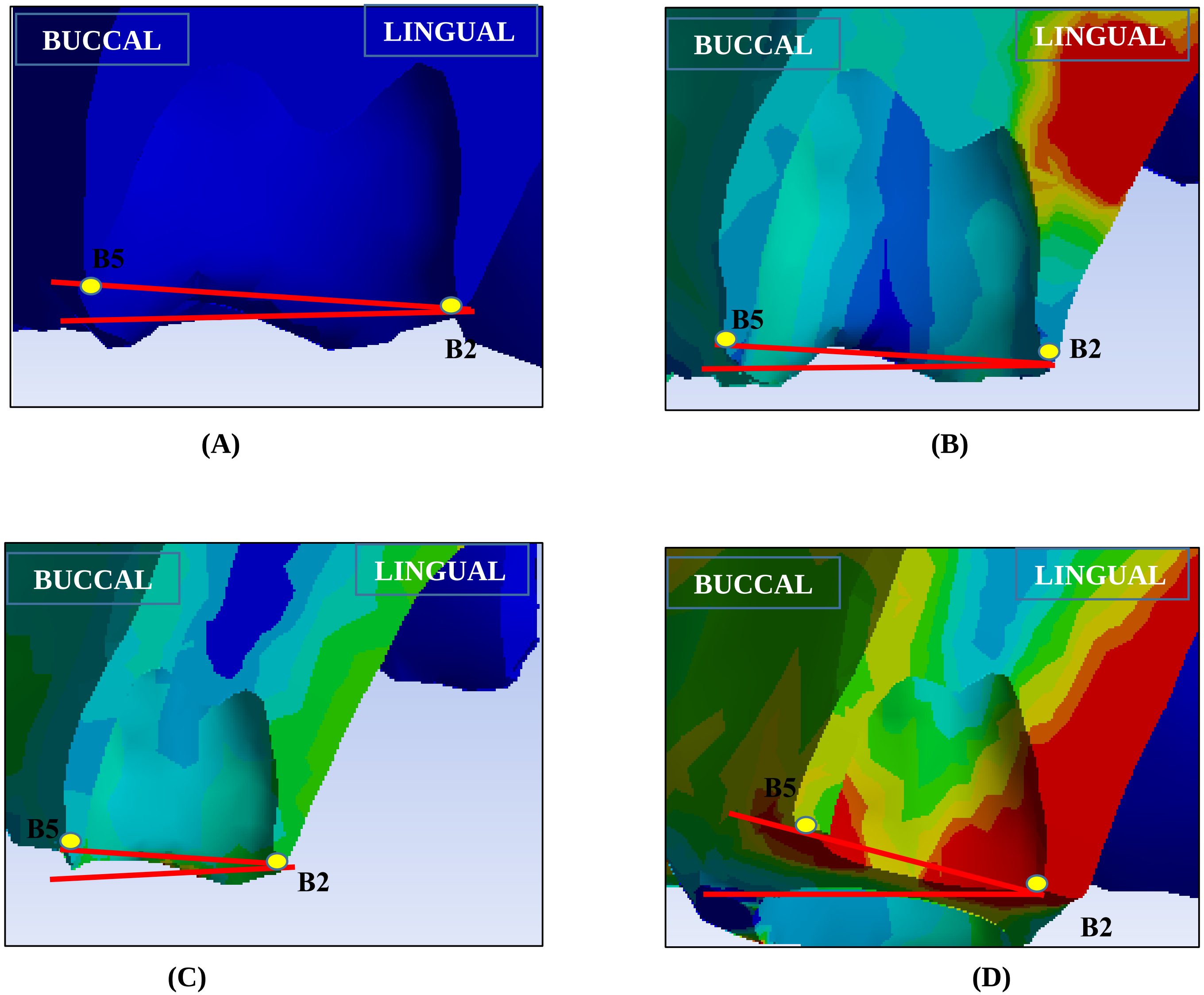


FIGURE-19 :ROTATIONAL MOVEMENT OF THE ALVEOLAR BONE IN FIRST MOLAR AREA (RIGHT SIDE) (A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4

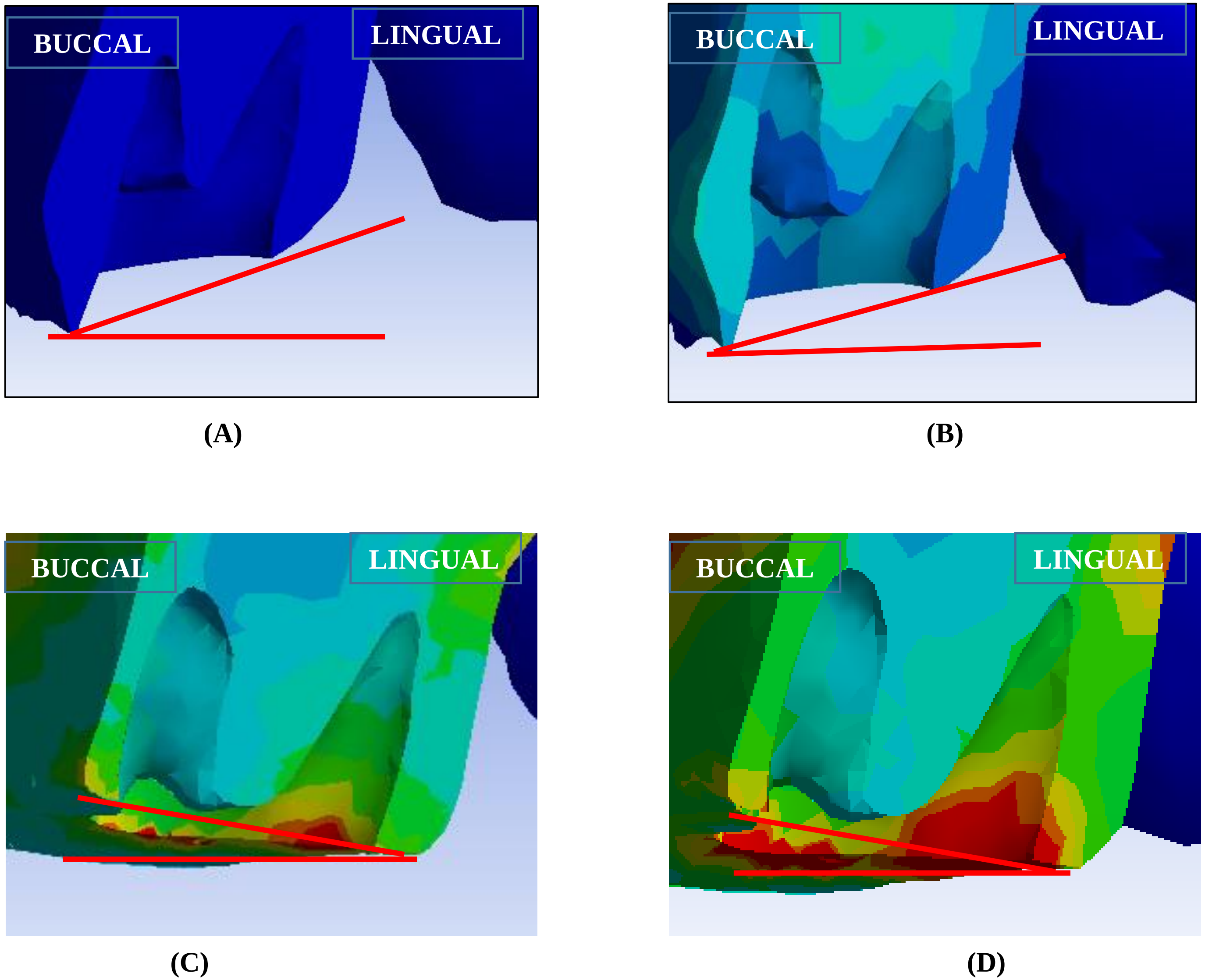
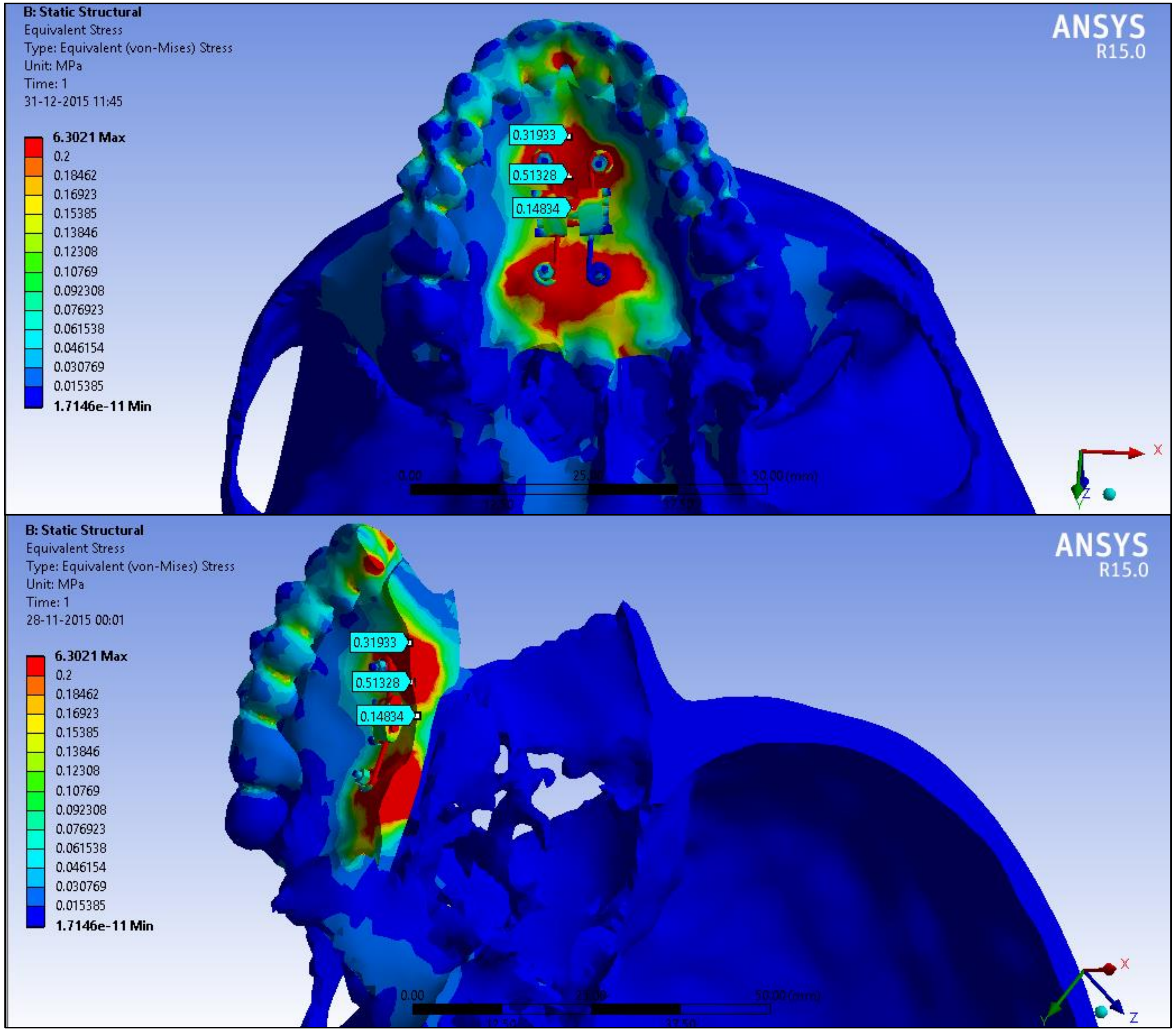


