Original Article

pISSN 2234-7518 • eISSN 2005-372X
https://doi.org/10.4041/kjod23.270

THE KOREAN JOURNAL of ORTHODONTICS
KJO

Tricortical versus bicortical anchorage in a double-screw tandem skeletal expander and a single-screw maxillary anchorage rapid palatal expander: A finite element analysis

Luca Brucculeri[a]
Federica Pellitteri[a]
Alfredo Salvatore Monterossi[a]
Emanuele Paoletto[b]
Giuliano Maino[a]
Luca Lombardo[a]

[a]Postgraduate School of Orthodontics, University of Ferrara, Ferrara, Italy
[b]Private Practice, Thiene, Italy

Objective: This study aims to employ finite element method (FEM) analysis to compare the differences between bicortical and tricortical anchorage of the posterior miniscrews in a single-screw miniscrew-assisted rapid palatal expansion (MARPE) and a double-screw tandem skeletal expander (TSE) under open and closed suture conditions. **Methods:** A cone beam computed tomography of the human skull of a 21.5-year-old female was utilized as a model for creating a FEM analysis. Simulations involved the insertion of four palatal miniscrews: two anterior ones with bicortical anchorage and two posterior ones (one with bicortical and another with tricortical anchorage), under open and closed suture conditions in a single-screw MARPE and double-screw TSE, resulting in a total of eight different simulation configurations. Evaluation parameters include total deformation (mm), Von Mises stress (MPa), and strain for each miniscrew body. **Results:** Tricortical anchorage of the posterior miniscrews provides greater anchorage, higher stress, and deformation on the anterior miniscrews in single-screw MARPE. Tricortical anchorage combined with a double-screw TSE promotes a more even distribution of force and stress on miniscrews under open suture conditions, leading to a parallel midpalatal suture opening along its entire length and height. **Conclusions:** FEM analysis revealed favorable midpalatal suture opening with equal force distribution and less stress when posterior tricortical anchorage in conjunction with double-screw TSE is applied.

Key words: Tricortical anchorage, Bicortical anchorage, Tandem skeletal expander, Miniscrew anchorage

Received December 18, 2023; Revised March 5, 2024; Accepted April 24, 2024.

Corresponding author: Federica Pellitteri.
Postgraduate School of Orthodontics, University of Ferrara, Via Luigi Borsari 46, Ferrara 44121, Italy.
Tel +39-3338899100 e-mail federica.pellitteri@hotmail.it

How to cite this article: Brucculeri L, Pellitteri F, Monterossi AS, Paoletto E, Maino G, Lombardo L. Tricortical versus bicortical anchorage in a double-screw tandem skeletal expander and a single-screw maxillary anchorage rapid palatal expander: A finite element analysis. Korean J Orthod. https://doi.org/10.4041/kjod23.270 Published online July 25, 2024.

INTRODUCTION

The prevalence of maxillary transverse deficiency is 8–23% in mixed dentitions and < 10% in adult orthodontic patients.[1,2] This condition can lead to various issues, including dental crowding, malocclusion, compromised facial aesthetics, and impaired nasal breathing.

Rapid palatal expansion (RPE) has emerged as a crucial treatment modality for individuals with transverse maxillary deficiency. RPE widens the upper jaw, correcting the underlying skeletal and dental problems and restoring harmony to the craniofacial complex.[3] Before starting RPE, it is essential to consider the skeletal maturity of the patient. Typically, children undergo RPE during their growth phase when the midpalatal suture is not fully fused. This allows for easier separation and expansion of the maxilla. However, in post-pubertal patients, the midpalatal suture is usually partially fused, making the expansion more challenging, often requiring additional treatment modalities such as surgically-assisted palatal expansion or miniscrew-assisted rapid palatal expansion (MARPE), which are differentiated into bone-borne rapid palatal expanders or tooth-bone-borne hybrid palatal expanders.[3-8]

Bishara and Staley[5] reported that the optimal age for maxillary expansion is before 15 years of age, as results are less predictable and unstable in older patients. Additionally, Jia et al.[9] compared maxillary transverse skeletal deficiency treated with rapid micro implant-assisted palatal expansion and dental expansion during the post-pubertal growth phase. They concluded that MARPE offers more predictable and significant skeletal expansion, less buccal tipping, and loss of alveolar bone height on anchor teeth. Hence, MARPE is a better alternative for individuals with maxillary skeletal deficits during the post-pubertal growth phase.[9,10]

Successful skeletal orthopedic expansion in MARPE depends on several factors, such as the effectiveness of the force applied, operator experience, cortical bone quality, and the surface contact area with the miniscrew within the cortical bone. Therefore, ensuring the stability of these miniscrew is crucial in achieving favorable outcomes in the expansion process, which directly exerts force on the basal bone.[6-11]

Lee et al.[6] studied the effects of anchoring monocortical and bicortical miniscrew on bone-supported palatal expansion using finite element model (FEM). Their findings demonstrated that bicortical miniscrew anchorage in orthodontic tooth movement provides better miniscrew stability and biomechanical advantages compared to monocortical anchorage. Consequently, bicortical miniscrew should be seriously considered in clinical scenarios where strong anchorage is needed. However, it is important to note that while primary stability may be improved with bicortical anchorage screws, secondary effects such as peri-implant stress, screw deformation, and transverse displacement were recorded.

