Comparative Finite Element Analysis of Stress Distribution during Maxillary Expansion Using MARPE, Cortico-Puncture, and Surgically Assisted Rapid Maxillary Expansion in Adults

Dr.Amit Maheshwari[1], Dr. Shubham L Popale[2,*], Dr.Rushikesh Sonawane[3], Dr.Shrushti Dhuldhar[4], Dr.Pranal Bhusari[5], Dr. Mital U Sewak[6]

[1]Professor, Department of Orthodontics and Dentofacial Orthopaedics, ACPM Dental College, Dhule, Maharashtra

[2,*]Post-graduate student, Department of Orthodontics and Dentofacial Orthopaedics, ACPM Dental College, Dhule, Maharashtra

[3]Consultant Orthodontist

[4]Post-graduate student, Department of Orthodontics and Dentofacial Orthopaedics, ACPM Dental College, Dhule, Maharashtra

[5]Post-graduate student, Department of Orthodontics and Dentofacial Orthopaedics, ACPM Dental College, Dhule, Maharashtra

[6]Post-graduate student, Department of Orthodontics and Dentofacial Orthopaedics, ACPM Dental College, Dhule, Maharashtra

***Corresponding author: Dr. Shubham L Popale, Post-graduate student, Department of Orthodontics and Dentofacial Orthopaedics, ACPM Dental College, Dhule, Maharashtra.**

Email: popaleshubham1402@gmail.com

ABSTRACT:

Background: Transverse maxillary deficiency in adults presents a significant clinical challenge due to increased resistance of the midpalatal and circummaxillary sutures. Various treatment modalities, including miniscrew-assisted rapid palatal expansion (MARPE), midpalatal cortico-puncture-assisted rapid maxillary expansion (RME), and surgically assisted rapid palatal expansion (SARPE) with or without pterygomaxillary disjunction (PMD), have been proposed to overcome this resistance. However, the biomechanical effects of these approaches remain incompletely understood. **Objective:** To compare stress distribution and displacement patterns produced by MARPE, midpalatal cortico-puncture-assisted RME, SARPE with PMD, and SARPE without PMD using three-dimensional finite element analysis. **Materials and Methods:** A three-dimensional finite element model of the craniofacial complex was constructed from computed tomography data. Four models were developed: Model 1—MARPE, Model 2—midpalatal cortico-puncture-assisted RME, Model 3—SARPE with bilateral pterygomaxillary disjunction, and Model 4—SARPE without bilateral pterygomaxillary disjunction. The models included cortical bone, cancellous bone, teeth, periodontal ligament, sutures, and mini-implants where applicable. A lateral expansion force of 100 N was applied to all models. Von Mises stress and displacement were evaluated at the frontomaxillary, zygomaticomaxillary, and frontozygomatic sutures, zygomatic arch, pterygoid plates, maxillary tuberosity, anterior and posterior nasal spines, midpalatal suture, alveolar bone, and mini-implants. **Results:** All expansion modalities produced stress concentration within the circummaxillary sutural system and generated transverse displacement of the maxillary complex. Surgically assisted models demonstrated greater skeletal displacement and a more favorable distribution of stresses compared with nonsurgical approaches. SARPE with pterygomaxillary disjunction exhibited the highest skeletal expansion and the least resistance from posterior maxillary structures. MARPE produced substantial skeletal effects while maintaining controlled stress distribution through miniscrew anchorage. Midpalatal cortico-puncture-assisted expansion showed an intermediate response, reducing resistance at the midpalatal suture compared with conventional expansion but generating less displacement than surgically assisted techniques. **Conclusions:** Among the modalities evaluated, SARPE with pterygomaxillary disjunction demonstrated the most effective biomechanical response for maxillary expansion in adults, resulting in greater skeletal displacement and reduced resistance from circummaxillary structures. MARPE emerged as an effective nonsurgical alternative, producing clinically significant skeletal expansion with favorable stress distribution. Midpalatal cortico-puncture provided moderate enhancement of expansion efficiency but was less effective than surgically assisted approaches. Three-dimensional finite element analysis offers valuable insight into the biomechanical behavior of different maxillary expansion techniques and may aid clinicians in selecting the most appropriate treatment modality for adult patients with transverse maxillary deficiency.

Keywords: Finite element analysis, MARPE, SARPE, Pterygomaxillary disjunction, Cortico-puncture, Adult maxillary expansion, Transverse maxillary deficiency.
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Introduction

Maxillary transverse deficiency (MTD) is a common dentofacial deformity characterized by a narrow maxillary arch and is frequently associated with posterior crossbite, dental crowding, and compromised facial esthetics. If not treated appropriately, it can lead to functional, occlusal, and periodontal problems. Rapid maxillary expansion (RME) is widely used to correct transverse maxillary deficiencies in growing patients by opening the midpalatal suture and increasing the transverse dimension of the maxilla. However, as skeletal maturity increases, fusion and interdigitation of the midpalatal and circummaxillary sutures result in greater resistance to expansion, making conventional RME less effective in adults.[1–3] To overcome this limitation, surgically assisted rapid maxillary expansion (SARME) has been recommended for skeletally mature patients. SARME involves surgical weakening of areas of skeletal resistance, allowing successful expansion of the maxilla. Although SARME has been shown to produce significant skeletal expansion, it is associated with surgical morbidity, increased treatment cost, and potential postoperative complications.[2,6,7,19,24] The role of pterygomaxillary disjunction during SARME remains controversial, as some authors suggest that it improves skeletal expansion, whereas others report satisfactory outcomes without this procedure.[7,12]

In recent years, mini-implant assisted rapid maxillary expansion (MARPE) has gained popularity as a less invasive alternative to SARME. By using mini-implants for skeletal anchorage, MARPE delivers expansion forces directly to the maxillary bone, reducing unwanted dental tipping and improving skeletal effects. Clinical and radiographic studies have demonstrated successful skeletal expansion in young adults treated with MARPE, making it an attractive option for the management of transverse maxillary deficiency.[3–5,25]

Another minimally invasive approach that has been proposed to facilitate maxillary expansion is mid-palatal cortico-puncture. This procedure involves creating small perforations in the cortical bone along the midpalatal suture to reduce resistance to expansion and stimulate localized bone remodeling. Despite its potential advantages, limited evidence is available regarding its biomechanical effects and effectiveness during maxillary expansion in adults.

A thorough understanding of stress distribution and displacement patterns produced by different expansion techniques is essential for selecting the most appropriate treatment modality. Finite element analysis (FEA) is a reliable and widely accepted method for evaluating the biomechanical response of craniofacial structures under various loading conditions. Previous FEA studies have demonstrated differences in stress distribution and displacement patterns among different maxillary expansion appliances and surgical approaches.[1,9–12]

Therefore, the present study was undertaken to compare the biomechanical effects of mini-implant assisted rapid maxillary expansion (MARPE), mid-palatal cortico-puncture assisted expansion, and surgically assisted rapid maxillary expansion with and without pterygomaxillary disjunction in adults using three-dimensional finite element analysis. The aim of this study was to evaluate and compare stress distribution and displacement patterns within the craniofacial complex and to identify the expansion modality capable of producing favorable skeletal expansion while minimizing undesirable dentoalveolar effects.