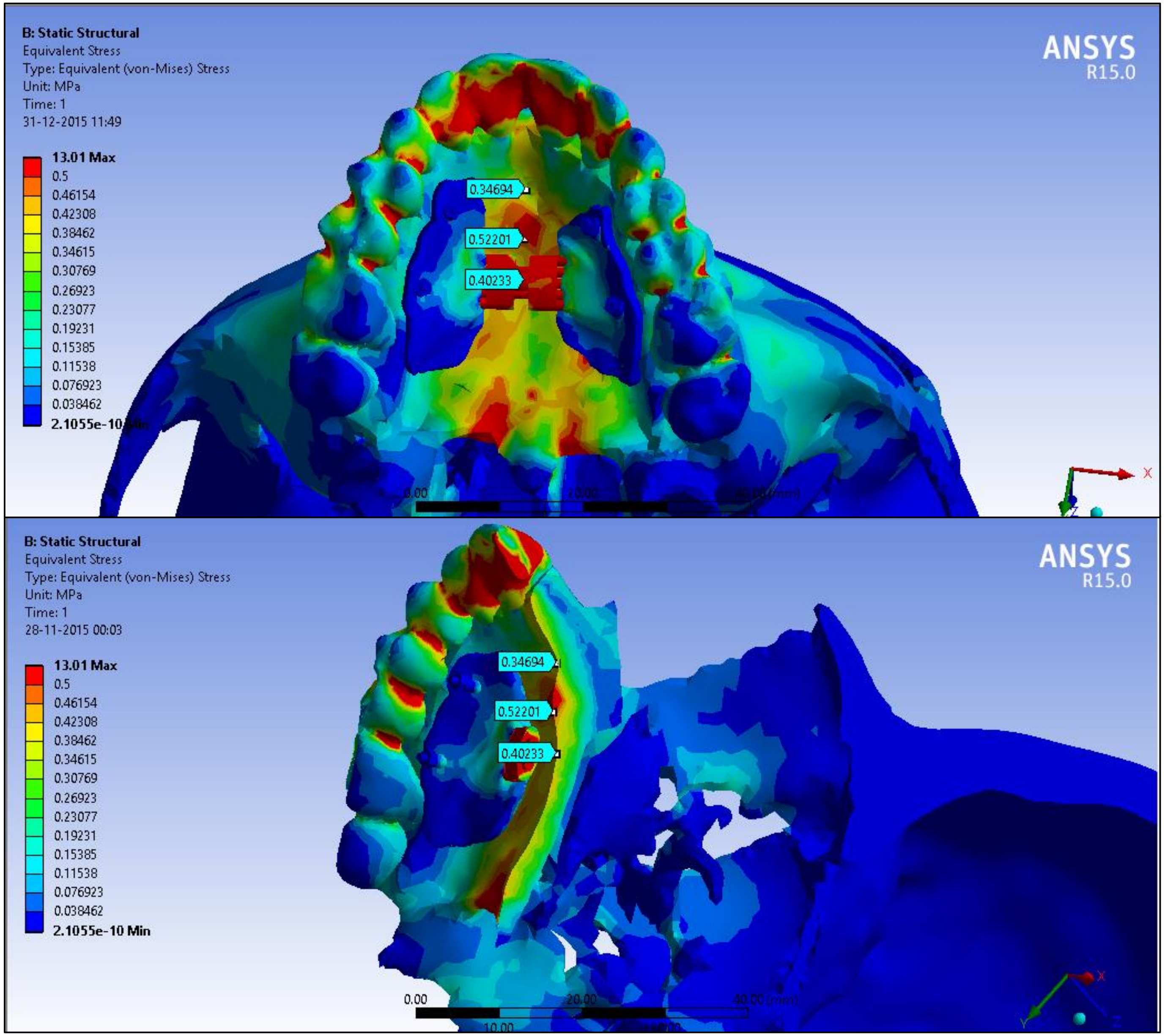
FIGURE-20 :VON-MISES STRESS DISTRIBUTION IN THE MID-PALATAL SUTURE - TYPE1



OCCLUSAL VIEW

CROSS SECTION VIEW

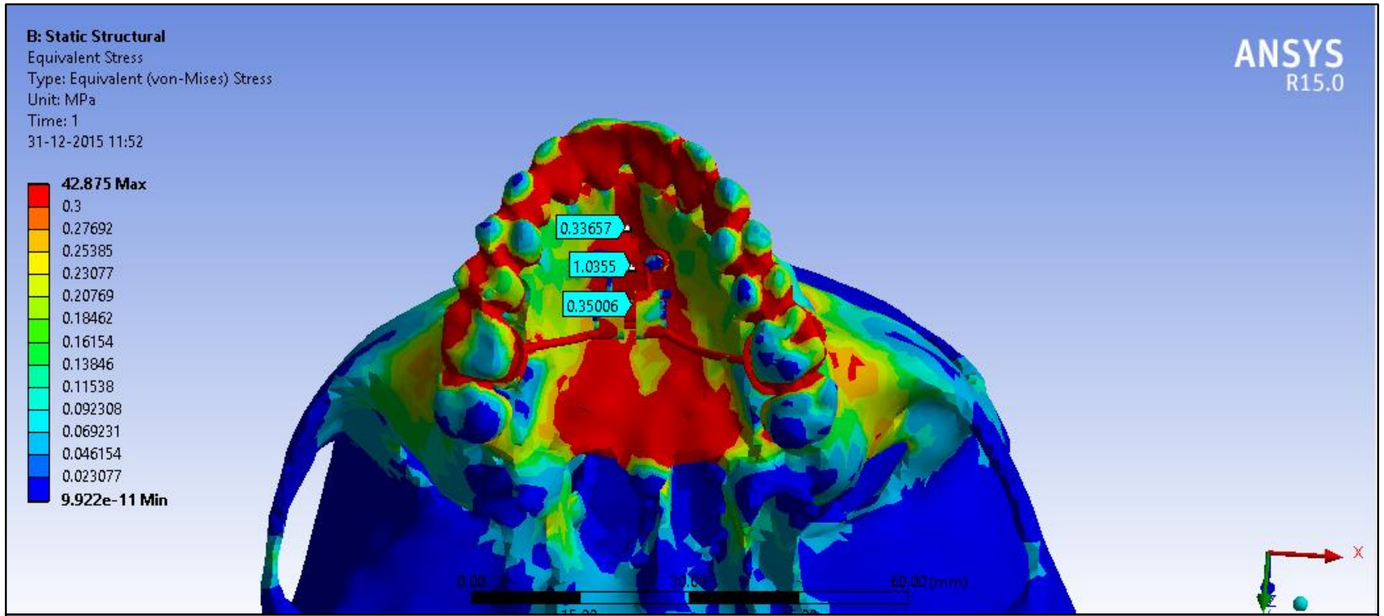
FIGURE-21 :VON-MISES STRESS DISTRIBUTION IN THE MID-PALATAL SUTURE -TYPE2



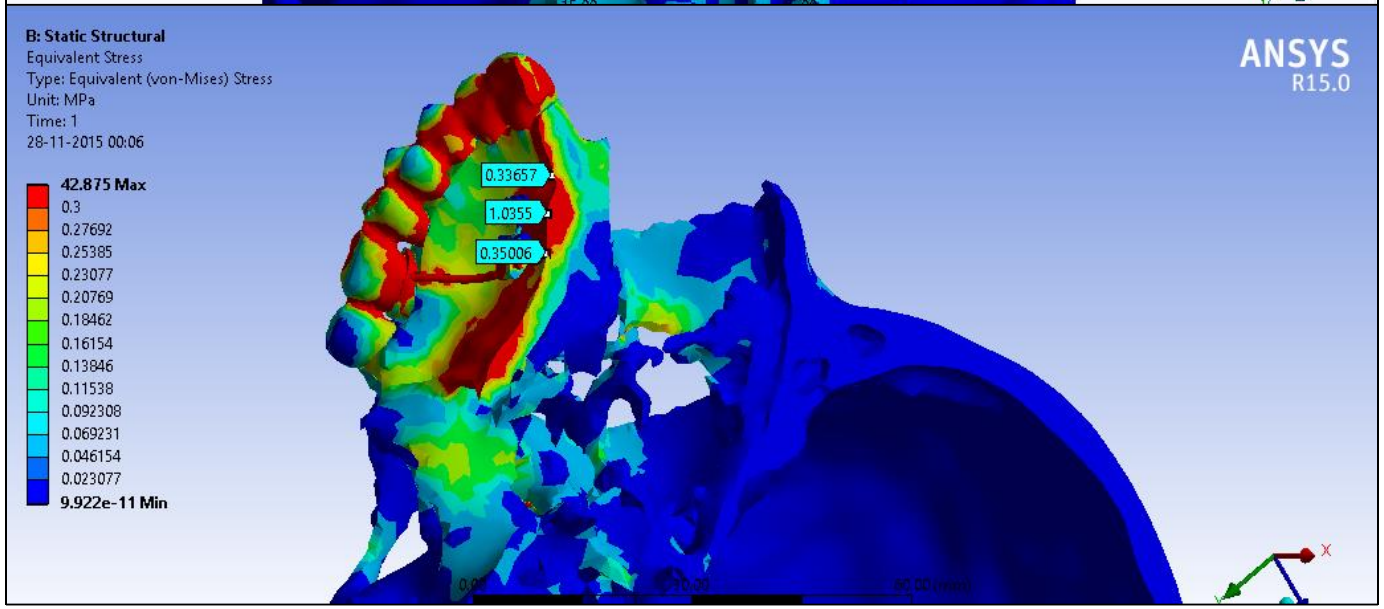
OCCLUSAL VIEW

CROSS SECTION VIEW

FIGURE-22 :VON-MISES STRESS DISTRIBUTION IN THE MID-PALATAL SUTURE - TYPE3

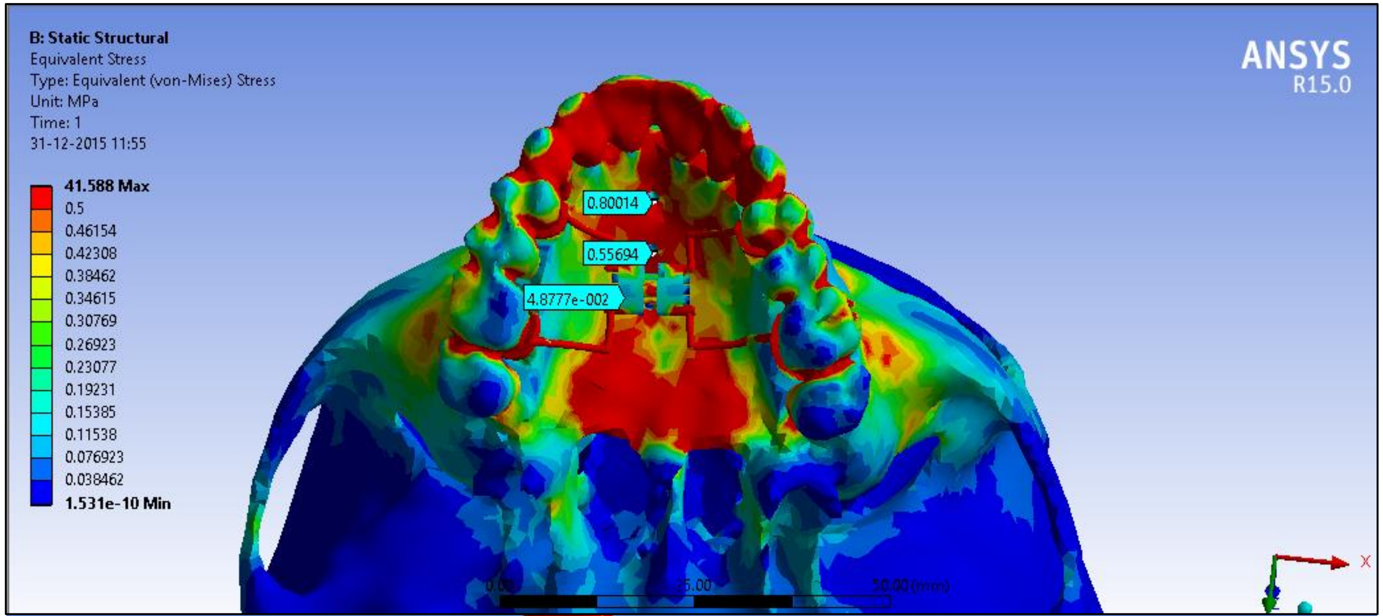


OCCLUSAL VIEW

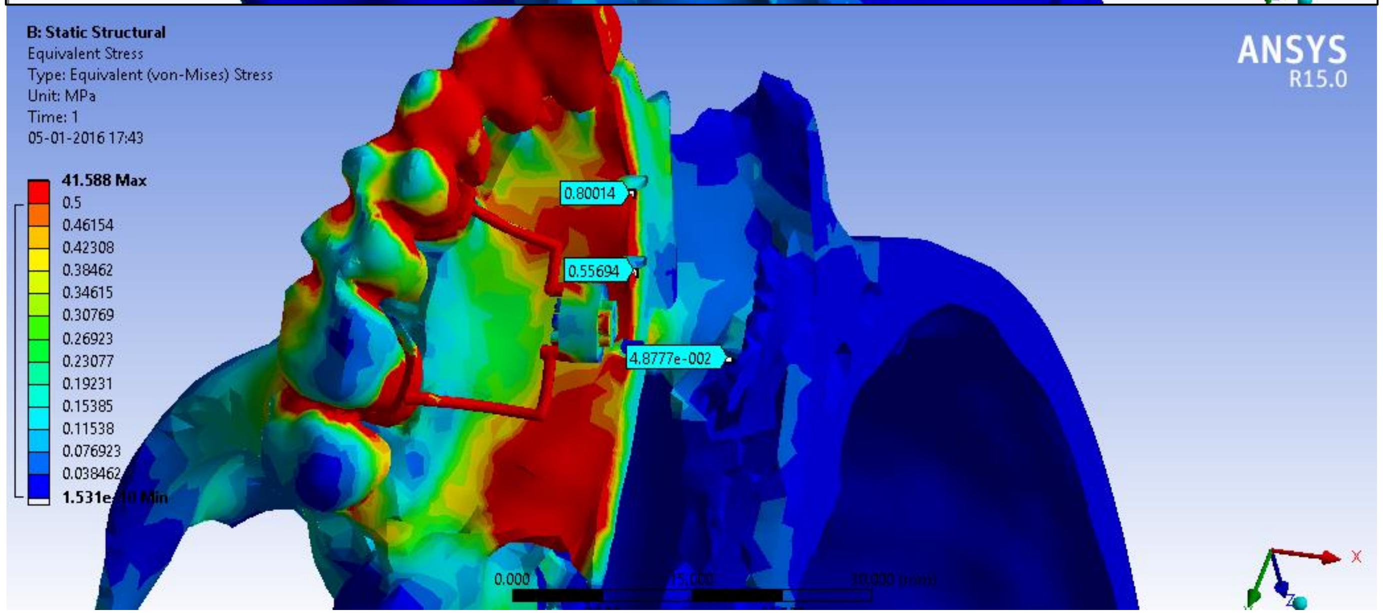


CROSS SECTION VIEW

FIGURE-23 :VON-MISES STRESS DISTRIBUTION IN THE MID-PALATAL SUTURE - TYPE4



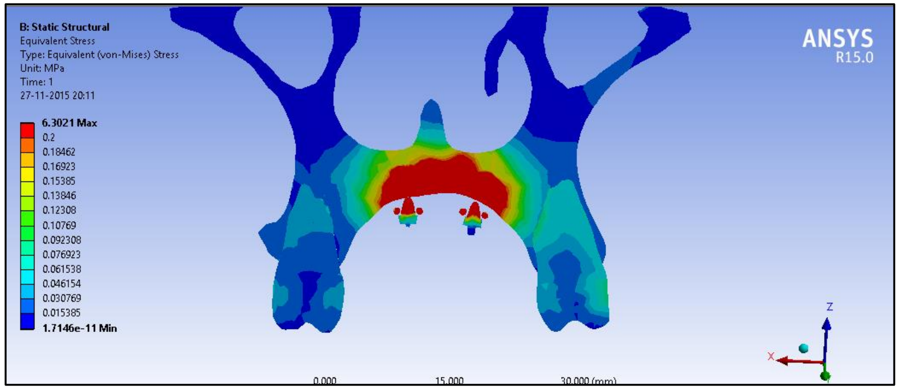
OCCLUSAL VIEW



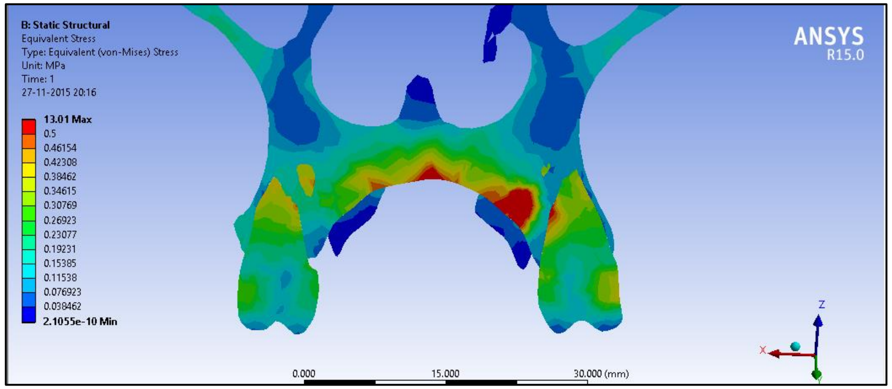
CROSS SECTION VIEW

FIGURE-24 :VON-MISES STRESS DISTRIBUTION IN CROSS SECTION IN FIRST PREMOLAR REGION

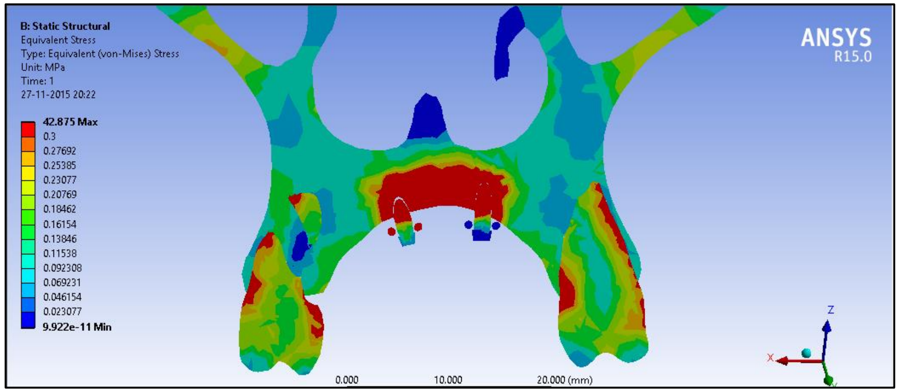
(A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4

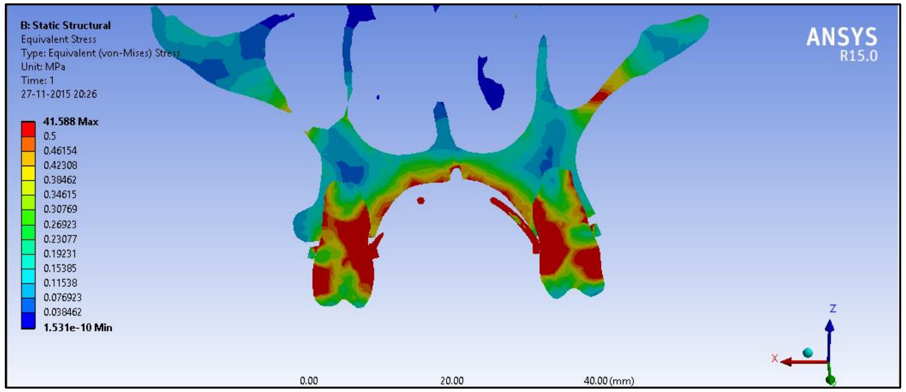


(A)



(B)



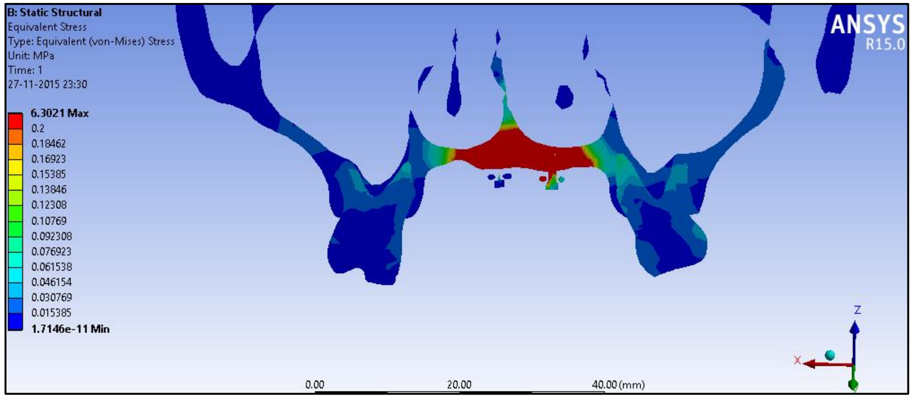


(C)

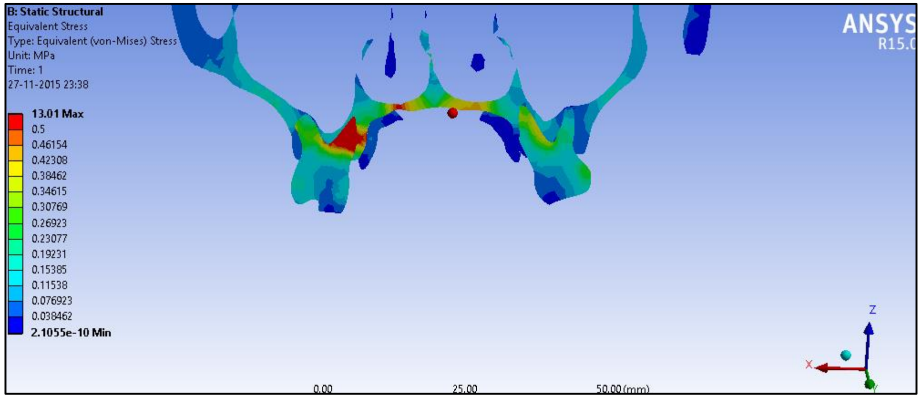
(D)

FIGURE-25 :VON-MISES STRESS DISTRIBUTION IN CROSS SECTION IN FIRST MOLAR REGION

(A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4



(A)



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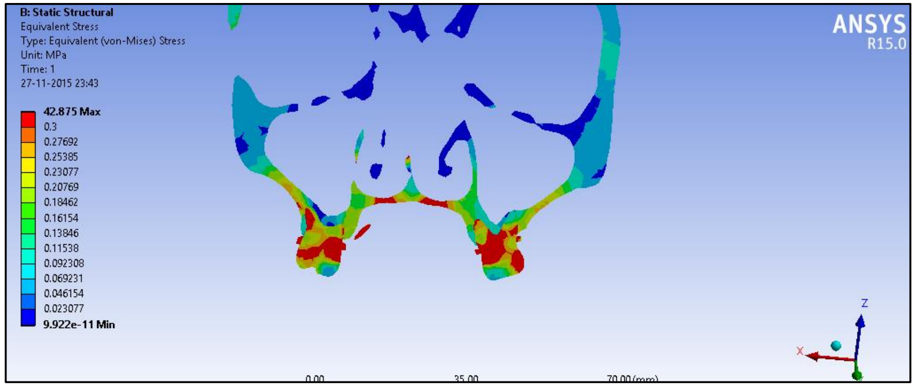
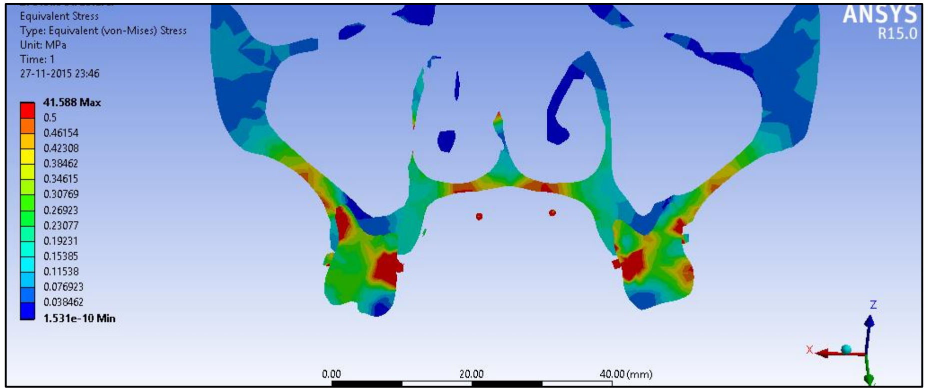


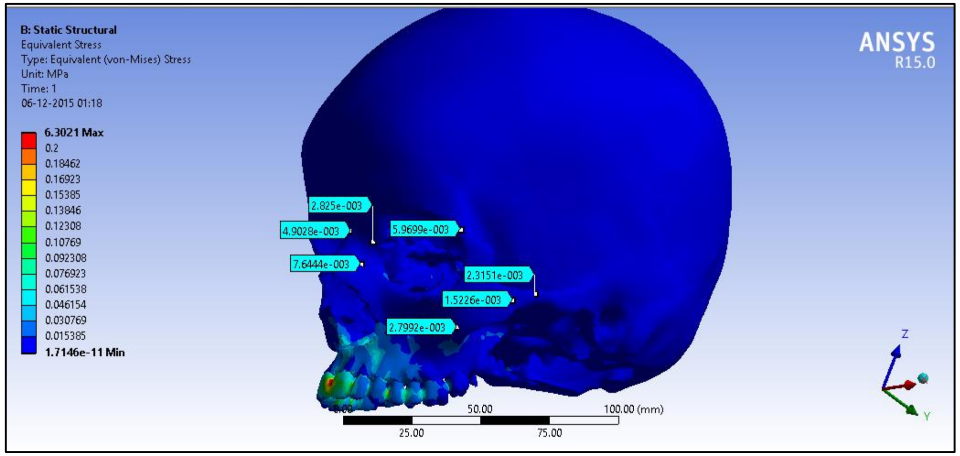
(C)



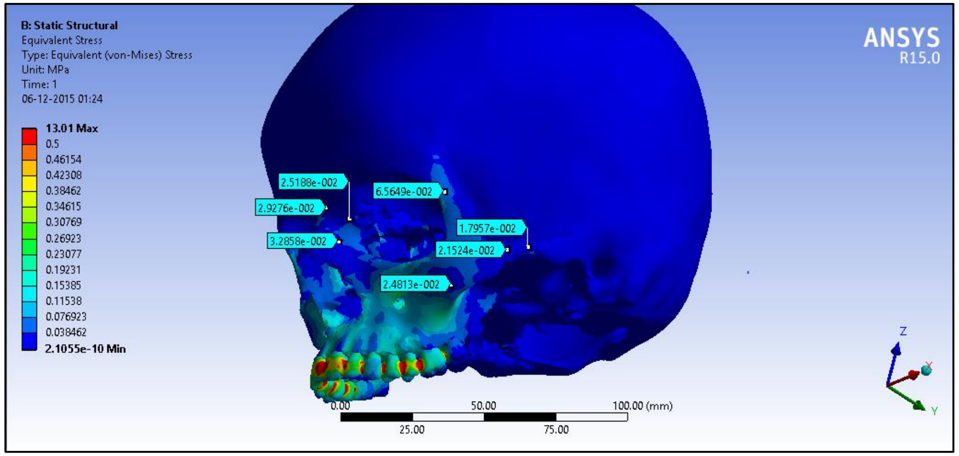
(D)

FIGURE-26 :VON-MISES STRESS DISTRIBUTION IN CIRCUMMAXILLARY SUTURES

(A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4



(A)



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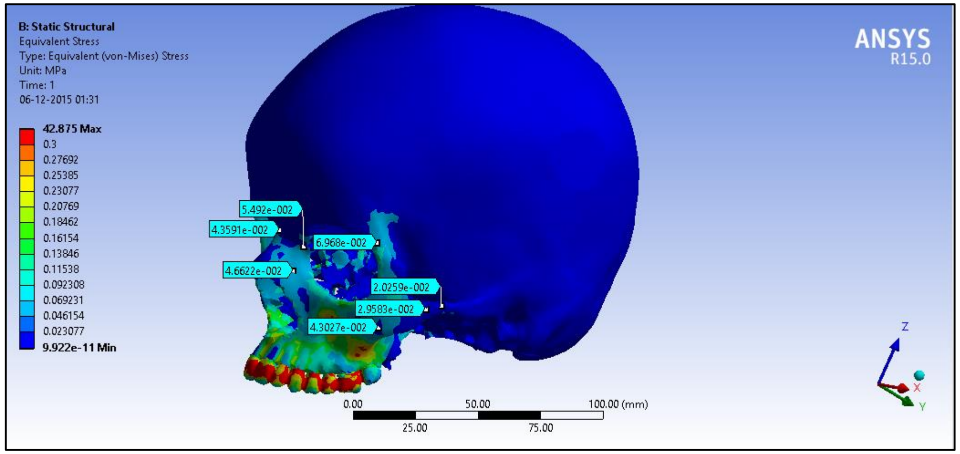
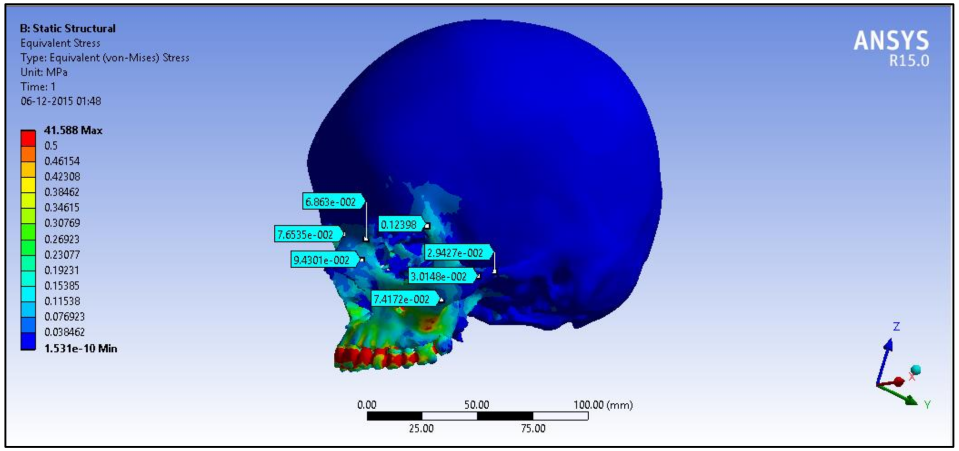


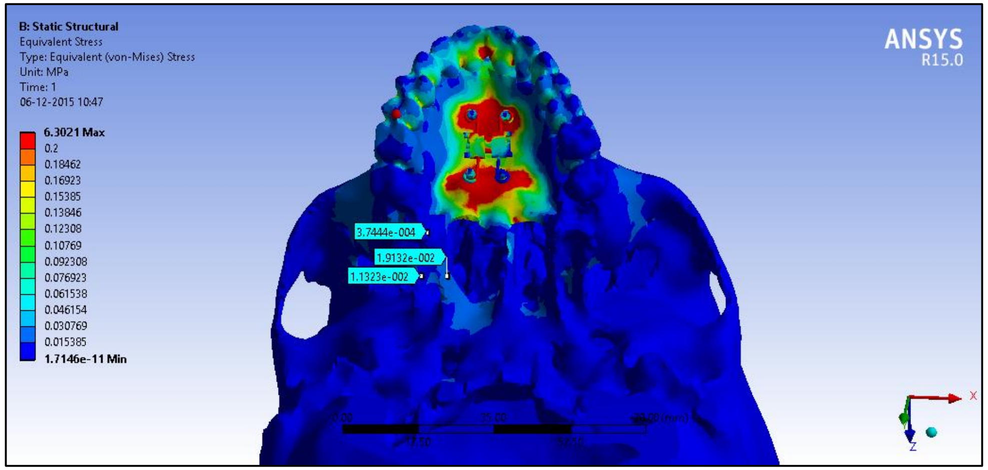
(C)



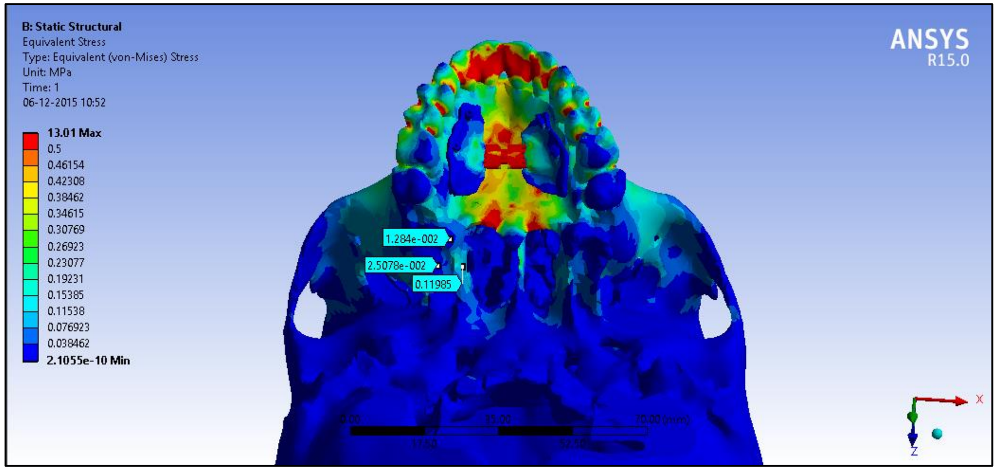
(D)

FIGURE-27 :VON-MISES STRESS DISTRIBUTION IN THE PTERYGOID PLATES

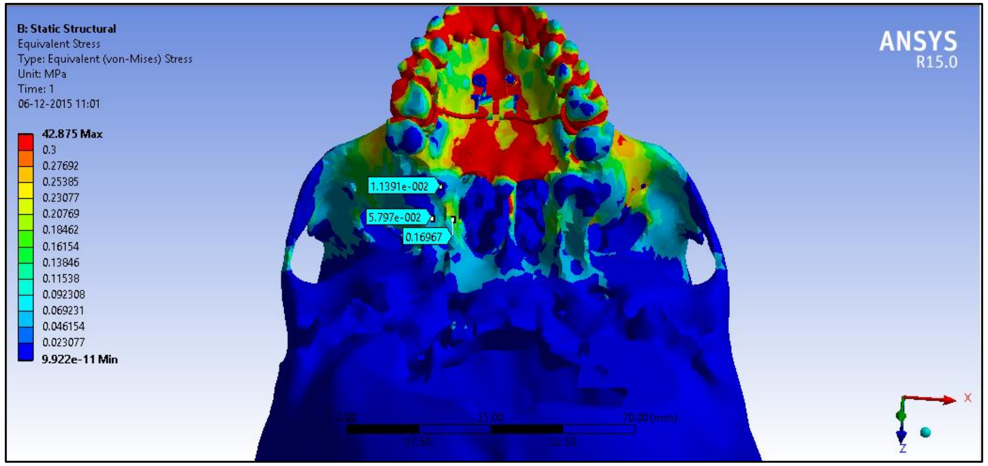
(A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4



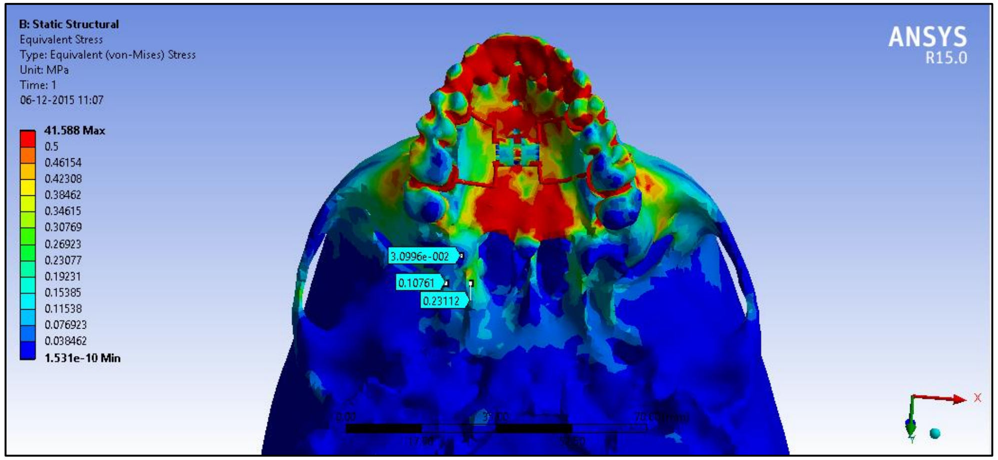
(A)



(B)

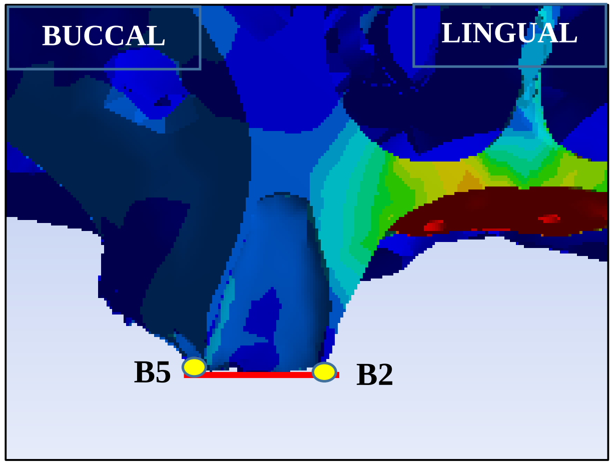


(C)

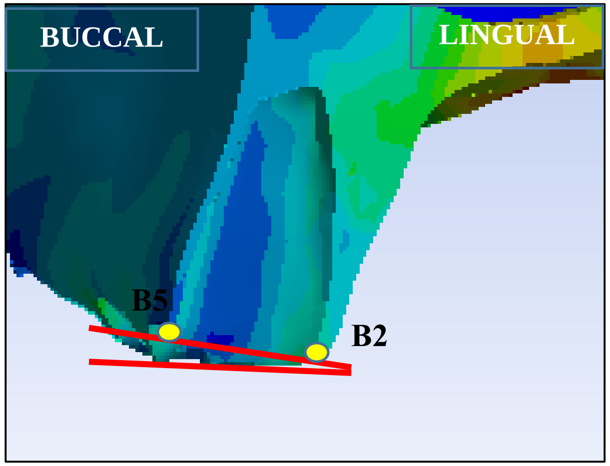


(D)

