TURKISH JOURNAL OF
ORTHODONTICS

DOI: 10.4274/TurkJOrthod.2023.2022.191

Original Article

Relationship Between Circummaxillary and Intramaxillary Suture Densities and Skeletal Effects of Rapid Maxillary Expansion

Ece Başal, Yasemin Bahar Acar

Marmara University Faculty of Dentistry, Department of Orthodontics, İstanbul, Turkey

Cite this article as: Başal E, Acar YB. Relationship Between Circummaxillary and Intramaxillary Suture Densities and Skeletal Effects of Rapid Maxillary Expansion. *Turk J Orthod.* 2024; 37(2): 72-78

Main Points

- Cervical vertebral stage can be a predictive parameter of bone density.
- The mean density of both midpalatal and circummaxillary sutures has a significant relationship with cervical vertebral stages.
- No significant correlation was found between the skeletal response and density measurements.

ABSTRACT

Objective: This retrospective clinical study aimed to evaluate the maturation of intramaxillary and circummaxillary suture systems and cervical vertebral maturation as predictors of the skeletal response achieved by rapid maxillary expansion (RME).

Methods: A Digital Imaging and Communication in Medicine dataset of 20 patients (mean age: 15.55 years) prior (T0) and after (T1: 3.5±0.5 months) to RME were retrieved from the archive and analyzed. Bone density values of midpalatal suture (MPS), zygomaticomaxillary suture (ZMS), zygomaticotemporal suture (ZTS), pterygopalatine suture (PPS), and transverse palatine suture (TPS) were measured. The cervical vertebral maturational stages (CVS) were examined. The linear distances between the most lateral points of the piriform apertures were measured as the anterior reference, and the medial margins of the greater palatine foramina on the axial slice were chosen as the posterior reference. The difference at T1-T0 was calculated as the skeletal response to RME at anterior and posterior skeletal references. Spearman's rho rank and Kruskal-Wallis tests were used.

Results: Mean density values of ZMS, PPS, ZTS, TPS, MPS-Anterior, and MPS-Posterior were 922.81, 807.44, 753.83, 640.77, 661.13, and 604.59 HU, respectively. Mean linear changes in anterior and posterior skeletal expansion were 2.93±1.78 and 1.93±2.52 mm. There was no significant relationship between maturation indicators and skeletal response. Significant relationships were found between CVS and MPS density and CVS and circummaxillary suture average density ($p \leq 0.05$).

Conclusion: Sutural density showed significant variations among CVSs. Although there was no correlation between skeletal response and density measurements, sutural density was found to be a promising indicator for future studies.

Keywords: Maxillary expansion, sutures, bone density

INTRODUCTION

Rapid maxillary expansion (RME) is a frequently used protocol for orthopedic opening of the midpalatal suture (MPS) for the correction of maxillary transverse deficiency in orthodontic practice. While treatment success can be obtained in young individuals by a skeletal response; in adults, treatment failure is attributed to increased rigidity of the facial skeleton and interlocking of the MPS.[1] The preferred method of treatment for individuals

Corresponding author: Ece Başal, **e-mail:** eceabuhan@hotmail.com
Received: December 19, 2022 **Accepted:** August 15, 2023 **Publication Date:** June 30, 2024

with complete bone development is the surgically assisted RME (SARME) protocol.[2] The choice of treatment is important in terms of reducing morbidity and preventing unnecessary surgical procedures. Whether the response to RME will be more dental or skeletal has conventionally been reported to be related to chronological age.[3] Additionally, other conventional methods such as hand-wrist radiographs, skeletal maturation assessment on cervical vertebral stages (CVS), or evaluation of the midpalatal sutural opening with occlusal radiography have been used to choose between treatment options.[4-7] While some studies support the treatment being in the prepubertal period, others have reported that orthopedic changes can be obtained in adults.[8-10] Likewise, cadaveric studies have shown that the developmental process of MPS has diversity among individuals, and detailed evaluation is essential.[11]

