# EVALUATION OF STRESS DISTRIBUTION AND DISPLACEMENT IN SKULL WITH MINISCREW SUPPORTED MAXILLARY EXPANSION DEVICE – A FINITE ELEMENT METHOD (FEM) ANALYSIS

***Dissertation submitted to***

**THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY**

***In partial fulfillment for the degree of***

**MASTER OF DENTAL SURGERY**

**BRANCH V**

**ORTHODONTICS AND DENTOFACIAL ORTHOPAEDICS**

**MAY - 2019**

# THE TAMILNADU Dr. M.G.R MEDICAL UNIVERSITY

# CHENNAI

## DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation titled **"EVALUATION OF STRESS DISTRIBUTION AND DISPLACEMENT IN SKULL WITH MINISCREW SUPPORTED MAXILLARY EXPANSION DEVICE – A FINITE ELEMENT METHOD (FEM) ANALYSIS"** is a bonafide and genuine research work carried out by me under the guidance of **Dr. Premalatha. M, M.D.S.,** Reader, Department of Orthodontics and Dentofacial Orthopedics, Ragas Dental College and Hospital, Chennai.

**Date:** 6/2/2019

**Place: Chennai**

**Dr. J. Lily**
Post Graduate Student
Department of Orthodontics and
Dentofacial Orthopedics,
Ragas Dental College and Hospital,
Chennai

# CERTIFICATE

This is to certify that this dissertation titled **"EVALUATION OF STRESS DISTRIBUTION AND DISPLACEMENT IN SKULL WITH MINISCREW SUPPORTED MAXILLARY EXPANSION DEVICE – A FINITE ELEMENT METHOD (FEM) ANALYSIS"** is a bonafide record work done by **Dr. J. Lily** under my guidance during her post graduate study period 2016-2019.

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

RAGAS DENTAL COLLEGE Chennai

**Guided by:**

6/2/2019

**Dr. Premalatha. M, M.D.S.,**
Reader,
Department of Orthodontics
Ragas Dental College and Hospital
Chennai.

DEPT. OF ORTHODONTICS
RAGAS DENTAL COLLEGE & HOSPITAL
UTHANDI, CHENNAI-600 119

**Head of Department:**

6/2/2019

**Prof. (Dr.) N.R. Krishnaswamy M.D.S.,**
**M. Ortho R.C.S. (Edin) Dip N.B. (Ortho)**
**Diplomate-Indian Board of Orthodontics**
Department of Orthodontics,
Ragas Dental College and Hospital,
Chennai.

Dr. N. R. KRISHNASWAMY
PROFESSOR & HEAD
Dept. of Orthodontics
RAGAS DENTAL COLLEGE & HOSP
2/102, East Coast Road
Uthandi, Chennai-600 119

**Dr. N. S. Azhagarasan, M.D.S.,**
Principal,
Ragas Dental College and Hospital, Chennai.

PRINCIPAL
RAGAS DENTAL COLLEGE AND HOSPITAL
UTHANDI, CHENNAI-600 119.

# THE TAMILNADU Dr. M.G.R MEDICAL UNIVERSITY
# CHENNAI

## PLAGIARISM CERTIFICATE

This is to certify the dissertation titled **"EVALUATION OF STRESS DISTRIBUTION AND DISPLACEMENT IN SKULL WITH MINISCREW SUPPORTED MAXILLARY EXPANSION DEVICE – A FINITE ELEMENT METHOD (FEM) ANALYSIS"** of the candidate **Dr. J. Lily,** for the award of **MASTER OF DENTAL SURGERY in BRANCH V - Orthodontics and Dentofacial Orthopedics.**

On verification with the urkund.com website for the purpose of plagiarism check, the uploaded thesis file from introduction to conclusion contains **2 percentage** of plagiarism, as per the report generated and it is enclosed in Annexure – II.

Date: 6/2/2019
Place: Chennai

J. Lily

**Dr.J. Lily**
Post Graduate Student,
Department of Orthodontics,
Ragas Dental College and Hospital,
Chennai

M. Premalatha 6/2/2019

**Dr. Premalatha. M, M.D.S.,**
Guide & Reader,
Department of Orthodontics,
Ragas Dental College and Hospital,
Chennai.

DEPT. OF ORTHODONTICS
RAGAS DENTAL COLLEGE & HOSPITAL
UTHANDI, CHENNAI-600 119

# ACKNOWLEDGEMENTS

*I would like to acknowledge and thank my beloved* ***Professor and Head, Dr. N. R. Krishnaswamy, M.D.S., M. Ortho (RCS, Edin), D.N.B. (Ortho), Diplomate of Indian board of Orthodontics,*** *Department of Orthodontics, Ragas Dental College and Hospital, Chennai. I consider myself extremely fortunate to have had the opportunity to train under him. His enthusiasm, integral view on research, tireless pursuit for perfection and mission for providing 'high quality work', has made a deep impression on me. He has always been a source of inspiration to strive for the better not only in academics but also in life. His patience and technical expertise that he has shared throughout the duration of the course has encouraged me in many ways.*

*I am privileged to express my extreme gratefulness to my respected guide,* ***Dr. Premalatha (Reader), M.D.S.****, for her guidance which helped me to complete this study. Her everlasting inspiration, encouragement, constructive criticism and valuable suggestions conferred upon me and has encouraged me.*

*My sincere thanks to* ***Professor A. Kanakaraj, Chairman, Dr. N.S. Azhagarasan, Principal****, Ragas Dental College for providing me with an opportunity to utilize the facilities available in this institution in order to conduct this study.*

*I would also like to acknowledge* ***Dr. Anand (Professor), Dr. Shakeel Ahmed (Professor), Dr. G. Jayakumar (Professor), Dr. Rekha Bharadwaj (Reader), Dr. Shobbana Devi (Reader), Dr. Sriram (Reader), Dr. Kavitha (Reader), Dr. Dhivya Lakshmi (Lecturer)*** *and* ***Dr. Bharath Ramesh (Lecturer)*** *for their support, enthusiasm & professional assistance throughout my post graduate course.*

*My heartfelt thanks to my wonderful batch mates,* ***Dr.Vidhya, Dr.Kowtham, Dr.Bajath, Dr.sheril , Dr.Grace, Dr. Maryam , Dr.Amrutha****, who were cheerfully available at all times to help me. Their support and friendship was constant during these last years, and I deeply appreciate it.*

*I also extend my gratitude to my juniors* ***Dr. Divya, Dr. Deepak, Dr. Muthu, Dr. Pradeep kumar, Dr. Sumin, Dr. Gerard jeevan, Dr. Nandhini,*** *and* ***Dr. Vaishnav*** *for their support.*

*I would like to thank* ***Mr. Ashok, Mr. Manikandan, Mr. Bhaskar, Sister Lakshmi, Sister Yamini, Sister Kanaka, Mrs. Uma,*** *and* ***the Scribbles team*** *for their co-operation and help during my course of study.*

*I would like to thank my friends* ***Dr. Sam Prasanth, Dr. Gopi, Dr. Aparna, Dr. Rishi, Dr. Vidhu*** *and* ***Dr. Santhosh Prabhu*** *for their constant encouragement, support and timely help.*

*I dedicate this study to my family. My husband* ***Dr. Arun Paul Charlu (M.D.S)*** *who has always appreciated me in every endeavours and has taught me* *to get through all the obstacles with clear vision. I would like to thank my parents for their unconditional love and support throughout my hard times in all stages of my life.  My mother* ***Mrs. A. Shebah Jeyasingh*** *and my father* ***Mr. D.John Jeyasing*** *who not only raised and nurtured me but also taxed themselves over the years for my success. A* **special dedication to** *my lovely little princess* **Miss. Ruth Grace** *who is the added spark and happiness of my life .I thank my daughter for her endurance, tender smile, love and understanding. They have been selfless in giving me the best of everything. I take this moment to express my never ending love and respect towards them. A Special and profound thanks to my brother* **J. Solomon** *for always standing by me and his unwavering support. I thank my family and relatives for upholding me with their prayers.*

*Above all I thank the most merciful and compassionate* **Almighty God,** *for his guidance and help throughout my life in all my endeavour and for that I am ever grateful. He has been my way, the light and the truth.*

**CONTENTS**


| S.NO. | INDEX | PAGE NO |
|---|---|---|
| 1. | INTRODUCTION | 1 |
| 2. | REVIEW OF LITERATURE | 5 |
| 3. | MATERIALS AND METHODS | 32 |
| 4. | RESULTS | 37 |
| 5. | DISCUSSION | 43 |
| 6. | SUMMARY & CONCLUSION | 73 |
| 7. | BIBLIOGRAPHY | 75 |
| 8. | ANNEXURES | - |

# *Introduction*

# INTRODUCTION

Transverse maxillary deficiency is a challenging situation, which affects the maxilla in all the three dimensions. It has been reported that 30% of the adult orthodontic patients and nearly 9.4% of the whole population have true maxillary deficiency presented with posterior crossbite.[13] The intraoral clinical features include crowding, reverse over jet, posterior cross bite or even scissors bite in case of severe maxillary constriction.[60]

In these patients dentoalveolar compensation might occur resulting in, proclination of anteriors, buccal tipping of upper posteriors and lingual rolling of lower posteriors. When the upper posteriors tip bucally, the overhanging palatal cusp might cause clockwise rotation of the mandible resulting in an increased lower anterior facial height.[78]

Maxillary transverse expansion (ME) is the treatment of choice for these patients. It was first introduced by **E. C. Angell in 1860**[5] and later developed by **T. M. Graber** in 1940. It was then popularized by **Hass**[39, 40, 41] in 1960s and has been extensively used over the past century. These appliances uses jackscrew like device to apply orthopedic force to split the MPS, separating the two maxillary halves to produce lateral displacement. This procedure was termed as Rapid Maxillary Expansion (RME).

The Haas or Hyrax type appliance uses teeth as anchor unit to apply laterally directed forces. They were called tooth-borne or tissue-borne appliances. In adults with heavily interdigitated and fused mid palatal suture

(MPS), the splitting becomes difficult or almost impossible, so prior to placing RME appliance the suture was split using Surgically Assisted Rapid Palatal Expansion (SARPE) [16].

The effects of RME treatment were extensively studied using CBCT, FEM, Photo-elastic model and Laser hologram[92]. The results showed

1. The opening of MPS is not parallel but in triangle fashion. In axial view the split is more in the incisal region compared to molars. In the coronal view the base of the triangle it is in the incisal region and the apex towards the nasal area. The reason being, high resistance provided by the pterygoid bone and the zygomatic buttress.
2. Dentoalveolar expansion due to buccal tipping of the posterior teeth contributed to 50% of the total expansion. This was because the teeth were used as the anchor unit to direct the force.

To overcome these problems, Mini-screws were added to these RME appliances to apply the force directly to the underlying basal bone. They were called as bone-borne appliance or Miniscrew Assisted Rapid Palatal Expansion.[23, 90]

Many such appliances with different designs have been developed and studied extensively. However, the results showed that the separation of the MPS still followed a triangular fashion, but to a lesser extent than that of the traditional RME and Significant amount of the buccal tipping of the molars were still seen[60, 26].

Authors like **Won Moon, Chuck Carlson, Jay Sung and others**[22], have made certain modifications to Miniscrew Assisted Rapid Palatal Expander and called them as Maxillary Skeletal Expanders. They claimed that their design produced more of parallel expansion of maxillary bone and negligible dental tipping. The changes which are suggested are, **Bi-cortical anchorage** of the **mini-screws implants**, **posterior placement of the implants** and **reduction in the rigidity** of the connecting wire[71].

In the literature, many analysis were conducted to study the stress distribution of these type of Miniscrew Assisted Rapid Palatal Expansion appliances and its effect on the craniofacial complex. But the FE model was obtained mostly from dry skull or only pretreatment CT images. Only **Ludwig**[70] had generated a FE model from a Patient's CT and superimposed the simulated image with that of the actual post treatment Sterolithographic image of the patient.

The aim of the study was to do a Finite Element Analysis (FEA) for the evaluation of stress distribution and displacement of skull with Miniscrew Assisted Rapid Palatal Expander. The Finite Element model was obtained from the CT images of a patient who had undergone maxillary expansion using such a device which followed all the above criteria.

Objectives are: -

1. To compare the simulated results of the FEM to the actual post expansion results of the patient by the means of superimposition

2. To evaluate the magnitude and pattern of displacement of the Cranio-facial complex
3. To evaluate Von Mises stress distribution of the craniofacial bones namely Maxilla, Nasal, Temporal, Sphenoid, Zygoma and the Mandible.
4. To evaluate Von Mises stress distribution in and around (a) Implants, (B) Expander device, (c) upper permanent first Molar.

# *Review of Literature*

# REVIEW OF THE LITERATURE

**Pre and postnatal growth of maxilla:**

The maxilla starts to develop as a maxillary process from the the first brachial arch (mandibular arch). Maxilla develops by intra membranous ossification and grows by the secondary displacement brought about by the growth of cranium till 6 – 7 years of age, followed by primary displacement and drift.

The circumaxillary sutures are arranged in such a way, that the growth of cranial base will push the maxilla downward and forward.[37,12]. The soft tissues present translate the maxillary complex downward and forward and simultaniously bone fills in the space that are opened at the posterior and superior sutures. This downward as well as forward growth of the maxilla is accompanied along with the resorption of the anterior surfaces of the maxilla by the process of surface remodeling.

Studies done by **Bjork and Skieller**[11] with implants showed that the two maxillary halves rotate in relation to each other along the tranverse plane during the stages of development. At the same time the maxilla gets displaced forward in the sagittal plane as well as rotates forward or backward along the vertical plane**.** They also found that, from age of 10 to adulthood, the width between the implants present bilaterally increased up to 9mm in the anterior region and 3mm in the posterior region, which indicated a greater amount of increase in the transverse growth in the posterior region compared to anterior region.

**Midpalatal suture maturation**:

**R. A. LATHAM**[61] 1971 did his study on the development, structure and growth of the mid-palatal suture in humans with 28 specimens which ranged from 6 weeks of embryonic life to 15 years of age. He found that the interpremaxillary suture started to form at about 45 days and the intermaxillary part around 12 weeks. There were three main patterns of growth:

(1) In the Initial time there was purely a sutural type of growth seen until 16 weeks of fetal life;

(2) Then the sutural growth combined with inferior surface remodeling of the entire palate, which was from 16 weeks until about 1-2 years of age which takes place when the growth of suture gets ceased.

(3) Continuous inferior palatal remodeling which happens (including the sutural area) without the growth of the suture. The change of the endosteal side of suture's bony plate, from a resorptive to a depository surface gives a criterion for the sutural growth to cease.

**Melsen. B**[75] 1975 said that the transverse growth of the midpalatal suture continued up to the age of 16 in girls and 18 in boys. On the basis of morphology, the development of the median suture was divided into three stages.

1. In the first stage the suture was short, broad, and Y shaped;
2. In the second stage the suture was more sinuous;
3. In the third stage interdigitation was so heavy that a separation of the two halves of the maxilla would not be possible without fracturing the interdigital processes[30].

The transverse dimension is the first to finish its growth, followed by sagittal and vertical. Due to this the truth about the suture's timing of fusion, and the timing of growth completion becomes the important information in treatment planning. It is a known fact that the midpalatal suture does not fuse fully until the ages of 15-18 years on an average and even in older individuals in some cases. **Bjork**[11] found that the mid palatal stuture fused at an age of 17 years.

**Heinrich wehrbien et al**[96] 2001 studied 30 occlusal radiograph from 10 subjects ranging from 18 to 38 years and compared with the suture morphology, mean sutural width and the degree of suture closure on stained sections and said that even if the suture is not visible in the radiograph the word suture obliteration and fusion should be avoided because he found that, even if suture was not seen in radiograph morphometrically it was not obliterated.

**Britta Knaup**[55] **and Heiner Wehrbein et al**[96] did a histomorphometric analysis of 22 human palate specimens from subjects of different ages (18–63 years) and concluded that the earliest ossification was registered in a 21-year-old man. The oldest subject without ossification was a 54-year-old man and concluded that the ossification of the midpalatal suture is not a valid reason for the increased transversal resistance encountered during rapid palatal expansion in younger subjects (≤ 25 years) as well as in many older individuals.

RME therapy with the Haas expander induces clinically significant and reproducible transverse changes at the dentoalveolar level in patients treated before or after the peak in skeletal growth velocity. Patients treated before the pubertal peak exhibit significant and more effective long-term changes at the skeletal level in both maxillary and circummaxillary structures. When RME treatment is performed after the pubertal growth spurt, maxillary adaptations to expansion therapy shift from the skeletal to the level of dentoalveolar region[39,40,41].

**Fernanda Angelieri et al**[4] studied the Cone-beam computed tomography (CBCT) images of 140 subjects (ages, 5.6-58.4 years) and defined the stages of midpalatal suture maturation in radiograph. He gave five maturational stage of the midpalatal suture which were identified and defined as follows; **stage A** which is a straight high-density line in the suture, with no or little interdigitation. **Stage B** is a scalloped appearance of the high density sutural line. **Stage C** is seen as two parallel, scalloped, high-density lines that are close to each other, separated in some areas by small low-density spaces. **Stage D** is were fusion is completed in the palatine bone, with no evidence of a suture. **Stage E** is fusion present anteriorly in the maxilla.

**Etiology of Maxillary Constriction**

The maxillary deficiency in the transverse plane is called maxillary constriction. The main etiologic factors of this deficiency are mouth breathing, harmful habits, like thumb sucking and/or pacifiers, and atypical phonation and swallowing. The passage of air through the nostrils, purified and warmed by the nasal hair, and the contact of the dorsum of the tongue at rest with the palate are the major stimuli of transverse growth of the maxilla during the craniofacial developmental period. The poor positioning of the tongue, the imbalance of perioral muscles, the lack of lip seal, together with the labial hypo tonicity, contribute to maxillary constriction [39,40,41].

There were no statistically significant difference in the prevalence of maxillary constriction between gender and ethnicity. Transverse deficiencies in maxillary width could be caused by genetic factors, environmental factors or a combination of both. It can also be because of craniofacial syndromes present with maxillary constriction like cleft palate[85,84]. **Harvold, Chierici and Vargervik**[47] did studies with rhesus monkeys and showed that blocking the nasal airways had forced them to convert to obligatory mouth breathers.

This change in the pattern of respiration led to lowering of tongue posture, rotation of the mandible, extrusion of molars and reduced transverse development of the maxilla.

**History of Rapid Maxillary Expansion:**

The use of rapid palatal expansion dates back to the year 1860, **E. C. Angell**[5] published in dental cosmos, a case where he had expanded the maxilla of a fourteen-and-a-half-year-old girl with a completely blocked out canine using thread, nut and two contra rotating screws. He claimed that maxillary expansion was achieved along with the separation of the mid palatal suture in 2 weeks' time. However, his work was criticized and countered by J.H. mcquillin who stated that if the maxilla was to be separated it would become loose[6].

**ANDREW J. HAAS**[39.40,41] in 1965 was a staunch believed of RME and he stated that those who remained indifferent to the RME procedure, notably were Angle, Case, Ketcham, and Dewey, and belived were responsible for its discontinuance in the country. He stated that "These very influential men believed they could gain all the benefits inherent to palatal expansion by conventional expansion of the buccal teeth without the possible risks involved in such a seemingly drastic procedure"[7].

Korkhaus is probably the one responsible for reintroducing the procedure when he visited the Department of Orthodontics at the University of

Illinois in 1956. He had a remarkable cephalometric records of cases treated with palatal expansion which aroused the curiosity of Allan G. Brodie and Haas.

Haas[39,40,41] experimented on pigs, and the salient findings of this study were that, (1) the procedure did not create pain. (2) The resistance offered by the mid palatal suture was minimum. Suture openings of 15 mm in two weeks could be achieved. (3) The mandibular teeth, up righted or expanded probably in response to altered forces of occlusion and change in muscle balance even without treatment. (4) Inter nasal width increased and changes up to 7 mm were recorded.

**Haas**[39,40,41], in 1961, carried out the procedure in pigs and proved the existence of the microscopic events, implicating that the technique employed in patients with atrophic maxilla achieve positive outcomes and the procedure was considered safe and as an alternative for more complicated cases, such as Class II malocclusion associated with posterior cross bite. Thereafter, other appliance designs were proposed with the same purpose as an alternative to correct malocclusions associated with transverse maxillary deficiency.

This concept of splitting the suture by the use of Rapid maxillary expansion protocol in order to expand the maxilla flourished during the early 1900s. These years were referred as the “maxillary expansion years” by both orthodontists and rhinologists. It was during this time that rhinologist Brown and many others, promoted maxillary expansion in order to increase the nasal permeability and to obtain more amount of nasal width[12].

**Issacson et al** (1964)[50,51] 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 became physiologically stable in a shorter treatment time with expansion procedures carried out at lower forces with slower activation. The resistance to the expansion is not mainly from the mid palatal suture but the remaining articulation of the maxilla with the surrounding bone

**Zimring et al** (1965)[50] 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 mid palatal suture which was split 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)[89] 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 a bodily rather than tipping movement. The facial sutures like nasal, maxillary-zygomatic and zygomaticotemporal showed evidence of cellular activity.

**Moss et al** (1968)[77] the other indications of rapid expansion of the maxilla are bilateral or severe unilateral crossbite in class I cases with 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)[95] examined the effects of R.M.E. on the basal bone posterior to the application of the force, showed that not only the maxilla but also the palatine bones moved apart along with the pterygoid processes of the sphenoid bone and splayed 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)[75,74] studied the change in morphology of the palatomaxillary region that takes place during the postnatal period which indicated that the area responding to a heavy functional demand for a mutual displacement of the bones involved were the maxilla, the palatine bone, and the sphenoid bone. A heavy interdigitation could 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)[10] reviewed the effects of expansion on facial structures, dentition, and periodontium. Patients who had lateral unilateral or bilateral posterior cross bites were selected. The constriction was either skeletal, dental, or a combination of both. The magnitude of the discrepancy between the maxillary and mandibular first molar and premolar widths 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.

**Estimate the need of expansion**

**Samir E Bishara**[10] in 1987 said to estimate the need for expansion in which the distance between the mesiobuccal cusp tips of the maxillary molars and the buccal grooves at the middle of the buccal surfaces of the mandibular first molars were measured. The difference between the mandibular value from maxilla for a normal occlusion had to be +1.6 mm (males) and + 1.2 mm (females).

**Raweya et al**[78] 2017 conducted a retrospective cohort research study on a randomly selected sample of 100 subjects. They gave an analysis called Case Western Reserve University analysis (CWRU's) to evaluate dental and skeletal constriction using Cone beam computer tomography. In this they gave the norms as 104 +/- 5 and 100 +/- 4 degree in the angle formed between the Maxillary canine and maxillary first molar respectively to a line tangent to the floor of the nasal cavity. For the mandible 97+/- 3 and 77 +/- 5 degree in the angle formed between the canine and first molar respectively to the line tangent to the lower border of the mandible. They concluded that when this angle increases it's a dental compensation for a skeletal constriction. Whereas when in reduces it indicates a dental compensation for a wide arch.

**Yun-Jin Koo et al in 2017**[57] evaluated the Dental casts and computed tomography (CT) data from 30 Individuals with normal occlusion and 30 with skeletal Class III malocclusions. Using the casts, dental arch widths were measured from the cusp tips, and basal arch widths were measured as the distance between the points at the mucogingival junction adjacent to the respective cusp tips. The Basal arch width's determined from Computed Tomography images were measured from the estimated Centre of resistance of the teeth. Suggesting a combined evaluation of both maxillomandibular BAW-CT difference (−0.39 +/- 1.87 mm) and BAW-cast difference (5.15 +/- 2.56 mm) of the first molar, as the Yonsei Transverse Index for the diagnosis of transverse deficiency.

**Effects of RME on the maxilla**

**Maxillary Halves:- Krebs**[58,59] showed the two halves of the maxilla to rotate in both the antero-posterior and frontal planes. **Haas**[39,40,41] and **Wertz**[97] found the maxilla was most frequently displaced downward and forward. After completion of expansion, the final position of the maxilla, was unpredictable and it was reported that the maxilla returned, partially or completely to its original position, In the frontal plane, the fulcrum of rotation for each of the maxillae was said to be approximately near the frontomaxillary suture. With the help of implants, the tipping of the maxilla was found to be between – $1^0$ and + $8^o$ relative to each other. This tipping also is the reason for expansion between molar and sutural expansions. Tipping of the two maxilla results in less increase in the width at the level of suture rather than the dental arch.

**Palatal vault:- Fried31** and **Haas**[39,40,41] reported that due to the result of the outward tilting of maxillary halves the palatine processes of the maxilla were lowered. Whereas, **Davis and Kronman**[28] reported that the palatal vault remained at its original height.

**Alveolar process**:- Lateral bending of the alveolar processes occurs early during RME due to the resiliency of the bone. Most of the forces applied usually tend to dissipate within 5 to 6 weeks. Rebound happens after stabilization is terminated, if any residual forces in the displaced tissues is allowed to act on the alveolar processes. Therefore, overcorrection of the constricted dental arches to compensate for the subsequent up righting of the buccal segment must be appreciated.[39, 40, 98]

**Maxillary anterior teeth:-** During active opening of the sutures, the incisors separate approximately half the distance the expansion screw has been opened[39,40,41], but the incisors separation cannot be used to determine the amount of suture separation[98]. Because following this separation, the incisor crowns tend to converge and establish contact. If a diastema is present before treatment, the space present originally is either maintained or reduced slightly. Elastic recoiling of the trans-septal fibers was thought to be the cause of the mesial tipping of the crowns. The continued pull of the fibers caused the roots to converge toward their original axial inclinations, once the crowns come into contact. This generally takes about 4 months. The maxillary central incisors seemed to be extruded relative to the S-N plane and in 76% of the cases they were upright or tipped lingually. This movement helped to shorten the arch length and to close the diastema. Whereas, The lingual tipping of the incisors might be caused by the stretching of the circumoral musculature.[39,40,41,98].

**Relation between amount of sutural separation and extent of molar expansion:-**

**Krebs**[58,59] placed implants in the alveolar process lingual to the upper canines and along the infrazygomatic ridge and buccal to the upper first molars, then studied the maxillary expansion with metallic implants.. He found the mean increase in intermolar distance measured on casts to be around 6 mm, while the average increase in infrazygomatic ridge implants was 3.7 mm. In 20 out of 23 patients examined, the distance of suture opening was equal to or lesser than one half the amount of dental expansion. And he also found that sutural opening was on average twice as large between the incisors compared to the molars.

**Maxillary posterior teeth**:-

Because of the alveolar bending and compression of the periodontal ligament that took place initially, it results in a definite change in the long axis of the posterior teeth. **Hicks**[48] found that the angulation between the right and left molars increased at the range of $1^0$ to $24^0$ at the time of expansion. Not all of the above changes are caused due to alveolar bending, but was also partly due to the dental tipping which wass usually accompanied by some amount of extrusion.

**Skeletal and Dental Effects of Rapid Maxillary Expansion:-**

**W. Morgan Davis and Joseph H. Kronman**[28] said that after RME "A" point moves forward as a result of splitting the palatal suture. The angle formed by SN and the palatal plane increased in approximately one half of the cases with a resultant lowering of "A" point. The mandibular plane angle tends to increase, thus opening the bite. In some cases, however, the mandibular plane decreased. No statistically significant changes were observed on the P.A. cephalograms. The intermolar width increases to a greater degree than does the intercuspid width. The mandibular molars have a tendency to follow the expanding maxillary molars. The roof of the vault does not lower as the result of midsutural expansion, but tends to remain at the same height.

**R. E. BROSSMA et al**[14] their finding indicated extensive remodeling to have occurred in the nasal cavity, lateral alveolar processes, inferior surface of the palate, and the floor, lateral as well as medial walls of the orbits. Lateral orbital changes terminated at the zygomatico-frontal suture anteriorly, and fronto-sphenoidal suture posteriorly. Medially, changes were limited to the structures below the fronto-ethmoidal and fronto-nasal sutures. Thus, the roof of the orbits formed by the frontal bone was unaffected by the procedure of maxillary expansion, indicating that all changes in the facial skeleton were restricted to the appendymal structures of the neurocranium. The cranial base remained unchanged.

**Donald J. Timms,**[95] Not only the maxillae but the palatine bones also moved apart, the pterygoid processes of the sphenoid bone splaying outward as far as their inferior portions are concerned.

**Chun-Hsi Chung and Blanca Font**[27] found that there was a slight forward and downward movement of the maxilla, induced by RPE treatment. The amount of forward displacement was small and might not be clinically significant. The mandible moved downward and backward and the anterior facial height increased significantly. Rapid palatal expansion treatment increased the interorbital, maxillary, and nasal widths significantly

**History of MARPE**

**Woods M et al 1997**[99] from the available literature, rapid maxillary expansion (RME) appears to be the treatment of choice for growing adolescents. This technique had however been shown to have a limited effect on mature teenagers and adult patients.

**Persson M, Thilander B in 1977**[83] explained that the progressive closure of the midpalatal suture increases the resistance of the maxilla to expansion in the late teen years.

**Asscherickx K et al 2005**[6] stated that in adult patients, the median palatal suture zone is the area of choice for the placement of palatal implants. In adolescents, however, the paramedian region is preferred I order to avoid possible growth impairment of the maxilla in a transverse direction by placing an implant in the median palatal suture.

**Garib DG et al 2006**[33] stated, 1. Orthodontic effect of RME reduces the buccal bone plate thickness of maxillary posteriors and increases the lingual bone plate thickness. 2. The tooth and tissue-borne expander caused minimal increase to the lingual bone plate thickness of the maxillary posterior teeth than the Hyrax expander. 3. RME induces bone dehiscence in anchor teeth in its buccal aspect, especially in those with thinner buccal bone plates. 4. The hyrax expander produced more reduction of first premolar buccal bone thickness than did the tooth-tissue borne expander.

**Handelman CS**[42,43,44] in 1997 stated that when RME was not feasible, surgically assisted rapid maxillary expansion (SARME) became the choice of treatment in both non-growing adolescents and adult patients. SARME allows for the midpalatal suture to be split and widening of the maxilla possible. SARME was reported to be successful in achieving a clinically significant expansion in non-growing patients.

**M. Y. Mommaerts**[76] 1999 stated that Dental fixation in SARPE entails a number of possible drawbacks such as loss of anchorage and skeletal relapse which could happen during and after the expansion period, cortical fenestration and buccal root resorption. A bone-borne titanium device which had interchangeable expansion modules was used with a callous distraction. The main drawback of this appliance was that they required flap elevation for placement and also increased the risk of infection and root injury.

In 2010, **Lee**[64] et al treated a 20-year old patient with severe transverse maxillary deficiency and mandibular prognathism prior to orthognathic surgery, He used miniscrews to secure the expansion appliance to the palate which was termed as MARPE (Mini Screw Assisted Rapid Palatal Expander)

Based on Lee's studies, **Moon** and **MacGinnis**[71] et al, developed the maxillary skeletal expander with four miniscrews which were placed parallel to the midpalatal suture and to the device.

**Lee et al 2014**[63] stated that the body of the expander should be placed posteriorly as close as possible to the junction of hard and soft palate. Since the greatest resistance against sutural opening is the pterygomaxillary complex. The forces ha to be applied more posteriorly in order to overcome the initial resistance and to bring about parallel opening the MPS. When forces are applied nearer to the center of resistance of the maxilla by means of MSI's, and not to teeth the force system is more favorable because of the homogeneous force dissipation. Which prevents buccal tipping and brings about a more parallel suture opening.

**Finite element analysis:-**

**Tanne et al (1987)**[92] 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 center of rotation of tooth.

**Kazuo tanne et al (1989)**[91] 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 of 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)**[52] evaluated the biomechanical effect of rapid maxillary expansion on the craniofacial complex by using a three-dimensional finite element model of the craniofacial skeleton. The rapid maxillary expansion produces an expansion force near the intermaxillary suture which also produced 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.

**Jafari et al (2003)**[54] evaluated the stress distribution and displacement of various craniofacial structure in his FEM study with RME. In which a V shaped displacement of maxilla was evident from the frontal view. The base of the pyramid was located towards the oral side and the apex facing the nasal bone. In the Occlusal view the two maxillary halve, dentoalveolar complex, base of maxilla, and the lateral walls of the nasal cavity separated more widely in the anterior region.

**Hansen et al (2007)**[45] analyzed the 3-dimensional changes seen in the 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)**[100] 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 analyzed.

The results were as follows:

1. There was lesser amount of compressive and greater amount of tensile stress on the circumaxillary suture area of the maxilla and zygomatic arch during the splitting of the MPS. The greatest stress was seen around the zygomaticomaxillary suture area of the.

2. The upward – forward rotation of the maxilla and zygomatic arch was decreased and also a greater amount of displacement was seen in all frontal, vertical, and lateral view during the opening of the mid-palatal suture,

3. During expansion, the frontal and lateral displacement increased gradually from upper to lower and from posterior to the anterior part of the maxilla, parallel to the zygomaticomaxillary suture line.

4. When directing the protraction force inferiorly from the occlusal plane along with RPE, passing through the center of resistance of the maxilla 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)**[35,36] did a FEM study on stress distribution along craniofacial sutures and displacement of various craniofacial structures with rapid RME therapy. He found that the distant structures of the craniofacial skeleton-zygomatic bone, temporal bone, and frontal bone-were affected by transverse orthopedic expansion forces. RME brings about expansion of the maxilla in both the molar and the canine regions and also causes a downward and forward displacement of the maxilla.

**Provatidis. C. G.(2008)**[86] systematically investigated 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 same method. Moreover, the way that the maxillary halves move away from each other (orthopedic effect) as well as the stress – strain field within the PDL and anchor teeth (orthodontic effect) were analyzed.

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 fibers.

2. FEA of models that consider the mid-palatal suture as unossified and the in-vitro experiment of the dry human skull both suggested 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 occured at the level of the dentition and decreases in an upward direction.

3. The frontomaxillary, nasomaxillary, the transverse palatal sutures, and the pterygomaxillary suture of the sphenoid bone does 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 un-ossified for maxillary expansion to occur.

4. The results showed that the maximum displacements were 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)**[62] developed a method and developed 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 had a downward and backward in both the 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)**[35,34,36,] compared the stress distribution along the various craniofacial sutures during the protraction of maxilla with and without expansion. The overall stresses dissipated after maxillary protraction with maxillary expansion were significantly greater than the protraction with facemask alone. After maxillary protraction the sutures associated with maximum von-mises stress were the sphenozygomatic followed by zygomaticomaxillary and zygomaticotemporal sutures. Great amount of stresses generated along the various craniofacial sutures after maxillary protraction with expansion are responsible for the disruption of the circumaxillary sutural system and probably facilitates the orthopedic effect of the facemask.

**Pawan Gautam et al (2009)**[35,34,36] evaluated two treatment modalities, maxillary protraction alone and maxillary protraction in combination with maxillary expansion and evaluated the displacement of various craniofacial structures. He found Forward displacement of the nasomaxillary complex with upward and forward rotation with maxillary protraction. A tendency for the anterior maxilla to constrict after maxillary protraction was evident. The amounts of displacement in the frontal, vertical, and lateral directions with MPS splitting were greater compared with no splitting of the MPS. Maxillary protraction combined with maxillary expansion appears to be a superior treatment modality for the treatment of maxillary retrognathism than maxillary protraction alone.

**Ludwig et al (2013)**[70] compared of a new viscoelastic finite element model with conventional FE model to accurately simulate rapid palatal expansion with a miniscrew-supported hybrid hyrax appliance. The newly developed visco-elastic model provided a suitable simulation of the clinical effects of the hybrid hyrax appliance.

**Lee et al (2014)**[63] analyzed stress distribution and displacement of the craniofacial structures between 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 portion than at posterior portion. High stresses was seen along the mid-palatal suture and the maxillofacial landmarks in the nonsurgical bone-borne type. Were as lesser in bone-borne rapid maxillary expanders with surgical type. The three 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 adults surgical assistance is required.

**MacGinnis et al (2014)**[84,85] they use finite element method (FEM) to determine the stress distribution and displacement within the craniofacial complex in miniscrew implant-assisted rapid palatal expansion (MARPE).

They concluded that:

1. Compared to the conventional expansion, stress distribution of MARPE showed less propagation to the buttresses as well as adjacent locations in the maxillary complex.
2. By exerting the 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 were sutures are fused. MARPE is also beneficial in young dolichofacial patients by preventing bone bending and dental tipping which can further increase the facial height.

# *Materials and Methods*

# MATERIALS AND METHODS

The sample for this study was selected from the patients, who reported to the Department of Orthodontics at Ragas Dental College and Hospital for routine orthodontic treatment. Ethical approval was obtained from the Institutional Review Board, and informed written consent was obtained from the participant.

The inclusion criteria for this study were 1. Patient above 18 years of age, 2. Constricted maxillary arch. Exclusion criteria were 1. Patients with previous orthodontic treatment 2.Presence of systemic diseases, 3. Patients with syndrome, cleft lip and palate, etc. 4. Severe anterior-posterior discrepancy 5. Grossly decayed or missing teeth.

A 19 year old female patient with a chief complaint of forwardly placed upper front teeth was selected for this study. The patient had a skeletal class II and Angle’s class II malocclusion. The pretreatment records included study models, CT, OPG, Lateral cephalogram and posterior-anterior view (which were generated from the CT).

The cephalometric analysis showed a skeletal class II with SNA- $88^0$, SNB- $82^0$, ANB- $6^0$, MP-$24^0$, Upper 1 to NA-$32^0$ and NB-$26^0$ (Fig:- 7,10. Table- 1)

(Fig: - 1-6). The model analysis done were as follows:-

1. **McNamara analysis**[76] of inter molar width showed 29.1mm (Average 30mm). (Fig:- 12)
2. **Andrew's**[90] upper molar basal arch width (52.2mm) to lower molar basal arch width(54.3mm) difference showed -2.3mm, (Fig:- 13)

Both **McNamara and Andrew's** showed a constriction of the maxillary arch.

The CT showed, a Midpalatal suture stage corresponding to the D stage, according to the classification of Angelieri[46]. The analysis that was done with CT were:-

1. **Yonsei's index**[77] BAW-cast difference was 11mm (average 15 +/- 2.56 mm), BAW- CT difference was 2.9 mm (−0.39 –/+ 1.87 mm), (Fig:- 14,15,17,18)
2. **Case Western Reserve university analysis**[78] for the upper right molar angle was 101.3$^{o}$ and upper left molar was 106.5 (100 +/- 4$^{o}$). Lower molar angle was 75.7$^{o}$ in the right and 72.3$^{o}$ (77+/- 5$^{o}$) in the left. (fig:- 19,20)

Both Yonsei's index and Case Western Reserve university analysis showed a maxillary arch constriction and dental compensation which had taken place. Therefore the patient was diagnosed with true maxillary transverse deficiency which indicated the need for expansion.

**Treatment progress**:-

The patient was decided to be treated with Miniscrew Assisted Rapid Palatal Expander. The time taken to start the treatment from the day that the patient reported took was over 5 months. The Miniscrew Assisted Rapid Palatal Expansion appliance consisted of four MSI's placed in line with the maxillary first molar. The dimensions of the MSI's were 1.8mm in diameter and 11mm in length which was sufficient enough to have a bi-cortical bone engagement. The connecting arms were of diameter 1.2mm which were soldered to the band of the first molar.

The appliance was activated 2 turns per day till the appearance of midline diastema clinically, followed by one turn per day till the required expansion was achieved. The total active treatment for expansion was 2 weeks'. The immediate post expansion impression and CBCT (Fig- 21, 22) which was taken, showed an expansion of 5.4mm in the ANS and 5mm in the PNS.

There was a near parallel expansion which could be appreciated in the CBCT.

**Generation of FE model**: -

A three dimensional FE model of the cranium, face, maxilla and mandible was generated using volumetric data from the pretreatment computed tomography Scan images of the patient. The computed tomography images were taken in slices of 1mm thickness from the vertex to the chin.

(Fig:- 23 - 28), 11 The DICOM CT images was converted to .STEP FORMAT using CREO parametric version 2.0. The .STEP format was imported to CREO parametric version 2.0, for geometrical clean-up of cranium, facial bone, maxilla and mandible, along with geometrical modelling of the implants, appliance and band. The assembly of all the objects was done using the same software.

The final assembled CAD model, were then imported to HYPERMESH software, for the conversion of Finite element model of the cranium, Facial bone, Maxilla, mandible and the appliance as a whole.

(Fig:-29), The finite element model was imported to ABACUS 6.13 software were the model was prepared for analysis set up, which includes steps like assigning the material properties (Table -2), applying the contact, interaction, loading and boundary conditions. The tight contacts are given in between the areas like, the band and teeth, as well as band and arm. The same way Surface contact were given between the sliding rod and the appliance, and also between implants and the appliance.

(Fig:- 30, 31) The interaction between the condyle and glenoid fossa were given a coupling form of interaction, which will make the mandible to behave like a hinge along the glenoid fossa.

(Fig:- 33) The loading arm was given in the region of the four screws. All the degree of freedom was arrested for the center rod of the appliance and the Foramen Magnum. The FE model was obtained

(Fig:- 34, 35) The MARPE appliance in the FE model was loaded with 5mm of displacement in the loading arms, which was 2.5 mm on each side. After this, the post expansion FE Model was obtained. To further validate the results, it was superimposed with the post expansion CBCT generated STL model. Since the post CBCT image had lot of noise due to the presence of the metal and also was taken in occlusion, the occlusal one third of the scanned post expansion digital model was used to create the occlusal surface of the post expansion STL image.

After validating the post expansion FE model the amount of displacement and stress distribution were seen in individual bones, in and around implants, maxillary permanent molars, Miniscrew Assisted Rapid Palatal Expander appliance and mandible.

