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QUANTITATIVE AND MORPHOLOGICAL EVALUATION OF MIDPALATAL SUTURE MATURATION USING CONE-BEAM COMPUTED TOMOGRAPHY: RETROSPECTIVE STUDY

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ABSTRACT

Objectives: The present study aimed to use CBCT in the 3D quantitative and morphologic assessment of midpalatal suture (MPS) maturation in support of its utility in orthodontic practice.

Methods: The study population included CBCT scans of 165 subjects: 78 males and 87 females aged 5-60 years old. They were assigned to six age groups: <10, 11–20, 21–30, 31–40, 41–50, and 51–60 years. Quantitative MPS assessment included MPS horizontal obliteration index (OI) and MPS total mean vertical OI. Morphologic assessment included the MPS maturation stages (A-E). Comparison between age groups and correlation between age and different variable were performed.

Results: In both males and females, the MPS horizontal OI showed significant increase between ages more than thirty years and ages below. The MPS total mean vertical OI showed significant increase between ages more than twenty years and ages below. There was statistically significant increase in the frequency of MPS maturation stages with increasing age with stage A significantly prevalent in age group ≤ 10, stage B in 11-20 years, stage C in 21-30 years in males and 11-30 years in females, stage D in 21-30 years in females, and stage E in ages 31-60 years.

Conclusion: Quantitative and morphologic assessment of the MPS using CBCT provided valuable information regarding the MPS maturation. The MPS should be appraised using CBCT for each patient requiring maxillary expansion as this will aid in decision making and predicting the treatment outcome.

KEYWORDS: Cone-beam computed tomography; Maturation; Midpalatal suture; Palatal expansion

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INTRODUCTION

The midpalatal suture (MPS) is one of the cranial sutures important in certain orthodontic interventions used in correcting transverse maxillary deficiency. [1,2] Transverse maxillary deficiency results in dental problems including posterior crossbite, dentition crowding, as well as deep and narrow palate. [3]

Transverse maxillary deficiency can be treated by expanding the maxilla to increase its width using conventional rapid maxillary expansion (RME) or surgically assisted rapid maxillary expansion (SARME) depending on the degree of maxillary development. [1,2,4] The MPS is a resistance site for expansion as it is the main site of the maxillary development.[5] As such, the selection between these orthodontic interventions depends on the MPS degree of obliteration where conventional expansion can be performed only when there is no suture fusion. [6]

Clinically, the selection between (RME) or (SARME) is based on the patient's chronological age as an indicator for suture maturation and fusion. [6] Studies proposed that RME should be performed before puberty and SARME after puberty in adolescents and adults. [7,8] However, it was reported that chronological age did not reflect the developmental stage of the MPS as open sutures had been observed in adult patients aged 27 and 32 years, [9] 54 years, [10] and even 71 years.[11] Moreover, other studies have reported successful RME treatment in adult patients. [12,13]

As such, it is essential to assess the MPS maturation for each patient individually for proper treatment planning and deciding whether an adult patient can have RME instead of SARME that requires higher cost and associated with pain and prolonged healing time. [6,14]

MPS maturation has been assessed by histologic evaluation of human palate specimens [9,10,15] and imaging methods including micro-CT, [11] The gold standard is the histologic examination; however, it could not be used is for in-vivo clinical assessment, the same applies to micro-CT that uses palate specimens. [14] Occlusal radiographs had been used; however, they were reported to be an unreliable after recording 50% of the films with false-positive results, [16] in addition to superimposition of adjacent structures which made their use to diminish in this regard and replaced by CT which allows the three-dimensional (3D) assessment of sutural changes without superimpositions. [17,18] Furthermore, (CBCT) was used to detect MPS ossification [14,19] with lower cost, reduced imaging time, and at lower radiation dose compared to CT. [20,21]

As such, this study aimed to use CBCT in the 3D quantitative and morphologic assessment of MPS maturation with age in support of its utility in orthodontic practice.

MATERIAL AND METHODS

Ethical considerations:

The present was study approved by the Ethics Committee, Faculty of Dentistry, Cairo University.

Sample size calculation

Using mid-palatal suture based on qualitative method on 5 grading scale (A-E) referenced by previous studies, sample size calculation with 95% confidence and 80% power is 121. This was increased to 165 for the purpose of age grouping.

Study sample

The study population included CBCT scans of 165 subjects: 78 males (47.3%) and 87 females (52.7%) aged 5-60 years old. They were assigned to six age groups for each sex: ≤10 years, 11-20 years, 21-30 years, 31-40 years, 41-50 years, and 51-60 years. CBCT scans were retrieved from the patients' CBCT database of the Oral and Maxillofacial Radiology Department, Faculty of Dentistry, Cairo

University, which were taken for different dental diagnostic purposes. CBCT scans with maxillofacial field of view (FOV), or maxillary FOV were included in the study. CBCT images of patients with trauma, impaction, and congenital or developmental anomalies were excluded from the study.

Imaging:

CBCT images were acquired using the Planmeca Promax 3D-Mid CBCT scanner (Planmeca, Helsinki, Finland). The scan specifications were as follows: (Tube voltage: 90 kV, tube current: 8 mA, exposure time: 13.5 s, FOV: 20 × 10 cm or 20 × 17 cm, voxel size: 0.4 mm). The primary images stored as 575 DICOM data files were imported and analyzed using In Vivo Dental software (Anatomage, San Jose, Calif).

For observer evaluation, CBCT data were exported anonymously to ensure the observer blindness.

Image analysis

For standardization of the image analysis, the software cursors were used to adjust the head orientation according to the examined region as follows:

MPS analysis

MPS length

On the midsagittal plane, the patient's head was reoriented so that the axial cursor concurred midway between the upper and lower borders of the hard palate. Next, we measured MPS length as the distance from the posterior margin of the incisive foramen to the point of intersection with a line tangent to the posterior margins of the two greater palatine foramina on the reconstructed axial plane. [8] **(Figure 1)**.

