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Correlation of skeletal development and midpalatal suture maturation

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Abstract

Objectives The aim of our study is to determine the relationship between MPS maturation and CVM stage determined from CBCTs.

Materials and methods CBCT images of 130 individuals (75 females, 55 males) with a mean age of 15.04 ± 3.11 (9.56–25.05 years) were analyzed. Images were analyzed using the i-CAT Vision software program. The cephalometric images to be examined were also obtained from the same CBCT images with the ImageJ program. The correlation between MPS and CVM stages was evaluated using the Spearman correlation test. The relationship between the skeletal developmental stage and MPS maturation, as assessed by the CVM method, was evaluated with the positive likelihood ratio.

Results Significant correlations were found between CVM and MPS maturation stages. Positive LHR values of cervical vertebral stages were obtained to define the maturation stages of the midpalatal suture. LHR values greater than ten were found between CS2, CS5, and CS6 and maturation stages B, D, and E, respectively. A 15–30% correlation was observed between CS3 and CS4 maturation stages B and C, respectively. A positive correlation of 15% was found between CS3 and stage C.

Conclusion MPS fusion is more likely to occur after CS4. The correlation between the CVM and MPS maturation stages is significant ($r = 0.858$). CVM stages CS2, CS4, and CS6 can be a preliminary indicator for MPS stages B, D, and E, respectively. CS5 shows that MPS fusion has occurred partially or completely.

Clinical relevance A significant relationship exists between skeletal developmental stages and suture maturation.

Keywords CBCT, Cervical vertebral maturation, Midpalatal suture, RME

Introduction

Rapid maxillary expansion (RME) is a frequently preferred approach in orthodontic treatment. The literature provides many indications, such as increasing the airway, gaining space, correcting the posterior cross-bite, eliminating occlusal discrepancies, and reducing the dark buccal corridors that may affect smile aesthetics [1].

Opening the midpalatal suture (MPS) with heavy forces is the expected effect of RME. However, opening a fully fused MPS with conventional appliances is impossible. Thus, patients whose growth and development are completed with increasing fusion with age are approached cautiously, and RME is preferred in younger individuals [2–4]. Surgical support or skeletal anchorage is required to provide expansion in older patients [5]. Circumstances in which sutural opening will be successful depending on the trial and error method, where various complications such as tissue damage, gingival recession, and falling of the abutment teeth may occur [6]. Thus, it will be

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beneficial for clinicians to be able to diagnose the separability of MPS.

Angelieri et al. [4] suggested that MPS maturation can be classified into five stages (stages A–E) by observing cone-beam computed tomography (CBCT) images. The possibility of failure of RME protocols can be determined using CBCT, but taking these images routinely from patients is not ethically appropriate. Cephalometric radiographs for orthodontic diagnosis can detect cervical vertebral maturation (CVM) and the skeletal developmental stage [7]. Suppose the degree of relationship between cephalometric radiographs and MPS maturation can be determined. In that case, the approach to the treatment of RME can be directed to surgery without the need for additional radiographs.

Our study aims to determine the relationship between the CVM stage and MPS maturation by utilizing CBCT images to reduce the need for additional diagnostic methods.

Materials and methods

CBCT images of 130 individuals (75 females, 55 males) with a mean age of 15.04 ± 3.11 (9.56–25.05 years) were taken from the faculty archives and analyzed. Ethics committee approval was obtained from Bolu Abant Izzet Baysal University Clinical Research and Ethics Committee.

Images were analyzed using the i-CAT Vision (Imaging Sciences International, Hatfield, PA, USA) software. The steps described by Angelieri et al. [4] were considered for imaging MPS sections (Fig. 1) and adjusting the patient's head position in different planes (Fig. 2).

Cephalometric images were obtained from the same CBCT images with the ImageJ program. The images were cropped, and only the cervical vertebra region was taken. No changes were made to the contrast or the brightness of these images. Images on PowerPoint with a black background were classified by one researcher in a dark room. The CVM stage was determined according to the protocol described by Bacetti et al. [8]. If the researcher was in a dilemma in determining the maturation stage, a three-dimensional image of the suture was created with 3D Slicer [9], and a detailed examination was performed (Fig. 3). Radiographs with better image quality, where MPS could be easily classified and the CVS stage could be clearly distinguished, were included in the study group.

