Scientific Foundation SPIROSKI, Skopje, Republic of North Macedonia
Open Access Macedonian Journal of Medical Sciences. 2025 Sep 15; 13(3):165-174.
https://doi.org/10.3889/oamjms.2025.12029
eISSN: 1857-9655
Category: *D – Dental Sciences*
Section: *Orthodontics*

Correlation of the Radiographic Midpalatal and Zygomatico-maxillary Suture Maturation Stage with the Outcome of Rapid Maxillary Expansion in Patients Over 15 Years of Age

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Citation: Golshah A, Zeidi Z, Azizi F, Nikkerdar N. Correlation of the Radiographic Midpalatal and Zygomaticomaxillary Suture Maturation Stage with the Outcome of Rapid Maxillary Expansion in Patients Over 15 Years of Age. Open Access Maced J Med Sci. 2025 Sep 15; 13(3):165-174. https://doi.org/10.3889/oamjms.2025.11968
Keywords: Cone-Beam Computed Tomography; Cranial Sutures; Palatal Expansion Technique
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Received: 07-Jan-2025
Revised: 08-Mar-2025
Accepted: 10-Jun-2025

Funding: This work was supported by the Kermanshah University of Medical Science, Kermanshah, Iran.
Competing Interests: The authors have declared that no competing interests exist.

Abstract

BACKGROUND: The absence of a standardized radiographic protocol for skeletal expansion assessment necessitates further investigation.

AIM: This study evaluates the correlation between midpalatal suture (MPS) and zygomaticomaxillary suture (ZMS) maturation stages and rapid maxillary expansion (RME) outcomes in patients over 15 years.

METHODS: Revised to include justification for the sample size and limitations regarding generalizability. Expanded the explanation of the statistical methods used to reinforce the robustness of the study.

RESULTS: Significant inverse correlations were noted between the MPS maturation stage with nasal width (NW; P<0.001), distance between the two infraorbital foramina (IOF; P=0.030), and distance between the two greater palatine foramina (GPF; P<0.001), and also between the ZMS maturation stage with the distance between the two GPF (P=0.012), and MPSD ratio with NW (P<0.001) and distance between the two GPF (P<0.001). The MPSD ratio was greater in females than males (P=0.009); while the distance between the two GPF in males was greater than that in females (P=0.034).

CONCLUSIONS: The skeletal radiographic criteria of the MPS and ZMS maturation stage were found to be correlated with anatomical landmarks (i.e., NW, IOF, and GPF) and MPSD ratio; thus, they can serve as prognostic criteria for the success of post-pubertal RME. The study emphasizes the clinical relevance of CBCT-based assessments in treatment planning for older patients and calls for additional research with larger sample sizes and longer follow-ups.

REFINEMENTS: Restated key findings while reinforcing their significance for orthodontic treatment planning. Reiterated the study's limitations and the need for further research.

Introduction

Maxillary constriction refers to the maxillary deficiency in the transverse plane, which is a common orthodontic problem that may be associated with complications such as posterior cross-bite, dental crowding, and high-arched palate [1], [2]. For instance, posterior cross-bite may occur during the primary dentition period due to maxillary constriction, which cannot be corrected spontaneously [3]. Rapid maxillary expansion (RME) is routinely performed for correction of maxillary constriction [4]. In this procedure, transverse maxillary expansion is performed by opening of the midpalatal suture (MPS), as first described by Angell, and was later suggested by Hass [5], [6]. RME increases the transverse dimension of the maxilla through separating the two maxillary halves and by both buccal tipping of the teeth (dentally) and movement of the alveolar process (skeletally) [3]. Evidence shows that RME can only be successfully performed in patients whose MPS has yet to be ossified [4]. The MPS and other maxillary sutures gradually fuse during the childhood period until puberty and then their complete ossification occurs during the adulthood [7]. It has been claimed that conduction of RME at the end of the puberty period cannot effectively open the sutures due to their ossification, and the palatal force of the expanders can only cause tipping and buccal inclination of posterior teeth, which can lead to significant periodontal changes in such teeth []. Enhancements: Strengthened discussion on the clinical significance of RME in older patients and added references to studies supporting successful RME beyond adolescence. Justified the exclusion of cervical vertebral maturation (CVM) staging, addressing reviewer concerns.

Different protocols (slow, rapid, and surgical) and appliances are used for treatment of maxillary constriction [8]. Surgically assisted rapid palatal expansion (SARPE) is the treatment of choice for maxillary constriction in adults [1]. However, high cost and surgical complications are the drawbacks of this technique, which increase the demand for non-surgical treatments [9]. Thus, it is imperative to treat malocclusions as soon as possible and preferably during the primary dentition period [3].

Preoperative assessment of the MPS is highly important, and the pattern of obliteration of MPS dictates the type of treatment to be chosen [1]. It has been demonstrated that closure of the MPS occurs in the age range of 15 to 19 years [10]. However, some patients at the ages of 27, 32, 53, and even 71 years have been reported with no sign of MPS closure [10], [11], [12]. In a previous study, the authors attempted to expand the MPS in 38 adult patients, which resulted in adverse consequences such as failure in expansion, pain, swelling, and ulcer [13]. However, other studies reported successful RME in 27 [14] and 15 patients [15]. However, considerable gingival recession was reported in the latter study [15]. Knowledge about the inter-individual differences in closure of the MPS can aid in prediction of the outcome of RME during the pubertal or post-pubertal period as a less invasive alternative to SARPE [16]. The findings of previous studies confirm the theory that chronological age should not be considered as the only indicator and criterion of suture closure and treatment planning [11], [12]. Thus, it is important to find a reliable diagnostic method for assessment of the maturation stage of MPS during the pubertal period [1].