# Figures

# FIGURES

**Fig: - 1. Pretreatment digital model of the maxillary arch - occlusal view**

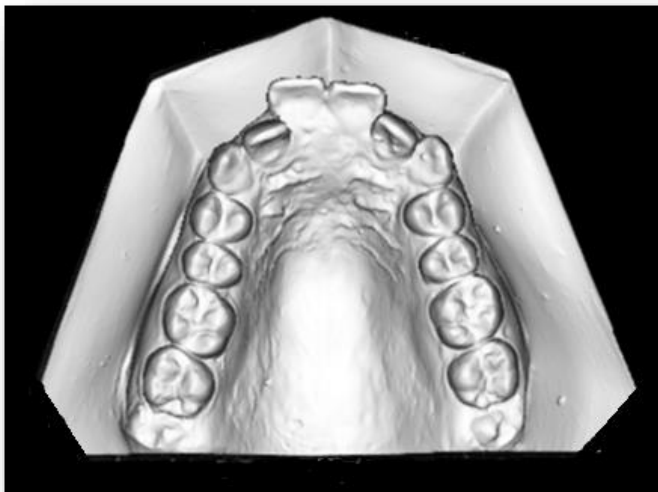


**Fig: - 2. Pretreatment digital model of the mandibular arch - occlusal view**

**Fig: - 3. Pretreatment digital model in occlusion- right side**

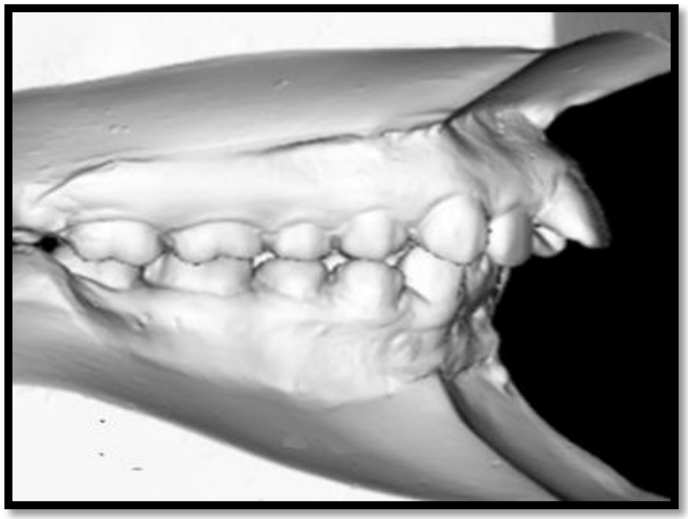


**Fig: - 4. Pretreatment digital model in occlusion- left side**

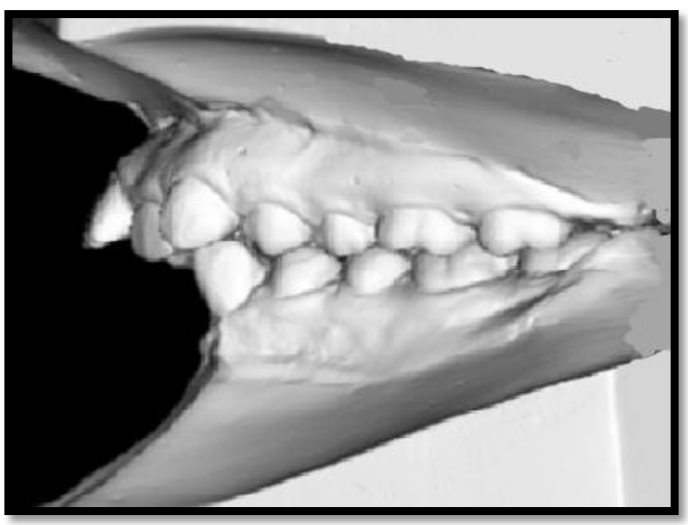


**Fig: -5. Pretreatment digital model in occlusion- frontal view**

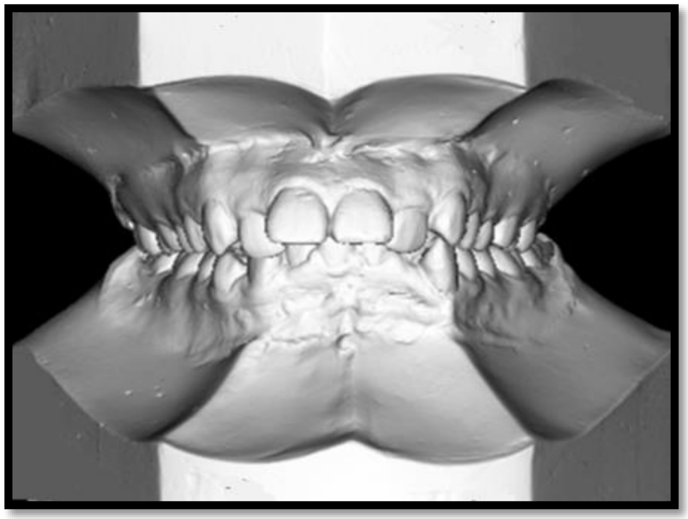


**Fig: -6. Pretreatment digital model in occlusion- lingual view**

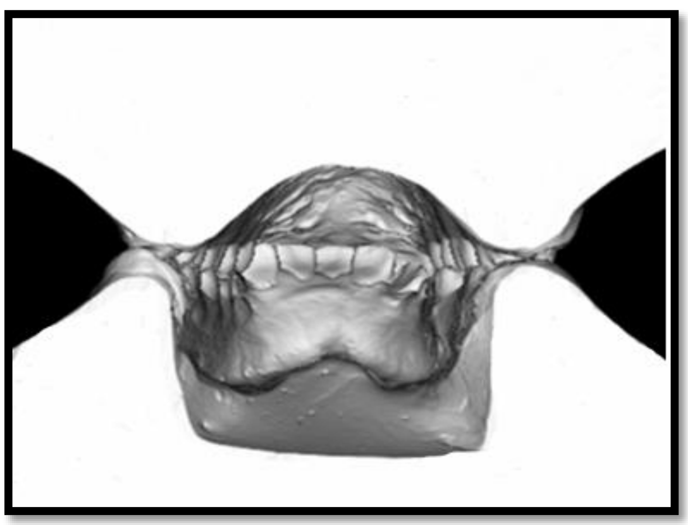


**Fig: - 7. Pretreatment lateral cephalogram**

**Fig: - 8. Pretreatment OPG**

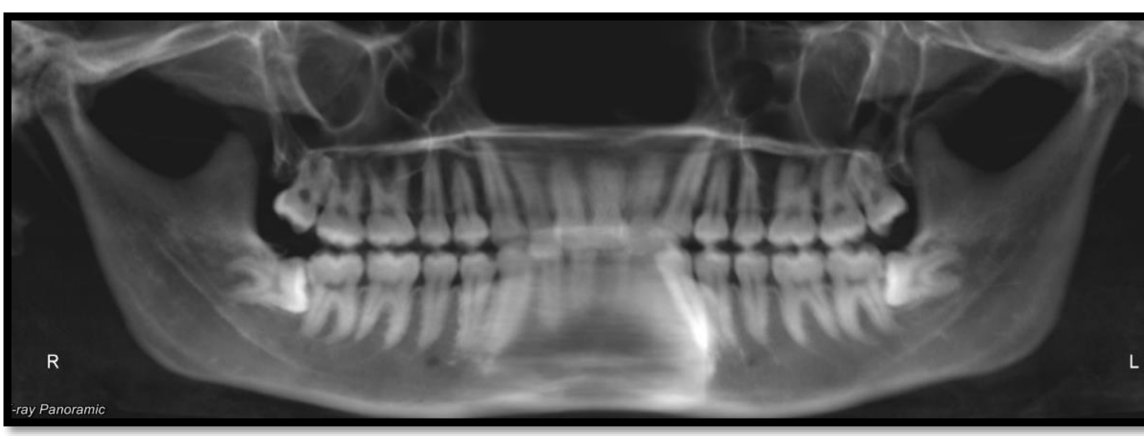


**Fig: - 9. Pretreatment posterior-anterior view.**

**Fig: - 10. Lateral cephalogram analysis and measurements – Steiner's**

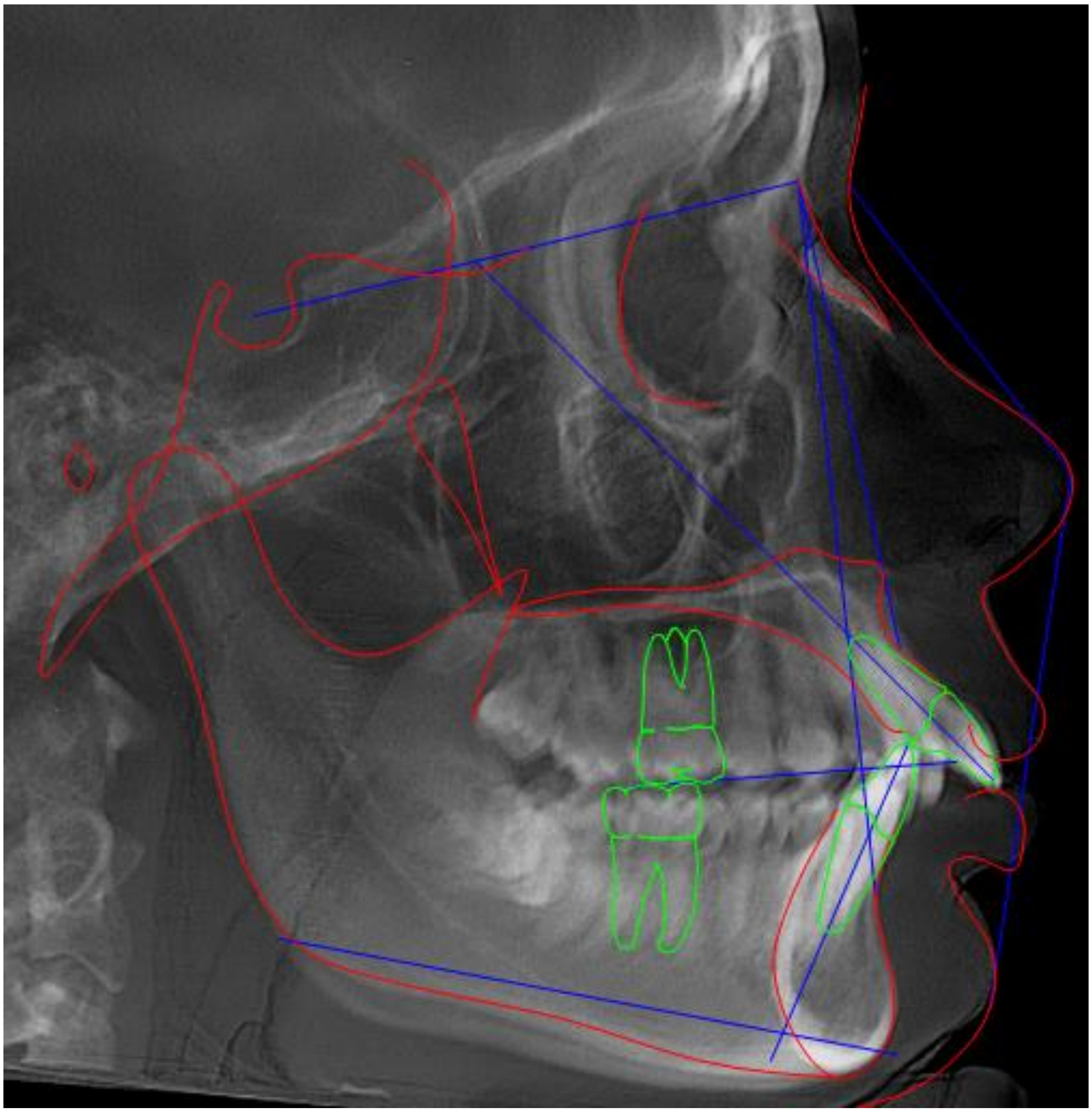
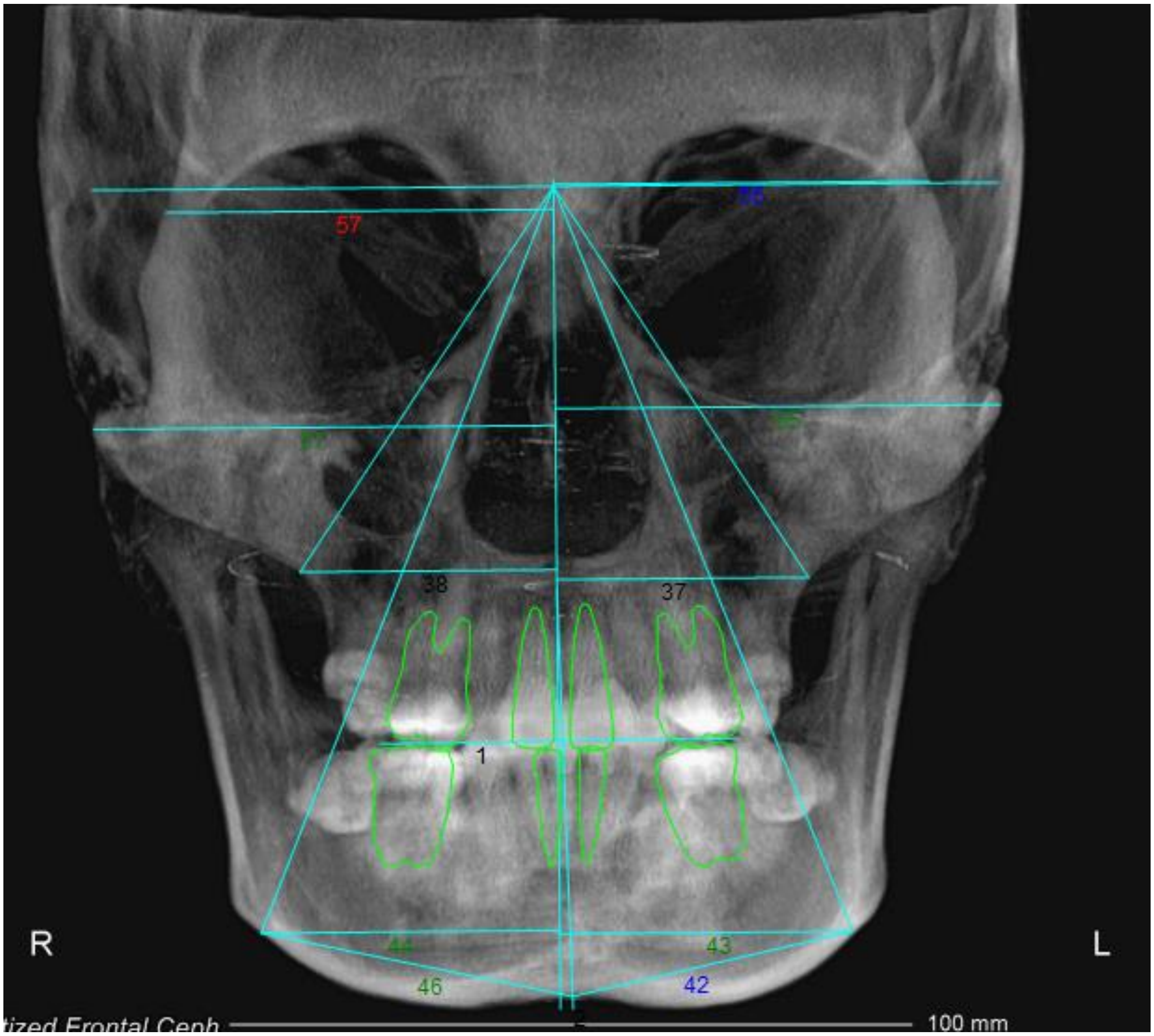


**Fig: - 11. Posterior – anterior view analysis and measurements – Grummons**



**MODEL ANALYSIS**

**Fig: -12. McNamara's model analysis for transverse discrepancy- maxilla. (inter molar width)**

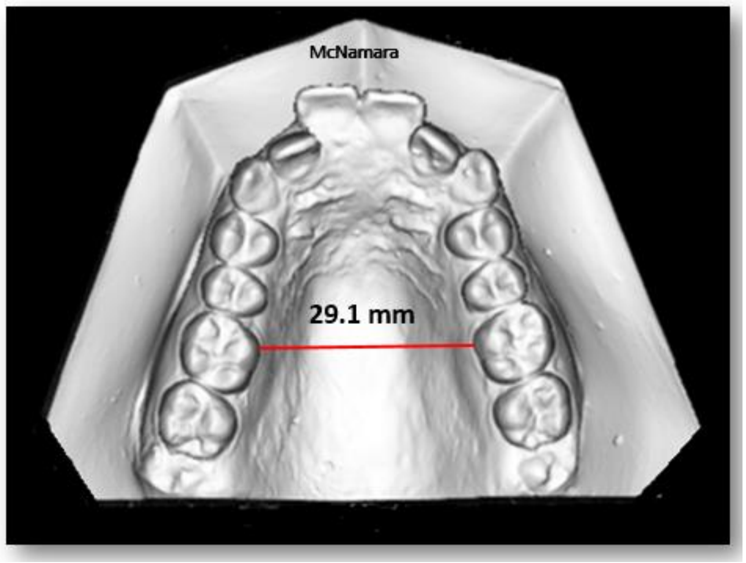



**Fig: -13. Andrews's model analysis for maxillary and mandibular base width.**

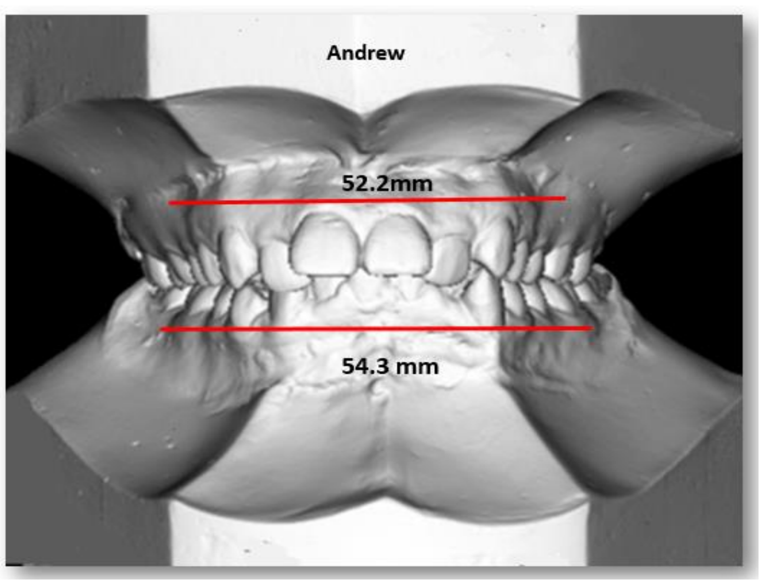


**Fig: - 14. Yonsei's analysis – maxillary arch (inter canine, inter premolar and inter molar width).**

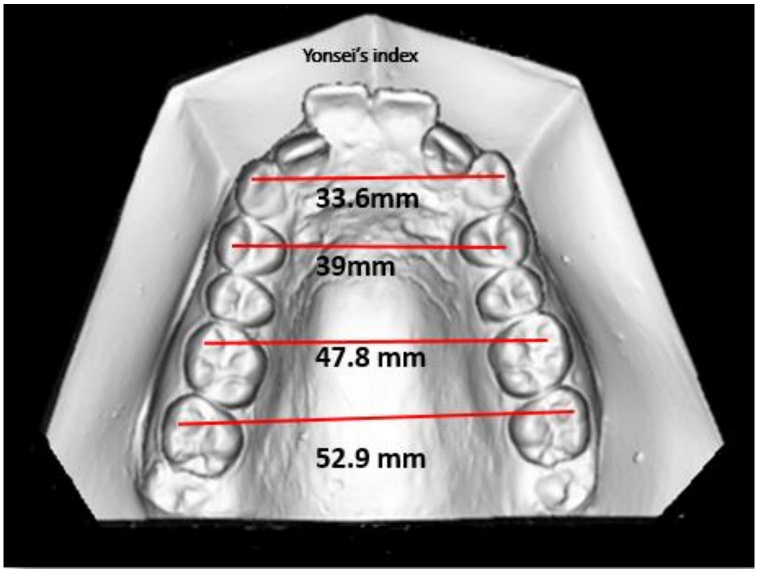



**Fig: -15. Yonsei's analysis – maxillary arch (inter canine, inter premolar and inter molar width).**

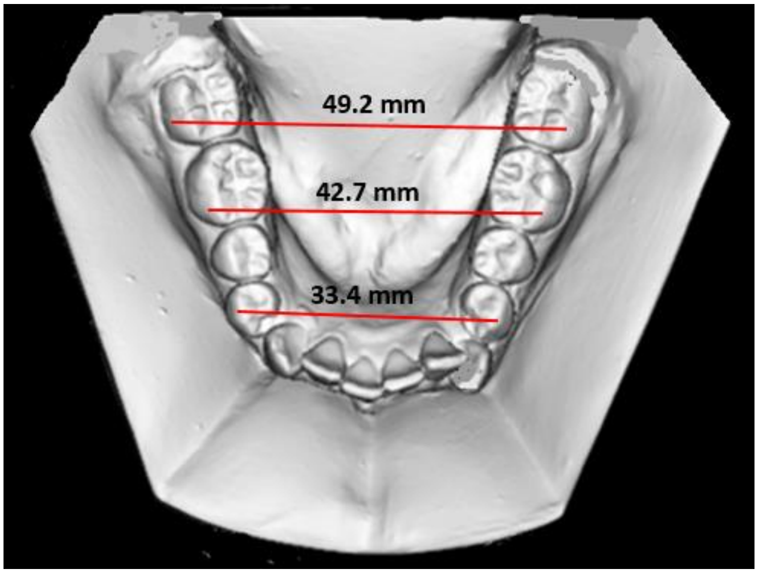
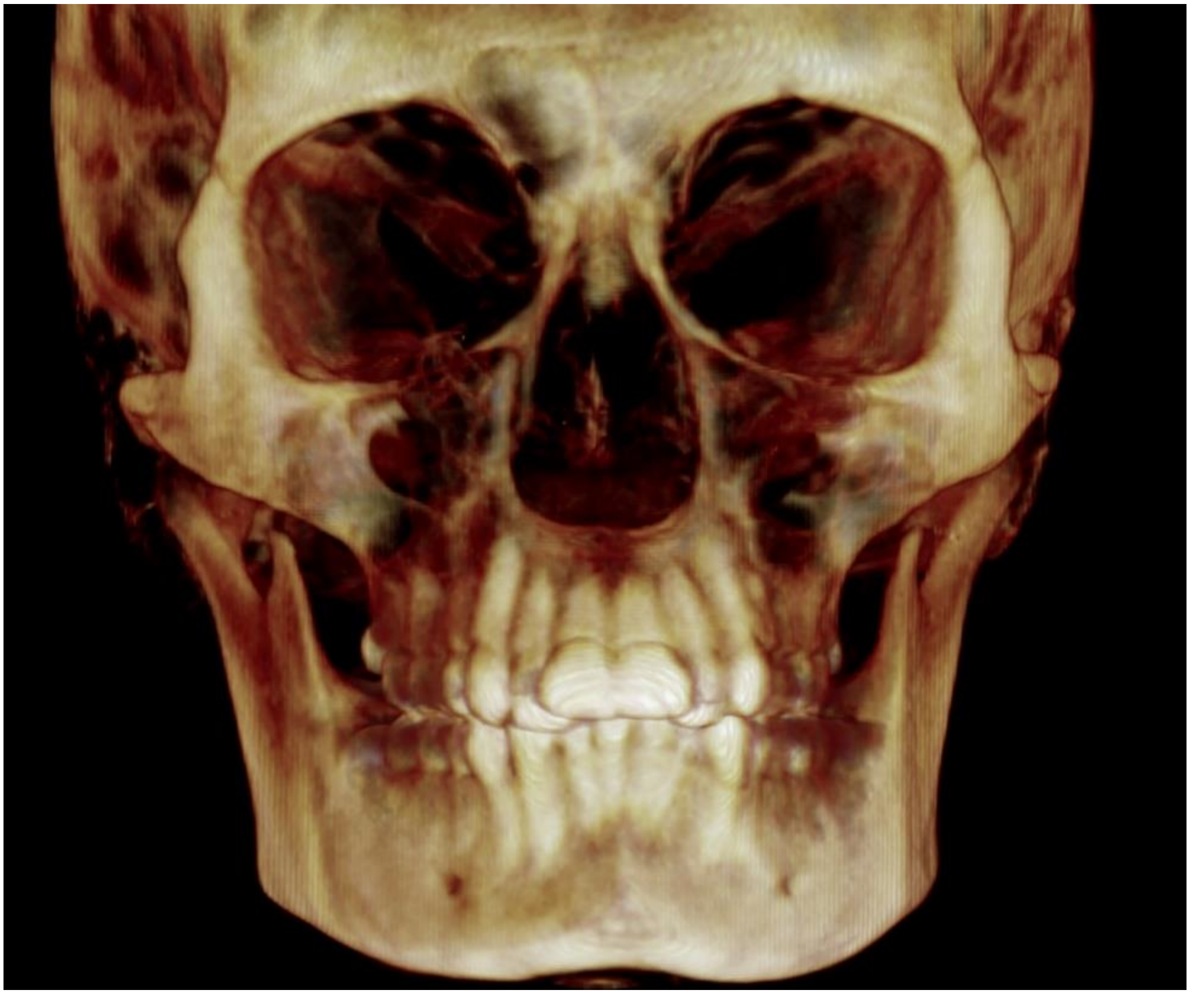


**Fig: -16. Pretreatment CT image- frontal view**



## CT ANALYSIS

**Fig: -17. Yonsei's analysis – maxillary arch (axial view at the level of molar root bifurcation).**

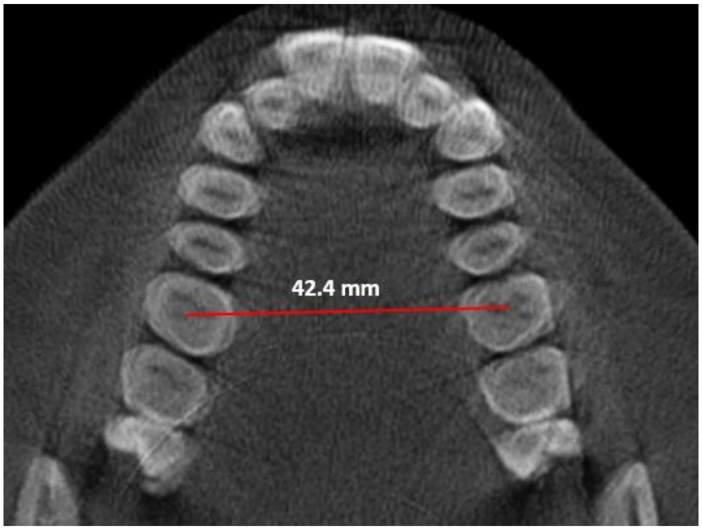



**Fig: - 18. Yonsei's analysis – mandibular arch (axial view at the level of molar root bifurcation).**

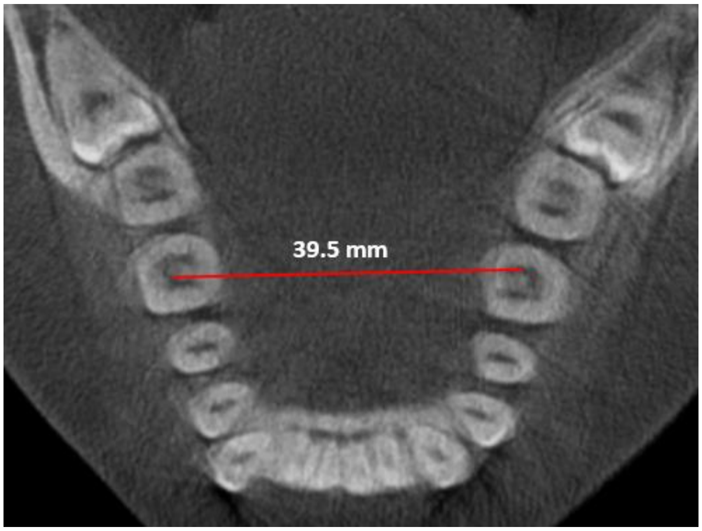


**Fig: - 19. CWRU's analysis- maxillary molar angulation in relation to nasal floor**

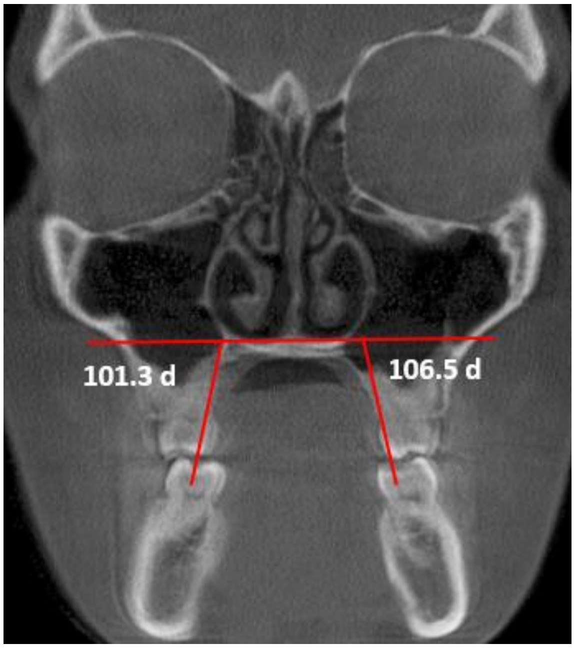



**Fig: -20. CWRU's analysis- mandibular molar angulation in relation to lower border of mandible.**

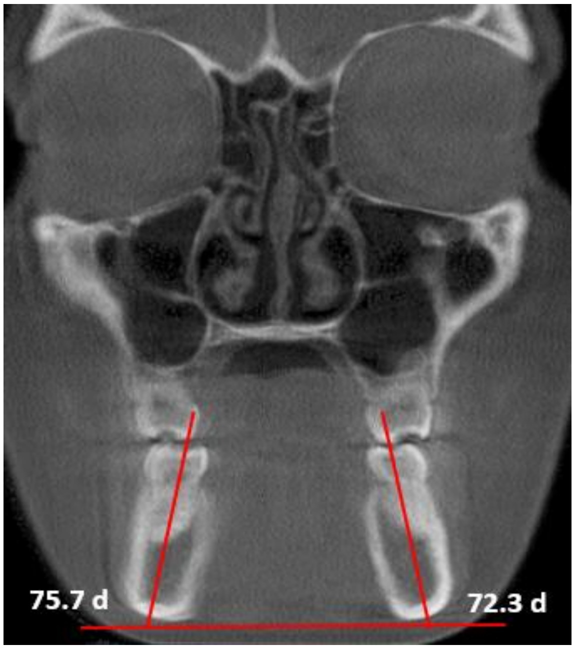
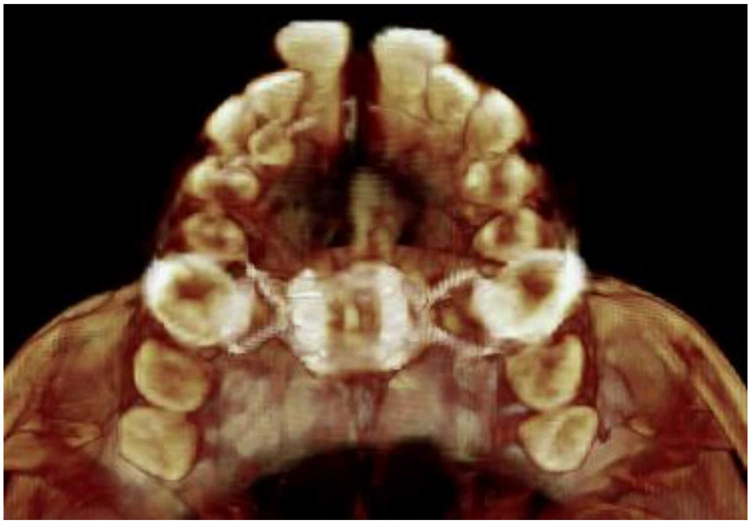


**Fig: -21 (a). Post treatment scanned model – Occlusal view**

**Fig: -21(b). Post treatment scanned model – frontal view**

**Fig: -21(c). Post treatment CBCT- frontal view**

**Fig: -22. Post treatment CBCT- occlusal view**



**STEP BY STEP GENERATION OF THE FINAL FE MODEL**

**Fig: - 23. Pretreatment CT- frontal view**

**Fig: - 24. Complete solid model of the skull- frontal view**

**Fig: - 25. Solid model of the cranium- frontal view**

**Fig: -26. Solid model of the mandible - frontal view**

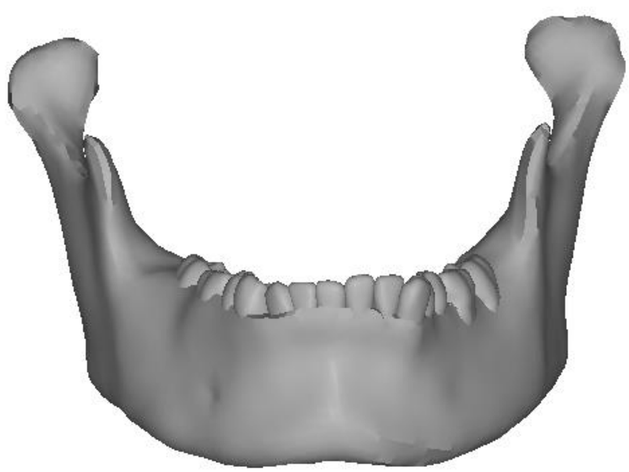


**Fig: -27. Generated solid model of the expander device with implants- frontal view**

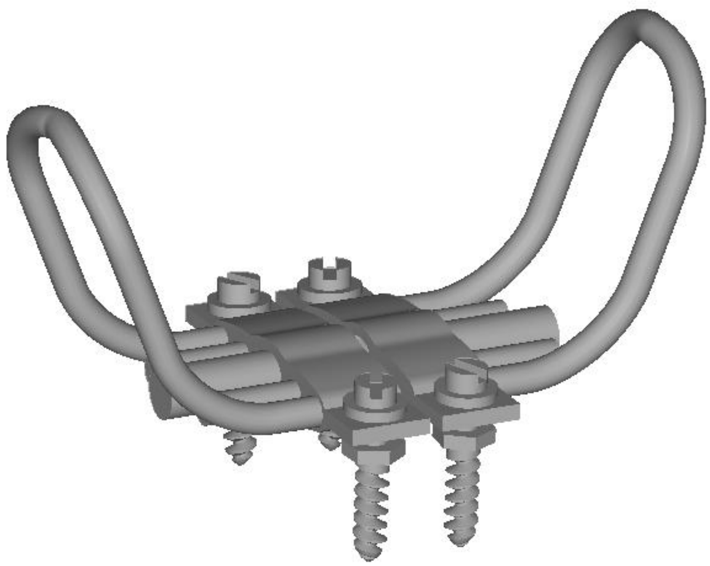


**Fig: -28. Generated solid model of the expander device with molar bands- occlusal view**

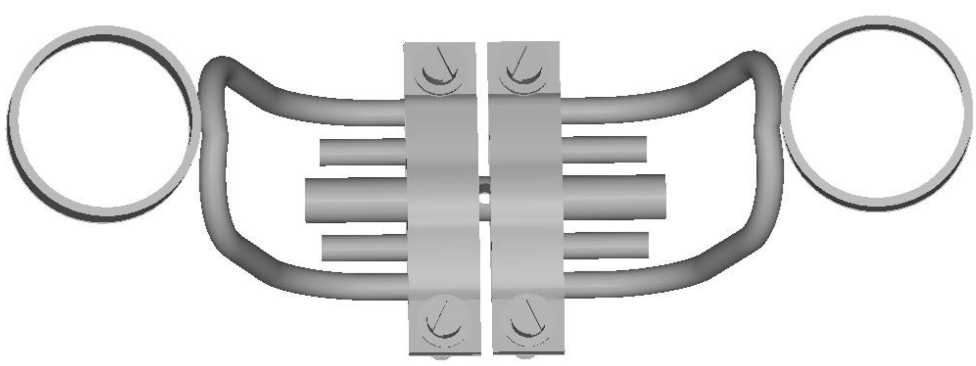


**Fig: -29. Assembly and assignment of the material property**

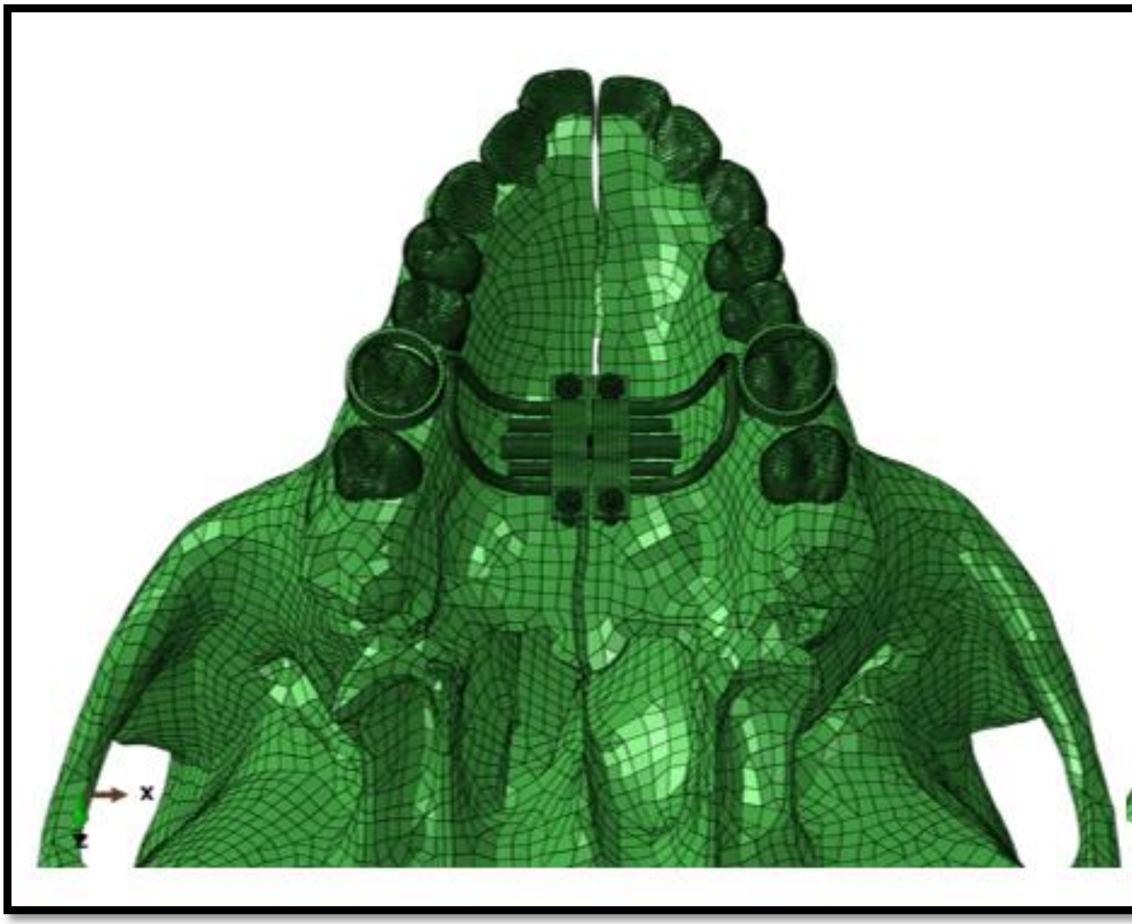


**Fig: - 30. The interaction of contact surfaces of FE model- occlusal view**

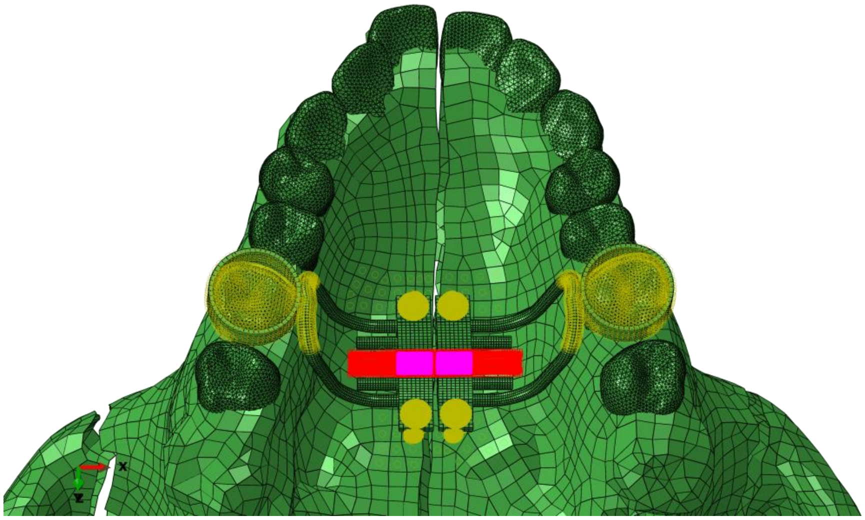


**Fig: -31. Interaction of the condyle to the glenoid fossa – sagittal view**

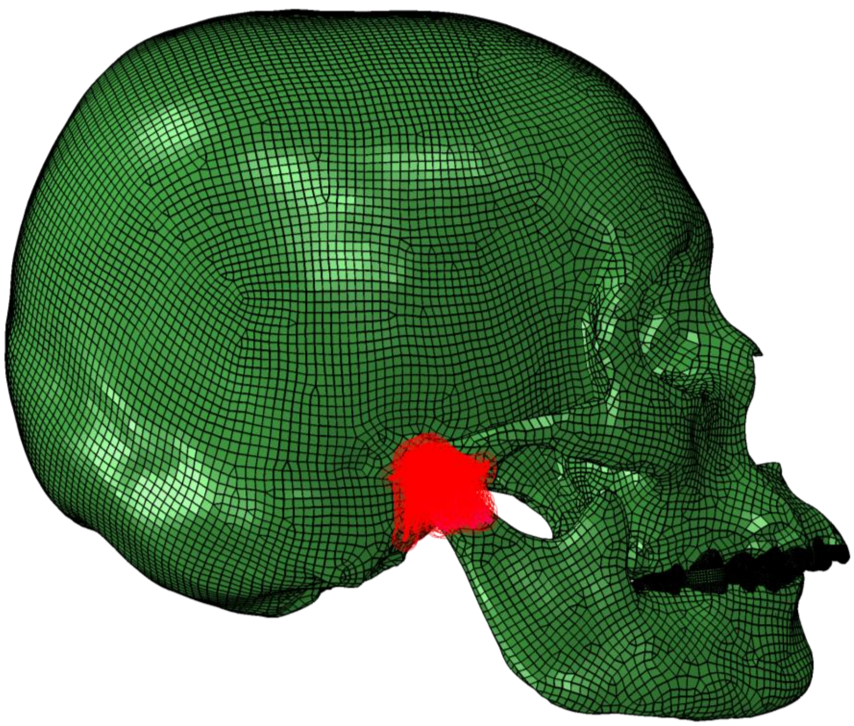


**Fig:- 32. Constrain of all degree of freedom in foramen magnum - occlusal view**

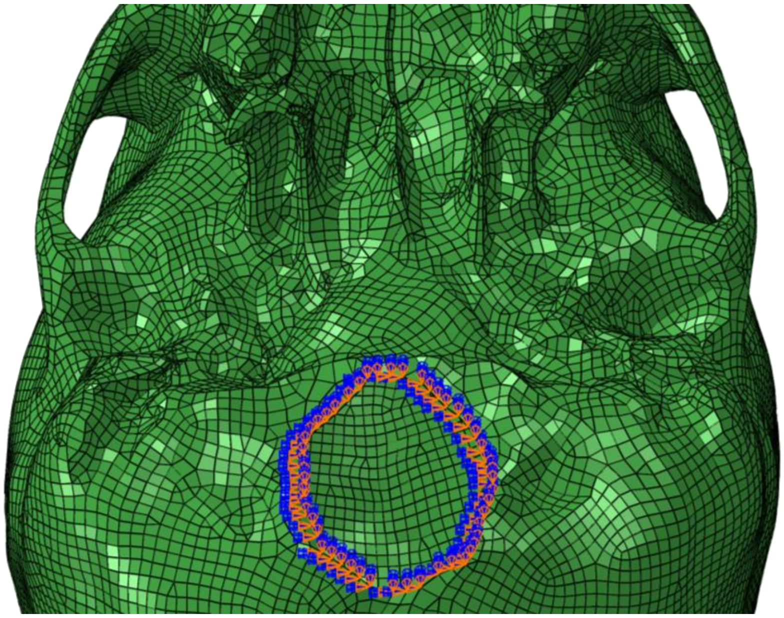


**Fig: - 33. Point of load application- occlusal view**

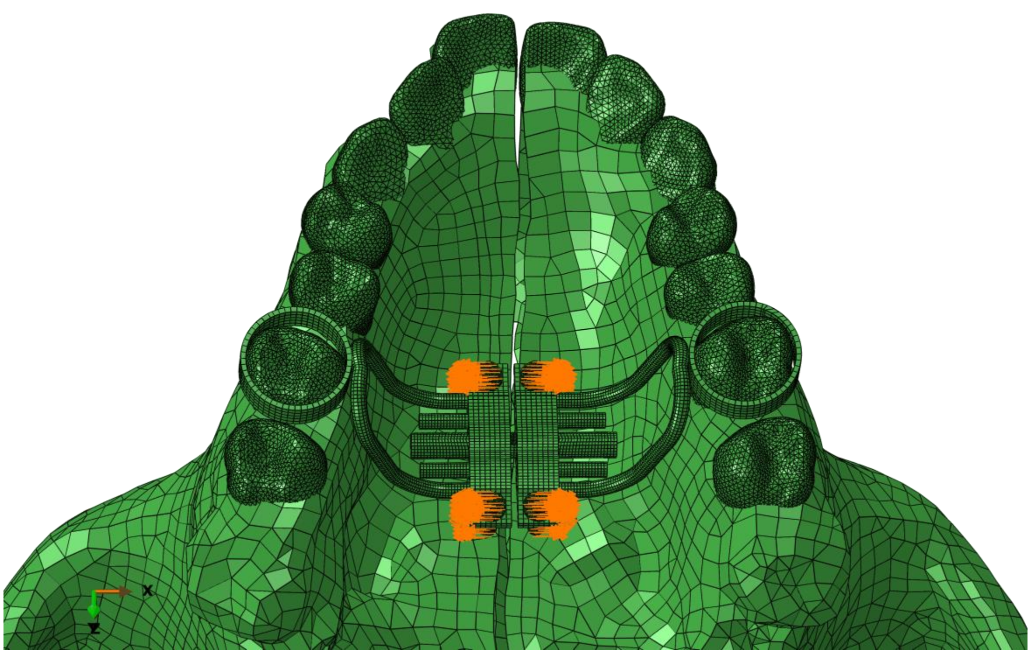


**Fig: -34. Completely generated FE model prior to loading- Frontal view**

**Fig: - 35. Simulated FE model after loading- Frontal view**

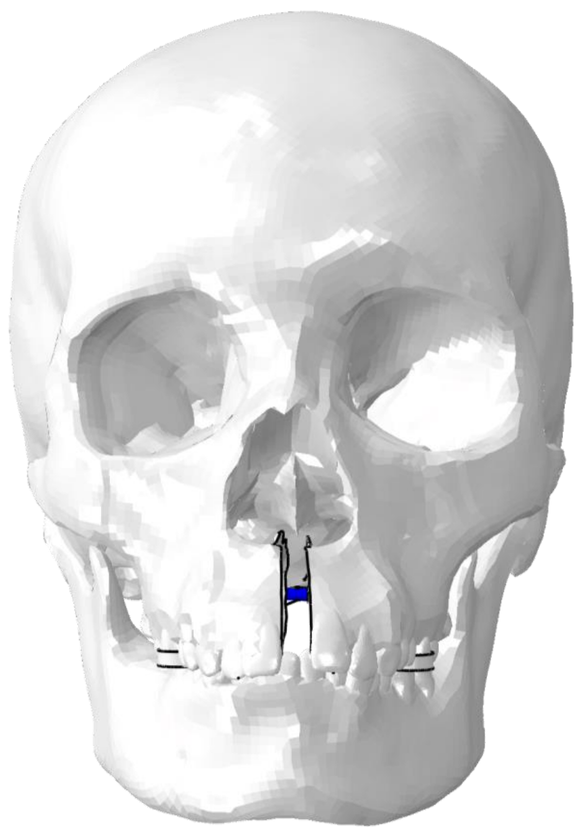


**Fig: - 36. Superimposition of the post expansion STL model generated from the patient's CBCT with simulated FE model- frontal view**

