Original Article

Relationship between maturation indices and morphology of the midpalatal suture obtained using cone-beam computed tomography images

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Objective: The purpose of this study was to determine whether predicting maturation of the midpalatal suture is possible by classifying its morphology on cone-beam computed tomography (CBCT) images and to investigate relationships with other developmental age indices. **Methods:** The morphology of the midpalatal suture was assessed by using CBCT images of 99 patients. Axial plane images of the midpalatal suture were classified into five stages according to the classification scheme. To make the assessment more accurate, the morphology and fusion of the midpalatal suture were additionally investigated on coronal cross-sectional planar images and volume-rendered images. Bone age was evaluated using the hand and wrist method (HWM) and cervical vertebrae method (CVM); dental age (Hellman's index), sex, and chronological age were also assessed. To evaluate relationships among variables, Spearman's rho rank test was performed along with crosstabs using contingency coefficients. **Results:** The HWM and CVM showed strong correlations with the maturation stage of the midpalatal suture, while other indices showed relatively weak correlations ($p < 0.01$). Through crosstabs, the HWM and CVM showed high association values with CBCT stage; the HWM demonstrated slightly higher values ($p < 0.0001$). Based on the HWM, the midpalatal suture was not fused until stage 6 in both sexes. **Conclusions:** Among developmental age indices, the HWM and CVM showed strong correlations and high associations, suggesting that they can be useful in assessing maturation of the midpalatal suture.
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Key words: Midpalatal suture, Cervical vertebrae, Hand-wrist, Cone-beam computed tomography

INTRODUCTION

Anteroposterior as well as transverse skeletal problems may co-exist in malocclusion patients. Maxillary constriction can cause posterior crossbite, dental crowding, and abnormal muscular function. In the orthodontic field, maxillary expansion is performed to correct maxillary transverse constriction and the tooth axes of the posterior teeth, alleviate dental crowding, and establish a favorable maxillomandibular relationship.[1]

However, according to Melsen,[2] responses to orthopedic maxillary expansion differ depending on the age and maturation of the patient. The interlock of the midpalatal suture increases as it matures, making skeletal expansion even more difficult. As a result, expansion of a matured maxilla leads to a tipping movement of the teeth, which increases the risk of relapse because the extent of dental expansion is greater than that of orthopedic expansion.

It is possible to expand the maxilla using a removable or fixed appliance in young patients because the structure of the suture is simple. However, with increased complexity of the suture, as occurs in adults, different treatment methods—such as surgically assisted rapid palatal expansion (SARPE)—should be used.[1] However, SARPE can cause postoperative side effects, discomfort, and psychological and economic burdens on patients.[3] Recently, a new method that can load orthopedic pressure directly to the bone (i.e., miniscrew-assisted rapid palatal expansion, MARPE) has been introduced in clinical practice. MARPE also can be considered at a certain level of maturation.[4,5]

Generally, various indices of maturation have been used to make decisions about treatment timing and method in orthodontics. An evaluation of skeletal age is one of the most important pieces of information in the diagnosis of growing children. The hand and wrist method (HWM)[6,7] and cervical vertebrae method (CVM)[8] are the most commonly used maturation indices. Hellman's index also is a popular method for assessing dental age.[9]

It is now possible to observe images of the midpalatal suture by using cone-beam computed tomography (CBCT); this is impossible with conventional radiography. Angelieri et al.[10] suggested that maturation of the midpalatal suture can be classified into five stages (stages A–E) by observing CBCT images. Through assessment of the midpalatal suture, they found it possible to minimize the failure of rapid maxillary expansion in adolescent and young adult patients. However, it is impossible to obtain routine CBCT radiography of every patient, and especially those without any diagnostic need (e.g., impacted tooth, cyst, and skeletal asymmetry). In addition, there are ethical concerns regarding unnecessary CBCT because of radiation exposure.

The aim of this study was to classify the maturation degree based on the morphology of the midpalatal suture by using CBCT images and to investigate relationships with conventional developmental age indices (indices of maturation). In doing so, we sought to determine whether using conventional developmental age indices can predict the morphology of the midpalatal suture and be used for maxillary expansion treatment planning.