FIGURE-28 :ROTATIONAL MOVEMENT OF THE ALVEOLAR BONE IN FIRST PREMOLAR AREA (RIGHT SIDE)(A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE4



(A)



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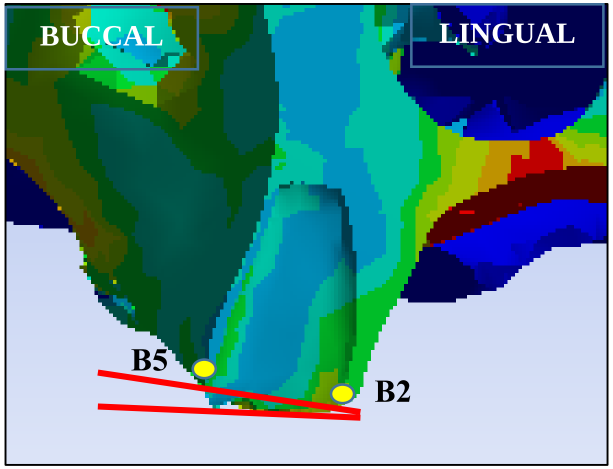

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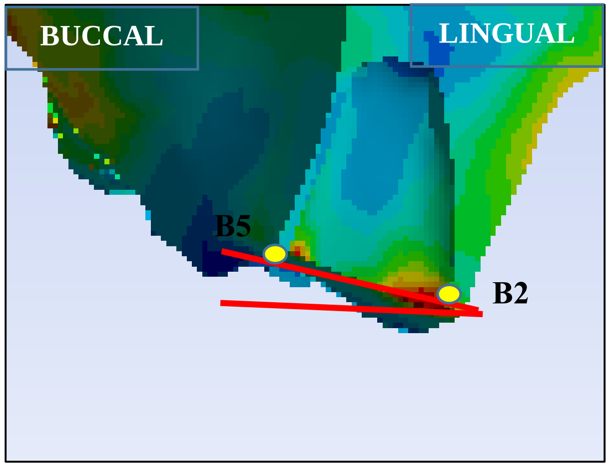
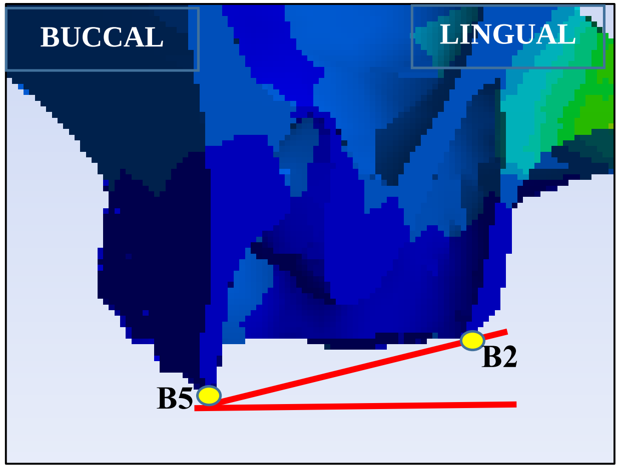
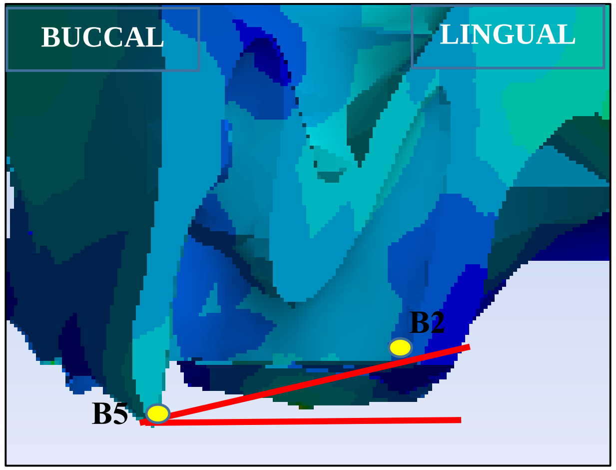


(D)

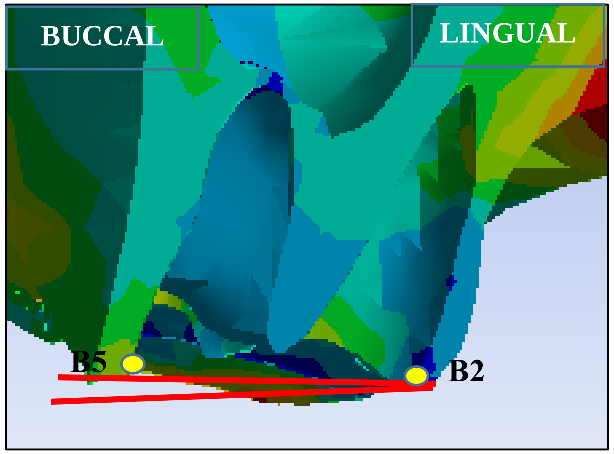
(FIGURE-29 :ROTATIONAL MOVEMENT OF THE ALVEOLAR BONE IN FIRST MOLAR AREA (RIGHT SIDE) (A)TYPE1,(B)TYPE2,(C)TYPE3,(D)TYPE



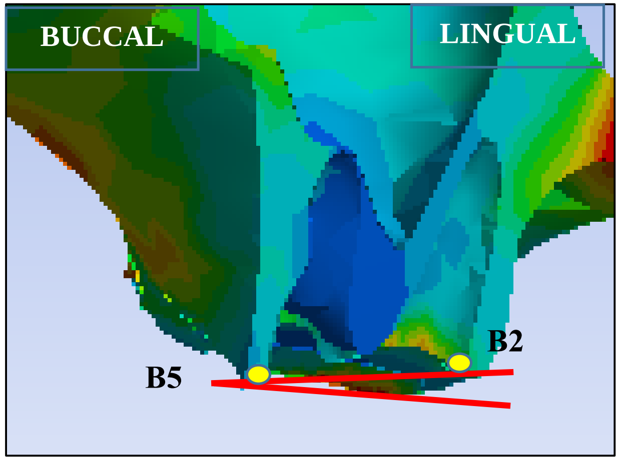
(A)



(B)



(C)



(D)

TABLE NO: 1- MATERIAL PROPERTIES AND ELEMENTS USED IN THE STUDY

S.NO	STRUCTURES	ELEMENTS AND NODES	YOUNG'SMODULUS (MPA)	POSSION'S RATIO
1.	Cortical Bone	Tetrahedral	13 700	0.30
2.	Cancellous Bone	Tetrahedral	1370	0.30
3.	Enamel	Tetrahedral	80 350	0.33
4.	Dentin	Tetrahedral	19 890	0.31
5.	Suture	Tetrahedral	10	0.49
6.	Titanium	Tetrahedral	113 000	0.33
7.	Resin	Tetrahedral	2 000	0.30

TABLE NO : 2 -NODES AND ELEMENTS OF EACH TYPE IN GROUP-A

GROUP-A	TYPE1	TYPE2	TYPE3	TYPE4
NODES	90087	109842	91847	94190
ELEMENTS	322235	401132	326383	333187

TABLE NO :3 -NODES AND ELEMENTS OF EACH TYPE IN GROUP-B

GROUP-B	TYPE1	TYPE2	TYPE3	TYPE4
NODES	85210	87571	86989	88075
ELEMENTS	294351	301558	299621	301703

Results

RESULTS

STRESS DISTRIBUTION: (GROUP-A)

Type1 showed that high stress was concentrated around miniscrew implants (Fig-10A). **In the mid-palatal suture** region, more stress was concentrated in between 1st and 2nd premolar regions followed by 2ndpremolar and 1stmolar and distal to canine with the maximum of **0.63975 MPa (Table-4, Graph-1). In cross section** the depth of penetration of maximum stress was more in the mid-palatal suture and minimum stress were observed around the roots **(Fig-10B).** Weaker stresses were distributed through the lingual alveolar bone of 1st premolar and 1st molar regions **(Fig-14A,15A)**. Weaker stresses were observed in the **circumaxillary sutural area,** among the sutures greater stress were observed in lateral pterygoid plate, medial pterygoid plate(Fig-17A) followed by zygomaticofrontal suture, zygomaticomaxillary suture, nasofrontal suture, zygomatic arch, frontomaxillary suture, nasomaxillary suture, zygomaticotemporal suture and pterygoid hamulus **(Fig-16A), (Table-5,Graph-2).**

Type2 showed that more stress was concentrated around the miniscrew implants **(Fig-11A). In the mid-palatal suture** region, more stress was concentrated in the premolar and canine region followed by first molar region with the maximum of **0.33555 MPa (Table-4,Graph-1). In cross section** the depth of penetration of stress was comparatively less in mid-palatal suture area and minimum stress were observed around the roots **(Fig-11B).** Moderate stresses were distributed through the lingual alveolar bone of the premolar and molar region **(Fig-14B,15B).**

In the circumaxillary sutural area, moderate amount of stress was concentrated in the medial pterygoid plate **(Fig-17B),** zygomaticofrontal suture, zygomaticomaxillary suture followed by nasofrontal suture, zygomaticarch, lateral pterygoid, frontomaxillary suture, nasomaxillary suture, zygomaticotemporal suture and pterygoid hamulus**.(Fig-16B), (Table-5,Graph-2).**

Type3 showed that high stress was concentrated around miniscrew implants in the anterior region **(Fig-12A). In the mid-palatal suture** region, more stress was concentrated in the premolar region followed by molar and canine region, with the maximum of **0.75947 MPa (Table-4,Graph-1). In cross section** the depth of penetration of maximum stress was more in the mid-palatal suture at the level of premolar region **(Fig-12B)** and moderate amount of stress were observed around the roots of molar teeth. Stronger amount of stresses were distributed through the lingual alveolar bone of the molar and premolar region **(Fig-14C,15C).**

In the circumaxillary suture region, stronger stress were observed in zygomaticofrontal suture, medial pterygoid plate **(Fig-17C)** nasofrontal suture followed by lateral pterygoid plate, frontomaxillary suture, nasomaxillary suture, zygomaticomaxillary suture, zygomaticotemporal suture, zygomatic arch and pterygoid hamulus (Fig-16C,Graph-5) with the maximum of **0.042562 MPa (Table-5,Graph-2).**

Type4 showed moderate amount of stress in the **mid-palatal region**, more in the canine followed by premolar and molar region, **(Fig-13A)** with the maximum of **0.38366Mpa (Table-4,Graph-1). In the cross section** depth of penetration of maximum stress in the mid-palatal suture were found to be minimum, stronger amount of stress were observed around the roots of premolar and molar tooth (**Fig-13B).** Moderate amount of stress were distributed through the lingual alveolar bone of premolar and molar region **(Fig-14D, 15D).**

In the circumaxillary suture region, higher level of stress were observed in medial pterygoid plate (Fig-17D), nasomaxillary suture, nasofrontal suture, followed by pterygoid hamulus, lateral pterygoid plate, zygomaticomaxillary suture, zygomaticofrontal suture, frontomaxillary suture, zygomaticotemporal suture, pterygoid hamulus and zygomatic arch **(Fig-16D)** with the maximum of **0.059402 MPa (Table-5, Graph-2).**

DISPLACEMENT OF THE ALVEOLAR BONE

(Tables 6-13) & (Graphs 3-10), represent the amount of 3D displacement of alveolar bone reference points at the **canine and first molar regions** respectively.

Types 1 and 2 showed forward displacement on the **x-axis**. In types 3 and 4 backward displacement of the alveolar bone was noticed, particularly in the premolar and first molar region **(Graph-11 & 15).**

In all types, the outward movement on the **y-axis** of anterior part was greater than posterior. However types 3 and 4 showed increased amount of displacement at the first premolar area. **(Graph-12 & 16).**

The lingual alveolar bone showed inferior displacement on the **z-axis** in all types. In type3 the buccal alveolar bone showed superior displacement in the anterior and inferior displacement in the posterior area **(Graph-13 & 17).**

The total displacement was larger in types 3 and 4 whereas the type1 showed the least total displacement for all teeth **(Graph-14 &18).**

The rotation of the line connecting the **buccal (B5) and lingual alveolar crest (B2)** at the 1st premolar region were larger in type 4 compared with other groups **(Fig-18D).** At the molar region it was larger in type3 and 4 and the least was in type1 **(Fig-19C, D & A),** which revealed a relatively parallel movement in type2 and type1 **(Fig-19B).**

DISPLACEMENT OF THE TEETH

(Tables 6-13) & (Graphs 3-10), represent the amount of 3D displacement of dental reference points at the **canine and first molar** regions respectively.

In type1, since the frontomaxillary suture was the center of rotation, palatal halves were displaced transversely with more expansion of the inferior part. The displacement of teeth followed the buccal rotational movement of the alveolar bone.

However**, type 2** showed parallel separation of the mid-palatal suture.

Type 3 showed more buccal rotation of the dentition in addition to the buccal rotational movement of the alveolar bone.

In **type 4** displacement of the teeth occurred first, then the transformation of the periodontal ligament and small amount of deformation of the alveolar bone **(Fig-18,19-D).** The change in alveolar bone was less than that in type3**. (Fig-18,19-C)**

In the constricted arch width model (Group-B) the concentration of **stress (Fig: 20-27), (Tables-14,15) & (Graph-19,20)** and the amount of **displacement (Tables: 16- 23,Graphs-21-36)** in all the types showed similar trend like Group-A. But the **magnitude was increased because of the increase in the depth of the palate**.

TABLE-4.STRESS DISTRIBUTION IN THE MIDPALATAL SUTURE (units in MPa)

GROUP-A STRESS PATTERN IN MIDPALATE SUTURE	TYPE1	TYPE2	TYPE3	TYPE4
DISTAL TO CANINE	0.067709	0.31408	0.21191	0.38366
BETWEEN 1ST&2ND PREMOLAR	0.63975	0.33555	0.75947	0.3329
BETWEEN 2ND &1ST MOLAR	0.12888	0.23137	0.28651	0.16008

GRAPH-1.STRESS DISTRIBUTION IN MIDPALATAL SUTURE

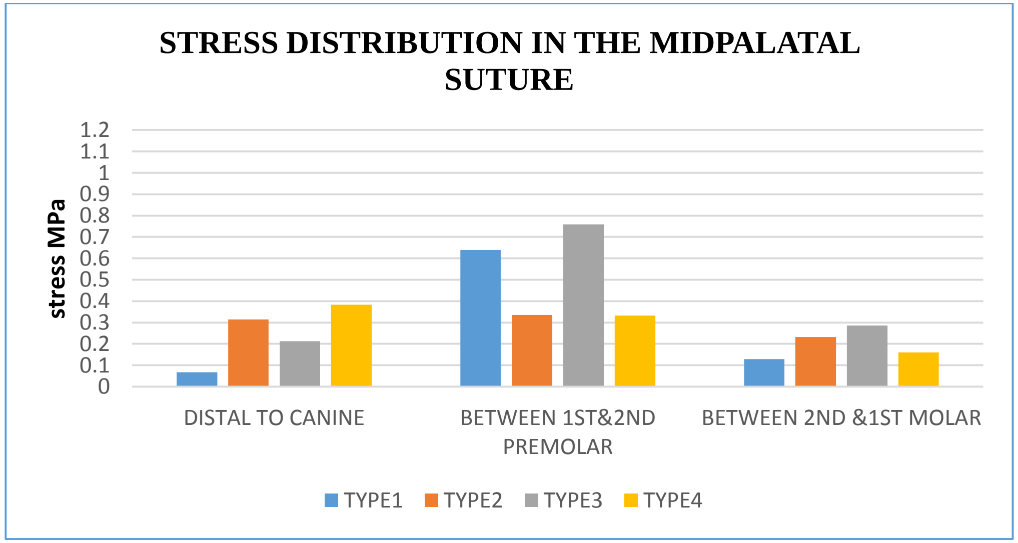


TABLE-5..STRESS DISTRIBUTION IN CIRCUMMAXILLARY SUTURES(units in MPa)

GROUP-A CIRCUM MAXILLARY SUTURES STRESS DISRTRIBTN	TYPE1	TYPE2	TYPE3	TYPE4
NASOFRONTAL SUTURE	0.0026348	0.015023	0.023968	0.031032
FRONTOMAXILLARY SUTURE	0.0012907	0.0078309	0.018805	0.027089
NASOMAXILLARY SUTURE	0.0012658	0.0050558	0.017159	0.039419
ZYGOMATICOFRONTAL SUTURE	0.0047774	0.027153	0.042562	0.029638
ZYGOMATICOMAXILLARY SUTURE	0.0028602	0.022052	0.014885	0.0307
ZYGOMATICOTEMPORAL SUTURE	0.0010408	0.003647	0.0161	0.022106
ZYGOMATIC ARCH	0.0024681	0.0091787	0.0056393	0.0095313
PTERYGOID HAMULUS	0.000029034	0.00016346	0.0010221	0.020528
LATERAL PTEYGOID PLATE	0.005118	0.0085125	0.021949	0.029313
MEDIAL PTERYGOID PLATE	0.0041303	0.028335	0.033272	0.059402

GRAPH-2.STRESS DISTRIBUTUION IN CIRCUMMAXILLARY SUTURES

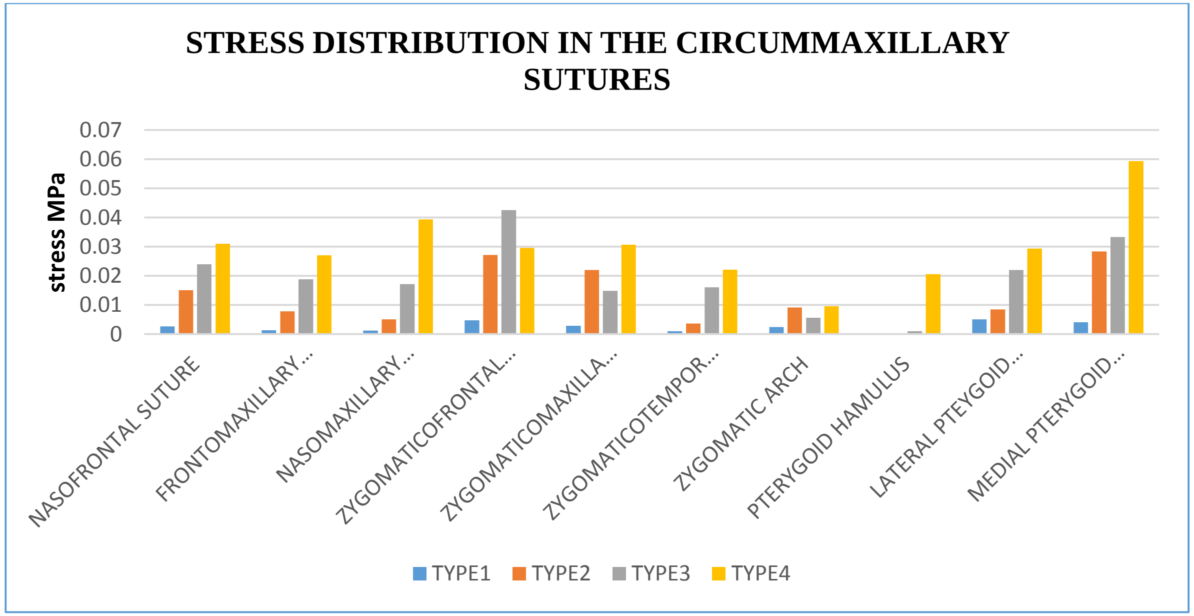


TABLE-6.DISPLACEMENT OF THE CANINE REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE ANTERO-POSTERIOR (*X*) DIRECTION.(units in mm)

GROUP-A DISPLACEMENT OF CANINE REFERENCE POINTS(X-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.ALV.CREST(B1)	0.000030172	0.000068879	-0.00041127	-0.0003416
SOCKET(B2)	0.000030129	0.00012308	-0.0002393	-0.00015501
BUCC.ALV.CREST(B3)	0.000051544	0.0002381	-0.00023573	-0.00022715
CUSPTIP(T1)	0.00005571	0.00022787	-0.00037576	-0.00054222
LINGUAL CEJ(T2)	0.000030541	0.000073346	-0.00039408	-0.00065088
ROOTAPEX(T3)	0.000014387	0.00010148	-0.00020071	-0.00019525
BUCCAL CEJ(T4)	0.000046254	0.00022006	-0.0002201	-0.0002672

GRAPH-3. DISPLACEMENT AT CANINE REFERENCE POINTS IN X-AXIS

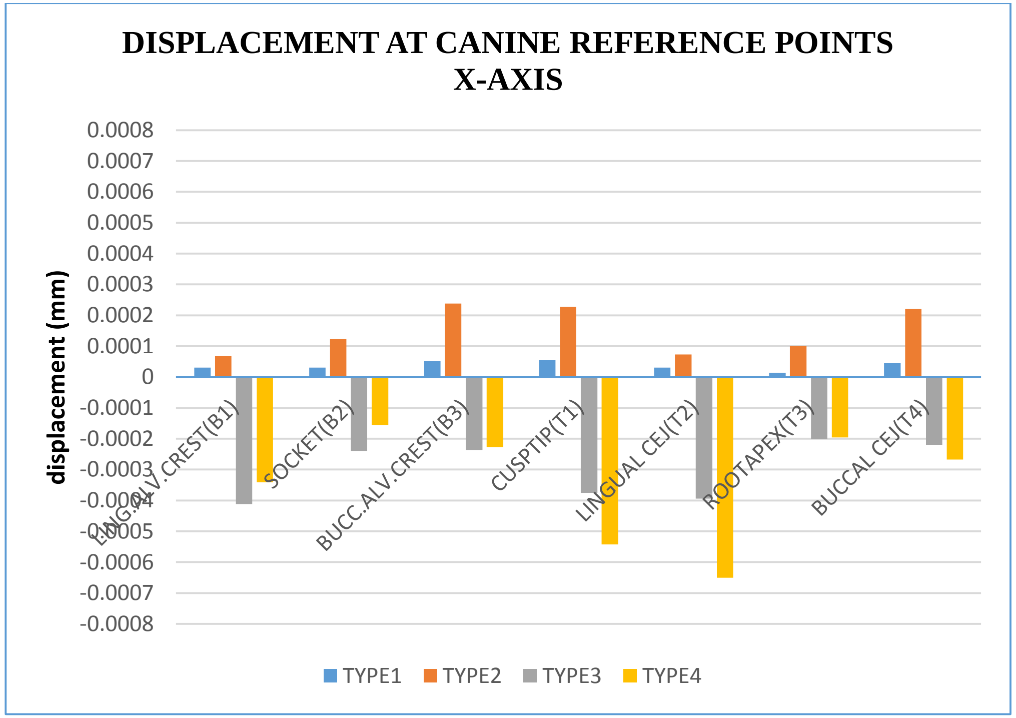


TABLE-7.DISPLACEMENT OF THE CANINE REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE, TRANSVERSE (*Y*) DIRECTION (units in mm)

REFERNCE POINTS(YAXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.ALV.CREST(B1)	6.8327E-06	0.000091601	0.00016633	0.00023864
SOCKET(B2)	-0.000013169	-7.0042E-06	0.00011265	0.00014963
BUCC.ALV.CREST(B3)	-0.000013904	-0.000073213	0.000077728	2.3169E-06
CUSPTIP(T1)	-6.7811E-06	8.4142E-06	0.00010065	0.000071668
LINGUAL CEJ(T2)	8.0765E-06	0.00010463	0.00022214	0.00033635
ROOTAPEX(T3)	-0.000010586	9.0107E-06	0.00013072	0.00017651
BUCCAL CEJ(T4)	-0.00001081	-0.00007492	0.000072968	0.00001801