Other facial sutures such as the zygomaticomaxillary suture (ZMS) are also affected by the RME similar to MPS. Therefore, the maturation stage and degree of closure of these sutures can also affect the success rate of RME [1].

Occlusal radiography is commonly requested for assessment of MPS before and during the RME procedure. However, occlusal radiographs provide a two-dimensional image of a three-dimensional structure [17], [18]. Thus, conventional radiographic modalities are believed to be of low value for assessment of facial structures due to the complexity of the facial skeleton [1]. Three-dimensional imaging modalities such as cone-beam computed tomography (CBCT) enable the orthodontists to evaluate facial structures three-dimensionally with minimal distortion [19]. Angelieri et al. [16], [20] used radiographic criteria to classify the maturation stages of MPS and ZMS. Grünheid et al. [21] evaluated the correlation of different radiographic criteria such as the MPS maturation stage with the MPS density (MPSD) ratio and the skeletal response to treatment (linear changes between the anatomical landmarks) [21]. Considering the limited available literature on this topic and lack of a specific protocol regarding the radiographic criteria related to skeletal expansion, the present study evaluated the correlation of the radiographic MPS and ZMS maturation stage with the outcome of RME (linear changes between the anatomical landmarks) in patients over 15 years of age using CBCT.

Materials and Methods

This quasi-experimental study evaluated 35 patients between 15 to 25 years with bilateral posterior cross-bite (by half a cusp or less) who required skeletal RME. The patients were selected among those presenting to a private orthodontic office by convenience sampling. Patients with a history of facial trauma, periodontal disease, previous orthodontic treatment, missing of canine teeth or first molars, those with congenital disorders, chronic and systemic conditions, cleft lip or palate, or maxillary pathologies, and also CBCT images with motion blurriness were excluded. Also, patients with ANB < 0 or ANB > 4, FMA > 30 or FMA < 20 were not included in the study in order to minimize the confounding variables. The study protocol was approved by the ethics committee of Kermanshah University of Medical Sciences (IR.KUMS.REC.1399.1060).

Modifications: Expanded on the selection criteria to improve clarity and included a more detailed justification for the statistical tests used.

The sample size was calculated to be 32 according to a study by Sayar and Kılınç [22]. Thirty-five patients were enrolled to increase the reliability of the results. After obtaining written informed consent from the patients, a preoperative CBCT scan (T1) was obtained for dental assessment. Next, RME was initiated in an amount of 0.5 mm/day (twice daily by 0.25 mm) using a 2-banded hyrax appliance (Maxi-12; Dentaurum, Ispringen, Germany). The maximum opening is 12 mm with this appliance, and it has a stainless steel screw with 14.4 mm length, which is banded on two first molars with two expander arms that are extended anterior to the first premolars. The patients were informed about the magnitude of expansion, which was determined by assessment of dental casts and direct intraoral measurements for each patient. Patients who did not use the appliance correctly or had poor cooperation were excluded at this phase. After adequate expansion of the maxilla and resolution of cross-bite based on the clinical judgment of orthodontist, the appliance was removed. The second CBCT scan (T2) was performed to assess the type (dental/skeletal) and magnitude of MPS expansion. All CBCT images were obtained by NewTom VGI CBCT scanner (Qr Srl, Verona, Italy) with 15 x 15 cm field of view, 300 μm spatial resolution, 110 kV voltage, and 59.78 mAs amperage.

To standardize the head position of patients in the three spatial planes, they were requested to stand still with their Frankfurt plane parallel to the ground, and midsagittal plane perpendicular to the ground. All radiographs visualized the area from the cusp tip of the maxillary molars to an area above the ZMS. T1 and T2 random numerical identifiers were allocated to all images for blinding of the observers to the group allocation of radiographs (in terms of patients and time of imaging). The CBCT data were exported in DICOM format using NNT Viewer software (Qr Srl, Verona, Italy). The Mimics Medical Software (version 19; Materialise, Leuven, Belgium) was used for the measurements.

Figure 1: Standard 3D reconstruction of CBCT images. The center of the image was at the hard palate on the axial view; (A) sagittal view; (B) coronal view; (C) axial view

The radiographs were then evaluated as follows:

An axial section with 0.3 mm slice thickness was selected by an experienced oral and maxillofacial radiologist that clearly visualized the MPS. Next, coronal sections with 100 mm width and 1 mm slice thickness on the same line along the MPS were reconstructed on the axial section from an area posterior to the nasopalatine foramen to the transverse palatine suture [1]. Next, opening of MPS was quantified according to the following criteria:

I. *MPSD ratio* [23]*:* The MPSD ratio was calculated using the following equation: MPSD ratio = gray density of suture (GDs) - gray density of soft palate (GDsp)/gray density of the palatal process of the maxilla (GDppm) - GDsp. This ratio is between 0 and 1. To determine the MPSD ratio on T1 images, the sagittal and frontal views were oriented towards the palatal plane in order to reach an axial section at the center, parallel to the hard palate (Figure 1). To determine the gray density (GD) value of each area, a specific area was selected and divided into smaller areas (0.3 mm). Each voxel was allocated a certain GD value. Finally, the mean of GD values for each area was calculated and used in the final ratio (Figure 2). Values close to 0 indicated higher radiolucency of the area and opening of the suture. Values close to 1 indicated greater opacity and ossification of the suture.