The articulations of the maxillary bone consist of transverse palatine suture (TPS), frontomaxillary suture, and zygomaticomaxillary suture (ZMS). The interdigitation and complexity of these sutures increase as development progresses, and may prevent the desired effects of orthopedic treatments.[12] In addition, previous studies have shown that all maxillary articulations, especially ZMS, zygomaticotemporal sutures (ZTS), and pterygopalatine sutures (PPS), cause resistance to RME.[5,13] Therefore, MPS and circummaxillary structures have been evaluated three dimensionally. Jang et al.[14] considered only MPS in their study, emphasizing that other resisting structures must be considered in RME. Angelieri et al.[15] proposed a visual five-stage classification of the morphological maturational stages of MPS and stated that it is possible to estimate the treatment results from stages. However, subsequent clinical studies on morphological stages did not find a significant relationship between these parameters.[16,17] Studies regarding the effects of MPS and circummaxillary rigidity on treatment results have conflicting results, and the relationship still needs to be investigated.[16,18] The aim of this retrospective clinical study was to evaluate intramaxillary and circummaxillary suture densities, CVSs, and their effect on skeletal expansion in a group of growing subjects who underwent RME.

METHODS

This retrospective study was approved by the Ethical Committee of Clinical Studies of Marmara University, Faculty of Dentistry (approval no.: 2019-281, date: 28.03.2019). The study sample comprised the computed tomography (CT) of 20 patients (mean age: 15.55; range: 13-17 years; eleven females, nine males) who had RME as part of their comprehensive orthodontic treatment in Marmara University, Department of Orthodontics between 2001 and 2004 years. CT data were retrieved from the clinical archive. Sample size calculation was performed using G*Power software (version 3.1.9.2, Heinrich-Heine-University Düsseldorf, Germany), considering the strong level of correlation between "MPS ratio" and "greater palatine foramina" parameters (r=-0.78) in a previous study by Grünheid et al.[16]. The calculation indicated that a minimum of 20 patients was required for a power of 0.80 and α level of 0.05 to obtain an effect size of 0.5. The inclusion criteria were as follows: permanent dentition, skeletal maxillary constriction with bilateral posterior crossbite, no systemic or periodontal diseases, no previous orthodontic treatment, and complete records. Expansion was performed using a bonded Hyrax expander activated at a rate of 0.5 mm/day and continued until the upper first molar palatal cusp tips aligned with the lower first molar buccal cusp tips.[19] The expander was kept for passive retention for 3 months. After removal of the expansion appliance, a transpalatal arch with arms extending to the premolars was placed to maintain further retention.

The CT images consisted of T0 (before treatment) and T1 (3.5±0.5 months after RME). T1 records were taken before placement of the transpalatal arch to avoid metal artifacts. CT volumes were obtained using the same spiral CT device (Siemens Sensation 40, Siemens Medical Solutions of Siemens, Erlangen, Germany) at 120 kV, 80-mAs, 12.6x12.6-cm field-of-view, 512x512-pixel matrix, 0.3-mm increment slices, and 0.4-mm voxel size. Digital Imaging and Communication in Medicine (DICOM) images were analyzed using Mimics v.20.0 (Materialize, Leuven, Belgium). The head position was verified by ensuring that the palatal plane was parallel to the true horizontal plane and the midsagittal plane was parallel to the midsagittal cursor line of the software in coronal and axial.

Density measurements:

1. ZMS: The midpoint of the suture was marked on the 3D model, and the density was measured in Hounsfield units (HU) in a 2x2-mm^2 area in the section on the sagittal plane (Figure 1a).

2. ZTS: The midpoint of the suture was marked on the 3D model, and density was measured in a 2x2-mm^2 area in the coronal and sagittal planes (Figure 1b).