Statistical analysis

The sample size was calculated using the G*power 3.1.9.7 program (Heinrich-Heine-University, Düsseldorf, Germany) to determine the minimum correlation of $r=0.4$ in response to an alpha of 0.05 and a power of 80%. The required number of patients was determined to be 46 for each sex [10]. Statistical package program SPSS V. 26.0

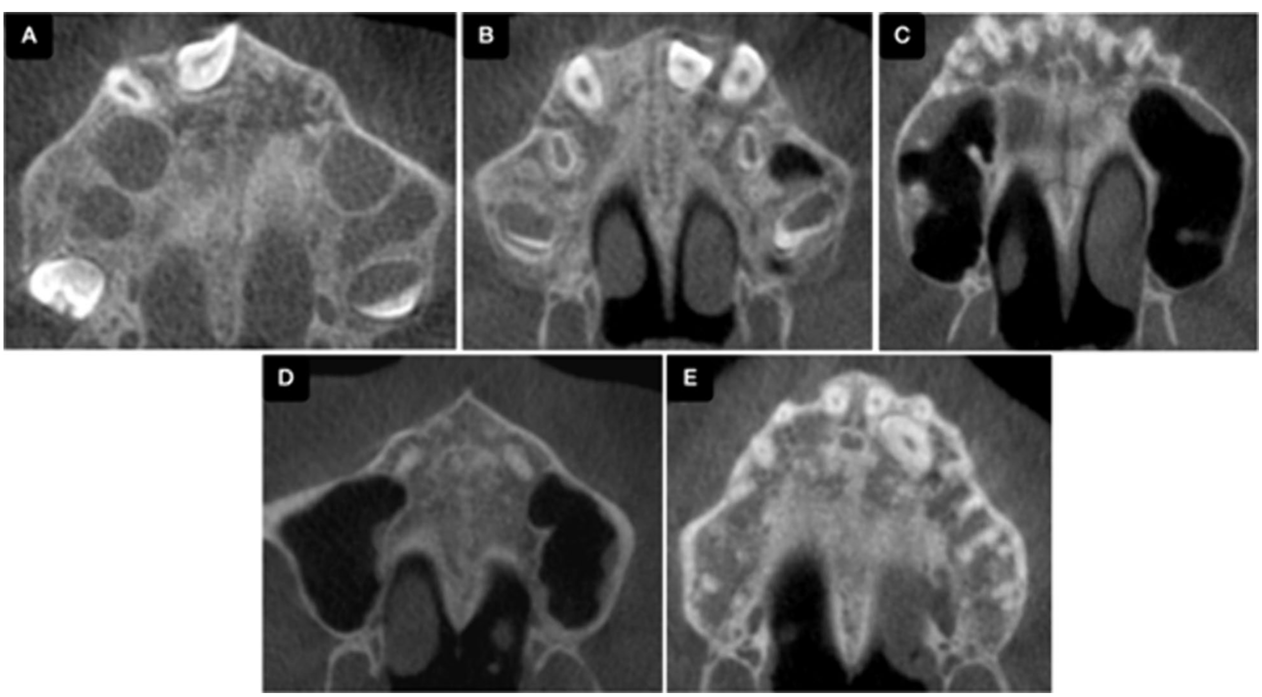

Fig. 1 Maturation stages of the MPS. **A** Straight suture borders with little or no interdigitation, **B** a notched high-density line at the midline with radioopaque borders, **C** two straight high-density lines with close proximity and some low-density areas in between, **D** sutural interdigitation is mostly completed with high-density lines at the midline, and **E** sutural fusion is completed. MPS cannot be identified