Rapid palatal expander configuration and miniscrew placement are the other key factors to ensure successful suture opening during the maxillary expansion treatment phase.[6,9-11] Therefore, FEM is used as a powerful tool for visualizing and quantifying the initial displacement and stress distribution caused by orthodontic forces. Through the creation of a three-dimensional (3D) computational model, FEM allows for the analysis of stress and strain distributions, as well as the simulation of different appliance conditions.[6,12,13] Recently, a new four-miniscrews expander configuration called the tandem skeletal expander (TSE) has been introduced and has reported clinically satisfactory results. This configuration has the potential to expand the maxilla more parallelly. Thanks to its design, the bone-borne double expansion screw of the TSE allows for the positioning of the expander with two off-centered expansion screws, one anterior and one posterior, even in cases where the palate is narrow and high. This design enhances the resistance to deformation of the expander and the supporting miniscrews.[14-16] However, no finite element studies have been carried out to actually verify the improvements of tricortical anchorage over bicortical anchorage in both one-screw expanders and two-screw expansion devices.

Furthermore, when planning TSE, two posterior miniscrews are inserted at an inclination to achieve tricortical anchorage. This is done to enhance the primary stability of the miniscrews, reduce bending, and minimize transverse displacement.[17]

This study aims to utilize FEM analysis to evaluate the differences between bicortical and tricortical anchorage of the posterior miniscrews in both single-screw MARPE and double-screw TSE under open and closed suture conditions.

MATERIALS AND METHODS

The study was approved by the ethical committee of the University of Ferrara (Approval number 24/2023). The informed consent was waived.

Cone beam computed tomography segmentation

A cone beam computed tomography (CBCT) of the human skull of a 21.5-year-old female, with a slice thickness of 0.30 mm, was utilized as a model for creating a FEM analysis. The Mimics software (version 15.0; Materialise, Leuven, Belgium) was employed to transform the data into a standard triangulation language model by segmenting each bone and virtually generating all cranial sutures (Figure 1).

The thicknesses of the cortical bone and cancellous bone were determined using the Mimics software by modifying the pre-established parameters based on the grayscale. Once the 3D skull model was generated, it was imported into the computer-aided design software Rhinoceros 7 (Robert McNeel & Associates, Seattle, WA, USA), where four miniscrews were positioned.

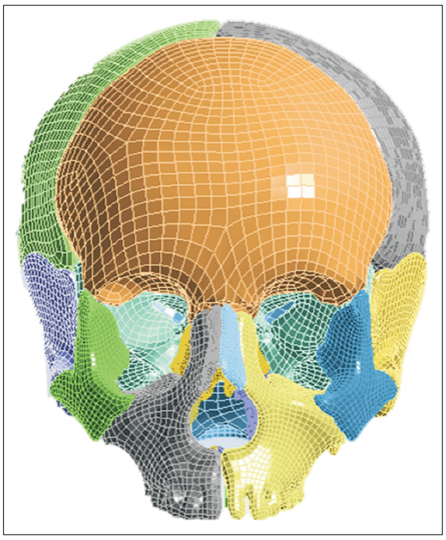

Figure 1. Standard triangulation language model of a skull for finite element analysis.

3D design

Two anterior konic screws, HDC Konic (Spider Screw, HdC, Thiene, Italy), with a central diameter of 2 mm and a length of 12 mm, were inserted for bicortical anchorage, with a depth of 2 mm in the nasal cortical bone. Regarding the two posterior miniscrews, two different anchorage configurations were created: (1) bicortical anchorage using HDC Konic miniscrews (Spider Screw, HdC) with a diameter of 2 mm and a length of 10 mm, inserted to a depth of 2 mm in the cortical bone (2) tricortical anchorage using HDC Konic miniscrews (Spider Screw, HdC) with a central diameter of 2 mm and a length of 12 mm. This configuration involved the cortical bone of the hard palate, the cortical bone of the inner wall of the maxillary sinus, and the cortical bone of the nasal floor (Palatal- Sinus- Nasion anchorage) (Figure 2).

Subsequently, using the same software, two different

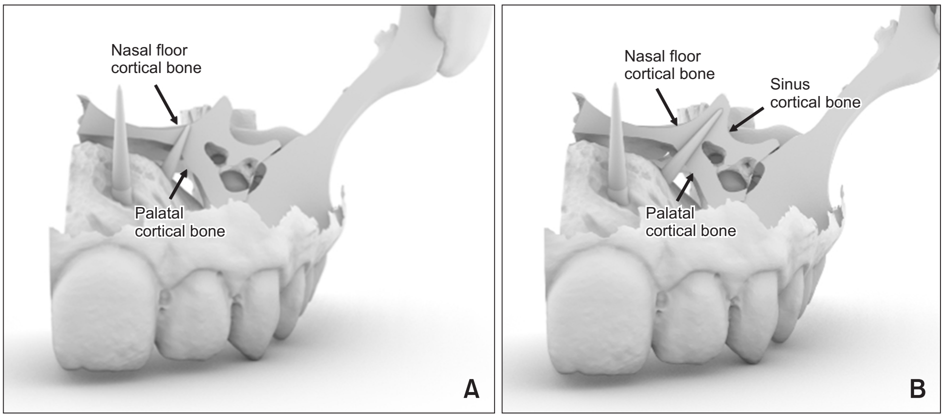

Figure 2. Standard triangulation language model of the upper jaw with the two configurations of posterior miniscrew anchorage: (**A**) bicortical and (**B**) tricortical.