MPS obliteration index (MPS OI)

OI was calculated twice; once along the horizontal dimension of the suture on the axial plane, and another along the vertical dimension of the suture on the coronal plane. MPS OI was calculated as the length of the obliterated part of the MPS divided by the total suture length and multiplied by 100 to determine the ossification percentage [11] (obliterated suture meant an invisible radiolucent area of the suture and increased bone density). ***The MPS horizontal OI*** was assessed on the axial plane along the MPS length where the length of the obliterated part was recorded, and OI calculated **(Figure 2: A-C)**. ***The MPS total mean vertical OI*** was assessed on the coronal plane as follows: The MPS was divided into four regions: anterior maxillary, middle maxillary, posterior maxillary, and palatal. Then, we examined two to three cuts in each region on the coronal plane. The OI of the MPS in all cuts of every region was calculated where the height of the obliterated part (from the nasal side to the oral side) of the MPS was divided by the total MPS height in each cut. Further, the mean OI values of cuts in each region and the total mean OI values of all regions were also calculated **(Figure 2: D-F)**.

Classification of the maturation stage of the MPS

MPS maturation stage was assessed on the axial plane according to Angelieri et al. [22] where the MPS maturation was classified into five stages: A, B, C, D, E **(Figure 3)**. Stage A: The MPS is practically a high-density sutural straight line with little or no interdigitation. Stage B: The MPS appears like a scalloped high-density line. Stage B can also indicate some areas, where two parallel, high-density, scalloped lines separated by small low-density spaces are observed. Stage C: MPS appears like two parallel, scalloped, high-density lines, separated by small low-density spaces in the maxillary and palatine regions of the suture. The suture can either be straight or irregular. Stage D: The MPS could not be visualized with maturation advancing from posterior to anterior in the palatine region, and there is an increased parasutural bone density than the maxillary region. In the maxillary region, there was no obliteration, and the suture can be observed as two adjacent high-density lines separated by small low-density spaces. Stage E: Obliteration of the MPS becomes visible in the maxilla, and the actual suture is not visible in at least a part of the maxilla. The bone density is the same as other palatine regions, and the parasutural bone density increased.

Method error:

All the images were assessed by a maxillofacial radiologist of more than 10 years of experience. To test the method's reliability, 42 (25%) randomly selected CBCT scans we reassessed after a month by the same maxillofacial radiologist to test the intraobserver agreement.-

Statistical analysis

For statistical analysis, imaging parameters evaluated were:

1. Quantitative parameters: MPS horizontal OI and MPS total mean vertical OI.
2. Morphologic stage: MPS maturation stages (A-E).

Statistical analysis was implemented using the statistical package for the social sciences (SPSS) version 26 (IBM Corp., Armonk, NY, USA). Quantitative variables were described using mean, standard deviation, median, minimum and maximum, and categorical variables using frequencies (number of cases) and relative frequencies (expressed as percentages). In normally distributed quantitative variables, unpaired t-test or one way analysis of variance (ANOVA) were used for comparison between groups using multiple comparison post hoc Bonferroni tests, whereas non-normally distributed quantitative variables were compared using nonparametric Kruskal–Wallis test and Mann–Whitney test. Chi-square (c^2) test of independence was used to compare categorical data, but when the expected frequency is less five in more than 25% of the cells, the Fisher's Exact test was employed instead. Correlating variables was performed using the Pearson correlation coefficient. The intrarater reliability was assessed for quantitative variables using the Intra Class Coefficient (ICC) and Cronbach's alpha reliability coefficient with their respective 95% confidence intervals (95% CI). According to the 95% confidence range of the ICC estimate, values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.9 indicate poor, moderate, good, and excellent reliability, respectively. The Kappa measure of agreement (k) to examine the agreement between qualitative variables. The strength of the Kappa coefficient agreement was as follows: 0 = poor, 0.01–0.20 = slight, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = substantial, and 0.81–1= almost perfect. P-value < 0.05 denotes statistical significance.

RESULTS

Regarding quantitative parameters, there was excellent intra-observer agreement for MPS horizontal OI and MPS total mean vertical OI (ICC = 0.996 and 0.993 respectively). Regarding the morphologic stage, there was an almost perfect intra-observer agreement for the MPS maturation stage (k= 0.966).

Descriptive analysis of the six age groups and comparison of the values of the quantitative study parameters between the different age groups in males and females are presented in **tables (1) and (2)** respectively. In both males and females, the MPS horizontal OI showed significant increase between ages more than thirty years and ages below (P< 0.001). Mean horizontal OI values were: (0.00%, 0.00%, 5.94%, 73.69%, 87.48%, and 100.00% in males) and (0.00%, 2.16%, 24.29%, 74.06%, 82.52%, and 100.00% in females) for age groups ≤10, 11-20, 21-30, 31-40, 41-50, and 51-60 years respectively. **Table (3)** reveals that in males, MPS horizontal OI started at 29 years old, no obliteration detected at all the age groups ≤ 10 years and 11-20 years, and 13 males (76.47%) of the age group 21-30 years. In females, MPS horizontal OI started at 19 years old, no obliteration was detected at all the age group ≤ 10 years, 20 females (95.23%) of the age group 11-20 years, and 9 females (47.36%) in the age range 21-26 years old.

Regarding MPS total mean vertical OI, **tables (1) and (2)** reveal significant increase between ages more than twenty years and ages below in males and females respectively (P< 0.001). Total mean vertical OI mean values were: (0.00%, 1.93%, 64.90%, 90.37%, 90.54%, and 99.97% in males) and (0.00%, 7.81%, 35.21%, 75.20%, 95.36%, and 99.76% in females) for age groups ≤10, 11-20, 21-30, 31-40, 41-50, and 51-60 years respectively. **Table (3)** demonstrates that in males, vertical obliteration started at 17 years old, there was no obliteration in all the age group ≤ 10 years, 18 males (90%) of the

TABLE (1): Descriptive statistics and comparison of the mean, SD, median, minimum, and maximum values of the quantitative study parameters between the different age groups in males.