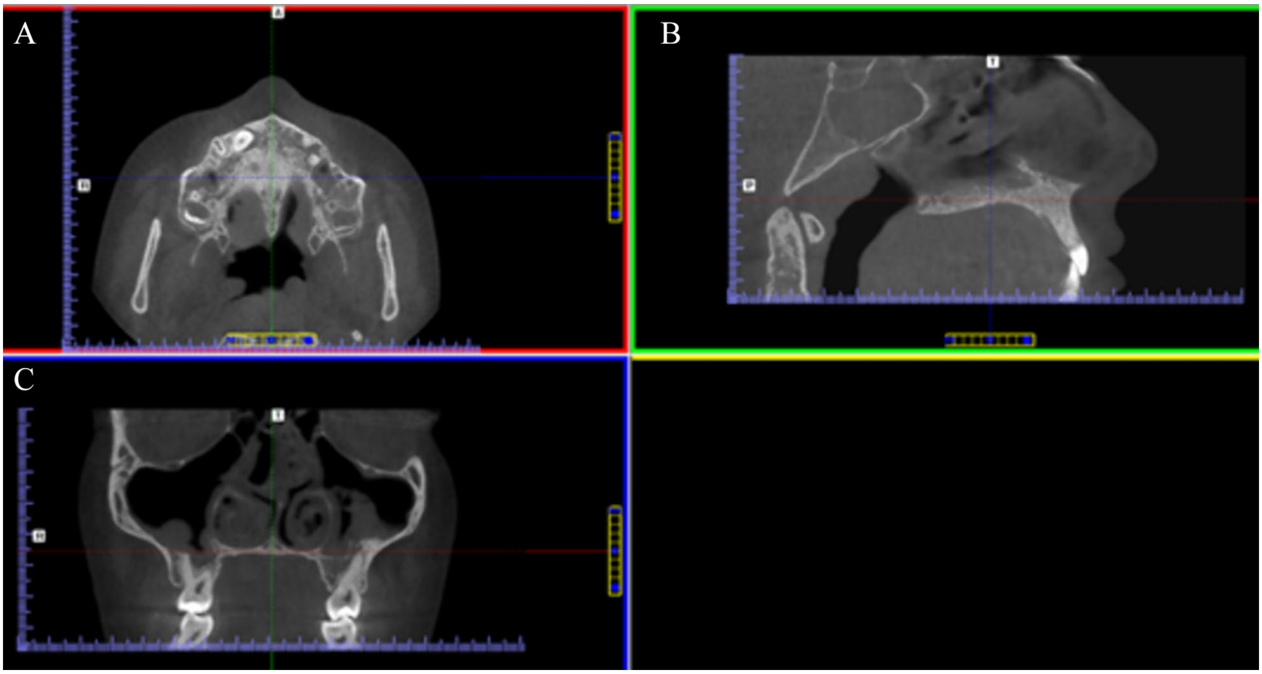

Fig. 2 Head reorientation and setting of the axial cross-sectional planar view: **A** axial section; **B** sagittal section; **C** coronal section

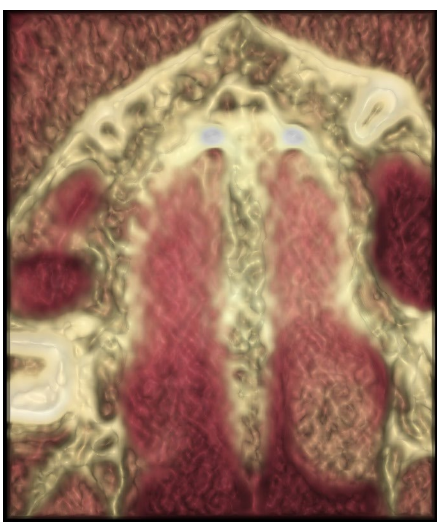

Fig. 3. 3D reconstruction of the suture using 3D Slicer

(Statistical Package for the Social Sciences, IBM, NY, USA) was used to evaluate the data. Shapiro–Wilk analysis was used to analyze the equality of the variance, and the data were distributed normally. Spearman correlation test was assessed for correlation between CVM and MPS maturation stages. To check within-observer reliability, the investigator reclassified the maturation stages of 30 randomly selected patients 1 month later. The measurement error was evaluated with the kappa test, and the results were interpreted with the Landis and Koch method [11].

The relationship between the skeletal developmental stage and MPS maturation, as assessed by the CVM method with the positive likelihood ratio (LHR). The LHR for a positive result indicates the probability of the condition being diagnosed (MPS maturation) increases when a test is positive (specific CVM stage) [12]. LHRs above 10 indicate the significance and often define an increase in disease probability (strong association) [13]. A positive LHR of 10 or more was considered a reliable indicator for any maturation stage. The statistical significance value was taken as $p < 0.05$.