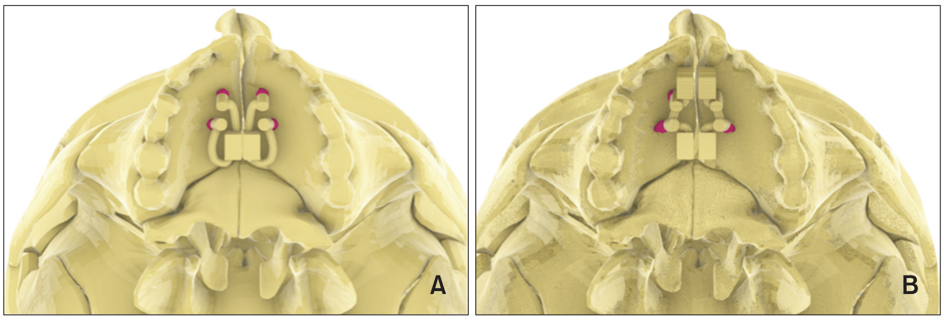

Figure 3. Design of the two bone-borne rapid palatal expanders miniscrew-assisted rapid palatal expansion, with four miniscrews: (**A**) with a single expansion screw and (**B**) tandem skeletal expander with two expansion screws (**B**).

 https://doi.org/10.4041/kjod23.270

expanders were designed: (1) MARPE with a single-screw expander with a posterior screw, chosen due to the narrow palatal conformation to facilitate the anterior placement of miniscrews, thereby maximizing palatal thickness, (2) TSE with a two-screw expander, with one screw positioned anteriorly and the other posteriorly, following the design specifications provided by the manufacturer (EP) (Figure 3). Each expander type was created with two different types of miniscrew anchorage: bicortical and tricortical.

These four expander models were exported from Rhinoceros 7 as 3D surface stereolithography files to generate finite element volumetric meshes for further analysis.

Finite element anlysis

The stereolithography files were then imported into the Ansys R1 software (version 19.2; ANSYS, Inc., Canonsburg, PA, USA) for FEM analysis. Volumetric mesh generation utilized tetrahedral elements, resulting in approximately 177,531 elements and 278,309 nodes for each skull model. Additionally, the body of each mini-implant consisted of approximately 72 nodes. Table 1 presents the material properties utilized in the study, where each material was assumed to possess homogeneity and isotropy characteristics.

For the four analyzed models, contacts were established between the different solid components comprising the skull, miniscrews, and the expander. Two different configurations were generated concerning the midpalatal suture: (1) bonded contact, where left and right maxillas were constrained together and could not slide relative to each other, simulating a clinically closed midpalatal suture; (2) rough contact, where the left and right maxillas were allowed to separate but could not slide relative to each other, simulating a clinically open midpalatal suture.

These configurations were applied to each type of expander MARPE and TSE and for both kinds of miniscrew anchorage (bicortical and tricortical), resulting in eight different simulation configurations. The simulating expansion was 0.25 mm for 40 steps, resulting in a 10 mm expansion in the transversal plane.

For each body of the four miniscrews (anterior left,

Table 1. The material properties utilized in the study

Variable	Young's modulus (E, MPa)	Poisson's ratio (v)
Cortical bone	13,700	0.30
Cancellous bone	1,370	0.30
Miniscrew (titanium)	110,000	0.33
Expander (stainless steel)	200,000	0.30

Table 2. Total deformation, Von Mises stress, and strain in the body of the four miniscrews with posterior bicortical anchorage

Suture		Miniscrew	Deformation (mm)		Stress (MPa)		Strain (mm/mm)	
			Min	Max	Min	Max	Min	Max
MARPE	Open	Anterior R	2.02	2.34	510.13	15,374.00	0.01	0.16
		Anterior L	2.00	2.30	430.71	14,722.00	0.01	0.21
		Posterior R	1.31	1.87	158.58	7,828.10	0.01	0.08
		Posterior L	1.27	1.74	195.63	8,238.00	0.01	0.09
	Closed	Anterior R	0.99	1.55	847.80	19,667.00	0.02	0.21
		Anterior L	1.02	1.59	626.28	19,255.00	0.02	0.28
		Posterior R	0.91	1.30	107.28	10,250.00	0.01	0.10
		Posterior L	0.98	1.34	178.99	12,098.00	0.01	0.11
TSE	Open	Anterior R	4.00	4.38	441.91	13,117.00	0.01	0.14
		Anterior L	4.12	4.55	464.56	12,528.00	0.01	0.18
		Posterior R	2.74	3.98	652.10	11,627.00	0.01	0.10
		Posterior L	2.87	3.95	558.78	11,325.00	0.01	0.15
	Closed	Anterior R	1.55	2.64	1,065.60	28,445.00	0.03	0.42
		Anterior L	1.57	2.64	1,521.30	27,195.00	0.03	0.55
		Posterior R	2.39	3.88	1,329.30	13,886.00	0.04	0.21
		Posterior L	2.45	3.85	969.37	14,776.00	0.02	0.27

MARPE, miniscrew-assisted rapid palatal expansion; TSE, tandem skeletal expander; R, right; L, left.

https://doi.org/10.4041/kjod23.270 www.e-kjo.org

anterior right, posterior left, and posterior right), the following parameters were evaluated: (1) total deformation (mm), representing the total displacement of each point in the structure relative to its initial position, needed to perform a finite element analysis simulation,[18] (2) Von Mises stress (MPa), which is a measure of the resistance of the material resistance to plastic deformation,[18] (3) strain, measuring the relative deformation of a material or structure in response to a load and is calculated as the ratio of the change in length of the material to its initial length.[18]

RESULTS

The total deformation (mm), Von Mises stress (MPa), and strain parameters for the bodies of the four miniscrews (anterior left, anterior right, posterior left, and posterior right) are presented in Table 2 for the expanders with posterior bicortical anchorage and in Table 3 for the expanders with posterior tricortical anchorage.

