ORIGINAL ARTICLE

Correlation between cervical vertebrae maturation stage and midpalatal suture maturation stage: an observational analytic study

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ABSTRACT

Introduction: Malocclusion is one of the major dental and oral health issues that can affect orofacial function, aesthetics, and psychosocial well-being. One of the treatments for malocclusion, especially class II and class III cases often associated with maxillary constriction, is Rapid Maxillary Expansion (RME). Successful RME treatment requires evaluation of the Midpalatal Suture Maturation Stage (MPSMS) using Cone-Beam Computed Tomography (CBCT). However, CBCT entails increased cost and radiation exposure. Meanwhile, the Cervical Vertebrae Maturation Stage (CVMS) serves as a biological indicator of skeletal growth. Unlike MPSMS, CVMS can be assessed using cephalograms, which are routinely used in orthodontics. This study aims to analyze the correlation between CVMS and MPSMS. **Methods**: This study used an observational analytic research design with a consecutive sampling method. Secondary data of cephalogram and CBCT images ofc 47 subjects aged 8–19 years were analyzed. CVMS was assessed using the Baccetti method, while MPSMS was evaluated using the Angelieri method. The Spearman rank correlation test was applied to assess the correlation between the two variables. This research was conducted at the Department of Orthodontics, Faculty of Dentistry, Trisakti University from September to December 2024. **Results**: The results showed a distribution of MPSMS stages (A to E) corresponding to increasing CVMS stages (CS1 to CS5). Spearman correlation analysis revealed a strong and highly significant positive correlation between CVMS and MPSMS, with a correlation coefficient of r=0.640 and p<0.001, consistent across the entire sample and within gender subgroups. **Conclusion**: There is a significant positive correlation between cervical vertebrae maturation stage and midpalatal suture maturation stage.

KEYWORDS

Cervical vertebrae, midpalatal suture, maturation stage, palatal expansion technique

INTRODUCTION

Orthodontics is a branch of dentistry that deals with facial and jaw growth, tooth development and occlusion, and the diagnosis and treatment planning of malocclusion. Malocclusion is a deviation from normal occlusion and is defined as an abnormal relationship between the teeth.[1] Malocclusion not only affects orofacial functions such as chewing, speaking, and swallowing, but can also cause psychosocial effects due to its impact on facial aesthetics. This highlights the importance of establishing an accurate diagnosis of malocclusion for effective orthodontic treatment planning.[2,3]

Maxillary transverse deficiency is a complex dentofacial deformity that may be associated with several conditions, including class II and class III malocclusions, which are frequently related to maxillary constriction, altered tooth inclination, posterior crossbite, occlusion disharmony, altered tongue posture and mouth breathing.[4,5] These conditions can be corrected using Rapid Maxillary Expansion (RME), an orthodontic appliance used for maxillary transverse deficiency by opening the sutures midpalatal.[6]

Indications for RME include severe maxillary constriction, unilateral or bilateral posterior crossbite involving multiple teeth, anteroposterior discrepancies, class II malocclusions with excessive maxillary growth, borderline skeletal Class III malocclusions, pseudo-Class III malocclusions, and cleft lip and palate with maxillary collapse.[7,8] The ideal age for RME is a up to 16 years in females and 18 years in males. However, individuals beyond those ages have been reported to exhibit no signs of midpalatal suture fusion. This suggests that the developmental stage of midpalatal suture fusion can vary significantly and may not correspond directly to chronological age.[9]

Midpalatal Suture Maturation Stage (MPSMS) is a classification method that determines the stage of midpalatal suture maturation. Initial assessments of the midpalatal suture were performed using occlusal radiographs. However, occlusal radiography is not considered reliable for evaluating midpalatal suture morphology, as the vomer and external nasal structures often superimpose the midpalatal area, potentially leading lead to misinterpretation of the radiographs regarding the fusion of the midpalatal suture.[10,11]

With technological advances, Cone-Beam Computed Tomography (CBCT) has enabled three-dimensional evaluation of maxillofacial structures. Angelieri et al. introduced a CBCT method to evaluate the MPSMS more accurately. CBCT is a technology that utilizes X-rays to produce high-resolution, three-dimensional images of the internal anatomical structures, particularly the skull and jaw bones. The advantages of CBCT include high image resolution and greater diagnostic accuracy in assessing the bone structure.

