Predictive factors for midpalatal suture maturation: a CBCT-based analysis

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SUMMARY

The midpalatal suture is a critical anatomical feature that contributes to the maturation and fusion of the maxillary process. This study uses axial and coronal maxillary CBCT images of 137 subjects to investigate the ossification stages of the midpalatal suture in various age groups and genders, as well as their connection to maxilla thickness. In order to determine the correlation between age and gender and the five phases of ossification, 137 CBCT images of the Indian population, with ages ranging from 10 to 69 years, were analysed. The study demonstrated a statistically significant correlation between ossification and various age groups, with a P value of less than 0.05. The ossification of the midpalatal suture is significantly correlated with age changes, which implies that the stages of ossification increase as age increases. Understanding the ossification stages of various ages is essential for the planning of treatment and is also essential in the field of forensic sciences.

Key words: Midpalatal suture – Cone Beam Computed Tomography – Skeletal maturation – Ossification

INTRODUCTION

Growth and development are the biological processes of living matter that continuously evolve from conception to maturity. As they are genetically inherited, each human being has a distinct path (Willershausen et al., 2019). A network of soft tissues known as the craniofacial sutures plays a critical role in the growth site acting as a functional and mechanical environment of the skull (Remesz et al., 2023). The midpalatal suture is a vital anatomical feature found in the roof of the mouth, specifically in the midline where the two maxillary bones meet. Development of the cranium and tooth alignment are significantly influenced by this structure. During infancy and childhood, this suture is flexible, allowing for growth and expansion of the maxillary bones. However, as individuals reach adulthood, the sutures typically fuse, resulting in a stable and rigid structure (Gao et al., 2022).

The process of ossification of one such suture, the mid-palatal suture, commences as a bony spur from the borders of the suture, as well as volumes of acellular tissues and irregularly calcified tissue within the sutural spaces. The number of spurs enhance as the suture matures and the

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spurs are formed in several areas (Persson and Thilander, 1977). Ossification progresses from the postero-anterior region of the suture, with the replacement of cortical bone by cancellous bone. Fusion takes place in the posterior region of the suture (Cohen, 1993). Age and gender influence the initiation and progression of mid-palatal suture unification (Persson and Thilander, 1977).

Cone Beam Computed Tomography (CBCT) is valuable in imaging the midpalatal suture due to its high resolution and 3D capabilities. It provides detailed views of the maxilla, allowing precise assessment of the suture's morphology, position, and fusion status. CBCT facilitates the accurate diagnosis of midpalatal suture abnormalities such as midline diastemas or incomplete fusion, which is crucial for orthodontic treatment planning and surgical interventions (Colonna et al., 2021).

The purpose of this study is to analyse the ossification/maturation stages based on the Angelieri et al. (2013) classification stages in different age groups and genders, as well as to evaluate the palatal bone height in the Indian population using the axial and coronal slices in the CBCT images.

MATERIALS AND METHODS

The institutional ethics committee has validated this descriptive, retrospective, monocentric study. Volumetric images produced in the large view modes were generated using Planmeca ProMax 3D. A convenient sampling technique was used, assuming an absolute precision of 5% and a confidence level of 95%. A total of 137 CBCT scans, 69 males and 68 females, were utilised between May 2023 and January 2024, which satisfied the following criteria.

