EVALUATION OF MIDPALATAL SUTURE MATURATION AND ITS CORRELATION WITH MAXILLARY SECOND MOLAR MINERALIZATION IN GROWING INDIVIDUALS

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ABSTRACT

OBJECTIVES

This study aimed to evaluate and correlate, using CBCT, the maturation stages of the mid-palatal suture (MPS) and the mineralization stages of the maxillary second molars in subjects to determine whether molar mineralization can predict MPS maturation.

METHODOLOGY

This study (cross-sectional) was conducted on 33 participants (aged 10-18 years). MPS maturation was assessed according to Angelieri et al., and second molar mineralization was evaluated using the Demirjian index from CBCTs. Spearman's correlation was used to assess the relationship between MPS maturation and second molar mineralization. Furthermore, partial correlation analysis was conducted to assess the relationship between these variables while controlling for age. Intra-examiner reliability was calculated utilizing intraclass correlation coefficients (ICC).

RESULTS

Intra-examiner reliability was high (ICC = 0.86). A significant moderate positive correlation was found between MPS maturation stages and second molar mineralization (ρ = 0.479, p = 0.005). When analyzed by gender, females showed a significant moderate correlation (ρ = 0.522, p = 0.018), whereas males showed a positive but non-significant correlation (ρ = 0.402, p = 0.173). Partial correlation analysis revealed a diminishing correlation between MPS maturation and molar mineralization (ρ = 0.282, p = 0.117).

CONCLUSION

A moderate correlation was observed between second molar mineralization and MPS maturation. However, the weakened correlation after adjustment for age indicates that the relationship is largely age dependent. Therefore, second molar mineralization may serve as a supporting indicator of MPS maturation rather than a definitive predictor.

KEYWORDS: *Mid-Palatal Suture Maturation (Mps), Demirjian Index, Molar Mineralization, CBCT.*

INTRODUCTION

Transverse maxillary deficiency is a challenging orthodontic problem with a prevalence of 8-22%.[1] It can lead to complex issues such as posterior crossbite, crowding, a V-shaped maxillary arch, a high and narrow vaulted palate, airway constriction, changes in tongue posture, and mouth breathing, all of which can deleteriously impact muscular function and esthetics.[2,3,4] Several treatment modalities exist for correcting transverse maxillary deficiency, which primarily depend on the maturation stage of the mid-palatal suture (MPS). MPS is an important anatomical structure that undergoes several changes over time. Initially described as broad and Y-shaped during infancy by Melson, its morphology changes gradually, eventually becoming fully interdigitated and fused.[4,5] Various orthopedic interventions induce the mid-palatal suture (MPS) separation, thereby attempting to correct the transverse maxillary deficiency and associated problems.[3,4,5,6,7] As the suture progresses towards fusion, its resistance to opening increases, diminishing response to skeletal expansion, noticeably post-puberty.[8,9] Several methods are being used for the evaluation of MPS, including 2D occlusal radiographs and 3D CBCT. Occlusal radiographs are considered inconclusive due to overlapping structures and the risk of false interpretation, given their 2D nature. [10] Currently, CBCT is preferred, as it provides a clear 3D view of the suture. In 2013, Angelieri et al. proposed a method of individual evaluation of MPS maturation using CBCT and determined five maturational stages (least to highly mineralized), fig 1.[5,10,11] Assessment of dental development is one of the supportive indicators for predicting growth phases. Generally, dental development can be evaluated at the tooth-eruption or tooth-formation stages. Currently, the Demirjian index is used in the literature for the assessment of tooth mineralization and calcification, among other methods.[12] The MPS maturation has