MATERIALS AND METHODS

Patient selection and radiography

Before the study commenced, we estimated the sample size needed to reach statistical significance. A power analysis with G*Power 3.1.9.2 (Universität Düsseldorf, Germany) showed that 93 subjects would be needed for a statistical power of more than 85% to detect significant differences with a 0.5 effect size and a significance level of $\alpha = 0.05$ (actual power = 0.851; critical chi-square = 31.41; noncentrality parameter $\lambda = 23.25$). Institutional review board approval was granted by the Wonkwang University Daejeon Dental Hospital (Daejeon, Korea) to conduct this study (IRB No. W1404/004-001).

From August 2009 to February 2014, patients between the ages of 7 and 20 years who visited the Department of Orthodontics, Wonkwang University Sanbon Dental Hospital (Gunpo, Korea) for orthodontic treatment and who underwent CBCT were selected. Among 319 patients in this group, 99 patients without any exclusion factors were selected for this study. The average ages of the sample groups were 14.3 ± 3.27 years (ages 8–18 years) and 13.56 ± 3.12 years (ages 6–20 years) for male and female subjects, respectively. The total distributions for sex and age are shown in Table 1. We collected data that had been obtained from each patient for orthodontic diagnosis including CBCT images for

Table 1. Sex and age demographics of the sample (n = 99)

Age (yr)	Sex		Total
	Female	**Male**	
< 10	11	10	21
≥ 10, < 12	22	14	36
≥ 12, < 14	7	6	13
≥ 14, < 16	5	3	8
≥16	14	7	21
Total	59	40	99
Mean of age ± SD	12.10±3.354	11.93±3.155	12.03±3.221

SD, Standard deviation.

assessment of the midpalatal suture, hand-wrist and cephalometric radiographs for bone age, and panoramic radiographs for dental age. The exclusion criteria were as follows:

1. Any experience with orthodontic treatment
2. Disease or medicine intake affecting bone metabolism
3. Omission of any diagnostic data, including CBCT images
4. Poor-quality images that were difficult to distinguish (e.g., blurry images)
5. More than 2 months' difference between the dates when CBCT and other radiographs were acquired

CBCT (PaX-Zenith3D; Vatech Korea Ind. Co., Gyeonggi-do, Korea) images were taken using the following parameters: 105 kVp, 6.2 mAs, 15–24 second scan time, 0.2 and 0.3 mm voxel sizes, and field-of-view, 16 cm × 14 cm. The images were converted to Digital Imaging and Communication in Medicine (DICOM) format. DICOM files were reconstructed into a three-dimensional image by multiplanar reformatting and volume rendering using imaging software (InVivoDental 5.0; Anatomage, San Jose, CA, USA). Cephalometric radiographs, panoramic radiographs, and hand-wrist radiographs were evaluated by using an exclusive imaging program (PiViewSTAR; Infinitt, Seoul, Korea).

All measurements were blind-tested by one orthodontist. A screen capture of every slide and image was taken and saved in JPEG file format for this study. Every slide and image was arranged on a black background and assessed on a 27-inch high-resolution (1,920 × 1,018 pixel) monitor using a viewer program (ACDSee Pro 6.2; ACD Systems International Inc., Victoria, BC, Canada). There was no modification made on the monitor or to the saved images, such as changing the brightness or contrast.

Reorientation of CBCT images

To standardize the CBCT images, head reorientation was performed. After making the position indicator visible, the vertical line of the cursor (green line) was matched to the axis of the palatal plane line (anterior nasal spine-posterior nasal spine; ANS-PNS) on an axial view (Figure 1A). At the same time, on a coronal view, the vertical line of the cursor was matched to the nasal septum, and the horizontal line of the cursor (orange line) was oriented parallel to the palatal plane (Figure 1B).