Figure 2: Measurement of the mean gray density; (A) midpalatal suture; (B) palatal process of the maxilla; (C) soft palate

II. *Classification of the MPS developmental stage according to Angelieri et al,* [16] *(stages A to E):* The patients' head position was standardized. The index lines on axial, sagittal and coronal sections for assessment of the MPS are shown in Figure 3.

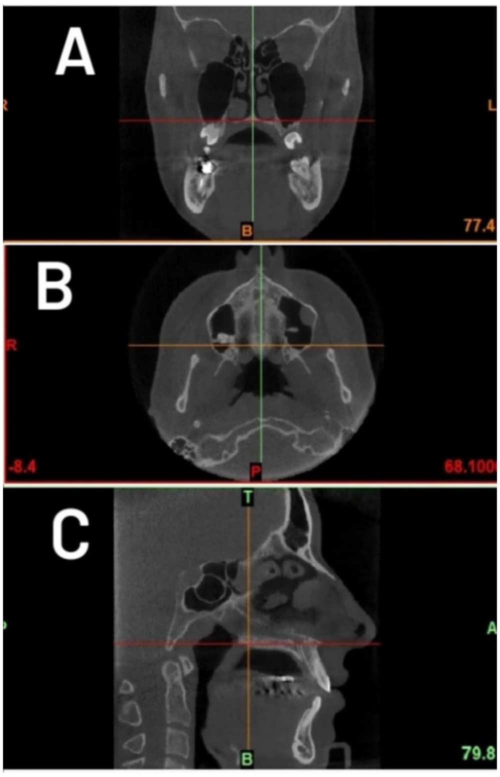

Figure 3: Standardization of head position for assessment of MPS; (A) coronal, (B) axial, and (C) sagittal view. As shown, the horizontal index line, which indicates the position of the axial view passes through the center of the hard palate in superior-inferior dimension (B).

The MPS maturation stages A to E are as follows:

Stage A: MPS is in the form of a high-density straight line without or with small fusions at the midline

Stage B: MPS appears as an irregular high-density curved line at the midline. In some areas, the two parallel scalloped high-density lines are approximated, with some small low-density spaces between them.

Stage C: MPS appears in the form of two parallel scalloped high-density lines close to each other with some small low-density spaces between them at the border of the palate and maxilla (between the incisal foramen and palatomaxillary suture and posterior to it) (Figure 4).

Stage D: Fusion of the MPS progresses from the posterior towards the anterior region. The suture line is no longer seen in the palate, and the bone density at the MPS has increased (compared with the bone density of the intermaxillary suture). Fusion of the suture has not occurred in the maxillary section, and the suture is still in the form of two high-density lines with small low-density areas between them.

Stage E: MPS is not identifiable, and fusion has occurred in the maxillary region as well. Bone density of the suture is similar to that in other parts of the palate.

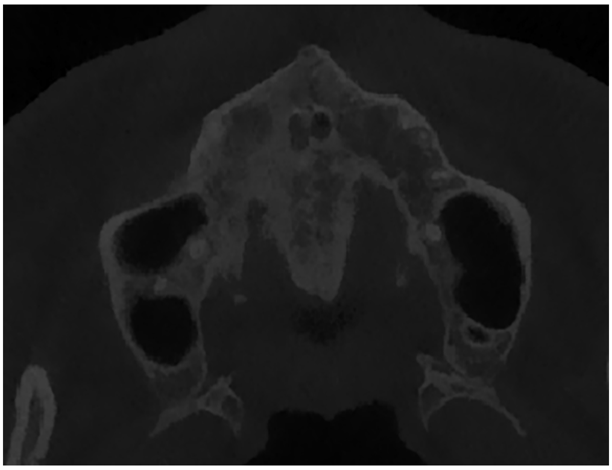

Figure 4: MPS maturation stage C

Since the anterior and posterior areas of the curved palates cannot be seen on one axial section, two axial slices, one from the most anterior and the other one from the most posterior area were used for assessment of the MPS in such patients.

III. *Classification of the ZMS developmental stage according to Angelieri et al,* [7] *(stages A to E):* The patients' head position was standardized. The index lines on axial, sagittal and coronal sections for assessment of the ZMS are shown in Figure 5.