been correlated with various parameters like chronological age, hand-wrist x-rays 4, and cervical maturation CVM.[3,10,13] Age is not a reliable parameter, as reports show patients with no signs of fusion at ages 27, 32, 54, and even 71 years.[3,14,15] Recently, some studies have been conducted to correlate dental age and tooth mineralization with MPS maturation. In 2020, Gao et al. investigated the correlation between MPS and Demirjian dental age. Correlation of left lower second molar and MPS had the highest Spearman coefficient (0.68), while that of left lower second premolar and MPS was the second highest (0.64).[16] In 2023, Ńefeldaitėet al. evaluated mineralization of the third molar and its correlation with MPS maturation. A correlation (statistically significant positive) was found between the stages of third-molar mineralization and mid-palatal suture maturation (ρ =0.814, P<0.01).[11] Another similar study was performed in India by Munusamy et al. in 2023, results showed a positive correlation between CVM Stage and MPS stage (ρ = 0.930), mandibular left second molar mineralization stage and MPS stage (ρ = 0.757), and CVM stage and mandibular left second molar mineralization stage (ρ = 0.760).[10] Some of these earlier correlation studies used OPG, a 2D imaging tool, to assess the tooth, leading to a preference for studying the lower second molar because of potential structural overlap in the maxilla that could impede accurate evaluation.[10] However, with the utilization of CBCT, we can readily and accurately examine the upper second molar, benefiting from a clearer 3D perspective. The maxillary second molar was also selected because a previous study reported the highest correlation coefficient.[17] Therefore, the objective of this study was to ascertain a correlation and determine whether the mineralization stages of the maxillary second molar could serve as a predictive indicator for the maturation stages of MPS.

METHODOLOGY

This cross-sectional study included 33 participants, and it was conducted at Rehman College of Dentistry (RCD) after approval from the institutional Ethical Review Committee (EC Ref No: RCD-23-03-170). Informed consent was obtained from patients and guardians for minors. The sample size was 33 participants. Based on a previously reported correlation coefficient of 0.68 between MPS maturation and dental mineralization by Gao et al., a confidence level of 99% and a statistical power of 90% were set, yielding a minimum required sample size of 33 participants.[16] non-probability convenience sampling was employed. The Age 10-18 (male/female) are coming to the Radiology department of RCD for dental diagnostics. Whole maxilla CBCTs with dentition, including second molars, and high-quality CBCTs without artifacts were included, whereas previous orthodontic treatment was excluded. Patients with craniofacial conditions or syndromes, CLP, and a history of trauma to the maxilla were excluded. Participants were further categorized into preadolescent and postadolescent groups based on chronological age. Individuals aged 10-14 years were classified as preadolescents and those aged 15-18 years as postadolescents. The CBCT records of patients aged 10-18 years who came to the Radiology Department were collected from RCD, Peshawar. These records were taken using the CBCT scanner Carestream CS 9000 (Carestream Dental, Atlanta, GA) with the following scanning parameters: 70 kVp, 10 mA, 10.8 s, and a voxel size of 200µm**.** All CBCT volumes were acquired with the patients in an upright posture, with their heads in a natural head position, the mandible fixed with a chin rest, and the Frankfort plane parallel to the ground. For analysis, all collected CBCT data were converted to DICOM (Digital Imaging and Communications in Medicine) format and then imported into CS 3D imaging v3.10.11 (Carestream Dental, Atlanta, GA). The acquired images were standardized and aligned such that the Frankfort Horizontal Plane was parallel to the floor. With the CS 3D imaging v3.10.11(Carestream Dental, Atlanta, GA), maxillary MPS were explored in the axial view of the multiplanar reconstruction. The thickness of the midsagittal cross-sectional slice was adjusted for better visualization of the palate and suture. The stages of MPS fusion were observed on these standardized CBCT images in the axial plane, based on the method provided by Angeileri et al. (Fig 1a(a-e).[5,10,11] The maxillary second molar mineralization stages were investigated according to the Demirjian index11 on acquired CBCTs (Fig 1b).