Total deformation

The minimum and maximum values of total deformation (mm) of the miniscrew body in the MARPE with bicortical anchorage were found to be 1.27 mm and 2.34 mm under open suture conditions, and 0.91 mm and 1.59 mm under closed suture conditions, respectively (Table 2). Conversely, with tricortical anchorage, the values were 0.99 mm and 2.55 mm under open suture conditions and 1.23 mm and 1.90 mm under closed suture conditions, respectively (Table 3 and Figure 4).

For the TSE, the minimum and maximum values of total deformation (mm) of the miniscrew body with bicortical anchorage were 2.74 mm and 4.55 mm under open suture conditions and 1.55 mm and 3.88 mm under closed suture conditions, respectively (Table 2). With tricortical anchorage, the values were 2.60 mm and 4.85 mm under open suture conditions and 1.81 mm and 3.71 mm under closed suture conditions, respectively (Table 3 and Figure 5).

The analysis of the total deformation overlap in conditions of open maxillary suture shows that both the MARPE with bicortical and tricortical anchorage, as well as the TSE with bicortical anchorage, result in alveolar bending and a V-shaped midpalatal suture opening (Figure 6A and 6B). However, the analysis of the TSE with open suture condition reveals a parallel opening of the midpalatal suture in both the sagittal and coronal planes (Figure 6C and 6D).

Von Mises stress

The minimum and maximum values of Von Mises stress (MPa) in the MARPE with bicortical anchorage were found to be 158.58 MPa and 15,374.00 MPa

Table 3. Total deformation, Von Mises stress, and strain in the body of the four miniscrews with posterior tricortical anchorage

Suture		Miniscrew	Deformation (mm)		Stress (MPa)		Strain (mm/mm)	
			Min	Max	Min	Max	Min	Max
MARPE	Open	Anterior R	2.06	2.44	523.61	13,549.00	0.00	0.09
		Anterior L	2.20	2.55	511.45	13,787.00	0.01	0.14
		Posterior R	1.44	2.03	299.78	9,389.00	0.01	0.16
		Posterior L	0.99	1.79	233.91	11,119.00	0.00	0.11
	Closed	Anterior R	1.42	1.85	687.04	21,058.00	0.02	0.23
		Anterior L	1.47	1.90	798.15	21,828.00	0.02	0.22
		Posterior R	1.23	1.70	58.22	13,337.00	0.00	0.12
		Posterior L	1.27	1.68	71.68	13,862.00	0.00	0.13
TSE	Open	Anterior R	4.11	4.54	406.59	11,319.00	0.01	0.13
		Anterior L	4.20	4.85	430.79	10,020.00	0.01	0.12
		Posterior R	2.60	3.96	978.02	13,792.00	0.01	0.12
		Posterior L	2.59	3.90	961.10	14,932.00	0.01	0.13
	Closed	Anterior R	1.83	2.66	1,225.50	28,640.00	0.04	0.46
		Anterior L	1.81	2.63	1,053.00	26,736.00	0.04	0.36
		Posterior R	2.40	3.71	1,734.30	37,651.00	0.02	0.25
		Posterior L	2.45	3.71	1,453.30	37,965.00	0.01	0.25

MARPE, miniscrew-assisted rapid palatal expansion; TSE, tandem skeletal expander; R, right; L, left.

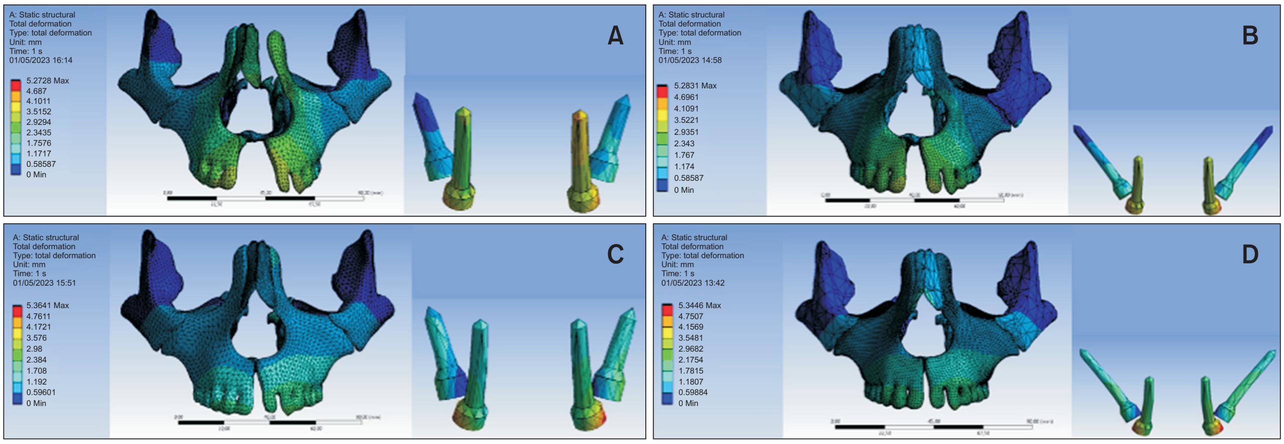

Figure 4. Total deformation (mm) in the single-screw miniscrew-assisted rapid palatal expansion in open suture condition: (**A**) posterior bicortical anchorage and (**B**) posterior tricortical anchorage. In closed suture condition: (**C**) posterior bicortical anchorage and (**D**) posterior tricortical anchorage.