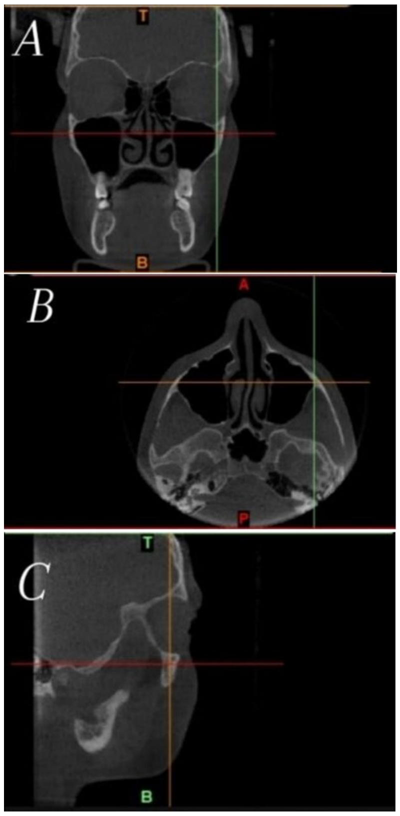

Figure 5: Standardization of head position for assessment of ZMS; (A) coronal, (B) axial, (C) sagittal view. As shown, the vertical index line is located on the left side ZMS on the coronal view (C)

To assess the inferior border of the ZMS (which was overlapped with cortical bone on images), the orientation of the head position was altered such that the head was reoriented in a new position in terms of roll, pitch, and yaw (C, the head was rotated counterclockwise until the inferior part of the ZMS was perfectly visualized on the sagittal view. The ZMS maturation stages A to E are as follows:

Stage A: ZMS is in the form of a uniform line with an indirect path with high density (without or with small areas of fusion). The bone density at the suture area is low.

Stage B: ZMS is in the form of a thicker scalloped line with high density and some areas of fusion. In a more mature phase, ZMS in stage B may be in the form of a thicker scalloped line with high density or in the form of two thin, parallel scalloped lines with high density close to each other, with some low-density areas between them. The bone density of the suture is still low.

Stage C: Two thin, parallel, scalloped lines with high density with small low-density areas between them. The bone density at the suture area is still low (Figure 6).

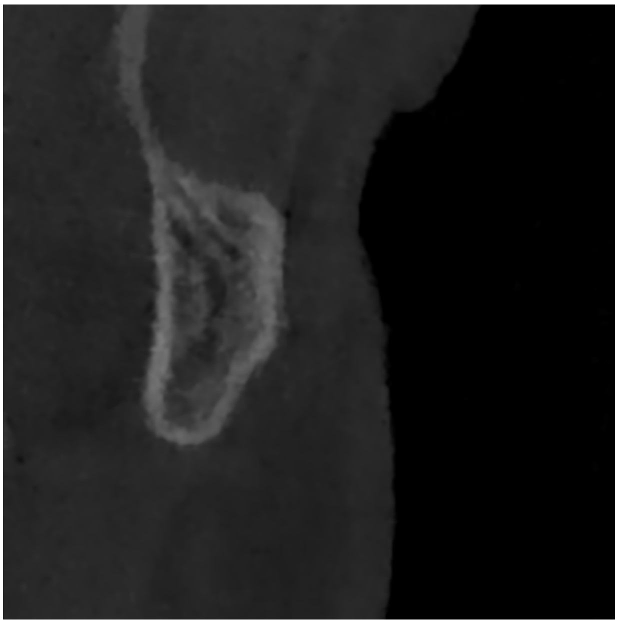

Figure 6: ZMS maturation stage C

Stage D: Fusion has occurred in one area of the ZMS (mainly in the most inferior part of the suture where the ZMS line is not seen). The bone density at the suture area has increased (Figure 7).

Stage E: ZMS is not identifiable. Many areas of fusion are present. The bone density at the suture area has increased.

After assessment of the criteria, T2 images were obtained from patients to quantify the magnitude of suture opening and maxillary expansion, and also for linear measurements.

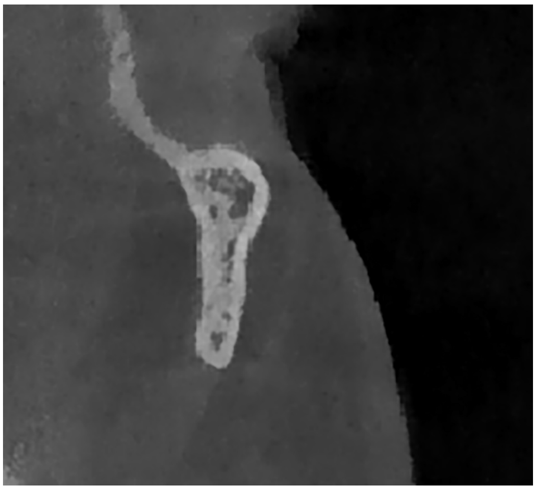

Figure 7: ZMS maturation stage D

IV. *Linear measurements* [21]*:* The magnitude of maxillary expansion was quantified by linear measurement of the distance between the anatomical landmarks at the two sides of the suture as follows:

A. Linear measurement of the distance between the greater palatine foramina (GPF) (Figure 8A).

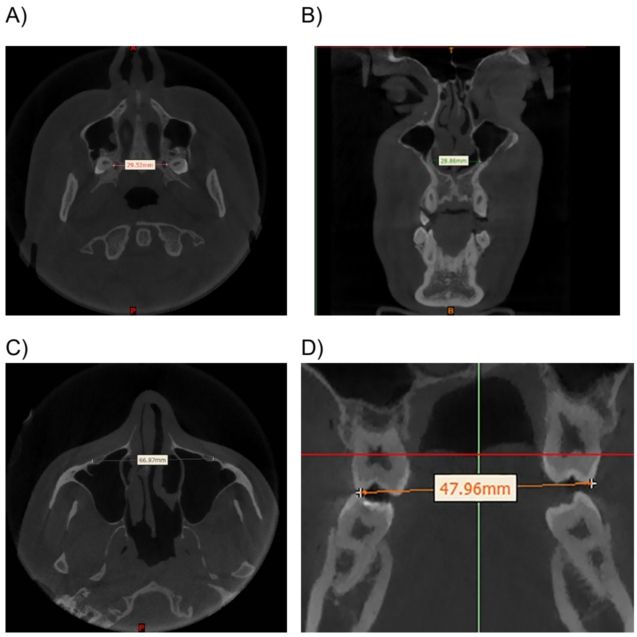

Figure 8: A) Linear measurement of the distance between the greater palatine foramina; B) Linear measurement of the nasal width; C) Linear measurement of the distance between the two infraorbital foramina (IOF); D) Linear measurement of the distance between the mesiopalatal cusp tips of the right and left maxillary first molars on the coronal view (intermolar cuspal width; IMCW)

B. Linear measurement of the nasal width (NW) (Figure 8B).

C. Linear measurement of the distance between the two infraorbital foramina (IOF) (Figure 8C).

D. Linear measurement of the distance between the mesiopalatal cusp tips of the right and left maxillary first molars on the coronal view (intermolar cuspal width; IMCW) (Figure 8D).

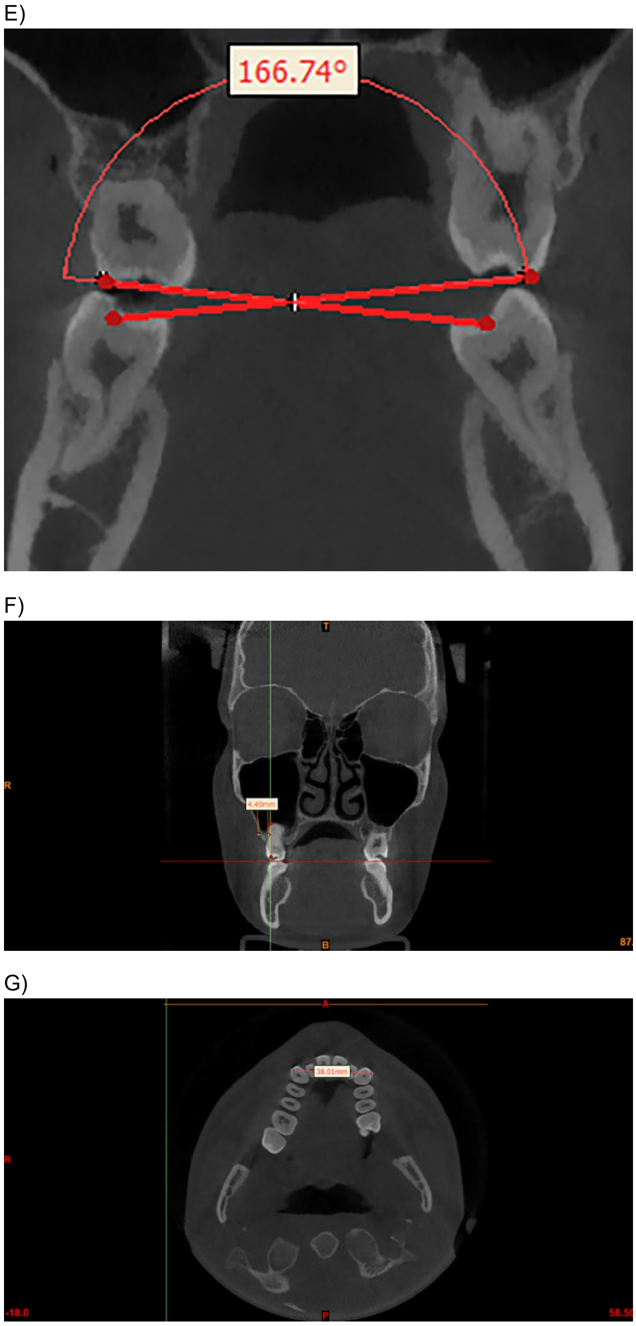

Figure 9: E) Angular measurement between the right and left maxillary first molars (intermolar angle - IAU6U6); F) Measuring the buccal cortical bone thickness at the site of upper right molar (BBTUR6); G) Linear measurement of the distance between the right and left maxillary canine cusp tips (intercanine cuspal width; ICCW)

E. Angular measurement between the right and left maxillary first molars (intermolar angle; IAU6U6) (Figure 9E)

F. Measuring the buccal cortical bone thickness at the site of upper right molar from the root surface to the most buccal bone surface (BBTUR6) (Figure 9F)

G. Linear measurement of the distance between the right and left maxillary canine cusp tips (intercanine cuspal width; ICCW) (Figure 9G)

To quantify the magnitude of skeletal expansion in each patient, the following equation was used: The estimated amount of expansion preoperatively for each patient/linear difference between T1 and T2.

To assess the intra-examiner reproducibility, all measurements were repeated by the same examiner after a 2-week interval.

An orthodontist assessed the postoperative radiographs of patients to ensure that the desired amount of expansion had been achieved based on his clinical judgment. If maxillary constriction and crossbite had been resolved, no further treatment (skeletal expansion) would be required. However, if dental expansion was not sufficient to compensate for the space shortage, and skeletal expansion was required, the hyrax appliance would be removed, adequate time would be allowed for expansion relapse, and the patient would be referred to as an oral and maxillofacial surgeon for SARPE. After completion of activation, the expander had passively remained in place for averagely 15 weeks. After the post-expansion retention period, the expander was removed, and pre-adjusted edgewise appliances were used to accomplish comprehensive orthodontic treatment.