GRAPH-4. DISPLACEMENT AT CANINE REFERENCE POINTS IN Y-AXIS

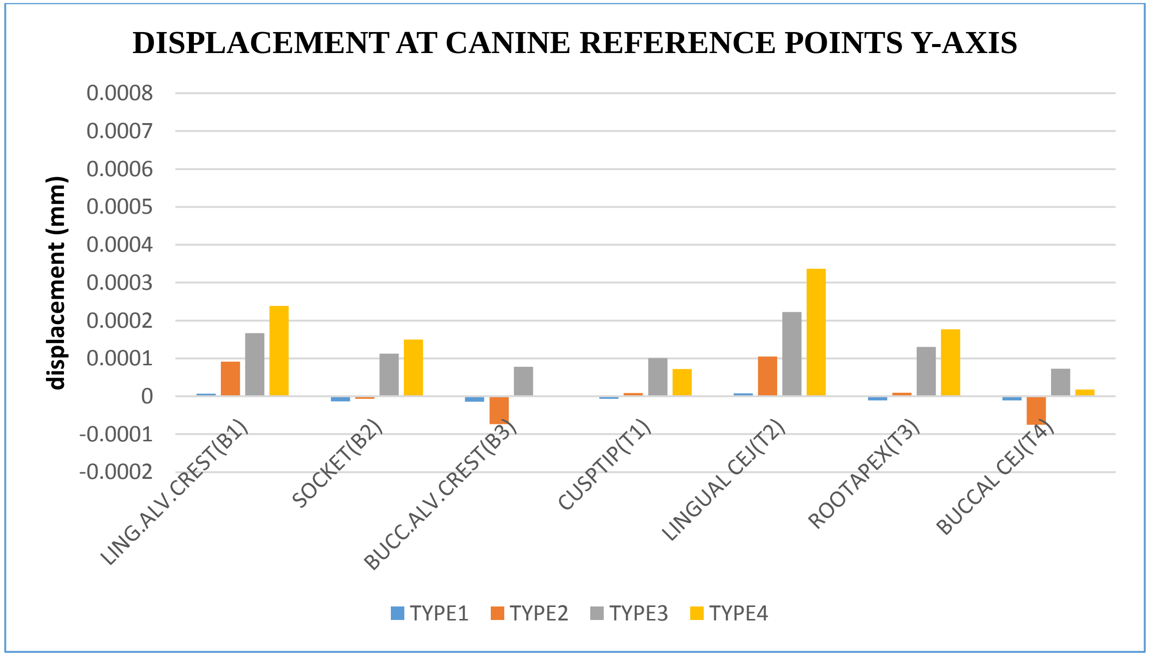


TABLE-8.DISPLACEMENT OF THE CANINE REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE VERTICAL (*Z*) DIRECTIONS.(units in mm)

REFERENCE POINTS (Z-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.ALV.CREST(B1)	6.0484E-06	-0.000019441	-0.000055982	-0.000055304
SOCKET(B2)	4.2699E-07	-0.000024713	-0.000013323	-0.000034805
BUCC.ALV.CREST(B3)	-4.7367E-06	-0.000059656	0.00015002	0.000034183
CUSPTIP(T1)	-3.9154E-06	-0.000050952	0.000008776	0.000043286
LINGUAL CEJ(T2)	5.8761E-06	-0.000025722	-0.000032312	-0.000062914
ROOTAPEX(T3)	5.5463E-06	-0.000026526	-0.0000239	-0.000046171
BUCCAL CEJ(T4)	-4.1635E-06	-0.000049843	0.000010058	0.000051534

GRAPH-5. DISPLACEMENT AT CANINE REFERENCE POINTS IN Z-AXIS

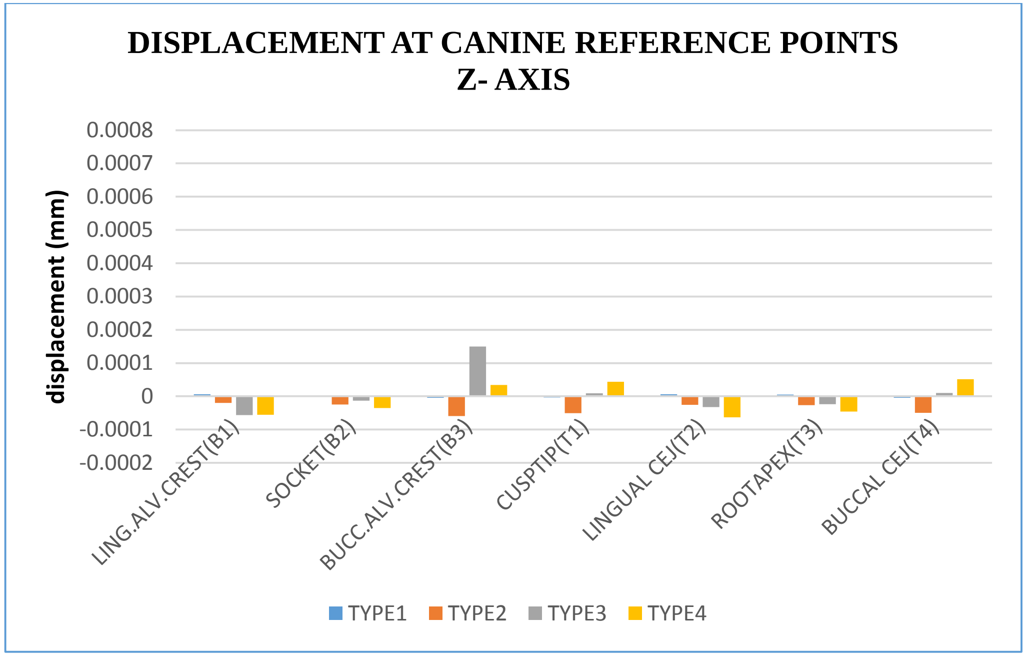


TABLE-9.DISPLACEMENT OF THE CANINE REFERENCE POINTS UNDER LOADING IN EACH TYPE IN XYZ DIRECTION (TOTAL DEFORMATION)units in mm)

REFERENCE POINTS (XYZ-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.ALV.CREST(B1)	0.000035232	0.00014767	0.0004625	0.00024285
SOCKET(B2)	0.00003245	0.00012385	0.00026042	0.00022503
BUCC.ALV.CREST(B3)	0.000055324	0.00025802	0.00023406	0.00029193
CUSPTIP(T1)	0.000056138	0.00025258	0.00038393	0.00056979
LINGUAL CEJ(T2)	0.000034633	0.00013011	0.00046349	0.00069994
ROOT APEX(T3)	0.000018123	0.00011554	0.00023925	0.00026673
BUCCAL CEJ(T4)	0.00004937	0.00021225	0.00023464	0.0004315

GRAPH-6. DISPLACEMENT AT CANINE REFERENCE POINTS IN XYZ-AXIS.

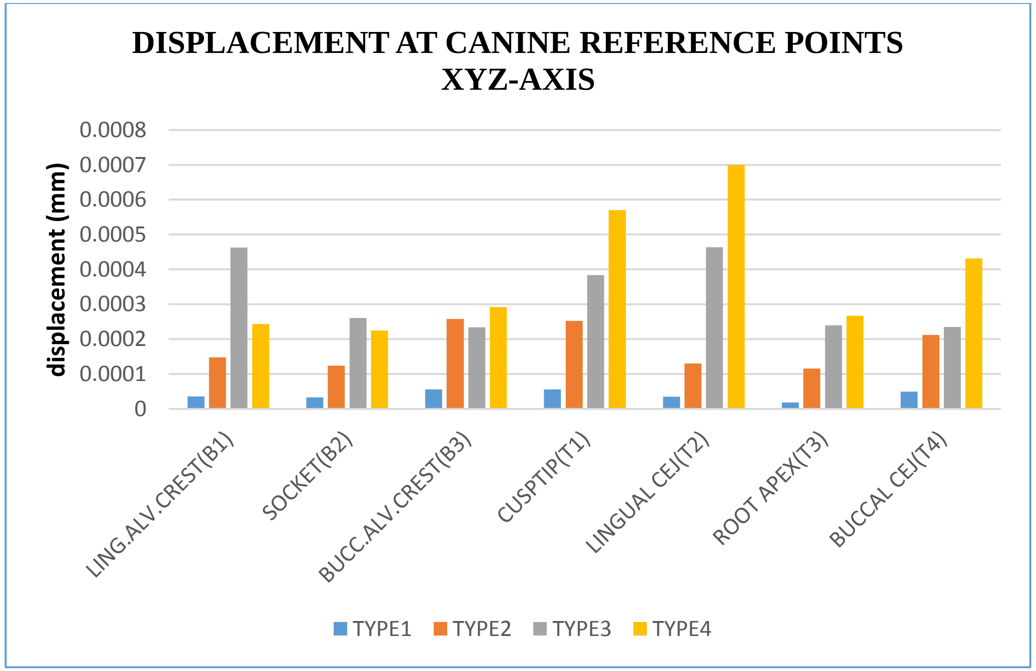


TABLE-10.DISPLACEMENT OF THE FIRST MOLAR REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE ANTERO-POSTERIOR (*X*) DIRECTION.(units in mm)

GROUP-A DISPLACEMENT OF MOLAR REFERENCE POINTS MONISHA (X-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.MID.ALV.BONE(B1)	0.000013176	-0.000076566	-0.00059102	-0.00050977
LING.ALV.BONE(B2)	-0.000012552	-0.00013532	-0.00074954	-0.0010814
LING.SOCKET(B3)	-0.000016612	-0.00010842	-0.00051175	-0.000717
MESIO BUCC SOCKET(B4)	-7.0478E-06	-0.000072005	-0.00035046	-0.00046891
BUCC.ALV.CREST(B5)	-0.000005423	-0.00015958	-0.00060626	-0.0008643
MESIO LING.CUSPTIP(T1)	-0.000010829	-0.00021384	-0.00098566	-0.0014839
LING.CEJ(T2)	-0.000014251	-0.00019696	-0.00083726	-0.0012135
LING.ROOT APEX(T3)	0.000017726	-0.00010703	-0.00042006	-0.00058085
M.B ROOT APEX(T4)	-0.00000717	-0.000061703	-0.00034659	-0.00045255
BUCCAL CEJ(T5)	-8.1913E-06	-0.00016107	-0.00073403	0.001064

GRAPH-7. DISPLACEMENT AT FIRST MOLAR REFERENCE POINTS IN X-AXIS

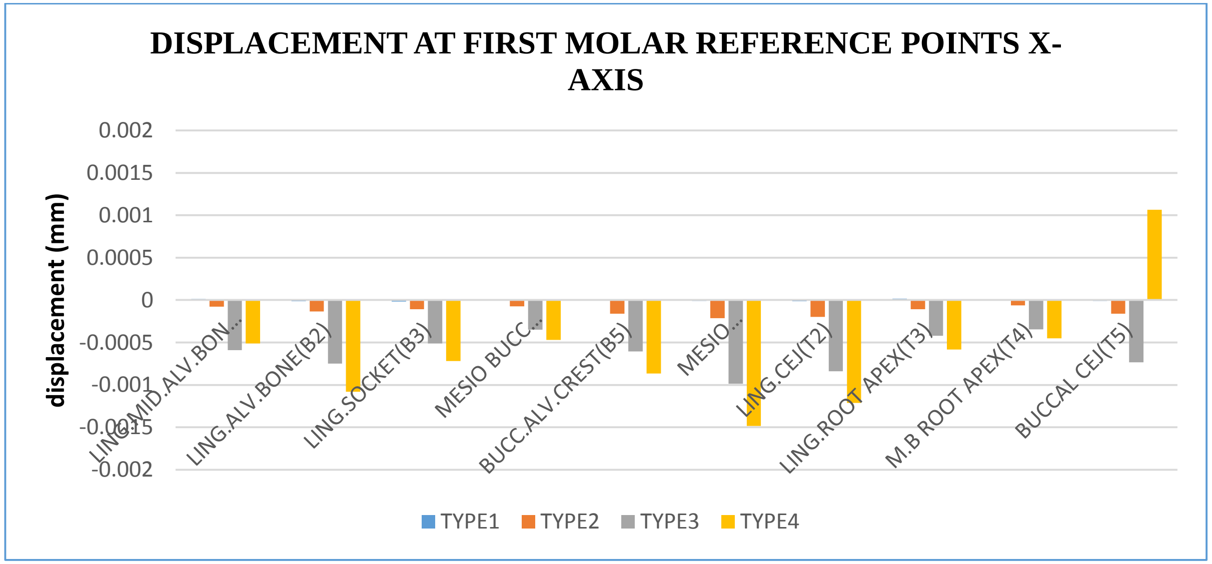


TABLE-11.DISPLACEMENT OF THE FIRST MOLAR REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE TRANSVERSE (*Y*) DIRECTIONS(units in mm)

REFERENCE POINTS (Y-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.MID.ALV.BONE(B1)	-0.000013539	-0.000047892	0.000065194	0.000043033
LING.ALV.BONE(B2)	-0.000018637	-0.000075642	8.0752E-06	-0.000012693
LING.ALV.BONE(B2)	-0.000020042	-0.000069283	0.000017725	-0.000016989
MESIO BUCC SOCKET(B4)	-0.000028836	-0.000012618	-0.000067009	-0.00013695
BUCC.ALV.CREST(B5)	-0.000033215	-0.00017237	-0.00013607	-0.00023444
MESIO LING.CUSPTIP(T1)	-0.000022637	-0.00013755	-0.000090164	-0.00022348
LING.CEJ(T2)	-0.000018448	-0.00010373	-2.3723E-06	-0.000066622
LING.ROOT APEX(T3)	-0.000016077	-0.000062716	0.000063727	0.000071364
M.B ROOT APEX(T4)	-0.000028958	-0.00012947	0.000058815	-0.00013535
BUCCAL CEJ(T5)	-0.000032397	-0.00017055	-0.00017895	-0.0003101

GRAPH-8. DISPLACEMENT AT FIRST MOLAR REFERENCE POINTS IN Y-AXIS

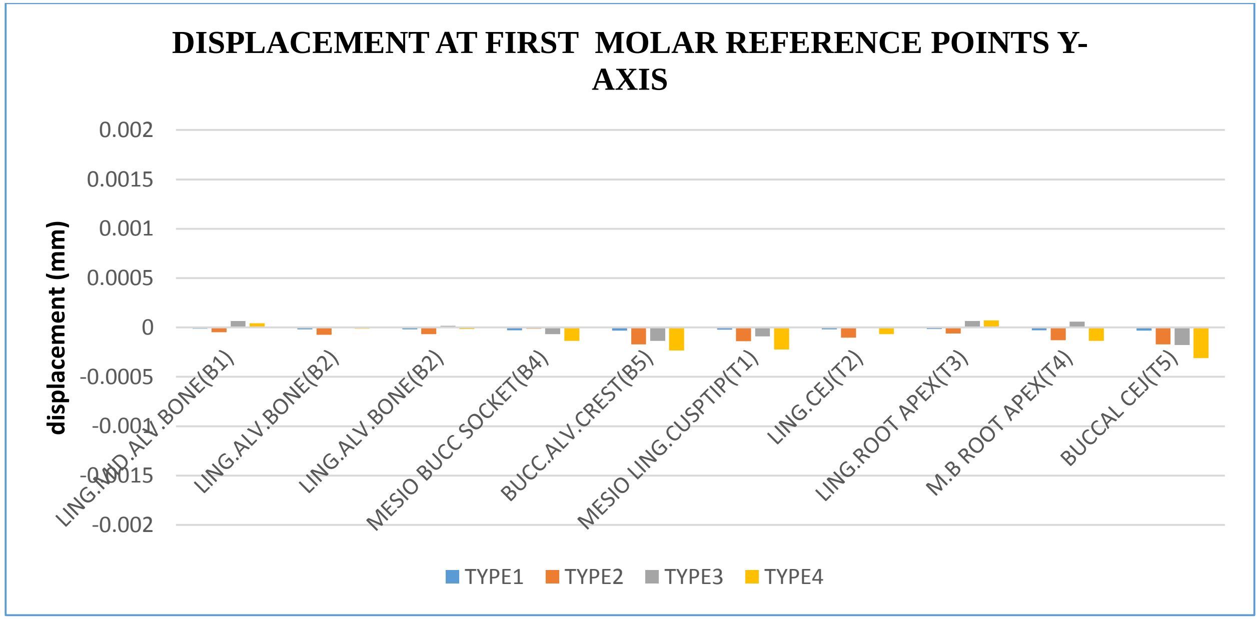


TABLE-12.DISPLACEMENT OF THE FIRST MOLAR REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE VERTICAL (*Z*) DIRECTIONS units in mm)

REFERENCE POINTS (Z-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.MIDALV.BONE(B1)	8.7419E-06	-0.000025708	-0.000080531	-0.00014018
LING.ALV.CREST(B2)	6.4178E-06	-8.5599E-06	-0.000013014	-6.8529E-06
LING.SOCKET(B3)	6.1509E-06	-5.3125E-06	-0.000029731	-0.000025413
MESIO BUCC.ALV.CREST(B4)	2.9341E-06	-0.000044428	-0.0002373	-0.00040428
BUCC.ALV.CREST(B5)	0.000002377	-0.000071146	-0.00028202	-0.00048594
MESIO LING.CUSP TIP(T1)	4.6233E-06	-5.8259E-06	-0.000085682	0.00011801
LING.CEJ(T2)	6.2293E-06	-0.00010973	-0.000024802	0.00001155
LING ROOT APEX(T3)	8.2323E-06	-0.000021528	-0.000041764	-0.000081509
M.B ROOT APEX(T4)	0.000002973	-0.00005592	-0.00022783	0.00039982
BUCCAL CEJ(T5)	0.000002562	-0.00006502	0.00029782	0.00049786

GRAPH-9. DISPLACEMENT AT FIRST MOLAR REFERENCE POINTS IN Z-AXIS

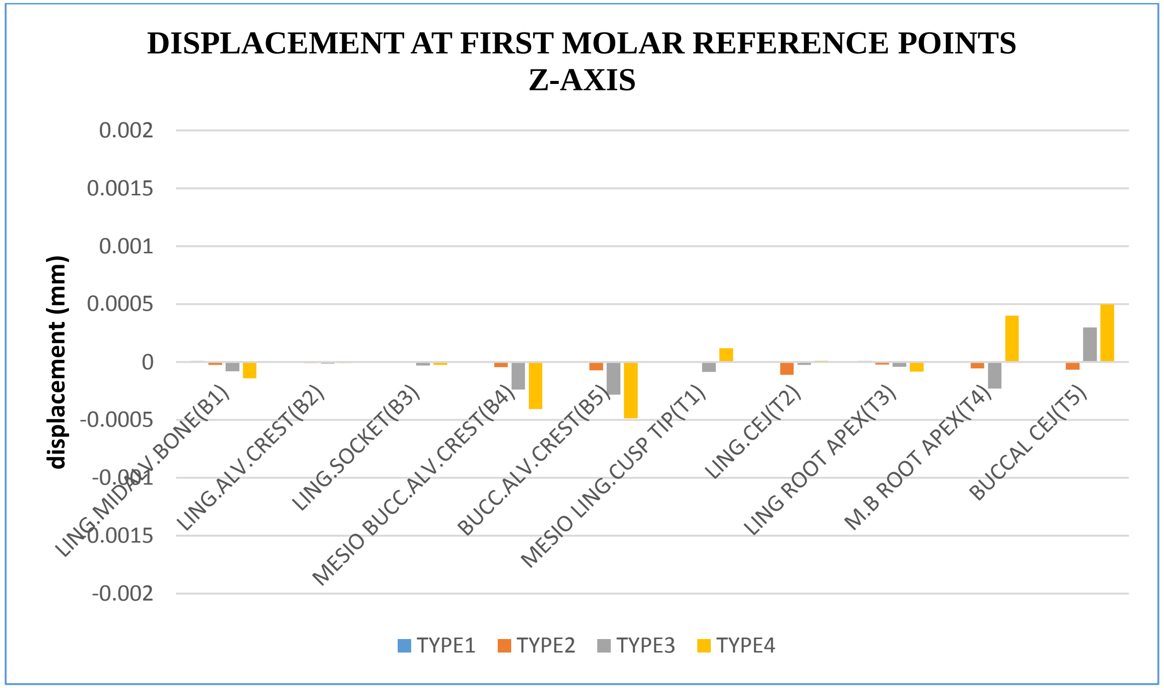
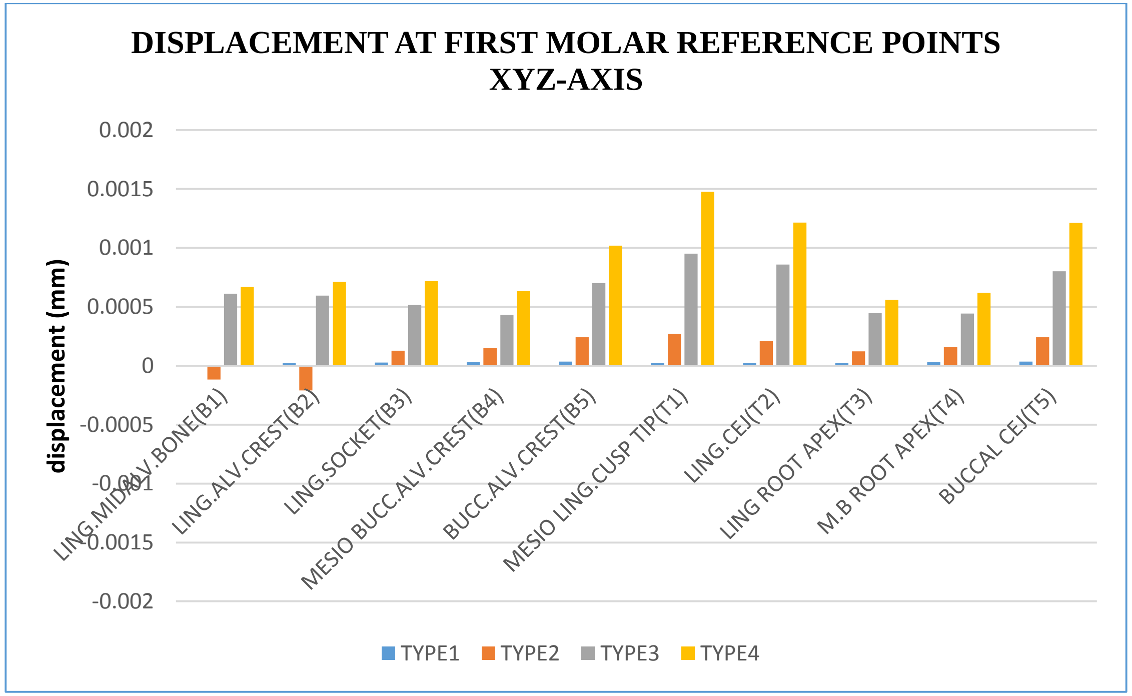


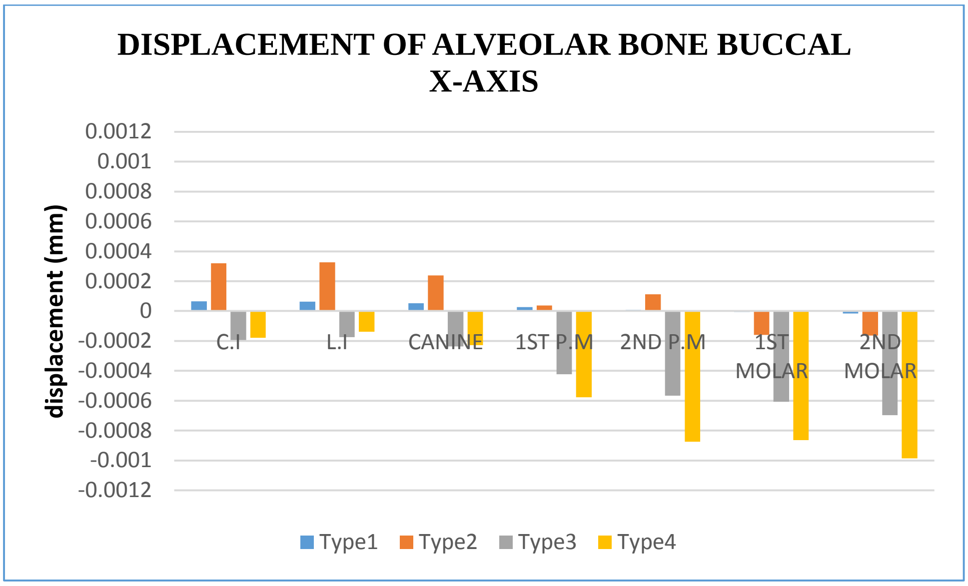
TABLE-13.DISPLACEMENT OF THE FIRST MOLAR REFERENCE POINTS UNDER LOADING IN EACH TYPE IN XYZ DIRECTION(TOTAL DEFORMATION(units in mm)

REFERENCE POINTS (XYZ AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.MIDALV.BONE(B1)	0.00002I797	-0.00011734	0.00061079	0.00066915
LING.ALV.CREST(B2)	0.000022517	-0.00020837	0.00059562	0.00071292
LING.SOCKET(B3)	0.000026453	0.00012816	0.00051604	0.00071791
MESIO BUCC.ALV.CREST(B4)	0.000029779	0.00015309	0.00043289	0.00063353
BUCC.ALV.CREST(B5)	0.000034145	0.00024215	0.00069992	0.0010194
MESIO LING.CUSP TIP(T1)	0.000024402	0.00027088	0.00095154	0.0014766
LING.CEJ(T2)	0.000022903	0.00021056	0.00085811	0.0012138
LING ROOT APEX(T3)	0.000025053	0.00012091	0.0004469	0.00055885
M.B ROOT APEX(T4)	0.000029784	0.0001573	0.0004436	0.00062039
BUCCAL CEJ(T5)	0.000033781	0.00024141	0.00080049	0.0012127