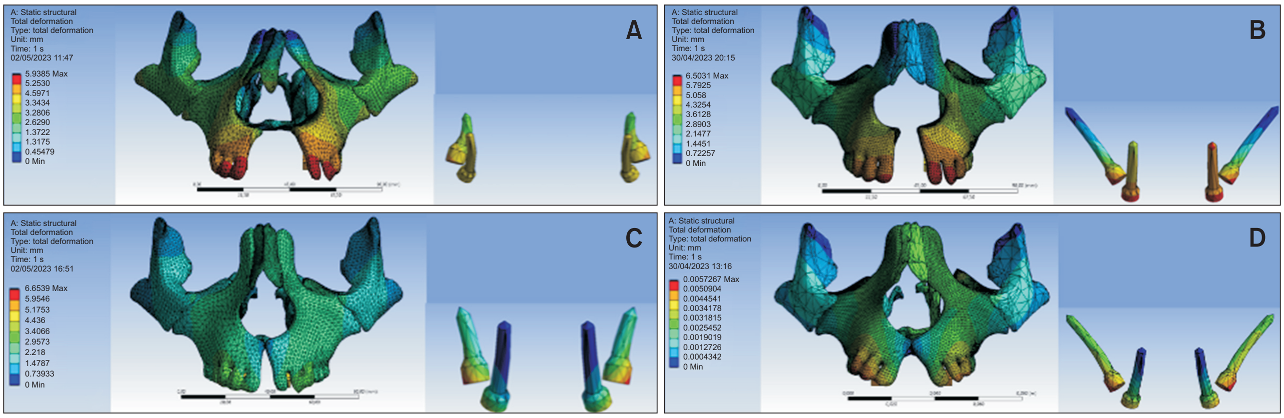

Figure 5. Total deformation (mm) in the double-screw tandem skeletal expander in open suture condition: (**A**) posterior bicortical anchorage and (**B**) posterior tricortical anchorage. In closed suture condition: (**C**) posterior bicortical anchorage and (**D**) posterior tricortical anchorage.

under open suture conditions, and 107.28 MPa and 19,667.00 MPa under closed suture conditions, respectively (Table 2). With tricortical anchorage, the minimum and maximum values were recorded as 233.91 MPa and 13,787.00 MPa under open suture conditions and 58.22 MPa and 21,828.00 MPa under closed suture conditions, respectively (Table 3).

For TSE with bicortical anchorage, the minimum and maximum values of Von Mises stress (MPa) were registered as 441.91 MPa and 13,117.00 MPa under open suture conditions and 969.37 MPa and 28,445.00 MPa under closed suture conditions, respectively (Table 2). In the devices with tricortical anchorage, the maximum and minimum values recorded for the TSE device were 406.59 MPa and 14,932.00 MPa under open suture conditions and 1,053.00 MPa and 37,965.00 MPa under closed suture conditions, respectively (Table 3).

Strain

The maximum and minimum strain values obtained during the analysis of the MARPE with bicortical anchorage are 0.01 and 0.21 under open suture conditions and 0.01 and 0.28 under closed suture conditions, respectively (Table 2). With tricortical anchorage, the values were 0.001 and 0.16 under open suture conditions, and 0.001 and 0.23 under closed suture conditions, respectively (Table 3).

In the TSE with bicortical anchorage, the minimum and maximum strain values were 0.01 and 0.18 under open suture conditions, and 0.02 and 0.55 under closed suture conditions (Table 2). For the tricortical anchorage, the minimum and maximum strain values were 0.01 and 0.13 under open suture conditions; under closed suture conditions, they were 0.02 and 0.46 (Table 3).