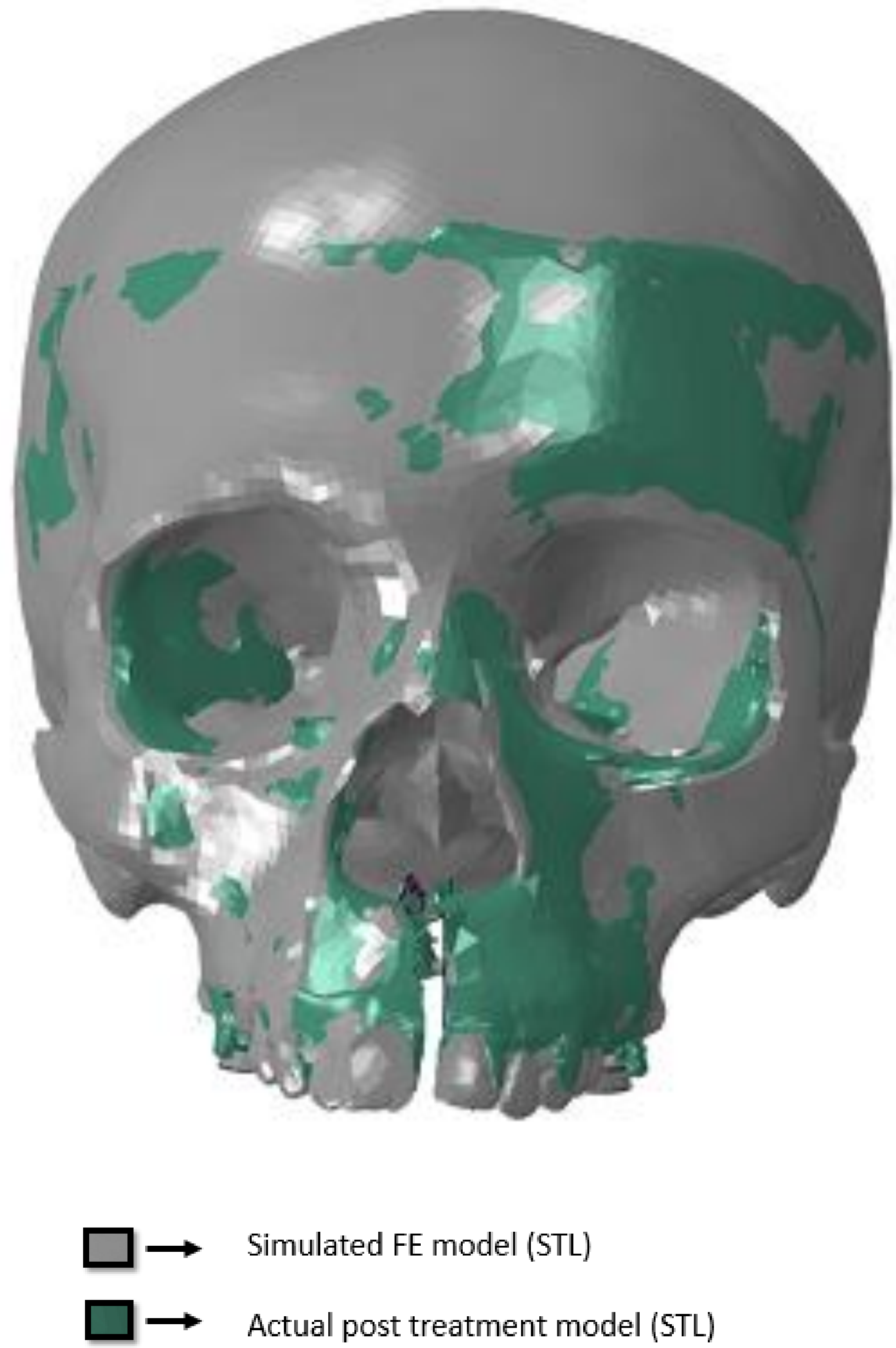


**Fig: - 37. Superimposition of the post expansion STL model generated from the patient's CBCT with simulated FE model- right sagittal view**

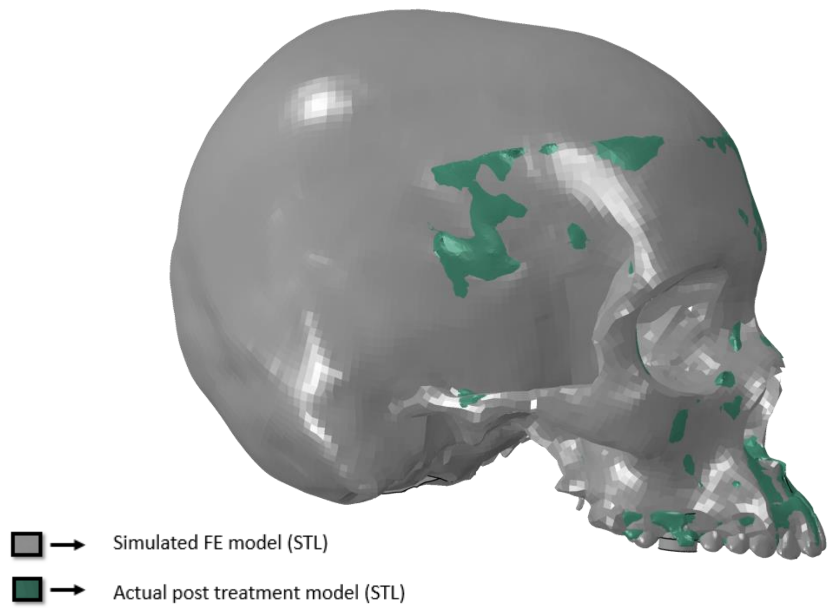



**Fig: - 38. Superimposition of the post expansion STL model generated from the patient's CBCT with simulated FE model- left sagittal view**

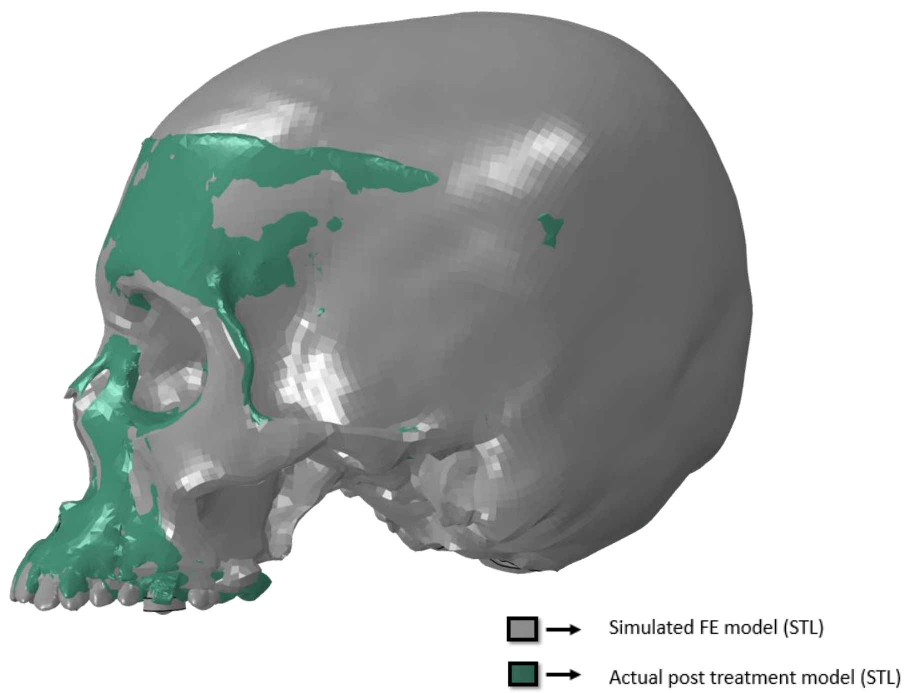


**Fig: -39. Superimposition of the post expansion STL model generated from the patient's CBCT with simulated FE model- occlusal view**

# DISPLACEMENT

**Fig: - 40. Magnitude and pattern of displacement- frontal view**

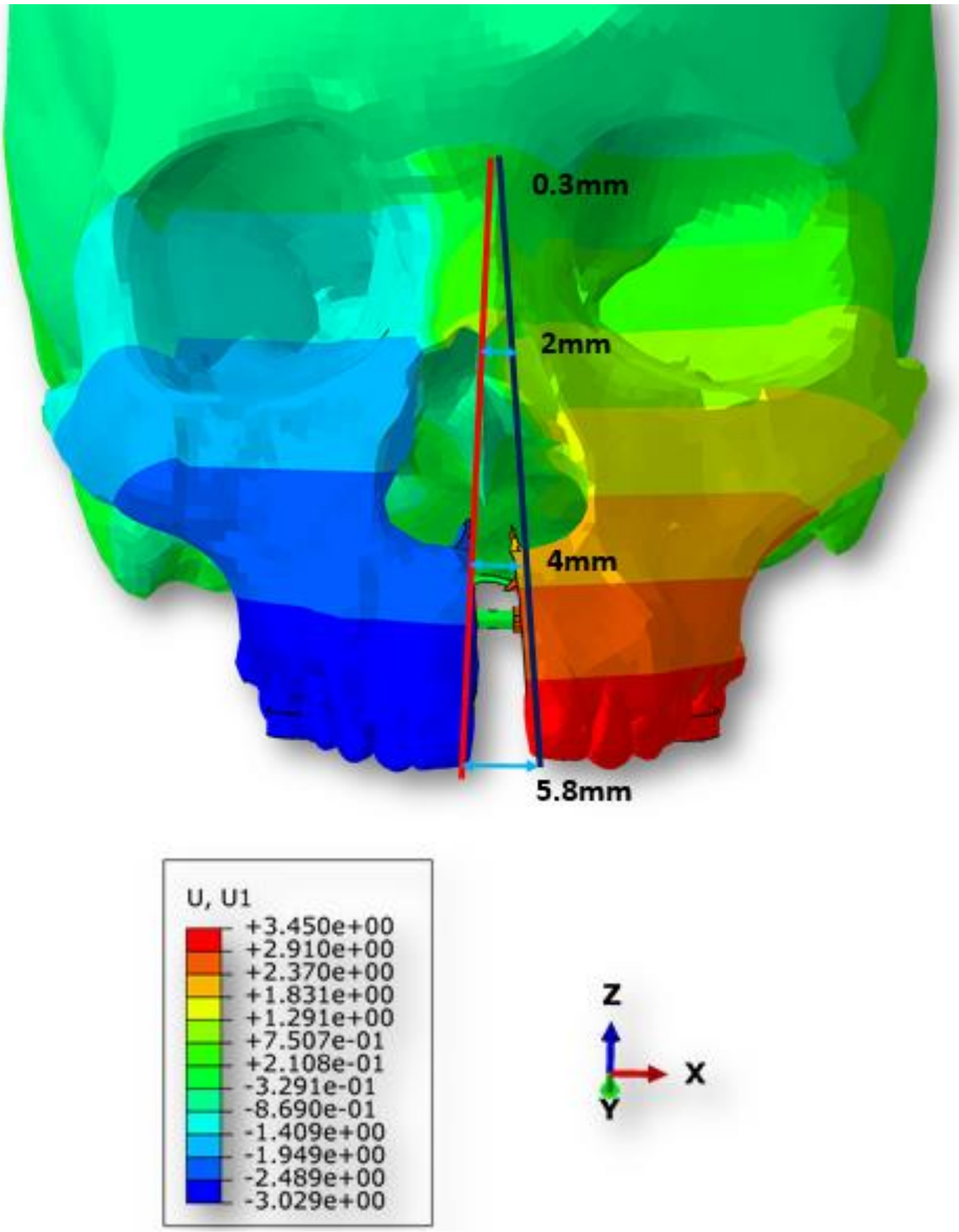


Fig: -41. Reference points- frontal view

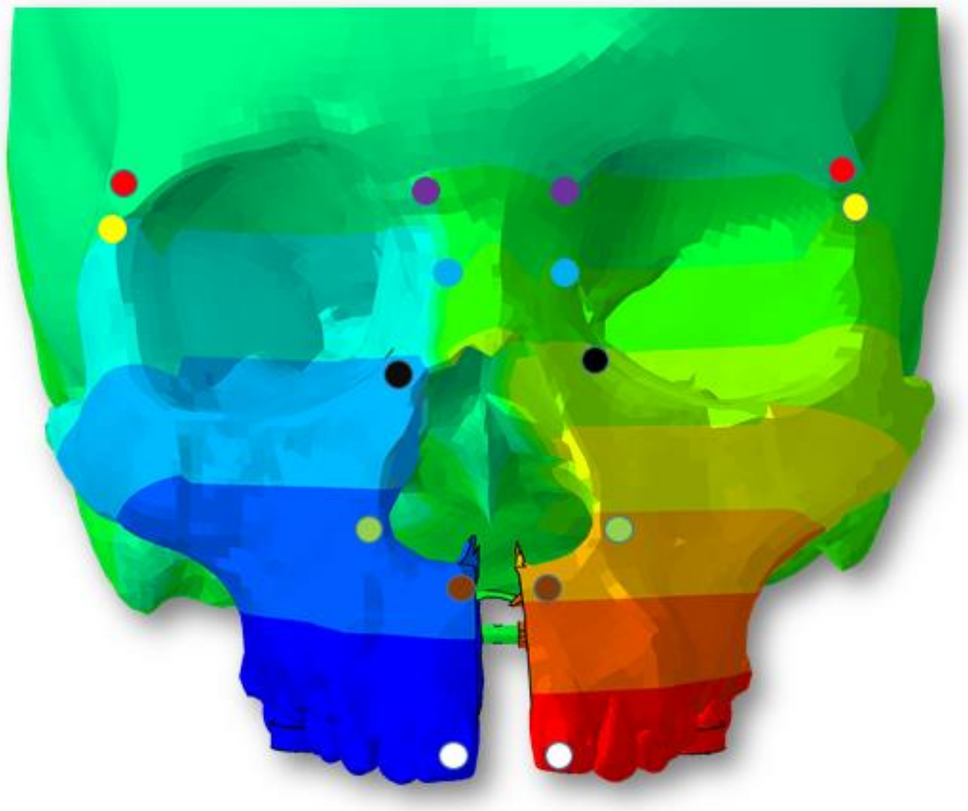


Fig: -42. Landmarks and reference points- frontal view

| Colour | Landmark | Element ID right | Element ID left |
|---|---|---|---|
| | Superior to Fronto-zygomatic suture (SFZS) | 414326 | 416915 |
| | Inferior to Fronto-zygomatic suture (IFZS) | 431641 | 432491 |
| | Fronto-maxillary suture (FMS) | 439488 | 439404 |
| | Frontal process of maxilla (FPM) | 439456 | 437505 |
| | Maxilla in line with inferior rim of orbit (OR) | 435601 | 437548 |
| | Lateral aspect of the nasal notch (NN) | 433650 | 438137 |
| | Anterior nasal spine (ANS) | 438542 | 438541 |
| | Incisal edge | 359020 | 347737 |

**Fig: -43. Magnitude and pattern of displacement- sagittal view**

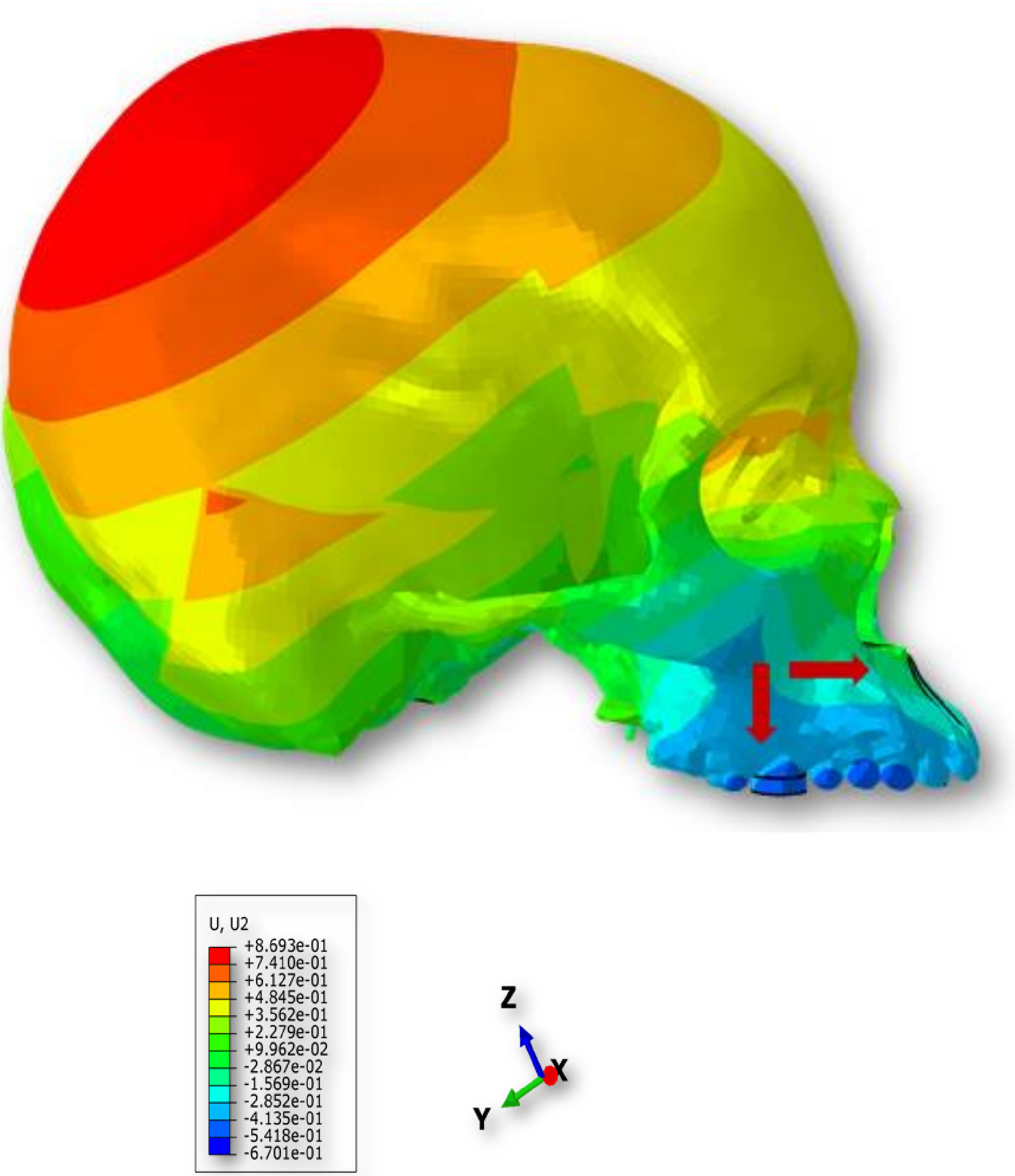


**Fig: -44. Reference points- sagittal view**

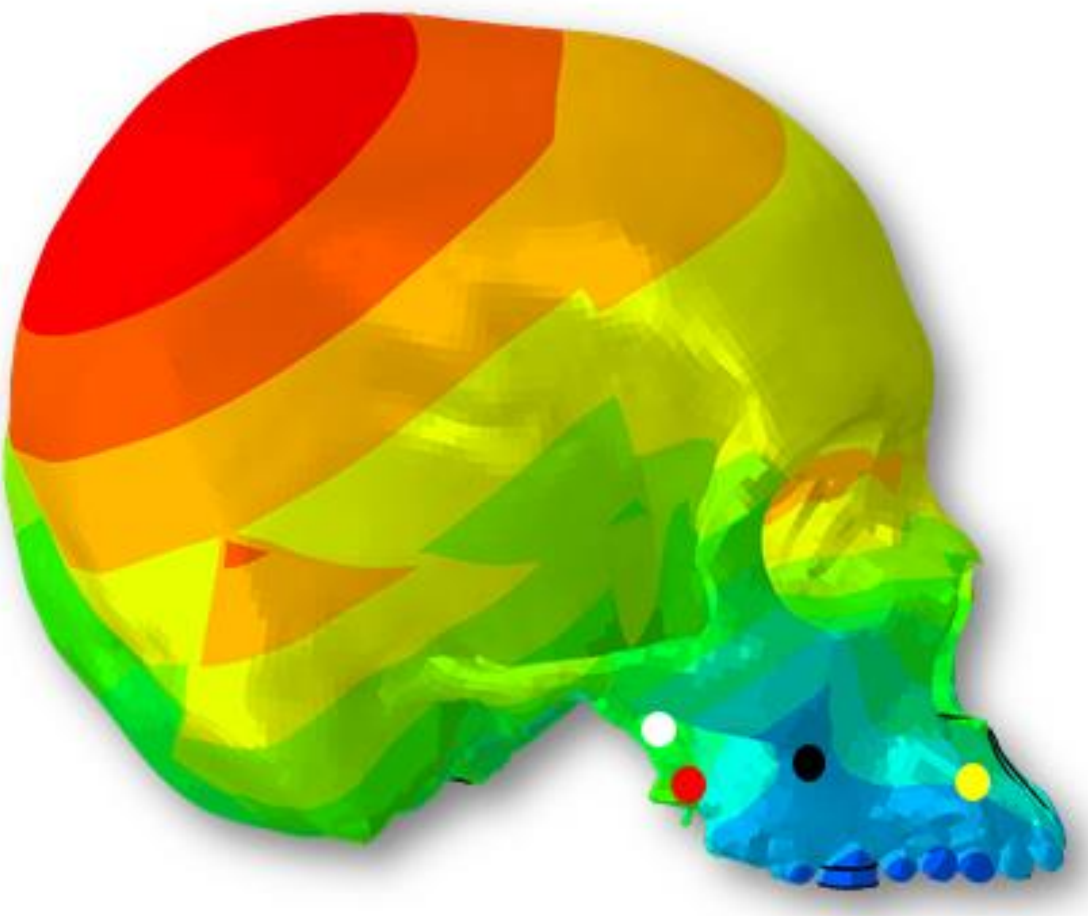


**Fig: -45. Landmarks and reference points- sagittal view**

| Colour | Land mark | Element ID right | Element ID left |
|---|---|---|---|
| | Superior point of lateral pterygoid plate (sup LP) | 414346 | 416958 |
| | inferior point of lateral pterygoid plate (inf LP) | 431677 | 432479 |
| | Infra zygomatic crest region (IZC) | 439482 | 439468 |
| | Canine eminence | 439499 | 437598 |

**Fig: - 46. Magnitude and pattern of displacement- occlusal view**

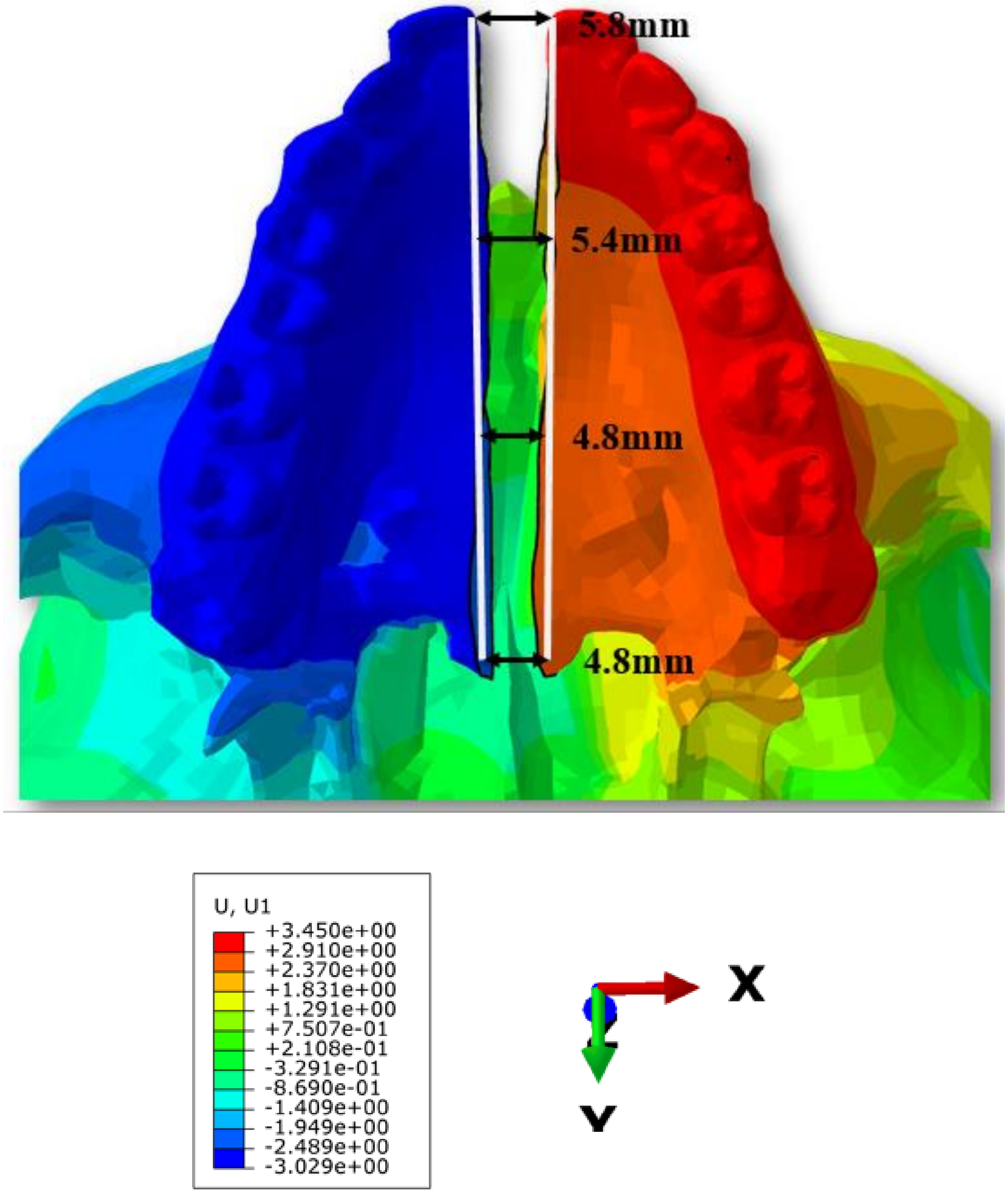


**Fig: -47. Reference points- occlusal view**

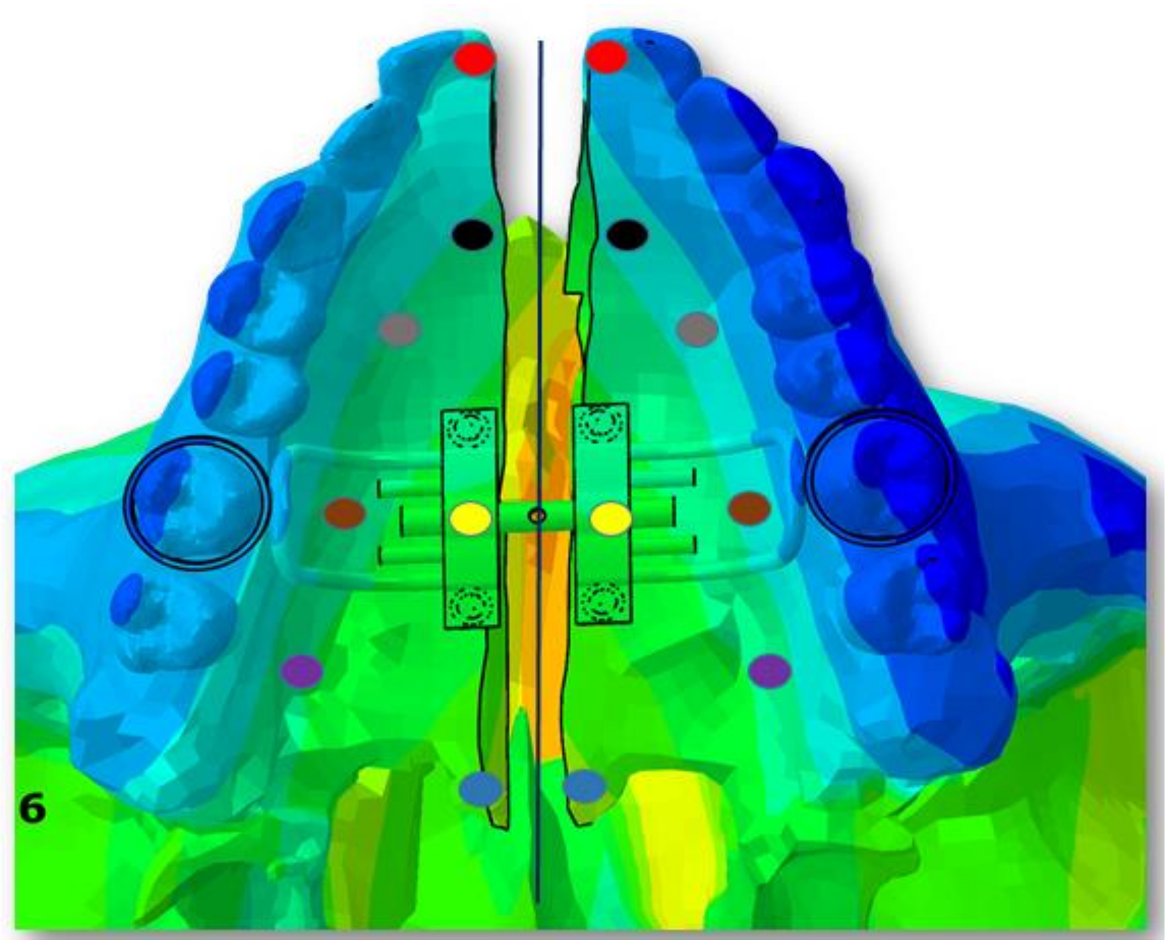



**Fig: -48. Landmarks and reference points- occlusal view**

| Colour | Landmark | Element ID right | Element ID left |
|---|---|---|---|
| | MPS insical level (MPS I) | 365376 | 346337 |
| | MPS canine level (MPS-C) | 438531 | 439154 |
| | MPS molar level (MPS-M) | 161376 | 147852 |
| | MPS PNS | 438831 | 439256 |
| | Basal bone PM | 438407 | 439230 |
| | Basal bone M | 438622 | 439098 |
| | Basal bone 2nd molar | 436953 | 433189 |

# Sphenoid bone

**Fig: -49. Sphenoid bone (axial view)**

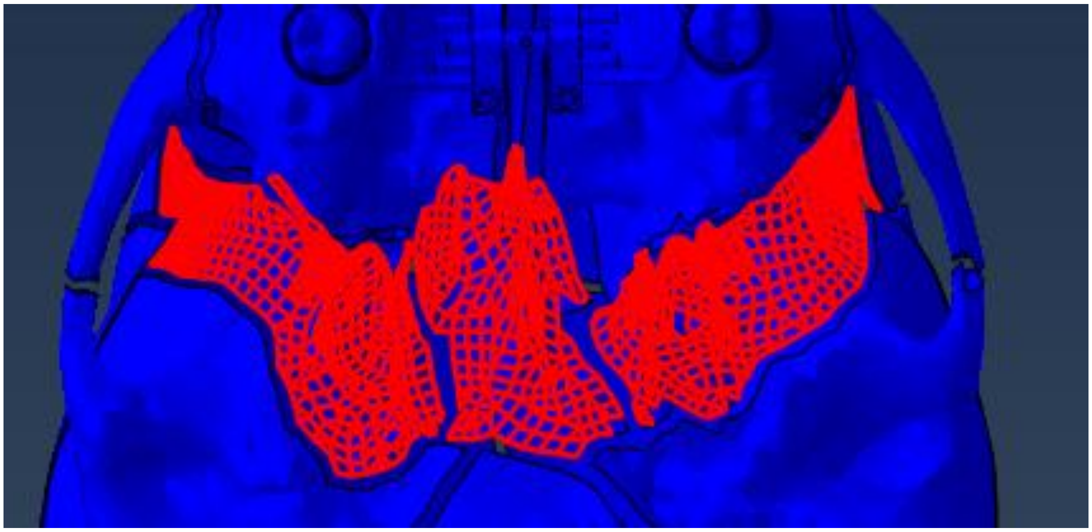


**Fig: -50. Magnitude and displacement pattern in sphenoid bone (axial view)**

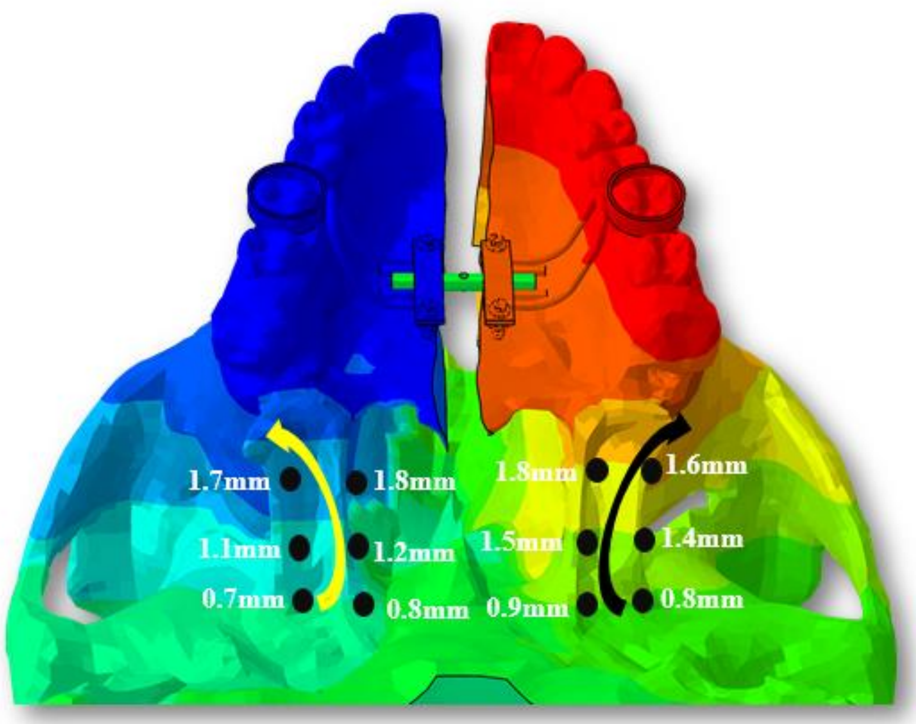


**Fig: -51. Reference points- sphenoid bone (axial view)**

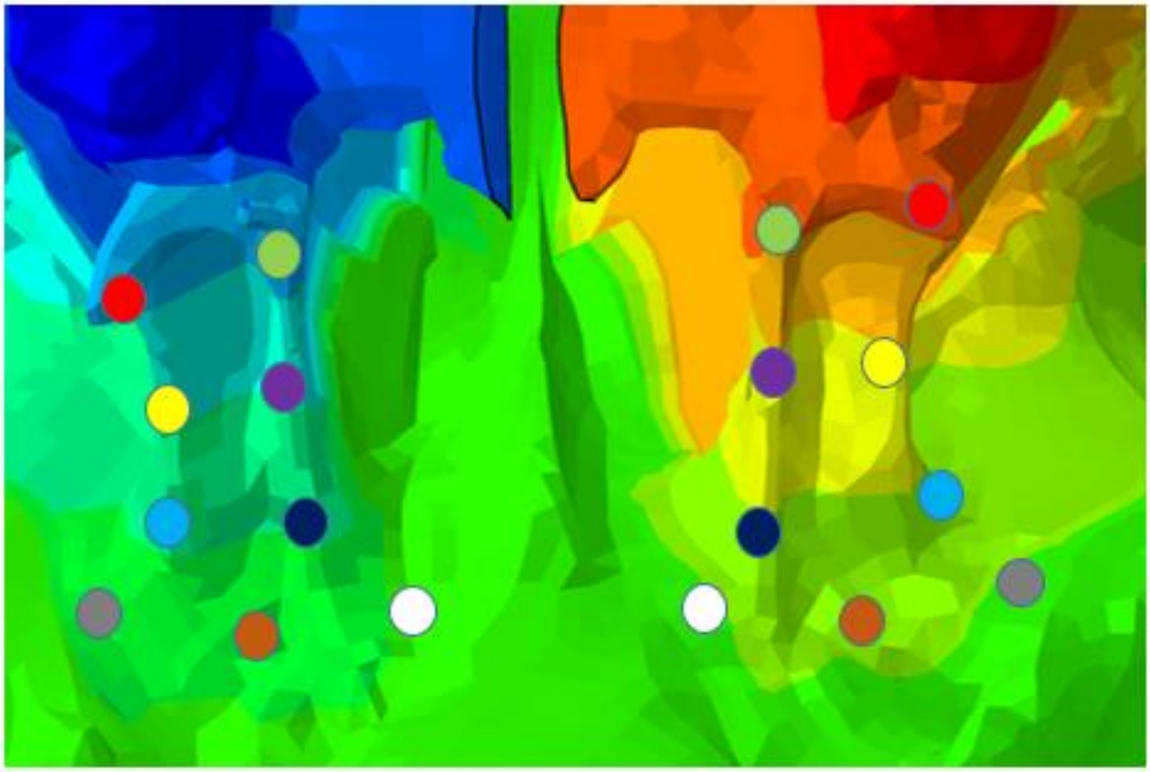


**Fig: -52. Landmarks and reference points- sphenoid bone (axial view)**

| Colour | Landmark | Element ID right | Element ID left |
|---|---|---|---|
| | Lateral most point of lateral pterygoid plate (lat- LP) | 431029 | 430697 |
| | Intermediate point of lateral pterygoid plate (IM-LP) | 430895 | 430775 |
| | Superior point of lateral pterygoid plate (sup- LP) | 430901 | 430725 |
| | Hamulus of medial pterygoid plate (H- MP) | 430110 | 430464 |
| | Intermediate point of medial pterygoid plate(IM-MP) | 430498 | 430523 |
| | Superior point of medial pterygoid plate (sup- MP) | 430429 | 431220 |
| | Infra temporal surface (IFS) | 430718 | 430139 |
| | pterygoid fossa (PF) | 430387 | 431272 |
| | Medial surface of medial pterygoid plate(MS-MP) | 430399 | 430220 |