Statistical analysis:

Data were analyzed using descriptive and inferential statistics. The intraclass correlation coefficient (ICC), the kappa coefficient, and the Bland-Altman plot were used for assessment of the reliability of the measurements. The Kolmogorov-Smirnov test was applied to analyze the normality of data distribution. Paired t-test and Monte Carlo Chi-square test were used for statistical analyses. The Pearson and Spearman's correlation coefficients were used to analyze the correlations. All statistical analyses were carried out using SPSS version 18 (SPSS Inc., IL, USA) at 0.05 level of significance.

Results

Considering the magnitude of expansion and based on the assessment of skeletal changes that occurred within 2 weeks of appliance therapy, none of the patients required surgery.

Revisions: Included additional details regarding the correlation between MPS/ZMS maturation stages and skeletal expansion. Clarified inverse relationships and their implications. Highlighted the reliability of CBCT in determining sutural maturity.

The kappa and ICC values were all over 0.95 for all variables, which indicated very high intra-examiner reproducibility ($P<0.001$). The Kolmogorov-Smirnov test showed normal distribution of all data ($P>0.05$).

Of 35 patients, 18 (51.4%) were females and 17 (48.6%) were males. The mean age of patients was 21.51±3.02 years. The Bland-Altman plot showed a mean difference of -3.8 for the GDsp, and 0.167 for the IAU6U6 between the two measurements. The mean MPSD ratio was found to be 0.62±0.09.

Table 1 presents the mean frequency of MPS and ZMS maturation stages.

Table 1: Mean frequency of MPS and ZMS maturation stages

Stage		Number	Percentage
MPS	Stage A	0	.0%
	Stage B	0	.0%
	Stage C	25	71.4%
	Stage D	9	25.7%
	Stage E	1	2.9%
ZMS	Stage A	0	.0%
	Stage B	0	.0%
	Stage C	18	51.4%
	Stage D	15	42.9%
	Stage E	2	5.7%

Table 2 presents the mean distance between the GPF and IOF, and NW at baseline and after the intervention, and their trend of change. A significant difference was noted in the linear distance between the two GPF at baseline and after the intervention (P<0.001), such that this value at baseline was smaller than that after the intervention. A significant difference was also found in the maximum NW at baseline and after the intervention (P<0.001) such that the mean NW at baseline was smaller than that after the intervention. The mean distance between the two IOF at baseline was significantly smaller than that after the intervention (P<0.001).

Table 2: Mean distance between the two GPF and IOF and NW at baseline (T1) and after the intervention (T2), and their trend of change

	T1		T2		Difference		P-value [a]
	Mean	SD	Mean	SD	Mean	SD	
GPF	34.40	2.61	35.76	2.79	1.36	.81	<0.001
NW	31.27	2.30	32.85	2.36	1.58	.89	<0.001
IOF	55.62	5.19	56.74	5.47	1.12	1.38	<0.001

[a] Paired t-test; SD: Standard deviation

Table 3 presents the mean IMCW, ICCW, IAU6U6, and BBTUR6 and their trend of change. As shown, the mean IMCW (P<0.001), ICCW (P<0.001), and IAU6U6 (P=0.040) at baseline were significantly smaller than the corresponding values after the intervention. Also, the mean BBTUR6 at baseline was significantly greater than that after the intervention (P<0.001).

No significant correlation was noted between the radiographic classification of MPS maturation stage and ZMS maturation stage (P=0.108). Significant inverse correlations were noted between the MPSD ratio and NW (ρ=-0.657, P<0.001), and distance between the two GPF (ρ=-0.723, P<0.001), MPS maturation stage and NW (ρ=-0.595, P<0.001), distance between the two IOF (ρ=-0.367, P=0.030), and distance between the two GPF (ρ=-0.690, P<0.001), and ZMS maturation and distance between the two GPF (ρ=-0.421, P=0.012). MPSD ratio and distance between the two IOF were not significantly correlated (ρ=-0.273, P=0.113). The ZMS maturation stage had no significant correlation with NW (ρ= -0.279, P= 0.104) or distance between the two IOF (ρ= -0.125, P= 0.474).

Table 3: Mean IMCW, ICCW, IAU6U6, and BBTUR6 at baseline (T1) and after the intervention (T2), and their trend of change

Variable	T1		T2		Difference		P-value [a]
	Mean	SD	Mean	SD	Mean	SD	
IMCW	53.36	3.74	59.35	3.22	5.99	2.76	<0.001
ICCW	36.29	2.55	38.06	2.70	1.77	.75	<0.001
IA U6-U6	169.03	2.75	170.46	3.93	1.43	3.96	0.040
BBT UR6	2.48	.90	2.10	.82	-.38	.26	<0.001

[a] Paired t-test; SD: Standard deviation

A significant difference was noted in MPSD ratio between males and females (P=0.009), and this variable was greater in females than males. MPS maturation stage (P=0.083) and ZMS maturation stage (P=0.197) were not significantly correlated with gender.

The difference in the distance between the two GPF was significant between males and females (P=0.034), such that this variable was greater in males than females. The distance between the two IOF (P=0.637) and NW (P=0.063) were not significantly different between males and females.