However, CBCT also has limitations: it is costly, offers limited soft tissue visualization and involves relatively high radiation exposure.[12] Orthodontic indications for CBCT include impacted teeth, angulation, morphology, and root resorption, supernumerary teeth, maxillary transverse dimension, jaw expansion, cleft lip and palate, TMJ morphology and pathology causing malocclusion, jaw pathology, respiratory tract morphology, vertical malocclusion, obstructive sleep apnea, and orthodontic implant placement.[13]

Lateral cephalogram is a radiographic technique commonly used in orthodontics that utilizes X-rays to produce two-dimensional images. Lateral cephalometric analysis is essential for assessing the facial skeleton, establishing a diagnosis, evaluating the shape of the face, planning orthodontic treatment, and monitoring the development of the skull and facial bone structure. The advantages of a cephalogram are that it provides a fairly detailed picture of the facial bone structure, including the relative position of the teeth, jaws, and skull bone. It is also cost-effective, and has relatively low radiation exposure.

The Cervical Vertebrae Maturation Stage (CVMS) is a well-established biological indicator used to assess the peak of puberty and predict further development of bone growth.[14] CVMS is particularly useful in determining the optimal time for intervention, especially in cases that require growth modification such as functional appliances, jaw expansion, headgear, skeletal anchorage devices, and orthognathic surgery planning.[15] Baccetti et al. introduced five new and simpler cervical vertebrae stages, namely CVMS I through CVMS V.[16]

There is considerable variability in the developmental stage of midpalatal suture fusion which is often unrelated to chronological age, therefore we can use CVMS to predict MPSMS seen on a cephalogram which is a routine radiograph in the field of orthodontics. If CVMS can reliably estimate MPSMS, this will benefit clinical applications.[17] The novelty is to find a method for predicting MPSMS without using CBCT and provide a more affordable, lower-radiation alternative for patient populations in settings such as Jakarta. Based on the background above, this study aims to evaluate the correlation between CVMS and MPSMS.

METHODS

This study was an observational analytic study with a consecutive sampling design. Researchers collected 47 cephalograms and CBCT scans, which were used as samples to analyze the stages of cervical vertebrae maturation and midpalatal suture maturation. Sequential observations were then performed to assess the relationship between CVMS and MPSMS. A total of 15 samples were randomly selected and re-evaluated after one month to conduct an agreement test and minimize interpretation bias. The inclusion criteria were patients who had never undergone orthodontic treatment and had simultaneously obtained cephalogram and CBCT data. Exclusion criteria included patients with pathological conditions and patients with trauma to the neck and palate.

The tools used in this study included a Dell Precision T7810 computer (Windows 7 Ultimate, Intel(R) Xeon(R) CPU ES-2623 v3, 2013, China) for sample selection, a MacBook Air M1 laptop (version 14.5, 2021, USA) to open and capture sample images, an iPad Pro (version 18.1.1, 2021, USA) for tracing, an Apple Pencil (2nd generation, 2018, USA) for manual tracing of CVMS and MPSMS, the Goodnotes Application (version 5.0, 2022, UK) for annotation. SPSS data analysis software (version 29.0, 2022, USA) was used for statistical analysis, i-Dixel 2.2 software for imaging processing, a Veraviewepocs 2D lateral cephalogram machine (90kV, 6.8mA, 4.8sec, DAP 10.8mGycm2, 2000s, Japan), and a Morita 3D CBCT machine (Accuitomo 170, axial view, FOV 100x100, slice thickness 2mm, 2011, Japan) to acquire CBCT images. The materials used were radiographic outputs from cephalograms and CBCTs.