Materials and Methods

A three-dimensional finite element analysis (FEA) was conducted to evaluate the biomechanical effects of different maxillary expansion techniques. Computed tomography (CT) scan data of a human skull were obtained using a spiral CT scanner and exported in Digital Imaging and Communications in

Medicine (DICOM) format. The DICOM images were imported into Mimics 8.11 software (Materialise, Belgium) for image segmentation and three-dimensional reconstruction of the craniofacial structures.

The reconstructed geometric model was transferred to HyperMesh 2019 (Altair Engineering, USA), where individual anatomical components, including cortical bone, cancellous bone, teeth, periodontal ligament (PDL), and craniofacial sutures, were discretized and converted into a finite element mesh. The meshed model consisted of nodes and elements representing the anatomical structures. Material properties were assigned according to previously published biomechanical studies. The finite element model was then imported into ANSYS 17.1 (ANSYS Inc., USA) for linear static analysis. Appropriate boundary conditions and loading parameters were applied, and the resulting stress and displacement patterns were evaluated.

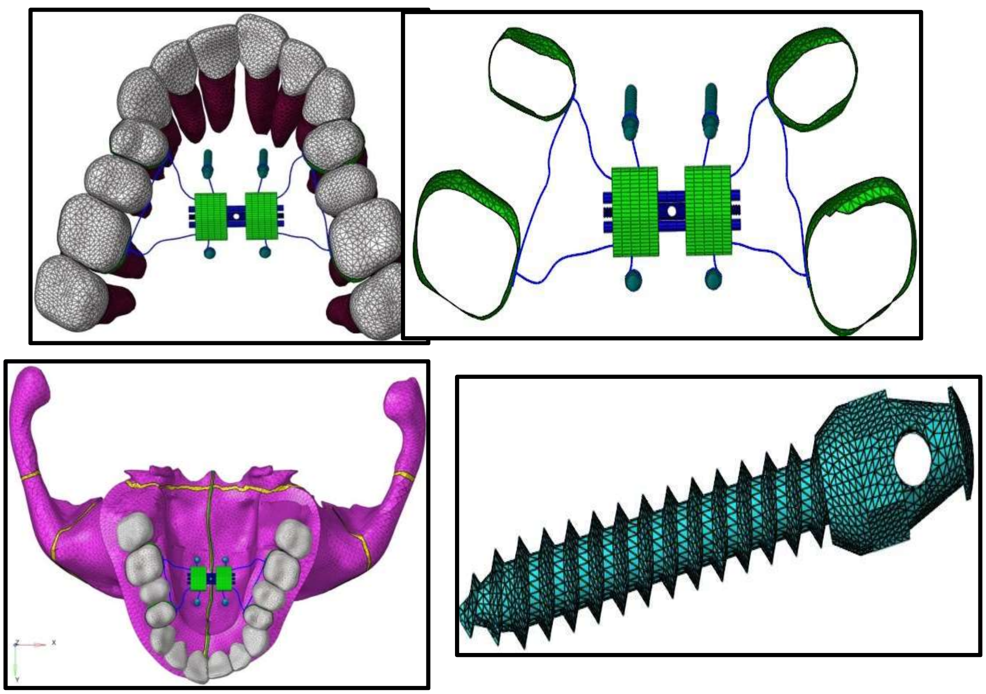
Finite Element Models

Four different expansion models were constructed and analyzed:

Model 1 (MARPE):

A miniscrew-assisted rapid palatal expander (MARPE) was designed with bands on the maxillary first premolars and first molars connected to a jackscrew through 0.9-mm stainless steel connectors. Four mini-implants (1.5 × 11 mm) were positioned bilaterally, with two placed between the canine and first premolar and two between the second premolar and first molar, approximately 3 mm lateral to the midpalatal suture. **(model[1])**

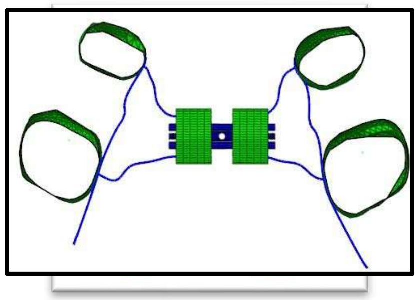
MODEL 1

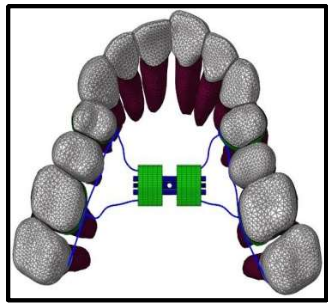


Model 2 (MARPE with Corticopuncture):

The MARPE model was modified by incorporating midpalatal corticopunctures. Corticopunctures measuring 2 mm in diameter and 1.8 mm in depth were created from the incisive canal region to the mesial aspect of the transverse palatine suture at 2-mm intervals. The perforations were generated by subtracting cylindrical volumes from the cortical and cancellous bone structures. **(model[2])**

MODEL 2

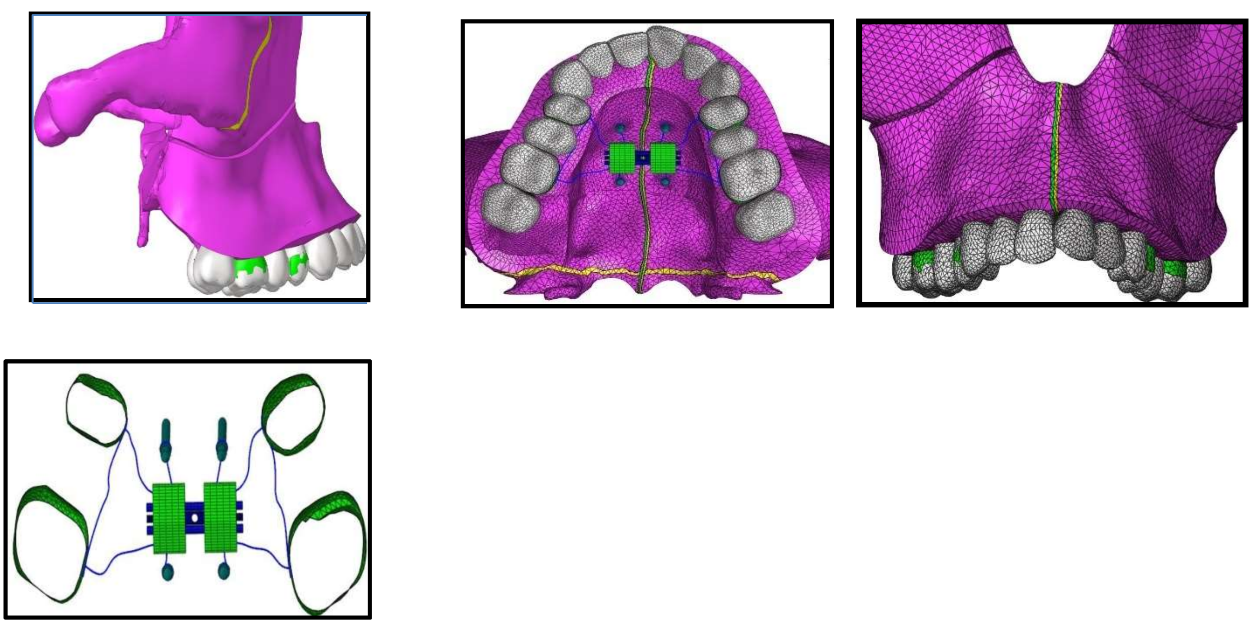




Model 3 (SARPE with Pterygomaxillary Disjunction):