Males		**Age groups**						
		≤ 10 years a	**11-20 years b**	**21-30 years c**	**31-40 years d**	**41-50 years e**	**51-60 Years f**	**P value**
Descriptive statistics	**Mean**	8.89	15.25	25.18	35.81	42.67	55.29	
	SD	1.27	2.43	2.90	3.12	2.18	3.99	
	Count	9	20	17	16	9	7	
	%	11.5	25.6	21.8	20.5	11.5	9.0	
Quantitative parameters								
▪ **MPS horizontal OI (%)**	**Mean**	0.00 d,e,f	0.00 d,e,f	5.94 d,e,f	73.69 a,b,c	87.48 a,b,c	100.00 a,b,c	< 0.001*
	SD	0.00	0.00	11.40	23.76	19.99	0.00	
	Median	0.00	0.00	0.00	77.48	100.00	100.00	
	Minimum	0.00	0.00	0.00	33.72	52.08	100.00	
	Maximum	0.00	0.00	30.60	100.00	100.00	100.00	
▪ **MPS total mean vertical OI (%)**	**Mean**	0.00 c,d,e,f	1.93 c,d,e,f	64.90 a,b,f	90.37 a,b	90.54 a,b	99.97 a,b,c	< 0.001*
	SD	0.00	6.92	25.91	13.42	12.85	0.07	
	Median	0.00	0.00	66.95	94.69	99.62	100.00	
	Minimum	0.00	0.00	0.00	46.56	66.87	99.82	
	Maximum	0.00	30.29	100.00	100.00	100.00	100.00	

SD: Standard Deviation, MPS: Midpalatal suture, OI: Obliteration index.

a-f: Denote the significance between age groups. Each column's age category has been assigned a letter: (≤ 10 years a, 11-20 years b, 21-30 years c, 31-40 years d, 41-50 years e, 51-60 years f). Letters present below the group mean indicate significance with the assigned groups. ****: P-value is statistically significant.***

TABLE (2): Descriptive statistics and comparison of the mean, SD, median, minimum, and maximum values of the quantitative study parameters between the different age groups in females.

Females		Age groups ≤ 10 years a	11-20 years b	21-30 years c	31-40 years d	41-50 years e	51-60 years f	P value
Descriptive statistics	**Mean**	8.25	15.57	24.63	35.67	44.00	55.83	
	SD	2.19	2.89	3.08	2.87	2.56	3.43	
	Count	8	21	19	21	12	6	
	%	9.2	24.1	21.8	24.1	13.8	6.9	
	Maximum	42.47	47.39	48.13	49.78	44.33	47.20	
Quantitative parameters								
▪ **MPS horizontal OI (%)**	**Mean**	0.00 d,e,f	2.16 d,e,f	24.29 d,e,f	74.06 a,b,c	82.52 a,b,c	100.00 a,b,c	< 0.001*
	SD	0.00	9.90	29.49	24.68	21.83	0.00	
	Median	0.00	0.00	17.36	74.17	99.98	100.00	
	Minimum	0.00	0.00	0.00	24.47	51.02	100.00	
	Maximum	0.00	45.36	85.00	100.00	100.00	100.00	
▪ **MPS total mean vertical OI (%)**	**Mean**	0.00 c,d,e,f	7.81 c,d,e,f	35.21 a,b,d,e,f	75.20 a,b,c	95.36 a,b,c	99.76 a,b,c	< 0.001*
	SD	0.00	12.39	24.02	21.02	7.48	0.58	
	Median	0.00	0.00	30.99	78.31	100.00	100.00	
	Minimum	0.00	0.00	0.00	29.37	81.71	98.58	
	Maximum	0.00	40.66	86.10	100.00	100.00	100.00	

SD: Standard Deviation, MPS: Midpalatal suture, OI: Obliteration index.

a-f: Denote the significance between age groups. Each column's age category has been assigned a letter: (< 10 years a, 11-20 years b, 21-30 years c, 31-40 years d, 41-50 years e, 51-60 years f). Letters present below the group mean indicate significance with the assigned groups. *: P-value is statistically significant.

age group 11-20 years, and only one 23 years old male in age group 21-30 years. In females, MPS vertical obliteration started in a 14 years-old girl, no obliteration was detected at all age group ≤ 10 years, 14 females (66.66%) aged 11-18 years old, two females aged 22- and 24-years old.

Regarding the MPS maturation stage in males, stages A and B only were found in age group ≤ 10 years. Stages A, B, and C were found in age group 11-20 years. Regarding the age group 21-30 years, stage C was the most frequent (82.35%), while stage B was observed in one case only and stage D was noticed in two cases. For age group 31-40 years, most cases showed stage E and three cases were stage D. For age groups 41-50 and 51-60, only stage E was recorded. In addition, there was statistically significant increase in the frequency of MPS maturation stages with increasing age, represented by symbols, with stage A significantly prevalent in age group ≤ 10, stage B in 11-20 years, stage C in 21-30 years, and stage E in ages 31-60 years **(Table 4, Figure 4)**.

Regarding females, stages A and B only were found in age group ≤ 10 years. Stages A, B, C, and one case stage D were found in age group 11-20 years where stages B and C prevailed. Regarding the age group 21-30 years, stage C was the most

TABLE (3): Prevalence of quantitative and morphologic study parameters in age groups 11-20 and 21-30 years in males and females.