To facilitate observation of the axial cross-sectional planar view of the midpalatal suture, it was established
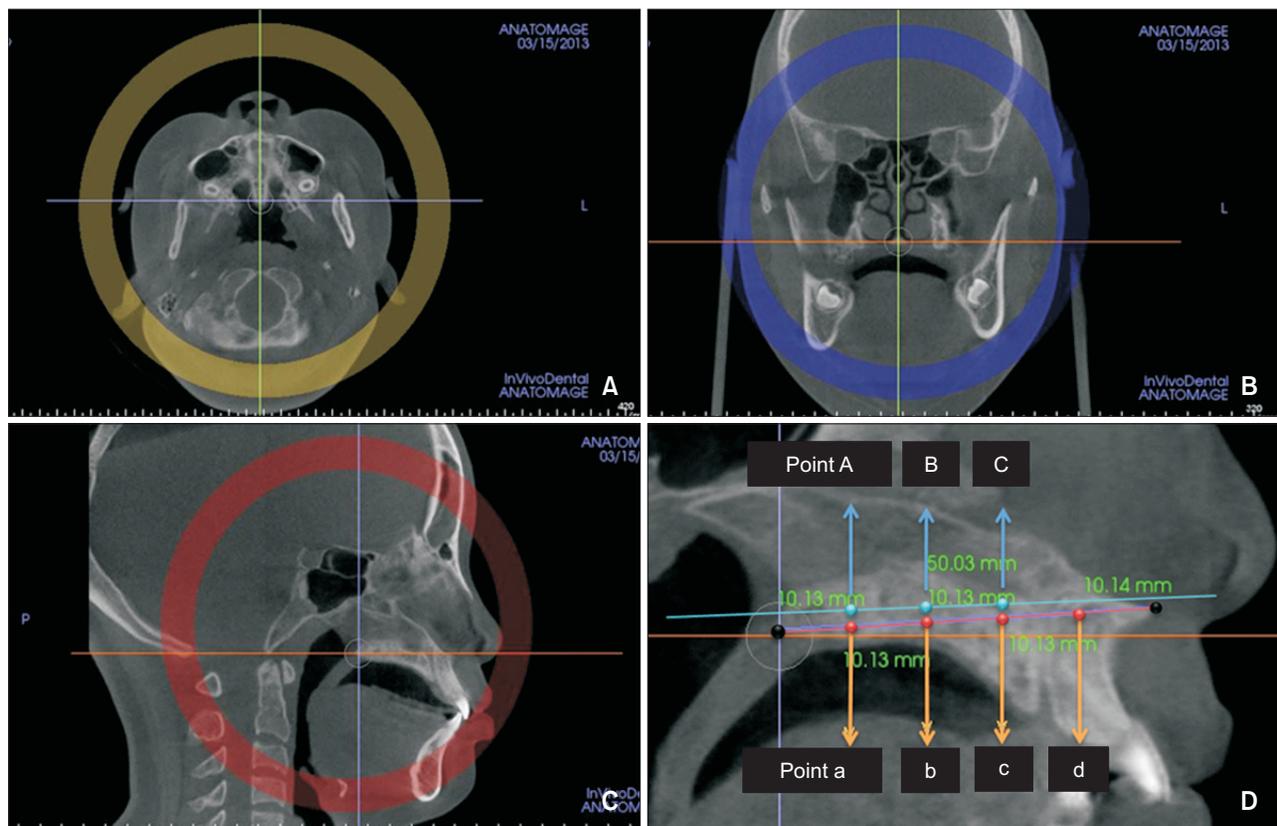

Figure 1. Head reorientation and setting of the axial cross-sectional planar view. **A**, An axial plane view; **B**, a coronal plane view; **C**, a sagittal plane view; and **D**, a midsagittal plane view.

that the horizontal line of the cursor would intersect the middle of the palate in the sagittal plane (Figure 1C). To evaluate the morphology of the midpalatal suture more accurately than in a previous study,[10] a new axial cross-sectional plane was established as follows: four points that divide the ANS-PNS into fifths in the midsagittal plane were defined as point a, point b, point c, and point d, starting at the nearest PNS point (Figure 1D). A vertical line was drawn from point a to the horizontal line of the cursor, and the points at which the extension of the vertical line met the upper and lower borders of the palatal bone were defined as point a' and point a", respectively. The midpoint of point a' and point a" was defined as point A. Point B and point C were defined using the same method (Figure 1D). Point D was excluded from measurement because images of the nasopalatine canal and midpalatal suture showed a high tendency to overlap. The horizontal line of the cursor was matched to a virtual line connecting point A,

point B, and point C (Figure 1D). The horizontal cross-sectional image that showed the midpalatal suture most evidently and seemed longest was selected by moving the horizontal line up and down in a 1-mm range. If it was impossible to find a line connecting all three points, the shape of the palate was considered a curve, and two horizontal cross-sectional images going through point A–point B and point B–point C were observed.

Classification of midpalatal suture maturation and verification of the staging process

CBCT images of the midpalatal suture were assessed on an axial plane view from stage A to stage E according to the classification scheme of Angelieri et al.[10] The morphology of the midpalatal suture was regarded as an indicator of maturation, similar to a previous study. Additionally, we defined "CBCT stage" as the determined morphological stage of the midpalatal suture.