# ZYGOMATIC BONE

Fig: -53. Zygomatic bone – sagittal view

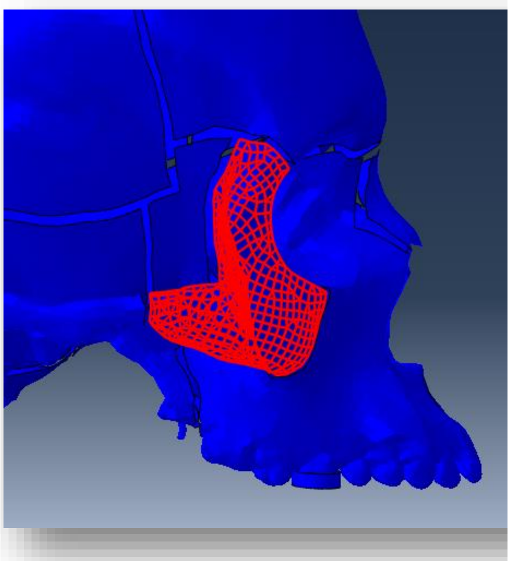


Fig: -54. Zygomatic bone – frontal view

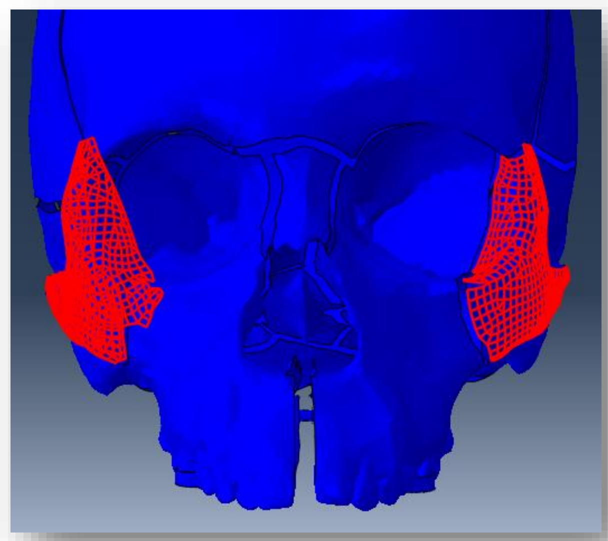
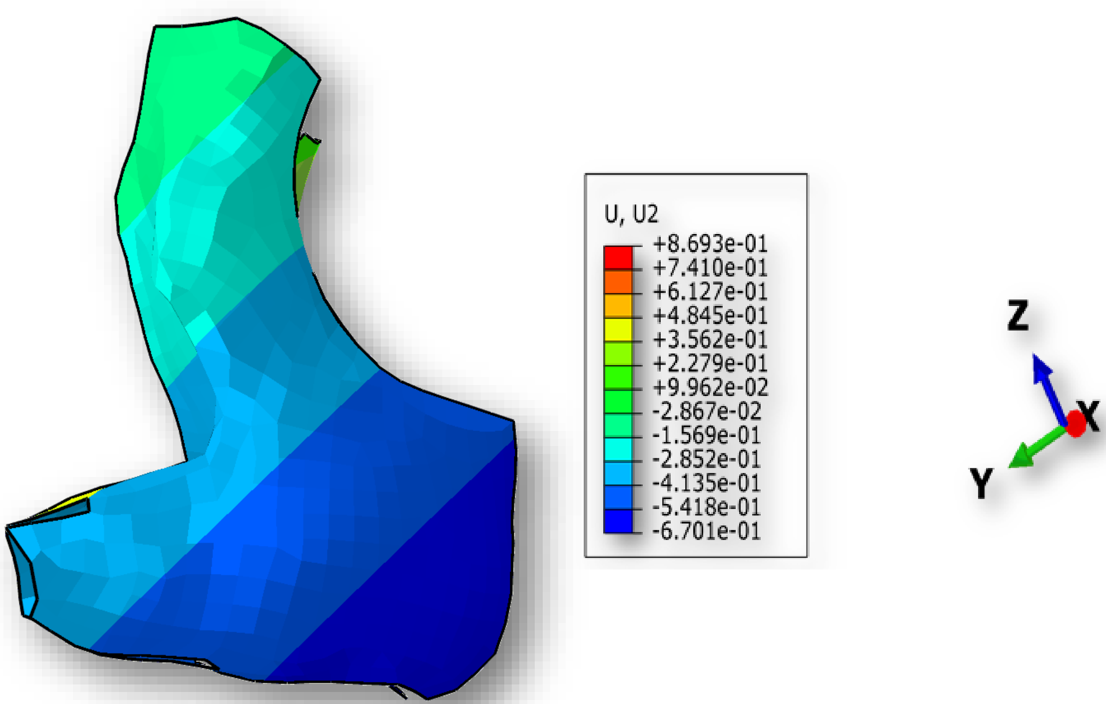


Fig: -55.Magnitude of displacement in the zygomatic bone – sagittal view



- **Fig: -56. Displacement pattern in zygomatic bone (frontal view)**

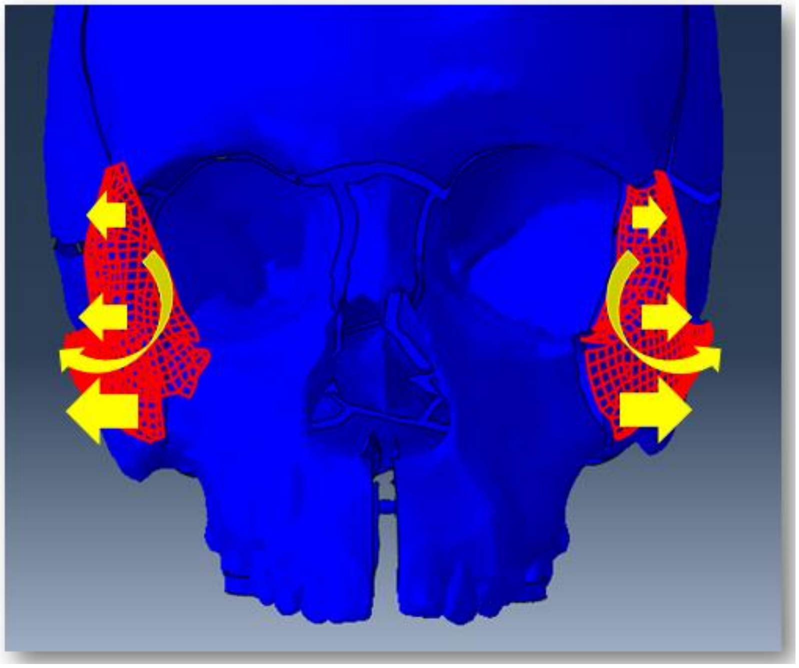


**Fig: -57. Displacement pattern in zygomatic bone (sagittal view)**

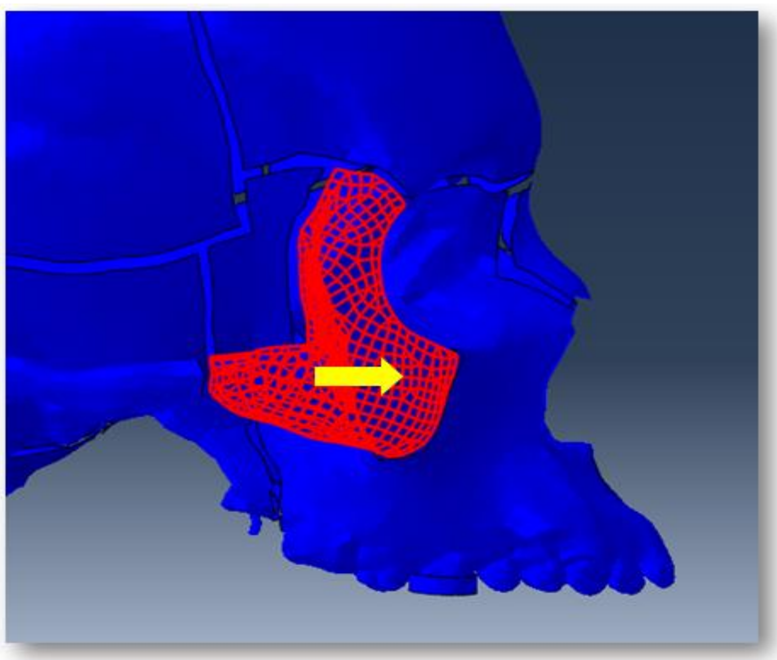


**Fig: -58. Reference points- zygomatic bone (sagittal view)**

**Fig: -59. Landmarks and reference points- zygomatic bone**

| Colour | Landmark | Element ID right | Element ID left |
|---|---|---|---|
| (yellow) | Inferior point of Fronto-zygomatic suture (FZS) | 414326 | 416915 |
| (black) | Zygomatico- maxillary suture (ZMS) | 431925 | 432629 |
| (red) | Facial surface (FS) | 431763 | 432054 |
| (purple) | Temporal process of zygomatic arch (TZA) | 431667 | 432823 |

# TEMPORAL BONE

**Fig: -60. Temporal bone- axial view**

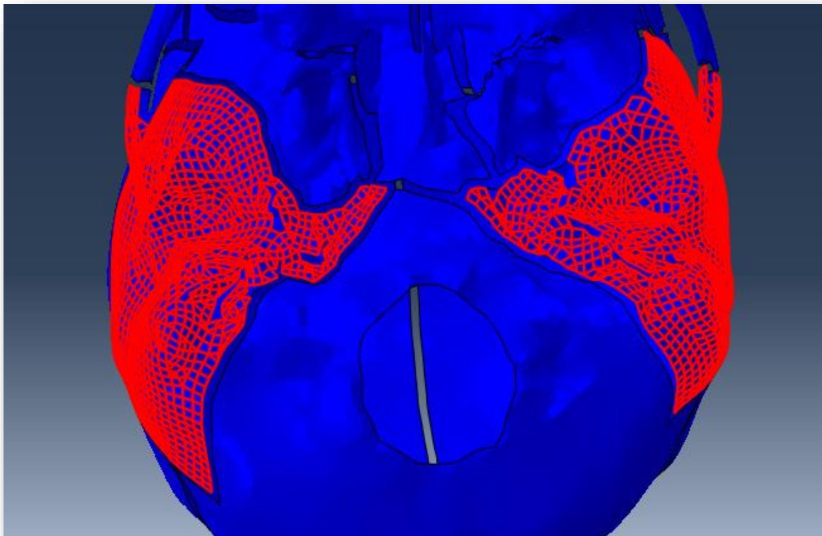


**Fig: -61. Temporal bone- sagittal view**

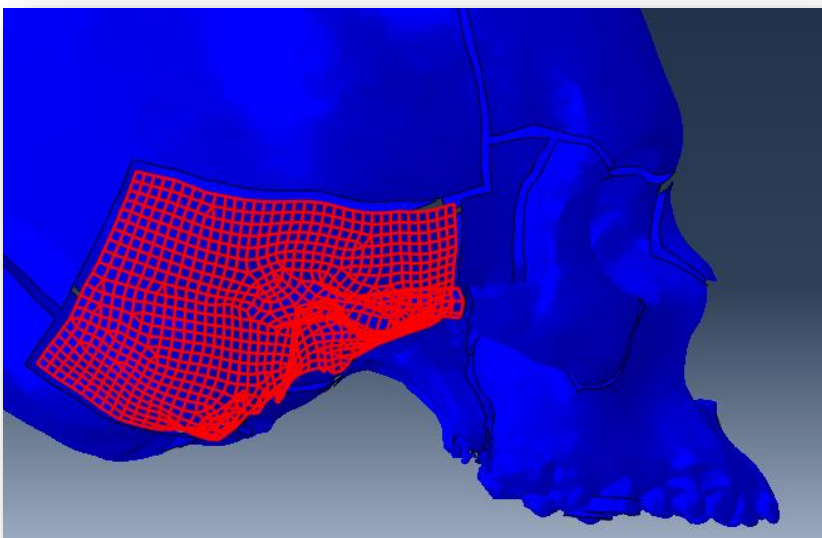


**Fig: -62. Reference points- temporal bone (axial view)**

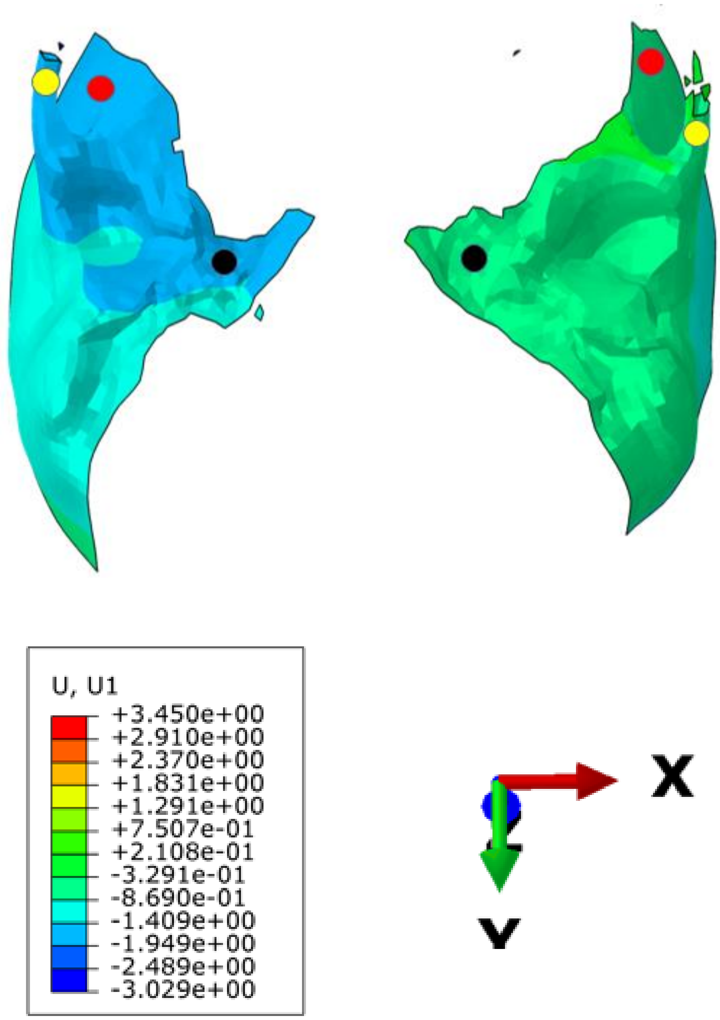



**Fig: -63. Landmarks and reference points- temporal (frontal view)**

| Colour | Landmark | Element ID right | Element ID left |
|---|---|---|---|
| | Squamous part of the temporal bone (SPT) | 431359 | 432368 |
| | Zygomatic process of temporal bone(ZTB) | 431894 | 432578 |
| | Infra temporal surface temporal bone (ITTB) | 431942 | 432479 |

# NASAL BONE

**Fig: -64. Nasal bone – frontal view**

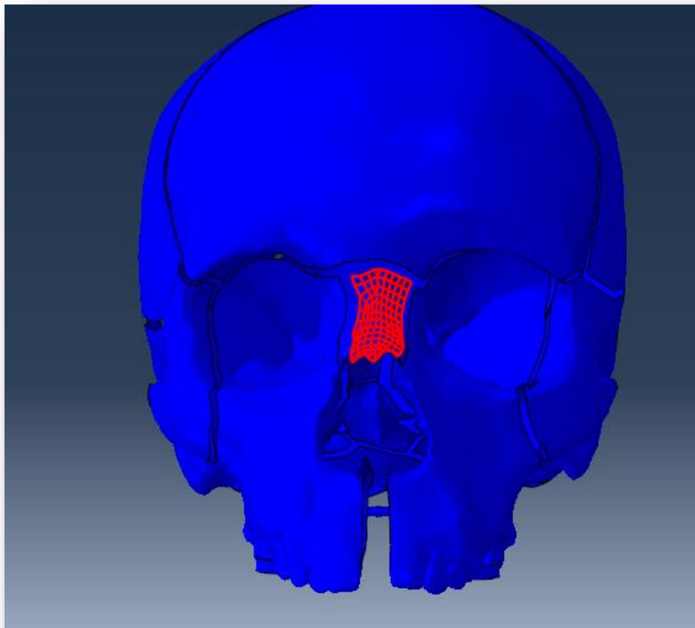


**Fig: -65. Magnitude and displacement pattern in nasal bone (frontal view)**

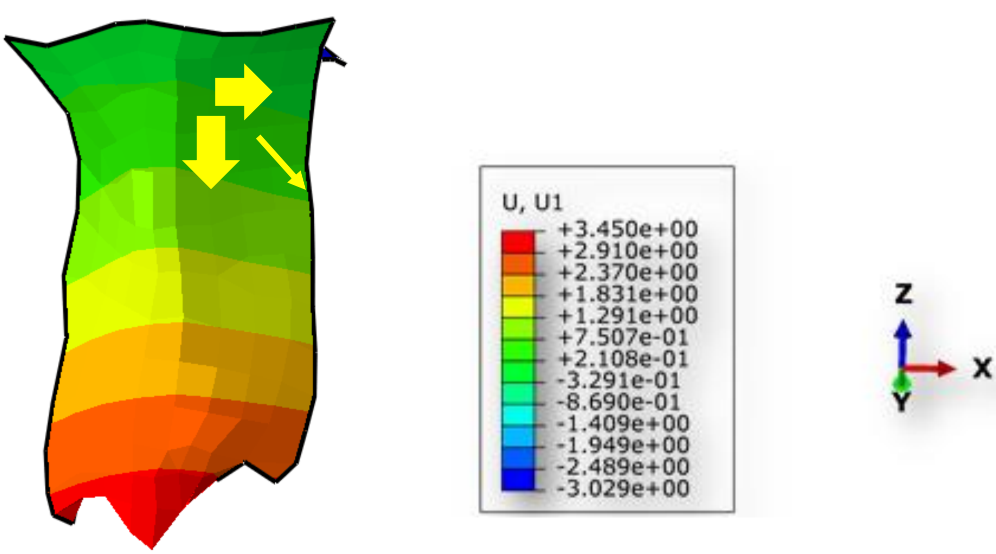


**Fig: -66. Reference points- nasal bone (frontal view)**

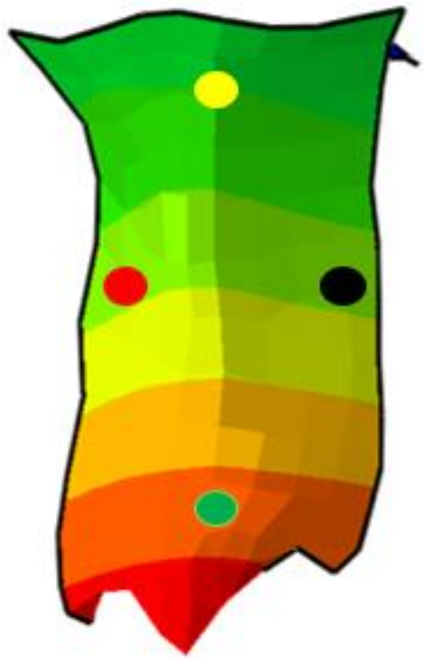


**Fig: -67. Landmarks and reference points- nasal (frontal view)**

| Colour | Landmark | Element ID |
|---|---|---|
| | Inferior (inf) | 439544 |
| | Right lateral (RT) | 439494 |
| | Left lateral (LT) | 439389 |
| | Superior (sup) | 439482 |

# PERMANENT UPPER FIRST MOLAR

**Fig: -68. Right and left permanent first molar- frontal view**

**Fig: -69. Magnitude and displacement pattern in upper first molar bone (frontal view)**

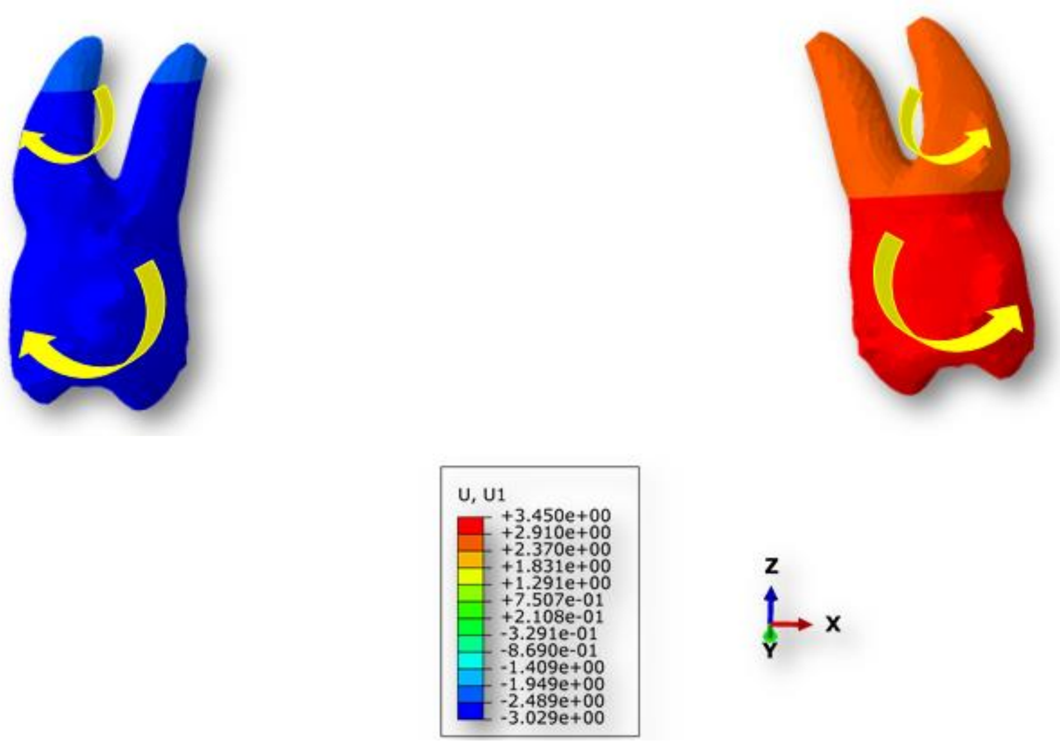


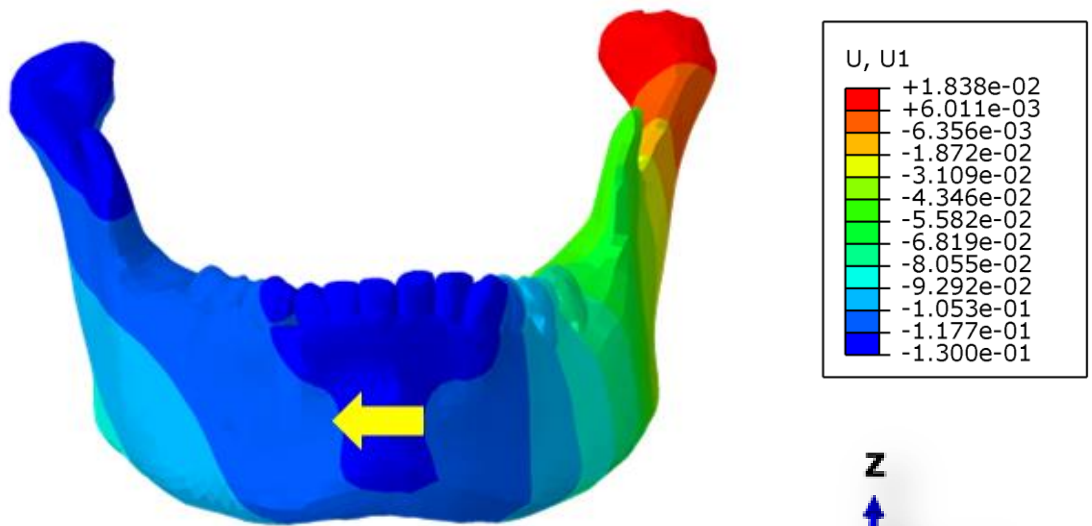
**Fig: -70. Reference points- right and left upper first permanent molar (frontal view)**

**Fig: -71. Landmarks and reference points- permanent upper first molars (frontal view)**

| Colour | Landmark | Element ID right | Element ID left |
|---|---|---|---|
| | Buccal cusp (BC) | 234960 | 214270 |
| | Lingual cusp (LC) | 235068 | 214761 |
| | Buccal root (BR) | 237965 | 228501 |
| | Lingual root (LR) | 255666 | 214203 |

# MANDIBLE

**Fig: -72. Magnitude and pattern of displacement in mandible- frontal view**



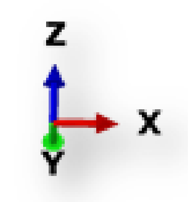




**Fig: -73. Magnitude and pattern of displacement in mandible- sagittal view**

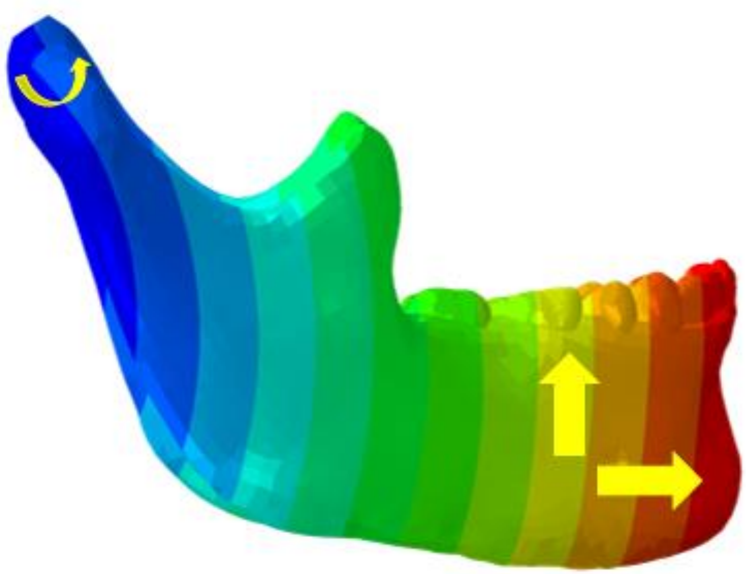


**Fig: -74(a). Reference points- mandible (frontal view)**

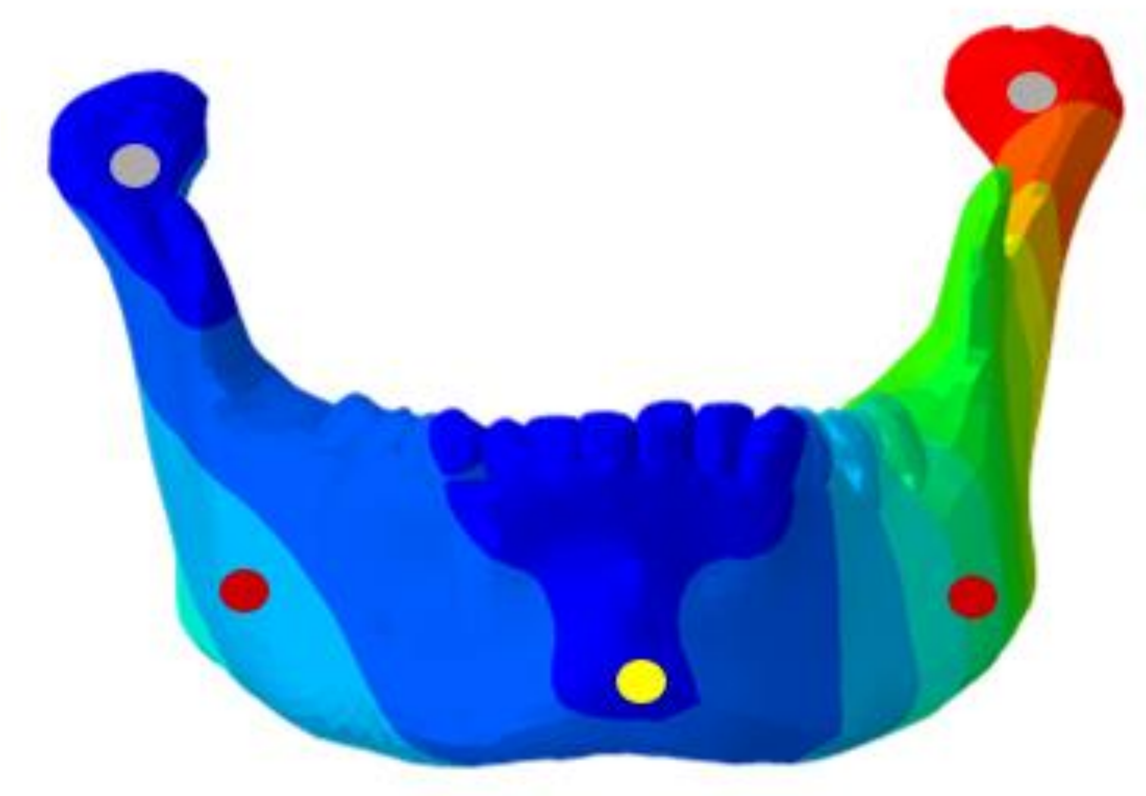


**Fig: -74(b). Landmarks and reference points- mandible (frontal view)**

| Colour | Landmark | Element ID right | Element ID left |
|---|---|---|---|
| | condyle | 169300 | 169400 |
| | gonial angle | 166834 | 170837 |
| | Symphysis ( sym) | 171100 | |