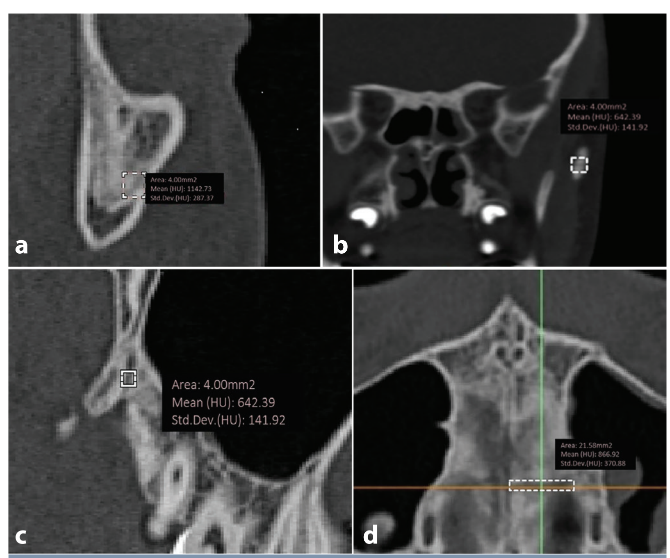

Figure 1. a) Density measurements of ZMS in sagittal view, b) Density measurements of ZTS in coronal view, c) Density measurements of PPS in sagittal view, d) Density measurements of TPS in axial view
ZMS, Zygomaticomaxillary suture; ZTS, Zygomaticotemporal sutures; PPS, Pterygopalatine sutures; TPS, Transverse palatine suture

3. PPS: The midpoint of the suture was marked on the 3D model, and density was measured in a 2x2-mm^2 area in the sagittal and axial planes (Figure 1c).

4. TPS: Density was measured in a rectangular area with a long edge along the suture and a short edge of 2 mm in the section where the TPS is most visible along the superoinferior thickness of the palate (Figure 1d). In patients with a deep palatal vault, it was not possible to visualize the entire suture lengthwise; therefore, the head orientation was arranged twice to visualize the right and left parts of the sutures in the axial section. Then, the two measurements were averaged.

Measurements of all circummaxillary sutures were made bilaterally, and the average value was named "Circummaxillary sutures' average density" (CSD).

5. MPS: Density was measured in 4x4-mm^2 areas at three different regions on an axial slice at the level of the palatal plane. MPS-Anterior (MPS-Ant) was measured distal to the incisive foramen. MPS-Middle was measured at the level of the line passing through the distal contacts of the left and right first premolars. MPS-Posterior (MPS-Post) was measured at the level of the first molars (Figure 2). The average of three measurements was recorded as (MPS-Ave).

For skeletal expansion, the most lateral points of the piriform aperture were selected as the anterior reference (Figure 3a). The medial margins of the greater palatine foramina were chosen as the posterior reference on the axial slice in the center of the hard palate (Figure 3b). The linear distance between these points was measured at T0 and T1, and the difference was accepted as the anterior and posterior skeletal response to RME.

CVS were evaluated on the lateral cephalogram extracted from the T0 DICOM volumes as described by Franchi et al.[6].

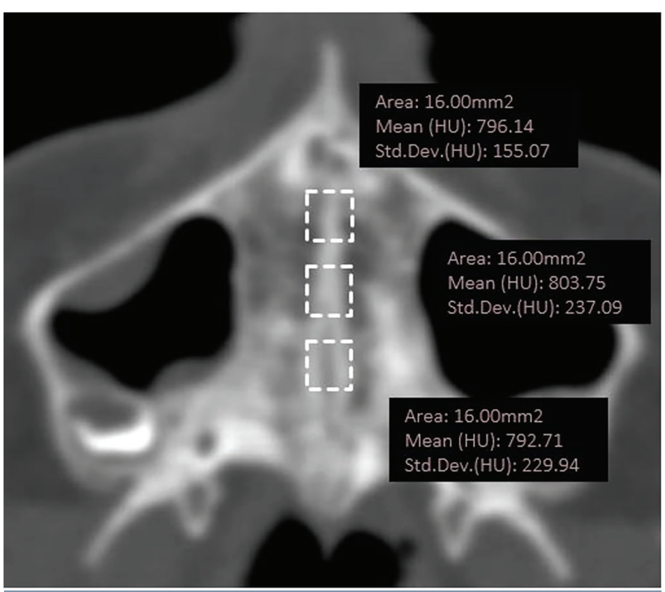

Figure 2. Density measurements of anterior, middle and posterior regions of MPS
MPS, Midpalatal suture