A surgically assisted rapid palatal expansion (SARPE) model with bilateral pterygomaxillary disjunction (PMJ) was constructed. Osteotomy lines with a thickness of 1 mm were simulated by removing cortical and cancellous bone in the designated surgical regions. Expansion mechanics were identical to those used in Model 1. **(model[3])**

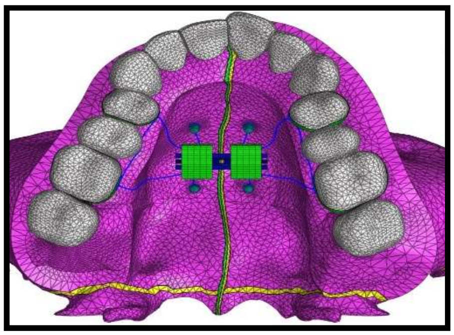
MODEL 3

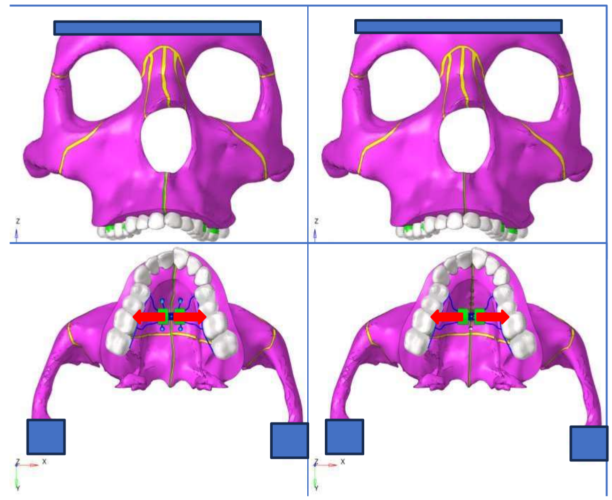


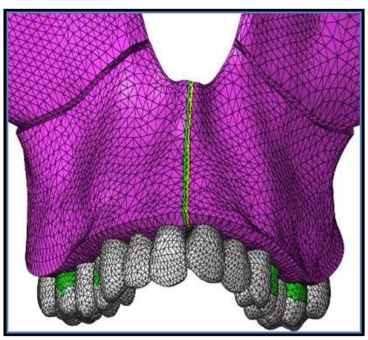
Model 4 (SARPE without Pterygomaxillary Disjunction):

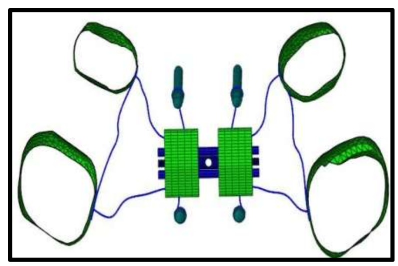
A SARPE model without bilateral PMJ separation was created. Surgical cuts were simulated using the same method as in Model 3, while preserving the pterygomaxillary junction. Expansion was performed using the same activation protocol as the MARPE model. **(model[4])**

MODEL 4





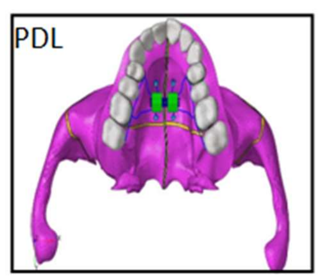




Loading Conditions and Outcome Measures

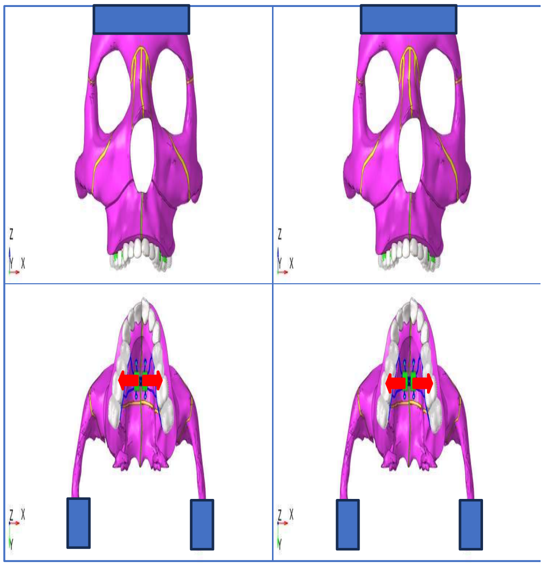
A lateral expansion force of 100 N was applied to all four models. The biomechanical response was assessed by evaluating von Mises stress distribution and displacement patterns throughout the craniofacial complex.

Stress and displacement values were analyzed at the frontomaxillary suture, zygomaticomaxillary suture, frontozygomatic suture, zygomatic arch, pterygoid hamulus, medial and lateral pterygoid plates, maxillary tuberosity, infraorbital margin, anterior nasal spine (ANS), posterior nasal spine (PNS), anterior and posterior regions of the midpalatal suture, mini-implants, and alveolar bone surrounding the teeth. The results obtained from the four models were compared to determine the biomechanical effectiveness of each maxillary expansion approach.



Loading outcome in model 1 & model 2

Loading outcome in model 3 & model 4

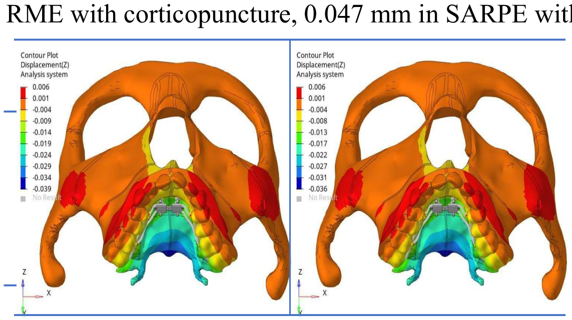


Results

Finite element analysis was performed to evaluate the displacement and stress distribution produced by four maxillary expansion modalities: MARPE (model 1), RME with midpalatal corticopuncture (model 2), SARPE with bilateral pterygomaxillary disjunction (PMJ) (model 3), and SARPE without PMJ (model 4). A lateral expansion force of 100 N was applied to all models, and displacement and von Mises stress distributions were assessed at selected craniofacial landmarks.

Displacement Analysis

Transverse displacement (X-direction) was observed in all models, with the greatest expansion occurring in the SARPE with PMJ model. Maximum transverse expansion was 0.030 mm in MARPE, 0.037 mm in RME with corticopuncture, 0.047 mm in SARPE with

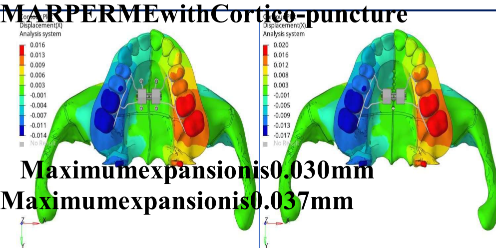


PMJ, and 0.043 mm in SARPE without PMJ. These findings indicate that surgical assistance, particularly with pterygomaxillary disjunction, enhanced skeletal expansion efficiency.