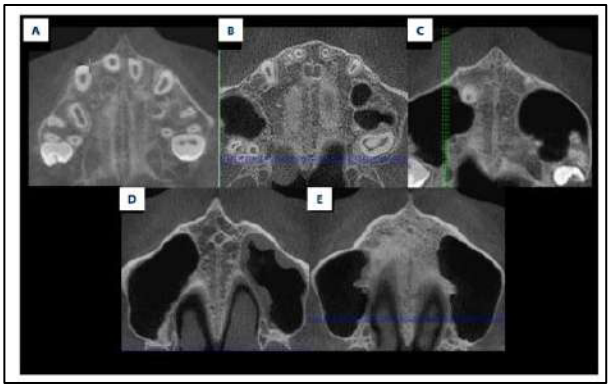

Fig 1a. Mid palatal suture maturation stages(a-e) according to Angeileri et al.[5]

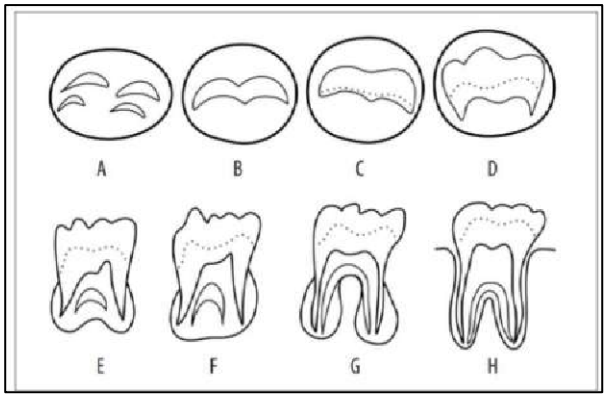

Figure 1b. Tooth mineralization stages(a-h) according to Demirjian et al. (1973).

Data were recorded and analyzed using SPSS version 25 (IBM Corp., Armonk, NY). For the quantitative variable (age), means and standard deviations were calculated. For all the qualitative variables (gender, MPS maturation stages, index), frequencies were calculated. Normality of the data was tested with the Shapiro-Wilk test, and nonparametric tests were applied. The correlation between the stages of midpalatal suture maturation and the maxillary second-molar mineralization was evaluated by Spearman's rank correlation coefficient (r) for the significance of the relationship. The significance for all statistical tests was set as $p \leq 0.05$. Furthermore, partial correlation analysis was performed, controlling for age.

RESULTS

A single examiner evaluated all CBCT images. To evaluate intra-examiner reliability, 10 CBCT scans were randomly reassessed after a two-week interval. Intraclass Correlation Coefficient (ICC) analysis demonstrated excellent agreement (ICC = 0.86). The study included 33 participants, 13 (39.4%) male and 20 (60.6%) female, aged 10 to 18 years (mean age of 14.97 ± 1.76 years). Analysis of suture maturation stages revealed that most participants were in Stage E (n = 18, 54.5%), followed by Stage B (n = 10, 30.3%). Stages C and D were less frequent, with 3 participants (9.1%) and 2 participants (6.1%), respectively. Assessment of second molar mineralization revealed that the majority of participants were in Stage H (n = 19, 57.6%), followed by Stage G (n = 7, 21.2%) and Stage F (n = 5, 15.2%). Only a small proportion were in the earlier stages, with one participant (3.0%) in each of Stages D and E. Spearman's correlation showed a significant, moderate positive correlation between second molar mineralization and suture maturation stages ($p = 0.005$, $\rho = 0.479$). This suggests that higher stages of second molar mineralization are associated with more advanced stages of suture maturation. Among male and female participants, a moderate positive and statistically insignificant correlation was observed between second molar mineralization and suture maturation ($\rho = 0.402$, $p = 0.173$) (Table 1), and a significant moderate positive and statistically significant correlation was found between second molar mineralization and suture maturation ($\rho = 0.522$, $p = 0.018$), respectively (Table 2). Based on the age categorization, preadolescent males exhibited early to intermediate suture stages (B-E) and second molar stages ranging from D to G, whereas females showed slightly more advanced stages, reaching F-H. Among postadolescents, nearly all males and females were in suture stage E and second molar stage H, indicating complete skeletal and dental maturation(Table 3). Overall, progression in second molar mineralization corresponded closely with higher suture maturation stages, particularly stage E, which aligned with stage H, suggesting a positive association between dental and skeletal maturation indicators without controlling for age. Furthermore, partial correlation analysis revealed that the correlation between second molar mineralization and MPS maturation diminished and lost statistical significance after adjusting for age ($\rho = 0.282$, $p = 0.117$). This implies that age-related developmental alterations may be partially responsible for the observed correlation (Table 4). In the total sample (N = 33), gender showed no significant correlation with suture maturation, second molar mineralization, or age (all $p > 0.05$). Significant moderate positive correlations were found between suture maturation and second molar mineralization (Spearman's $\rho = 0.479$, $p = 0.005$), between age and suture maturation ($\rho = 0.390$, $p = 0.025$), and between second molar mineralization and age ($\rho = 0.447$, $p = 0.009$). These results indicate that both dental and skeletal maturation advance with chronological age and are moderately associated with each other.