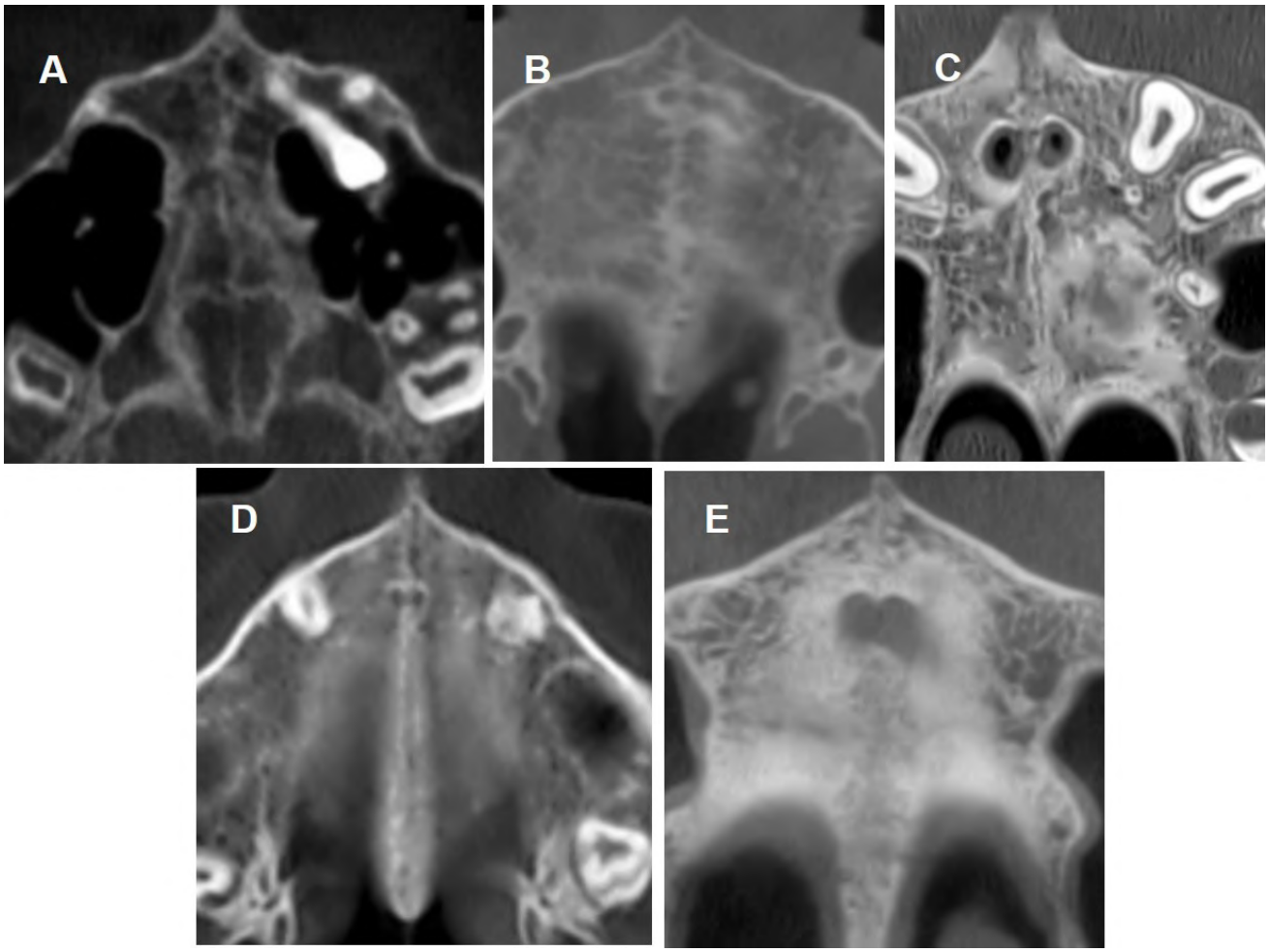

Fig. 1.- CBCT images of different stages in palatal maturation. **A:** shows straight line with high density. **B:** shows sutural lines with high density and toothed edge. **C:** two sutural lines with high density that are parallel to each other and a little distance with each other. **D:** complete ossification without observation of the sutural line. **E:** complete ossification of maxillary bone.

Inclusion criteria

1. CBCT images of subjects ranging in age from 10-69 years.
2. CBCT images with optimum diagnostic quality.
3. Ideal axial and coronal sections of optimum diagnostic CBCT images showing maxillary region.

Exclusion criteria

1. CBCT of axial and coronal images that do not depict the maxillary region or the midpalatal suture clearly.
2. Images with developmental defects, surgical defects or pathology involving the maxilla.
3. Inadequate image quality, including images with exposure artefacts, subject artefacts, and inherent artefacts.

Radiographic images that satisfy the inclusion criteria were further analysed for ossification in 5 stages in the axial section, which include: (Fig. 1)

- Stage A: a linear line with a high density.
- Stage B: sutural lines with notched edges and highly dense.
- Stage C consists of two sutural lines that are densely packed and running side by side to each-other, with a small space between them.
- Stage D: completely ossified without evidence of sutural line.
- Stage E: involves entirely ossified maxillary bone in individuals of different ages and genders.