# STRESS DISTRIBUTION

**Fig: -75(a). Stress distribution of the skull – frontal view**

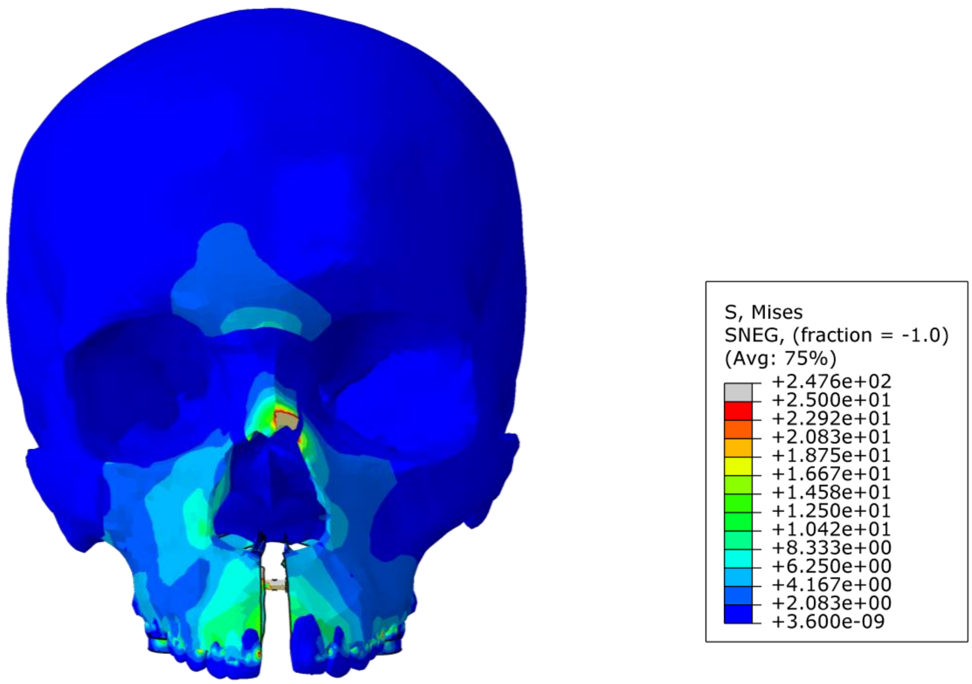



**Fig: -75(b) Stress distribution of the skull –right sagittal view**

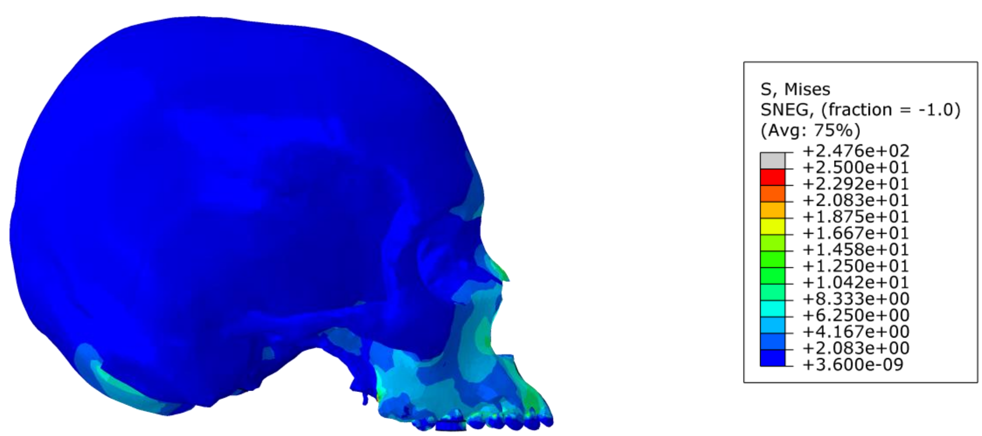


**Fig: -76(a). Stress distribution of the skull –left sagittal view**

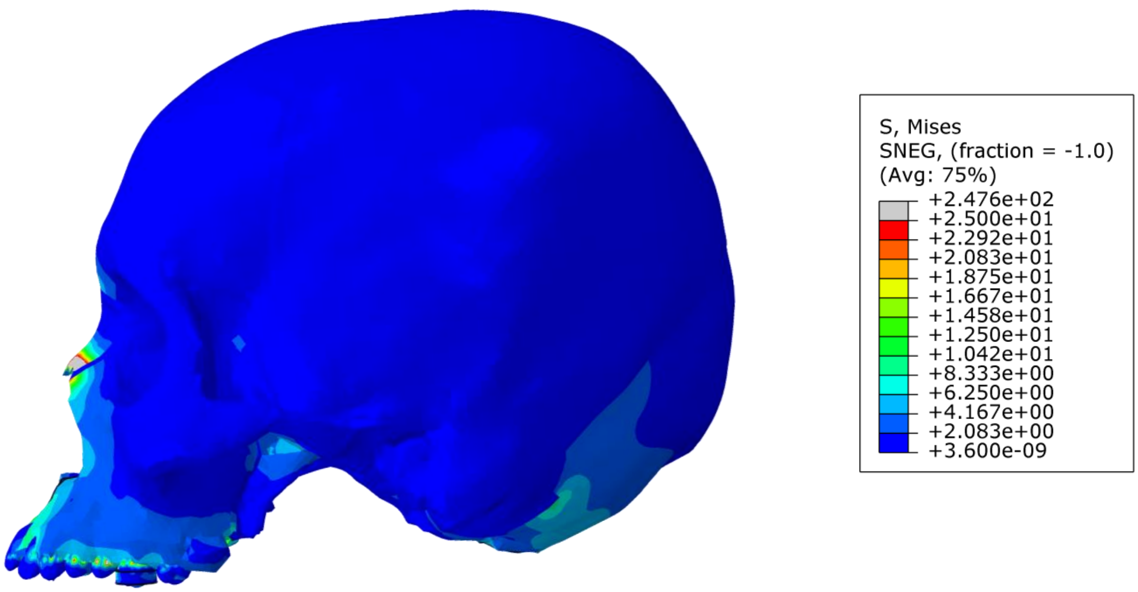



**Fig: -76(b). Stress distribution of the skull –occlusal view**

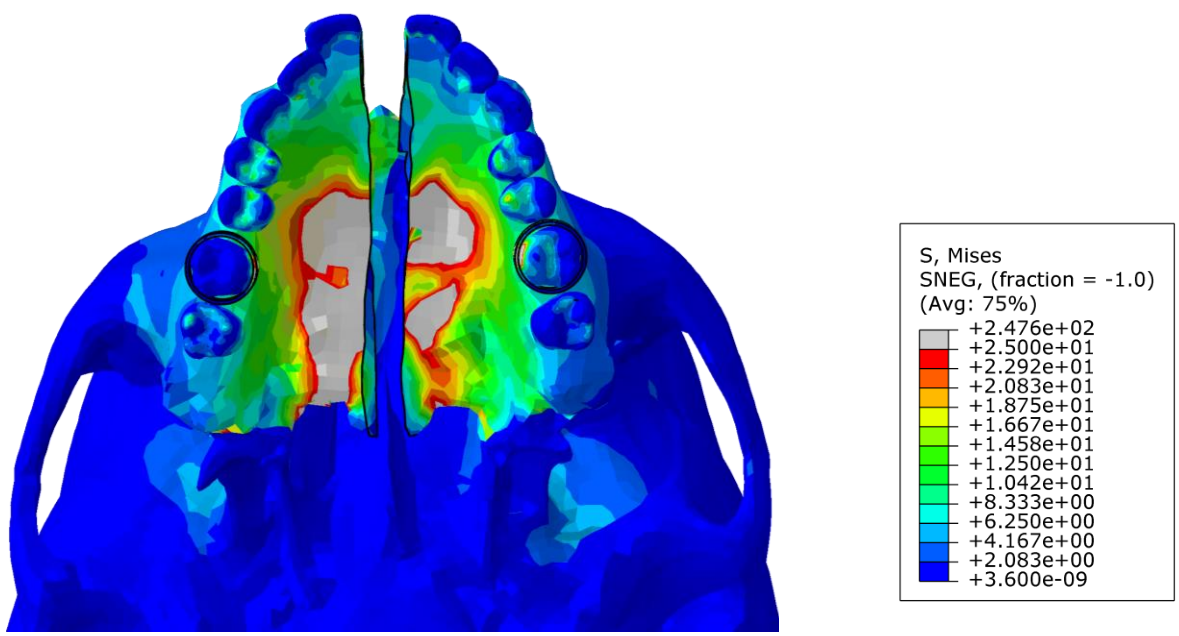


**Fig: -77. Stress distribution of maxilla – frontal view**

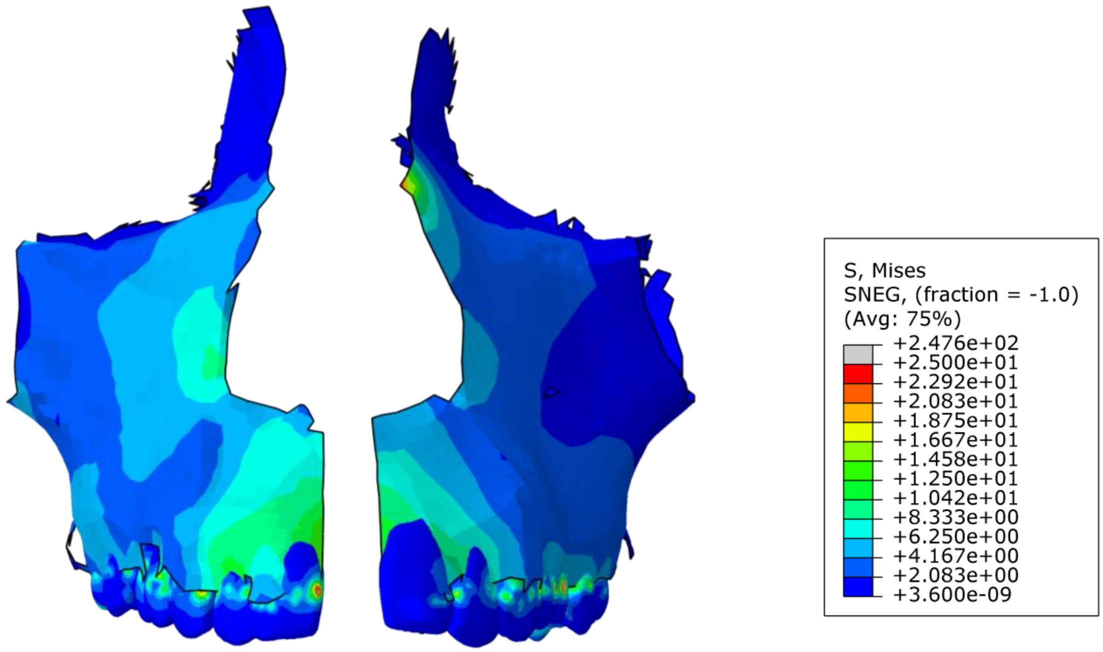



**Fig: -78. Stress distribution of maxilla – occlusal view**

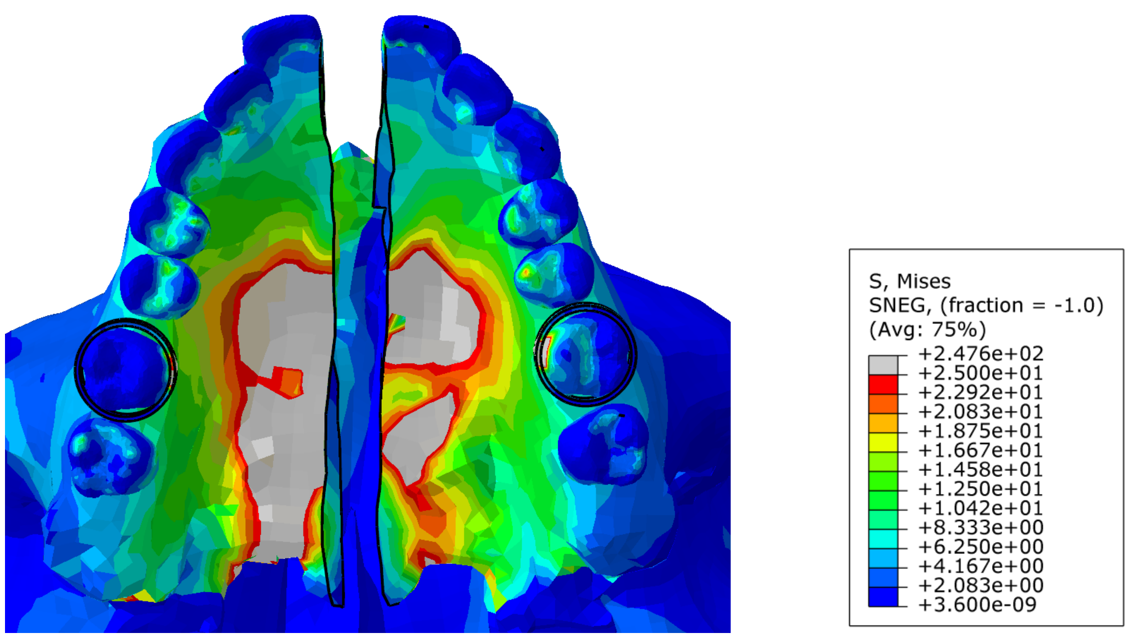


**Fig: -79. Stress distribution of sphenoid bone – axial view**

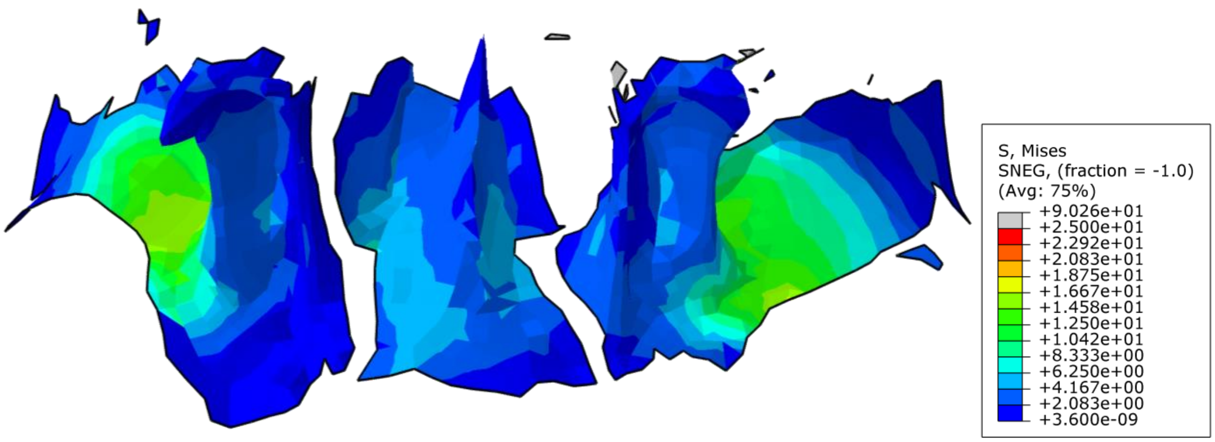



**Fig: -80. Stress distribution of zygomatic bone – sagittal view**

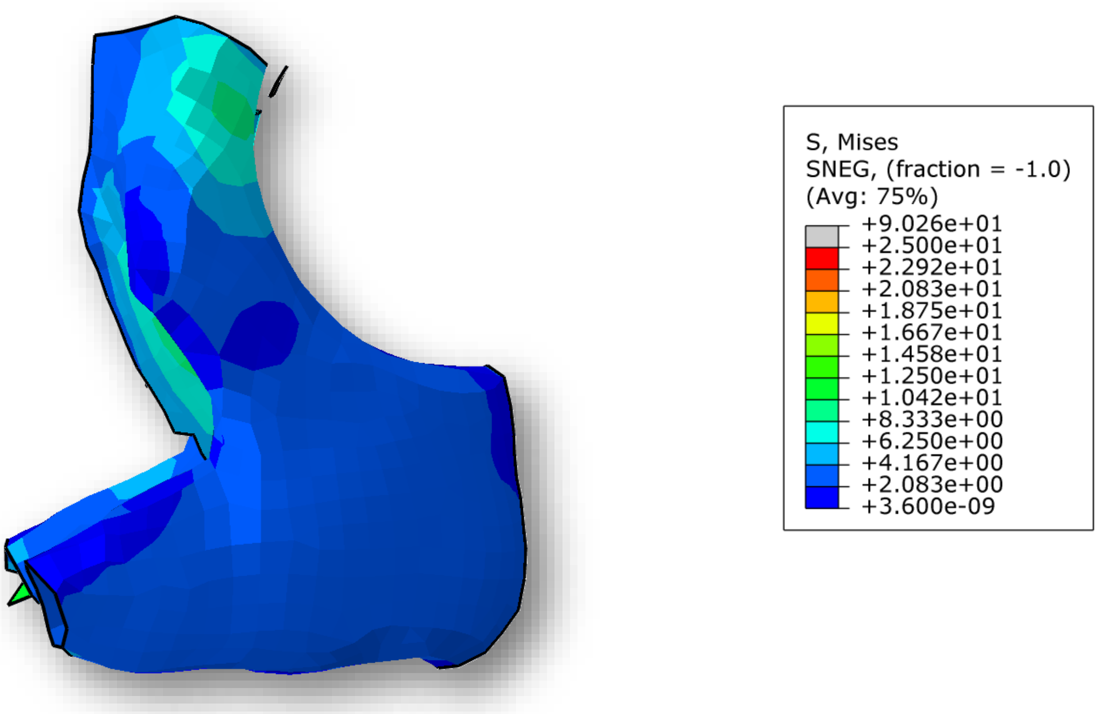


**Fig: -81. Stress distribution of nasal bone – frontal view**

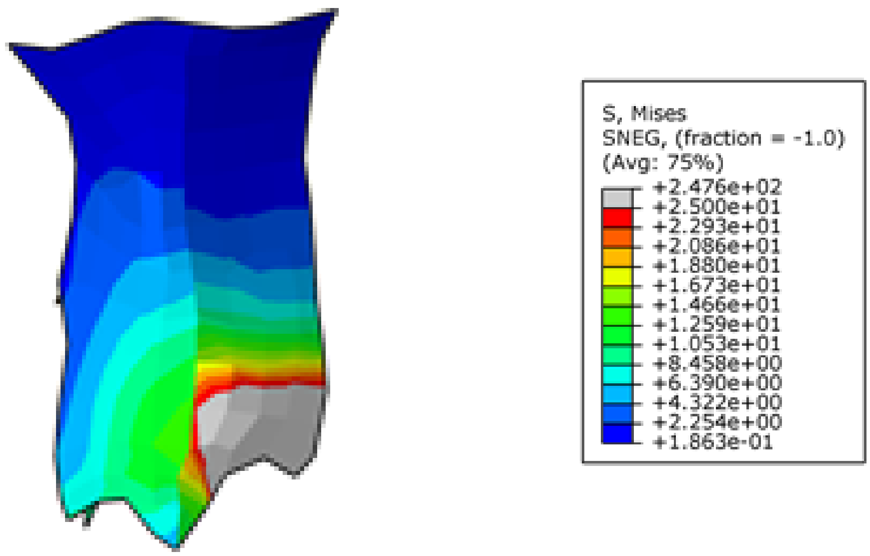



**Fig: -82. Stress distribution of permanent upper first molars – frontal view**

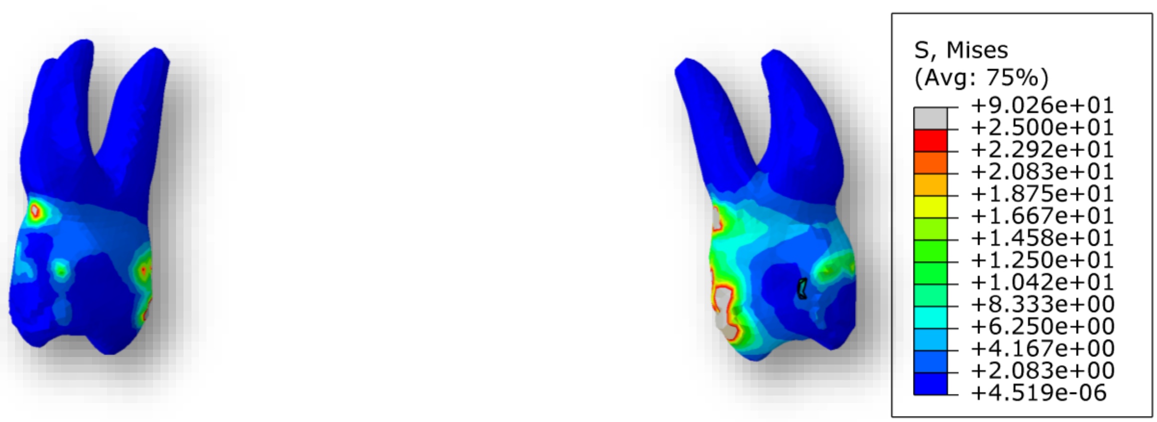


**Fig: -83. Stress distribution of mandible – frontal view**

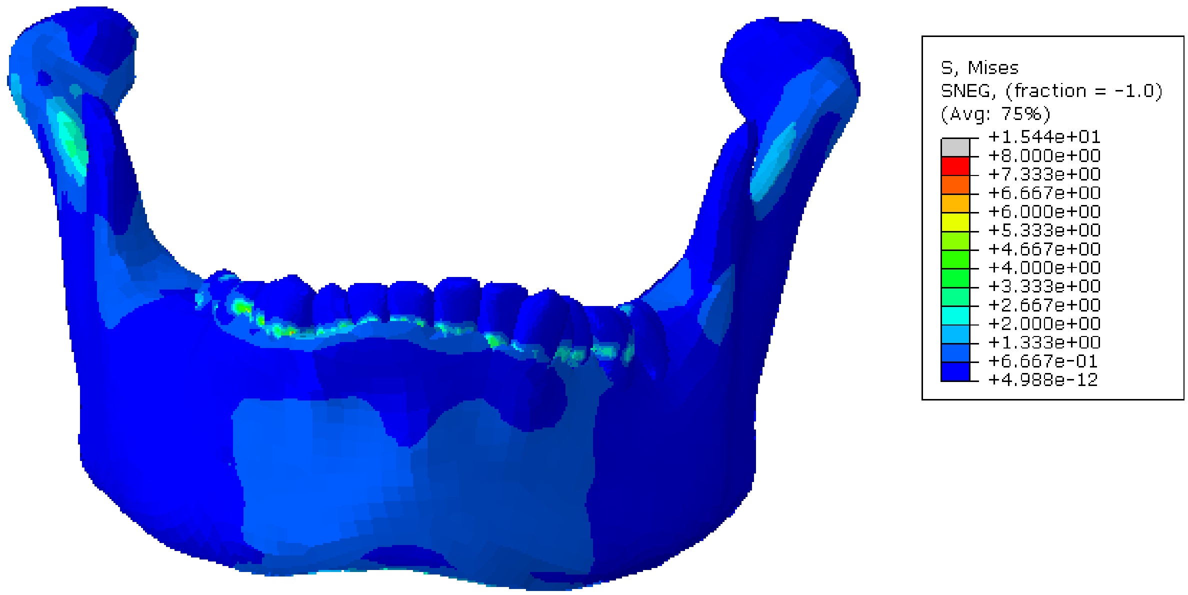



**Fig: -84. Stress distribution of mandible – sagittal view**

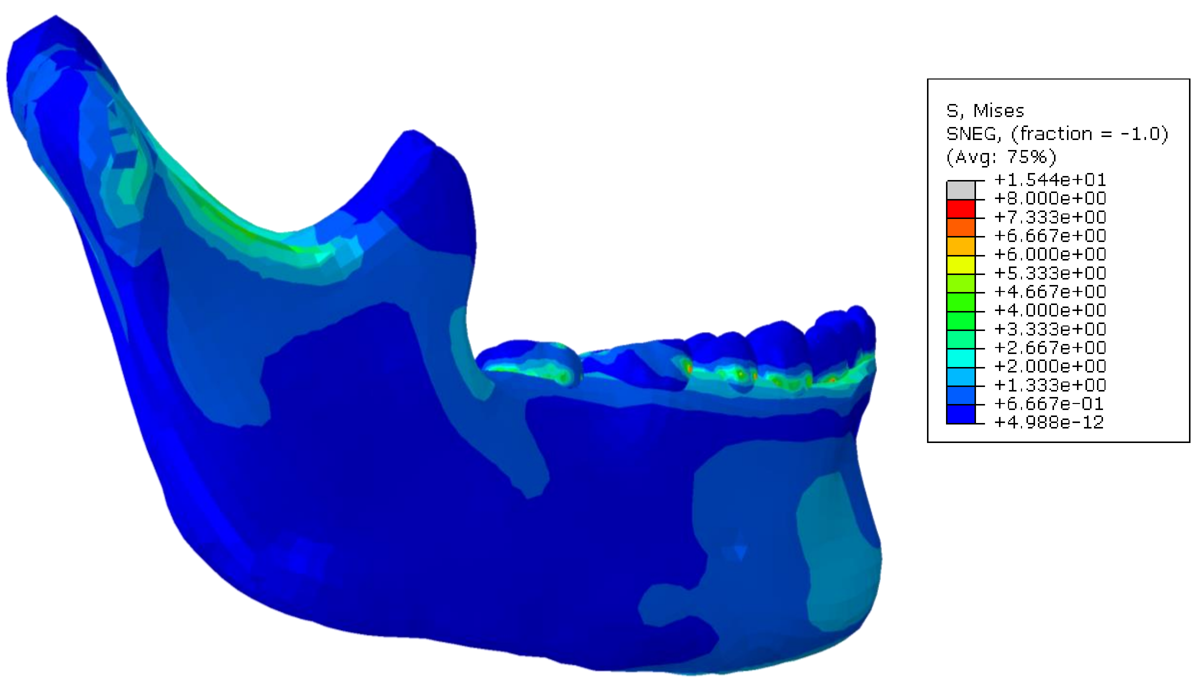


**Fig: 85. Stress distribution in implants –frontal view (a) right, (b), left**

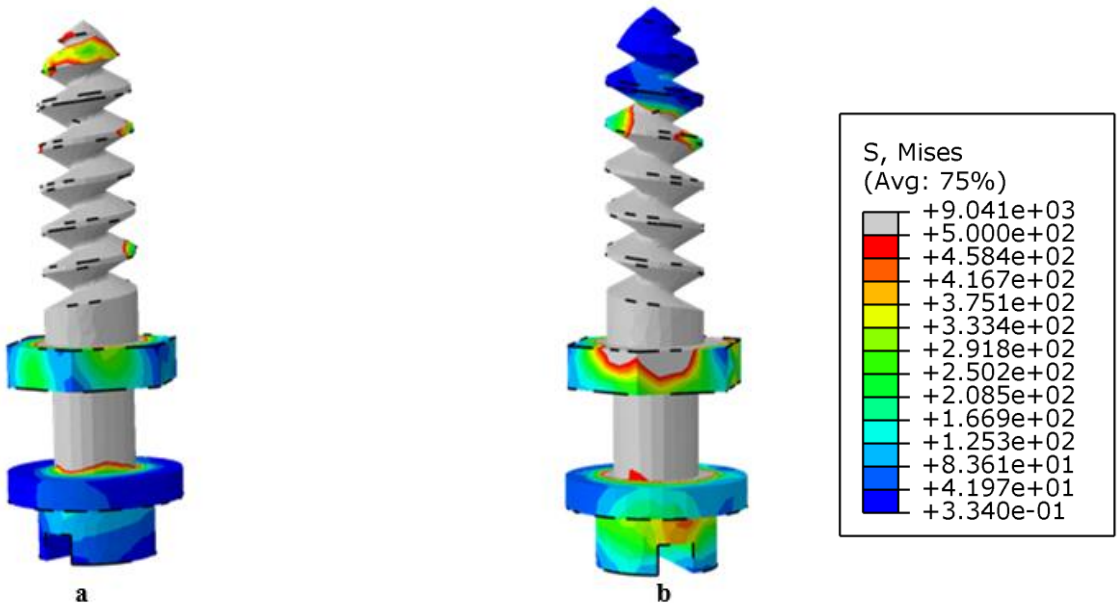
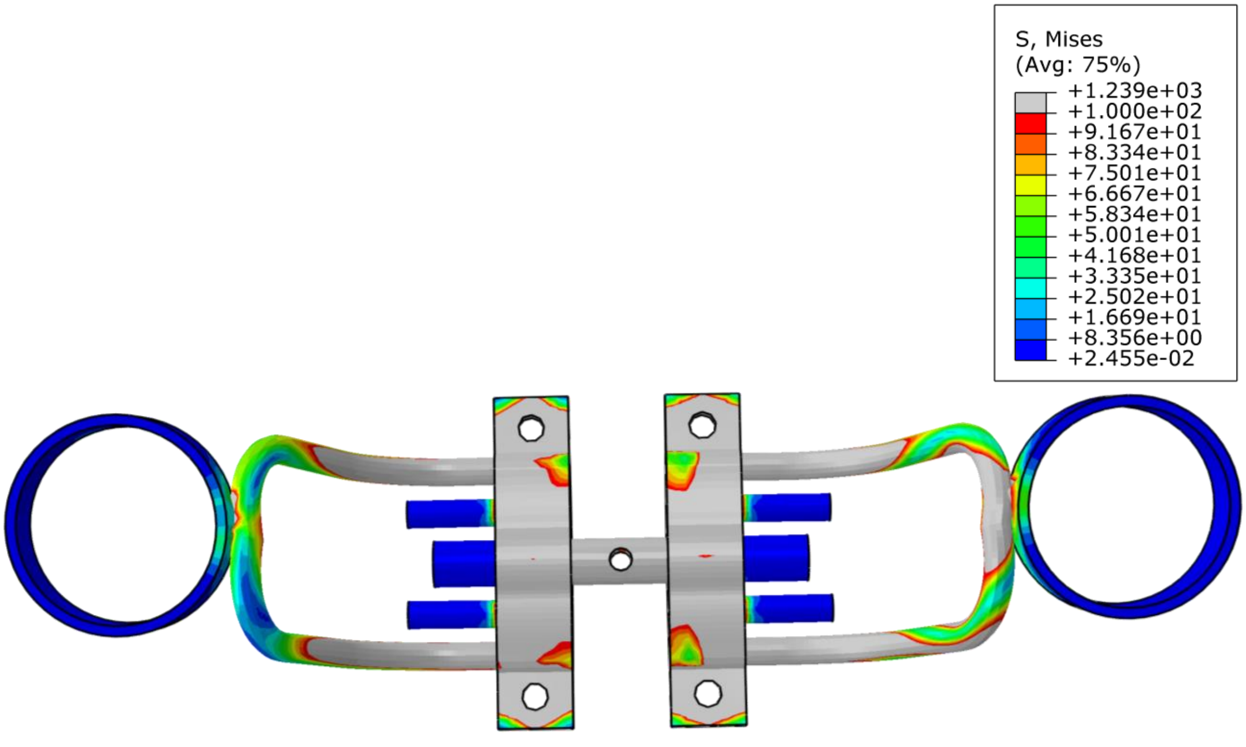



**Fig: -86. Stress distribution in appliance – occlusal view**



# *Tables and Graphs*

**Table:-1 STEINER'S ANALYSIS**

| Measurement | Mean | Actual | Inference |
|---|---|---|---|
| SNA | 82° | 88° | Orthognathic maxilla |
| SNB | 80° | 82° | Retrognathic mandible |
| ANB | 2° | 6° | Cl II skeletal pattern |
| MPA | 32° | 24° | Low mandibular plane angle |
| Pog-NB | 0° | 0.9° | Orthognathic chin |
| Upper 1-NA/mm | 22°/4mm | 32°/8mm | Proclined & forwardly placed upper incisors |
| Lower 1-NB/mm | 25°/4mm | 29°/6mm | Proclined & forwardly placed lower incisors |

**Table:- 2 MATERIAL PROPERTY OF THE FE MODEL**

| STRUCTURES | ELEMENTS AND NODES | YOUNG'S MODULUS (MPA) | POISSON'S RATIO |
|---|---|---|---|
| Cortical Bone | Tetrahedral | 13 700 | 0.30 |
| Cancellous Bone | Tetrahedral | 1370 | 0.30 |
| Applaince | Tetrahedral | 193.00 | 0.33 |
| Tooth | Tetrahedral | 20.700 | 0.30 |
| Suture | Tetrahedral | 10 | 0.49 |
| Stainless steel | Tetrahedral | 210,000 | 0.33 |
| Periodontal ligament | Tetrahedral | 0.7 | 0.49 |

**Table:- 3 DISPLACEMENT IN MAXILLA- FRONTAL VIEW**

| Landmarks | Transverse Right (mm) | Transverse Left (mm) | Sagittal Right (mm) | Sagittal Left (mm) | vertical Right (mm) | vertical Left (mm) |
|---|---|---|---|---|---|---|
| Superior to fronto-zygomatic suture | 0.2 | 0.1 | 0 | 0 | 0 | 0 |
| Inferior to fronto-zygomatic suture | 0.9 | 0.3 | -0.2 | -0.2 | -0.3 | -0.32 |
| Fronto-maxillary suture | 0.9 | 0.2 | -0.2 | -0.3 | -0.4 | -0.43 |
| Frontal process of Maxilla | 1 | 0.5 | -0.3 | -0.3 | -0.3 | -0.3 |
| Maxilla in line with inferior orbital rim | 1.5 | 1 | -0.2 | -0.2 | -0.4 | -0.4 |
| Nasal Notch | 2.1 | 1.8 | -0.2 | -0.2 | -0.4 | -0.41 |
| ANS | 2.5 | 2.2 | -0.2 | -0.2 | -0.3 | -0.35 |
| Incisal edge | 2.8 | 3.2 | -0.3 | -0.2 | -0.3 | -0.4 |

**Table:- 4 DISPLACEMENT IN MAXILLA- SAGITTAL VIEW**

| Landmarks | Transverse Right (mm) | Transverse Left (mm) | Sagittal Right (mm) | Sagittal Left (mm) | Vertical Right (mm) | Vertical Left (mm) |
|---|---|---|---|---|---|---|
| Superior point of lateral pterygoid plate | 1.1 | 0.8 | 0 | 0 | 0.2 | 0.3 |
| Inferior point of lateral pterygoid plate | 1.8 | 2.2 | 0 | 0.1 | 0.3 | 0.5 |
| Infra zygomatic crest | 2.4 | 2.3 | -0.3 | -0.4 | -0.3 | -0.35 |
| canine eminence | 2.4 | 2.8 | -0.3 | -0.4 | -0.32 | -0.4 |

**Table: -5 DISPLACEMENT IN MAXILLA- OCCLUSAL VIEW**

| Landmarks | Transverse Right (mm) | Transverse Left (mm) | Sagittal Right (mm) | Sagittal Left (mm) | Vertical Right (mm) | Vertical Left (mm) |
|---|---|---|---|---|---|---|
| MPS- incisal level | 2.8 | 3 | -0.3 | -0.3 | -0.2 | -0.3 |
| MPS-Canine level | 2.6 | 2.7 | -0.2 | -0.2 | 0 | -0.2 |
| MPS-Molar level | 2.5 | 2.4 | 0 | 0 | 0 | 0 |
| MPS-PNS | 2.5 | 2.4 | -0.1 | -0.2 | -0.3 | -0.3 |
| Basal bone-premolar | 2.6 | 2.8 | -0.1 | -0.2 | -0.2 | -0.3 |
| Basal Bone-Molar | 2.5 | 2.7 | -0.1 | -0.2 | -0.2 | -0.3 |
| Basal Bone-2nd Molar | 2.4 | 2.6 | 0 | 0 | -0.1 | -0.1 |

**Table: -6 DISPLACEMENT IN SPHENOID BONE**

| Landmarks | Transverse Right (mm) | Transverse Left (mm) | Sagittal Right (mm) | Sagittal Left (mm) | Vertical Right (mm) | Vertical Left (mm) |
|---|---|---|---|---|---|---|
| Lateral most point of lateral pterygoid plate | 1.9 | 2.1 | 0.1 | 0.1 | 0 | 0.4 |
| Intermediate point of lateral pterygoid plate | 1.3 | 1.4 | 0 | 0.1 | 0.2 | 0.3 |
| Superior point of lateral pterygoid plate | 1 | 1 | 0 | 0 | 0.2 | 0.2 |
| Hamulus of medial pterygoid plate | 2 | 2.2 | 0.1 | 0 | 0.1 | 0.1 |
| Intermediate point of medial pterygoid plate | 1.2 | 1.4 | 0.1 | 0 | 0 | 0.1 |
| Superior point of medial pterygoid plate | 0.9 | 0.9 | 0.1 | 0 | 0.1 | 0.1 |
| Medial surface of medial pterygoid plate | 0.8 | 0.8 | 0.2 | 0 | 0.15 | 0.2 |
| pterygoid fossa | 0.6 | 0.5 | 0 | 0 | 0 | 0.1 |
| Infra temporal surface | 0.7 | 0.5 | 0.2 | 0.1 | 0.1 | 0.1 |

**Table:-7 DISPLACEMENT IN ZYGOMATIC BONE**

| Landmarks | Transverse Right (mm) | Transverse Left (mm) | Sagittal Right (mm) | Sagittal Left (mm) | Vertical Right (mm) | Vertical Left (mm) |
|---|---|---|---|---|---|---|
| Inferior point of Fronto-zygomatic suture | 0.9 | 0.7 | -0.2 | -0.2 | 0.3 | 0.4 |
| Zygomatico-maxillary suture | 1.8 | 1.6 | -0.2 | -0.2 | 0.5 | 0.6 |
| Facial surface | 1.5 | 1.3 | -0.1 | -0.2 | 0.6 | 0.7 |
| Temporal process of zygomatic arch | 1.2 | 1.3 | 0 | 0 | 1 | 1.1 |

**Table:- 8 DISPLACEMENT IN TEMPORAL BONE**

| Landmarks | Transverse Right (mm) | Transverse Left (mm) | Sagittal Right (mm) | Sagittal Left (mm) | Vertical Right (mm) | Vertical Left (mm) |
|---|---|---|---|---|---|---|
| Squamous part of the temporal bone (SPT) | 0.2 | 0.1 | -0.1 | -0.05 | 0.1 | 0.15 |
| Zygomatic process of temporal bone(ZTB) | 1 | 1.4 | -0.1 | -0.2 | 1 | 1.1 |
| Infra temporal surface temporal bone (ITTB) | 0.1 | 0.15 | 0 | 0 | 0.1 | 0 |

**Table:-9 DISPLACEMENT IN NASAL BONE**

| Landmarks | X Axis- Transverse (mm) | Y Axis- Sagittal (mm) | Z Axis- vertical (mmm) |
|---|---|---|---|
| Inferior | 0 | -0.4 | -0.25 |
| Right lateral | 0.1 | -0.3 | -0.3 |
| Left lateral | 0.3 | -0.3 | -0.3 |
| Superior | 0.6 | -0.35 | -0.35 |

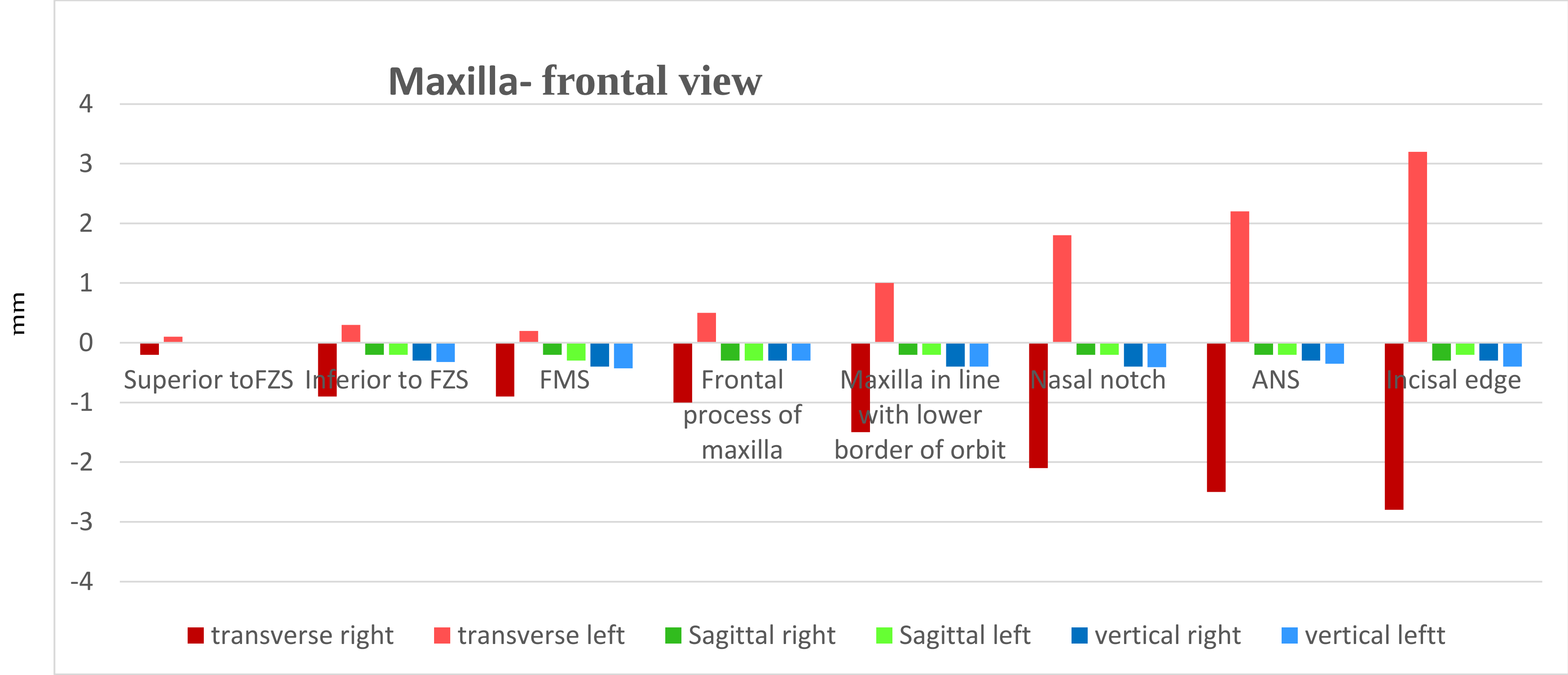
**Table:-10 DISPLACEMENT IN PERMANENT UPPER FIRST MOLAR**

| Landmarks | Transverse Right (mm) | Transverse Left (mm) | Sagittal Right (mm) | Sagittal Left (mm) | Vertical Right (mm) | Vertical Left (mm) |
|---|---|---|---|---|---|---|
| Buccal cusp | 2.8 | 3.2 | -0.4 | -0.4 | -0.4 | -0.6 |
| Lingual cusp | 2.9 | 3.3 | -0.4 | -0.4 | -0.3 | -0.5 |
| Buccal root | 2.4 | 2.5 | -0.2 | -0.2 | -0.4 | -0.6 |
| Lingual root | 2.5 | 2.6 | -0.2 | -0.2 | -0.3 | -0.5 |

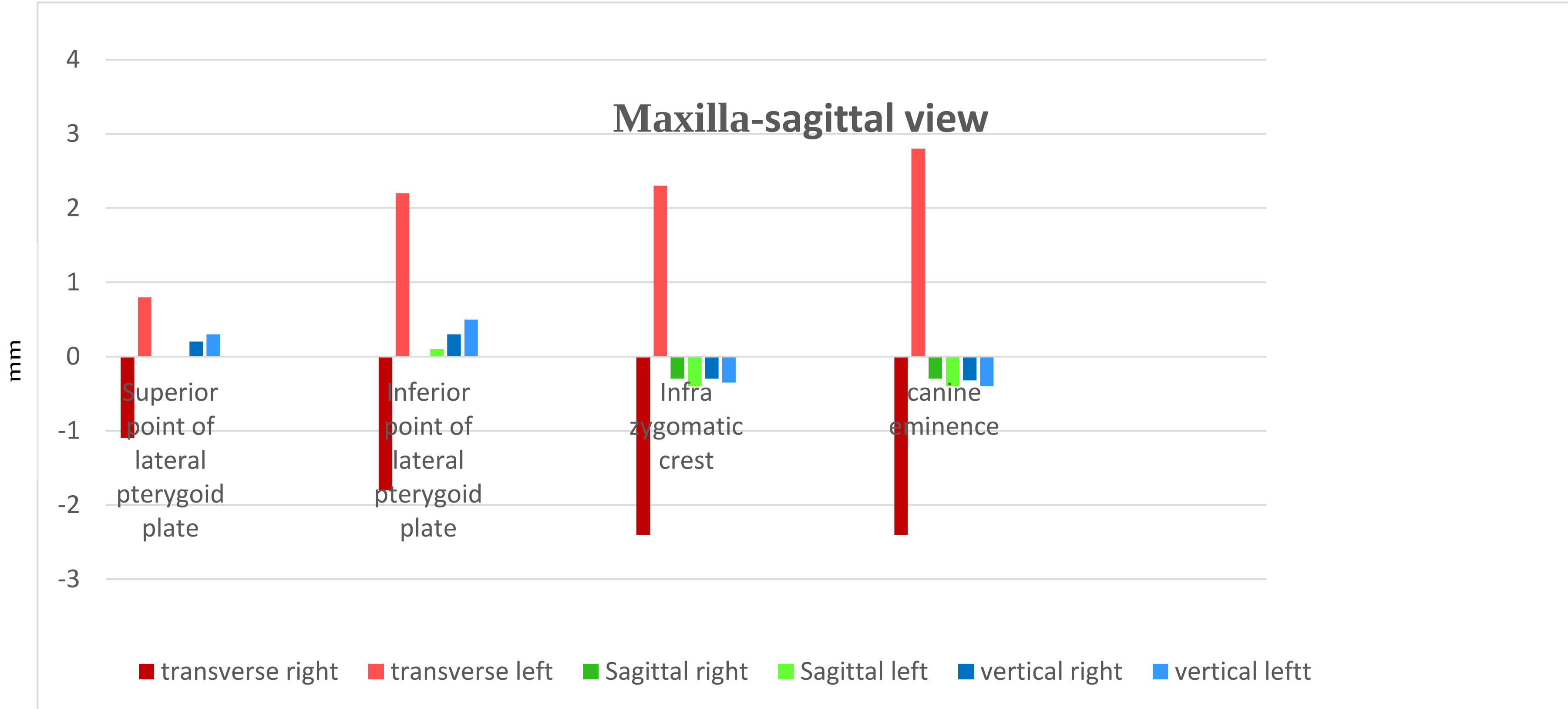
**Table: -11 DISPLACEMENT IN MANDIBLE**

| Landmarks | Transverse Right (mm) | Transverse Left (mm) | Sagittal Right (mm) | Sagittal Left (mm) | Vertical Right (mm) | Vertical Left (mm) |
|---|---|---|---|---|---|---|
| Condyle | -0.1 | 0 | 0 | 0 | 0.4 | 0.4 |
| Gonial Angle | -0.1 | 0 | -0.5 | -0.7 | 0.4 | 0.4 |
| Symphysis | -0.1 | -0.1 | -0.6 | -0.6 | 0.8 | 0.8 |

**Graph 1:- Displacement in maxilla- frontal view, transverse - x axis, Sagittal y- axis, vertical z – axis (measurement in mm)**

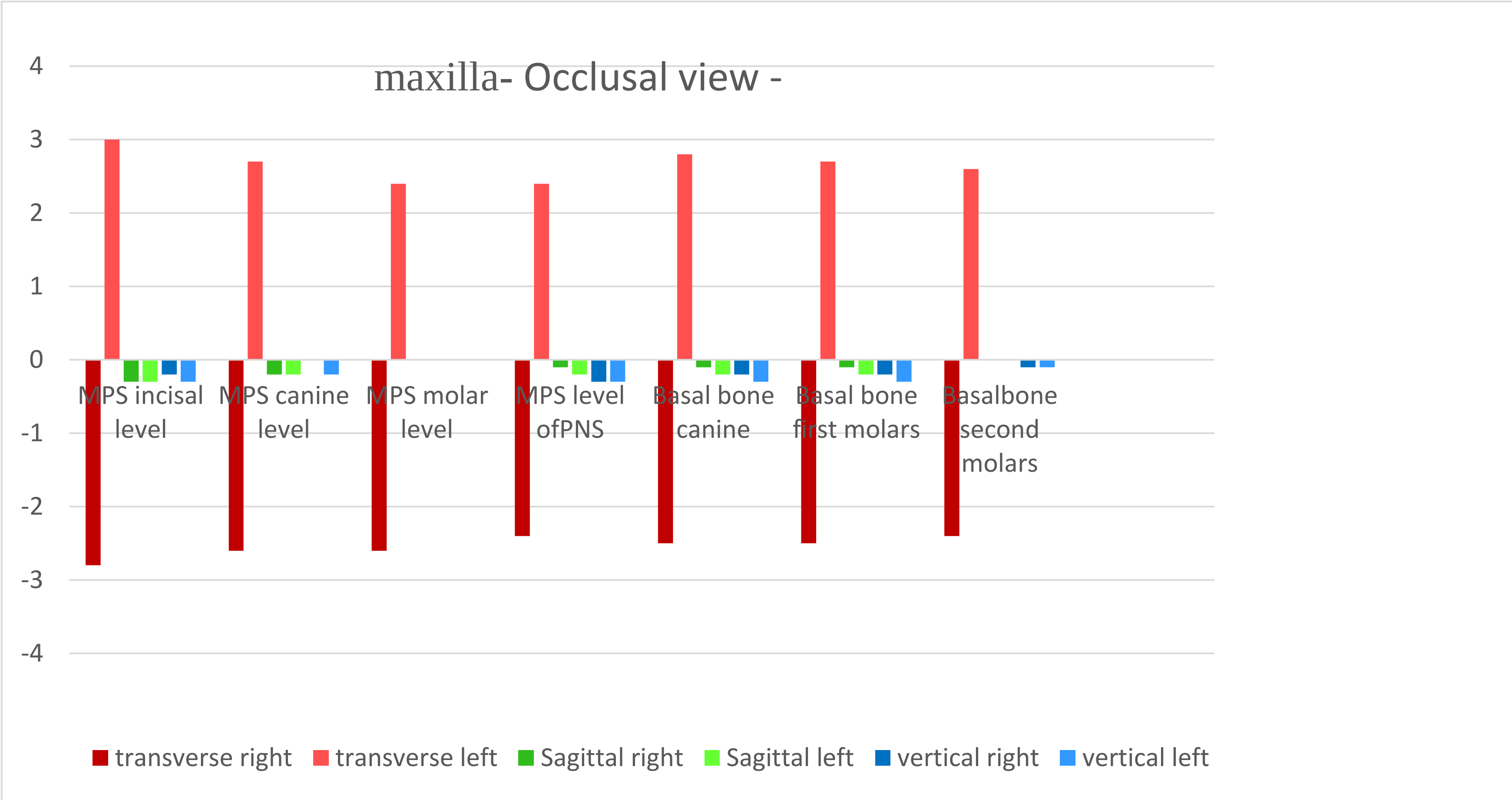


**Graph 2:- Displacement in sagittal view of maxilla, transverse - x axis, Sagittal y- axis, vertical z – axis (measurement in mm)**