Results

The analysis applied to evaluate the consistency between the observations showed that Kappa values for CVM and MPS were significantly higher (Kappa coefficient: 0.827 and 0.956; $p < 0.001$). According to the Landis and Koch scale, weighted kappa coefficients showed a high level of agreement [11].

The distribution of different skeletal developmental stages according to MPS maturation stages and the demographic characteristics of the subjects at different maturation stages are given in Table 1. A significant relationship was found between skeletal developmental stages and suture maturation ($P < 0.01$, Spearman $r = 0.858$).

Table 1 Distributions of the MPS maturation stages according to the cervical vertebra stages ($N=130$)

Skeletal maturation stages						MPS maturation stages					Correlation coefficient
CVM	**Total**	**F**	**M**	**Mean**	**STd**	**A**	**B**	**C**	**D**	**E**	**0.858***
CS1	1	–	1	–	–	1	–	–	–	–	
CS2	8	4	4	10.09	0.25	3	5	–	–	–	
CS3	40	20	20	12.91	1.04	1	21	18	–	–	
CS4	33	21	12	14.58	1.56	–	4	22	7	–	
CS5	25	14	11	16.42	1.8	–	–	4	20	1	
CS6	21	16	7	19.77	2.94	–	–	–	10	13	

Correlations between MPS maturation stages and cervical vertebra stages are quantified through the Spearman rho correlation coefficient

F Female; *M* male

* $p<0.001$

Table 2 LHRs for the cervical vertebra stages for the diagnosis of MPS maturation stages ($N=130$)

Skeletal Maturation stages	Midpalatal Suture stages				
CVM	**A**	**B**	**C**	**D**	**E**
CS1	–	–	–	–	–
CS2	0.822	29.286	–	–	–
CS3	–	3.684	1.599	–	–
CS4	–	0.502	3.909	0.676	–
CS5	–	–	1.023	10.054	0.273
CS6	–	–	–	0.314	10.77

LHR likelihood ratio

Table 3 Chronologic age for subjects at the different MPS maturation stages

Midpalatal suture stages	Chronologic age (Y)				
	N	**Mean**	**Std. dev.**	**Minimum**	**Maximum**
Females					
A	1				
B	13	12.25	1.09	10.09	13.55
C	28	13.68	1.41	11.62	16.96
D	25	16.33	1.91	12.72	19.68
E	8	20.62	3.06	16.31	25.05
Males					
A	3	9.79	0.31	9.56	10.14
B	15	12.95	1.17	10.35	15.32
C	19	14.33	1.58	11.90	17.10
D	12	16.81	0.85	15.20	18.15
E	6	21.99	1.72	20.07	24.32

Positive LHRs of cervical vertebral stages are given in Table 2 to identify MPS maturation. LHR values higher than ten were found between skeletal development stages CS2, CS5, and CS6 and suture maturation stages B, D, and E, respectively. A 15–30% correlation was observed between CS3 and CS4 and between B and C maturation stages, respectively [13]. A positive relationship of 15% was found between CS3 and CS5 and stage C. The distribution of midpalatal suture maturation stages by gender according to chronological age is given in Table 3.

Discussion

Transversal maxillary constriction is a critical problem frequently encountered and must be resolved first. The literature has no consensus on the safe age limit for maxillary expansion. The maturation stage of the MPS differs between individuals according to chronological age. Thus, predicting the successful outcome of RME protocols is challenging, especially in young adults [3, 14]. CBCT is a reliable method for describing MPS maturation and predicting RME. [4]. However, only some patients can obtain CBCT images, because it may cause more radiation and increase patient costs.

The onset of fusion of the midpalatal suture has been associated with the rate of skeletal development and the transverse growth pattern of the maxilla [3]. The skeletal developmental stage is evaluated from hand-wrist [15] or cephalometric radiographs (CVM) [8]. Sagittal images of cervical vertebrae indicate the skeletal developmental stage [16].

Pichai et al. [17] reported that developmental stage detection by vertebral analysis from cephalometric radiographs reduces radiation exposure and is as valid as hand and wrist radiographs. Our study used the 6-stage method defined by Baccetti et al. [8]. Thus, the phase separation can be made quickly.