Determination of the cervical vertebrae maturation stages (CVMS I-V) was based on the Baccetti method. CVMS stage I is characterized by flat inferior borders on all three cervical vertebrae, with the possible exception of a concavity at the inferior border of C2; the bodies of C3 and C4 are trapezoidal, where the superior borders of the vertebral bodies taper from posterior to anterior. CVMS stage II shows concavities at the inferior borders of C2 and C3; the bodies of C3 and C4 may be either trapezoidal or horizontally rectangular. In CVMS stage III has concavities at the inferior borders of C2, C3, and C4; with the bodies of C3 and C4 appearing horizontally rectangular. CVMS stage IV also presents concavities at the inferior borders of C2, C3, and C4; but at this stage, at least one of the bodies of C3 or C4 is rectangular, while the other remains horizontally rectangular. CVMS stage V include concavities at the inferior borders of C2, C3, and C4; with at least one of the bodies of C3 or C4 appearing vertically rectangular and the other is square (Fig. 1).[16] Two investigators were involved in evaluating the data: S.N., an undergraduate student in faculty of dentistry, and S.P.A.A., a dental radiology specialist.

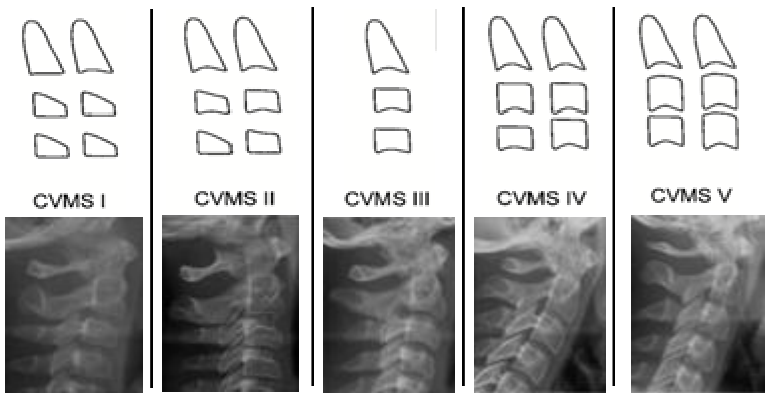

Figure 1. Cervical vertebrae maturation stage according to the Baccetti method[16,17]

Determination of the midpalatal suture maturation stages (Stages A-E) followed the Angelieri method. Stage A, the midpalatal suture appears as a straight line with high density (unfused suture). Stage B, the midpalatal suture appears as a curved line with high density (unfused suture). Stage C, the midpalatal suture appears as two curved lines parallel to each other (beginning of suture fusion). Stage D, the midpalatal suture appears as two curved lines on the front of the palate that disappear toward the back (partial suture fusion). Stage E, complete absence of the midpalatal suture (complete suture fusion) (Fig. 2).[6,18]

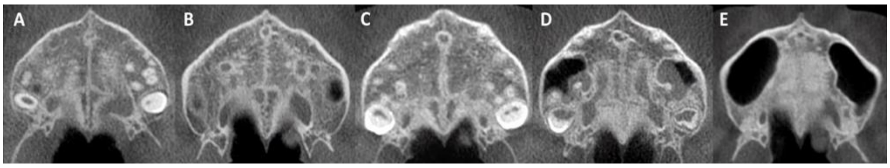

Figure 2. Midpalatal suture maturation stage according to the Angelieri method[6,18]

Weighted Kappa was used to assess inter-rater agreement between S.N. and S.P.A.A. in the interpretation of CVMS and MPSMS. Agreement was evaluated at a single time point. If disagreement occurred between the two raters and was ≤20%, the result was accepted. If disagreement exceeded 20%, re-examination was conducted. Spearman's rank correlation test was used to analyze the correlation between CVMS and MPSMS. The level of significance determined for this study was $p<0.05$ and a correlation coefficient greater than 0.8 was considered strong.

RESULTS

The Weighted Kappa test was used to assess the inter-rater agreement in observing skeletal maturation using CVMS and midpalatal suture maturation using MPSMS. The results showed a Weighted Kappa value of 0.894.The distribution of CVMS and MPSMS observed in the samples is presented in Table 1. The sample consisted of 47 individuals aged 8-19 years. Among CVMS classifications, the most frequent was the fourth cervical stage, while for MPSMS, stage C was the most commonly observed.