Age	**Number of cases**		**MPS horizontal obliteration**		**MPS vertical obliteration**		**MPS stage**	
11-20 years	**(Males) (n=20)**	**(Females) (n=21)**	**(Males) (n=20)**	**(Females) (n=21)**	**(Males) (n=20)**	**(Females) (n=21)**	**(Males) (n=20)**	**(Females) (n=21)**
11	1	3	-	- - -	-	- - -	**A**	**A,B,C**
12	2	0	- -		- -		**A,B**	
13	3	2	- - -	- -	- - -	- -	**A,B,B**	**A,B**
14	1	4	-	- - - -	-	- - - +	**B**	**B,B,B,C**
15	4	1	- - - -	-	- - - -	-	**A,B,B,B**	**B**
16	2	2	- -	- -	- -	- -	**A,B**	**B,B**
17	3	3	- - -	- - -	- - +	- - +	**B,B,C**	**B,B,C**
18	3	2	- - -	- -	- - +	- +	**B,B,C**	**C,C**
19	0	2		- +		+ +		**C,D**
20	1	2	-	-	-	+ +	**B**	**C,C**
21-30 years	**(Males) (n=17)**	**(Females) (n=19)**	**(Males) (n=17)**	**(Females) (n=19)**	**(Males) (n=17)**	**(Females) (n=19)**	**(Males) (n=17)**	**(Females) (n=19)**
21	1	4	-	- - - -	+	+ + + +	**C**	**C,C,C,C**
22	2	3	- -	- + +	+ +	- + +	**C,C**	**B,D,D**
23	3	1	- - -	-	+ + -	+	**C,C,C**	**C**
24	3	1	- - -	-	+ + +	-	**B,C,C**	**C**
25	0	2		- +		+ +		**C,D**
26	4	3	- - - -	- + +	+ + + +	+ + +	**C,C,C,C**	**C,D,D**
27	0	2		+ +		+ +		**D,E**
28	0	0						
29	2	1	+ +	+	+ +	+	**C,C**	**E**
30	2	2	+ +	+ +	+ +	+ +	**D,D**	**D,E**

MPS: Midpalatal suture, +: obliteration present, -: no obliteration

frequent (42.1%), followed by D, while stage B was observed in only one case and stage E was noticed in three cases. For age group 31-40 years, most of the cases showed stage E and stage D was found in three cases. For age groups 41-50 and 51-60, only stage E was observed. In addition, there was statistically significant increase in the frequency of MPS maturation stages with increasing age, with stage A prevalent significantly in age group ≤ 10 years, stage B in 11-20 years, stage C in 11-30 years, stage D in 21-30years, and stage E in ages 31-60 years (**Table 5, Figure 4**).

Table (4) and (5) also reveal that open MPS (Stages A, B, and C) was found in 44 males and 37 females: a total of 81 out of 165 individuals under study (49 %).

Pearson correlation coefficients showed significant positive correlation between age and MPS horizontal OI, MPS total mean vertical OI, and MPS stage in the whole sample (r = 0.876, 0.882, and 0.890 respectively), among females (r =0.873, 0.905, and 0.877 respectively), and among males (r= 0.881, 0.868, and 0.912 respectively) (**Table 6**).

TABLE (4): Comparison of midpalatal suture maturation stages between the different age groups in males.

MPS stage	Males	Age groups ≤ 10years a	11-20 years	21-30 years c	31-40 years d	41-50 years e	51-60 years f	Total	chi square/ Fisher's exact	P value
A	Count	8 b,c,d,e,f	5 a,c,d	0 a,b	0 a,b	0 a	0 a	13	158.061	<0.001*
	Expected Count	1.5	3.3	2.8	2.7	1.5	1.2	13.0		
	% within Age groups	88.9%	25.0%	0.0%	0.0%	0.0%	0.0%	16.7%		
B	Count	1 b	13 a,c,d,e,f	1 b	0 b	0 b	0 b	15		
	Expected Count	1.7	3.8	3.3	3.1	1.7	1.3	15.0		
	% within Age groups	11.1%	65.0%	5.9%	0.0%	0.0%	0.0%	19.2%		
C	Count	0 c	2 c	14 a,b,d,e,f	0 c	0 c	0 c	16		
	Expected Count	1.8	4.1	3.5	3.3	1.8	1.4	16.0		
	% within Age groups	0.0%	10.0%	82.4%	0.0%	0.0%	0.0%	20.5%		
D	Count	0	0 d	2	3 b	0	0	5		
	Expected Count	0.6	1.3	1.1	1.0	0.6	0.4	5.0		
	% within Age groups	0.0%	0.0%	11.8%	18.8%	0.0%	0.0%	6.4%		
E	Count	0 d,e,f	0 d,e,f	0 d,e,f	13 a,b,c	9 a,b,c	7 a,b,c	29		
	Expected Count	3.3	7.4	6.3	5.9	3.3	2.6	29.0		
	% within Age groups	0.0%	0.0%	0.0%	81.3%	100.0%	100.0%	37.2%		
Total	Count	9	20	17	16	9	7	78		
	Expected Count	9.0	20.0	17.0	16.0	9.0	7.0	78.0		
	% within Age groups	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%		

MPS: Midpalatal suture.

Each column's age category has been assigned a letter: (< 10 years a, 11-20 years b, 21-30 years c, 31-40 years d, 41-50 years e, 51-60 years f). Letters present below the group mean indicate significance with the assigned groups.

****: P-value is statistically significant.***

TABLE (5): Comparison of midpalatal suture maturation stages between the different age groups in females.

	Females		Age groups						Total	chi square/ Fisher's exact	P value
			≤ 10years a	11-20 years	21-30 years c	31-40 years d	41-50 years e	51-60 years f			
MPS stage	A	**Count**	7 b,c,d,e,f	2 a	0 a	0 a	0 a	0 a	9	144.54	<0.001*
		Expected Count	0.8	2.2	2.0	2.2	1.2	0.6	9.0		
		% within Age groups	87.5%	9.5%	0.0%	0.0%	0.0%	0.0%	10.3%		
	B	**Count**	1 b	10 a,c,d,e,f	1 b	0 b	0 b	0 b	12		
		Expected Count	1.1	2.9	2.6	2.9	1.7	0.8	12.0		
		% within Age groups	12.5%	47.6%	5.3%	0.0%	0.0%	0.0%	13.8%		
	C	**Count**	0 b,c	8 a,d,e	8 a,d,e	0 b,c	0 b,c	0	16		
		Expected Count	1.5	3.9	3.5	3.9	2.2	1.1	16.0		
		% within Age groups	0.0%	38.1%	42.1%	0.0%	0.0%	0.0%	18.4%		
	D	**Count**	0c	1c	7a,b,e	3	0 c	0	11		
		Expected Count	1.0	2.7	2.4	2.7	1.5	0.8	11.0		
		% within Age groups	0.0%	4.8%	36.8%	14.3%	0.0%	0.0%	12.6%		
	E	**Count**	0 d,e,f	0 d,e,f	3 d,e,f	18 a,b,c	12 a,b,c	6 a,b,c	39		
		Expected Count	3.6	9.4	8.5	9.4	5.4	2.7	39.0		
		% within Age groups	0.0%	0.0%	15.8%	85.7%	100.0%	100.0%	44.8%		
Total		**Count**	8	21	19	21	12	6	87		
		Expected Count	8.0	21.0	19.0	21.0	12.0	6.0	87.0		
		% within Age groups	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%		