Results:

Displacement contours in X direction'mm'

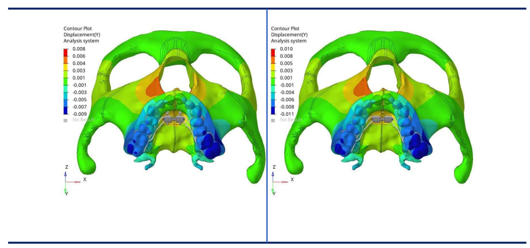
MARPERMEwithCortico-puncture



Maximumexpansionis0.030mm Maximumexpansionis0.037mm

SARPEwithbilateral Pterygomaxillary SARPE

Without bilateral disjunction pterygomaxillary disjunction



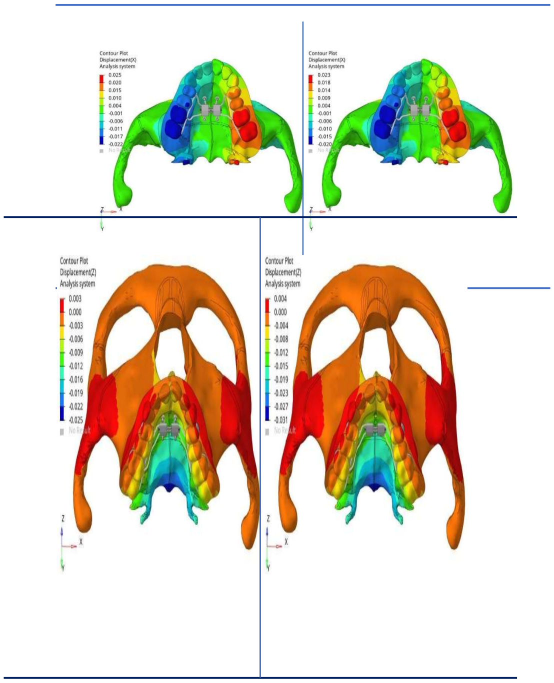
Maximum expansionis0.047mm Maximumexpansionis0.043m

Among the evaluated landmarks, the alveolar bone surrounding the teeth demonstrated the highest transverse displacement. Values increased progressively from 0.014 mm in MARPE to 0.017 mm in corticopuncture-assisted expansion, reaching 0.022 mm in SARPE with PMJ and 0.020 mm in SARPE without PMJ.

Displacement contours inYdirection'mm'

MARPE
RMEwithCortico-puncture

SARPEwithbilateral Pterygomaxillarydisjunction
SARPEwithoutbilateral Pterygomaxillary disjunction



Vertical displacement (Z-direction) was predominantly downward (extrusive) in all models. The largest vertical displacement occurred at the posterior nasal spine and posterior region of the midpalatal suture. The SARPE with PMJ model demonstrated the greatest downward displacement at the posterior nasal spine (-0.039 mm), followed closely by the posterior midpalatal suture (-0.039 mm). MARPE and corticopuncture-assisted models exhibited comparatively lower values.

Displacement contours in Z direction'mm'

MARPERME with Cortico-puncture

SARPEwithbilateral
SARPEwithout bilateral

Pterygomaxillarydisjunction
Pterygomaxillarydisjunction

Displacement of the frontomaxillary, zygomaticomaxillary, and frontozygomatic sutures was relatively small but consistently greater in the SARPE groups than in the non-surgical expansion models, indicating more effective transmission of expansion forces to the circummaxillary sutural system.

Landmarks	Model 1			Model 2			Model 3			Model 4		
	Displacement'mm'			Displacement'mm'			Displacement'mm'			Displacement'mm'		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Frontomaxillary Suture	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0
Zygomatico-Maxillary Suture	0.003	0.002	-0.002	0.004	0.003	-0.003	0.004	0.003	-0.005	0.004	0.003	-0.003
Frontozygomatic Suture	0.002	0.001	0	0.002	0.002	0.001	0.003	0.002	0	0.003	0.002	0
Zygomatic Arch	0.003	0.002	-0.002	0.004	0.003	-0.002	0.004	0.003	-0.003	0.004	0.003	-0.002
Pterygoid Humus	0.014	-0.005	-0.019	0.017	-0.005	-0.018	0.011	0.013	-0.032	0.009	0.012	-0.029
Medial Pterygoidplate	0.002	0.001	-0.017	0.004	0.001	-0.018	0.003	0.002	-0.023	0.003	0.002	-0.02
Layteral Pterygoidplate	0.002	0.001	-0.008	0.002	0.002	-0.009	0.004	0.002	-0.014	0.003	0.002	-0.014
Maxillary tuberosity	0.006	-0.002	-0.005	0.007	-0.002	-0.006	0.006	-0.002	-0.007	0.007	-0.002	-0.006
Infraorbital margin	0.002	0.001	-0.001	0.003	0.003	-0.001	0.003	0.002	-0.001	0.003	0.002	-0.001
posterior nasalspine	0.001	0.002	-0.025	0.001	0.002	-0.031	0.001	0.004	-0.039	0.001	0.003	-0.036

Table1:Displacementcomparisonforlandmarks

Anterior nasal spine	**0**	**0.004**	**-0.004**	**0.001**	**0.005**	**-0.005**	**0.001**	**0.007**	**-0.006**	**0.001**	**0.006**	**-0.005**
Mid-palatal sutureAnterior	**0.002**	**0**	**-0.002**	**0.003**	**0.001**	**-0.003**	**0.004**	**0.001**	**-0.003**	**0.003**	**0.001**	**-0.002**
Mid-palatal suture Posterior	**0.001**	**0.002**	**-0.025**	**0.002**	**0.002**	**-0.031**	**0.001**	**0.002**	**-0.039**	**0.001**	**0.001**	**-0.037**
Mini-implants	**0.002**	**0.004**	**-0.012**	**0.002**	**0.004**	**-0.014**	**0.003**	**0.006**	**-0.018**	**0.003**	**0.005**	**-0.016**
Alveolar bone around the teeth	**0.014**	**-0.007**	**0.003**	**0.017**	**-0.009**	**0.004**	**0.022**	**-0.011**	**0.006**	**0.02**	**-0.01**	**0.006**

Von Mises Stress Analysis

Stress distribution analysis demonstrated that the highest von Mises stresses were concentrated around the mini-implants in all four models. The mini-implant stress values were 34.85 MPa in MARPE, 39.65 MPa in corticopuncture-assisted expansion, 52.15 MPa in SARPE with PMJ, and 50.26 MPa in SARPE without PMJ. These findings indicate that the mini-implants acted as the primary load-bearing structures during expansion.

The alveolar bone surrounding the teeth exhibited the second-highest stress concentrations, with values of 7.07 MPa, 9.16 MPa, 11.02 MPa, and 9.56 MPa in Cases 1–4, respectively. Stress levels were consistently greater in the surgically assisted models, reflecting increased skeletal force transmission.