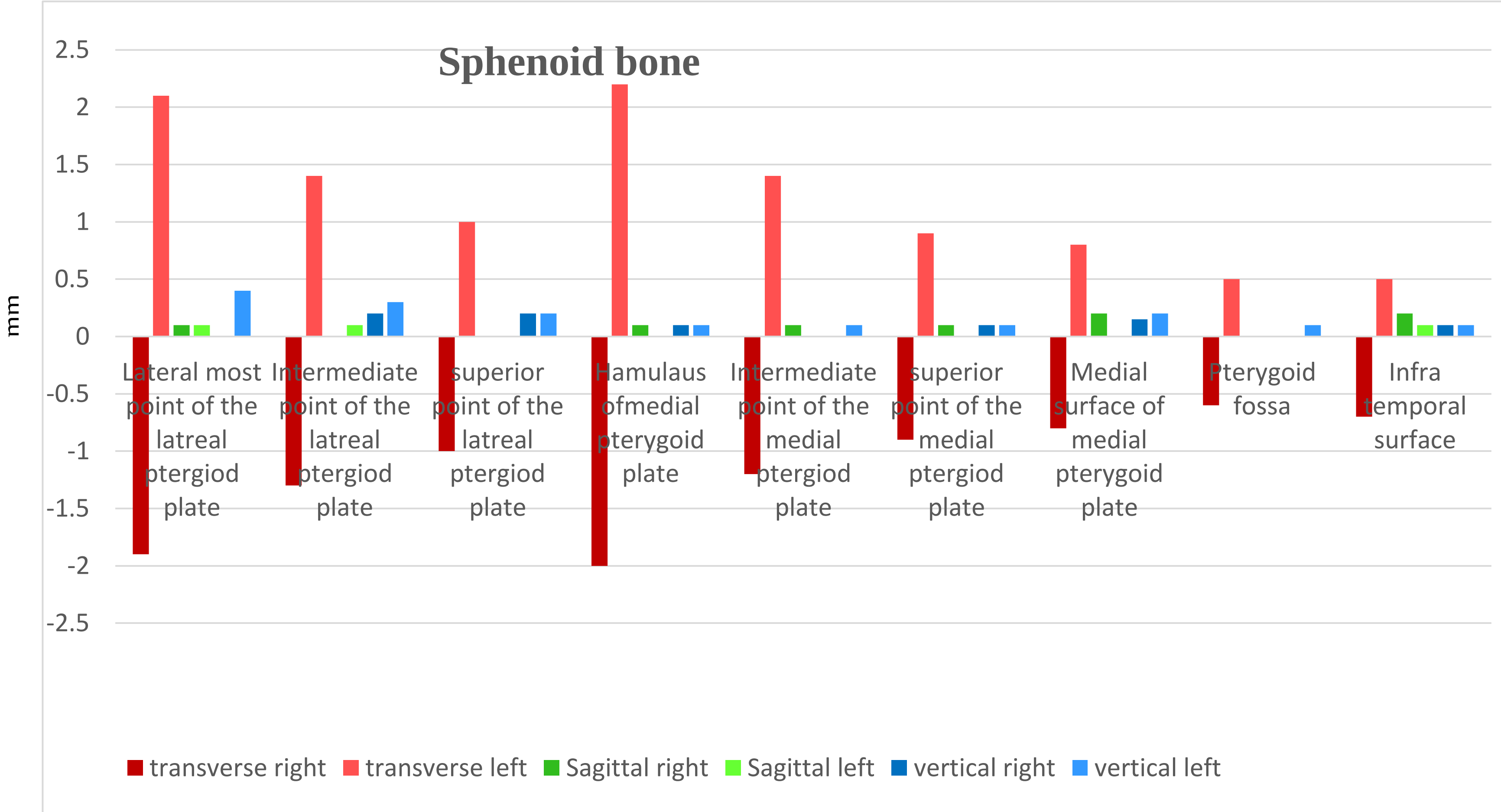


**Graph 3:- Displacement in occlusal view of maxilla, transverse - x axis, Sagittal y- axis, vertical z – axis**

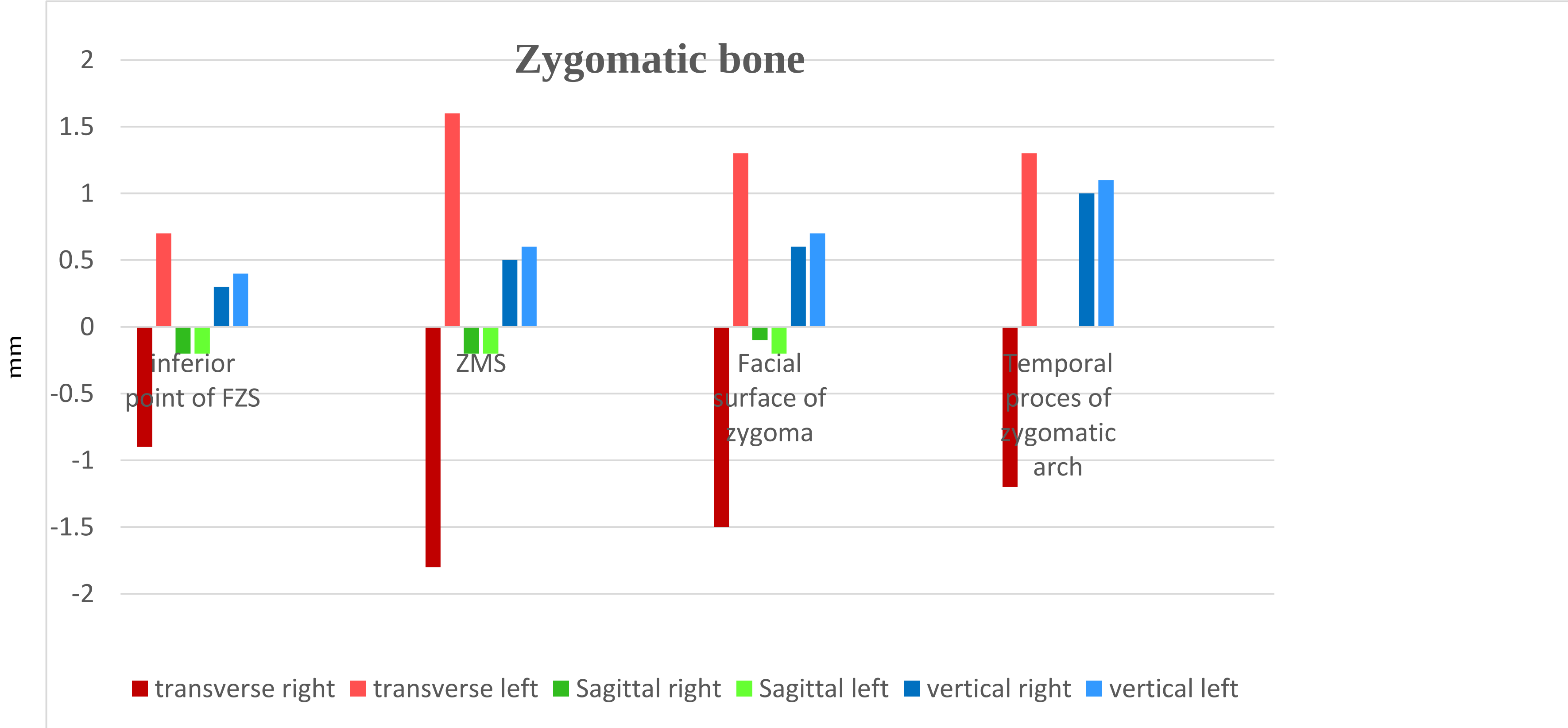
**(measurement in mm)**



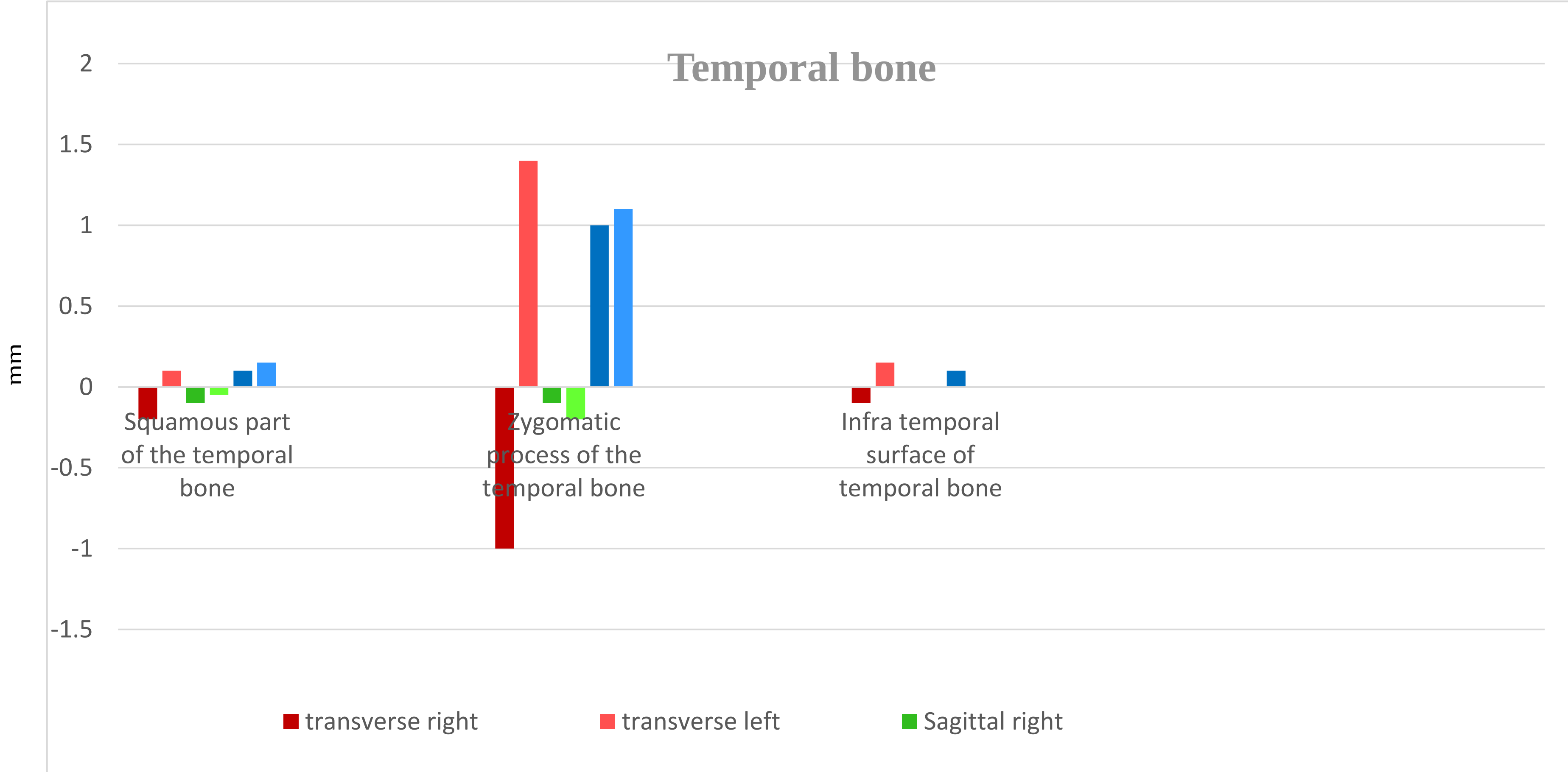
**Graph 4:- Displacement in sphenoid bone, transverse - x axis, Sagittal y- axis, vertical z – axis (measurement in mm)**



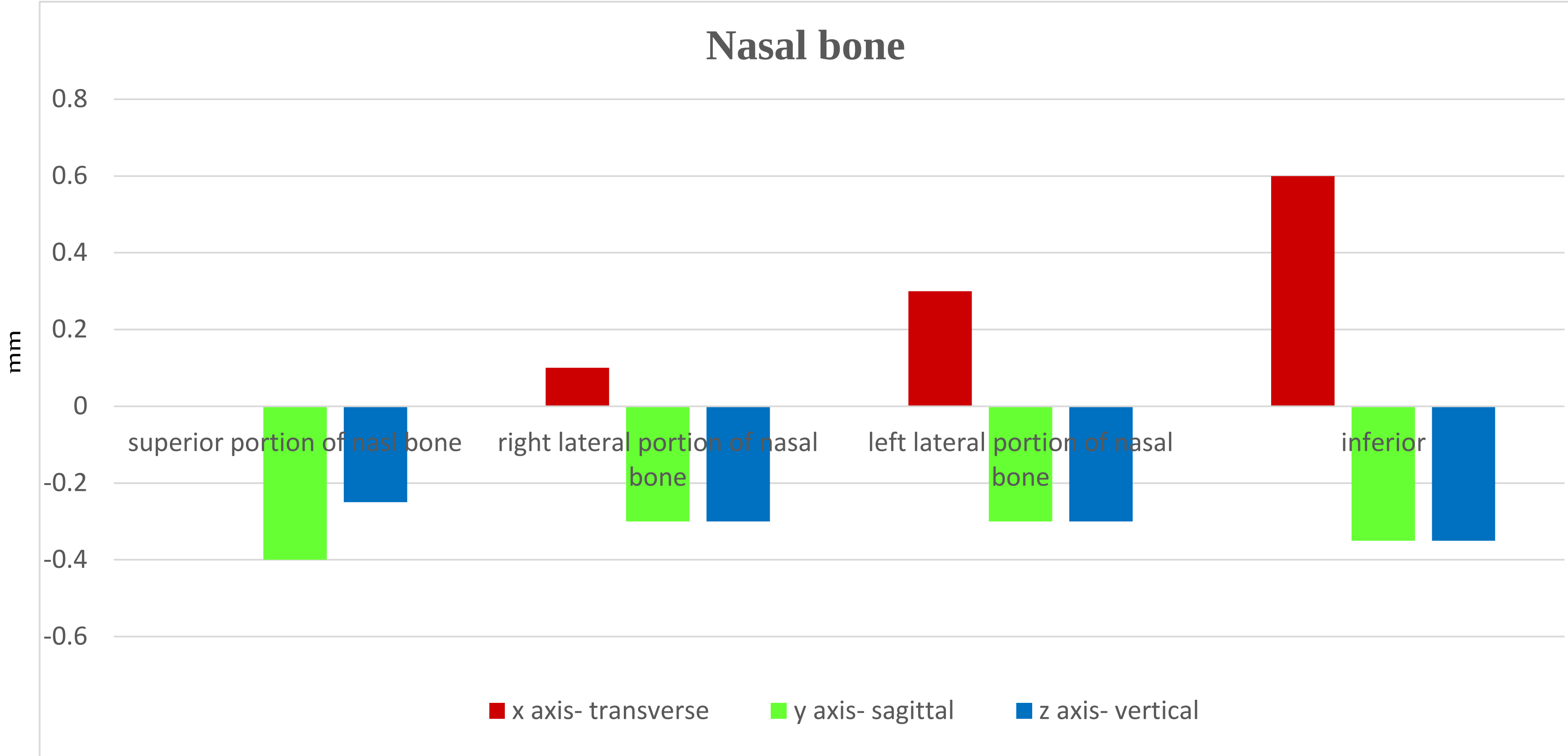
**Graph 5:- Displacement in zygomatic bone, transverse - x axis, Sagittal y- axis, vertical z – axis (measurement in mm)**



**Graph 6:- Displacement in temporal bone, transverse - x axis, Sagittal y- axis, vertical z – axis (measurement in mm)**

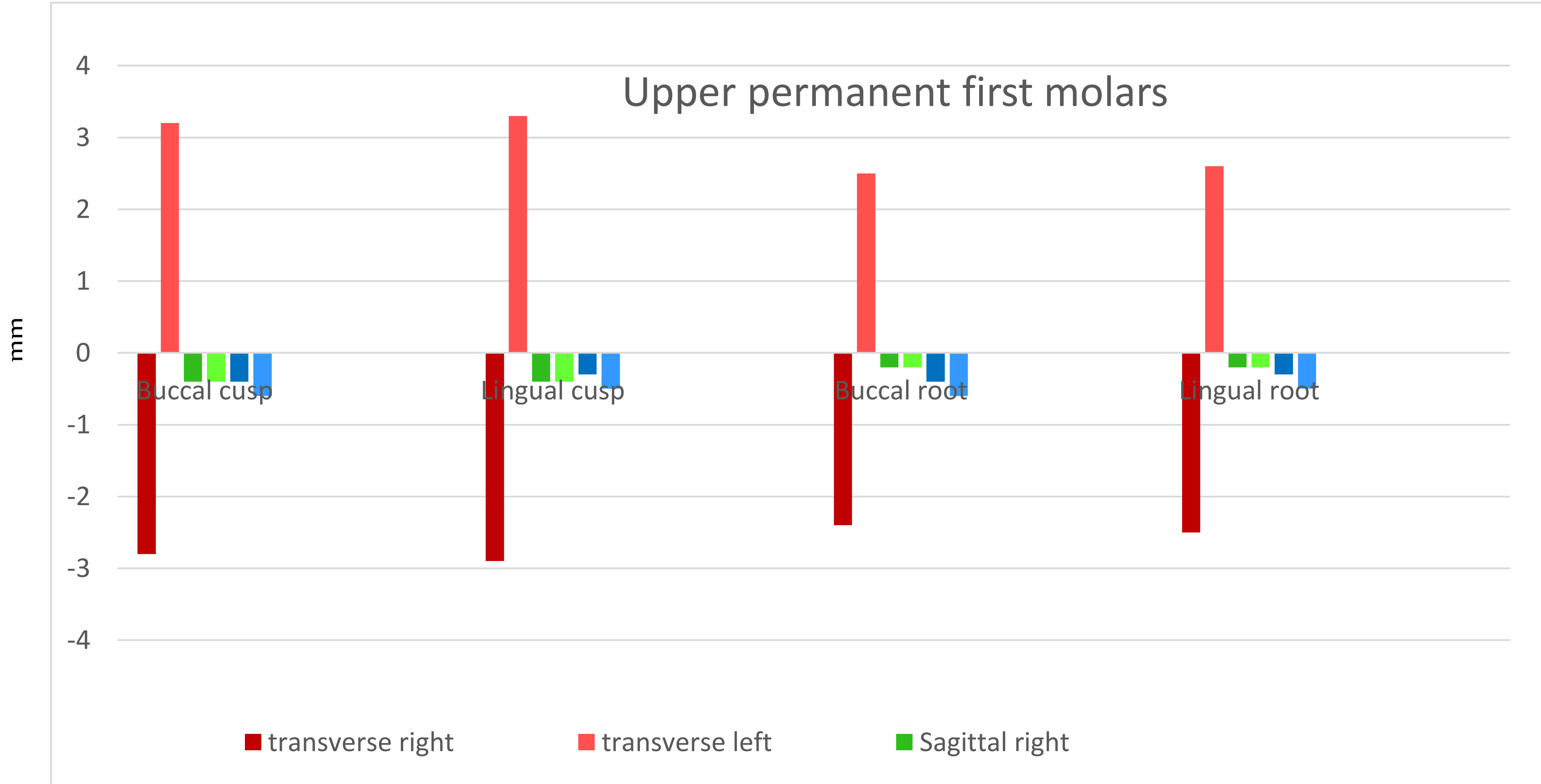


**Graph 7:- Displacement in nasal bone, transverse - x axis, Sagittal y- axis, vertical z – axis (measurement in mm)**

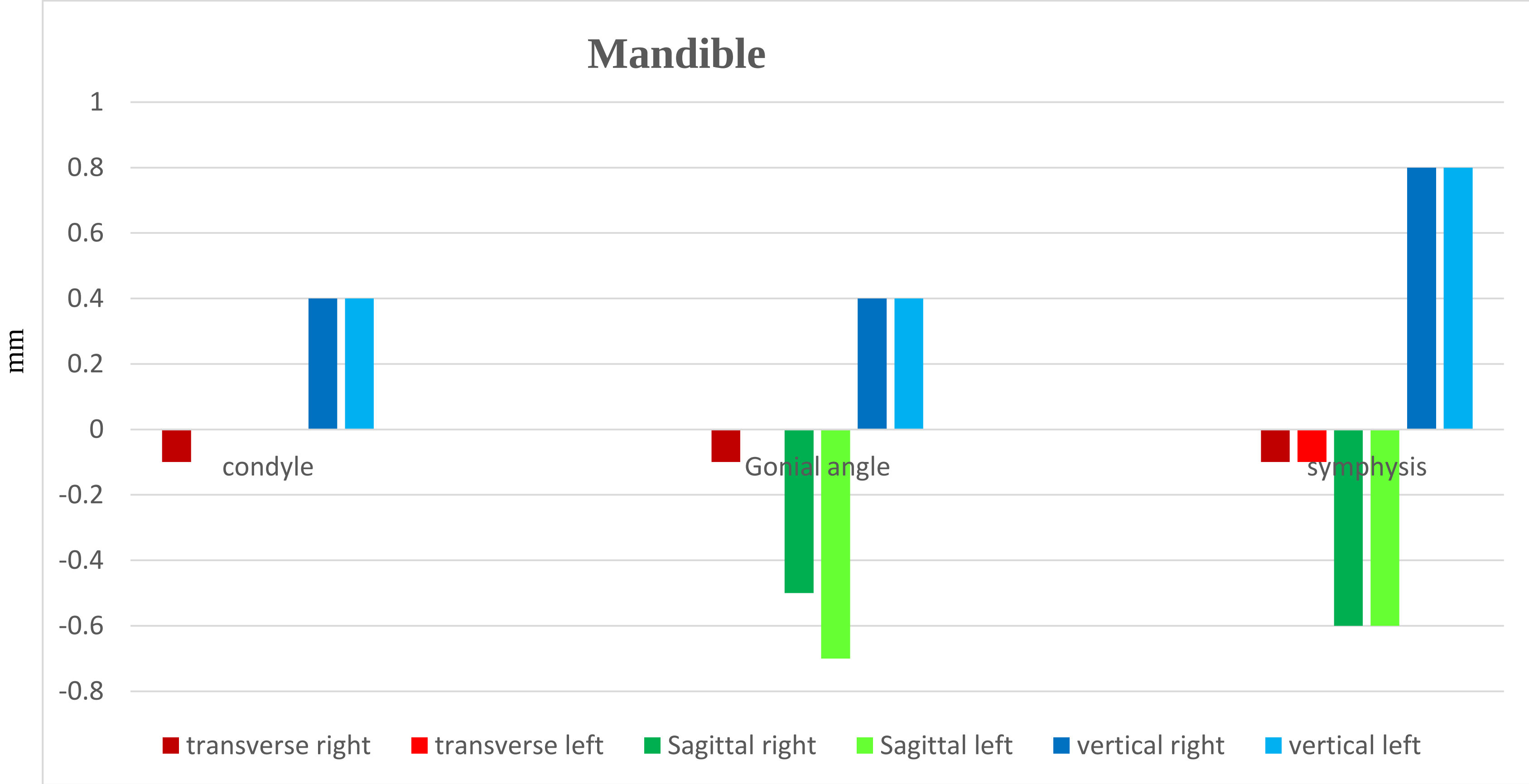


**Graph 8:- Displacement in upper permenet first molars, transverse - x axis, Sagittal y- axis, vertical z –axis**

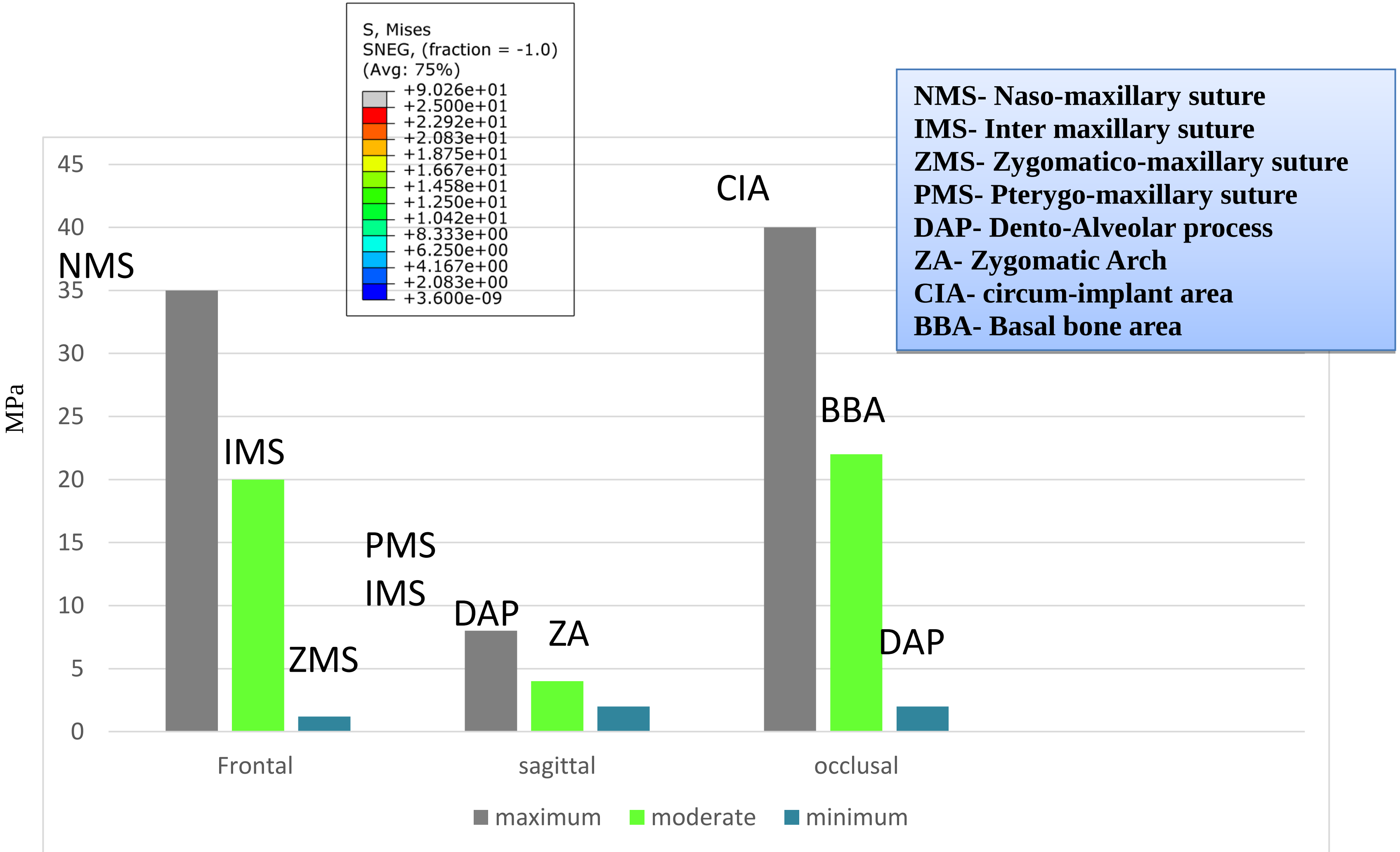
**(measurement in mm)**



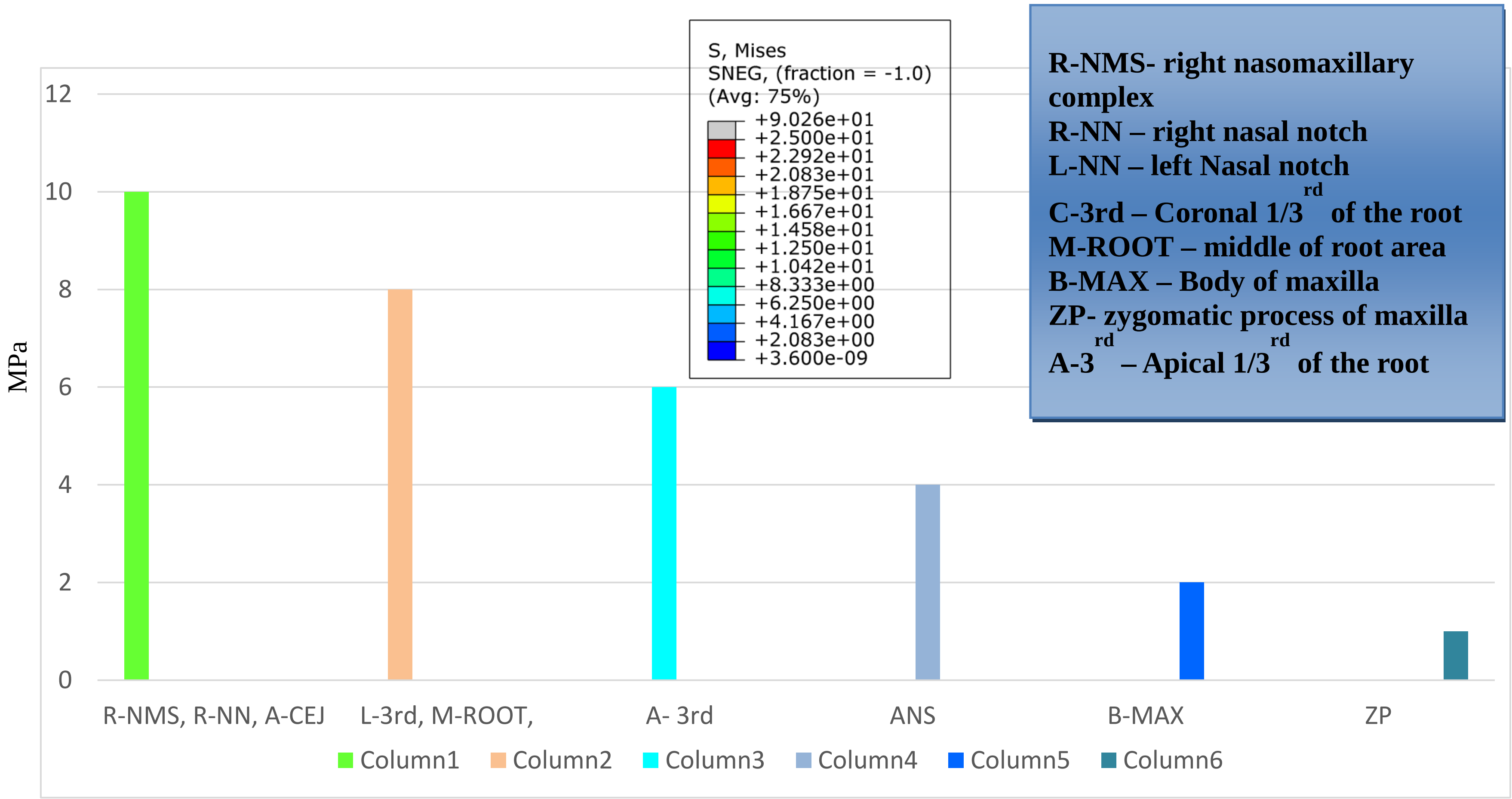
**Graph 9:- Displacement in mandible, transverse - x axis, Sagittal y- axis, vertical z – axis. (measurement in mm)**



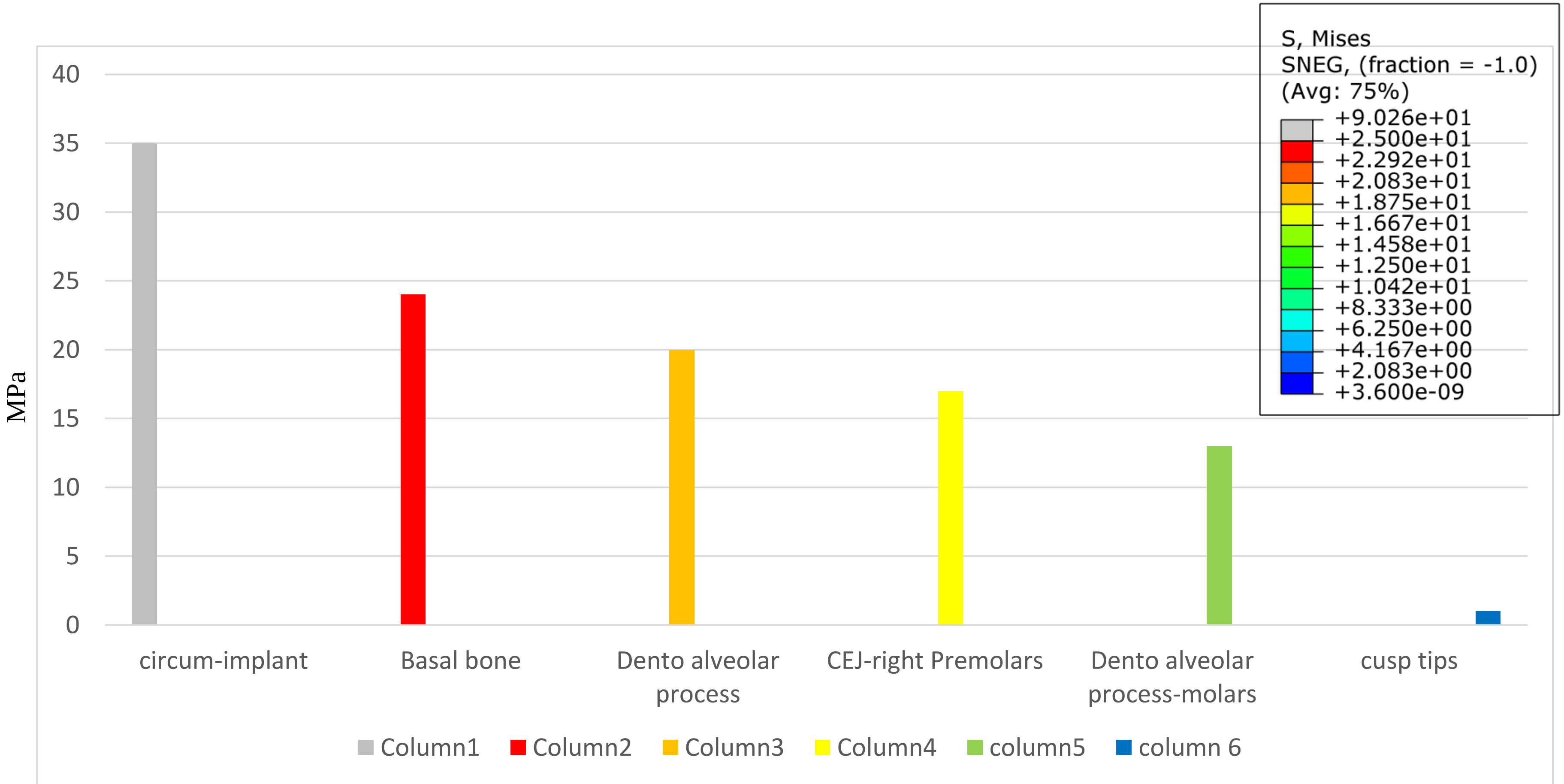
**Graph 10:- Stress distribution in frontal, sagittal and occlusal view of cranium.(measurement in MPa)**



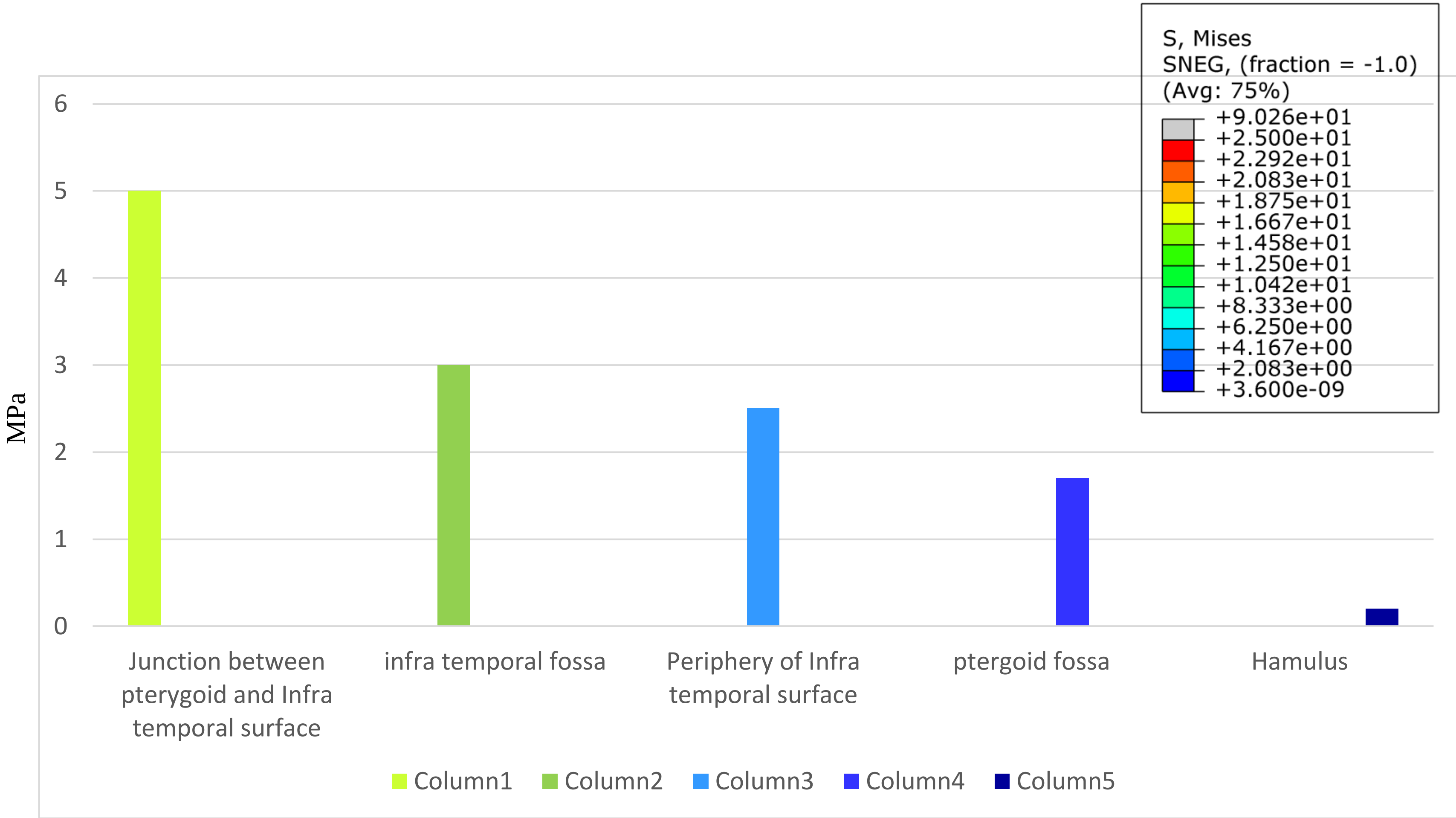
**Graph 11:- Stress distribution in the frontal view of maxilla (measurement in MPa)**



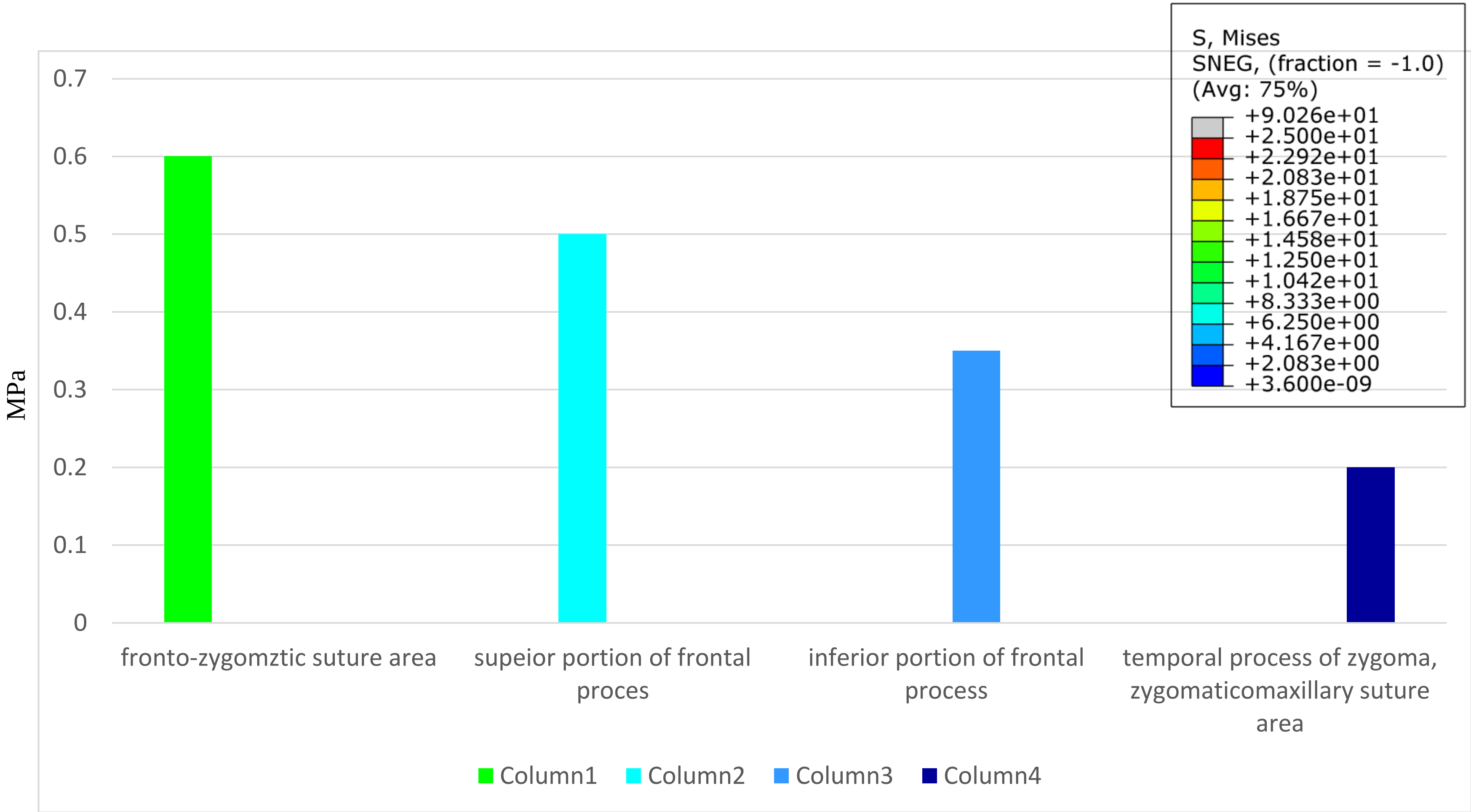
**Graph 12:- Stress distribution in occlusal view of maxilla (measurement in MPa)**



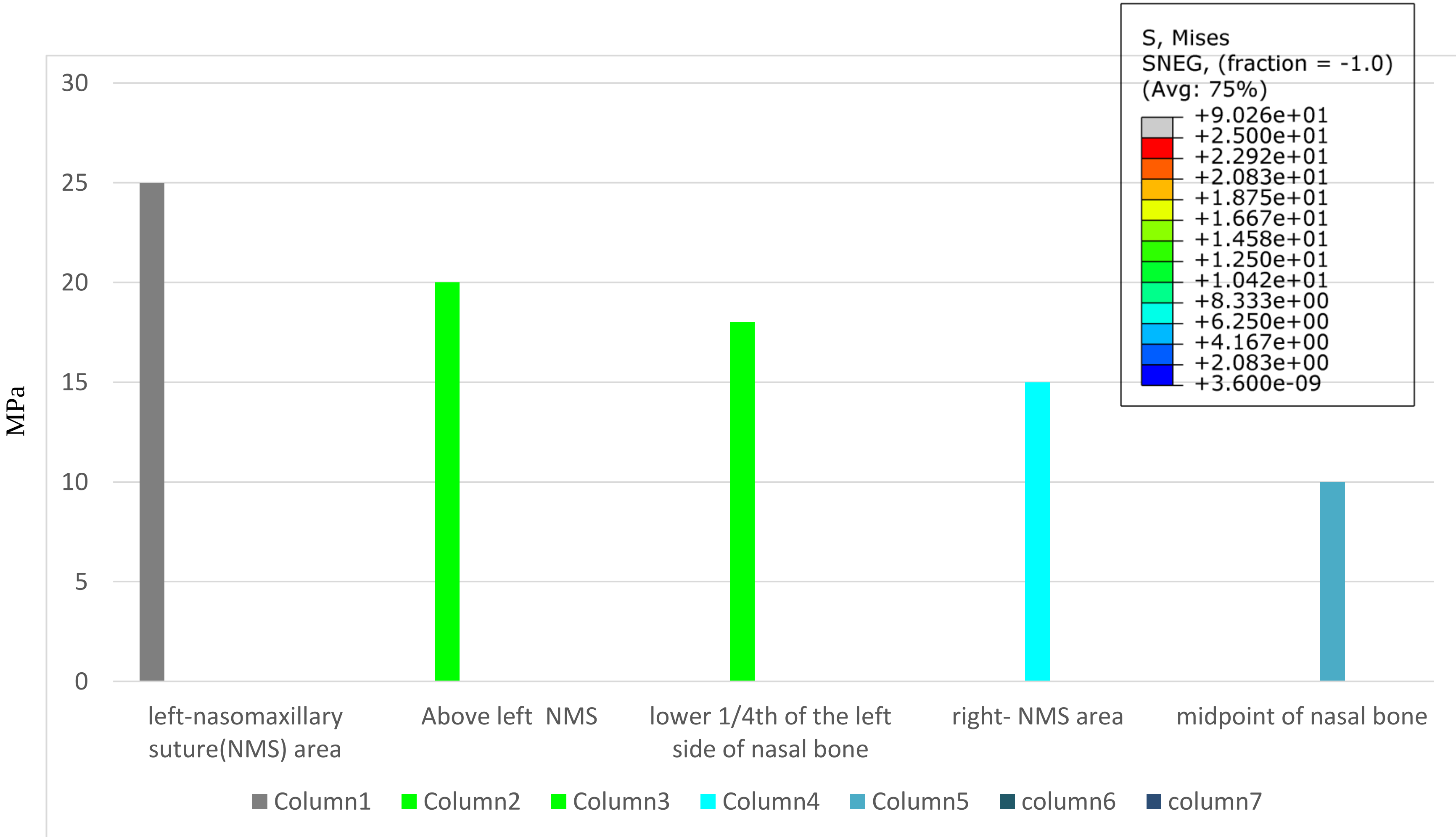
**Graph 13:- Stress distribution in sphenoid bone (measurement in MPa)**