Age had a significant direct correlation with MPSD ratio (ρ=0.436, P=0.009), MPS maturation stage (ρ=0.665, P<0.001), and ZMS maturation stage (ρ=0.418, P=0.013). Age had no significant correlation with the distance between the two IOF (ρ=-0.008, P=0.965) or NW (ρ=-0.226, P=0.191). A significant inverse correlation was found between age and the distance between the two GPF (ρ=-0.393, P=0.020).

Discussion

In patients requiring RME, orthodontists encounter two main issues namely the technique of expansion (orthopedic or surgical) and the type of response (skeletal or dental) [22]. Closure of the maxillary sutures approximately occurs at ages 14-15 in females and 15-16 in males [5]. Skeletal maturation during the post-pubertal period leads to progressive closure of the MPS and subsequently increased resistance and decreased skeletal response to RME. Resultantly, separation of the two maxillary halves does not occur [21]. The majority of researchers believe that response to RME is mainly skeletal in younger patients while in older individuals, mainly dental expansion occurs [22], [24]. Although surgical maxillary expansion is possible at any time, expansion by multi-segmental osteotomy is the most unpredictable procedure among all orthognathic surgeries due to its high recurrence rate [16], [25], [26]. Recently, some studies reported successful expansion treatment in patients over 15 years of age [14], [15]. Also, some histological studies showed variations in the skeletal maturation stage (for MPS and other maxillary sutures) in patients of the same age [25], [26], [27]. Moreover, Angelieri et al. [16] showed variations in MPS maturation stage in children of the same chronological age. Thus, an individual assessment of the skeletal maturation stage can serve as an important prognostic factor for the success of RME [21]. Improvements: Strengthened discussion on inter-individual variability in sutural maturation and the role of age. Elaborated on why CBCT is superior to conventional radiographs for sutural evaluation. Addressed potential clinical applications and future research directions. Incorporated reviewer suggestions on discussing the need for validation studies in a clinical setting.

The present study evaluated the correlation of the radiographic MPS and ZMS maturation stage with the outcome of RME (linear changes between the anatomical landmarks) in patients over 15 years of age using CBCT. In the present study, the Angelieri's classifications were used for assessment of the maturation stage of MPS [16] and ZMS [7] in patients between 15 to 25 years using CBCT. The MPS maturation stages A and B were not seen in any patient. Stage C had the highest frequency (71.4%) followed by stages D (25.7%) and E (2.9%). By an increase in age, the frequency of stages D and E increased. These findings indicate that during the pubertal and post-pubertal period, the primary maturation stages of MPS and ZMS are rarely seen. This finding was in agreement with the results of Angelieri et al [16]. On the other hand, higher frequency of stage C in older patients indicates that the chronological age alone cannot serve as a suitable predictor for the success of RME. In the present study, no significant difference was noted between males and females in the mean frequency of MPS maturation stages. Some other studies also reported that stage C followed by stages D and E were the most common during the post-pubertal period [4], [28].

Evidence shows that maxillary expansion affects not only the MPS, but also many other facial sutures such as the transverse palatine suture, zygomaticotemporal suture, and zygomaticomaxillary suture [20], [29], [30]. Although the transverse palatine suture can also resist maxillary expansion, this suture is very thin, and classification of its maturation stage on CBCT scans is currently not possible [20]. Kambara [30] showed that ZMS had a similar or even more complex maturation process compared with other maxillary sutures according to histological findings. Thus, other maxillary sutures probably have a similar or less complex maturation process compared with ZMS [20]. On the other hand, due to the high thickness of ZMS, it can be clearly observed on CBCT scans unlike the transverse palatine suture and the zygomaticotemporal suture [20]. Also, radiographic assessment of ZMS showed a maturation process similar to that of MPS [16]; thus, in the present study, the maturation stages of both MPS and ZMS were evaluated.

As mentioned above, the maturation of ZMS was also evaluated in this study. Stages A and B were not seen in any patient. Stages C (51.4%), D (42.9%), and E (5.7%) were most commonly seen. By an increase in age, the frequency of stages D and E increased. The mean frequency of ZMS maturation stages was not significantly different between males and females. In the present study, in contrast to that of Kajan et al, [1] no significant correlation was found between the MPS and ZMS maturation stages. Difference between their results and ours may be due to different age groups of patients (7-25 years in their study).