All measurements were made by one examiner, blind-tested during analysis with the help of random numeric identifiers, and repeated 3 months later.

Statistical Analysis

All statistical calculations were performed using SPSS 25.0 (IBM Corp, NY, USA). The conformity of the variables to the normal distribution was examined using Kolmogorov-Smirnov test. Intraexaminer agreement was assessed using the intraclass correlation coefficient (ICC) for continuous variables and the Kappa coefficient for categorical variables. Correlations between variables were assessed using the Spearman correlation coefficient. Variables that did not conform to normal distribution were compared with Kruskal-Wallis test.

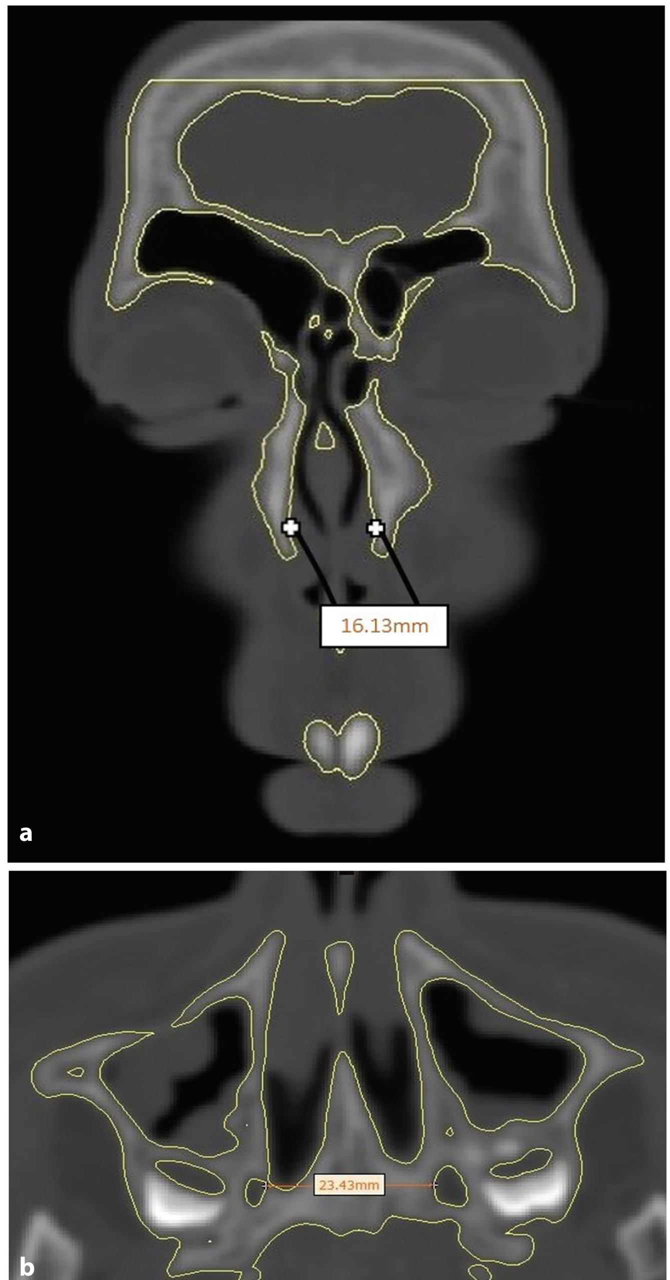

Figure 3. a) Anterior skeletal expansion measurements in coronal view, **b)** Posterior skeletal expansion measurements in coronal view

Then, Mann-Whitney U test with Bonferroni adjustment was performed as post-hoc test for pairwise comparison of significant variables. Statistical significance was determined at $p<0.05$.