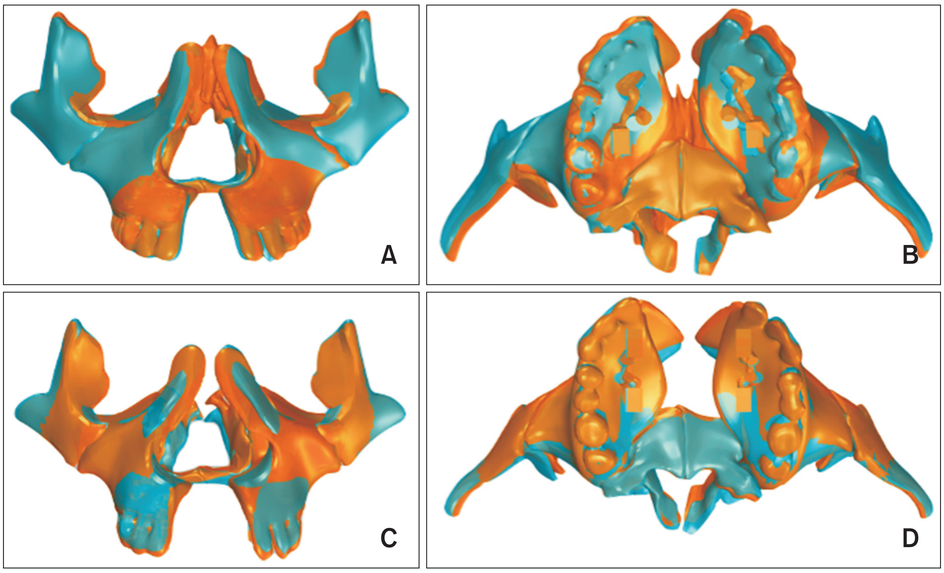

Figure 6. Overlaps of the skeletal results from the finite element method analysis under open suture conditions for miniscrew-assisted rapid palatal expansion with bicortical anchorage (blue) and tricortical anchorage (orange): (**A**) frontal view and (**B**) occlusal view, For tandem skeletal expander with bicortical anchorage (blue) and tricortical anchorage (orange): (**C**) frontal view and (**D**) occlusal view.

DISCUSSION

In patients beyond their growth phase, when the median palatal suture is partially ossified, miniscrew-supported rapid palatal expanders have proven effective in addressing transverse issues. However, this type of expansion, typically described as 'V-shaped,' does not always result in a parallel suture opening along its entire sagittal and coronal dimensions.[1,19] Undesirable effects include miniscrews and alveolar bone bending, resulting in forward and downward movement of the maxilla.[14,19] Lee et al.[6] demonstrated through FEM analysis that bicortical anchorage of miniscrews is superior to the monocortical anchorage in terms of reduced miniscrew deformation and fracture, increased stability, and anchorage with a more parallel sutural opening. Additionally, in patients with partially ossified median palatal sutures, the positioning of the expansion screw is crucial in breaking and overcoming the posterior ossification resistance, facilitating a parallel suture opening.[20-25]

The results of this study indicate that the total deformation of the miniscrew body is greater in the anterior miniscrews compared to the posterior ones across all configurations (both bicortical and tricortical), except for the TSE configuration with closed suture. In the TSE configuration, higher deformation values were observed in the posterior miniscrews compared to the anterior ones for both types of anchorage.

The stress pattern observed in MARPE and TSE configurations follows a similar trend. Under open suture conditions and tricortical anchorage, there is less stress on both anterior and posterior miniscrews compared to the open suture condition with bicortical anchorage. Conversely, under closed suture conditions and tricortical anchorage, the stress is higher for all anterior and posterior miniscrews compared to the closed suture condition with bicortical anchorage. The difference between bi- and tricortical anchorage of the posterior miniscrews results in a doubling of stress on the posterior miniscrews for tricortical anchorage compared to bicortical, observed in both expanders. However, while the stress values on the anterior miniscrews show no variation between bi- and tricortical anchorage, they undergo a slight decrease in the TSE configuration due to the lower moment generated between the miniscrew and the expansion screw.

Regarding the strain, in both configurations of the MARPE and TSE devices with bicortical anchorage, the deformation is consistently greater in the anterior screws, both under open and closed suture conditions. However, in both devices with tricortical anchorage, the strain is higher in the posterior screws under open suture conditions and higher in the anterior screws under closed suture conditions.

The presence of a closed suture appears to be a determining factor in increasing stress and deformations on the anchoring screws. Chang et al.[26] conducted an *in-vivo* and FEM study investigating the role of midpalatal and circummaxillary suture ossification levels on bone-borne rapid maxillary expansion using CBCT. Their findings indicated that with closed circummaxillary sutures, the reaction force on the expander could increase by 30–40%, depending on the stage of ossification. These results align with the findings of our study, where the presence of a closed suture associated with tricortical anchorage and subsequent greater anchoring of the posterior miniscrews seems to be responsible for greater deformation on the anterior miniscrews for both analyzed devices.

In the TSE, the presence of two expansion screws seems to lead to a more even distribution of forces across all four anchoring screws, unlike the MARPE, where there is greater stress on the anterior screws compared to the posterior ones. This disparity arises from the distance between the point of force application and the expansion screw generating the force. In the MARPE, the distance between the anterior miniscrews and the expansion screw is greater than the distance with the posterior miniscrews, creating a greater force moment and resulting in more substantial deformation and stress on the anterior miniscrews. Conversely, in the TSE, the presence of two expansion screws allows for equal distances between the centers of force application and the miniscrews, resulting in similar force moments and a more even distribution of force.[25]

The analysis of total deformation overlaps in the upper jaw reveals that both MARPE with bicortical and tricortical anchorage under open suture conditions produce alveolar bending, with more significant expansion observed in the palatal portion of the upper jaw compared to the upper portion (Figure 6A and 6B). Notably, tricortical anchorage results in more pronounced alveolar bending than bicortical anchorage, indicating a more significant expansion with tricortical anchorage. Conversely, there is a difference between open suture conditions with bicortical anchorage and tricortical anchorage in the TSE. With bicortical anchorage, the TSE induces alveolar bending in the two portions of the upper jaw, similar to the single-screw expander. However, the two-screw expander with tricortical anchorage generates a parallel opening of the midpalatal suture in both the transverse and coronal planes, facilitating a bodily expansion of the maxilla (Figure 6C and 6D).

Single-screw MARPE expansion produces a greater anterior suture opening than posteriorly and a greater alveolar bending in the coronal plane. Clinically, this leads to a greater suture opening in the lower third of the maxilla. Conversely, the expansion achieved with the TSE is less pronounced at the lower third level. Still, it demonstrates a more parallel expansion along the entire height of the maxilla in the coronal plane, favoring a greater expansion also at the level of the middle third. This is particularly beneficial for patients with skeletal Class III with maxillary deficiency.