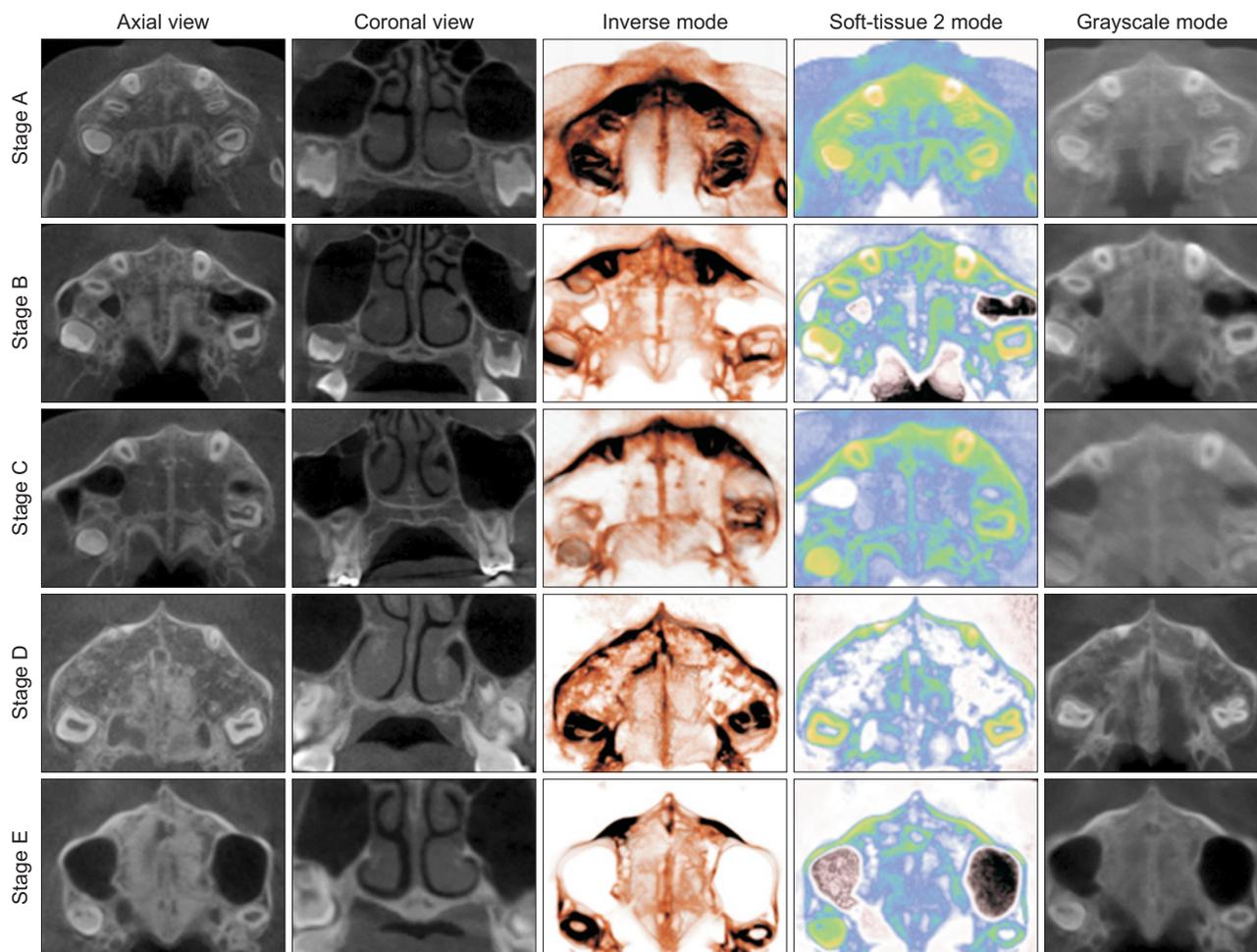To make the assessment more accurate, maturation of

Figure 2. Cone-beam computed tomography images of the midpalatal suture and volume-rendered images according to maturation stage.

the midpalatal suture was reconfirmed on a horizontal cross-sectional image by additionally investigating its morphology and fusion on a coronal cross-sectional planar view and on volume-rendered images.