RESULTS

Descriptive statistics of the study are shown in Table 1. There was no significant relationship between maturation indicators

Table 1. Descriptive statistics of the sample group

	T0		T1		Difference		p-value
	Mean	SD	Mean	SD	Mean	SD	
Anterior skeletal expansion (mm)	20.98	1.84	23.91	1.94	2.93	1.78	<0.001*
Posterior skeletal expansion (mm)	26.46	2.89	28.39	2.84	1.93	2.52	<0.001*
	Mean	SD					
MPS-Anterior (HU)	661.13	165.04					
MPS-Posterior (HU)	604.59	189.45					
ZMS (HU)	922.81	219.28					
PPS (HU)	807.44	144.92					
ZTS (HU)	753.83	190.64					
TPS (HU)	640.77	124.36					

*p<0.05
SD, Standard deviation; HU, hounsfield units; MPS, midpalatal suture; ZMS, zygomaticomaxillary suture; PPS, pterygopalatine suture; ZTS, zygomaticotemporal suture; TPS, transverse palatine suture

Table 2. Relationship between maturation indicators and skeletal response

		Anterior skeletal expansion (mm)			Posterior skeletal expansion (mm)		
Continuous variables		Correlation coefficient		p-value	Correlation coefficient		p-value
CSD (HU)		-0.089		NS	0.035		NS
ZMS (HU)		0.196		NS	0.165		NS
PPS (HU)		0.215		NS	0.018		NS
ZTS (HU)		-0.190		NS	-0.101		NS
TPS (HU)		0.406		NS	0.235		NS
MPS-Anterior (HU)		0.142		NS			
MPS-Posterior (HU)					-0.226		NS
Categorical variable		Mean	SD		Mean	SD	
Cervical vertebral maturation	CS3	2.42	1	p=0.037*	1.43	2.09	NS
	CS4	4.55	0.94		2.86	1.24	
	CS5	2.59	2.28		1.54	1.08	
	CS6	1.81	1.15		1.64	1.99	

*p<0.05
NS, not significant; SD, Standard deviation; HU, hounsfield units; CSD, circummaxillary sutures' average density; ZMS, zygomaticomaxillary suture density; PPS, pterygopalatine suture density; ZTS, zygomaticotemporal suture density; TPS, transverse palatine suture density; MPS, midpalatal suture density

Table 3. Relationship between intramaxillary and circummaxillary sutures' density values and cervical vertebral maturation

		MPS-Ave (HU)			CSD (HU)		
		Mean	SD	p-value	Mean	SD	p-value
Cervical vertebral maturation	3	525.86[a]	139.54	p=0.016*	625.65[x]	106.3	p=0.024*
	4	558.56[a,b]	130.67		661.88[x,y]	155.71	
	5	729.91[a,b]	17.01		804.93[x,y]	67.79	
	6	802.75[b]	138.02		869.22[y]	34.67	

*p<0.05
[a, b], Indicates the results of pairwise comparisons for MPS-Ave parameter. Different letters mean statistically significant differences; [x, y], Indicates the results of pairwise comparisons for CSD parameter. Different letters mean statistically significant differences
NS, not significant; SD, Standard deviation; HU, hounsfield units; CSD, circummaxillary sutures' average density; MPS-Ave, Average value of anterior, middle and posterior measurements for midpalatal suture density

(CSD, MPS-Ant, MPS-Post) and skeletal response (Table 2). CVS and anterior expansion amount showed a statistically significant correlation. When Mann-Whitney U test with Bonferroni adjustment was performed on the results of the pairwise comparisons, there was no statistically significant difference between the groups.