The clinical validity of the TSE with tricortical anchorage has been confirmed by the clinical cases presented by Maino et al.[14] and Cremonini et al.[16] Using CBCT, they demonstrated a parallel opening of the midpalatal suture along its entire length, highlighting the TSE as a viable alternative to surgically assisted expansion approaches.

It is important to note that to achieve tricortical anchorage, the required length of miniscrews may be greater, depending on the palatal thickness of the patient.[27-30] In this study, miniscrews measuring 10 mm in length were utilized for effective bicortical anchorage, while 12 mm long miniscrews were employed to achieve tricortical anchorage. This allowed a greater portion of the miniscrew body to engage with the cortical bone. Yoon et al.[31] reported that employing longer miniscrews increases the amount of surrounding bone over the entire length of the miniscrew, leading to effective stress distribution.

The primary limitation of our study is its reliance on FEM, which allows for the theoretical analysis of the force expression, deformation, and stress on the upper jaw and the anchoring miniscrews. However, it does not consider clinical factors that could potentially influence outcomes. Therefore, future *in-vivo* studies are necessary to assess the behavior of tricortical anchorage and the TSE at various stages of ossification of the midpalatal suture.

CONCLUSIONS

Our study demonstrated that utilizing tricortical anchorage of the posterior miniscrews provides greater anchorage, resulting in higher stress and deformation on the anterior miniscrews when the single screw MARPE is applied. Tricortical anchorage, in combination with a TSE, promotes a more even distribution of force and stress on miniscrews under open suture conditions. This results in a parallel midpalatal suture opening along its length and height.

Future research should explore the clinical implications of tricortical anchorage in orthodontic practice, including its long-term effects on treatment outcomes and patient satisfaction. Additionally, investigations into novel anchorage methods and their impact on maxillary expansion can further refine orthodontic techniques and improve patient care.

AUTHOR CONTRIBUTIONS

Conceptualization: LL, LB, GM, FP. Data curation: LB, FP. Formal analysis: FP, LB, ASM. Methodology: LB, FP, LL. Writing–original draft: FP, ASM, LL. Writing–review & editing: LL, GM, EP.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

None to declare.

REFERENCES

1. da Silva Filho OG, Santamaria M Jr, Capelozza Filho L. Epidemiology of posterior crossbite in the primary dentition. J Clin Pediatr Dent 2007;32:73-8. https://doi.org/10.17796/jcpd.32.1.h53g027713432102
2. Egermark-Eriksson I, Carlsson GE, Magnusson T, Thilander B. A longitudinal study on malocclusion in relation to signs and symptoms of cranio-mandibular disorders in children and adolescents. Eur J Orthod 1990;12:399-407. https://doi.org/10.1093/ejo/12.4.399
3. Feres MF, Raza H, Alhadlaq A, El-Bialy T. Rapid maxillary expansion effects in Class II malocclusion: a systematic review. Angle Orthod 2015;85:1070-9. https://doi.org/10.2319/102514-768.1
4. Angelieri F, Cevidanes LH, Franchi L, Gonçalves JR, Benavides E, McNamara JA Jr. Midpalatal suture maturation: classification method for individual assessment before rapid maxillary expansion. Am J Orthod Dentofacial Orthop 2013;144:759-69. https://doi.org/10.1016/j.ajodo.2013.04.022
5. Bishara SE, Staley RN. Maxillary expansion: clinical implications. Am J Orthod Dentofacial Orthop 1987;91:3-14. https://doi.org/10.1016/0889-5406(87)90202-2
6. Lee RJ, Moon W, Hong C. Effects of monocortical and bicortical mini-implant anchorage on bone-borne palatal expansion using finite element analysis. Am J Orthod Dentofacial Orthop 2017;151:887-97. https://doi.org/10.1016/j.ajodo.2016.10.025
7. 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. Am J Orthod Dentofacial Orthop 2016;149:716-28. https://doi.org/10.1016/j.ajodo.2015.04.043
8. Maino BG, Paoletto E, Lombardo L, Siciliani G. From planning to delivery of a bone-borne rapid maxillary expander in one visit. J Clin Orthod 2017;51:198-207. https://pubmed.ncbi.nlm.nih.gov/28652504/
9. Jia H, Zhuang L, Zhang N, Bian Y, Li S. Comparison of skeletal maxillary transverse deficiency treated by microimplant-assisted rapid palatal expansion and tooth-borne expansion during the post-pubertal growth spurt stage. Angle Orthod 2021;91:36-45. https://doi.org/10.2319/041920-332.1
10. Lin L, Ahn HW, Kim SJ, Moon SC, Kim SH, Nelson G. Tooth-borne vs bone-borne rapid maxillary expanders in late adolescence. Angle Orthod 2015;85:253-62. https://doi.org/10.2319/030514-156.1
11. Lim HJ, Choi YJ, Evans CA, Hwang HS. Predictors of initial stability of orthodontic miniscrew implants. Eur J Orthod 2011;33:528-32. https://doi.org/10.1093/ejo/cjq122
12. Seong EH, Choi SH, Kim HJ, Yu HS, Park YC, Lee KJ. Evaluation of the effects of miniscrew incorporation in palatal expanders for young adults using finite element analysis. Korean J Orthod 2018;48:81-9. https://doi.org/10.4041/kjod.2018.48.2.81
13. Koç O, Pamukçu H, Kocabalkan AA. Comparison of 3 different bone-borne type expansion appliances used in surgically-assisted rapid palatal expansion: a finite element analysis. Am J Orthod Dentofacial Orthop 2023;163:e23-33. https://doi.org/10.1016/j.ajodo.2022.12.001
14. Maino BG, Paoletto E, Cremonini F, Liou E, Lombardo L. Tandem skeletal expander and MAPA protocol for palatal expansion in adults. J Clin Orthod 2020;54:690-704. https://pubmed.ncbi.nlm.nih.gov/33476295/
15. Arreghini A, Palone M, Maino BG, Paoletto E, Lombardo L. A digitally planned tandem skeletal expander and hybrid aligner approach. J Clin Orthod 2023;57:32-44. https://pubmed.ncbi.nlm.nih.gov/37196191/
16. Cremonini F, Ansaloni MC, Cremonini A, Maino BG, Paoletto E, Pellitteri F, et al. Severe transverse discrepancy in adult Class III patient: parallel rapid palatal expansion with a bone-borne tandem expansion screws (TSE) followed by lingual fixed appliance for a non-surgical treatment: a case report. Int Orthod 2022;20:100599. https://doi.org/10.1016/j.ortho.2021.11.001
17. Nucera R, Costa S, Bellocchio AM, Barbera S, Drago S, Silvestrini A, et al. Evaluation of palatal bone depth, cortical bone, and mucosa thickness for optimal orthodontic miniscrew placement performed according to the third palatal ruga clinical reference. Eur J Orthod 2022;44:530-6. https://doi.org/10.1093/ejo/cjac007
18. Tickoo S. Finite element analysis with ANSYS Workbench 2019 R2. Delhi: Bpb Publications; 2019. https://books.google.co.kr/books/about/Finite_Element_Analysis_with_Ansys_Workb.html?id=SZxizQEACAAJ&redir_esc=y
19. de Oliveira CB, Ayub P, Ledra IM, Murata WH, Suzuki SS, Ravelli DB, et al. Microimplant assisted rapid palatal expansion vs surgically assisted rapid