Table 1. Distribution of samples based on CVMS and MPSMS

Age	n	CVMS (n)					MPSMS (n)				
		CS1	CS2	CS3	CS4	CS5	A	B	C	D	E
8-10	11	4	1	-	5	1	2	3	5	1	-
11-13	12	5	1	3	1	2	4	6	2	-	-
14-16	13	2	2	5	4	-	1	5	4	3	-
17-19	11	-	-	1	7	3	-	-	4	5	2
Total	47	11	4	9	17	6	7	14	15	9	2

The distribution of MPSMS stages across CVMS classifications demonstrates a gradual pattern of midpalatal suture maturation and fusion (from stage A to E) as cervical vertebrae maturation progresses (from CS1 to CS5), as shown in Table 2. Again, the fourth cervical stage was the most frequent CVMS stage, and MPSMS stage C was the most frequent among all categories.

Sample distribution according to the results of skeletal maturation assessment using CVMS and the results of midpalatal suture maturation assessment using MPSMS stages by gender is shown in Table 3. The majority of male and female participants were classified under the fourth cervical stage of CVMS. Similarly, stage C of MPSMS was the most common across both male and female.

Table 2. Distribution of MPSMS according to CVMS (n/%)

CVMS	MPSMS					Total
	A	B	C	D	E	
CS1	4/36,4	6/54,5	1/9,1	-	-	11
CS2	-	3/75	1/25	-	-	4
CS3	2/22,2	3/33,3	3/33,3	1/11,1	-	9
CS4	1/5,9	1/5,9	8/47	6/35,3	1/5,9	17
CS5	-	1/16,7	2/33,3	2/33,3	1/16,7	6
Total	7	14	15	9	2	47

Table 3. Distribution of CVMS and MPSMS samples by gender

CVMS	Gender				Total	%
	Male		Female			
	n	%	n	%		
CS1	7	26,9	4	19,1	11	23,4
CS2	2	7,7	2	9,5	4	8,5
CS3	4	15,4	7	33,3	11	23,4
CS4	9	34,6	8	38,1	17	36,2
CS5	4	15,4	0	0	4	8,5
Total	26	100	21	100	47	100

MPSMS	Gender				Total	%
	Male		Female			
	n	%	n	%		
A	4	15,4	3	14,3	7	14,9
B	6	23,1	8	38,1	14	29,8
C	8	30,8	7	33,3	15	31,9
D	7	26,9	2	9,5	9	19,1
E	1	3,8	1	4,8	2	4,3
Total	26	100	21	100	47	100

Scatter plots were used to visualize the correlation between CVMS and MPSMS. The correlation between CVMS and MPSMS based on all samples was linear (Fig. 3A), while the correlation for males was also linear (Fig. 3B), and for females was monotonic (Fig. 3C).

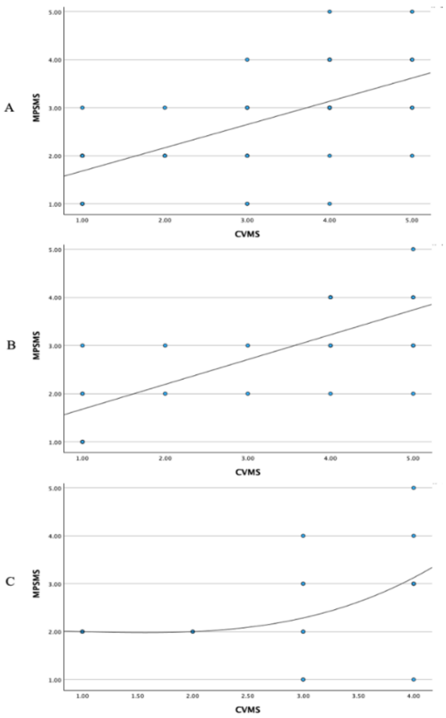

Figure 3. Scatterplot graphs showing the relationship between CVMS and MPSMS. (A) All samples (B) Male (C) Female

The Spearman rank correlation test was conducted to determine the correlation between CVMS and MPSMS. The results for male, female, and total samples are shown in Table 4. Overall, a strong and statistically significant correlation was found between CVMS and MPSMS across all groups.