Among the craniofacial structures, the lateral pterygoid plate demonstrated the highest stress concentration, reaching 1.96 MPa in SARPE with PMJ and 1.89 MPa in SARPE without PMJ. The medial pterygoid plate also showed substantial stress accumulation, with maximum values of 1.53 MPa and 1.45 MPa in the respective SARPE models. Similarly, the zygomatic arch exhibited increased stress levels in the surgically assisted groups (1.53 MPa and 1.40 MPa) compared with MARPE (1.04 MPa) and corticopuncture-assisted expansion (0.97 MPa).

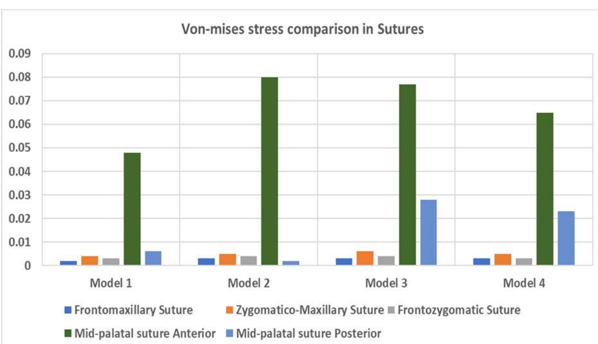
The infraorbital margin and anterior nasal spine experienced moderate stress concentrations, whereas relatively low stresses were observed at the frontomaxillary, zygomaticomaxillary, and frontozygomatic sutures. The anterior midpalatal suture exhibited greater stress than the posterior region in all models, suggesting that expansion forces were concentrated predominantly in the anterior portion of the palate.

Overall, SARPE with bilateral pterygomaxillary disjunction produced the greatest skeletal displacement and the highest stress transmission throughout the craniofacial complex, followed by SARPE without PMJ. RME with corticopuncture demonstrated greater displacement and stress distribution than conventional MARPE, indicating that corticopuncture enhanced skeletal response to expansion forces.

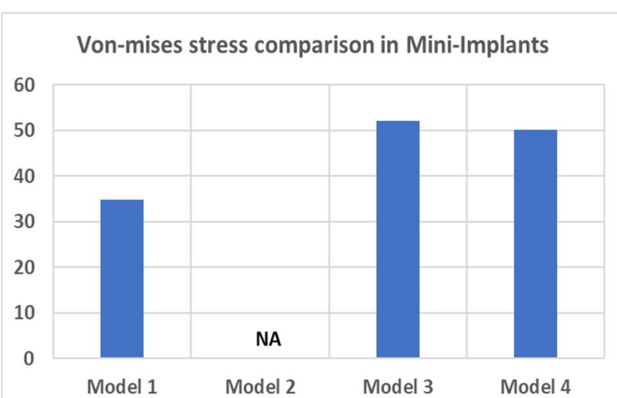
Table2:Von-Misesstress comparison for landmarks

Landmarks	**Model 1**	**Model 2**	**Model 3**	**Model 4**
	Von-Mises Stress(MPa)	**Von-Mises Stress(MPa)**	**Von-Mises Stress(MPa)**	**Von-Mises Stress(MPa)**
Frontomaxillary Suture	**0.002**	**0.003**	**0.003**	**0.003**
Zygomatico-Maxillary Suture	**0.004**	**0.005**	**0.006**	**0.005**
Frontozygomatic Suture	**0.003**	**0.004**	**0.004**	**0.003**
Zygomatic Arch	**1.044**	**0.971**	**1.53**	**1.4**
Pterygoid Humus	**0.217**	**0.142**	**1.52**	**1.39**
Medial Pterygoidplate	**0.592**	**1.33**	**1.53**	**1.45**
Layteral Pterygoidplate	**1.08**	**1.546**	**1.96**	**1.89**
Maxillary tuberosity	**0.7**	**0.879**	**0.756**	**0.712**

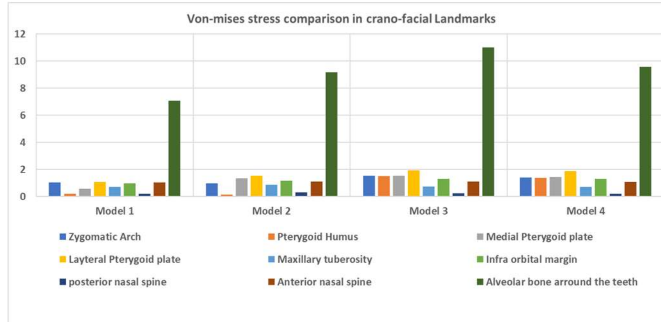
Infraorbital margin	0.985	1.181	1.326	1.301
Posterior nasal spine	0.207	0.303	0.233	0.225
Anterior nasal spine	1.038	1.113	1.107	1.086
Mid-palatal suture Anterior	0.048	0.08	0.077	0.065
Mid-palatal suture Posterior	0.006	0.002	0.028	0.023
Mini-implants	34.85	39.65	52.15	50.26
Alveolar bone around the teeth	7.069	9.162	11.021	9.56



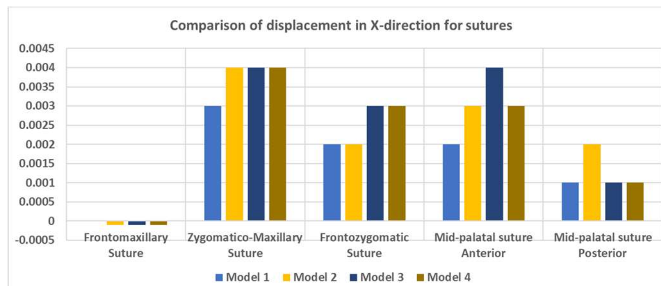
Graph 1- von mises stress comparison in suture



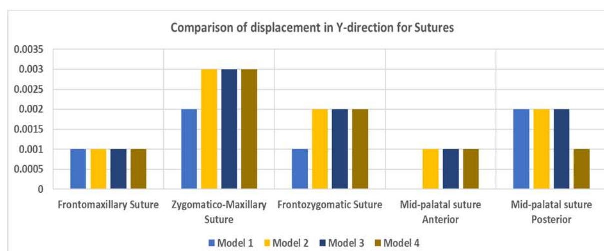
Graph 2- von mises stress comparison in Mini implant



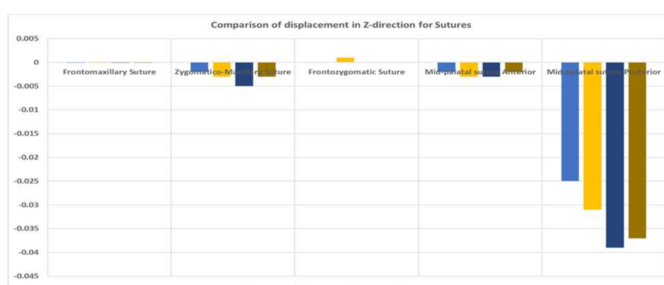
Graph 3- von mises stress comparison in craniofacial landmarks



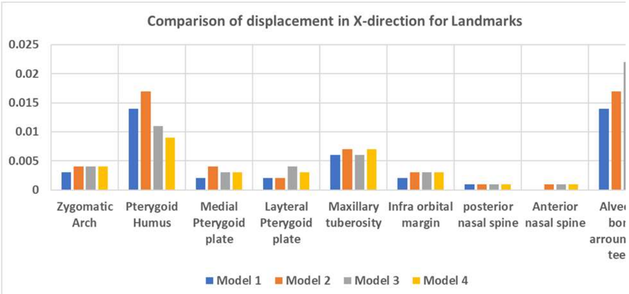
Graph 4- comparison of displacement in X direction for sutures