palatal expansion for maxillary transverse discrepancy treatment. Am J Orthod Dentofacial Orthop 2021;159:733-42. https://doi.org/10.1016/j.ajodo.2020.03.024
20. Cantarella D, Dominguez-Mompell R, Mallya SM, Moschik C, Pan HC, Miller J, et al. Changes in the midpalatal and pterygopalatine sutures induced by micro-implant-supported skeletal expander, analyzed with a novel 3D method based on CBCT imaging. Prog Orthod 2017;18:34. https://doi.org/10.1186/s40510-017-0188-7
21. 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 J Orthod 2017;22:110-25. https://doi.org/10.1590/2177-6709.22.1.110-125.sar
22. Cantarella D, Savio G, Grigolato L, Zanata P, Berveglieri C, Lo Giudice A, et al. A new methodology for the digital planning of micro-implant-supported maxillary skeletal expansion. Med Devices (Auckl) 2020;13:93-106. https://doi.org/10.2147/MDER.S247751
23. 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. Prog Orthod 2018;19:33. https://doi.org/10.1186/s40510-018-0229-x
24. Lee HK, Bayome M, Ahn CS, Kim SH, Kim KB, Mo SS, et al. Stress distribution and displacement by different bone-borne palatal expanders with micro-implants: a three-dimensional finite-element analysis. Eur J Orthod 2014;36:531-40. https://doi.org/10.1093/ejo/cjs063
25. 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. Prog Orthod 2014;15:52. https://doi.org/10.1186/s40510-014-0052-y
26. Chang CJ, Chen MJ, Chang CH, Chang HC. Investigation of the role of midpalatal and circummaxillary sutures in bone-anchored rapid maxillary expansion using a verified finite-element model. Am J Orthod Dentofac Orthop 2023;163:198-209. https://doi.org/10.1016/j.ajodo.2021.10.019
27. Ludwig B, Glasl B, Kinzinger GS, Lietz T, Lisson JA. Anatomical guidelines for miniscrew insertion: vestibular interradicular sites. J Clin Orthod 2011;45:165-73. https://pubmed.ncbi.nlm.nih.gov/21785201/
28. Gracco A, Lombardo L, Cozzani M, Siciliani G. Quantitative evaluation with CBCT of palatal bone thickness in growing patients. Prog Orthod 2006;7:164-74. https://pubmed.ncbi.nlm.nih.gov/17143344/
29. Negrisoli S, Angelieri F, Gonçalves JR, da Silva HDP, Maltagliati LÁ, Raphaelli Nahás-Scocate AC. Assessment of the bone thickness of the palate on cone-beam computed tomography for placement of miniscrew-assisted rapid palatal expansion appliances. Am J Orthod Dentofacial Orthop 2022;161:849-57. https://doi.org/10.1016/j.ajodo.2021.01.037
30. Gracco A, Luca L, Cozzani M, Siciliani G. Assessment of palatal bone thickness in adults with cone beam computerised tomography. Aust Orthod J 2007;23:109-13. https://doi.org/10.2478/aoj-2007-0017
31. Yoon S, Lee DY, Jung SK. Influence of changing various parameters in miniscrew-assisted rapid palatal expansion: a three-dimensional finite element analysis. Korean J Orthod 2019;49:150-60. https://doi.org/10.4041/kjod.2019.49.3.150