Table 4. Results of the Spearman rank correlation test between CVMS and MPSMS

			MPSMS
CVMS	Male	Correlation Coefficient	0,672
		P Value	<0,001
		N	26
	Female	Correlation Coefficient	0,514
		P Value	0,017
		N	21
	Total	Correlation Coefficient	0,640
		P Value	<0,001
		N	47

DISCUSSION

This study was an observational analytic study with a consecutive design that used secondary data in the form of cephalograms and CBCT scans as research samples. Data were collected from 2012 to 2024. The selected age range of 8-19 years represents a period of active growth in children and adolescents in Indonesia,during which significant changes occur in the structure of the facial bones and jaws.[19] In this age range, individuals undergo several important stages in their biological development, including the growth of teeth and facial skeletons, which form the basis for determining effective orthodontic treatment.[20] The age range of subjects in this study aligns with that used by Liu et al., who included participants aged 8-20 years.

The distribution of samples based on CVMS and MPSMS (Table 1) is consistent with the findings of Liu et al., Luz et al., and Jang et al. Liu et al. applied the same age grouping approach used in this study, in which 8-10 years represents the mixed dentition period, 11-13 years corresponds to the early-to-peak puberty, 14-16 years marks the post-peak puberty, and 17-20 years represents the age range typically used for adult orthodontic treatment planning. These groupings are base on differing treatment strategies for each developmental stage. In contrast, Luz et al.'s did not use age grouping and only included participants aged 11-14 years, whereas Jang et al. followed the same age grouping as Liu et al.'s study, which is also applied in this study. The sample size in this study is smaller, primarily due to ethical limitations regarding radiation exposure, CBCT imaging involves higher radiation doses, so scans could not be obtained for all orthodontic patients unless clinically indicated.[21]

The distribution of MPSMS stages according to CVMS (Table 2) also aligns with the studies of Liu et al., Luz et al., and Jang et al., all of which demonstrated a gradual progression of midpalatal suture maturation and fusion along with advancing cervical vertebral stages. While Liu et al., Luz et al., and Jang et al., used the CVMS classification system with stages CS1-CS6 (Baccetti, 2002), the present study used a more recent five-stages version (CS1-CS5) proposed by Baccetti in 2005. This updated classification offers clearer morphological transitions between stages, which helps reduce ambiguity in inter-rater interpretation.[21]

The distribution of CVMS and MPSMS by gender (Table 3) is in agreement with Jang et al., who also observed a balanced distribution of male and female participants. Statistical analysis using the Spearman rank correlation test demonstrated a strong correlation between CVMS and MPSMS, with a correlation coefficient value of r=0.640 (Table 4), confirming a significant relationship between two variables.[22] This finding is consistent with previous research by Luz et al.[9] with a value of r=0.6916; Mahdian et al. reports the value of r=0.691 in female and r=0.754 in male participants. However, Mahdian et al. did not report the overall correlation for all samples.[23]

This study is also in line with research by Liu et al.[6], who found a strong correlation with a value of r=0.867 using a larger sample size and a different classification strategy. They grouped CS1-CS6 into three broader categories (prepubertal stage, pubertal stage, and postpubertal stage) and the midpalatal suture stages A-E into no fusion of the midpalatal suture stage, partial or complete fusion of the midpalatal suture, and transitional stage as it implies the beginning of fusion of the midpalatal suture. Jang et al. reported an even higher correlation (r=0.874) with a larger sample size and used a different CVMS classification system (CS1-CS6). It is important to note that racial and ethnic variations were present across all studies.[24]

This study confirms that there is a strong relationship between CVMS and MPSMS, suggesting that CVMS potentially can be used as a reliable indicator for predicting MPSMS. The Spearman rank correlation revealed stronger correlations in male participants than in females, consistent with previous studies. The difference in correlation results between males and females may be attributed to biological differences in growth patterns. Since individuals in active growth phases have a greater chance of success in RME treatment because their bones are more responsive to expansion.[25,26]

The limitation of the study is the use of a non-probability sampling method with a cross-sectional design. Future research should adopt a prospective study design and consider simplifying MPSMS stages into two categories such as pre-fusion and fusion, as this may enhance clinical applicability.

CONCLUSION

It was concluded that there is a significant and strong correlation between CVMS and MPSMS in the Jakarta population aged 8–19 years. Based on the results of this study, the clinical implication of this study is that RME is recommended during CVMS stages CS1 to CS3, with CS2 being the most optimal stage. However, RME is not recommended for patients in CVMS stages CS4 and CS5.

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