When the coronal cross-sectional image was observed as showing fusion at all three points (point A–point C), it was categorized as stage E. If only some points showed fusion, it was judged as stage D. If the suture was open at all three points, it was judged as "before stage C"; if there were two high radiopaque lines with low density in the middle of the suture, or if the suture was not fused, it was considered as stage C. If only some points showed "stage C conditions," it was judged as stage B. If there was no stage C condition and a mixture of opacity was observed at all three points, or if only one weak radiopaque line was observed, it was judged as stage A.

Then, the volume-rendered computed tomography image was clipped with a minimum unit of a 5-mm thickness, including the midpalatal suture. Opacity, brightness, and contrast were adjusted to maximize visibility on an axial plane view. Among the rendering modes in the software, only three modes (i.e., gray scale mode, inverse mode, and soft tissue 2 mode) that clearly visualized the midpalatal suture were used. Final maturation of the midpalatal suture was determined by reconfirming the result from each volume rendering mode (Figure 2).

Maturation assessments by bone age, dental age, and chronological age

The skeletal maturation indicator (SMI) proposed by Fishman[6,7] was used on hand-wrist radiographs to evaluate bone age. The CVM was used on cephalometric radiographs, as suggested by Hassel and Farman.[8] Dental age was assessed by applying the Hellman's index to a panoramic radiograph.[9] The chronological age and sex of each patient were investigated.

Statistical analysis

All statistical calculations were performed with IBM SPSS Statistics software ver. 22.0 (IBM Co., Armonk, NY, USA). The distribution and percentage of each measurement and age were calculated. After measurement, 30 samples were selected randomly from the same patient group after 2 months and re-assessed with the same method. The intra-class correlation coefficient (ICC) was calculated to test the reliability of the CBCT stage, and developmental age indices were determined by one investigator. There was high intra-rater reliability according to the results of ICC. ICC values were 0.995 ($p < 0.05$) for CBCT stage, 0.996 ($p < 0.05$) for the HWM, 0.991 ($p < 0.05$) for the CVM, and 0.992 ($p < 0.05$) for Hellman's index.

To observe correlations between CBCT stages and each maturation index, Spearman's rho rank order correlation analysis was performed. Additionally, the same analyses were performed to test for differences between the sexes. A crosstab analysis by contingency coefficients was performed to determine associations between CBCT stages and each maturation index. Assessment was

Table 2. Demographics of the sample for all indices

Index		Data
CBCT stage	A	19 (19.2)
	B	14 (14.1)
	C	27 (27.3)
	D	19 (19.2)
	E	20 (20.2)
HWM	1	13 (13.1)
	2	5 (5.1)
	3	20 (20.2)
	4	5 (5.1)
	5	2 (2.0)
	6	7 (7.1)
	7	4 (4.0)
	8	2 (2.0)
	9	8 (8.1)
	10	2 (2.0)
	11	31 (31.3)
CVM	1	22 (22.2)
	2	17 (17.2)
	3	11 (11.1)
	4	7 (7.1)
	5	14 (14.1)
	6	28 (28.3)
Hellman's dental age	IA	0 (0)
	IC	0 (0)
	IIA	1 (1.0)
	IIC	2 (2.0)
	IIIA	16 (16.2)
	IIIB	17 (17.2)
	IIIC	21 (21.2)
	IVA	31 (31.3)
	IVC	8 (8.1)
	VA	3 (3.0)

Values are presented as number (%). Both sexes are included. CBCT stage, Midpalatal suture maturation stage using cone-beam computed tomography images; HWM, hand and wrist method; CVM, cervical vertebrae method.

Table 3. Distribution of the HWM according to CBCT stage (n = 99)

HWM	CBCT stage														
	A			B			C			D			E		
	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T
1	8	4	12	1		1									
2	1		1	1	1	2	1	1	2						
3	4	2	6	5	2	7	2	5	7						
4				2		2	1	2	3						
5					1	1		1	1						
6					1	1	1	5	6						
7							1	1	2		2	2			
8								1	1		1	1			
9							1	4	5	1	2	3			
10														2	2
11										5	8	13	4	14	18

HWM, Hand and wrist method; CBCT stage, midpalatal suture maturation stage using cone-beam computed tomography images; M, distribution of the male group; F, distribution of the female group; T, distribution of the total sample group.