Lee and Mah [18], Mahdian et al. [19], Jang et al. [20], and Angelieri et al. [21] reported a correlation between CVM and MPS maturation stages. In our study, a high correlation coefficient was observed between CVM and MPS stages, revealing that MPS maturation was associated with skeletal growth. However, for the evaluation of MPS maturation stages, positive likelihood values of 10 and above, which can be considered a reliable diagnostic tool for a particular CVM stage, were found to be variable [22].

When positive LHR values of each CVM stage were analyzed to evaluate each stage of MPS maturation, the results showed that CS2, CS5, and CS6 could be used to reliably identify stages B, D, and E, respectively. Another study observed that only CS2 and CS3 could be used for the reliable identification of stages B and C [21].

In the last two stages of MPS maturation (D and E), mucosal ulceration, prominent buccal tipping of posterior teeth, severe pain, and gingival recession and external root resorption, which are complications of an unsuccessful RME application, may be encountered. Thus, surgical support may be a better approach for maxillary expansion [23–27].

We should note that stages D and E, which show MPS fusion before the CS4 stage, were not observed in the same way as in the previous studies [19–21]. In addition, Kwak et al. [28] showed that, similar to our research, suture fusion in patients with CS5 and CS6 did not occur in all cases. Our study observed MPS stage C in 16% of postpubertal subjects in CS5. This finding explains why the midpalatal suture separates in some postpubertal patients. Studies of human autopsies have shown significant interindividual differences in the onset of closure and progression of closure with age [3, 29, 30].

Regarding the age of the patients, our study found that MPS fusion started at the age of 15 in males and 12 in females. Mahdian et al. [19] reported that fusion began at 12 in females and 13 in males, while Jang et al. [20] reported that it started at 11. In addition, Angelieri et al. [21] observed suture fusion in patients aged 14–18 years. Studies support that suture maturation is more strongly associated with skeletal development than age.

Although the exact correspondence of the stages cannot be said, there is a strong relationship between the CVM and MPS maturation stages when the results of our study are examined. It has also been shown that the suture is not fused before CS4 and that palatal expansion can be performed without surgery. Clinicians should remember that the midpalatal suture is not the only factor in the expansion achieved with conventional RME procedures. It should not be forgotten that other sutures, such as zygomaticotemporal, zygomaticofrontal, and zygomaticomaxillary sutures with which the maxilla is in contact, also play a role in the effectiveness and success of the treatment [31, 32].

The correlational nature of the statistical analysis and the different numbers of patients between the CVS groups in the sample group are the main limitations of this study. Further studies with larger study groups can provide valuable insights into this subject. Also, artifacts may appear on radiographs of young children during the initial phases of skeletal development. The CVM method exhibits low consistency among different observers when assessing variations in vertebral body shapes. Additionally, the timing between CVM phases remains not entirely clear.

Conclusion

The study's results for the diagnostic value of the skeletal developmental stage for assessing MPS maturation are summarized below.

1. CVM stages CS2, CS4, and CS6 can be preliminary indicators for MPS stages B, D, and E, respectively.
2. In CVM, CS5 indicates partial or complete MPS fusion has occurred (stages D and E).
3. For postpubertal patients, 16% of patients in CS5 indicate stage C, where RME would be more successful. For this reason, it is crucial to evaluate the midpalatal suture individually.
4. In our study, fusion status was not detected in the midpalatal suture before the age of 12 in women and before the age of 15 in men.
5. Fusion of the midpalatal suture is more likely after the CS4 stage determined for the skeletal development stage. A significant relationship exists between skeletal developmental stages and suture maturation ($r = 0.858$).

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None.

Author contributions
Y.H. and M.B. designed the study. Y.H. collected data and entered it. Y.H. and M.B. made the analysis and interpretation. Y.H. and M.B. conducted a literature review. Y.H. wrote the main manuscript text. Y.H. prepared figures. All authors reviewed the manuscript.

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Availability of data and materials
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The Clinical Research and Ethics Committee of Bolu Abant Izzet Baysal University approved all study procedures (Decision No: 2023/69). This study was carried out in accordance with the Declaration of Helsinki. Informed consent was obtained from all volunteers and/or legal guardian(s).

Competing interests
The authors declare no competing interests.

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