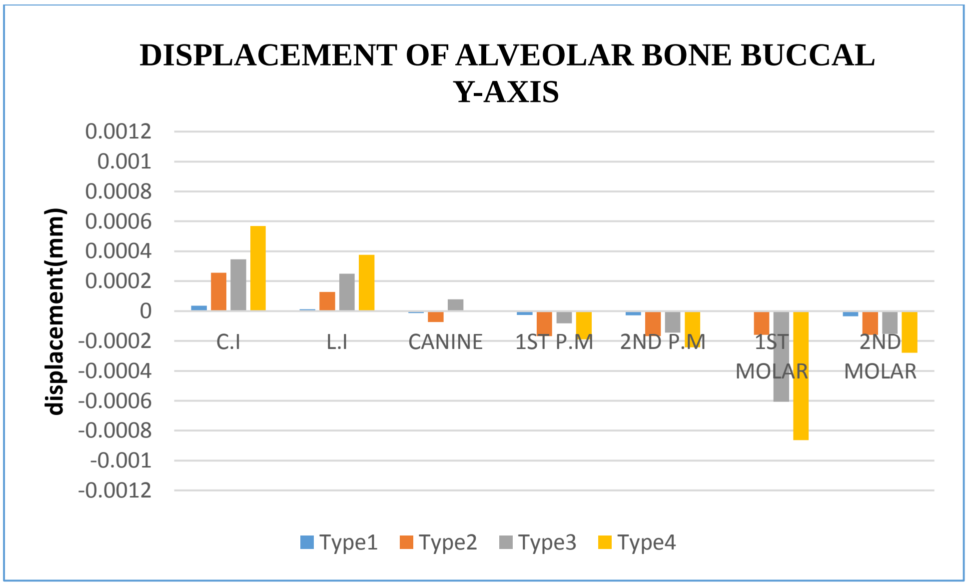
GRAPH-10. DISPLACEMENT AT FIRST MOLAR REFERENCE POINTS IN XYZ-AXIS



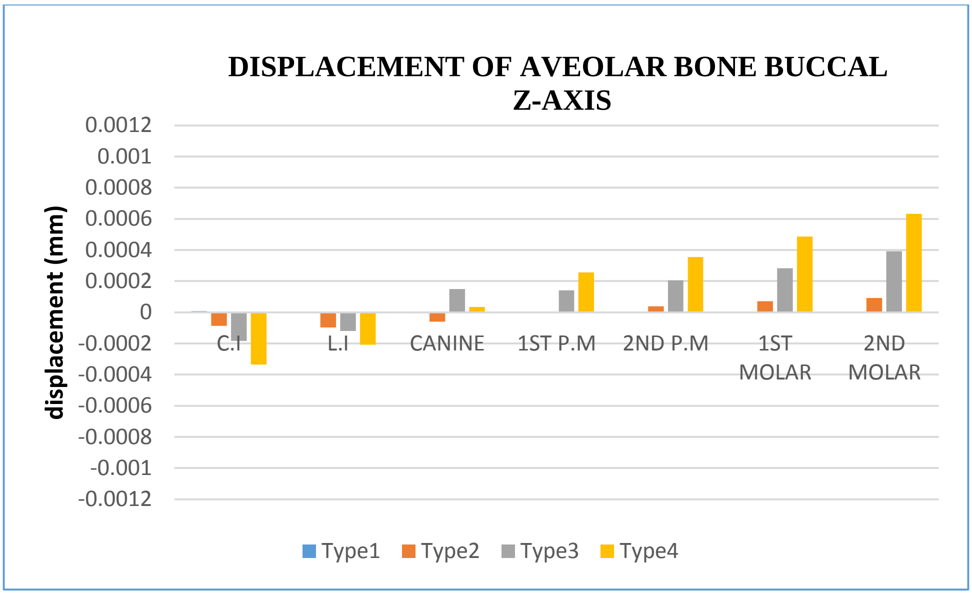
GRAPH-11.DISPLACEMENT OF ALVEOLAR BONE BUCCAL IN X- AXIS



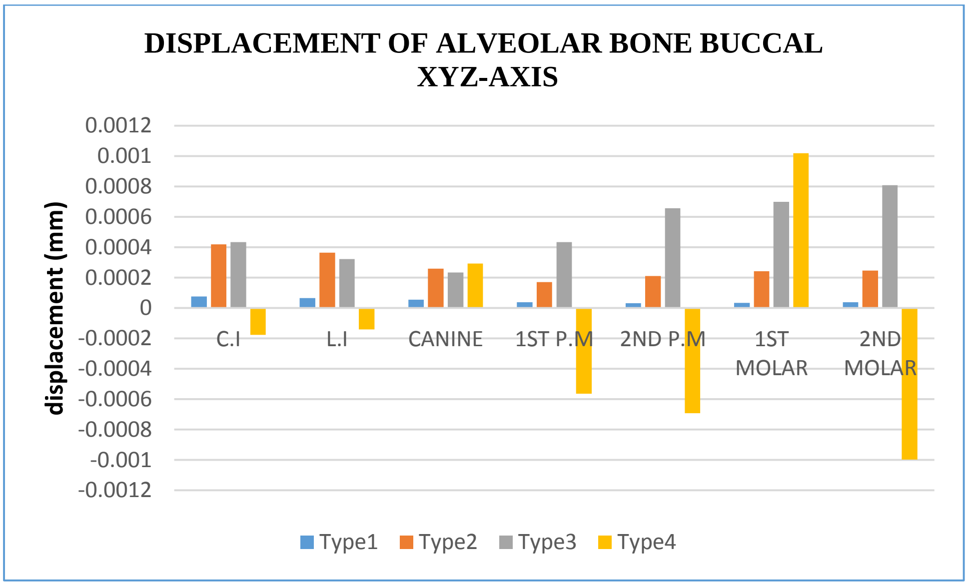
GRAPH-12. .DISPLACEMENT OF ALVEOLAR BONE BUCCAL IN Y- AXIS



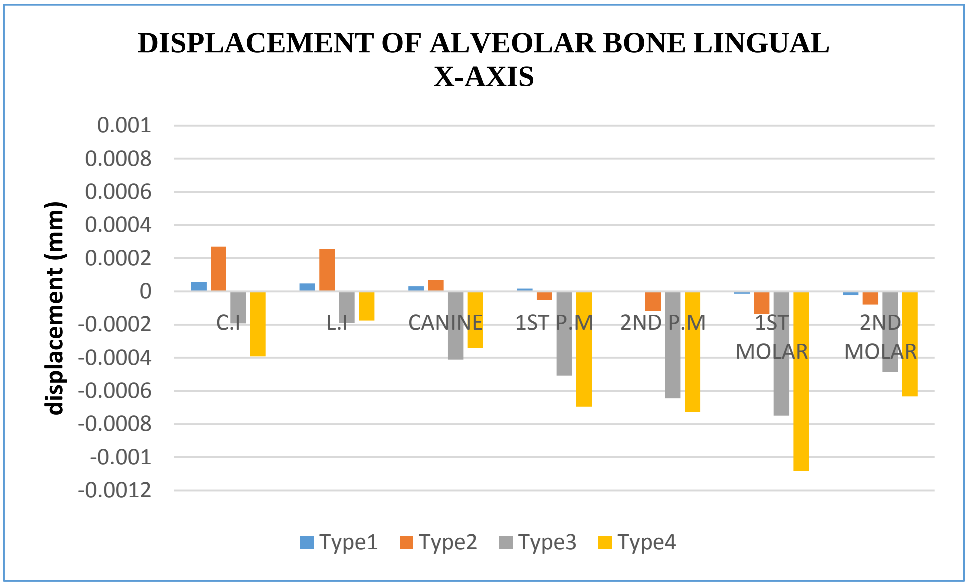
GRAPH-13.DISPLACEMENT OF ALVEOLAR BONE BUCCAL IN Z- AXIS



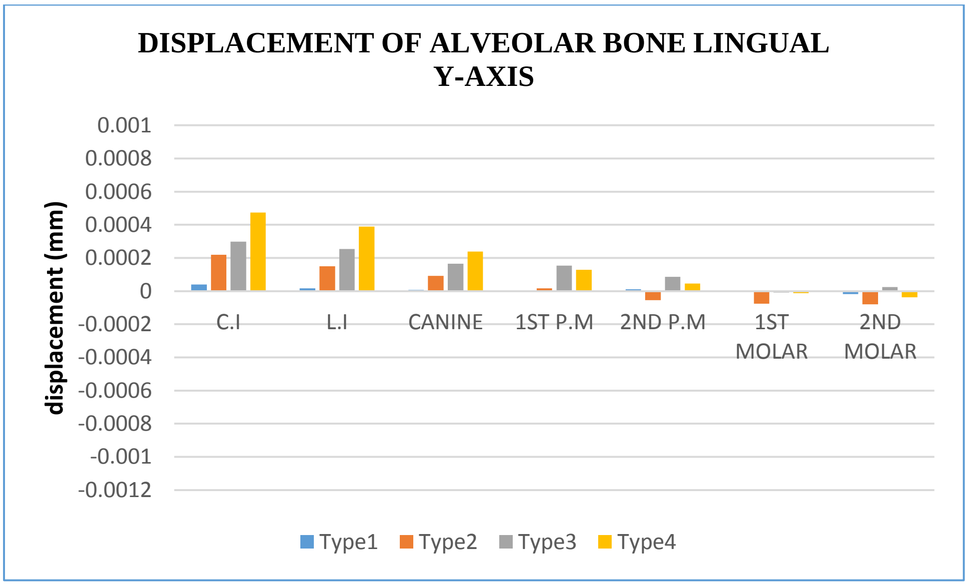
GRAPH-14.DISPLACEMENT OF ALVEOLAR BONE BUCCAL IN XYZ-AXIS



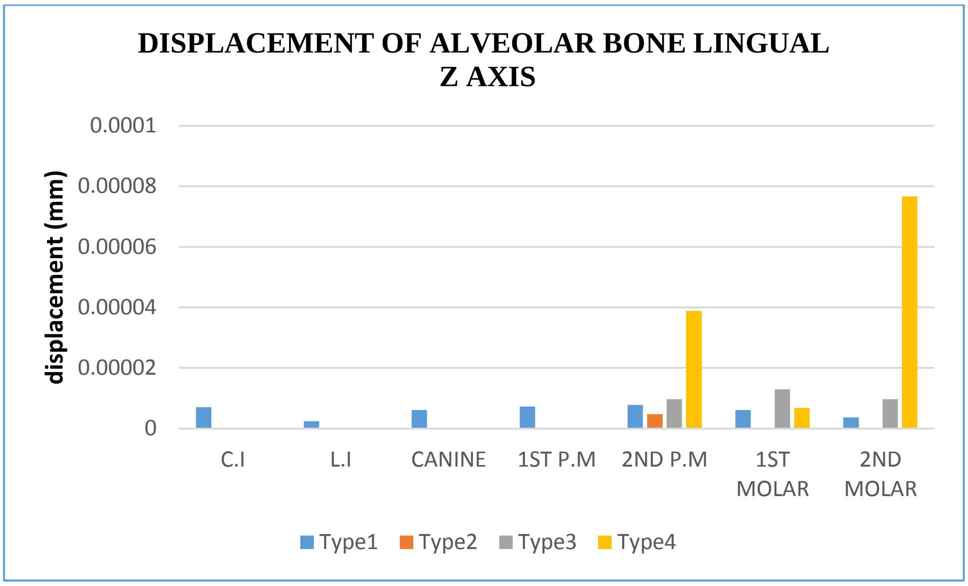
GRAPH-15.DISPLACEMENT OF ALVEOLAR BONE LINGUAL IN X –AXIS



GRAPH-16.DISPLACEMENT OF ALVEOLAR BONE LINGUAL IN Y –AXIS



GRAPH-17.DISPLACEMENT OF ALVEOLAR BONE LINGUAL IN Z –AXIS



GRAPH-18.DISPLACEMENT OF ALVEOLAR BONE LINGUAL IN XYZ –AXIS.

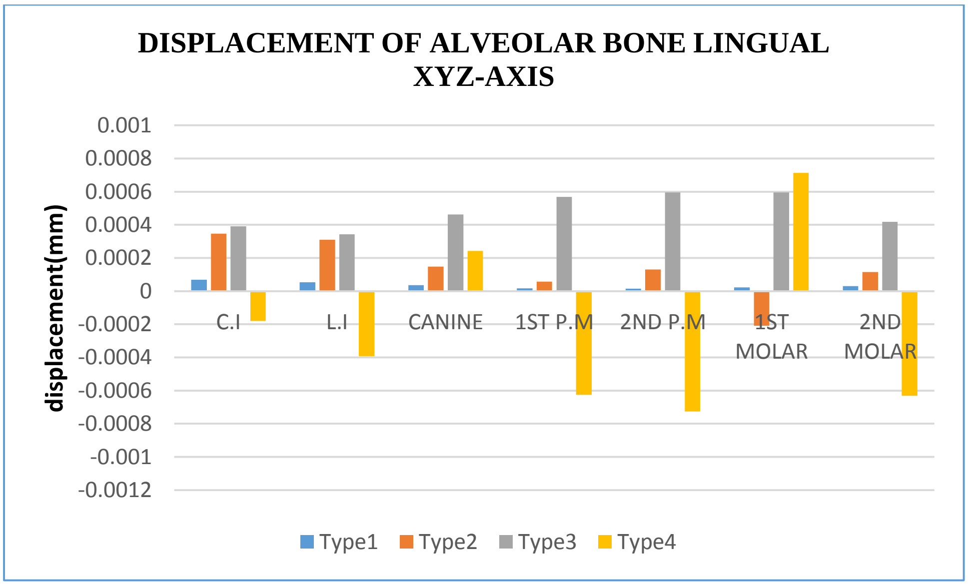


TABLE-14.STRESS DISTRIBUTION IN THE MIDPALATAL SUTURE (units in MPa)

GROUP-BSTRESS DISTRIBUTION IN MIDPALATAL RAPHE	TYPE1	TYPE2	TYPE3	TYPE4
DISTAL TO CANINE	0.31933	0.34694	0.33657	0.80014
BETWEEN 1ST &2ND PREMOLAR	0.51328	0.52201	1.0355	0.55694
BETWEEN 2ND PREMOLAR &1ST MOLAR	0.14834	0.40233	0.35006	0.048777

GRAPH-19.STRESS DISTRIBUTION IN MIDPALATAL SUTURE

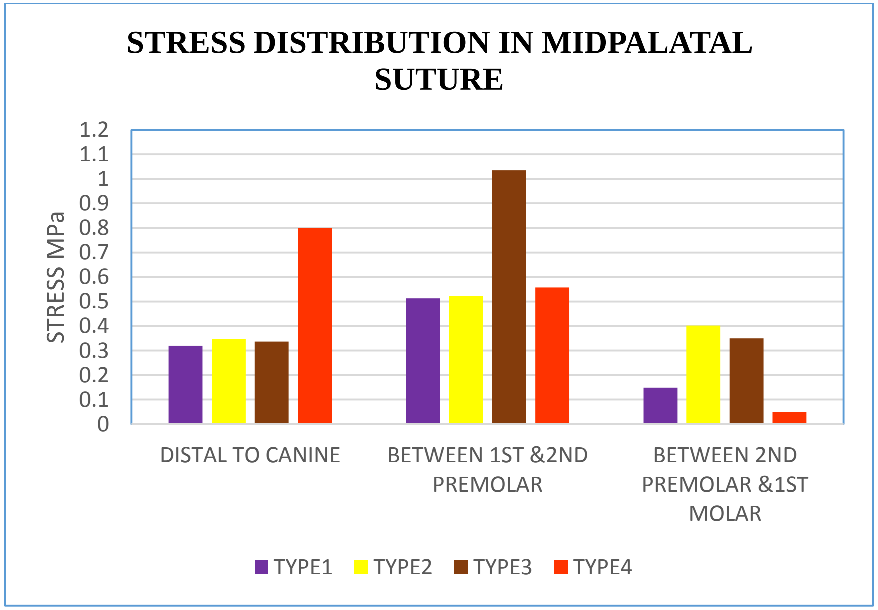


TABLE-15.STRESS DISTRIBUTION IN CIRCUMMAXILLARY SUTURES(units inMPa)

GROUP-B CIRCUM MAXILLARY SUTURES STRESS DISTRIBTN	TYPE1	TYPE2	TYPE3	TYPE4
NASOFRONTAL SUTURE	0.0049028	0.029276	0.043591	0.076535
FRONTOMAXILLARY SUTURE	0.002825	0.025188	0.05492	0.06863
NASOMAXILLARY SUTURE	0.0076444	0.032858	0.046622	0.094301
ZYGOMATICOFRONTAL SUTURE	0.0059699	0.065649	0.06968	0.12398
ZYGOMATICOMAXILLARY SUTURE	0.0027992	0.024813	0.043027	0.074172
ZYGOMATICOTEMPORAL SUTURE	0.0015226	0.021524	0.029583	0.030148
ZYGOMATIC ARCH	0.0023151	0.017957	0.020259	0.029427
PTERYGOID HAMULUS	0.00037444	0.01284	0.011391	0.030996
LATERAL PTEYGOID PLATE	0.011323	0.025078	0.05797	0.010761
MEDIAL PTERYGOID PLATE	0.019132	0.11985	0.16967	0.23112

GRAPH-20..STRESS DISTRIBUTUION IN CIRCUMMAXILLARY SUTURES

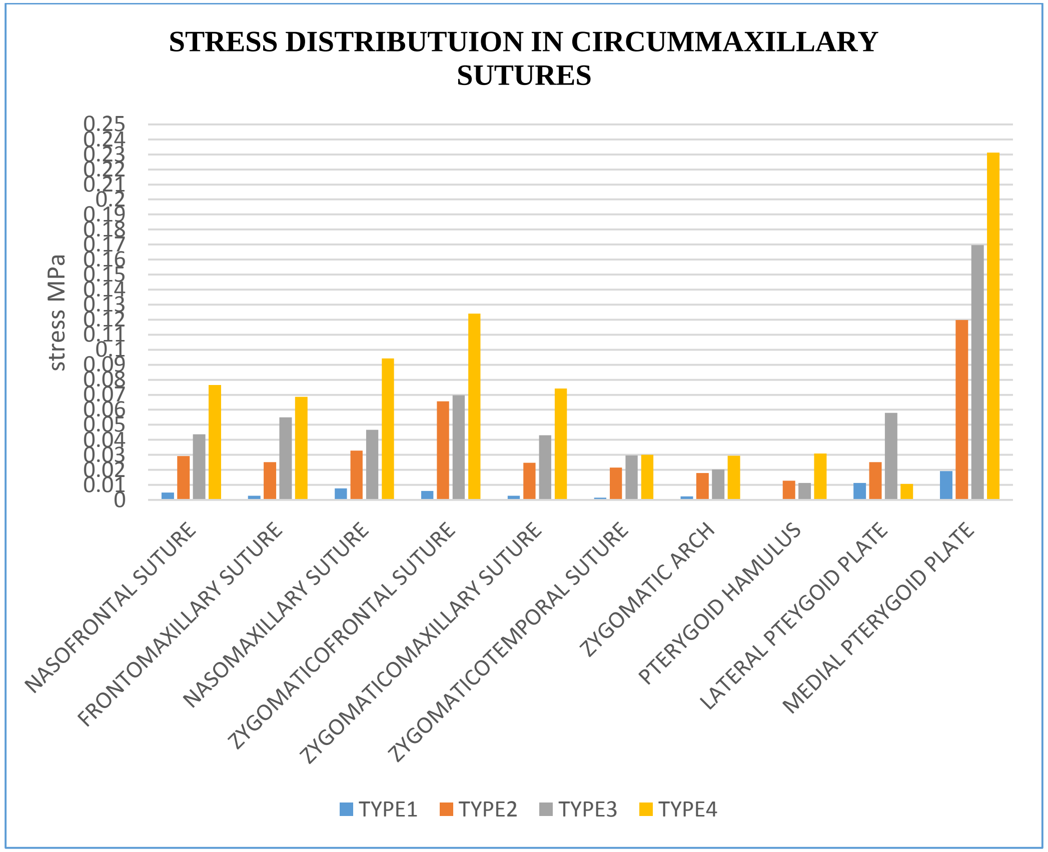


TABLE-16.DISPLACEMENT OF THE CANINE REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE ANTERO-POSTERIOR (*X*)DIRECTION.(units in mm)

GROUP-B DISPLACEMENT OF CANINE REFERENCE POINTS (X-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.ALV.CREST(B1)	-0.000067829	-0.00046718	-0.000074004	-0.00044551
SOCKET(B2)	-0.000073791	-0.00024478	-6.6912E-06	0.0002288
BUCC.ALV.CREST(B3)	-0.000057601	-0.00033627	-0.00013843	-0.000054723
CUSP TIP(T1)	-0.000068733	-0.00057147	-0.00042263	-0.00070977
LINGUAL CEJ(T2)	-0.000080576	-0.00054465	-0.00037737	-0.00061369
ROOT APEX(T3)	-0.000088136	-0.00029115	-0.000090149	-0.00013074
BUCCAL CEJ(T4)	-0.000065755	-0.00037993	-0.00014221	-0.000083821

GRAPH-21. DISPLACEMENT AT CANINE REFERENCE POINTS IN X-AXIS

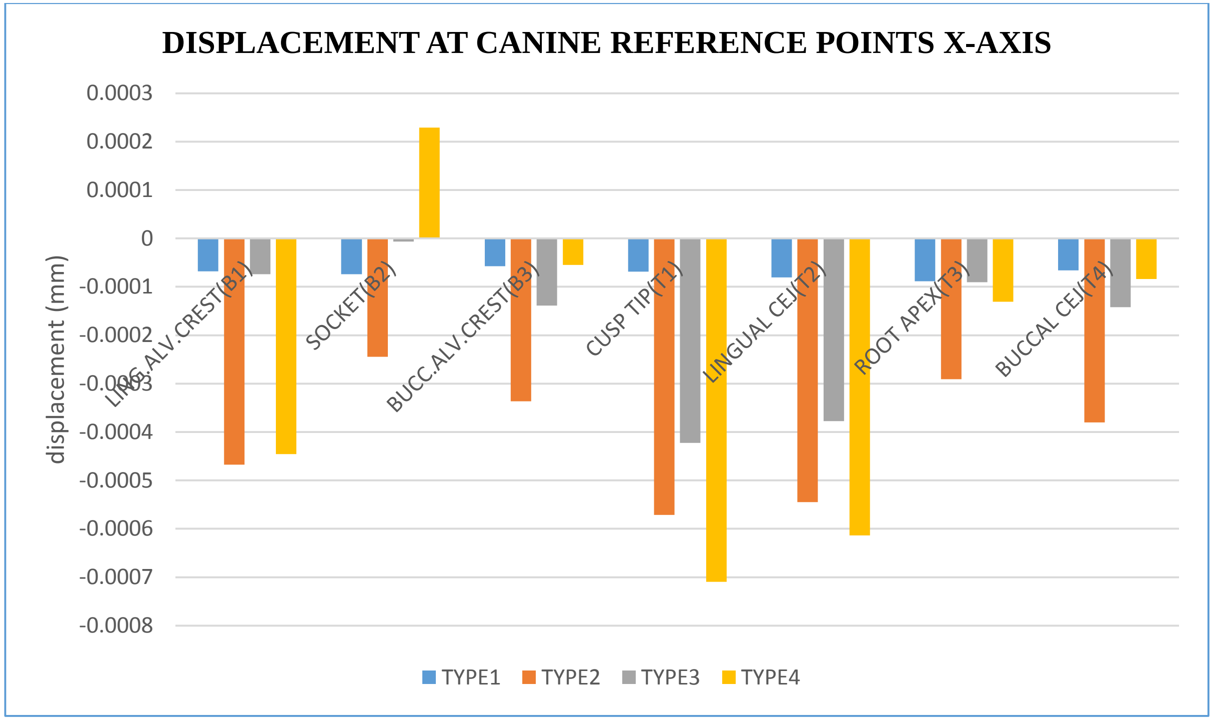


TABLE-17.DISPLACEMENT OF THE CANINE REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE, TRANSVERSE (*Y*) DIRECTION (units in mm)

REFERENCE POINTS (Y-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.ALV.CREST(B1)	-5.9651E-06	0.00032431	0.00049801	0.0007019
SOCKET(B2)	-0.00002258	0.00017557	0.00032682	0.00041702
BUCC.ALV.CREST(B3)	-0.000031479	0.000069935	0.00016881	0.00011413
CUSP TIP(T1)	-8.9362E-06	0.00019584	0.00033597	0.00037595
LINGUAL CEJ(T2)	0.000009511	0.00034922	0.00054566	0.00075742
ROOT APEX(T3)	-0.000018461	0.00020552	0.00032112	0.00047509
BUCCAL CEJ(T4)	-0.000031128	0.00023711	0.00016355	0.000105