MPS: Midpalatal suture. Each column's age category has been assigned a letter: (< 10 years a, 11-20 years b, 21-30 years c, 31-40 years d, 41-50 years e, 51-60 years f). Letters present below the group mean indicate significance with the assigned groups. *: P-value is statistically significant

TABLE (6): Pearson correlation analysis between age and the study parameters

Age		MPS horizontal OI	MPS total mean vertical OI	MPS stage
Whole sample	**r**	0.876	0.882	0.890
	P value	< 0.001*	< 0.001*	< 0.001*
	N	165	165	165
Males	**r**	0.881	0.868	0.912
	P value	< 0.001*	< 0.001*	< 0.001*
	N	78	78	78
Females	**r**	0.873	0.905	0.877
	P value	< 0.001*	< 0.001*	< 0.001*
	N	87	87	87

MPS: Midpalatal suture, OI: Obliteration index, r: correlation coefficient *: P-value is statistically significant,

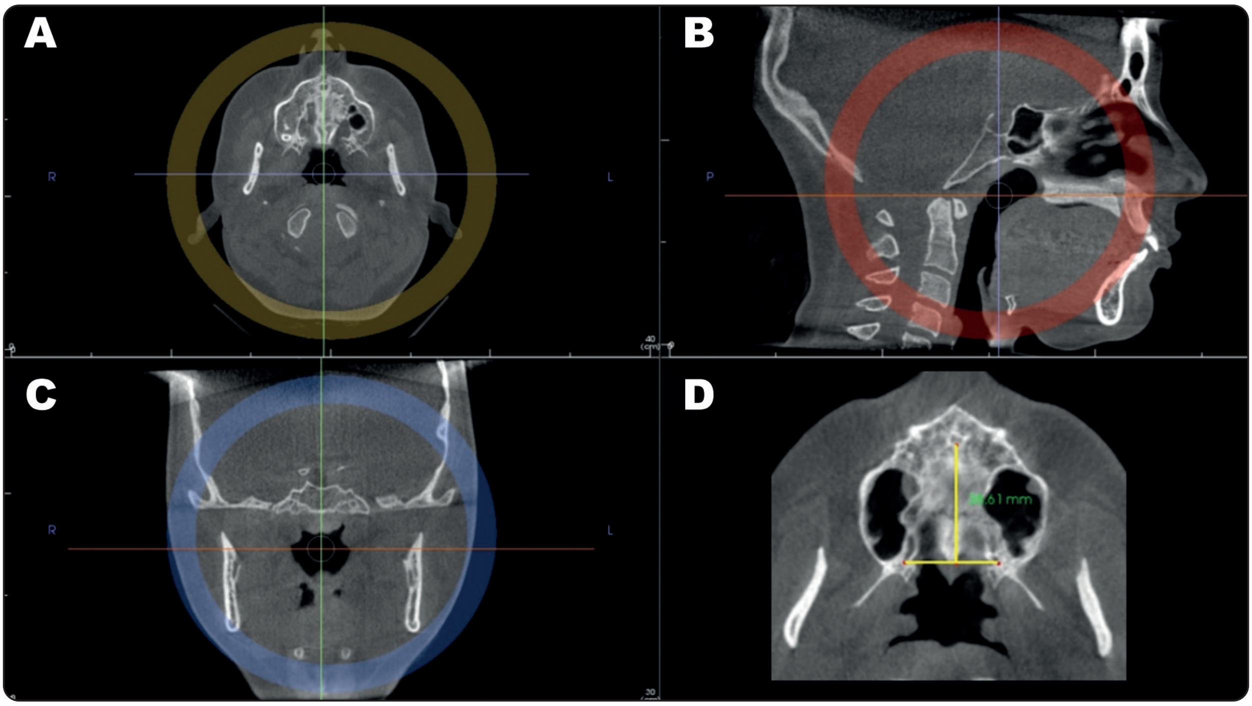

Fig. (1): CBCT images revealing MPS length measurement: (A, B, C) Orientation lines on the (A) axial, (B) sagittal, and (C) coronal planes, (D) MPS length was measured on the axial plane as the distance from the posterior margin of the incisive foramen to the intersecting point with a line tangent to the posterior margins of the two greater palatine foramina.