Table 4. Distribution of the CVM according to CBCT stage (n = 99)

CVM stage	CBCT stage														
	A			B			C			D			E		
	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T
1	10	4	14	2	2	4	2	2	4						
2	3	1	4	5		5	2	6	8						
3		1	1	3	2	5	1	4	5						
4							1	4	5		2	2			
5							1	3	4	3	6	9		1	1
6								1	1	3	5	8	4	15	19

CVM, Cervical vertebrae method; CBCT stage, midpalatal suture maturation stage using cone-beam computed tomography images; M, distribution of the male group; F, distribution of the female group; T, distribution of the total sample group.

Table 5. Distribution of Hellman's dental age according to CBCT stage (n = 99)

Hellman's index	CBCT stage														
	A			B			C			D			E		
	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T
IIA					1	1									
IIC	1	1	2												
IIIA	7	5	12	1	1	2		2	2						
IIIB	3		3	3	1	4	2	6	8		2	2			
IIIC	2		2	4		4	4	7	11		3	3		1	1
IVA				2	1	3	1	5	6	4	7	11		11	11
IVAC										2	1	3	2	3	5
VA													2	1	3

CBCT stage, Midpalatal suture maturation stage using cone-beam computed tomography images; M, distribution of the male group; F, distribution of the female group; T, distribution of the total sample group.

Table 6. Distribution of chronological age according to CBCT stage (n = 99)

Chronologic age	CBCT stage														
	A			B			C			D			E		
	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T
6		1	1												
7		2	2	1		1									
8	3	2	5	1		1		1	1						
9	4	1	5		1	1	2	2	4						
10	4		4	3	1	4		6	6		1	1			
11	2		2	3	1	4	2	7	9		4	4		2	2
12				2		2	2		2		1	1		1	1
13					1	1		3	3	1	1	2		1	1
14							1	1	2		1	1		2	2
15										1		1	1	1	2
16										1	1	2		5	5
17											4	4	1	3	4
18											2	2	1	1	2
19										1		1			
20														1	1

CBCT stage, Midpalatal suture maturation stage using cone-beam computed tomography images; M, distribution of the male group; F, distribution of the female group; T, distribution of the total sample group.

performed by using gamma (γ) and Kendall's tau-b (τ-b) as association measures. Additionally, crosstab analyses between the sexes were performed to find any sex differences.

RESULTS

Demographics of the sample

The distribution of the total sample and the sexes related to each developmental age index according to CBCT stage (maturation of the midpalatal suture) are presented in Tables 2 to 6.

Correlation between indices using a rank order correlation analysis

Correlations between CBCT stage and developmental age indices (HWM, CVM, and Hellman's dental age) or chronological age were investigated. The same analysis was performed according to sex (Table 7). All values showed statistically significant correlations ($p < 0.01$). The HWM and CBCT stage showed an especially strong correlation (0.904) and the CVM and CBCT stage showed a strong correlation (0.874). Correlations between CBCT stage and Hellman's index for chronological age were relatively weak (0.777 and 0.774, respectively). In male subjects, a strong correlation was observed between CBCT stage and the HWM (0.857). The CVM also showed a strong correlation (0.813), and this result was similar in female subjects (0.887 and 0.862, respectively).

Association between indices using contingency coefficients

The results of the crosstab analysis between CBCT stage and the HWM, CVM, Hellman's index, and chronological age are presented in Table 8. All measurements showed significant correlations ($p < 0.0001$). Crosstab analysis by contingency coefficients showed that the HWM and CVM had the highest γ and Kendall's τ-b values. When compared, the HWM and CVM both showed significantly high values, but the HWM showed a slightly higher value (γ = 0.924 > 0.905, Kendall's τ-b = 0.087 > 0.784). The association between Hellman's index and chronological age also reached a significant level, but the contingency coefficient values were lower than those for the HWM and CVM (γ = 0.809 and 0.741; and Kendall's τ-b = 0.673 and 0.635, respectively).

The crosstab analysis according to sex also showed that the HWM and CVM were significantly higher, while Hellman's index and chronological age were relatively lower (Table 8).