GRAPH-22. DISPLACEMENT AT CANINE REFERENCE POINTS IN Y-AXIS

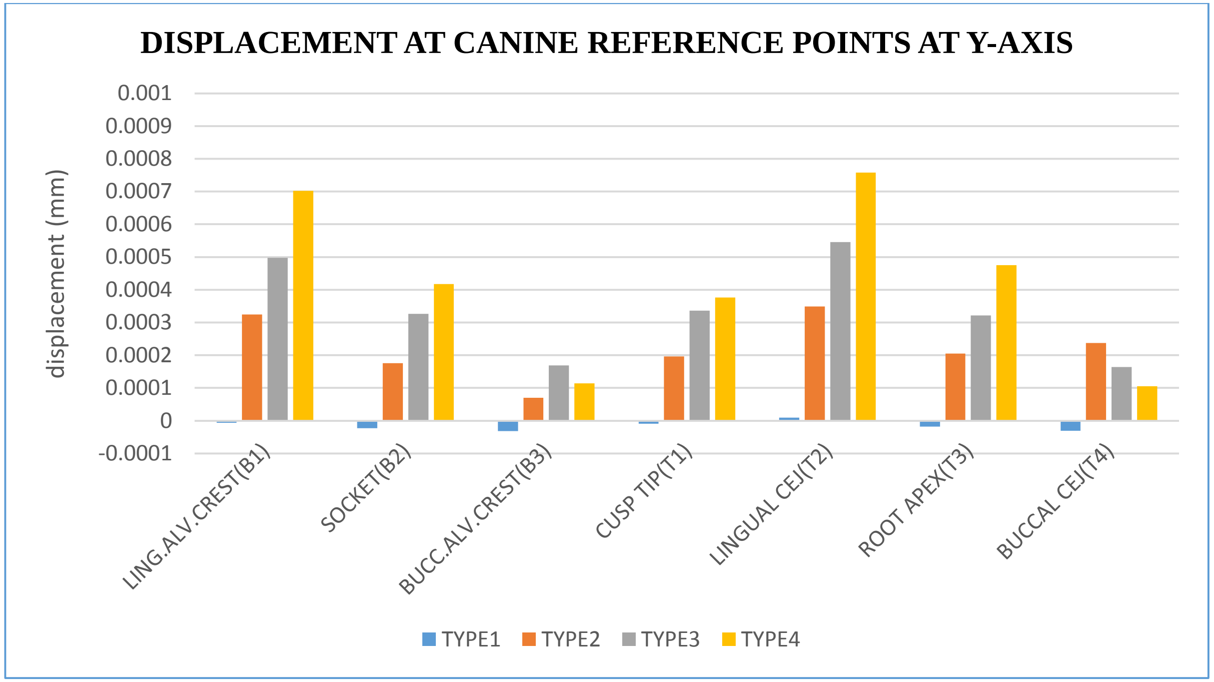


TABLE-18.DISPLACEMENT OF THE CANINE REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE VERTICAL (*Z*) DIRECTIONS. (units in mm)

REFERENCE POINTS (Z-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.ALV.CREST(B1)	9.6055E-06	-0.000060586	-0.00019608	-0.0003363
SOCKET(B20	4.5649E-06	-0.000047003	-0.00021775	-0.00034729
BUCC.ALV.CREST(B3)	4.8862E-06	-0.000038905	-0.00017905	-0.00027964
CUSP TIP(T1)	3.3384E-06	-0.000016297	-0.00015055	-0.00022643
LINGUAL CEJ(T2)	8.7001E-06	-0.000065146	-0.00020594	-0.00036309
ROOT APEX(T3)	6.8197E-06	-0.00006378	-0.00020619	-0.00035418
BUCCAL CEJ(T4)	2.9357E-06	-0.000030255	-0.00019394	-0.00026508

GRAPH-23. DISPLACEMENT AT CANINE REFERENCE POINTS IN Z-AXIS

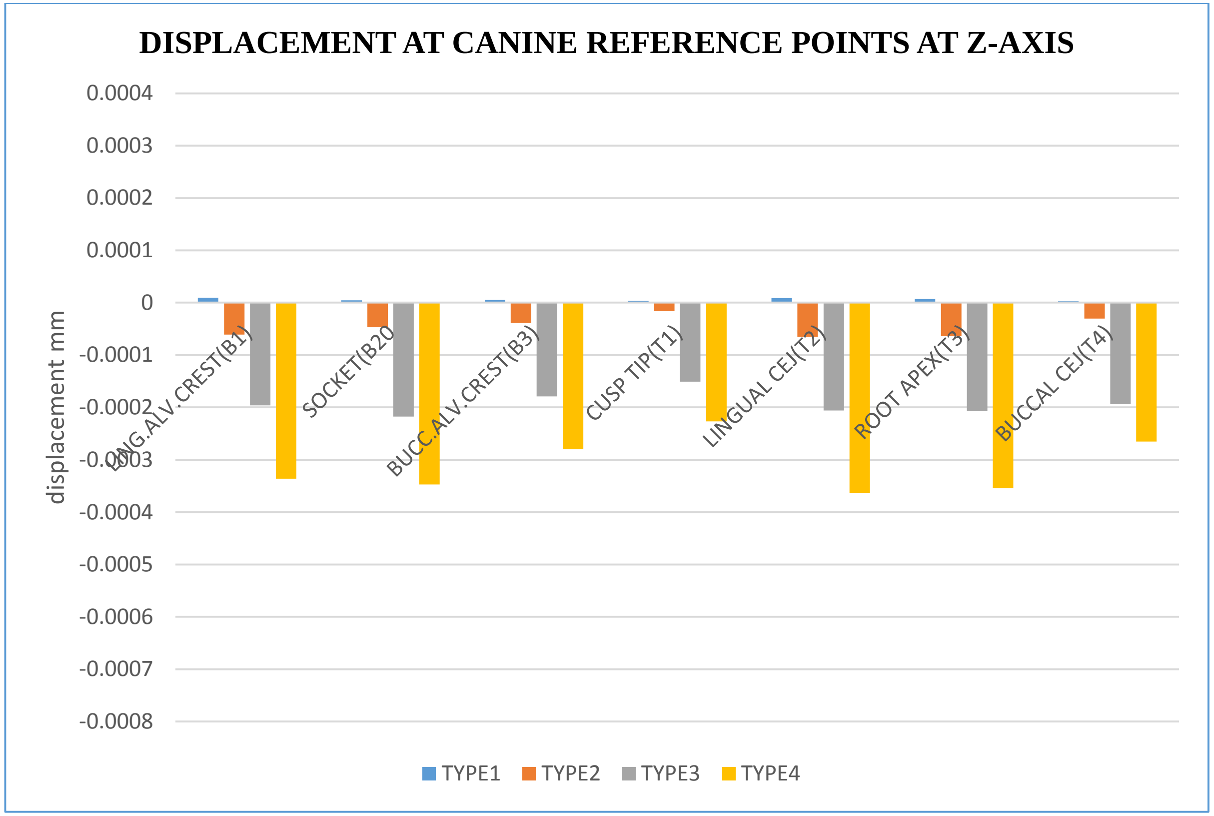


TABLE-19.DISPLACEMENT OF THE CANINE REFERENCE POINTS UNDER LOADING IN EACH TYPE IN XYZ DIRECTION(TOTAL DEFORMATION) (units in mm)

REFERENCE POINTS (XYZ)	TYPE1	TYPE2	TYPE3	TYPE4
LING.ALV.CREST	0.00008867	0.00065204	0.00068246	0.00072523
SOCKET	0.000076322	0.00029119	0.00043407	0.00062202
BUCC.ALV.CREST	0.000071578	0.0003358	0.00027964	0.0003044
LINGUAL CUSPTIP	0.000070322	0.00065094	0.00060095	0.00086406
LINGUAL CEJ	0.000086245	0.00065491	0.00067438	0.00010369
ROOT APEX	0.000091829	0.00034281	0.00038744	0.00071675
BUCCAL CEJ	0.000072703	0.00037477	0.00028299	0.00028051

GRAPH-24 DISPLACEMENT AT CANINE REFERENCE POINTS IN XYZ-AXIS

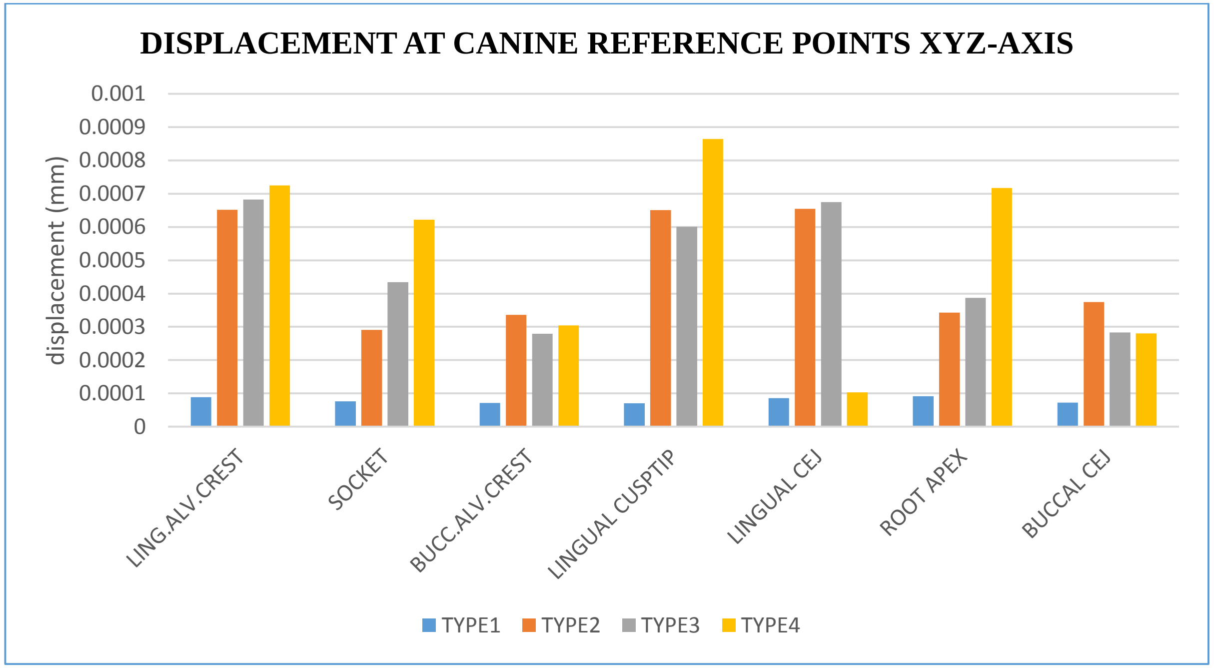


TABLE-20.DISPLACEMENT OF THE FIRST MOLAR REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE ANTERO-POSTERIOR (*X*)DIRECTION. (units in mm)

GROUP-BDISPLACEMENT OF MOLAR REFERENCE POINTS PUNITHA (X-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.MIDALV.BONE	-0.00012684	-0.0005033	-0.0006941	-0.00089173
LING.ALV.CREST	-0.0001315	-0.00075697	-0.0003952	-0.0004276
LING.SOCKET	-0.00011822	-0.00035523	-0.000329172	-0.0003898
MESIO.BUCC.SOCKET	-0.00010494	-0.00043396	-0.00024	-0.00026053
BUCC.ALV.CREST	-0.00012684	-0.00059572	-0.00066878	-0.00083409
MESIO.LING CUSP TIP	-0.0001573	-0.0011195	-0.0014785	-0.0022222
LINGUAL CEJ	-0.00014062	-0.00087247	-0.0011781	-0.0017604
LINGUAL ROOT APEX	-0.00011855	-0.00035451	-0.00037643	-0.00040219
M.B ROOT APEX	-0.0001034	-0.00041238	-0.00025343	-0.00016095
BUCCAL CEJ	-0.00013138	-0.00075665	-0.00096073	-0.001268

GRAPH-25. DISPLACEMENT AT 1ST MOLAR REFERENCE POINTS IN X-AXIS

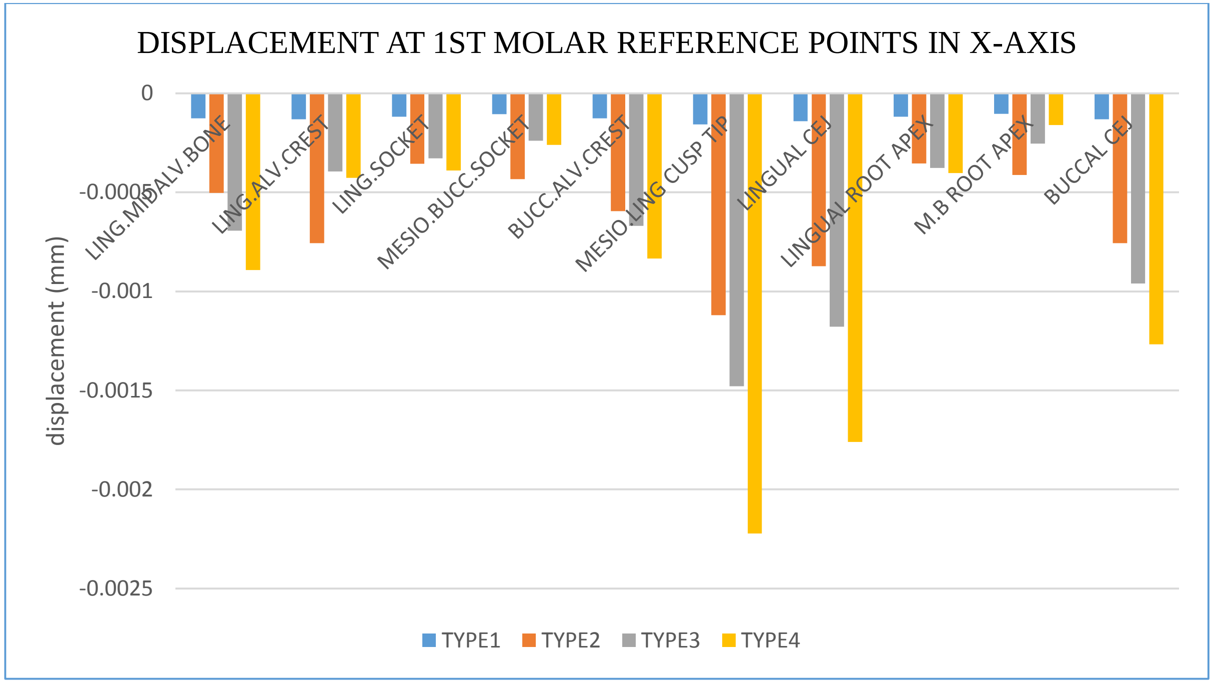


TABLE-21.DISPLACEMENT OF THE FIRST MOLAR REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE TRANSVERSE (*Y*) DIRECTIONS(units in mm)

REFERENCE POINTS (Y-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING.MIDALV.BONE	-0.000017161	0.00021981	0.00038121	0.00054494
LING.ALV.CREST	-0.000022907	0.00016076	0.00027544	0.00039986
LING.SOCKET	-0.000014625	0.0001794	0.00031834	0.00040637
MESIO.BUCC.SOCKET	-0.000031649	0.000020744	0.000056803	-0.000067332
BUCC.ALV.CREST	-0.000038031	-0.000060761	0.00015009	-0.00032585
MESIO.LING CUSP TIP	-0.000035208	0.000028231	0.000066615	0.000024649
LINGUAL CEJ	-0.00002642	0.00009253	0.00021204	0.00026101
LINGUAL ROOT APEX	-0.000014383	0.00019682	0.00034004	0.0004673
M.B ROOT APEX	-0.000031452	0.000022973	0.000027926	-0.000025812
BUCCAL CEJ	-0.000044268	-0.000085389	-0.00022608	-0.00048895

GRAPH-26. DISPLACEMENT AT 1ST MOLAR REFERENCE POINTS IN Y-AXIS

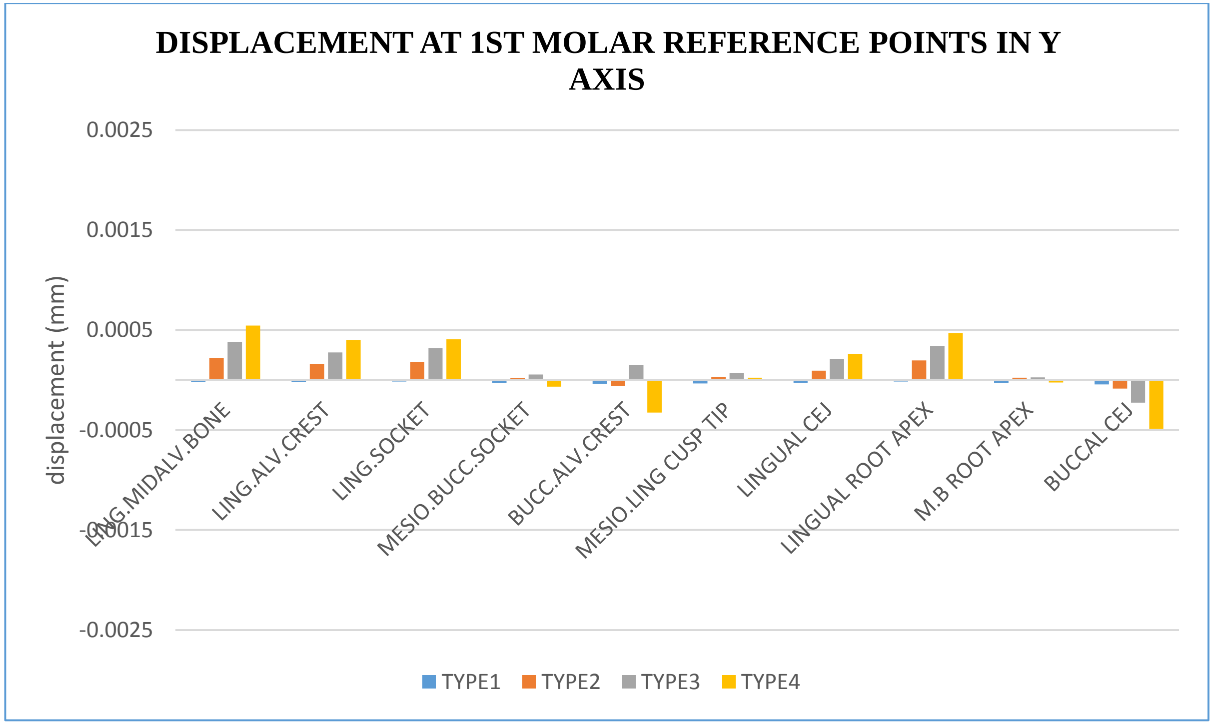


TABLE-22.DISPLACEMENT OF THE FIRST MOLAR REFERENCE POINTS UNDER LOADING IN EACH TYPE IN THE VERTICAL (Z) DIRECTIONS(units in mm)

REFERENCE POINTS (Z-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING MIDALV.BONE(B1)	-1.9133E-06	-0.00017859	-0.00037702	-0.00057243
LING ALV CREST(B2)	7.5295E-06	-0.000086926	-0.00021657	-0.0002489
LING.SOCKET(B3)	4.8726E-06	-0.000010301	-0.00028396	-0.00046065
M.B SOCKET(B4)	0.000018493	-0.00012709	0.000021144	0.00012328
BUCC.ALV.CREST(B5)	0.000027468	0.00027554	0.00023518	0.00036839
M.L CUSPTIP(T1)	0.000009237	0.000047195	-0.000030801	-0.000053523
LING CEJ(T2)	3.0694E-06	-0.000054257	-0.00017059	-0.00029701
LINGUAL ROOT APEX(T3)	4.2845E-06	-0.00014321	-0.00033165	-0.00053038
M.B ROOT APEX(T4)	0.000018018	0.00011384	0.000035966	0.000038956
BUCCAL CEJ(T5)	0.000027912	0.0002806	0.00032408	0.0004956

GRAPH-27. DISPLACEMENT AT 1ST MOLAR REFERENCE POINTS IN Z-AXIS

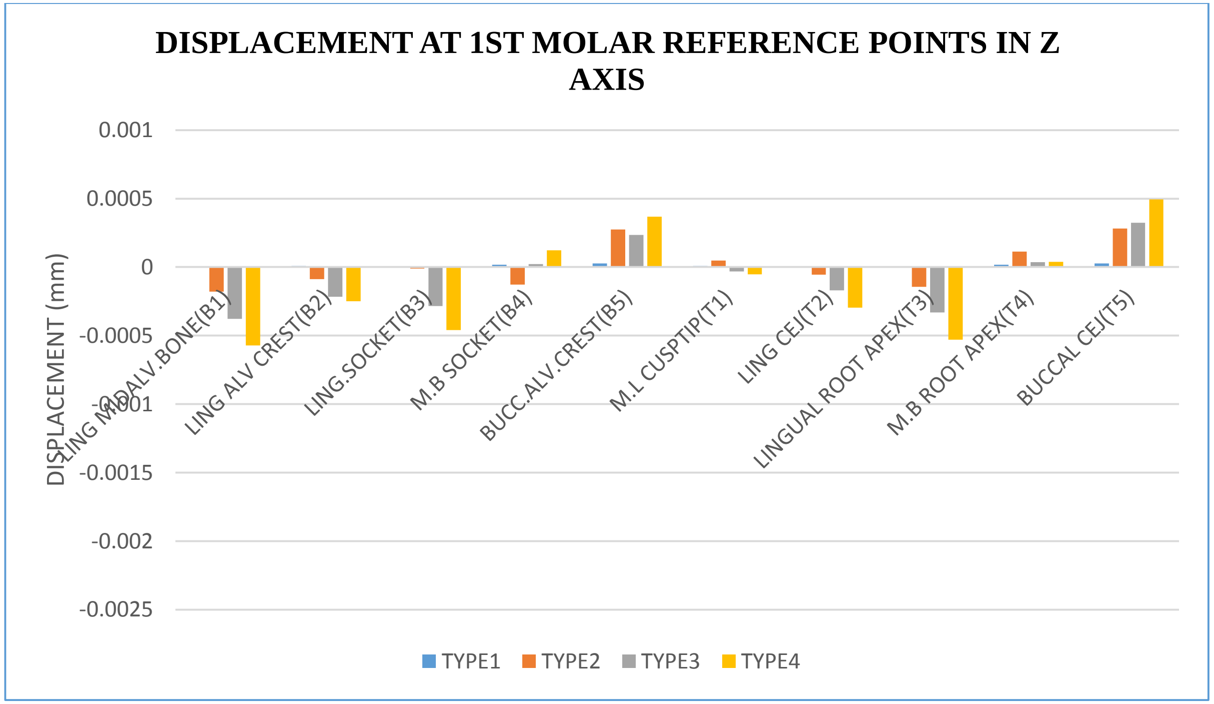
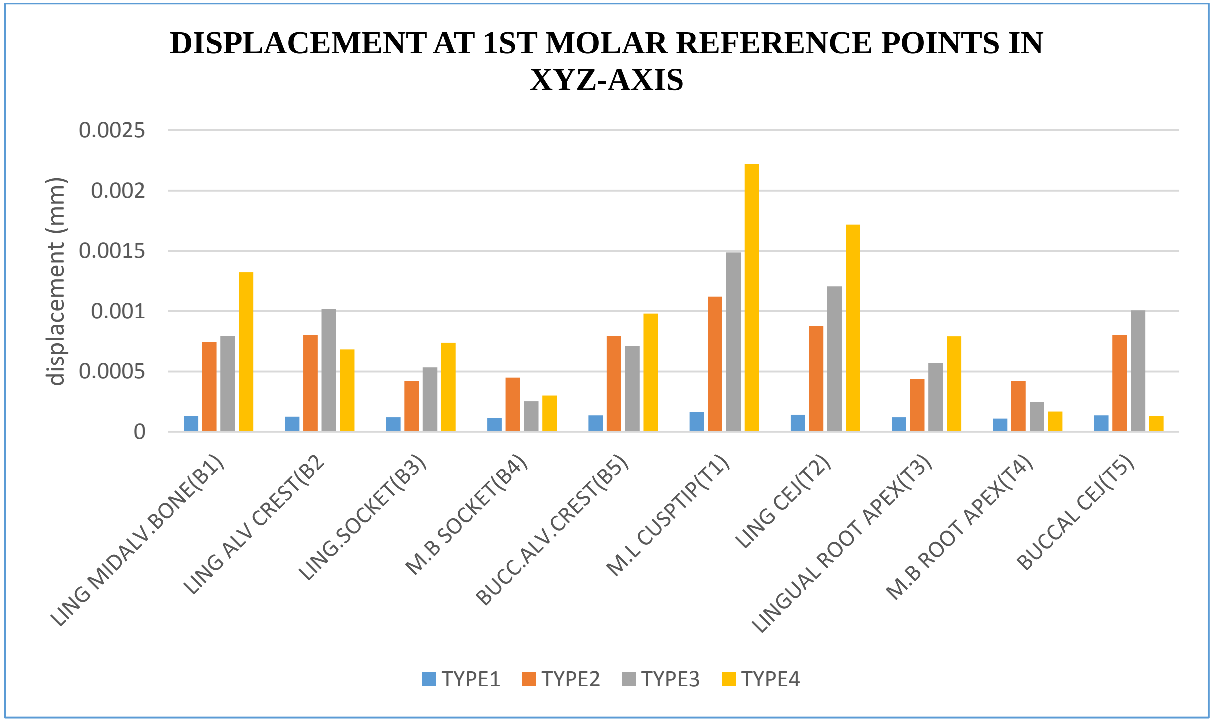