Table 1: Distribution of the Mid-palatal Suture Maturation Stages according to Second Molar Mineralization Stages in Males (n = 13)

Mean Age (yrs)	SD	Second Molar Mineralization Stage	MPS Maturation Stage B	C	D	E	Total
12.0	–	D	00	01	00	00	01
–	–	E	00	00	00	00	00
13.0	0.00	F	01	00	01	00	02
14.5	0.58	G	02	00	00	01	03
16.5	0.76	H	02	00	00	05	07

Note: Spearman's rho = 0.402, p = 0.173 (statistically insignificant positive correlation).

Table 2: Distribution of the Mid-palatal Suture Maturation Stages according to Second Molar Mineralization Stages in Females (n = 20)

Mean Age(yrs)	SD	Second Molar Mineralization Stage	MPS Maturation Stage B	C	D	E	Total
	–	D	00	00	00	00	00
13.0	–	E	00	00	00	01	01
14.7	0.58	F	01	02	00	00	03
15.3	0.58	G	02	00	00	02	04
16.7	0.65	H	02	00	00	10	12

Table 3: Distribution According to Categories of Age

Categories of Age	Gender	Suture Maturation	Second Molar Mineralization					Total
			D	E	F	G	H	
Preadolescent	Male	B		00	01	01	02	04
		C		00	01	00	00	01
		D		01	00	00	00	01
		E		00	00	02	00	02
	Total			01	02	03	02	08
	Female	B			01	02	01	04
		C			01	00	00	01
		D			01	00	01	02
		E			00	01	03	04
	Total				03	03	05	11
Postadolescent	Male	E					05	05
							05	05
	Female	B	00			01	01	02
		C	01			00	00	01
		E	00			00	06	06
	Total		01			01	07	09

Table 4:Interpretation of Partial Correlation

Variables	Partial Correlation (r)	p-value
Second molar mineralization ↔ MPS maturation (controlling for age)	0.282	0.117