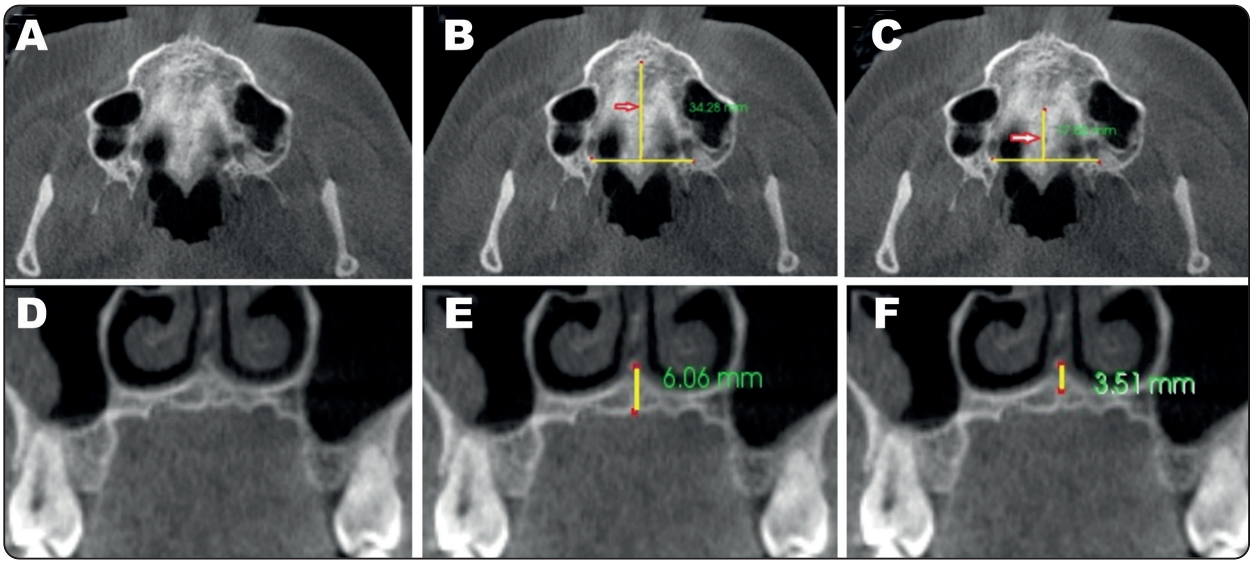

Fig. (2): Axial CBCT images (A, B, C) revealing MPS horizontal obliteration index assessment. (A) Partially obliterated MPS, (B) Total MPS length along the line indicated by the arrow, and (C) The length of the obliterated part of the MPS along the line indicated by the arrow. Coronal CBCT images (D, E, F) revealing MPS vertical obliteration index assessment. (D) Partially obliterated MPS, (E) Total MPS length, and (F) The length of the obliterated part of the MPS.

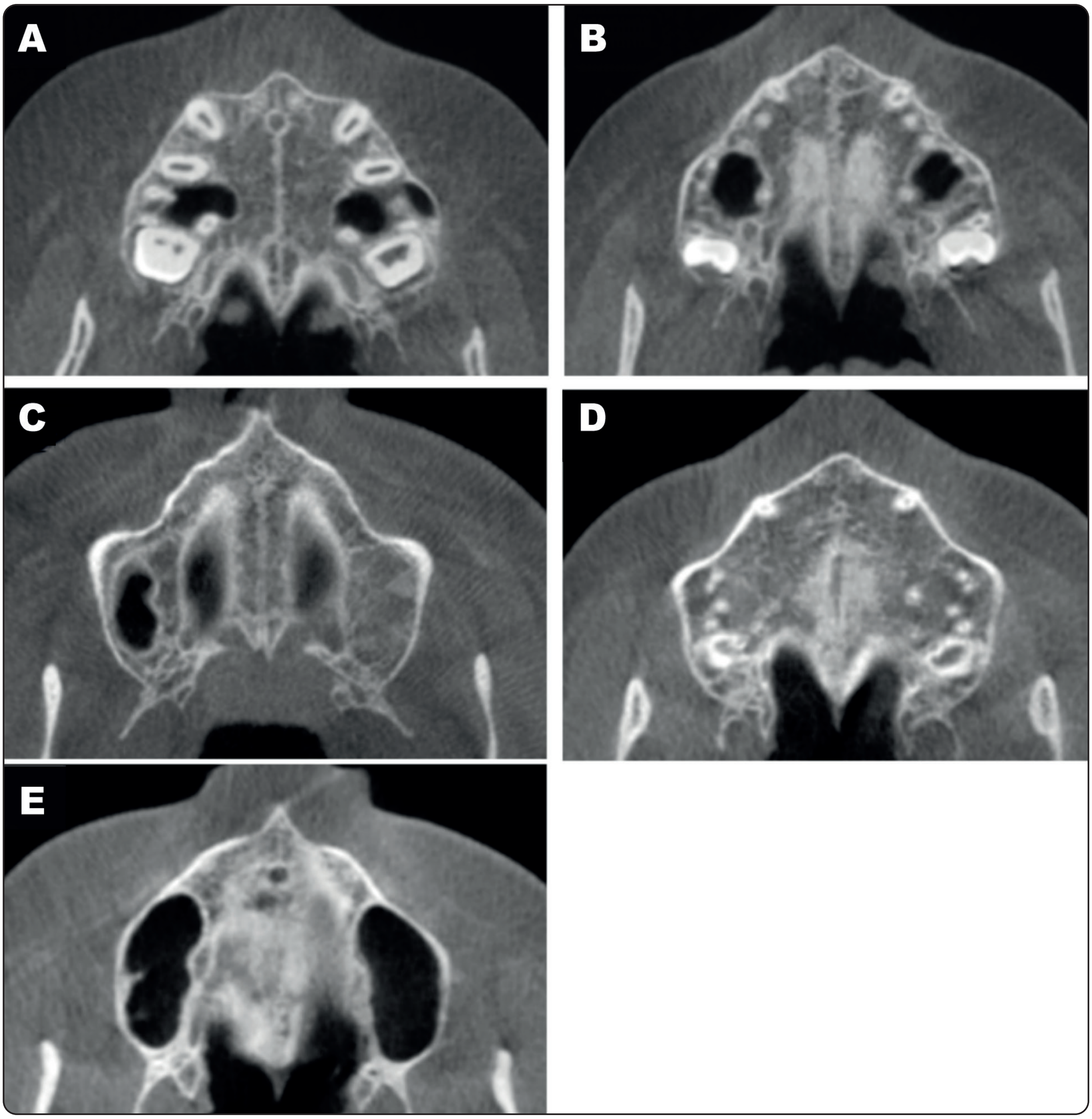

Fig. (3): Axial CBCT images revealing MPS maturation stages. (A) Stage A: MPS is nearly a straight high-density sutural line with little or no interdigitation. (B) Stage B: MPS assumes an uneven shape and looks like a scalloped high-density line. (C) Stage C: MPS looks like two parallel, scalloped, high-density lines separated by small low-density spaces in the suture maxillary and palatine regions. (D) Stage D: MPS has been obliterated in the palatine region, with maturation proceeding from posterior to anterior. (E) Stage E: Obliteration of the MPS has occurred in the maxilla. The actual suture is not visible in at least a portion of the maxilla. The bone density at this stage is the same as other palate regions, and the parasutural bone density is increased.