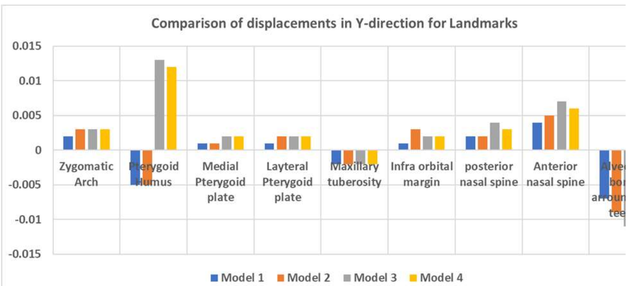
Graph 5- comparison of displacement in Y direction for sutures



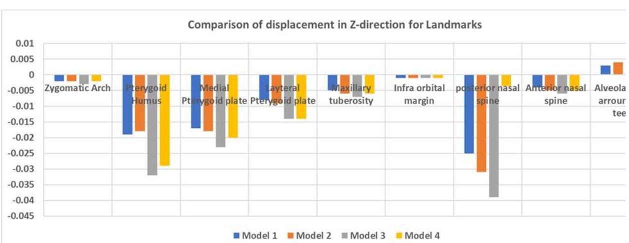
Graph 6- comparison of displacement in Z direction for suture



Graph 7- comparison of displacement in x direction landmarks



Graph 8- comparison of displacement in Y direction for landmarks



Graph 9- comparison of displacement in Z direction for landmarks

Transverse displacement (X-axis) increased progressively from the MARPE model to the surgically assisted models. The greatest skeletal displacement was observed in SARPE with bilateral pterygomaxillary disjunction (Model 3), followed by SARPE without PMJ (Model 4), RME with mid-palatal corticopuncture (Model 2), and MARPE (Model 1).

Among the circummaxillary sutures, the zygomaticomaxillary suture demonstrated greater transverse displacement than the frontomaxillary and frontozygomatic sutures in all models, indicating greater transmission of expansion forces to the zygomatic buttress. The frontomaxillary suture exhibited minimal displacement, suggesting limited movement at this region.

The pterygoid hamulus and pterygoid plates showed marked inferior (negative Z-axis) displacement, particularly in the surgically assisted models. Model 3 demonstrated the greatest vertical displacement at the pterygoid hamulus (−0.032 mm), indicating greater release of posterior maxillary resistance after bilateral pterygomaxillary disjunction.

The posterior nasal spine (PNS) and posterior mid-palatal suture exhibited the greatest inferior displacement among all landmarks. The maximum displacement was recorded in Model 3 (−0.039 mm), whereas Model 1 demonstrated the least displacement (−0.025 mm). These findings suggest that surgical assistance enhanced posterior opening of the maxilla.

Displacement of the anterior nasal spine (ANS) and the anterior mid-palatal suture also increased progressively from Model 1 to Model 3, reflecting greater anterior skeletal expansion in surgically assisted procedures.

The alveolar bone surrounding the teeth demonstrated the highest transverse displacement among all evaluated structures. The maximum value was observed in Model 3 (0.022 mm), followed by Model 4 (0.020 mm), Model 2 (0.017 mm), and Model 1 (0.014 mm), indicating greater skeletal expansion with surgical intervention.

Mini-implant displacement was observed in Models 1, 3, and 4. Greater displacement was recorded in the surgically assisted models than in MARPE, suggesting increased transfer of expansion forces through the skeletal anchorage system.

The highest stress concentration was consistently observed in the mini-implants, confirming that skeletal anchorage absorbed most of the expansion forces. Maximum stress was recorded in Model 3 (52.15 MPa), followed by Model 4 (50.26 MPa), Model 2 (39.65 MPa), and Model 1 (34.85 MPa). This indicates that surgically assisted expansion transferred greater forces to the anchorage system.

The alveolar bone surrounding the teeth exhibited the second highest stress concentration. Stress values increased from 7.07 MPa in MARPE to 11.02 MPa in SARPE with bilateral PMJ, indicating greater force transmission to the supporting bone during surgically assisted expansion.

Among the circummaxillary structures, the lateral pterygoid plate showed the highest stress concentration, reaching 1.96 MPa in Model 3. The medial pterygoid plate also demonstrated increased stress, particularly in the surgically assisted groups. These findings indicate that the pterygoid region represents one of the principal areas resisting maxillary expansion.

The zygomatic arch exhibited considerable stress in all models, with values ranging from 0.97 MPa to 1.53 MPa. The highest stress was observed in Model 3, followed by Model 4, reflecting greater load transmission through the zygomatic buttress after surgical release.

Stress values at the infraorbital margin and anterior nasal spine remained moderate across all models, whereas the frontomaxillary and frontozygomatic sutures demonstrated minimal stress accumulation, indicating limited mechanical loading in these regions.

The mid-palatal suture showed relatively low stress values compared with other craniofacial structures. Slightly greater stress was observed at the anterior portion than at the posterior portion in all models.

Overall, the stress analysis demonstrates that SARPE with bilateral PMJ generated the greatest stress concentration throughout the craniofacial skeleton, followed by SARPE without PMJ, RME with corticopuncture, and MARPE. The highest stresses were localized at the mini-implants, alveolar bone, zygomatic arch, and pterygoid plates, confirming these structures as the principal load-bearing regions during maxillary expansion.

Discussion:

Maxillary transverse deficiency is a common skeletal discrepancy that can adversely affect occlusion, arch coordination, facial esthetics, and airway dimensions. Although conventional rapid maxillary expansion is effective in growing patients, increasing skeletal maturity results in greater resistance from the midpalatal and circummaxillary sutural systems, limiting the skeletal effects of expansion. Consequently, alternative treatment modalities such as mini-implant assisted rapid maxillary expansion (MARPE), surgically assisted rapid palatal expansion (SARPE), and adjunctive procedures aimed at reducing skeletal resistance have been developed for adult patients.[1–7]

The present three-dimensional finite element study compared the biomechanical effects of MARPE, midpalatal cortico-puncture assisted expansion, SARPE without pterygomaxillary disjunction (PMD), and SARPE with PMD. The results demonstrated that all modalities produced skeletal displacement and stress distribution throughout the craniofacial complex; however, significant differences were observed in the magnitude and pattern of displacement.

Among all the models evaluated, SARPE with PMD produced the greatest transverse displacement. This finding supports the concept that the pterygomaxillary junction represents one of the primary areas of resistance during maxillary expansion. Surgical separation of the pterygomaxillary junction reduces posterior resistance and allows expansion forces to be transmitted more effectively through the maxillary complex. Similar findings were reported by Han et al.[12] and Lee et al.[1], who observed greater skeletal displacement and more favorable force distribution following surgical release of resistance areas. Likewise, Sangsari et al.[7], in their systematic review and meta-analysis, concluded that pterygomaxillary disjunction can facilitate maxillary expansion by reducing posterior skeletal resistance.