Kappa value had a mean value of 0.961 and ICC had a mean value of 0.909.

Significant differences were found between the mean values of both MPS-Ave and CSD in the CVS groups between CVS3 and CVS6 (p=0.049 and p=0.041 respectively) (Table 3). The mean values of density in CVS6 were found to be higher than those in CVS3.

DISCUSSION

In orthodontic practice, there is a lack of definitive guidelines concerning the choice between RME and SARME, despite the frequent use of RME. Previous studies have reported conflicting results regarding the relationship between maturation indicators and biological responses to RME. Researchers have emphasized the need to evaluate the maturation level of circummaxillary and midpalatal sutures,[13,20] which shows developmental diversity between postpubertal individuals.[10] However, the relationship between RME outcomes and resistance caused by articulations of the maxillary bone has not been adequately investigated, while studies have focused on MPS from various aspects. Therefore, the current study investigated the relationship between the skeletal effects of RME and circummaxillary and intramaxillary suture densities.

Cone-beam CT (CBCT) is a valid tool for 3D imaging in dentistry. However, the major limitation of studies investigating bone density on CBCT is the low standardization between scanners, which causes variability in the Hounsfield scale.[21] On the other hand, CT has superior reliability for bone mineral density quantification.[18] Comparative studies have confirmed the reliability and high accuracy of CT for quantitative and qualitative analyses as a valuable diagnostic supplement to subjective bone density evaluation.[22] The advantages of obtaining CT volumes in a short-term T0-T1 period were eliminating the influence of growth and the possible additional effects of post-expansion treatment procedures in the transverse dimension.

During measurements, to prevent any drawbacks that may result from head positioning, the measurements were verified on all planes and 3D masks, reference points with repeatability were preferred, and reference planes were created, thereby reducing the margin of error. Nonetheless, the scoring of these structures may be a possible limitation of our study due to anatomical factors.

The circummaxillary sutures, despite the thin nature of their structures, were visible in our sample group because of the superior reliability of the qualitative evaluation of CT. Standardized measurements were achieved by choosing a rectangular area in the middle of the sutures instead of volumetric density measurements, considering the 2D anatomy. For skeletal expansion measurements, anatomical points from the study by Grünheid et al.[16] were selected. The greater palatine foramen provides information about skeletal expansion in the posterior region of the hard palate, while the lateral margins of the piriform aperture are the region affected by the pyramidal effects of RME treatment. A common feature of these two regions is that they are easily identifiable and reproducible and are not be affected by the devices used in the treatment because they are not related to the dental structures.

Angelieri et al.[23] divided the stages of their classification into prepubertal (A-C) and postpubertal groups (D-E) and stated that while shifting from RME to SARME, it would be beneficial to perform detailed pretreatment evaluations for postpubertal individuals using 3D images. However, this conclusion was not tested clinically. In another study, the sample group who underwent RME was divided into two groups, as in Angelieri et al.[15], and compared the changes that occurred after RME on CBCT, but did not find a significant difference.[17] Grünheid et al.[16] used CBCT images and reported that there was no significant correlation between morphological stages, CVS, and skeletal response to RME. Grünheid et al.[16] also proposed an indirect parameter, "midpalatal suture density ratio" (MPSD-Ratio). MPSD-Ratio showed a significant negative correlation with the skeletal effects of RME, and they concluded that MPSD-Ratio can become a clinical predictor. However, in the following study on MPSD-Ratio with a larger sample, it was concluded that MPSD-Ratio is not an accurate predictor.[24] In this study, there was no significant relationship between sutural density and skeletal expansion, which is consistent with previous studies.