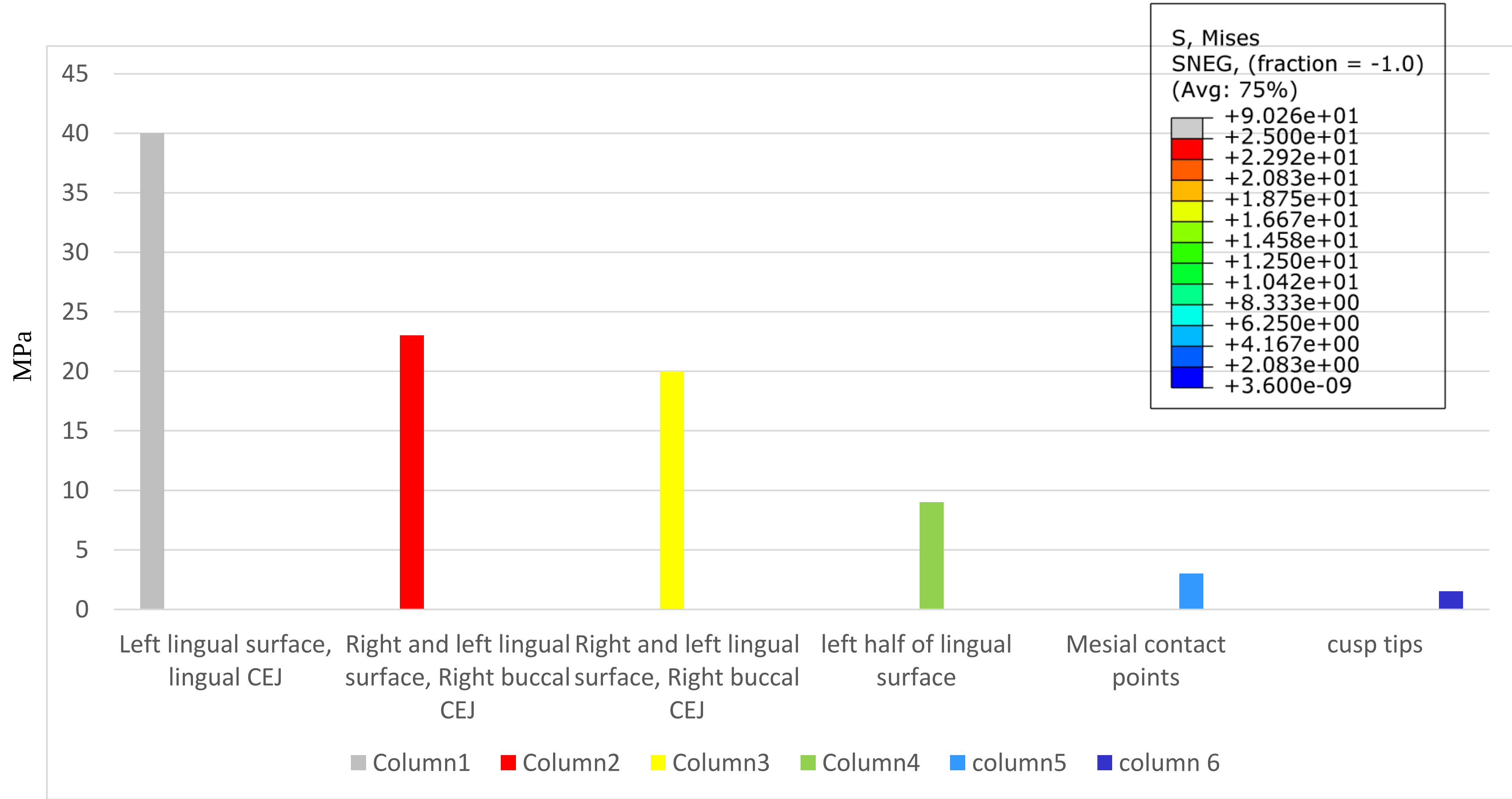
**Graph 14:- Stress distribution in the zygomatic bone (measurement in MPa)**



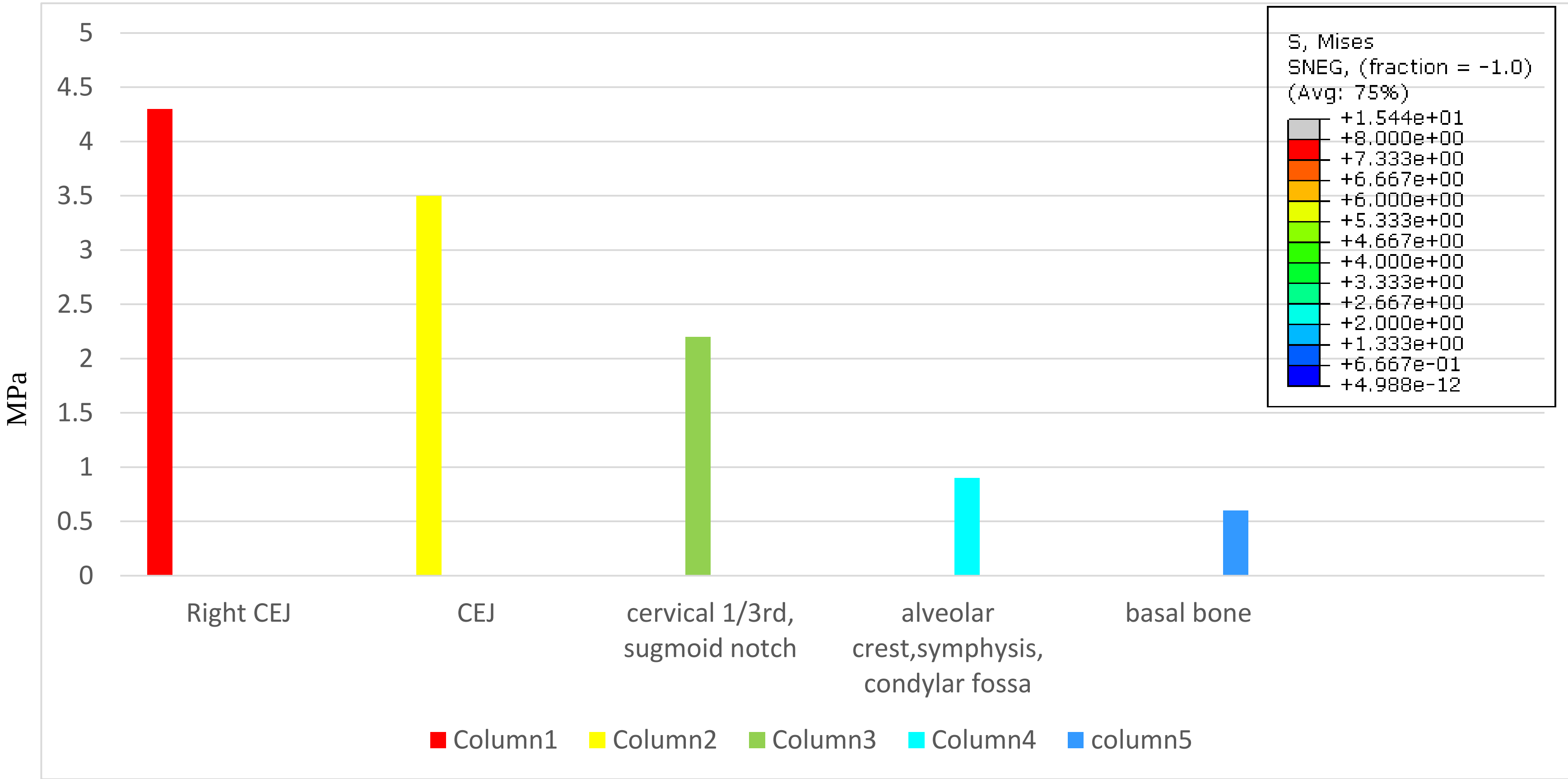
**Graph 15:- Stress distribution in the nasal bone (measurement in MPa)**



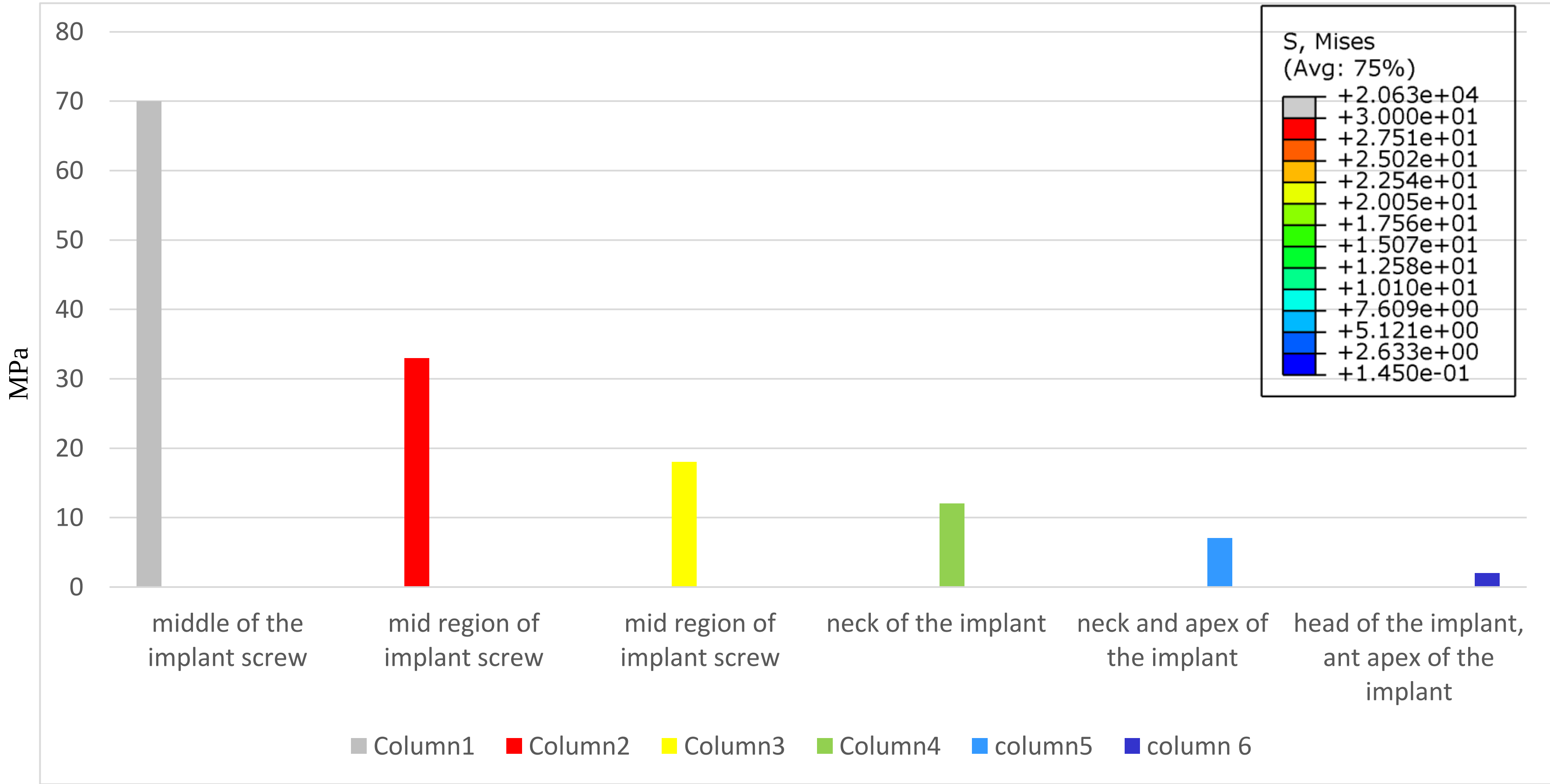
**Graph 16:- Stress distribution in the upper permanent first molars (measurement in MPa)**



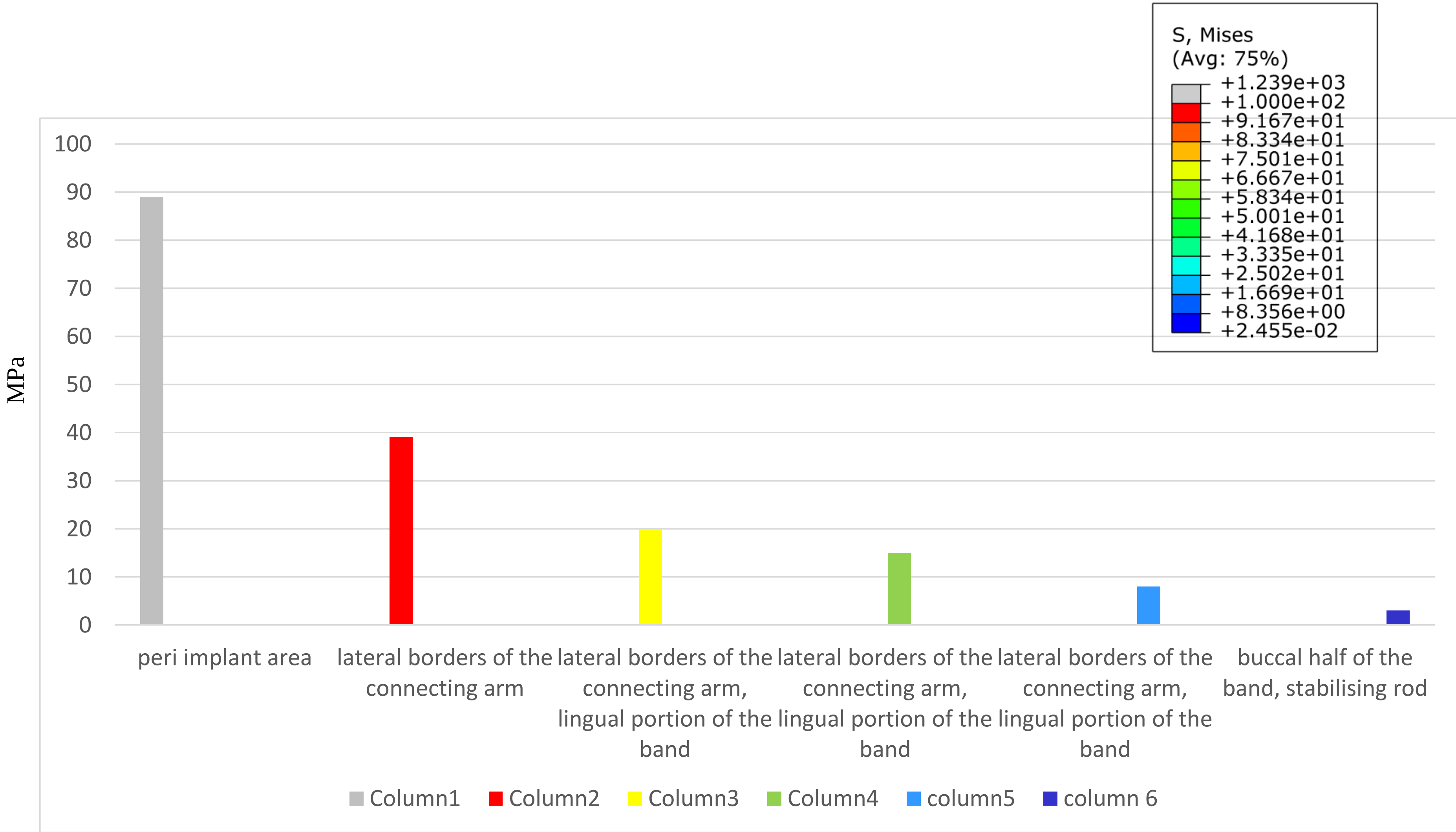
**Graph 17:- Stress distribution in the mandible (measurement in MPa)**



**Graph 18:- Stress distribution in the implants (measurement in MPa)**



**Graph 19:- Stress distribution in the appliance (measurement in MPa)**



# *Results*

# RESULTS

**Superimposition** (Fig 36-39)

The superimposition of the simulated FE model with the immediate post expansion CBCT image (STL) showed more than 95% correlation. The FE model showed a slight exaggeration than the actual model in all three planes of space.

## Displacement

The magnitude, pattern of displacement and stress distribution were analyzed both visually and numerically in the region of interest, which were as follows; maxilla, sphenoid bone, frontal bone, zygomatic bone, temporal bone, mandible, maxillary molars and mini-implants.

**Frontal view**: (Fig 40-42, Table-3, Graph -1)

Maximum amount of expansion was seen in the incisal edge (6mm) region followed by nasal aperture (1.7mm on each side) and the least in the fronto-nasal suture (1mm), with negligible amount of displacement above the fronto zygomatic suture (0.1m). The expansion had a ‘v’ shaped pattern with the apex towards the fronto-nasal suture and base towards the dentition.

**Sagittal view** (Fig 43-45, Table-4, Graph -2)

The maxilla had a downward (0.3mm) and forward (0.4mm) movement. The pterygoid plates showed no movement in the sagittal view.

**Occlusal view** (Fig 46-48, Table-5, Graph -3)

The maximum amount of displacement was seen in the incisal edge (5.8mm), followed by the canine and premolar (5.3mm) region and the least amount was seen in the PNS (4.9mm) in the transverse direction. The Midpalatal suture had a near parallel expansion with the difference of 1mm more in the anterior incisal region when compared to the most posterior point near PNS.

**Sphenoid bone** (Fig 49-52, Table-6, Graph -4)

Maximum displacement in transvers direction was seen in the free ends of the pterygoid plates (2mm) and the least amount was seen near the infra temporal fossa. The pterygoid plate had a lateral bend.

**Zygomatic bone** (Fig 53-59, Table-7, Graph -5)

The zygomatic bone overall had a forward (0.2mm) and lateral displacement (0.5mm). It had a rotational pattern with the center of rotation above the FZS.

**Temporal bone** (Fig 60-63, Table-8, Graph -6)

Maximum displacement was seen in the zygomatic process of temporal bone 1.2mm seen in the lateral direction and 1mm in the downward direction.

**Nasal bone** (Fig 64-67, Table-9, Graph -7)

The nasal bone had an overall forward (0.3mm), downward (0.3mm) and lateral displacement towards the left (0.1 to 0.6mm).

**Upper permanent first Molars** (Fig 68-71, Table-10, Graph -8)

Maximum amount displacement was seen in the buccal cusp (3mm) and the least amount seen in the root region (2.5mm) in the transverse axis.

**Mandible** (Fig 72-74a&b, Table-11, Graph -9)

The maximum displacement was seen in the symphysis (0.6mm forward, 0.8mm upward) and the least in the condyle region (0.6mm upward). The mandible was displaced in a forward and upward movement. It had a slight displacement towards the right of negligible amount (0.1mm).

## STRESS DISTRIBUTION

**Maxilla overall view** (Fig 75 a&b, Graph -10)

Frontal: - The maximum amount of stress of 35 MPa was seen in the Naso-maxillary suture and the least of 2 MPa is seen in the Zygomatico-maxillary suture.

Sagittal: - Maximum of 15 MPa stress was seen in the Pterygo-Maxillary and inter-Maxillary sutures and the least amount of 3 MPa was seen in the Zygomatic Arch.

Occlusal: - The maximum stress of 40 MPa was seen in the Circum-Implant area and the least in the Dento-alveolar region of stress 3 MPa and gradually reducing as it reaches the teeth.

**Maxilla Frontal view** (Fig 76 a&b, Graph -11)

The right side Nasomaxillary complex, nasal notch, coronal 1/3$^{rd}$ region of the root had 10MPa, followed by 8MPa in lower 1/3$^{rd}$ and mid root region of root. 6MPa in apical 1/3$^{rd}$ portion of the root region. 4MPa in ANS, 2MPa in body of maxilla and 1MPa in zygomatic process of the maxilla.

**Maxilla occlusal view** (Fig 77 a&b, 78, Graph -12)

35MPa stress was seen the circum-implant region, followed by 24MPa in Basal bone area, 20MPa in dentoalveolar process, 17MPa near the right premolar CEJ region, 13MPa in dentoalveolar process of molars and 2MPa in cusp tips.

**Sphenoid bone** (Fig 79, Graph -13)

5MPa stress was seen in the junction between pterygoid and infra temporal surface, followed 2.5MPa in peripheral region of infra temporal surface, 1.8MPa in pterygoid fossa and 0.2Mpa in the pterygoid hamulus.

**Zygomatic bone** (Fig 80, Graph -14)

0.6MPa was seen in the fronto-zygomatic suture area followed by 0.5MPa in the superior portion of frontal process, 0.35MPA in the inferior portion of frontal process, and 0.2mm in the temporal process of zygoma along with the zygomaticomaxillary suture area.

**Nasal Bone** (Fig 81, Graph -15)

25MPa stress was seen in the left nasomaxillary suture area followed by 20MPa above the left nasomaxillary suture, 15MPa in the lower $1/4^{th}$ of the left side of nasal bone, 10MPa in the right nasomaxillary suture, 4MPa in the midpoint of nasal bone and 2MPa above the midpoint of the nasal bone.

**Upper permanent first molars** (Fig 82, Graph -16)

The maximum stress of 40 MPa was seen in the left lingual surface and CEJ, followed by 22MPa in the right and left lingual surface along with right buccal CEJ, 20MPa in the right and left lingual surface and eight buccal CEJ, 8MPa in the left half of the lingual surface, 3MPa in the mesial contact point and the lest in the cusp tips with 2MPa.

**Mandible** (Fig 83, 84, Graph -17)

4.25MPa of stress was seen in the right CEJ region of the dentition followed by 3.5MPa in the CEJ of all the dentition, 2.25MPa in the cervical 1/3$^{rd}$'s and sigmoid notch, 0.8MPa in the alveolar crest, symphysis and condylar fossa and the lest in the basal bone region with stress of 0.6MPa.

**Mini-implants** (Fig 85, Graph -18)

The maximum stress of 70MPa was seen in the neck of the implant followed by 32MPa in the apex of the implant, 18MPa in the apex and gingival portion of the head, 8MPa in the coronal portion of the implant head and the least stress of 1MPa in the coronal most portion of the implant head.

**Appliance** (Fig 86, Graph -19)

The maximum stress of 90MPa was seen in the peri-implant area followed by 39MPa in the lateral borders of the connecting arm, 20MPa to 8MPa in the junction between the lateral borders of the connecting arm and lingual portion of the band and the least stress of 2MPa in the buccal half of the band and stabilizing Rod.

# *Discussion*

# DISCUSSION

Maxilla is the second largest bone of the face, it is a paired bone. The maxilla has a body and four processes namely the frontal, zygomatic, alveolar and palatine. Zygomatic process of maxilla articulates with zygomatic bone through zygomatico-maxillary suture. The frontal process projects upwards and backwards to articulate with the nasal margin of frontal bone and nasal bone by fronto-maxillary and naso-maxillary suture. The alveolar process bears the socket for the upper teeth, posterior border articulates with the horizontal plate of palatine bone and medially with the opposing palatine process of the maxilla. Therefore maxilla as a whole articulates superiorly with three bones nasal, frontal and lacrimal; medially with five namely ethmoid, inferior nasal concha, vomer, palatine and opposing maxilla; laterally with zygomatic bone.

Pterygoid process projects downwards from the junction of greater wing and body of sphenoid behind the third molar. Inferiorly it divides into medial and lateral pterygoid plates which are fused anteriorly to articulate with perpendicular plate of palatine bone.[75]

**Issacson et al**[50, 51] had explained, that the resistance of facial skeleton to maximum transverse displacement increases with age and maturation. They also emphasized that the maximum resistance is not due to the midpalatal suture but by the surrounding maxillary articulation. **Kokich**, **Scott and Sicher**[56] had said the circum-maxillary sutures (CMS) remains open till the middle of adulthood whereas some authors said that the CMS begins to close parallel to the cranial sutures timing but do not mature to the same extent.

The time of closure of some of the circum-maxillary sutures are, fronto maxillary at 68 - 71 years, fronto nasal 68 years, nasomaxillary 68 years, fronto zygomatic 72 years, zygomatico-maxillary 70 – 72 years and the intermaxillary sutures at 20 - 25 years. The transverse growth in the midpalatal suture continued up to the age of 16 in girls and 18 in boys,[83]. The palatine bone acts as the borderline area by articulating with sphenoid bone (base of skull) and the maxilla (facial skeleton). **Melsen**[88,89] stated, that during postnatal period the maxilla, palatine bone and sphenoid respond to heavy functional demand and therefore heavy inter-digitation can be expected. This can exhibit high resistance to both vertical and horizontal displacement of the maxilla in later stages of development.

**Heinrich wehrbien et al[96]** 2001 studied 30 occlusal radiograph from 10 subjects ranging from 18 to 38 years and compared with the suture morphology, mean sutural width and degree of sutural closure on stained sections and said that even if the suture is not visible in radiograph the word suture obliteration and fusion should be avoided because they found that even if suture was not seen in radiograph morphometrically it was not obliterated.

**Britta Knaup[55] and Heiner Wehrbein**[96]et al, did histomorphometric study and found that the earliest ossification was registered in a 21-year-old man. The oldest subject without ossification was a 54-year-old man. So they concluded that the ossification of the midpalatal suture is not a valid reason for the increased transversal resistance encountered during rapid palatal expansion in younger subjects (≤25 years) as well as in many older persons.

**Fernanda Angelieri et al**[4] 2015, studied the Cone-beam computed tomography images of 140 subjects. He divided the MPS into five stages of maturation and defined them as

1. Stage A, straight high-density sutural line, with no or little interdigitation
2. Stage B, scalloped appearance of the high-density sutural line.
3. Stage C, 2 parallel, scalloped, high-density lines that were close to each other, separated in some areas by small low-density spaces.
4. Stage D, fusion completed in the palatine bone, with no evidence of a suture; and
5. Stage E, fusion anteriorly in the maxilla.

He concluded that at stage C, less skeletal response would be expected than at stages A and B, since there are many bony bridges along the suture. For patients at stages D and E, surgically assisted RME would be necessary, as the fusion of the midpalatal suture would have already taken place either partially or totally.

The most common problem seen in the maxilla is “Transverse Maxillary deficiency syndrome” termed by **James. A. McNamara**[72,73]. This can be seen in class II and Class III skeletal malocclusion. Almost 30% of Class II and 57%

of Class III skeletal malocclusion, presents with transverse maxillary deficiency.

Maxillary transverse deficiency can present itself clinically as cross bite or scissors bite, the other two most common features were crowding and proclination. All of which are a derivative's, from discrepancies between the size of the teeth and the size of the bony bases. If the position of the maxillary dentition reflects the skeletal discrepancy, it results in cross bite. The maxillary constriction can be camouflaged by the dentition as buccal tipping of the upper and lingual tipping of the lower posterior, this might result in absence of cross bite or scissors bite. Another clinical manifestation of transverse deficiency is the dark space that might be present in the corner of the lips during smiling, which **Vanersdall** termed as "negative space" [72,73]. Some patient might also have airway obstruction leading to sleep apnoea.

Maxillary transverse deficiency can be diagnosed using various methods like smile analysis, model analysis, cephalometric analysis and also transverse analysis from CBCT images.

Clinically the transverse maxillary deficiency can present itself with cross bites, crowding, arch widths measured at the muccogingival junction and dental crowns will be reduced, buccolingual inclination of posterior teeth will have an amount of compensation, and the shape and height of the palatal vault might be deep. There may be minimal soft tissue changes associated with a maxillary transverse deficiency including paranasal hollowing, a narrow nasal base, deepened nasolabial folds, and zygomatic hypoplasia.[85]

Model analysis to access maxillary transverse dimension using dental casts to assess are **McNamara's**[72,73] simple rule of thumb which is "maxillary arches less than 31 mm will need orthopaedic or surgically assisted expansion", **Andrews**[2] analysis is also another valuable tool in diagnosing transverse deficiency in which the maxillary width is represented by the distance between the right and left most concave points lying on the maxillary vestibule, at the level of the mesiobuccal cusp of the first molars. Mandibular width is defined as the distance between the right and left WALA ridges located at the level of the mesiobuccal groove of the first molars. To assess transverse deficiency, the difference between the mandibular and maxillary widths is calculated, which should ideally be equal. It also gives an estimate of the amount of maxillary skeletal expansion required. **Yonsei's index**[45] transverse index accessed the maxilla to mandibilar BAW-cast Difference measured from model (5.15 +/- 2.56 mm).

In the 1990s, Posteroanterior cephalograms (PAC'S) became popular and most readily available, as well as reliable radiographs for evaluating transverse skeletal discrepancies. Some of the PAC's used were Rickett's, Grummons, Hewitts, Graysons and Ricketts Rocky Mountain Analysis.

With the advent of CBCT many measurements could be done accurately, which was otherwise difficult using standards cephalometric analysis. Some of such CBCT analysis are Case Western Reserve University analysis[78] which might reveal the extent of buccal tipping of maxillary molars and the degree of dental compensation. Yonsei's index which suggested that the combined evaluation of both maxilla-mandibular BAW-CT difference (−0.39 +/- 1.87 mm) and BAW-cast difference of the first molars could be used for the accurate diagnosis of the underlying maxilla-mandibular transverse discrepancy[45,78].

Rapid maxillary expansion (RME) procedures have been used over the past century[7], and have been shown to be a valuable aid in the orthodontic treatment of young patients exhibiting maxillary collapse, pseudo-class III malocclusions, and respiratory ailments[10, 40, 41]

The expansion protocol can be either a slow (SME) or rapid (RME) type. Some of the slow maxillary expansion appliance are the W-arch, quad helix, coffin spring, etc. and these appliance were activated a rate of 1mm per week. In SME there is more of dentoalveolar tipping and suture split can be brought about only in a very young individuals and patients with cleft lip and cleft palate.

RME appliances like the Minnie expander, Haas, Hyrax, etc. all of which contains a Jackscrew anchored to the teeth via a rigid connecting wire. The opening of the jackscrew produces the expansion force. These appliances are activated at the rate of 0.5 to 1mm per day, and might produce orthopaedic forces of about 3 to 10 lbs. which can easily split the midpalatal suture in young individuals and force the two maxillary halves laterally.[41, 48, 52]. This can be well appreciated clinically by the appearance of midline diastema between the two central incisors. For adults, however, this is not the case due to the increase in interdigitation of midpalatal suture and decreased elasticity of bone, [93] rendering the splitting of MPS almost impossible.

**Bell and Epker**[9] combined the RME with surgical assistance to bring about expansion and to correct the transverse discrepancies in adult. Surgically assisted RPE (SARPE) apart from having high rate of morbidity is an invasive procedure, can also result in lateral rotation of the two maxillary halves with less horizontal translation.[113] In addition, may also be detrimental to the periodontium and has been shown to result in an increased rate of relapse during the post retention period.

Therefore **Lee**[64] in the year 2010 used miniscrew implants to anchor the expansion device to the palate directly in an adult patient and thus Miniscrew Assisted Rapid Palatal Expansion came into play. The use of MARPE distributes the stress throughout the palate, and thereby decreases the concentration of the stress around the anchor teeth.[52] This Miniscrew Assisted Rapid Palatal Expansion even though it split the MPS, it was in a triangular fashion with more of splitting in the anterior than in the posterior.

The results of all these appliances were studied extensively and documented using many methods. All the results showed that

1. The splitting of MPS is not parallel but in triangular fashion with more expansion seen in the anterior than in the posterior region.
2. Dental expansion contributes to almost 50% of total expansion achieved.

3. Miniscrew Assisted Rapid Palatal Expander seems to produce better expansion and lesser extent of dental tipping when compared to the conventional RME's.

Recently many modifications were done in Miniscrew Assisted Rapid Palatal Expander. To maximize the skeletal expansion and to negate the dental tipping. Authors like Won Moon and Matt McGinnis have introduced newly modified MARPE device called Maxillary skeletal expander. They claim that their design produced an almost perfect parallel split of the MPS when certain factors were followed

The factors that were considered are

1. Stability of the implant: - To increase the stability the length and width of the implant should be sufficient enough to have bi-cortical bone engagement (palatine surface and the nasal floor), which can withstand the heavy anchorage demand. This will prevent the bending of the implant.
2. Placement of the expander appliance: - The appliance were placed as posterior as possible to overcome the resistance offered by the pterygoid plates and the zygomatic buttress.
3. Rigidity of the connecting arms:- reducing the diameter of the wire connecting the implant to the molars were beneficial, as they only partially translate the force to the molars and undergoes more deformation within themselves.[26, 46, 70]

The treatment results of these appliances were very promising and studied either using CBCT of the patients or by FE model which were generated from a dry skull and the effect of individual modifications like bi-cortical anchorage were evaluated separately[65].

But the literature showed none of the authors have studied the effect of such appliance in an actual patient and had evaluated the stress distribution in circum-maxillary bones using FE model created from the same patient except **Ludwig**[70]. But his study emphasized more on the design of FE model.

The aim of the study was to do a Finite element analysis (FEA) of the stress distribution and displacement of the skull with Miniscrew Assisted Rapid Palatal Expansion. The FE model, was obtained from the CBCT image of a patient who had undergone maxillary expansion using Miniscrew Assisted Rapid Palatal Expander.

The finite element analysis is a reliable method, to see the stress distribution generated by the use of expansion appliance.[59] Finite element method (FEM) replaces a complex structure by assembling simple elements interconnected at points called nodes. These assembled elements can represent any shape or defined model.[102] the material properties can be assigned to each element according to the clinical model. Load can be applied to that model and the distribution of displacements and stresses can be visualised.

In this present study a CT model of a 19 year old female, who had undergone maxillary transverse expansion with Mini Screw Assisted Rapid Maxillary Expansion was used to create the FE model. The subject had a skeletal class II with angles class II div 1 malocclusion and had a constricted maxillary arch. The model of the Miniscrew Assisted Rapid Palatal Expansion device was constructed to closely resemble the device used in the subject. The design has four MSI's placed in line with the molars taking the first molar as the anchor unit, the MSI's had a bi-cortical bone engagement and the connecting arm had a diameter of 1.2mm. A displacement of 5mm was given in the FE model since the subject exhibited 5mm of expansion.

Most of the authors, who had used FEM analysis to evaluate the stress induced on the craniofacial complex during expansion, have generated their FE model from CT scans images[52, 54, 70, 87]. Moreover when compared to CBCT, an FE model from CT image will have very less noise which is mandatory to get a clear and precise replication of the original structures. Since the whole skull along with individual bones and sutures were considered for evaluation in this present study, a patient with pre-treatment CT was selected.

**SUPERIMPOSITION**: - (Fig 36-39)

To further validate the results, the simulated FEM model was superimposed on the immediate post CBCT generated STL model. The post expansion CBCT reduces the amount of radiation exposure when compared to CT. The superimposition was done by taking the external reference points like natural head position, Mastoid process, foramen magnum and vault of the skull. The other areas had undergone deformation and therefore could not be taken as the reliable reference point.

The superimposed result showed more than 95% of correlation between the two models. The slight exaggeration of the results from FE model might be because the MPS was given complete patency whereas the patient had interdigitation of MPS to a significant level as revealed by the pre-treatment CBCT.

**THE DISPLACEMENT**: -

The displacement of each bone is seen in all three dimensions x-transverse (+ve is towards left side, -ve is towards right side), y- antero-posterior (+ve is backward, -ve is forward) and Z- is vertical (+ve is upward, -ve is downward).

**Frontal view** (Fig 40-42, Table-3, Graph -1)

The maxilla in the frontal view shows a triangular V-shaped pattern of separation with the apex towards the nasal cavity and base towards the central incisor. There was almost no displacement noted in the area above the frontal zygomatic suture in all the three planes of space. Least amount of displacement was seen in the region closer to the fronto-Zygomatic suture. The areas far from the fronto-zygomatic suture towards the occlusal surface had the greatest amount of displacement.

**Iseri**[52]**, Jafari**[54]**, Ludwig**[70] and **Provatidis**[86] all in their FEM study with both RME and MARPE have found a V-shaped expansion **which is similar** to this present study.

Some authors had suggested that the fronto-zygomatic, zygomatico-maxillary and zygomatico-temporal sutures as the main centres of resistance to rapid maxillary expansion. There has always been a debate on the location of centre of rotation. Some authors have established the centre of rotation at the fronto-maxillary suture, whereas others believed to it be closer to superior orbital fissure. **Canterella et al** [18,19,20] 2018 had found this centre of rotation for the zygomatico-maxillary complex to be slightly above the superior aspect of the fronto-Zygomatic suture.

The present study is in **accordance** to the finding of **Canterella et al**[18,19,20] since there was almost no displacement that could be seen above the fronto-zygomatic suture. Further, more amount of expansion is seen overall in the right side when compared to the left side which was also suggested by **Canterella et al**[18,19,20]. He had given a hypothesis, that it could be associated with circum-maxillary suture which may not become loose in the same proportion on the both side. Therefore during expansion this might result in more displacement on one side compare to the other leading to asymmetrical expansion. The other reason being the density and the morphology of the bones especially the zygomatic buttress and pyramidal process which may not be identical on both side.

**Sagittal View: -** (Fig 43-45, Table-4, Graph -2)

The zygomatico-maxillary complex as a whole showed a downward and forward displacement whereas the pterygoid plates did not show any forward movement.

This cannot happen unless there is a disjunction in the pterygo-palatine suture.

**Iseri et al**[52] 1998 in his FEM model analysed the outcome of tissue-borne RME appliance and found the central incisors and molars to have a downward (extrusive) movement.

**Jafari et al**[54] 2003 applied a transverse force in maxillary first premolar and first molar crown region of an FEM model. He noted that the maxilla, central incisors and molars where displaced downward and forward. Both of the above study **correlate with** the present study**.**

**Lee et al**[62] 2009 applied an expansion force of 100gms on the first premolar and molar crown surface of FE model. He observed that the maxilla moved downward and backward, which **does not correlate** to our study. He explained that the reason for this could be the boundary condition set for the model. In his study the elements in the most superior position where fully constrained whereas in **Iseri, Jafari** and our study the constrained where given in the foramen magnum.

**H.K.Lee et al**[63] 2014 in his FEM study compared four appliance, two appliance where bone-borne appliance, one hyrax appliance supported with miniscrew and the other was a conventional hyrax with surgical assistance. He found that the maxilla moved downward and forward in both the hyrax screw but in the bone-borne appliance the maxilla moved downward and backward. He has explained that in his study that the reason for this difference in results could be the inclusion of premolar and molars in the hyrax appliance.

**Ludwig et al**[70] 2013 did a finite element analysis on a FE model with **Wilmes** appliance. In this study he compared the conventional finite model with a viscoelastic model. He found that in both the models the maxilla moved downward and forward which is consistent with the result of this study.

**Melsen**[75,74] studied the pterygo-palatine area and stated that disarticulation of these bones where possible only in infantile and earlier adolescent period whereas in the later juvenile and earlier adolescent it was always accompanied by fracture of the heavy interdigitation.

**Canterella**[18,19,20] et al 2018 as shown the disjunction of the pterygo-palatine suture in 9 out of 15 subjects. He suggested that the fulcrum of rotation of the maxilla to be more posterior and lateral in MARPE when compared to tooth-borne appliance. Since the maxilla is located medially and anteriorly to this fulcrum of rotation, during expansion the maxilla tends to move laterally and anteriorly. This movement further helps in disarticulation of the pterygo-palatine suture.

**OCCULSAL VIEW** (Fig 46-48, Table-5, Graph -3)

The FEM simulation showed a near parallel split of the midpalatal suture. Only a 1mm more of expansion was seen in the anterior ANS region when compared to the posterior. The expansion that had taken place in the PNS area is 94% to that of the ANS area.

In the FEM study done by **Iseri**[52]**, Provitidis**[85]**, Jafari**[54]**, Lee**[62] in there RME model and **Ludwig**[70] in his MARPE model all showed a v-shaped expansion, with the base in incisor area and the apex towards the PNS.

**H.K. LEE et al**[63] in his bone-borne FE model found more amount of expansion taking place near PNS when compared to ANS region. In the hyrax group they found more expansion in the premolar region. This studies is in **Contrast to** the result of our study.

**H.K. LEE et al**[63] in his study explains that the difference in his study could be because the mid-palatal suture area of the FE model was filled with cortical and cancellous bone. Moreover, the force was given in the posterior part of the palate which had thinner cortical bone when compared to the anterior. However, one of his bone-borne appliance which had the mini-screws placed in the palatal slope showed a parallel splitting of the mid-palatal suture which **coincides** with our study.

**Won Moon**[65] in his FEM study on monocortical and bicortical anchorage stated that, more amount of transverse expansion had taken place in the bicortical anchorage.

**Park et al**[81] showed the mid-palatal suture to split more in the posterior region compared to the anterior this also differs from our study. He explained that this **disagreement** could be due to the specification and structure of the FE model, the other reason was the activation protocol. An activation of only 0.25mm was given, therefore the deformation might have been limited to the suture alone, with no participation of the resistance which would have been offered by the zygomatic buttress.

Several clinical as well as FEM analysis have reported a v-shaped split in the MPS with more in the anterior region and progressively reducing towards the PNS region. This is due to the heavy interdigitation of the pterygo-palatine suture and the zygomatic buttress and this resistance the resistance proved to be difficult to overcome.