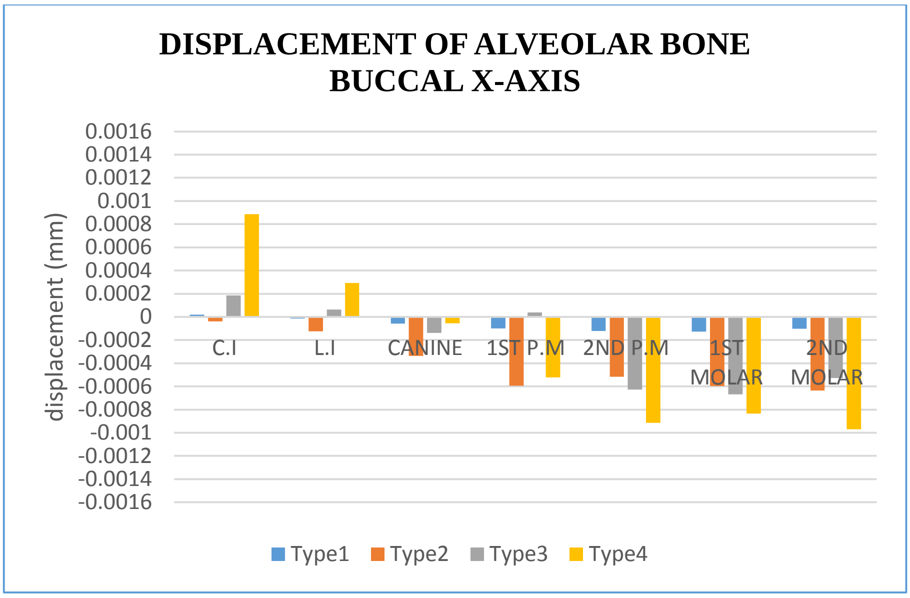
TABLE-23.DISPLACEMENT OF THE FIRST MOLAR REFERENCE POINTS UNDER LOADING IN EACH TYPE IN XYZ DIRECTION(TOTAL DEFORMATION(units in mm)

REFERENCE POINTS (XYZ-AXIS)	TYPE1	TYPE2	TYPE3	TYPE4
LING MIDALV.BONE(B1)	0.00012987	0.00074375	0.00079286	0.0013234
LING ALV CREST(B2	0.00012635	0.0008016	0.0010198	0.00068311
LING.SOCKET(B3)	0.00011928	0.00042105	0.00053336	0.00073899
M.B SOCKET(B4)	0.00011106	0.00044882	0.00025218	0.00029967
BUCC.ALV.CREST(B5)	0.00013661	0.000793	0.0007124	0.00098063
M.L CUSPTIP(T1)	0.0001612	0.0011197	0.0014881	0.0022183
LING CEJ(T2)	0.00014206	0.00087758	0.0012053	0.001719
LINGUAL ROOT APEX(T3)	0.00011947	0.00043816	0.00057092	0.00079035
M.B ROOT APEX(T4)	0.00010873	0.00042231	0.00024548	0.00016767
BUCCAL CEJ(T5)	0.00013694	0.00080253	0.0010058	0.00013107

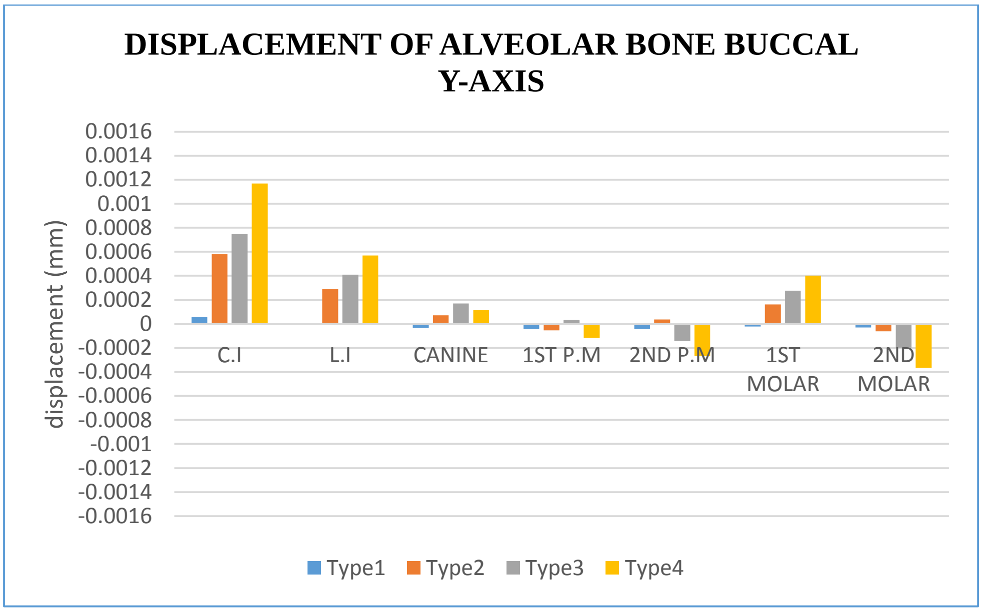
GRAPH-28. DISPLACEMENT AT 1ST MOLAR REFERENCE POINTS IN XYZ-AXIS



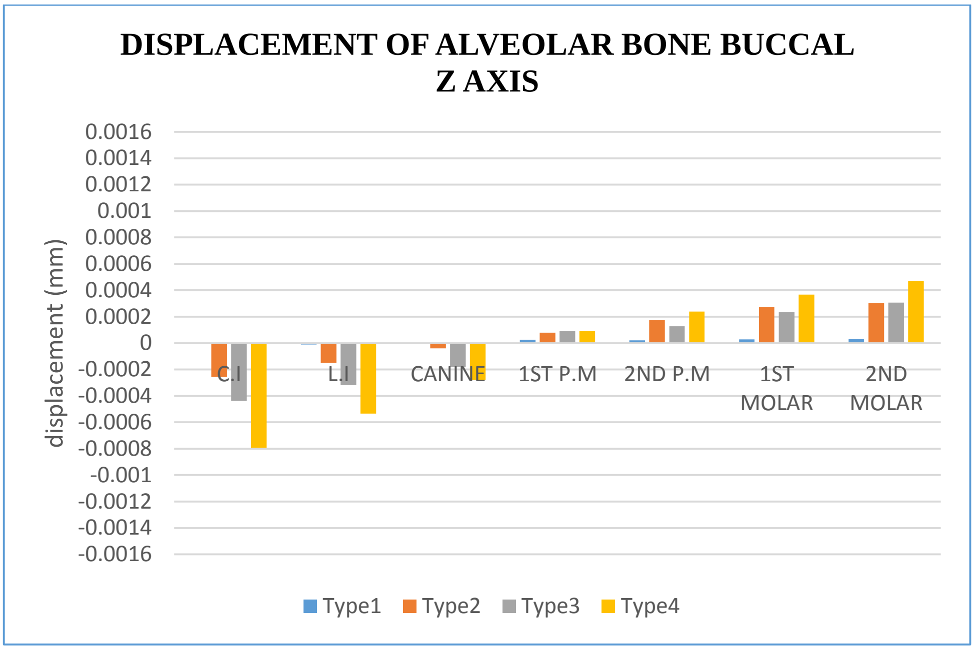
GRAPH-29.DISPLACEMENT OF ALVEOLAR BONE BUCCAL IN X- AXIS



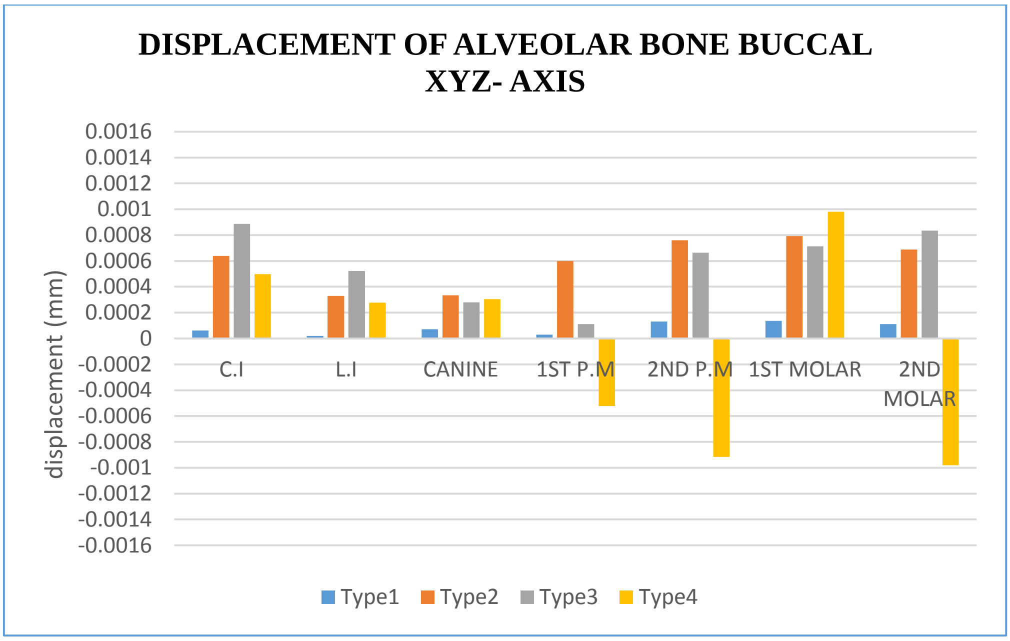
GRAPH-30. DISPLACEMENT OF ALVEOLAR BONE BUCCAL IN Y- AXIS



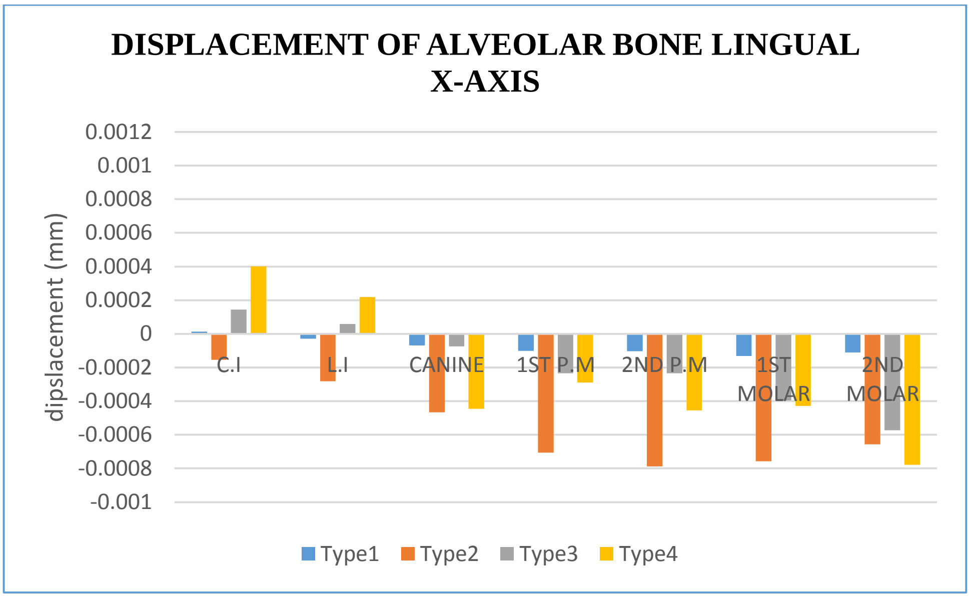
GRAPH-31.DISPLACEMENT OF ALVEOLAR BONE BUCCAL IN Z- AXIS



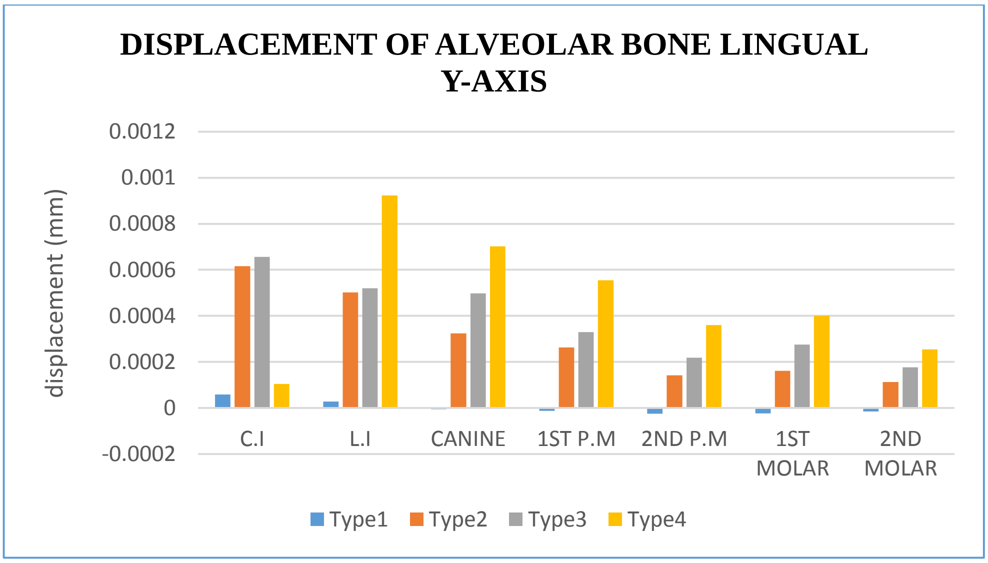
GRAPH-32.DISPLACEMENT OF ALVEOLAR BONE BUCCAL IN XYZ- AXIS



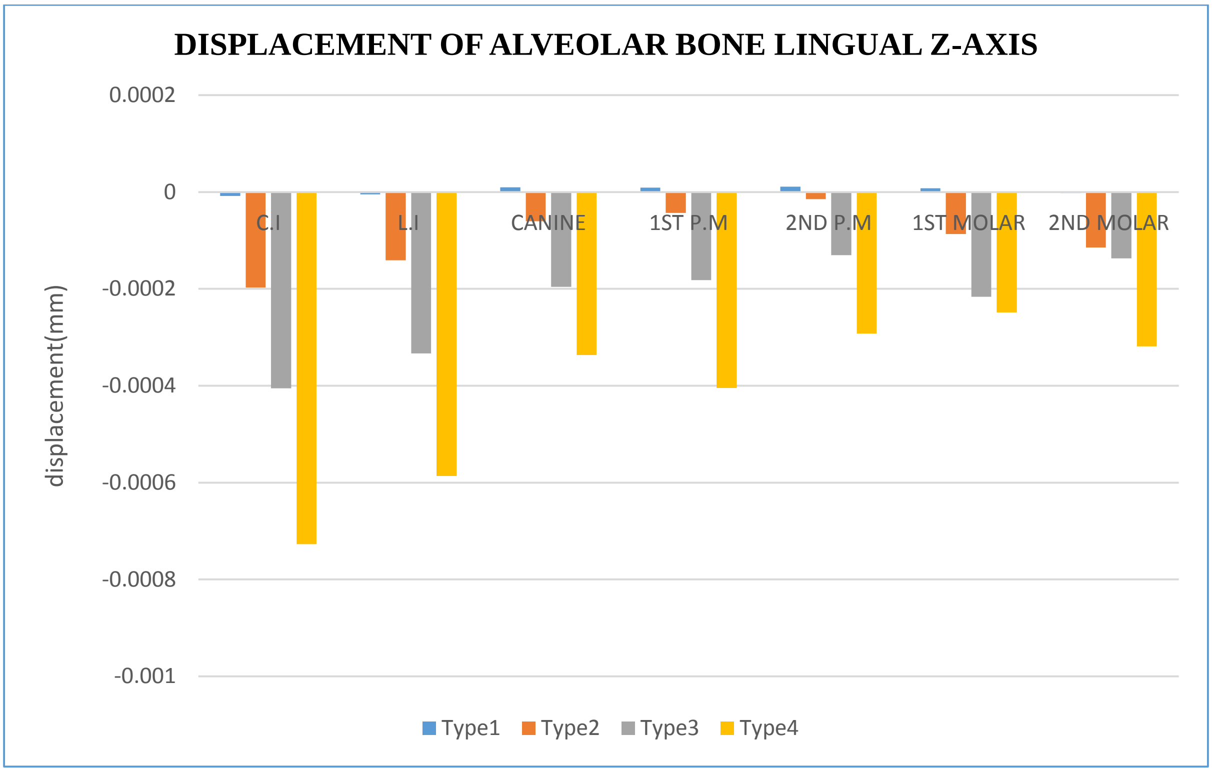
GRAPH-33.DISPLACEMENT OF ALVEOLAR BONE LINGUAL IN X -AXIS



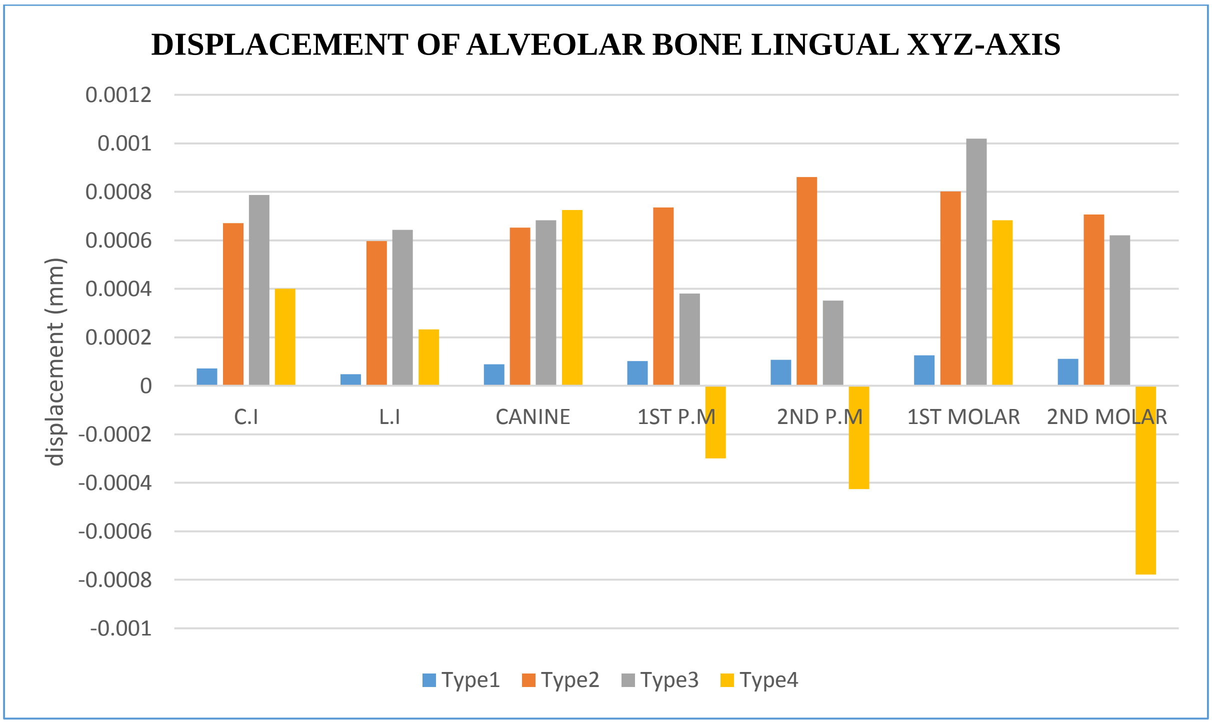
GRAPH-34.DISPLACEMENT OF ALVEOLAR BONE LINGUAL IN Y -AXIS



GRAPH-35.DISPLACEMENT OF ALVEOLAR BONE LINGUAL IN Z -AXIS



GRAPH-36.DISPLACEMENT OF ALVEOLAR BONE LINGUAL IN XYZ -AXIS



Discussion

DISCUSSION

Rapid maxillary expansion (RME) is a dramatic procedure with a long history. Rapid Maxillary expansion or palatal expansion as it is called, occupies unique niche in dentofacial therapy.[11] Rapid maxillary expansion (RME) has been used in orthodontic practice for the correction of posterior crossbite and dental crowding as well as to facilitate correction of malocclusions with the overall objective to widen the maxilla by separating the mid-palatal suture and the circumaxillary sutural system. RME had been proposed since the 19th century by **Angell** to correct maxillary constriction. Since the pioneering work of **Angell**[11] 150 years ago that introduced the concept that the maxilla can be expanded by opening the mid-palatal suture. The landmark work of **Haas**[9] made RME a routine in many orthodontic practices, beginning in the 1960's.

Understanding individual variability in the fusion of the mid-palatal suture is essential in identifying prospectively which late adolescent or young adult patient can have RME as a less-invasive alternative to surgically assisted expansion. The mid-palatal suture has been described as an end-to-end type of suture with characteristic changes in its morphology during growth. In the infantile period, **Melsen**[15] reported that the mid-palatal suture is broad and Y-shaped in its frontal sections. Many studies have advocated that most of the resistance to mid-palatal suture separation in adults is due to fusion of the circumaxillary sutures.

Melsen[79] histologically examined the maturation of the mid-palatal suture at different developmental stages. In the **‘‘infantile’’ stage (up to 10 years of age),** the suture was broad and smooth, whereas in the **‘‘juvenile’’ stage (from 10 to 13 years)** it had developed into a more typical squamous suture with overlapping sections. Finally, during the **‘‘adolescent’’ stage (13 and 14 years of age)** the suture was wavier with increased interdigitation. In their 1982 study, **Melsen**[15] also included observations of the **‘‘adult’’ stage** of the suture that noted synostoses and numerous bony bridge formations across the suture.

Various techniques and appliance designs have been used to widen a narrow maxilla. Of which the technique of conventional rapid palatal expansion was advocated to establish skeletal expansion. However, in skeletally mature patients, conventional RME is known to have a limited effect on the mid-palatal suture and resulted in dentoalveolar tipping with the consequent cause of unfavourable periodontal effects.[21,23,39,45,66] To overcome the increased thickness of bony structures, reduced elasticity, and increased interdigitated median palatal suture, SARME has been the accepted treatment modality for adults.[50,65,99] The necessity for this surgical approach in adult patients is that it provides maximum resistance to opening of the mid-palatal suture. Traditionally, the mid-palatal suture has been thought to be the area of greatest resistance to expansion **(Melsen, 1975; Timms and Vero, 1981).**[79,110] Later studies have emphasized the zygomatic buttress and the pterygomaxillary junction as critical areas of resistance **(Lines, 1975; Bell)**.[14,73] Nevertheless the surgical procedure also increases the risk of morbidity for the patient and there is a lack of consensus with respect to skeletal efficiency and stability. Hence, a better alternative would be the use of skeletally anchored expansion, which alleviates the need for a surgical procedure.

Conventional rapid maxillary expansion devices acquires anchor from the dentition and they widen the upper arch in transverse direction mainly by the separation of the two maxillary halves along the mid-palatal suture and also by tipping and extruding the maxillary posterior teeth.[58,96] Root resorption of the buccal teeth was also reported with the use of conventional rapid maxillary expansion appliance.[56,107] Later with the advent of temporary anchorage devices (TADs) like miniscrew implants, several authors advocated these **TADs** to directly anchor the rapid maxillary expansion appliance to the maxillary bone without disturbing the dentition since the forces can be applied directly to basal bone increasing the skeletal effects of the treatment.[47,54,64,75,120]

Earlier implants used to anchor the RPE appliance onto the palate required more invasive surgical exposure by raising the palatal mucosal flap. Disadvantages of these methods are their invasiveness and carries the risk of root injury and the need for surgical implantation.[47,90] However these drawbacks were overcome by the utilization of palatal miniscrew implants specially designed. Over the recent years, these bone-anchored maxillary expanders were popularly used to achieve skeletal maxillary expansion in adults who required surgically assisted RPE **(SARPE)** procedure.

Periodontal status is of particular interest in orthodontics, especially when expansion movements are involved. Many studies have addressed the relationship between orthodontics and periodontics, focusing on the effects of tooth movement on the intact or reduced periodontium.[36,39] The expansion force delivered produces areas of compression on the periodontal ligament of the supporting teeth. Thereafter, alveolar bone resorption leads to tooth movement in the same direction. Tooth-borne expanders, which concentrate the force at the dentoalveolar area, might be more iatrogenic from a periodontal standpoint and might cause more **root resorption** than tooth-tissue-borne expanders, which distribute the force between the anchorage teeth and the palatal surface.[52] **Greenbaum and Zachrisson,[44] Northway and Meade,[86] Vanarsdall and Watson [116]** suggested only that RME could cause bone dehiscences based on clinical observation of attachment loss and gingival recession on the buccal aspect of maxillary posterior teeth.