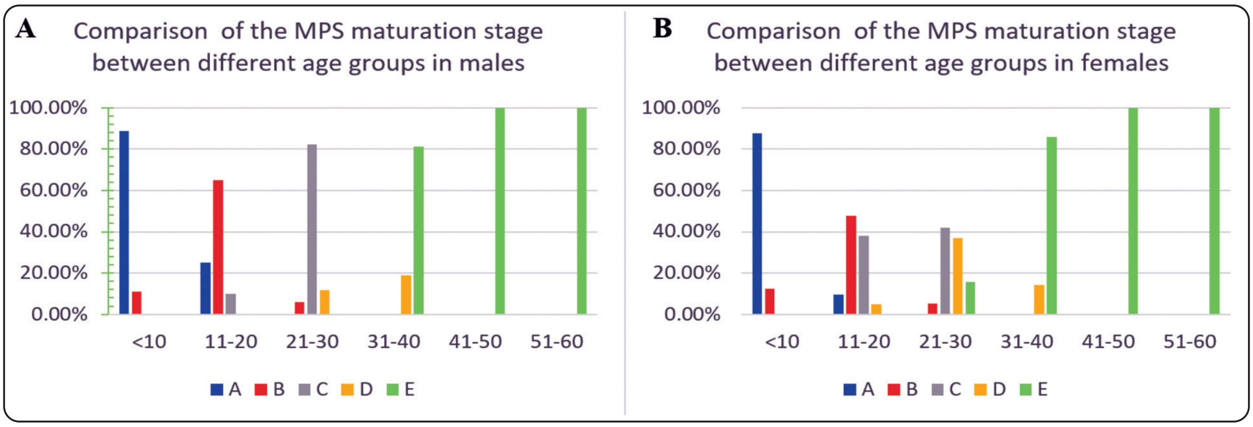

Fig. (4): Bar charts representing the percentages of occurrence of the MPS maturation stages in males (A) and females (B).

DISCUSSION

Open midpalatal suture is a vital solution to orthodontic problems in patients with maxillary deficiency and malocclusion cases. [23] Therefore, the aim of the present study was to evaluate the MPS maturation state quantitatively and morphologically using CBCT.

The present study revealed that the both the horizontal and vertical suture obliteration increased with age in both males and females. The MPS horizontal OI showed significant increase between ages more than thirty years (MPS horizontal OI range: 33.72%-100% in males and 24.47%-100% in females) and ages below (MPS horizontal OI range: 0%-30.6% in males and 0%-85% in females). In addition, MPS horizontal OI started at the age of 29 years old in males and at 19 years old in females, and no obliteration was observed in13 males (76.47%) aged 21-28 years and 9 females (47.36%) aged 21-26 years old of the age group 21-30 years. This was in agreement with Haghanifar et al. [24] in their CBCT study on the degree of MPS ossification in 10-year age group individuals with age range of 10 to 70 years, they showed that ossification increased with aging with some cases of completely open sutures observed in individuals older than 20-years old. In a study assessing the sutural biology, Cohen stated that no relationship exists between growth termination and sutural closure, as at the age of 7 years when almost 95% of the growth of the maxilla terminates, the suture is not closed. [25]

In the present study, the MPS total mean vertical OI showed significant increase between ages more than twenty years (MPS total mean vertical OI range:0-100% in both males and females) and ages below (MPS total mean vertical OI range:0-30.29% in males and 0-40.66% in females) indicating suture closure with age. Moreover, vertical obliteration started in males at 17 years where below this age no obliteration occurred, besides, one 23 years old male patient had no obliteration at all. Regarding females, vertical obliteration started in a 14 years-old girl, however, 14 females (66.66%) of this age group aged 11-18 years old did not show any suture obliteration. In addition, no suture obliteration was detected in two females aged 22- and 24-years old. This was in accordance with Kajan et al. [26] who evaluated the MPS opening depth in 167 CBCT scans of patients aged 7-25 years, they found that the percentage of MPS opening decreased with increasing age, moreover, they found MPS to be non-obliterated in some of the individuals in the age group 20-25 years. This was also near to Persson & Thilander [10] in their histologic examination of specimens from the palate of 24 subjects (15–35 years) who recorded ossification to start in a 15-year-old girl, however, no signs of ossification were observed in a 27-year-old female, further, marked amount of closure was rarely found younger than the third decade of life. Knaup et al. [9] in their study on 22 specimens of human palate from subjects aged (18-63 years) revealed that MPS obliteration is age dependent where there was a significant increase in the OI between ages $\leq$ 25 and $\geq$ 26 years old, the earliest signs of ossification were observed in a 21-year-old man; however, no ossification was detected in a 54-year-old man, moreover, the mean overall obliteration was 0-13.1% in their studied sample. Korbmacher et al. [11] in their micro-CT study on 28 specimens of human palate from individuals (14–71 years) revealed very low mean OI (0%-7.3%) in all the studied sample and reported that ossification was not age dependent, moreover, no obliteration was detected in a 71-year-old female which was similar to N'Guyen et al. [27] who found incomplete MPS ossification in their study on palatal specimens of human subjects older than 70 years. Willershausen et al. [15] in their study on 12 palatal specimens of individuals aged 20-80 years found obliteration as age-dependent, they found low/no obliteration (mean of 2%) in the 20–39-year age group and (mean of 8%) in the 60-80 year group. However, full vertical obliteration was not reported, in contrast to the present study, complete MPS vertical obliteration was detected in some cases starting from the age group (31-40 years) and proceeded in older age groups.