**Gautam et al**[34,35,36] in his finite element study on conventional RME had reported the centre of rotation to be located in between the lateral and medial pterygoid plates. Therefore, during conventional RME the pterygoid plates acts as a hinge around which the maxilla rotates results in a v-shaped expansion.

**Canteralla et al**[34,35,36] in there clinical trial with MARPE showed an almost perfectly parallel split of the MPS, which is similar to our study. This indicates that more amount of expansion taken place in the posterior part of the maxilla, along with disarticulation of the pterygoid sutures displacing the fulcrum of rotation slightly behind the pterygoid plates

In RME the v-shaped expansion where reported to have greater benefit where the nasal stenosis was primarily in the anterior-inferior region, while the stenosis in posterior-superior part of the nasal airway did not benefit much. When parallel expansion is achieved the nasal airway stenosis in the posterior region might also be benefitted.

**SPHENOID BONE** (Fig 49-52, Table-6, Graph -4)

The lateral pterygoid and the medial pterygoid had a lateral bending movement with more of bending seen in the free ends, which gradually decreased as it neared the cranial base. The pterygoid fossa and the infra-temporal surface had almost no displacement. The free ends of the lateral pterygoid plates showed almost 2mm of lateral bending.

Not much of an emphasis is given for the displacement of sphenoid bone in the literature. Only **Jafari et al**[54] as described about the sphenoid bone in his FEM analysis. He found that the inferior part (the free ends) of the lateral pterygoid plates bent laterally and diminished in the regions which were closer to the cranial base. There was no displacement seen in the rest of the sphenoid bone, which is similar to our study.

**Melsen**[75,74] stated that the pterygoid plates of the sphenoid bone were the limiting factor for the ability of the palatine bone to separate along the MPS.

**Canteralla et al**[18,19,20], has shown the width of opening in right and left pterygoid process to be 1.35mm and 2.17mm respectively.

**ZYGOMATIC PROCESS** (Fig: - 37 - 40, Table: -7)

Zygomatic bone had a forward and lateral displacement. The forward displacement was minimal as a whole, whereas the lateral displacement was more near the zygomatico-maxillary suture and gradually decreased towards the temporal process of the zygomatic bone (zygomatic arch) and further decreasing towards the fronto-zygomatic suture. Overall this zygoma rotated along with the zygomatico-maxillary complex with fronto-zygomatic suture as the fulcrum.

**Garib et al**[33] 2005 and **Leonardi**[66], suggested that the sutures which directly articulate with the maxilla had greater changes when compared to the sutures further away.

**Canteralla et al**[18,19,20] in his clinical trials, saw a negligible increase in the upper inter-zygomatic distance whereas the lower inter-zygomatic distance was more which is similar to our study. They elucidated that the zygomatico-maxillary complex rotated outward with a centre of rotation located near the fronto-zygomatic suture.

**TEMPORAL BONE** (Fig 60-63, Table-8, Graph -6)

The zygomatic process of the temporal bone (zygomatic arch) showed lateral and a superior displacement whereas the other area showed negligible amount of displaced.

**Jafari**[54], had shown no significant displacement in the temporal, parietal, frontal, sphenoid and occipital bone by using RME. In the MARPE appliance the expansion force is nearer to the centre of resistance were as, in RME the expansion force is given via the anchor tooth. Therefore, the MARPE appliance is able to overcome the resistance of most of the circummaxillary sutures bringing about changes in sphenoid, zygomatic, temporal and nasal bone

**NASAL BONE** (Fig 64-67, Table-9, Graph -7)

The nasal bone was displaced as a whole slightly to the left with a mild downward movement. The literature has not emphasised much on the displacement of nasal bone. But some authors have showed the displacement in nasal septum in their CBCT studies.

**UPPER PERMENENT FIRST MOLAR** (Fig 68-71, Table-10, Graph -8)

The crown and the root showed lateral displacement of 3mm and 2.5mm average respectively. The crown had a slight increase in lateral displacement of 0.5mm compared to the root suggesting a very negligible amount of tipping with more of translation. The molars also showed a mild extrusion and forward movement.

**Iseri et al**[52], also showed a mild extrusion of the molars

**H.K.Lee**[63], found more amount of buccal rotation of the teeth in the miniscrew assisted hyrax and conventional hyrax with surgical assistance when compared to bone-borne appliance in the FEM analysis.

**Lu Lin et al**[67], compared tooth-borne and bone-borne appliance (C expander) in his clinical trial and found the tooth-borne appliance to have a greater buccal tipping of posterior teeth, when compared to the bone-borne appliance.

**Chuck Carlson et al**[22] 2016, clinically noticed the dental tipping to be less in MARPE, as the force exerted during expansion is designed in such a way that, it is dissipated on the bone through mini-implants before the teeth are affected.

**Starnbach**[89], stated that the minimal tipping that was seen could be most likely due to the bodily rotation of the zygomatico-maxillary complex on each side.

**MANDIBLE** (Fig 72-74, Table-10, Graph -8)

The mandible showed a very slight forward and upward rotation.

**Giampietra Farromato et al**[29] 2011, in his clinical study compared the pre-treatment and post retention (6 months) lateral cephalogram of growing patients who had undergone expansion. He found that in class I subject, the mandible move forward but not in a statistically significant manner. In class II subject mandible had a statistically significant forward movement. In class III subjects the mandible had a downward and a backward rotation.

**Caralina Baratiera et al**[8] 2011, evaluated the CBCT of 17 children, who underwent RME. They found the mandible to have a clockwise rotation immediately post treatment. But during the retention period, the mandible moved forward.

**McNamara and Brudon**[72,73], stated that the over expanded maxillary arch may encourage the mandible to have a forward position. The authors contend that class II malocclusions have a strong transverse component and that the over expanded maxillary arch may encourage the forward positioning of the mandible to reduce the tendency of buccal crossbite and provide a more comfortable occlusal relationship. Hence, the teeth themselves may act as an ‘‘**Endogenous functional appliance**”.

## STRESS DISTRIBUTION

### MAXILLA AND ZYGOMATICO-MAXILLARY COMPLEX

**FRONTAL VIEW** (Fig 75 a&b, Graph -10)

The maximum stress in the frontal view was seen in the nasomaxillary suture followed by dissipated stress in the nasal notch (lateral wall of the nose) and around the intermaxillary suture (above the central incisor). Stress where found near the frontonasal suture and molar region but to a lesser extent.

**Iseri et al**[52], in his RME FE model showed the maximum stress to be located around the anterior-superior part of the zygomatic bone followed by the nasal notch, external wall of the orbit, canine fossa, and molar region and lesser amount of force in the frontal bone and the zygomatic arch

**Jafari et al**[54], did FEM analysis in a RME device model and showed increased amount of stress in the nasomaxillary suture followed by frontonasal suture and zygomatic process

**Ludwig et al**[70]**,** in his MARPE FE model showed maximum stress along the infra zygomatic crest, suture of orbits and posterior part of zygoma.

**Macginnis and Won-moon et al**[71]**,** applied two sets of expansion forces to mimic the conventional hyrax and MARPE. In the MARPE model there was a decreased amount of stress around the infra orbital foramen region and the other areas, when compared to the hyrax model. The hyrax showed more stress around the wall of the orbit and zygoma.

**Larissa et al**[45]**,** compared a hyrax and bone borne FE model and observed that for one activation in the tooth borne appliance the tensile stress was seen in the buccal bone of the molars, zygomatic process, nasal floor, and inner walls of the nasal cavity. Whereas, compressive stress was seen in the median wall of the orbit. In the bone borne device increased tensile stress was seen in the lower edge of the orbit and the nasal floor compressive stress was seen dissipated around the canine fossa and lateral wall of the nasal cavity.

**Hartona Ben et al**[46]**,** compared a FE model of RME and MSE and saw increased stress concentration around the nasal and infra orbital region in the RME model. In the MSE model the stress where displaced on the maxillary and fronto nasal area.

When evaluating the literature of FEA, the RME group showed increased amount of stress in more areas when compared to MARPE. Weather it is RME or MARPE kind of expansion procedure, it seems to create stress in the maxillary molar, zygomatic process and external wall of the orbit, which can bring about dizziness and feeling of heavy pressure around the bridge of nose, eyes and mostly throughout the face. Therefore in individuals who have very heavy sutural interdigitation and bone density expansion must be done with surgically assisted expansion.

**MAXILLA AND ZYGOMATICO-MAXILLARY COMPLEX**

**SAGITTAL VIEW** (Fig: - 75 & 76)

In the sagittal view Von Misses stress was noted to be more near the superior portion of the pterygomaxillary suture, infra zygomatic crest (IZC) and pterygoid plates near the cranial base. Evenly distributed around the buccal bone of molars and CEJ and a very minimal stress is seen near the zygomatico maxillary suture area.

**Iseri et al**[52] in their study showed maximum concentration of stress in the zygomatic bone, pterygoid plates, canine and molar region. To a lesser extent in the zygomatic arch.

**Jafari et al**[54], maximum stress were seen in the zygomatico maxillary suture, frontal process of zygoma, zygomatic arch and zygomatico temporal suture.

In **Ludwig**'s[70] study greatest stress was found to be in the IZC and pterygomaxillary complex.

**MacGinnis and Won Moon**[71], the RME group the maximum stress were present in zygomatico maxillary suture, zygomatic buttress and pterygoid plates. Whereas, MARPE showed mild stress in the zygomatico maxillary suture and buccal bone of molars

**Hartono et al**[46], RME group showed increased stress level in temporal bone, maxilla, pterygomaxillary complex and buccal bone of molars. The maxillary expander group showed equal stress distribution on the maxilla and no stress on the buccal bone of molars.

On the whole, the RME group showed more amount of overall stress in the lateral view. **Hartono** in his MSE group found almost no stress in the buccal bone of molars. Whereas, lesser amount of stress was seen in the buccal bone in the present study. The reason could be the amount of activation. The maximum displacement simulated in the previous study is 1.5mm. Whereas, 5mm of displacement was given in our study.

**Manuel O. Lagrevere**[60] 2010 and **Lu Lin** 2015[67] compared tooth borne appliance to bone borne appliance in their clinical study, and stated that more amount of dental tipping was seen in the tooth borne appliance group. Our study reports a lesser amount of stress in the buccal bone adjacent to the molar area. This will reduce some of the detrimental effects of expansion, like buccal bone and root resorption.

**MAXILLA**

**OCCLUSAL VIEW** (Fig 77 a & b78, Graph -12)

The maximum stress was seen in the implant region and it reduced towards the dentition to almost no stress on the cusp tips. There was some amount of stress seen in the CEJ of dentition which could be due to the opening of the MPS and bending of the alveolar bone around the dentition.

Similar results were seen in the study by **Ludwig et al**[70]**, H.K.Lee**[63] in their tooth-bone borne and bone-borne model, **MacGinnis et al**[71,] in their MARPE model, **Robert .J.Lee et al**[65] and **Hartono et al**[46]**.**

**Tanner M. Nassef et al**[42] in there study of bone-borne appliance with acrylic plates showed high stress in the palate with almost no stress concentration around the miniscrew.

**Iseri et al[52], Jafari et al[54], H.K.Lee et al[63] and MacGinnis et al[71]** in their tooth borne appliance model showed more of stress concentration around the dentition rather than near the MPS.

The MARPE appliance applies the stress closer to the centre of resistance as well as fulcrum of rotation and therefore it can bring about translatory movement of the maxilla. The peak stress is seen in the palate adjacent to the MPS and to a lesser extent in the dentoalveolar region, which will reduce the dentoalveolar tipping and enhance more of translatory movement of the two halves of the maxilla.

**SPHENOID BONE** (Fig 79, Graph -13)

Maximum stress in the sphenoid bone is seen in the area closer to the cranial base (infra temporal surface) that is the area adjacent to the lateral pterygoid plate. The pterygoid fossa shows stress to a lesser extent.

Only one of the studies by **Holberg et al[49]**, showed a clear picture of stress in the cranial base for different amount of bending of the pterygoid plate. In which an increased amount of stress was seen in the sphenoid jugum.

In his study he said that there is a complex stress that is dissipated in the cranial base during the rapid maxillary expansion procedure. In young individuals were the bony elasticity is very high this does not create any undue effect. Whereas in adults it can result in hyperthesia, transient disorder in eye motility, discrete temporary neurologic disorder in the presence of micro fracture. Therefore expansion must be done with caution in older adults with increased density of bone.

**ZYGOMATIC AND NASAL BONE** (Fig 80, Graph -14)

There was almost no stress that could be seen in the zygomatic bone. When the setting was changed in order to detect minute stresses after which minimum stress were seen near the fronto zygomatic suture (FZS) in the frontal process. For instance if 35MPa of stress was seen in the peri-implant region then only 0.6MPa of stress could be appreciated near the FZS. 25MPa of stress could be seen in the nasomaxillary suture area of the nasal bone.

**Iseri et al**[52] noticed a high stress concentration in the zygomatic bone (external surface of zygomatic bone).

**Jafari et al**[54] saw an increased amount of stress in the frontal process of the zygomatic bone and in the fronto nasal suture area. Both **Iseri and Jafari** in their RME model showed more amount of stress when compared to the present study.

**Matt MacGinnis et al**[71] in his RME model showed moderate amount of stress in the lateral nasal suture and zygomatico maxillary suture area. In MARPE model very mild stress were seen near the zygomaticomaxillary suture area which is consistent with our study. The difference in stress level could be due to the fact that more amount of stress is taken up by the midpalatal suture and the other reason being the force application near the centre of resistance in

MARPE, which overcomes the resistance offered by the circummaxillary suture.

**UPPER PERMENENT FIRST MOLARS** (Fig 82, Graph -16)

More amount of stress was noted in the palatal surface and to a lesser extent in the buccal surface.

**H.K.Lee**[63] in his bone-borne appliance where the miniscrews were placed adjacent to the MPS showed no stress in the roots of the teeth. In the bone-borne appliance with miniscrews in the palatal slope region, lesser amount of stress were seen in the roots of the premolars. On the other hand, the MARPE as well hyrax type appliance showed high amount of stress in the roots of the anchor teeth and premolar.

**Hartono et al**[46] saw increased stress in the enamel and dentin of the palatal surface in the RME. Where as in the dentine and enamel of the distopalatal cusp of the molars in the MSE group. The stress level were less comparing to this study one reason could be due to the lesser amount of displacement(1.5mm) given by **Hartono** comparing to this study (5mm). Again the design of the appliance might have influenced the stress distribution on the molars.

**MADNDIBLE** (Fig 83, 84, Graph -17)

The mandible showed minimal of stress of 4MPa in the CEJ, sigmoid notch and pterygoid fovea. Further mild stress around the symphysis region.

There was no study done to analyse the displacement and stress distribution in the mandible during RME. This is the first study to see the displacement and stress distribution in the mandible during RME. The mandible to maxilla was given a hinge type of relationship, since the movement of the mandible will be within the rotatory movement of condyle in the glenoid fossa.

**MINI-IMPLANTS** (Fig 85, Graph -18)

The mini-implants have increased amount of stress in the mid region of the threaded portion, reducing towards the cervical and apical region.

**Lee, Moon and Hong**[65] in their FEM analysis compared the mono-cortical and bi-cortical engagement of the mini implant. The found more stress concentration in the mono-cortical when compared to the later. Which is **consistent** with the present study.

The bone implant interface is of utmost importance for the success of the implants. Reducing the stress around the cervical region of the bone implant interface will reduce the risk of implant failure. In this study the overall as well cervical region of the implant showed lesser amount of stress, which is well below the "**pathologic overload window**".

**APPLIANCE** (Fig 86, Graph -19)

The maximum Von Misses stress was seen in the implant supported region and it reduces along the connecting arms, almost disappearing as it reaches the outer end of the bands.

**Ludwig et al**[70] in his study noticed that even though displacement of 7.8mm was given in the FE- Model as well as in the clinical situation. Some of the structures opened only half as much. He stated that the delicate arms of the expander could only partly transmit the force. This is because the arms had underwent considerable deformation within themselves.

This is the first study to compare the clinical post treatment results with FEM result and to explain in detail, the displacement and stress on each individual bone. The mandible and appliance have also been explained in detail.

**Limitations**: - This is the study done in a FE model using CBCT images of a single individual, therefore its interpretation for other individuals must be done with careful consideration. The whole process is considered to have taken place after the split of MPS since the MPS is considered to be patent.

# *Summary & Conclusion*

# SUMMARY AND CONCLUSION

The aim of the study is to do a Finite element analysis (FEA) of stress distribution and displacement from CT images of a patient who had undergone maxillary expansion using Miniscrew Assisted Rapid Palatal Expansion. The Miniscrew Assisted Rapid Palatal Expander appliance had 4 mini- implants with bi-cortical bone engagement, in line with the first and second molar. The diameter of the connecting wires had 1.2mm of diameter, thereby reducing the rigidity of the wire.

1. To compare the simulated results of the FEM to the actual post expansion results of the patient by the means of superimposition.
2. To evaluate the magnitude and pattern of displacement of the Cranio-facial complex.
3. To evaluate the Von misses stress distribution of all the bones including areas in and around (a) Implants, (B) Expander device, (c) Upper Permanent first Molar, (d) Mandible.

A near parallel expansion was seen in the occlusal view with a deviation of 1mm more in the ANS compared with PNS. In the frontal view v-shaped expansion could be seen with base towards the dentition and apex towards the nasal bone. The zygomatico-maxillary complex had a lateral rotation with the fronto-zygomatic suture as the fulcrum of rotation. There was very minimal amount of changes that could be noticed in the temporal, nasal and sphenoid bone. A good amount of lateral bending of the pterygoid plates could be noticed with disjunction in the Pterygo-maxillary complex. The molar had a very minimal tipping and more of lateral translation.

When Von misses stress was studied, there was high amount of stress seen near the MPS and posterior part of the palate and around peri-implant area. The cervical bone implant interface and the anchor teeth had less amount of stress.

Based on this FEM study we conclude that:-

- Posterior placement and bi-cortical bone engagement of the appliance brings about more expansion in the posterior region, by exerting more force against the resistance offered by the pterygomaxillary complex
- Bi-cortical bone engagement decreases stress around the cervical region of the bone implant interface and thereby increasing the success rate of the implant.
- Decreasing the rigidity of the connecting wires reduces the tipping of the anchor teeth since they have a considerable deformation within themselves, dissipating the stress before it reaches the anchor teeth.

Modified type of Miniscrew Assisted Rapid Palatal Expansion seems to be bring about more of skeletal expansion and less of dental tipping in adults. However it must be used with caution in individuals with high bone density and heavy sutural interdigitation.

# *Bibliography*

# BIBLIOGRAPHY


1. **Adkins MD, Nanda RS, Currier GF.** Arch perimeter changes on rapid palatal expansion. American Journal of Orthodontics and Dentofacial Orthopedics. 1990 Mar 1;97(3):194-9.
2. **Andrews LF.** The six elements of orofacial harmony. Andrews J. 2000;1:13-22.
3. **Angelieri F, Franchi L, Cevidanes LH, Bueno-Silva B, McNamara Jr JA.** Prediction of rapid maxillary expansion by assessing the maturation of the midpalatal suture on cone beam CT. Dental press journal of orthodontics. 2016 Dec;21(6):115-25.
4. **Angelieri F, Franchi L, Cevidanes LH, McNamara Jr JA.** Diagnostic performance of skeletal maturity for the assessment of midpalatal suture maturation. American Journal of Orthodontics and Dentofacial Orthopedics. 2015 Dec 1;148(6):1010-6.
5. **Angell EC.** Treatment of irregularities of the permanent or adult teeth. Dent. Cosmos. 1860;1:599-600.
6. **Asscherickx K, Hanssens JL, Wehrbein H, Sabzevar MM.** Orthodontic anchorage implants inserted in the median palatal suture and normal transverse maxillary growth in growing dogs: a biometric and radiographic study. The Angle Orthodontist. 2005 Sep;75(5):826-31.

7. **Baccetti T, Franchi L, Cameron CG, McNamara Jr JA.** Treatment timing for rapid maxillary expansion. The Angle Orthodontist. 2001 Oct;71(5):343-50
8. **Baratieri C, Alves Jr M, Sant'anna EF, Nojima MD, Nojima LI. 3D** mandibular positioning after rapid maxillary expansion in Class II malocclusion. Brazilian dental journal. 2011;22(5):428-34.
9. **Bell WH, Epker BN.** Surgical-orthodontic expansion of the maxilla. American journal of orthodontics. 1976 Nov 1;70(5):517-28.
10. **Bishara SE, Staley RN.** Maxillary expansion: clinical implications. American Journal of Orthodontics and Dentofacial Orthopedics. 1987 Jan 1;91(1):3-14.
11. **Björk A, Skieller V.** Growth of the maxilla in three dimensions as revealed radiographically by the implant method. British Journal of Orthodontics. 1977 Apr 1;4(2):53-64.
12. **Boryor A, Hohmann A, Wunderlich A, Geiger M, Kilic F, Sander M, Sander C, Böckers T, Sander FG**. In-vitro results of rapid maxillary expansion on adults compared with finite element simulations. Journal of biomechanics. 2010 May 7;43(7):1237-42.
13. **Braun S, Bottrel JA, Lee KG, Lunazzi JJ, Legan HL**. The biomechanics of rapid maxillary sutural expansion. American Journal of Orthodontics and Dentofacial Orthopedics. 2000 Sep 1;118(3):257-61.

14. **Brossman RE, Bennett CG, Merow WW**. Facioskeletal remodelling resulting from rapid palatal expansion in the monkey (Macaca cynomolgus). Archives of oral biology. 1973 Aug 1;18(8):987-IN3.
15. **Brunetto DP, Sant'Anna EF, Machado AW, Moon W.** Non-surgical treatment of transverse deficiency in adults using Microimplant-assisted Rapid Palatal Expansion (MARPE). Dental press journal of orthodontics. 2017 Feb;22(1):110-25.
16. **Byloff FK, Mossaz CF.** Skeletal and dental changes following surgically assisted rapid palatal expansion. The European Journal of Orthodontics. 2004 Aug 1;26(4):403-9.
17. **Byrum AG.** Evaluation of anterior-posterior and vertical skeletal change vs. dental change in rapid palatal expansion cases as studied by lateral cephalograms. American journal of orthodontics. 1971 Oct 1;60(4):419.
18. **Cantarella D, Dominguez-Mompell R, Mallya SM, Moschik C, Pan HC, Miller J, Moon W.** Changes in the midpalatal and pterygopalatine sutures induced by micro-implant-supported skeletal expander, analyzed with a novel 3D method based on CBCT imaging. Progress in orthodontics. 2017 Dec 1;18(1):34.
19. **Cantarella D, Dominguez-Mompell R, Moschik C, Mallya SM, Pan HC, Alkahtani MR, Elkenawy I, Moon W**. Midfacial changes in the coronal plane induced by microimplant-supported skeletal expander, studied with cone-beam computed tomography images. American

Journal of Orthodontics and Dentofacial Orthopedics. 2018 Sep 1;154(3):337-45.

20. **Cantarella D, Dominguez-Mompell R, Moschik C, Sfogliano L, Elkenawy I, Pan HC, Mallya SM, Moon W.** Zygomaticomaxillary modifications in the horizontal plane induced by micro-implant-supported skeletal expander, analyzed with CBCT images. Progress in orthodontics. 2018 Dec;19(1):41.
21. **Capelozza LF, Cardoso JN, Ursi WJ.** Non-surgically assisted rapid maxillary expansion in adults. The International journal of adult orthodontics and orthognathic surgery. 1996;11(1):57-66.
22. **Carlson C, Sung J, McComb RW, Machado AW, Moon W.** Microimplant-assisted rapid palatal expansion appliance to orthopedically correct transverse maxillary deficiency in an adult. American journal of orthodontics and dentofacial orthopedics. 2016 May 1;149(5):716-28.
23. **Chaconas SJ, Caputo AA.** Observation of orthopedic force distribution produced by maxillary orthodontic appliances. American journal of orthodontics. 1982 Dec 1;82(6):492-501.
24. **Chang JY, McNamara Jr JA, Herberger TA.** A longitudinal study of skeletal side effects induced by rapid maxillary expansion. American journal of orthodontics and dentofacial orthopedics. 1997 Sep 1;112(3):330-7.

25. **Choi SH, Shi KK, Cha JY, Park YC, Lee KJ.** Nonsurgical miniscrew-assisted rapid maxillary expansion results in acceptable stability in young adults. The Angle Orthodontist. 2016 Mar 3;86(5):713-20.

26. **Christie KF, Boucher N, Chung CH.** Effects of bonded rapid palatal expansion on the transverse dimensions of the maxilla: a cone-beam computed tomography study. American journal of orthodontics and dentofacial orthopedics. 2010 Apr 1;137(4):S79-85.

27. **Chung CH, Font B.** Skeletal and dental changes in the sagittal, vertical, and transverse dimensions after rapid palatal expansion. American journal of orthodontics and dentofacial orthopedics. 2004 Nov 1;126(5):569-75.

28. **Davis WM, Kronman JH.** Anatomical changes induced by splitting of the midpalatal suture. The Angle Orthodontist. 1969 Apr;39(2):126-32.

29. **Farronato G, Giannini L, Galbiati G, Maspero C.** Sagittal and vertical effects of rapid maxillary expansion in Class I, II, and III occlusions. The Angle orthodontist. 2011 Mar;81(2):298-303.

30. **Fricke-Zech S, Gruber RM, Dullin C, Zapf A, Kramer FJ, Kubein-Meesenburg D, Hahn W.** Measurement of the midpalatal suture width: A comparison of flat-panel volume computed tomography to histomorphometric analysis in a porcine model. The Angle Orthodontist. 2011 Aug 3;82(1):145-50.

31. **Fried KH.** Palate-tongue relativity. The Angle Orthodontist. 1971 Oct;41(4):308-23.
32. **Gardner GE, Kronman JH.** Cranioskeletal displacements caused by rapid palatal expansion in the rhesus monkey. American journal of orthodontics. 1971 Feb 1;59(2):146-55.
33. **Garib DG, Henriques JF, Janson G, Freitas MR, Coelho RA.** Rapid maxillary expansion—tooth tissue-borne versus tooth-borne expanders: a computed tomography evaluation of dentoskeletal effects. The Angle Orthodontist. 2005 Jul;75(4):548-57.
34. **Gautam P, Valiathan A, Adhikari R.** Maxillary protraction with and without maxillary expansion: a finite element analysis of sutural stresses. American Journal of Orthodontics and Dentofacial Orthopedics. 2009 Sep 1;136(3):361-6.
35. **Gautam P, Valiathan A, Adhikari R**. Skeletal response to maxillary protraction with and without maxillary expansion: a finite element study. American Journal of Orthodontics and Dentofacial Orthopedics. 2009 Jun 1;135(6):723-8.
36. **Gautam P, Valiathan A, Adhikari R.** Stress and displacement patterns in the craniofacial skeleton with rapid maxillary expansion: a finite element method study. American Journal of Orthodontics and Dentofacial Orthopedics. 2007 Jul 1;132(1):5-e1.
37. **Ghoneima A, Abdel-Fattah E, Hartsfield J, El-Bedwehi A, Kamel A, Kula K.** Effects of rapid maxillary expansion on the cranial and

circummaxillary sutures. American Journal of Orthodontics and Dentofacial Orthopedics. 2011 Oct 1;140(4):510-9.

38. **Glassman AS, Nahigian SJ, Medway JM, Aronowitz HI**. Conservative surgical orthodontic adult rapid palatal expansion: sixteen cases. American journal of orthodontics. 1984 Sep 1;86(3): 207-13.
39. **Haas AJ.** Long-term posttreatment evaluation of rapid palatal expansion. The Angle Orthodontist. 1980 Jul;50(3):189-217.
40. **Haas AJ.** Rapid expansion of the maxillary dental arch and nasal cavity by opening the midpalatal suture. The Angle Orthodontist. 1961 Apr;31(2):73-90.
41. **Haas AJ.** The treatment of maxillary deficiency by opening the midpalatal suture. The Angle Orthodontist. 1965 Jul;35(3):200-17.
42. **Handelman C.** Palatal expansion in adults: the nonsurgical approach. American journal of orthodontics and dentofacial orthopedics: official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2011 Oct;140(4):462-4.
43. **Handelman CS**, Wang L, BeGole EA, Haas AJ. Nonsurgical rapid maxillary expansion in adults: report on 47 cases using the Haas expander. The Angle Orthodontist. 2000 Apr;70(2):129-44.

44. **Handelman CS.** Nonsurgical rapid maxillary alveolar expansion in adults: a clinical evaluation. The Angle Orthodontist. 1997 Aug;67(4):291-308.

45. **Hansen L, Tausche E, Hietschold V, Hotan T, Lagravère M, Harzer W. Skeletally**-anchored rapid maxillary expansion using the Dresden Distractor. Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie. 2007 Mar 1;68(2):148-58.

46. **Hartono N, Soegiharto BM, Widayati R.** The difference of stress distribution of maxillary expansion using rapid maxillary expander (RME) and maxillary skeletal expander (MSE)—a finite element analysis. Progress in orthodontics. 2018 Dec 1;19(1):33.

47. **Harvold EP, Chierici G, Vargervik K.** Experiments on the development of dental malocclusions. American journal of orthodontics. 1972 Jan 1;61(1):38-44.

48. **Hicks EP.** Slow maxillary expansion: a clinical study of the skeletal versus dental response to low-magnitude force. American Journal of Orthodontics. 1978 Feb 1;73(2):121-41.

49. **Holberg C, Rudzki-Janson I.** Stresses at the cranial base induced by rapid maxillary expansion. The Angle Orthodontist. 2006 Jul;76(4):543-50.

50. **Isaacson RJ, Ingram AH.** Forces produced by rapid maxillary expansion: II. Forces present during treatment. The Angle Orthodontist. 1964 Oct;34(4):261-70.

51. **Isaacson RJ, Wood JL, Ingram AH.** Forces produced by rapid maxillary expansion: I. Design of the force measuring system. The Angle Orthodontist. 1964 Oct;34(4):256-60.

52. **Işeri H, Tekkaya AE, Öztan Ö, Bilgic S.** Biomechanical effects of rapid maxillary expansion on the craniofacial skeleton, studied by the finite element method. The European Journal of Orthodontics. 1998 Aug 1;20(4):347-56.

53. **Ja Jr M. brudon Wl.** orthodontics and Dentofacial orthopedics. ann arbor. Mich: Needham Press Inc. 2001;73:256-62.

54. **Jafari A, Shetty KS, Kumar M.** Study of stress distribution and displacement of various craniofacial structures following application of transverse orthopedic forces—a three-dimensional FEM study. The Angle Orthodontist. 2003 Feb;73(1):12-20.

55. **Knaup B, Yildizhan F, Wehrbein H**. Age-related changes in the midpalatal suture. Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie. 2004 Nov 1;65(6):467-74.

56. **Kokich VG.** Age changes in the human frontozygomatic suture from 20 to 95 years. American Journal of Orthodontics and Dentofacial Orthopedics. 1976 Apr 1;69(4):411-30.

57. **Koo YJ, Choi SH, Keum BT, Yu HS, Hwang CJ, Melsen B, Lee KJ.** Maxillomandibular arch width differences at estimated centers of resistance: Comparison between normal occlusion and skeletal Class

III malocclusion. The Korean Journal of Orthodontics. 2017 May 1;47(3):167-75.

58. **Krebs A.** Expansion of the midpalatal suture, studied by means of metallic implants. Acta Odontologica Scandinavica. 1959 Jan 1;17(4):491-501
59. **Krebs AA.** Rapid expansion of midpalatal suture by fixed appliance: an implant study over a 7 year period. Trans Eur Orthod Soc. 1964;40:131-42.
60. **Lagravere MO, Major PA, Flores-Mir C.** Dental and skeletal changes following surgically assisted rapid maxillary expansion. International journal of oral and maxillofacial surgery. 2006 Jun 1;35(6):481-7.
61. **Latham RA.** The development, structure and growth pattern of the human mid-palatal suture. Journal of anatomy. 1971 Jan;108(Pt 1):31.
62. **Lee H, Ting K, Nelson M, Sun N, Sung SJ.** Maxillary expansion in customized finite element method models. American Journal of Orthodontics and Dentofacial Orthopedics. 2009 Sep 1;136(3):367-74.
63. **Lee HK, Bayome M, Ahn CS, Kim SH, Kim KB, Mo SS, Kook YA.** Stress distribution and displacement by different bone-borne palatal expanders with micro-implants: a three-dimensional finite-element analysis. European journal of orthodontics. 2012 Nov 11;36(5):531-40.
64. **Lee KJ, Park YC, Park JY, Hwang WS.** Miniscrew-assisted nonsurgical palatal expansion before orthognathic surgery for a patient with severe mandibular prognathism. American Journal of Orthodontics and Dentofacial Orthopedics. 2010 Jun 1;137(6):830-9.

65. **Lee RJ, Moon W, Hong C**. Effects of monocortical and bicortical mini-implant anchorage on bone-borne palatal expansion using finite element analysis. American Journal of Orthodontics and Dentofacial Orthopedics. 2017 May 1;151(5):887-97.

66. **Leonardi R, Sicurezza E, Cutrera A, Barbato E.** Early post-treatment changes of circumaxillary sutures in young patients treated with rapid maxillary expansion. The Angle Orthodontist. 2011 Jan;81(1):36-41.

67. **Lin L, Ahn HW, Kim SJ, Moon SC, Kim SH, Nelson G.** Tooth-borne vs bone-borne rapid maxillary expanders in late adolescence. The Angle Orthodontist. 2014 Jun 19;85(2):253-62.

68. **Lin Y.** Comparison of skeletal and dental changes with MSE (Maxillary Skeletal Expander) and Hyrax appliance using CBCT imaging (Doctoral dissertation, UCLA)

69. **Lines PA.** Adult rapid maxillary expansion with corticotomy. American journal of orthodontics. 1975 Jan 1;67(1):44-56.

70. **Ludwig B, Baumgaertel S, Zorkun B, Bonitz L, Glasl B, Wilmes B, Lisson J.** Application of a new viscoelastic finite element method model and analysis of miniscrew-supported hybrid hyrax treatment. American Journal of Orthodontics and Dentofacial Orthopedics. 2013 Mar 1;143(3):426-35.

71. **MacGinnis M, Chu H, Youssef G, Wu KW, Machado AW, Moon W.** The effects of micro-implant assisted rapid palatal expansion

(MARPE) on the nasomaxillary complex—a finite element method (FEM) analysis. Progress in orthodontics. 2014 Dec 1;15(1):52.

72. **McNamara Jr JA**. Components of Class II malocclusion in children 8–10 years of age. The Angle Orthodontist. 1981 Jul;51(3):177-202.
73. **McNamaraa JA.** Maxillary transverse deficiency. American Journal of Orthodontics and Dentofacial Orthopedics. 2000 May 1;117(5):567-70.
74. **Melsen B.** Biological reaction of alveolar bone to orthodontic tooth movement. The Angle Orthodontist. 1999 Apr;69(2):151-8.
75. **Melsen B.** Palatal growth studied on human autopsy material: a histologic microradiographic study. American journal of Orthodontics. 1975 Jul 1;68(1):42-54.
76. **Mommaerts MY.** Transpalatal distraction as a method of maxillary expansion. British Journal of Oral and Maxillofacial Surgery. 1999 Aug 1;37(4):268-72.
77. **Moss JP.** Rapid expansion of the maxillary arch. II. Indications for rapid expansion. JPO: the journal of practical orthodontics. 1968 May;2(5):215-3.
78. **Mostafa RY, Bous RM, Hans MG, Valiathan M, Copeland GE, Palomo JM.** Effects of Case Western Reserve University's transverse analysis on the quality of orthodontic treatment. American Journal of Orthodontics and Dentofacial Orthopedics. 2017 Aug 1;152(2):178-92.

79. **Nada RM, Fudalej PS, Maal TJ, Bergé SJ, Mostafa YA, Kuijpers-Jagtman AM.** Three-dimensional prospective evaluation of tooth-borne and bone-borne surgically assisted rapid maxillary expansion. Journal of Cranio-Maxillofacial Surgery. 2012 Dec 1;40(8):757-62.
80. **Nassef TM, Eldakroury AE, Mostafa NM, Elhiny OA**. A Computerized Numerical System to Evaluate the Effects of Skeletally Anchored Haas Palatal Expander. American Journal of Biomedical Engineering. 2016;6(5):133-8.
81. **Park JH, Bayome M, Zahrowski JJ, Kook YA.** Displacement and stress distribution by different bone-borne palatal expanders with facemask: a 3-dimensional finite element analysis. American Journal of Orthodontics and Dentofacial Orthopedics. 2017 Jan 1;151(1):105-17.
82. **Pavlin D, Vukicevic D.** Mechanical reactions of facial skeleton to maxillary expansion determined by laser holography. American journal of orthodontics. 1984 Jun 1;85(6):498-507.
83. **Persson M, Thilander B.** Palatal suture closure in man from 15 to 35 years of age. American journal of orthodontics. 1977 Jul 1;72(1): 42-52.
84. **Proffit WR, Fields Jr HW, Sarver DM**. Contemporary orthodontics. Elsevier Health Sciences; 2006 Dec 8.
85. **Proffit WR, Fields Jr HW, Sarver DM**. Ortodontia contemporânea. Elsevier Brasil; 2007.

86. **Provatidis CG, Georgiopoulos B, Kotinas AA, McDonald JP.** Evaluation of craniofacial effects during rapid maxillary expansion through combined in vivo/in vitro and finite element studies. The European Journal of Orthodontics. 2008 Oct 1;30(5):437-48.
87. **Reddy JN.** Energy and variational methods in applied mechanics: with an introduction to the finite element method. New York: Wiley; 1984.
88. **Schuster G, Borel-Scherf I, Schopf PM.** Frequency of and complications in the use of RPE appliances—results of a survey in the Federal State of Hesse, Germany. Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie. 2005 Mar 1;66(2): 148-61.
89. **Starnbach H, Bayne D, Cleall J, Subtelny JD.** Facioskeletal and dental changes resulting from rapid maxillary expansion. The Angle Orthodontist. 1966 Apr;36(2):152-64.
90. **Storey, E., 1973**. Tissue response to the movement of bones. American Journal of Orthodontics 64, 229–247. doi:10.1016/0002-9416(73)90017-1
91. **Tanne K, Hiraga J, Sakuda M.** Effects of directions of maxillary protraction forces on biomechanical changes in craniofacial complex. The European Journal of Orthodontics. 1989 Nov 1;11(4):382-91.
92. **Tanne K, Sakuda M, Burstone CJ.** Three-dimensional finite element analysis for stress in the periodontal tissue by orthodontic forces.

American Journal of Orthodontics and Dentofacial Orthopedics. 1987 Dec 1;92(6):499-505.

93. **Tausche E, Hansen L, Hietschold V, Lagravère MO, Harzer W.** Three-dimensional evaluation of surgically assisted implant bone-borne rapid maxillary expansion: a pilot study. American Journal of Orthodontics and Dentofacial Orthopedics. 2007 Apr 1;131(4):S92-9.
94. **Timms DJ, Vero D.** The relationship of rapid maxillary expansion to surgery with special reference to midpalatal synostosis. British Journal of Oral Surgery. 1981 Sep 1;19(3):180-96.
95. **Timms DJ.** A study of basal movement with rapid maxillary expansion. American journal of orthodontics. 1980 May 1;77(5):500-7.
96. **Wehrbein H, Yildizhan F.** The mid-palatal suture in young adults. A radiological-histological investigation. The European Journal of Orthodontics. 2001 Apr 1;23(2):105-14.
97. **Wertz R, Dreskin M**. Midpalatal suture opening: a normative study. American journal of orthodontics. 1977 Apr 1;71(4):367-81.
98. **Wertz RA.** Skeletal and dental changes accompanying rapid midpalatal suture opening. American journal of orthodontics. 1970 Jul 1;58(1):41-66.
99. **Woods M, Wiesenfeld D, Probert T.** Surgically-assisted maxillary expansion. Australian dental journal. 1997 Feb;42(1):38-42.

100. **Yu HS, Baik HS, Sung SJ, Kim KD, Cho YS**. Three-dimensional finite-element analysis of maxillary protraction with and without rapid palatal expansion. The European Journal of Orthodontics. 2007 Jan 11;29(2):118-25.

101. **Zhou Y, Long H, Ye N, Xue J, Yang X, Liao L, Lai W.** The effectiveness of non-surgical maxillary expansion: a meta-analysis. European journal of orthodontics. 2013 Jul 4;36(2):233-42.

# *Annexures*

# ANNEXURE – I

**RAGAS DENTAL COLLEGE & HOSPITAL**
(Unit of Ragas Educational Society)
Recognized by the Dental Council of India, New Delhi
Affiliated to The Tamilnadu Dr. M.G.R. Medical University, Chennai
2/102, East Coast Road, Uthandi, Chennai - 600 119. INDIA
Tele : (044) 24530002, 24530003 - 06. Principal (Dir) 24530001 Fax : (044) 24530009

<u>TO WHOM SO EVER IT MAY CONCERN</u>

Date: 18-01-19

Chennai.

From,

The Institutional Review Board,

Ragas Dental College and Hospital,

Uthandi, Chennai-600119.

The Dissertation topic titled **"FEM EVALUATION OF STRESS DISTRIBUTION AND DISPLACEMENT WITH MINISCREW SUPPORTED MAXILLARY EXPANSION DEVICE "** submitted by **Dr. J LILY** has been approved by the Institutional Review Board of Ragas Dental College & Hospital.

Dr. N S Azhagarasan, M.D.S
Member Secretary,
Institutional Ethical Board,
Ragas Dental College and Hospital,
Uthandi, Chennai-600119.

# ANNEXURE – II

URKUND

## Urkund Analysis Result

**Analysed Document:** FEM evaluation of stress distribution and displacement with miniscrew supported maxillary expansion device.docx (D47391967)
**Submitted:** 1/30/2019 5:50:00 AM
**Submitted By:** drarunpaul81@gmail.com
**Significance:** 2 %

Sources included in the report:

https://docplayer.net/11764244-Three-dimensional-evaluation-of-implant-supported-rapid-maxillary-expansion-vs-traditional-tooth-borne-rapid-maxillary-expansion-using-cone-beam.html
http://www.authorstream.com/Presentation/indiandentalacademy-2142843-arch-expansion-orthodontics/

Instances where selected sources appear:

3