DISCUSSION

There have been many attempts to determine whether

Table 7. Results of Spearman's rho rank order correlation analysis

Index		CBCT stage	HWM	CVM	Hellman	Age
Total	CBCT stage	-	0.904[†]	0.874[†]	0.777[†]	0.774[†]
	HWM	0.904[†]	-	0.945[†]	0.859[†]	0.883[†]
	CVM	0.874[†]	0.945[†]	-	0.791[†]	0.824[†]
	Hellman	0.777[†]	0.859[†]	0.791[†]	-	0.868[†]
	Age	0.774[†]	0.883[†]	0.824[†]	0.868[†]	-
Male	CBCT stage	-	0.857[†]	0.813[†]	0.823[†]	0.785[†]
	HWM	0.857[†]	-	0.915[†]	0.873[†]	0.906[†]
	CVM	0.813[†]	0.915[†]	-	0.797[†]	0.834[†]
	Hellman	0.823[†]	0.873[†]	0.797[†]	-	0.932[†]
	Age	0.785[†]	0.906[†]	0.834[†]	0.932[†]	-
Female	CBCT stage	-	0.887[†]	0.862[†]	0.742[†]	0.781[†]
	HWM	0.887[†]	-	0.932[†]	0.850[†]	0.902[†]
	CVM	0.862[†]	0.932[†]	-	0.781[†]	0.844[†]
	Hellman	0.742[†]	0.850[†]	0.781[†]	-	0.804[†]
	Age	0.781[†]	0.902[†]	0.844[†]	0.804[†]	-

CBCT stage, Midpalatal suture maturation stage using cone-beam computed tomography images; HWM, hand and wrist method; CVM, cervical vertebrae method; Hellman, Hellman's dental age; Age, chronological age.
[†]Significant difference by Spearman's rho rank order correlation analysis ($p < 0.01$).

Table 8. Analysis of associations between CBCT stage and maturation indices using crosstabs

	Total		Male		Female	
	γ	τ-b	γ	τ-b	γ	τ-b
CBCT stage–HWM	0.924[‡]	0.807[‡]	0.897[‡]	0.772[‡]	0.924[‡]	0.787[‡]
CBCT stage–CVM	0.905[‡]	0.784[‡]	0.870[‡]	0.741[‡]	0.912[‡]	0.772[‡]
CBCT stage–Hellman	0.809[‡]	0.673[‡]	0.870[‡]	0.738[‡]	0.823[‡]	0.656[‡]
CBCT stage–Age	0.741[‡]	0.635[‡]	0.778[‡]	0.671[‡]	0.786[‡]	0.662[‡]

CBCT stage, Midpalatal suture maturation stage using cone-beam computed tomography images; HWM, hand and wrist method; CVM, cervical vertebrae method; Hellman, Hellman's dental age; Age, chronological age; γ, gamma as an association measure for the crosstabs; τ-b, Kendall's tau (τ)-b as an association measure for the crosstabs.
[‡]Significant difference by contingency coefficients ($p < 0.0001$, highly significant).

surgical procedures are necessary to expand the maxilla. SARPE has been recommended by Timms and Vero[11] for patients aged 25 years and older and by Epker and Wolford[12] for those aged 16 years and older. Moreover, many other studies recommended various ages from 14 to 20 years and older.[13-15] However, accurate clinical guidelines regarding treatment timing for maxillary expansion are not available. Additionally, existing studies have shortcomings in that they suggested appropriate treatment timing in chronological age; however, it is generally known that chronological age is not a precise index in predicting skeletal maturation, and these studies did not assess the midpalatal suture itself.[16,17] Therefore, the aim of this study was to investigate the relationship between various developmental age indices

including skeletal age and the morphology of the midpalatal suture.

To evaluate the morphology of the midpalatal suture according to maturation, CBCT images were assessed by conventional methods.[10,18] However, conventional methods have limitations, including the possibility of the images appearing different depending on the position of the cross-sectional slice. If the cross-sectional slice is not positioned properly in the middle of the midpalatal suture, the practitioner can misjudge the CBCT stage. Therefore, in this study, it was established that the cross-section slice would intersect the middle of the palate, and maturation of the midpalatal suture also was evaluated based on a coronal cross-sectional planar view and on various volume-rendered images (Figures 1 and 2).

Angelieri et al.[10] reported that stage A was observed mostly in the early childhood period from 5 to 11 years of age (four of five subjects), and stage B was observed mostly up to 13 years of age (50 of 57 subjects). These results were similar to those in our study. Stage A was observed mostly in ages 5 to 10 years, and stage B was observed mostly in ages 10 to 12 years (Table 6). In this study, fusion of the midpalatal suture below age 11 was not seen; compared with Angelieri et al.,[10] stage C had a relatively more dense distribution from 9 to 14 years of age in the current study, probably because of differences in the experimental method and race (Table 6).