MPS maturation was reported to be different from other cranial sutures where its fusion is affected by the masticatory forces that act on the maxillary bones during the lifetime; therefore, the decrease in masticatory function due to teeth loss and higher frequency of soft diet consumption that occur due to aging might be causes of the open MPS observed in elderly. [27,28]

Regarding the MPS maturation stages, the present study revealed significant increase of the MPS maturation stage with age which was in accordance with previous studies. [8,9,21,23,24] Stages A and B were observed in the first two decades among our study sample, where stage A prevailed in the age group ≤10 years and stage B prevailed in the age group 11–20 years among both males and females with statistical significance, similar to Katti et al.[21] in their study on 200 CBCT scans of individuals 11-50 years who found that stages A and B were prevalent in age group 11-20 years. Moreover, this was close to Angelieri et al., [22] in their study of 140 CBCT scans aged 5.6 - 58.4 years, who reported the prevalence of stage A at the age 5-11 years, and stage B was up to 13 years of age. Further, Jimenez-Valdivia et al. [29] in their study on CBCT scans of 200 individuals aged 10 - 25 years old reported that stages A and B were prevalent in the age range of 10-15 years old. Similar to the present study, Ghasemi et al. [23] in their study on CBCT scans of 178 patients aged 10 -70 years old found stage B to be most prevalent in age group 10-19 years. However, Haghanifar et al. [24] reported high prevalence of stage A in the age 10-19 years, while stage B occurred with similar distribution among all the age groups.

Regarding stage C, it was observed in 2 males and 8 females among the 41 individuals in the age group (11–20 years) and in 14 males and 8 females among the 36 individuals in the age group (21–30 years) with frequency 24.39% and 61.11% in the two groups, respectively. This was very close to Katti et al. [21] who reported stage C prevalence of in 60% of age group 21-30 years and 40% in age 31-40 years. Haghanifar et al. [24] revealed that stage C prevalence was 31.2 % and 34.3% among age groups 20–29 years and 30–39 years respectively. On the other hand, stage C was prevalent at younger ages where Angelieri et al. [22] reported stage C to occur mainly from 11 to 18 years of age and in only 4 of 32 adult cases >18 years old which was in line with Jimenez-Valdivia et al. [29] who observed stage C prevalence of 45.2% at age group (10-15 years).

For stage D, which denotes the start of MPS fusion, it was most prevalent in the age group 21–30 years. This was in agreement with Angelieri et al. [22] who reported stage D highest prevalence in adults aged >18 years old. Further, the present study results denoted that stage D started at 19 years old in females and 30 years old in males. Ghasemi et al. [23] found stage D to start at age group 20-29 which was like Katti et al. [21] where stage D started at 21-30 years. However, Haghanifar et al. [24] reported stage D only in people over 40 years. On the other hand, Jimenez-Valdivia et al. [29] reported MPS fusion below 15 years.

Regarding stage E, which denotes MPS palatal and maxillary fusion, this stage occurred with a lower percentage (8.3%) among females in the age group 21-30 years; however, it frequently occurred above 30 years of age and occurred in all individuals above 40 years old in both males and females which was along with Angelieri et al. [6] who studied 78 CBCT scans from individuals aged 18-66 years and found that stage E prevalence increased above 30 years of age. Likewise, Angelieri et al. [22] revealed the highest frequency of stage E among adults >18 years. Similarly, Ghasemi et al. [23] denoted the start of stage E above 30 years of age with the highest frequency at age 50-59 years old. Also, Haghanifar et al. [24] did not find stage E below 30 years and reported a prevalence (47%) in the >50 years old group. Jimenez-Valdivia et al. [29] observed the highest frequency of stage E (55.7%) among the (20–25 year) age group which was the oldest group in their study.

Angelieri et al. [22] postulated that RME is effective in stages A, B, and to some extent stage C, but in stages D and E SARME is recommended because the MPS fusion at stage D would prevent sutural opening in the molar region if RME is applied, even if an anterior diastema, as an effect of RME to widen the arch, is observed. Conventional intervention after fusion starts may lead to extrusion of premolars or molars and subsequent periodontal injury. [22]

Pearson correlation coefficient in the present study revealed significant positive correlation between age and all the study parameters in the whole study sample which further confirm the MPS maturation with age.

The present study results denoted that MPS maturation started earlier in females than in males which was in line with several studies. [22,29] Puberty often begins at a lower age in females than males. This implies that females frequently go through the pubertal growth spurt at an earlier age. [30]

It should be noted that, besides the MPS, other circumaxillary sutures i.e., zygomaticomaxillary suture, frontomaxillary suture, and the spheno-occipital synchondrosis contribute to RME success. [14,26,31] It was reported that the opening of the zygomaticomaxillary suture helps to decrease the orthopedic forces applied on the MPS to expand the maxilla.[26] However, the states of closure of other circumaxillary sutures were not addressed in the present study.

Despite of the present study findings that the MPS OI and MPS maturation stages increased with age; yet there was diversity in the occurrence of MPS obliteration, results of the MPS OI, and maturation stages at the second and third decades. This was the reason behind the detailed assessment of MPS obliteration and maturation stage in every patient of these two age groups (11-20 years and 21-30 years) and track the exact time of initiation of MPS obliteration per group. The vertical suture obliteration started at 17 years of age in males at 14 years in females with MPS maturation stage C. On the other hand, neither horizontal nor vertical obliteration were seen in one 23 years old male and one 24 years old female, both at stage C too. The present study results conform to those of previous studies [6,9,10,15,21,22,32] where the chronological age was unreliable for defining the MPS developmental stage. Moreover, the MPS maturation stage alone may be insufficient as the MPS showed vertical obliteration at stage C which was recognized as acceptable in conservative RME treatment. Accordingly, both the MPS stage and the suture obliteration using MPS OI (both horizontal and vertical) should be assessed as they, to a great extent, may serve as predictors for the maxillary expansion treatment success and give a chance for conservative RME treatment in late adolescent and adult patients. In addition, not only the presence of obliteration is of concern, but also the degree of ossification matters, as stated by Persson & Thilander [10] MPS obliteration should not exceed 5 % to achieve satisfactory treatment results.

CONCLUSION

The combined in vivo 3D quantitative and morphologic assessment of the MPS using CBCT provided valuable information regarding the MPS maturation. The chronological age was undependable in specifying the MPS maturation stage; consequently, the MPS should be appraised using CBCT for each patient requiring maxillary expansion as this will aid the orthodontist in decision making whether conservative or surgically assisted and in predicting the treatment outcome.

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