According to **Melsen,**[79] buccolingual tooth movement can occur concurrently with or through the alveolar bone. However, when the force magnitude induces indirect bone resorption, the osteoclast resorb the bone plate of the external surface in the direction of the periodontal ligament, therefore leading to tooth movement through the thin alveolar bone plate. The intense force delivered on the supporting teeth during activation of the expansion screw leads to hyalinization of the periodontal ligament on the pressure side.[22,58]

The tooth-borne expander produced more bone dehiscences on the buccal aspect of the supporting teeth than did the tooth-tissue-borne expanders.[38,98] **Haas**[10] defined the tooth-tissue-borne expander as an appliance with maximum anchorage, because it has 3 areas of force distribution—the palate, the periodontal ligament fibers, and the buccal bone plate. He regarded the tooth-borne expander as having deficient anchorage because of force transmission only to the periodontium. **Ramieri et al,**[93] suggested that a bone-anchored appliance has fewer detrimental effects on the periodontium than a tooth-borne anchorage device.

New appliances, such as the **MARPE** have been tested in orthodontic patients with hopes of avoiding the unwanted side effects of traditional RPE and most of the studies are limited in the precise evaluation of the biomechanical effect of orthopedic forces, and it is difficult to suggest exactly what is taking place physiologically.[40,47,109,117] Recent studies have demonstrated that **FEM** is a viable method to study stress, strain, and force distributions when evaluating orthodontic problems, specifically transverse deficiencies. In a non-invasive way, FEM makes it possible to compare the effects of conventional hyrax and MARPE expansion forces on the craniofacial complex. The treatment effect of RME have been extensively studied through various methods including analysis of **strain gauges (Tanne; miura et al),**[107] **photoelastic models (Chaconas; Lima et al., 2011),**[22] **laser holography (Pavlin and Vukicevic, 1984),**[33] are all highly sensitive techniques able to measure extremely small initial deformations of bone on macerated skulls. Unfortunately, most of these techniques are limited in their ability to measure internal displacements and strain–stress levels in a complicated structure such as the craniofacial skeleton.[114] On the other hand, **the Finite Element Method (FEM),** which has been successfully applied to the mechanical study of stresses and strains in the field of engineering, makes it practicable to elucidate biomechanical components, such as displacements in living structures.[107,108] Finite element analysis is a mathematical method in which the shape of complex geometric objects and their physical properties are computer constructed. This method was first used in orthodontics by **Thresher and Saito (1973)**[111] to study stresses in human teeth. This method has proved effective in many dental fields such as simulation of tooth movement and optimization of orthodontic mechanics. Such an extensive use has been primarily done because of its advantage of **simulating various treatment approaches without exposing animals or humans to any adverse effects;**[111] **the actual amount of stress experienced at any given point can be theoretically measured; the tooth, alveolar bone, periodontal ligament, and craniofacial bones can be simulated; the displacement of the tooth and the craniofacial complex can be visualized graphically; the point of application, magnitude, and direction of a force may easily be**

varied to simulate the clinical situation, reproducibility does not affect the physical properties of the involved material; and the study can be repeated as many times.[67]

The experimental method **employed in the present study permitted the visualization of bone reactions, even with the lowest loading degree**. One should be aware that the structural and spatial relationships of various craniofacial components vary among individuals. It is important to realize that these factors may contribute to varied responses of the craniofacial components on loading.[33,46,50]

Model generation: **Our finite element model is constructed from a CT scan of an average maxillary arch and constricted maxillary arch deficient patient records**. The geometry of the cranium was obtained using the CT data. CT represents a well-established method of medical imaging with high-quality sagittal sections of the inner structure of the body**.**[67] **It has a number of advantages over previous reconstruction methods, particularly the ability to automatically locate object boundary outlines and produce shaped 3D images of reconstructed data (Moaddab et al. , 1985 ; Hart et al.,1992 ; Sprawls,1992 ; Mehta et al.,1997)**.[49] Previous finite model studies done by **Gautam, Jafari, Iseri et al.,**[4,46,90] have taken CT scan images of 2.5 mm, 5 mm, and 10 mm intervals for FEM generation**. In the present study, modeling was done using CT scan images taken at 1 mm slice thickness and 0.5 mm interval** which means that when compared to earlier

FEM studies the STL model generated in this study was in detail with **higher accuracy**. Commercially available software was used, firstly to reconstruct the craniofacial complex into a 3D model, and secondly to divide the model into FEs and construct the mesh. The division of each section into FEs was based on the outer geometry of the skull. The construction of the mesh was done automatically by the software where the geometry of the model was simple and manually where the anatomy was more complex. **In the present study,** the FEM model of the cranium was generated **using MIMICS** software and **ANSYS version 15.0.** In the present study we have taken two groups of models (Group A –average arch and Group B-constricted arch) with four types of expansion appliances.

The types of expanders used in the present study are as follows:

Type 1- 4 miniscrew implants placed lateral to mid-palatal suture,

Type 2- 4 miniscrew implants placed at the palatal slope (two between the canine and first premolar, two between the second premolar and first molar).

Type 3- 2 miniscrew implants placed lateral to mid-palatal suture (between the canine and first premolar) and connected to the expander with conventional hyrax arms soldered on the first molar.

Type 4: conventional tooth borne appliance assisted by perforations using miniscrew implants in the mid-palatal suture region.

FEM - RPE studies have generated models that are **isotropic** with only mid-palatal suture. The mid-palatal suture certainly is important; however, skeletal resistance to maxillary expansion will emanate primary to the three maxillary buttresses: pterygomaxillary, zygomaticomaxillary, and nasomaxillary.[19,46] In order to achieve an accurate representation of the nasomaxillary complex, the circumaxillary sutures are essential**. In the present study, the following sutures were included: frontozygomatic, frontomaxillary, zygomaticomaxillary, zygomaticotemporal, the medial and lateral pterygoid plates, zygomatic arch and, mid-palatal sutures.**

Therefore, in order to study all the biological phenomena that take place, a number of assumptions were made in the construction and the analysis of the FEM developed in this study that may, in theory, lead to less precision in the results:

In accordance with the assumptions of earlier craniofacial FE studies **(Tanne *et al.*,1989,1995; Tanne and Sakuda,1991; Ruan *et al.*,1994**),[107,108]linearly elastic and isotropic behaviour for the full thickness of bone with a modulus of elasticity equal to **13700 MPa** was assumed.

The skull was packed at the cranial base along the foramen magnum (i.e. all degrees of freedom were constrained) and the total mechanical load applied resulted from the expansion caused by the displacement of the midline screw of the RME appliance similar **to the present study.**

Force application: **Isaacson et al, (1964),**[95] **and Isaacson and Ingram (1964)**[94] measured forces created by a rapid palatal expansion appliance and reported that a single activation created between **3 and 10 pounds** of force that decayed rapidly at first and continued to decrease slowly. In **1965, Zimring and Isaacson**[58] found that maximum forces during RME treatment ranged from **16.6 to 34.8 lb**. **Proffit et al** has mentioned that activation of rapid palatal expander at the rate of two times daily will create a force of about 10 to 20 pounds of pressure across the mid-palatal suture. Hence in **the present study** we applied **45N** of force to achieve sufficient separation of two halves of the maxillary segments. **Lee.J** [70] **et al** in his finite element study reported that the maximum amount of orthodontic force that can be tolerated by the miniscrew implant is about 400gms. An important finding of the study done by **Surendra shetty et al.,**[101] 2012 was the bending of titanium miniscrew implant at the neck region under horizontal loading. This might be explained by the difference in the modulus of elasticity between stainless steel and titanium alloys and the strength of these materials. Because titanium alloy is far weaker material with a smaller modulus of elasticity compared with stainless steel, it bends at thinnest region (neck). To prevent this bending the neck region should be as wide as head region and shoulder of the implant. It was concluded that conical type of miniscrew implant with a length of 10mm and a diameter of 2mm composed of either titanium or stainless steel alloy can safely resist the high level of orthopaedic forces.

Morarend et al.,[81] suggested a large diameter 2.5 mm mono cortical screw will be another viable option to resist heavy orthopaedic forces.

Biomechanics: Nanda[85] has shown that facial sutures and periodontal tissues behave in a similar manner in response to applied force systems. The teeth and craniofacial bones are essentially constrained bodies; one by the periodontium, and the other by sutures. Consequently, the biomechanical principles involved in tooth movement may be applied to craniofacial bones. In addition, **Christiansen and Burstone**[25] and others have repeatedly shown that in order to forecast the movement of a constrained body (describing its center of rotation), the equivalent force system at its center of resistance must be known. **Lee et al**[71] have identified the locations of the centers of resistance of the dentomaxillary complex in the **sagittal and frontal views**, one can relate the force systems of mid-palatal sutural expansion to the centers of resistance of the attendant osseous structures. When an expansion force is applied, as seen in the frontal view through activation of the Hyrax appliance, an equivalent moment and force result at the centers of resistance of each maxillary half.

Previous studies have identified the **center of resistance** of the maxilla in both the sagittal and frontal views. From a frontal view, the centers are referred to as an intersection of two axis: the first through the crista galli and the second through the most inferior points of the zygomatico maxillary sutures bilaterally. The center of resistance is located at the perpendicular intersection of these two axes. From a lateral view, the center of resistance is located along a line passing through the distal contact of the maxillary first molar to the functional plane and then taking half of the distance from the functional plane to the inferior border of the orbit. The fulcrum of the maxillary rotation is at the frontomaxillary suture, and as a result, there exists a triangular intermaxillary diastasis with its base at the level of the upper incisors and the apex at the level of the nasal cavity.[71] **From a clinical perspective, placement of the jackscrew should be as close to the center of resistance as possible to effect a more translatory movement of the maxillary halves.**[76]

With a conventional hyrax, it is impossible to direct the force from the jackscrew through the center of resistance to produce pure bodily movement.[102] It is believed that with a **more rigid** expansion appliance, the center of rotation will move superiorly and posteriorly. In the MARPE simulation groups, the point of force application is closer to maxillary fulcrum of rotation as well as the center of resistance. According to **Braun et al.,** this change in force application will result in a more linear separation of the maxillary halves. In addition, the point of force application is at the peak of the palate, which prevents the unwanted dental movement and the bending of the maxillary complex that can often take place in conventional hyrax expansion. If the mid-palatal suture is completely fused, stress will not be distributed to the surrounding structures because the palate is able to withstand the lateral force applied by the MARPE.

Biomechanically, there are two centers of rotation, one at the frontonasal suture, and the other is distal to the mid-palatal suture in the area of the third molar. In a study by Stanley Braun et al, the (micro-stress) patterns on the zygoma are fundamentally translatory, implying a primary shearing stress in the zygomaticotemporal sutures, primary compression and shearing stresses in the zygomaticomaxillary and zygomaticofrontal sutures. In the occlusal view, the fringe patterns points to a center of rotation at the distal aspect of the maxillary mid-palatal suture approximating the distal one third of the third molars.[102]

If less tipping were desired (in the frontal view) and a more linear opening of the maxillary suture antero posteriorly (in the occlusal view), the fabricated structure joining the sutural opening mechanism to the teeth would have to be more rigid. By increasing the rigidity of both the sutural expansion device and the wires joining it to the teeth, the moment induced by the necessary offsets from the dentomaxillary centers of resistance are reduced or countervailed, resulting in reduced equivalent moment-to-force ratios at the centers of resistance. This causes the center of rotation to migrate superiorly in the frontal view, reducing the degree of tipping, and in the occlusal view, the center of rotation would migrate further posteriorly, resulting in a more linear separation of the mid-palatal suture. The sutural expansion designs that uses an acrylic interface with the teeth are far less stiff than those constructed solely of soldered stainless steel wire. These type expansion devices allow for a greater degree of undesirable maxillary half tipping in the frontal and occlusal planes during mid-palatal sutural expansion.

The predictability of orthopaedic expansion is greatly reduced after 15 years of age **(Melsen, 1975; Baccetti et al., 2001).**[12,79] The stability of the treatment outcome of the RME with or without surgical assistance was dubious (**Alpern and Yurosko, 1987; Cross and McDonald, 2000; Lagravère *et al*., 2006; Baysal *et al*., 2011)**.[5,13,29,69] Consequently, bone-borne expanders with TADs can be a viable treatment option. Since the forces can be directly applied to the basal bone, the amount of skeletal effect of treatment may increase. The major advantage of the bone-borne devices is claimed to derive from the fact that the forces are acting directly to the bone at the mechanically desired level. Therefore, expansion by bone-borne devices would be expected to have a more parallel movement with less tipping of the maxillary halves compared with expansion by tooth-borne devices Thus, **the purpose of the present study was to compare treatment effect of different designs of bone-borne appliances using miniscrew implants.**

Recent articles about treatment effects of these bone-borne expanders demonstrated contradictory results. A case report applied a combined design incorporating miniscrew implants placed in the paramedian area with bands on teeth as an anchorage for RME, showed a successful treatment outcome

(Lee *et al*., 2010).[72] Another study has applied skeletal anchorage to the palatal slopes, which is similar to type 2 of the present study. It was concluded that there was no significant differences between this design and the tooth-borne RME **(Lagravere et al., 2010).**[75]

Lee et al., 2010;2012, Lagravère et al (2010) and Bayome et al [53,72,74] concluded that more expansion in the posterior part of maxilla which contradicts with our results. This was because the mid-palatal suture area of the finite model was filled with cortical and cancellous bone adopting the properties of the mid-palatal suture (young' s modulus) which is different from our study. **Lee**[53] **et al.,2012** moreover stated that the load was directly applied to the posterior palate that was a thinner cortical bone than anterior area**.** **Lagravere et al 2006**,[69] concluded that more expansion on the posterior part was achieved by surgically assisted expansion. Whereas **Davidovitch *et al*, (2005)** [30] stated that parallel expansion occurred in both anterior and posterior segment of maxilla **.**On the other hand, **Akkaya *et al* (1998)**[2] **and Wertz (1970)**[117] reported that transverse expansion was larger in the anterior part in agreement with the results of the **present study.** The discrepancy among these clinical studies might be due to different appliances, age of the subjects, levels of the maturity of their mid-palatal sutures, or biomechanical systems combined with the shape and density of the palate.

Previous studies showed that the mid-palatal and pterygomaxillary sutures are the primary anatomic resistance to expansion (**Chaconas and**

Caputo, 1982).[22] **This agrees with the high-stress concentrations in the mid-palatal suture in the present FE model**. Interestingly, Nonparallel displacement of the maxillary halves was reported with the wider opening to the anterior **(Lee et al., 2009)**[48]. However, **in the present study transverse expansion in all types occurred largely in the anterior area compared with posterior part of maxilla.** In the region of mid-palatal area**, Type 1- high stress values** were seen in the region between first and second premolar followed by between second premolar and first molar, distal to canine. **Type 2- high stress values** were seen in the region between first and second premolar followed by distal to canine, between second premolar and first molar. **Type 3- high stress values** were seen in the region between first and second premolar followed by between second premolar and first molar, distal to canine. **Type 4- high stress values** were seen in the region distal to canine followed by between first and second premolar, second premolar and first molar. Depth of penetration of concentrated high stress values were seen in type 1 compared with other groups. Uniform distribution of stress were seen in type2 compared with other groups.

In the present study there is a very minimum rotation of alveolar bone buccally in type2 compared with type1, 3 and 4. Of all types, type 2 seemed to be the more efficient bone-anchored maxillary expander because the stress was distributed widely throughout the palate**,** decreasing the stress around the miniscrew implant and resulting in dentoalveolar expansion without buccal inclination of the dentition**.** Therefore, it would be advisable to apply bone-anchored device in adults instead of the tooth-borne expanders.

In the present study, the largest transverse displacement of the dentoalveolar unit was seen in **type 4** followed by types 3, 2, &1. However in **type 2**, alveolar expansion was achieved without buccal inclination of the dentition because the expander was not connected to teeth. On the other hand, type 4 showed more buccal inclination.

In type 4 in order to reduce the bone resistance we have placed three holes in the canine, 1st and 2nd premolar regions with miniscrew implants to reduce the résistance created by mid-palatal suture. But we are not able to come to any fruitful findings in relation to **bone perforations** and needs further research. On observation weaker stress were seen on the mid-palatal suture area, whereas high stress concentration on the alveolar bone around the anchorage teeth. In addition the change in angle between the line connecting the palatal and buccal alveolar crests (B2-B5) before and after the application of force suggesting more dentoalveolar tipping compared with types 3, 1, 2.

A previous study showed that the central incisors moved downward and backward in both solid and fused-suture models but moved **primarily downward** in the patent-suture model **(Lee *et al*., 2009).**[48]However, extrusion movement was reported in surgically assisted rapid maxillary expansion under different surgical conditions (**Han *et al*., 2009, Lee et al., 2012**).[53,112] Also, a clinical study noted downward and forward displacement of the maxilla during expansion **(Doruk *et al.*, 2004)**.[32] **In the present study, all types showed extrusive displacement of the dentoalveolar unit, except type1 and type2. In particular type4 and type3 showed more extrusive movement.**

In the **antero-posterior direction**, the anterior teeth moved lingually except with complicated surgical procedures including Le-FortI, paramedian osteotomy, and pterygomaxillary separation **(Han et al., 2009)**[112].However**, in the present study the displacement occurred anteriorly** in type1 & 2 and posteriorly in types 3 and 4.This might be because types 3 and 4 included the 1st premolar and molar in the design whereas types 1 and 2 were completely bone-borne in agreement with the study done by **Lee et al.,2012**.[53] This inconsistency between the studies might be due to the difference in the model construction and different design of the expanders might have played a role.

Previous studies have shown that the mid-palatal and malar bones, and the zygomaticomaxillary, zygomaticotemporal, and pterygomaxillary sutures had the primary anatomic resistance to expansion.[14,22,73,110] This agrees with the high stress concentrations in the mid-palatal and zygomaticomaxillary sutures in **our FE models**. The deep anatomic effects of the transverse orthopedic forces were observed (a) by the stress in the areas of the zygomatic processes namely the zygomaticomaxillary and zygomatico temporal sutures (b) by the high stress levels in the areas of the maxillary bone, in the maxillary molar area, frontozygomatic suture and frontal process of maxilla.[46]

Interestingly, **nonparallel** displacement of the maxillary halves was reported, with a wider opening in the anterior area; this agrees **with our results**.

Gautam[90] et al evaluated **stress patterns in the craniofacial skeleton** with RME. They showed that the maximum stresses were found along the frontomaxillary, nasomaxillary, and frontonasal sutures. A study using the technique of photoelasticity reported that the stresses generated by the expansion appliance activation during RME produced a demonstrable increase in the stresses at the frontonasal suture.[22] Similarly, a finite element study[25 48,100] evaluating stress distribution along the craniofacial sutures with RME demonstrated that the maximum stresses were experienced by the medial aspect of the frontomaxillary suture, the superior portion of the nasomaxillary suture, and the lateral aspect of the frontonasal suture. Pterygomaxillary suture indicates its rigid interdigitation and high resistance to expansion. **Jafari[4] et al** demonstrated **maximum stresses in the nasofrontal, and nasomaxillary sutures, with considerably lower stresses in the other articulations similar to type 4 in the present study**. **Won moon et al.,[76] 2014** concluded that MARPE groups display significantly less stress around the three main buttresses. In addition the point of force application is at the peak of the palate, which prevents the unwanted dental movement and the bending of the maxillary complex that can often take place in conventional hyrax expansion is in agreement with the findings of the present study.

The **Hybrid hyrax** is effective for RPE and can be employed especially in patients with reduced anterior dental anchorage as stated by **Benedict wilmes et al., 2010**. **Sebastian baumgaertel and Benedict wilmes[16] et al 2013** created a new realistic model for the simulation of rapid palatal expansion treatment by applying **viscoelastic** material properties to the bone. The simulation suggested that hybrid hyrax appliance is a biomechanically effective method for palatal expansion that prevented the side effects of conventional tooth-borne RME. The findings of the above study supports the present study.

Previous studies have evaluated the stress distribution and displacement pattern produced by rapid palatal expansion using different appliances in an average arch models. **The uniqueness of the present study is that we have evaluated the stress distribution and displacement pattern by fabricating four various designs of expanders in an average maxillary arch versus constricted maxillary arch models using finite element method for the first time.** Comparing group-A and B, **Group-B** showed similar pattern of stress and displacement but the magnitude was increased which is attributed to the increase in the depth of the palate. In connection with the above line, recently a study done by (**Yosuke et al 2014)**[119]**,** stated that as the palate deepened the arm strain increased and the effect of RME decreased, modified arm shapes promote expansion of the maxillary dental arch, anchor screws increased the effect of RME generating parallel mid-palatal suture expansion , combining the screws and arms enhances the efficiency of results.

One of the ultimate goals of orthodontics is **long term stability** of the achieved results. **Chamberland**[106] **et al, 2008** concluded that SARPE achieves a net skeletal expansion of 67% of total change compared with 50% in non-surgical expansion group. In previous studies TAD assisted maxillary expansion was used for more skeletal expansion to minimize relapse. Maxillary expansion occurs as a result of skeletal, alveolar bone bending and dentoalveolar. The results of the present study will help us to understand the stress distribution and displacement effect of various RME designs and to customize the hybrid expansion appliance to suite the complexity of problem.

The study involving mathematical modelling based on a dry skull, the results might differ from actual clinical scenario. In such models, although the hexahedron is more accurate than tetrahedron, it produces a complicated design of miniscrew implants as stated by **Lee et al**[100]**.,** 2014. In the previous studies the FEM values were found to be greater when compared with the FEM values of the present study since the results are likely to depend on a patient's level of bone maturity, the skull and the material properties in the study represented those of an adult. To rationalize the use of surgically assisted RME with variability in numerous factors (eg, shape of the palate and other anatomic structures, maturity of the suture, density of the bones) affecting the biomechanical system of maxillary expansion, it would be difficult for 1 FE model to represent every clinical situation. Nevertheless, it can be claimed that FE models suggest what the biologic response will be, especially in patients with similar shapes and properties of anatomic structures. In addition, the 3D FE analyses evaluated only the initial stress distribution and displacement patterns. Therefore, simulation of the full effect of the treatment, including consideration of the biologic factors contributing to the reaction of the maxillofacial structure, is required. The addition of the palatal soft tissues to the model might improve the accuracy of the simulation. Also, the addition of creep strain to the FE model and the application of cycles of force over a period of time might produce a better resemblance to the clinical scenario, and a future clinical study is recommended to assess the effects of the bone-borne expander to evaluate sequential expansion.

Summary and Conclusion

SUMMARY AND CONCLUSION

The **purpose** of the study is to assess the stress distribution and displacement of the maxilla and teeth in an average and constricted arch width models according to different designs of RME using miniscrew implants on a 3D FE model of the skull.

Two groups of FEM models, **Group-A** (average maxillary arch) and **Group-B** (constricted maxillary arch) were constructed. The maxilla including teeth and alveolar bone were sectioned into 1-mm tetrahedrons and the skull sectioned into 5mm tetrahedrons. For the FE modelling a computed tomography scan of a skull is converted to STL file using MIMICS followed by meshing the geometric model. The final constructed FE model is then imported in to ANSYS version 15.0 software. There were 4 designs of rapid maxillary expanders. In type 1-four miniscrew implants were placed 3mm lateral to mid-palatal suture. In type 2-four miniscrew implants were placed beneath the alveolar ridge at the palatal slope: two between the canines and first premolar, two between the second premolar and first molars. The miniscrew implants were connected to expander through an acrylic resin cover. In type 3- two miniscrew implants placed 3mm lateral to mid-palatal suture and connected to the expander with conventional hyrax arms soldered on the first molar. In type 4- conventional tooth-borne appliance assisted by perforations using miniscrew implants in mid-palatal suture at 3 points from the incisive papilla to the last molar, (i) perforation placed distal to canine,

(ii) perforation placed between first and second premolars, (iii) perforation placed between second premolar and first molar were added to the FE models. Expanders were activated transversely for 0.5 mm and force of 45 newtons (N) were applied to achieve sufficient separation of two halves of the maxillary segments. Geometric nonlinear theory was applied to evaluate Von-Mises stress distribution and displacement.

Therefore the conclusions made from the present study are:

1. Type 1 showed high stress concentration in the mid-palatal suture followed by types 2, 3 and 4.
2. Type 4 showed more amount of dentoalveolar displacement followed by types 3, 2 and 1.
3. Type 2 showed uniform amount of stress distribution with minimal dentoalveolar rotation.
4. Group- B showed high magnitude of stress and displacement compared with Group-A which is attributed to the increase in the depth of palate.
5. Customizing RME design (HYBRID) for every individual patients helps us to achieve the desired results with minimum relapse.

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The thesis topic **"THREE DIMENSIONAL EVALUATION OF STRESS DISTRIBUTION AND DISPLACEMENT BY MINISCREW IMPLANTS ASSISTED PALATAL EXPANDER - A FINITE ELEMENT STUDY"**, submitted by **Dr.K.T.SHARANYA DHEVI**, has been approved by the institutional review board of Ragas Dental College & Hospital on 22nd june, 2015.

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ANNEXURE -II

DECLARATION 0F PLAGIARISM CHECK

From,

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To

The Head of the Department
Department of Orthodontics and Dentofacial Orthopedics
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SUB: Declaration of plagiarism check of my dissertation to be submitted to the "The TamilNadu Dr.M.G.R. Medical University"-April 2016.

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Yours Sincerely
K.T. SharanyaDhevi