According to Korbmacher et al.[25] the bone density of MPS and fracture resistance, which increase with age, are the most reliable parameters regarding anatomical resistance to RME. Although density measurements of circummaxillary sutures have been reported as the contributory resistance regions that might affect the success of RME[13] and they showed bony displacement in response to RME,[26] CSD was not evaluated previously. Therefore, there have been no studies to compare the results of this study regarding CSD measurements. Acar et al.[18] measured volumetric bone density from various 3D segments of the maxillary bone in patients with RME. They found a highly significant correlation between the density of MPS, maxillary buttresses, and intermolar angle increase. However, they also concluded that they were not sufficient parameters to predict the prognosis.[18] Lee et al.[27] reported that Le Fort I corticotomy or PPS separation does not result in different results than separation of solely MPS during RME treatment. These results are consistent with our findings.

Study Limitations

In the current study, significant differences in both MPS and CSD values were observed between CVS3 and CVS6. The relationship between circummaxillary sutural density and CVS has not been previously investigated. On the other hand, the relationship between MPS density and CVS was evaluated in previous studies, and the results were consistent with our findings.[9,20] As bone maturation progresses, the negative effect of the increase in sutural density on the treatment response was also reported previously.[8] The idea of achieving sutural maturation from lateral cephalograms as a routine orthodontic record, which has a lower dose of exposure, is valuable. For this reason, a larger sample would favor the reliability of the results regarding the relationship between CVS and sutural density. In addition, this study was limited by several factors. CT can be considered an outdated imaging technique for dentistry due to its adverse effects and should only be limited to cases in which it is mandatory. The CT data used in this study were obtained almost 15 years ago for airway evaluation when CBCT was not commonly used. Its suitability for measuring density, examining very thin structures like the sutures, and thinner slice thickness makes it the modality of choice in this study because circummaxillary sutures are on extremely small scales and irregular.

CONCLUSION

Although no correlation was found between the skeletal response to RME and the circummaxillary and intramaxillary sutural densities, the significant difference between CVS3 and CVS6 in terms of MPS-Ave and CSD can be promising in a larger sample size with a wider age range. Within its limitations, this study confirms that CVS classification is a strong maturation predictor, showing a significant relationship with MPS-Ave and CSD.

Ethics Committee Approval: Ethical approval was obtained from the Ethics Committee of Marmara University Faculty of Dentistry (approval no.: 2019-281, date: 28.03.2019).

Informed Consent: The study was retrospective, so no written informed consent was obtained.

Authorship Contributions: Concept - Y.B.A.; Design - E.B.; Supervision - Y.B.A.; Materials - E.B.; Data Collection and/or Processing - E.B; Analysis and/or Interpretation - Y.B.A.; Literature Review - E.B.; Writing - E.B.; Critical Review - Y.B.A.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study has received no financial support.