The female subject sample was distributed somewhat more toward the upper side in Table 6 than the male sample at the same CBCT stage in this study, meaning that maturation occurred earlier in female subjects than in male subjects (Tables 3–6). These findings were similar to those in a prior study.[10] This coincides with the fact that pubescent growth begins and is completed 2 years earlier in females than in males.[19] However, because the number of samples in this study was not sufficient and the female sample showing stage D or E was larger than in the male sample, it was difficult to conclude if there was a difference between the sexes.

The correlation analysis in this study showed statistical significance for all index values (Table 7). Among them, the HWM and CVM showed strong correlations with CBCT stage (0.904 and 0.874, respectively), while chronological age and Hellman's dental age showed relatively weak correlations (0.774 and 0.777, respectively). This result was similar to the findings of other studies showing strong correlations between facial skeletal growth and skeletal age.[19,20] A difference is that previous studies evaluated facial size by linear growth of the mandible, but the current study evaluated maturation of the midpalatal suture.

Because of statistical weakness, it was impossible to compare relative usability among each index with values from the correlation analysis. Thus, a crosstab analysis using a contingency coefficient was performed additionally (Table 8).[21] When the crosstab analysis was performed with CBCT stages, the HWM (γ = 0.924, Kendall's τ-b = 0.807) and CVM (γ = 0.905, Kendall's τ-b = 0.784) showed higher values than chronological age (γ = 0.741, Kendall's τ-b = 0.635) and Hellman's dental age (γ = 0.809, Kendall's τ-b = 0.673). This means that maturation based on the morphology of the midpalatal suture was more consistent with skeletal age than with chronological age or dental age. This further demonstrates that when predicting the morphology of the midpalatal suture, it can be expected that skeletal age (HWM and CVM) is a more useful index than either chronological or dental age. There has been no study comparing developmental age indices and CBCT findings

in the manner of the current study; only studies about the clinical usability and predictability of the HWM and CVM have been performed.[8,17,22,23]

As presented in Table 8, the crosstab analysis between the HWM and CBCT stage showed higher values than the analysis between the CVM and CBCT stage in both sexes. This illustrates that the HWM is more suitable for predicting maturation based on the morphology of the midpalatal suture, reflecting a result similar to those of other studies. Recently, Beit et al.[24] and Mellion et al.[25] reported that the CVM offered no advantage over chronological age in assessing skeletal age or predicting the pubertal growth spurt. However, Mellion et al.[25] reported that although the HWM is not accurate, it nonetheless is useful in predicting the maximum growth period and in assessing skeletal age because of the repeatability of measurements and least inter-observer error. Beit et al.[24] also suggested that the HWM has more reproducibility, sensitivity, and accuracy in predicting the maximum growth period because the sesamoid bone serves as a certain landmark.

It is notable that before stage 6 of the HWM, stage D or E (i.e., fusion of the suture) was not observed in either the male group or female group (Table 3). There was no fusion before stage 3 of the CVM in the female group or before stage 4 in the male group (Table 4). Only when stage 10 or 11 of the HWM and stage 5 or 6 of the CVM appeared did stage E become evident, meaning that there was total fusion of the suture (Tables 3 and 4). Therefore, nonsurgical maxillary expansion may be recommended before stage 6 in the SMI and before stage 3 in the CVM, and a surgical approach may be considered after these stages are recognized; direct assessment of the midpalatal suture using CBCT may be recommended.

An issue that must be considered in maxillary expansion is other anatomical structures that resist expansion force. It is well known that resisting anatomical structures include not only the midpalatal suture, but also the zygomaticotemporal suture, zygomaticofrontal suture, and zygomaticomaxillary suture, among others.[26-28] Only the midpalatal suture was considered in this study.

Another issue that must be considered in this study is that the morphology on the radiographic image can differ from the actual structure of the midpalatal suture itself.[29] Histological assessment and micro computed tomography may be needed to evaluate maturation of the midpalatal suture with greater accuracy.[10]

CONCLUSION

In this study, we evaluated maturation stage based on the morphology of the midpalatal suture on CBCT images, and investigated correlations and associations

between the maturation stage of the midpalatal suture and developmental age indices. Among developmental age indices, the HWM and CVM showed strong correlations and high associations with the maturation stage of the midpalatal suture on CBCT images, meaning that these methods can be used to speculate on the maturation of the midpalatal suture according to its morphology.

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