MPSD ratio was the next radiographic criterion that was evaluated in the present study for assessment of the maturation of MPS. In early childhood, the MPS is in the form of a large gap between the two maxillae, filled with connective tissue. Since this tissue is not calcified, it appears radiolucent and its GD is similar to that of soft tissue. Thus, the MPSD ratio is close to zero at this time [21]. During the post-pubertal period, thin bone trabeculae start to form at the edges of the suture, and result in a mixture of non-calcified connective tissue and calcified bone tissue, increasing the MPSD ratio [21]. During the adulthood, the bone trabeculae are increasingly fused, and the suture is calcified similar to the cortical bone, yielding a MPSD ratio close to 1 [21]. The MPSD ratio has several valuable clinical applications. Its first application is to help in determining the type of treatment (RME or SARPE) in patients (adolescents and young adults) with unpredictable response to the conventional RME [21]. Its second application is for estimation of skeletal response before expansion [21]. These applications of MPSD ratio make it a valuable clinical diagnostic parameter, making the RME a short and effective treatment option with minimal unwanted consequences [21]. The mean MPSD ratio in our study population was 0.62, and approximated 1 by an increase in age of patients, indicating further ossification of the suture at older ages. In this study, the mean MPSD ratio in females was greater than that in males, which indicates greater ossification of MPS in females. Since the skeletal response to RME is pyramidal, more superior anatomical landmarks such as the IOF and more inferior anatomical landmarks i.e. NW and GPF were evaluated in this study similar to the study by Grünheid et al [21]. Selection of GPF enables the measurement of the magnitude of skeletal expansion in the posterior part of the hard palate. Also, measurement of the distance between the two GPF is reproducible [21]. The NW and the distance between the two IOF were measured in this study because they are more superior skeletal landmarks, and the skeletal effects of RME are pyramidal [31]. Measurement of the distance between the two IOF, similar to the distance between the GPF, is reproducible [21].

Of the landmarks evaluated in this study, only the distance between the two GPF had a significant inverse correlation with age. By an increase in age, the distance between the two GPF decreased due to the effect of RME. Also, the change in this distance in males was greater than that in females, which means that greater skeletal changes occur in males due to RME than in females. The distance between other landmarks was not significantly different in males and females in different ages. The present results were in agreement with the findings of Grünheid et al, [21] showing a significant correlation between the MPS maturation stage and MPSD ratio and changes in linear distances between the anatomical landmarks. They showed a significant inverse correlation between the MPSD ratio and the distance between the two GPF and IOF. Chronological age, cervical vertebral maturation stage, and MPS maturation stage had no significant correlation with the skeletal expansion measurements. They concluded that the MPSD can serve as a prognostic factor for skeletal response to RME. In the present study, a significant inverse correlation was noted between the MPSD and the distance between the two GPF and NW. In contrast to the study by Grünheid et al, [21] a significant inverse correlation was noted between the MPS maturation stage and all three anatomical landmarks. According to the present results, the MPSD and MPS maturation stage can both serve as prognostic factors for the skeletal response to RME. In the current study, in addition to MPS, the maturation stage of ZMS and its correlation with the change in distance between the anatomical landmarks were evaluated. The ZMS maturation stage had a significant inverse correlation only with the distance between the two GPF. In general, comparison of the results of different studies on this topic is not directly possible due to differences in age range of the study populations, and assessment of different landmarks, which explain the differences in the results [21].

The cervical vertebral maturation stage was not evaluated in this study because a previous study showed that this radiographic criterion had no significant correlation with skeletal response to RME [21]. As mentioned earlier, it has been claimed that after the age of 15, the sutures are ossified in most patients. Thus, RME may not be able to open the sutures, and the palatal force applied by the expanders can only cause tipping and buccal inclination of posterior teeth, and lead to significant periodontal problems [3].

Another objective of the present study was to assess the 3D skeletal-dental changes. For this purpose, dental changes (first molar and canine) and alterations in the buccal cortical plate thickness at the site of first molar (BBTUR6) were evaluated in this study to control for the side effects of the conventional RME in the study population. The results showed a significant difference between the preoperative and postoperative measurements. A reduction in the mean BBTUR6 by 0.38 mm was noted, which does not appear to be clinically important. An increase also occurred in IAU6-U6 (1.43°, which was not statistically significant), IMCW, and ICCW. The results showed that the increase in distance and tipping of the posterior teeth (5.99 mm) was greater than that of canine teeth (1.77 mm). Clinically, inter-molar dental expansion was greater than skeletal expansion while this was not the case for inter-canine expansion. This result was in agreement with previous findings [32], [33].

In general, in patients over 15 years with transverse maxillary deficiency, a CBCT scan may be requested and the radiographic criteria of the MPS and ZMS maturation and their correlation with the amount of skeletal expansion can be used to determine the most suitable treatment plan (RME/SARPE) and predict the success rate of RME. Assessment of the MPSD and its correlation with the change in distance between the landmarks (NW and GPF) following RME indicated that this parameter can serve as a prognostic factor for the success of RME in patients over 15 years of age. Also, since in the present study, all radiographic criteria (MPS and ZMS maturation stage and MPSD) had a significant correlation with change in distance between the two GPF following RME, it may be concluded that this landmark was the most predictable criterion among the tested landmarks, and had a greater correlation with the treatment success. Furthermore, the buccal bone resorption at the site of molar teeth in use of the hyrax appliance for RME in patients over 15 years did not appear to be clinically significant. Thus, this modality can be used for patients in this age range.

Considering the small sample size and single center nature of this study, clinical generalizability of the results is limited. Further studies are required to assess the correlation of radiographic criteria and skeletal response to RME in larger study populations, different races, and different age groups.

Conclusion

The skeletal radiographic criteria of the MPS and ZMS maturation stage were found to be correlated with anatomical landmarks (i.e. NW, IOF, and GPF) and MPSD ratio; thus, they can serve as prognostic criteria for the success of post-pubertal RME, and to find the most appropriate treatment plan (RME/SARPE) for patients between 15-25 years. Refinements: Restated key findings while reinforcing their significance for orthodontic treatment planning. Reiterate the study's limitations and the need for further research.

Acknowledgement

This work was supported by the Kermanshah University of Medical Science, Kermanshah, Iran.

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