REFERENCES

1. Lines PA. Adult rapid maxillary expansion with corticotomy. *Am J Orthod*. 1975;67(1):44-56. [CrossRef]
2. Gill D, Naini F, McNally M, Jones A. The management of transverse maxillary deficiency. *Dent Update*. 2004;31(9):516-521. [CrossRef]
3. Fishman LS. Chronological versus skeletal age, an evaluation of craniofacial growth. *Angle Orthod*. 1979;49(3):181-189. [CrossRef]
4. Fishman LS. Radiographic evaluation of skeletal maturation. A clinically oriented method based on hand-wrist films. *Angle Orthod*. 1982;52(2):88-112. [CrossRef]
5. Revelo B, Fishman LS. Maturational evaluation of ossification of the midpalatal suture. *Am J Orthod Dentofacial Orthop*. 1994;105(3):288-292. [CrossRef]
6. Franchi L, Baccetti T, McNamara JA Jr. Mandibular growth as related to cervical vertebral maturation and body height. *Am J Orthod Dentofacial Orthop*. 2000;118(3):335-340. [CrossRef]
7. Wehrbein H, Yildizhan F. The mid-palatal suture in young adults. A radiological-histological investigation. *Eur J Orthod*. 2001;23(2):105-114. [CrossRef]
8. Baccetti T, Franchi L, Cameron CG, McNamara JA Jr. Treatment timing for rapid maxillary expansion. *Angle Orthod*. 2001;71(5):343-350. [CrossRef]
9. Thadani M, Shenoy U, Patle B, Kalra A, Goel S, Toshinawal N. Midpalatal suture ossification and skeletal maturation: a comparative computerized tomographic scan and roentgenographic study. *J Indian Acad Oral Med Radiol*. 2010;22(2):81-87. [CrossRef]
10. Capelozza Filho L, Cardoso Neto J, da Silva Filho OG, Ursi WJ. Non-surgically assisted rapid maxillary expansion in adults. *Int J Adult Orthodon Orthognath Surg*. 1996;11(1):57-66. [CrossRef]
11. Persson M, Thilander B. Palatal suture closure in man from 15 to 35 years of age. *Am J Orthod*. 1977;72(1):42-52. [CrossRef]
12. Kapust AJ, Sinclair PM, Turley PK. Cephalometric effects of face mask/expansion therapy in Class III children: a comparison of three age groups. *Am J Orthod Dentofacial Orthop*. 1998;113(2):204-212. [CrossRef]
13. Chaconas SJ, Caputo AA. Observation of orthopedic force distribution produced by maxillary orthodontic appliances. *Am J Orthod*. 1982;82(6):492-501. [CrossRef]
14. Jang H-I, Kim S-C, Chae J-M, et al. Relationship between maturation indices and morphology of the midpalatal suture obtained using cone-beam computed tomography images. *Korean J Orthod*. 2016;46(6):345-355. [CrossRef]
15. 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(5):759-769. [CrossRef]
16. Grünheid T, Larson CE, Larson BE. Midpalatal suture density ratio: A novel predictor of skeletal response to rapid maxillary expansion. *Am J Orthod Dentofacial Orthop*. 2017;151(2):267-276. [CrossRef]
17. Sayar G, Kılınç DD. Rapid maxillary expansion outcomes according to midpalatal suture maturation levels. *Prog Orthod*. 2019;20(1):27. [CrossRef]
18. Acar YB, Motro M, Erverdi AN. Hounsfield Units: a new indicator showing maxillary resistance in rapid maxillary expansion cases? *Angle Orthod*. 2015;85(1):109-116. [CrossRef]
19. Krebs A. Midpalatal suture expansion studies by the implant method over a seven-year period. *Rep Congr Eur Orthod Soc*. 1964;40:131-142. [CrossRef]
20. Samra DA, Hadad R. Skeletal Age-related Changes of Midpalatal Suture Densities in Skeletal Maxillary Constriction Patients: CBCT Study. *J Contemp Dent Pract*. 2018;19(10):1260-1266. [CrossRef]
21. Abo Samra D, Hadad R. Midpalatal suture: evaluation of the morphological maturation stages via bone density. *Prog Orthod*. 2018;19(1):29. [CrossRef]
22. Lagravère MO, Carey J, Toogood RW, Major PW. Three-dimensional accuracy of measurements made with software on cone-beam computed tomography images. *Am J Orthod Dentofacial Orthop*. 2008;134(1):112-116. [CrossRef]

23. Angelieri F, Franchi L, Cevidanes LH, McNamara JA Jr. Diagnostic performance of skeletal maturity for the assessment of midpalatal suture maturation. *Am J Orthod Dentofacial Orthop*. 2015;148(6):1010-1016. [CrossRef]

24. Titus S, Larson BE, Grünheid T. Midpalatal suture density ratio: Assessing the predictive power of a novel predictor of skeletal response to maxillary expansion. *Am J Orthod Dentofacial Orthop*. 2021;159(2):e157-e167. [CrossRef]

25. Korbmacher H, Schilling A, Püschel K, Amling M, Kahl-Nieke B. Age-dependent three-dimensional microcomputed tomography analysis of the human midpalatal suture. *J Orofac Orthop*. 2007;68(5):364-376. [CrossRef]

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

27. 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. [CrossRef]