DISCUSSION

The maturation stage of the mid-palatal suture (MPS) plays a pivotal role in determining successful outcomes of rapid maxillary expansion (RME). MPS is the key anatomical structure that enables transverse expansion of the maxilla in growing individuals. This study aimed to evaluate the correlation between the maturation stage of MPS and the mineralization stage of the maxillary second molar using cone-beam computed tomography (CBCT) in growing patients. The results demonstrated a statistically significant, moderate positive correlation between MPS maturation and second molar mineralization stages, suggesting that higher levels of molar mineralization are associated with more advanced stages of suture maturation. These findings suggest that dental mineralization may provide additional information regarding MPS maturation. MPS can be assessed with an occlusal radiograph; however, the two-dimensional nature of this imaging modality can create challenges and limit diagnostic accuracy due to the superimposition of the vomer and other nasal structures. The classification of MPS maturation is chosen for its demonstrated simplicity, accuracy, and reproducibility.[5] To evaluate the mineralization stages of maxillary second molars, the Demirjian index is used, as it is simple and reproducible. Maxillary second molars were assessed because existing literature focuses on mandibular second molars, with limited research on maxillary molars. The results of this study are consistent with findings of previous literature demonstrating a relationship between dental and skeletal maturation. Gao et al. (2020) reported a positive correlation between Demirjian stages of the mandibular second molar and MPS maturation.[16] Similarly, Munusamy et al. (2023) observed significant positive correlations between the mandibular second molar, cervical vertebral maturation (CVM), and MPS stage, reinforcing the potential of using dental mineralization as a predictor of suture development.[10] Likewise, Ńefeldaitė et al. (2023) found a stronger correlation between third molar mineralization and MPS maturation.[1] Another study by Booth et al. in 2024 showed a weak correlation between MPS and third molar mineralization, since many people have congenitally missing third molars. [18] Interestingly, the current study's findings showed that chronological age was not a reliable predictor of MPS maturation or molar mineralization, as age correlations were weak and statistically insignificant among males. However, when both genders were analyzed collectively, significant moderate correlations emerged between suture maturation and age and between second molar mineralization and age. These results align with previous studies reporting considerable individual variation in MPS fusion timing, with some individuals showing open sutures beyond age 30.[3,14,15] This underscores the inadequacy of chronological age as a standalone indicator for clinical decision-making in maxillary expansion therapy. Further partial correlation analysis, controlling for age, indicated that age-related developmental changes may partially explain the observed relationship between second molar mineralization and MPS maturation. Therefore, dental mineralization should be considered a supportive indicator rather than an independent predictor of MPS maturation. Gender differences were also observed in our study: females exhibited a significant moderate correlation between second molar mineralization and MPS maturation, while the correlation among males, although positive, was not statistically significant, possibly due to the small sample size. This may reflect the generally earlier onset of skeletal and dental maturation in females compared to males, consistent with findings from other studies. The present outcomes of our study may reinforce the notion that dental development can serve as an auxiliary indicator of

skeletal maturity when evaluating candidates for maxillary expansion. Since the success of conventional rapid maxillary expansion (RME) depends on the degree of MPS fusion, assessing second molar mineralization on routine CBCT (limited FOV) or panoramic radiographs may provide a low-radiation, accessible screening tool. Patients in earlier mineralization stages are more likely to show less advanced suture maturation; however, treatment decisions should not be based solely on dental mineralization.

LIMITATIONS

Nonetheless, the study's cross-sectional design limits causal inference, and its relatively small sample size limits generalizability. Another limitation of this study was the uneven distribution of MPS maturation stages, with the majority of participants in stages B and E and no subjects in stage A. This may have affected the strength of observed correlations and could limit generalizability across the complete spectrum of MPS maturation. Variations in molar mineralization timing across populations and individual genetic factors should also be considered. Future multicenter studies with larger, age-stratified samples are recommended to refine predictive thresholds and to explore the quantitative aspects of suture density and bone thickness in three dimensions.

CONCLUSIONS

A moderate positive correlation was observed between MPS maturation and maxillary second molar mineralization, suggesting that molar mineralization stages may provide some useful information regarding MPS maturation status. However, after controlling for age, the correlation weakened and lost statistical significance, suggesting that age may substantially influence both MPS maturation and dental mineralization. Therefore, although second molar mineralization may serve as an adjunctive indicator of MPS maturation, it should not be used as a sole predictor for clinical decision-making.

CONFLICT OF INTEREST: None

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AUTHORS CONTRIBUTION

Salka Urooj *- Concept & Design; Data Acquisition; Critical Revision; Supervision; Final Approval*

Ayesha Iftikhar *- Concept & Design; Data Acquisition; Data Analysis/Interpretation; Critical Revision; Final Approval*

Sohrab Shaheed *- Concept & Design; Data Acquisition; Drafting Manuscript; Critical Revision; Supervision; Final Approval*

The authors accept responsibility for all aspects of the work and will ensure that any concerns regarding the accuracy or integrity of any part are properly investigated and resolved.