Although SARPE without PMD also demonstrated substantial skeletal expansion, the displacement values were lower than those observed in the PMD model. This observation suggests that residual resistance from the pterygoid region continues to influence the expansion process when pterygomaxillary separation is not performed. Nevertheless, the difference between the two SARPE models was relatively small, which is consistent with clinical studies reporting successful expansion with both techniques.[7,13,14] Therefore, the decision to perform PMD should be based on the severity of transverse deficiency, skeletal maturity, and the clinician's assessment of surgical risks and benefits.

The MARPE model demonstrated effective skeletal expansion despite the absence of surgical intervention. The use of mini-implants enables direct transfer of expansion forces to the palatal bone, thereby reducing dependence on dental anchorage and minimizing undesirable dentoalveolar effects. These findings are in agreement with the studies of Park et al.[5] and Baik et al.[3], who reported significant skeletal expansion and reduced dental tipping following MARPE treatment in young adults. Similarly, de Oliveira et al.[4] concluded that MARPE can provide outcomes comparable to SARPE in selected adult patients while avoiding surgical morbidity. The lower displacement observed in the MARPE model compared with SARPE may be attributed to the persistence of circummaxillary sutural resistance, which remains intact despite skeletal anchorage.[1,9]

The model incorporating midpalatal cortico-puncture demonstrated greater displacement than MARPE but less than both SARPE models. Cortico-puncture is intended to reduce cortical bone resistance and stimulate localized bone remodeling through the regional acceleratory phenomenon. The findings of the present study suggest that weakening the midpalatal cortical bone improves the transmission of expansion forces across the suture, resulting in enhanced skeletal expansion. Although evidence regarding cortico-puncture-assisted expansion remains limited, the observed displacement pattern indicates that this minimally invasive approach may improve the effectiveness of non-surgical expansion in adults while avoiding the morbidity associated with SARPE. The results also support the concept that reduction of local skeletal resistance can significantly influence expansion outcomes.

Analysis of displacement in the vertical and anteroposterior directions revealed that maxillary expansion is a three-dimensional phenomenon. Considerable displacement was observed at the posterior nasal spine and adjacent craniofacial structures, particularly in the surgically assisted models. Similar observations were reported by Boryor et al.[10] and Han et al.[12], who demonstrated that expansion forces are distributed throughout the craniofacial skeleton rather than being confined to the midpalatal suture. These findings emphasize the importance of evaluating expansion effects in all three planes of space.

The stress distribution patterns observed in this study were concentrated mainly around the mini-implants, zygomaticomaxillary complex, circummaxillary sutures, and pterygoid region. These structures have consistently been identified as the major areas resisting maxillary expansion.[9,10,12] The highest von Mises stress values were recorded around the mini-implants, indicating their critical role in transmitting orthopedic forces directly to the maxillary skeleton. Similar stress concentration patterns around skeletal anchorage units were reported by Lee et al.[9], who demonstrated that bone-borne expanders effectively transfer forces to the surrounding craniofacial structures while minimizing dental loading.

Significant stress concentration was also observed in the zygomaticomaxillary region. The zygomatic buttress forms an important component of the circummaxillary resistance system and contributes substantially to the distribution of expansion forces. Previous finite element studies have consistently reported high stress accumulation in this region during both tooth-borne and bone-borne expansion procedures.[1,9,10] The present findings further confirm the biomechanical significance of the zygomaticomaxillary complex during transverse maxillary expansion.

In the SARPE models, notable stress concentration was identified within the pterygoid plates. This finding reinforces the role of the pterygomaxillary junction as a major resistance site in adult maxillary expansion. Following pterygomaxillary disjunction, stress appeared to be distributed more uniformly throughout the craniofacial skeleton, which may explain the greater skeletal displacement observed in this model. Similar observations were reported by Han et al.[12] and Kaya et al.[11], who found that surgical reduction of posterior resistance improved force distribution and enhanced skeletal expansion.

From a clinical perspective, the present findings suggest that SARPE with PMD is the most effective modality for achieving maximum skeletal expansion in adults with severe transverse maxillary deficiency. However, the increased invasiveness, cost, and potential complications associated with surgery must be carefully considered.[6,19] MARPE offers an effective non-surgical alternative capable of producing clinically significant skeletal expansion while minimizing dentoalveolar side effects.[3–5] Midpalatal cortico-puncture may serve as an intermediate treatment option for patients requiring enhanced expansion but who are unwilling or unsuitable to undergo surgical intervention.

The limitations of this study should be acknowledged. Finite element analysis assumes that biological tissues are homogeneous, isotropic, and linearly elastic, which may not accurately represent the complex behavior of living tissues. Furthermore, biological processes such as bone remodeling, soft tissue adaptation, individual anatomical variations, and long-term treatment stability could not be simulated. Therefore, the findings should be interpreted as a biomechanical representation of expansion mechanics rather than a direct prediction of clinical outcomes.

Overall, the present study demonstrated that reducing skeletal resistance significantly improves maxillary expansion efficiency. Among the evaluated modalities, SARPE with pterygomaxillary disjunction produced the greatest skeletal displacement and most favorable biomechanical response, whereas MARPE provided an effective non-surgical alternative with satisfactory skeletal effects. These findings contribute to a better understanding of the biomechanics of adult maxillary expansion and may assist clinicians in selecting the most appropriate treatment modality according to individual patient requirements.

Conclusion:

This study used FEM to compare different rapid maxillary expansion methods, including MARPE, RME with midpalatal corticopuncture, and SARPE with and without pterygomaxillary disjunction. The models incorporated a Hyrax expander along with four mini-implants, strategically positioned to ensure controlled force application. A lateral expansion force of 100 Newtons (N) was applied, and displacement and Von-Mises stress distribution were analyzed across key anatomical landmarks.

1.This study examined different methods of expanding the upper jaw and their impact on movement and force distribution.SARPE with PMJ separation showed the most expansion, followed by SARPE without PMJ, RME with corticopuncture, and MARPE.

2.Mini-implants absorbed the highest forces, proving their importance in carrying the load during expansion.

3.The zygomatic arch and pterygoid plates also experienced stress, showing their role in force transmission.The posterior nasal spine moved the most, especially in RME with corticopuncture, which caused noticeable downward displacement.

4.Cortical bone absorbed the most stress, helping to stabilize the jaw, while cancellous bone transferred very little force.Titanium mini-implants played a key role in force transmission, ensuring expansion occurred in a controlled manner.

5.SARPE with PMJ separation proved to be the most effective technique for achieving maximum skeletal expansion.

6.Mini-implants helped spread forces efficiently, preventing unwanted movement of surrounding structures.

7.Choosing the right expansion method should depend on the patient's bone structure and treatment goals.Understanding stress distribution is important for planning orthodontic treatments effectively.

8.This study highlights the need for precise force application to avoid unnecessary movement or excessive stress on key anatomical areas.

Limitation:-

1.The assumption of uniform force application does not consider real-world variations in appliance placement, patient anatomy, or physiological responses.Soft tissue influences were not included in the analysis, even though they play a role in post-expansion stability and relapse potential.

2.Long-term follow-up data was absent, making it difficult to assess the durability of skeletal changes and potential relapse over time.The analysis focused on immediate effects after force application and did not evaluate long-term skeletal adaptations or dental compensations.

3.Patient-specific factors such as age, sex, or pre-existing skeletal conditions were not considered, even though they significantly influence treatment outcomes.

4.The study primarily examined mechanical aspects of expansion, without considering biological responses, which could affect treatment success.

5.Clinical validation through patient studies is necessary to confirm the effectiveness of different expansion techniques in diverse populations.

References:

1. Lee SC, Park JH, Bayome M, Kim KB, Araujo EA, Kook YA. Effect of bone-borne rapid maxillary expanders with and without surgical assistance on the craniofacial structures using finite element analysis. Am J Orthod Dentofacial Orthop. 2014;145(5):638–648. doi:10.1016/j.ajodo.2013.12.029.

2. Gauthier C, Voyer R, Paquette M, Rompré P, Papadakis A. Periodontal effects of surgically assisted rapid palatal expansion evaluated clinically and with cone-beam computerized tomography: 6-month preliminary results. Am J Orthod Dentofacial Orthop. 2011;139(4 Suppl 1):S117-28. doi:10.1016/j.ajodo.2010.06.022.

3. Baik HS, Kang YG, Choi YJ. Miniscrew-assisted rapid palatal expansion: A review of recent reports. J World Fed Orthod. 2020;9(Suppl 1):S54–S58. doi:10.1016/j.ejwf.2020.08.004.

4. de Oliveira CB, Ayub P, Ledra IM, Murata WH, Suzuki SS, Ravelli DB, Santos-Pinto A. Microimplant assisted rapid palatal expansion vs surgically assisted rapid palatal expansion for maxillary transverse discrepancy treatment. American Journal of Orthodontics and Dentofacial Orthopedics. 2021 Jun 1;159(6):733-42.

5. Park JJ, Park YC, Lee KJ, Cha JY, Tahk JH, Choi YJ. Skeletal and dentoalveolar changes after miniscrew-assisted rapid palatal expansion in young

adults: A cone-beam computed tomography study. Korean J Orthod. 2017;47(2):77-86. doi:10.4041/kjod.2017.47.2.77.

6. Carvalho PHA, Moura LB, Trento GS, Holzinger D, Gabrielli MAC, Gabrielli MFR, Pereira Filho VA. Surgically assisted rapid maxillary expansion: a systematic review of complications. Int J Oral Maxillofac Surg. 2019. doi:10.1016/j.ijom.2019.08.011.

7. Sangsari AH, Sadr-Eshkevari P, Al-Dam A, Friedrich RE, Freymiller E, Rashad A. Surgically assisted rapid palatomaxillary expansion with or without pterygomaxillary disjunction: a systematic review and meta-analysis. Journal of Oral and Maxillofacial Surgery. 2016 Feb 1;74(2):338-48.

8. Kayalar E, Schauseil M, Kuvat SV, Emekli U, Fıratlı S. Comparison of tooth-borne and hybrid devices in surgically assisted rapid maxillary expansion: a randomized clinical cone-beam computed tomography study. Journal of Cranio-Maxillofacial Surgery. 2016 Mar 1;44(3):285-93

9. 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. 2014 Oct 1;36(5):531-40.

10.Boryor A, Geiger M, Hohmann A, Wunderlich A, Sander C, Sander FM, Sander FG. Stress distribution and displacement analysis during an intermaxillary disjunction—a three-dimensional FEM study of a human skull. Journal of biomechanics. 2008 Jan 1;41(2):376-82.

11. Kaya N, Seker ED, Yücesoy T. Comparison of the effects of different rapid maxillary expansion techniques on craniofacial structures: a finite element analysis study. Prog Orthod. 2023;24:7. doi:10.1186/s40510-023-00459-2.

12. Han UA, Kim Y, Park JU. Three-dimensional finite element analysis of stress distribution and displacement of the maxilla following surgically assisted rapid maxillary expansion. Journal of Cranio-Maxillofacial Surgery. 2009 Apr 1;37(3):145-54.

13. Zandi M, Miresmaeili A, Heidari A. Short-term skeletal and dental changes following bone-borne versus tooth-borne surgically assisted rapid maxillary expansion: a randomized clinical trial study. Journal of Cranio-Maxillofacial Surgery. 2014 Oct 1;42(7):1190-5.

14. Blæhr TL, Mommaerts MY, Kjellerup AD, Starch-Jensen T. Surgically assisted rapid maxillary expansion with bone-borne versus tooth-borne distraction appliances—a systematic review. International Journal of Oral and Maxillofacial Surgery. 2019 Apr 1;48(4):492-501.

15. Toklu MG, Germec-Cakan D, Tozlu M. Periodontal, dentoalveolar, and skeletal effects of tooth-borne and tooth-bone-borne expansion appliances. American journal of orthodontics and dentofacial orthopedics. 2015 Jul 1;148(1):97-109.

16. 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. 2012 Jan;82(1):145-50.

17. Kronfeld R. Histologic study of the influence of function on the human periodontal membrane. The Journal of the American Dental Association (1922). 1931 Jul 1;18(7):1242-74.

18. Sandikçiolu M, Hazar S. Skeletal and dental changes after maxillary expansion in the mixed dentition. American Journal of Orthodontics and Dentofacial Orthopedics. 1997 Mar 1;111(3):321-7.

19. Carvalho PH, Moura LB, Trento GS, Holzinger D, Gabrielli MA, Gabrielli MF, Pereira Filho VA. Surgically assisted rapid maxillary expansion: a systematic review of complications. International Journal of Oral and Maxillofacial Surgery. 2020 Mar 1;49(3):325-32.

20. Sandıkçıoğlu M, Hazar S. Skeletal and dental changes after maxillary expansion in the mixed dentition. Am J Orthod Dentofac Orthop. 1997;111(3):321–7.

21. Öztürk M, Doruk C, Özeç İ, Polat S, Babacan H, Bıçakcı AA. Pulpal blood flow: effects of corticotomy and midline osteotomy in surgically assisted rapid palatal expansion. J Craniomaxillofac Surg. 2003;31(2):97–100. doi:10.1016/S1010-5182(02)00188-9.

22. Ramieri GA, Spada MC, Austa M, Bianchi SD, Berrone S. Transverse maxillary distraction with a bone-anchored appliance: dento-periodontal effects and clinical and radiological results. Int J Oral Maxillofac Surg. 2005;34(4):357–63. doi:10.1016/j.ijom.2004.10.011.

23. Halicioğlu K, Kiki A, Yavuz İ. Maxillary expansion with the memory screw: a preliminary

investigation. Korean J Orthod. 2012;42(2):73–9. doi:10.4041/kjod.2012.42.2.73.

24. Lagravère MO, Major PW, Flores-Mir C. Dental and skeletal changes following surgically assisted rapid maxillary expansion. Int J Oral Maxillofac Surg. 2006;35(5):481–7. doi:10.1016/j.ijom.2006.01.025.

25. Storto CJ, Garcez AS, Suzuki H, Cusmanich KG, Elkenawy I, Moon W, Suzuki SS. Assessment of respiratory muscle strength and airflow before and after microimplant-assisted rapid palatal expansion. Angle Orthod. 2019;89(5):725–32. doi:10.2319/070518-504.1.