In the coronal section, the thickness of the midpalatal suture was analysed among different age groups.

Statistical analysis

Statistical analysis was carried out, with a 95% confidence level, using chi-square test for qualitative data and an independent t test was employed for quantitative data. The demographic data were evaluated using descriptive statistics. A p value less than 0.05 will be considered statistically significant.

RESULTS

The study's participants included individuals aged between 10 and 69 years. Among 137 subjects, 26 (18.97%) were between the ages of 10-19, 34 (24.81%) were between the ages of 20-29, 13 (9.48%) subjects were between the ages of 30-39, 20 (14.59%) subjects were between the ages of 40-49, 25 (18.24%) subjects were between 50-59 and 19 (13.86%) subjects were between 60-69, respectively (Table 1). Based on the ossification stages, 14 were stage A, 29 were stage B, 43 were stage C, 30 were stage D and 21 were stage E (Table 2).

Table 1. Frequency and percentage of study participants grouped by age.

AGE RANGE	FREQUENCY	PERCENTAGE
10-19	26	18.97%
20-29	34	24.81%
30-39	13	9.48%
40-49	20	14.59%
50-59	25	18.24%
60-69	19	13.86%
TOTAL	**137**	**100**

Table 2. Frequency and percentage of the study participants according to the ossification stage.

OSSIFICATION STAGE	FREQUENCY	PERCENTAGE
A	14	10.21%
B	29	21.16%
C	43	31.38%
D	30	21.89%
E	21	15.32%
TOTAL	**137**	**100**

Among the 69 males, 7 had stage A, 19 had stage B, 21 had stage C, 13 had stage D and 9 had stage E. Of the 68 females, 7 had stage A, 10 had stage B, 22 had stage C, 17 had stage D and 12 had stage E, which showed a p value of 0.438 which is statistically insignificant among genders (Table 3).

Table 3. Study participant frequency and percentage according on gender and ossification stage

OSSIFICATION STAGE	A	B	C	D	E	TOTAL	P value
MALE	7	19	21	13	9	69	0.438
FEMALE	7	10	22	17	12	68	
TOTAL	**14**	**29**	**43**	**30**	**21**	**137**	

Table 4. Frequency and percentage of study participants categorised by age and ossification stage.

OSSIFICATION STAGE	10-19	20-29	30-39	40-49	50-59	60-69	TOTAL	p value
A	6	3	1	0	4	0	14	<0.001
B	6	11	7	2	1	2	29	
C	10	12	5	6	6	4	43	
D	4	8	0	6	9	3	30	
E	0	0	0	6	5	10	21	
TOTAL	**26**	**34**	**13**	**20**	**25**	**19**	**137**	

The prevalence and probability of the ossification phases varied significantly among the different age groups, with a p value >0.05, as depicted in (Table 4). The relation between the thickness and ossification were statistically negligible, with a p value of 0.396 during chi-square analysis.

DISCUSSION

Sutures are growth centres that play a vital role in active areas of bone formation and deposition that contribute to overall craniofacial development. The ability of the sutures to grow until early adulthood allows the skull to expand in parallel to the growth of the brain. Compared to other mammals, humans have a delayed pattern of ossification in their sutures, which allows postnatal development of the skull. The suture that connects the two palatal shelves is known as the midpalatal suture, which helps in the fusion and expansion of the maxillary arch through the process of ossification. This fusion typically occurs during the late teenage years or early adulthood. As ossification progresses, the midpalatal suture gradually loses its flexibility and becomes a rigid, immovable structure, effectively joining the two maxillary bones into a single unit (Latham, 1971).

The present study evaluates higher age groups because the midpalatal suture holds significance in forensic anthropology in determining age as it undergoes morphological changes with increasing age (Willershausen et al., 2019). Based on the previous literature, a large sample size with a wide range of age groups is recommended. Cohen et al. theorized that there is no significant relation between the age and the termination of growth in an individual. This signifies that even though 95% of the growth of the maxilla is completed by the age of 7 years, which does not necessarily indicate the closure of the suture (Cohen, 1993). Haghanifar et al. (2017) revealed that incomplete fusion of the suture in individuals over 40 years of age. Therefore, it is necessary to get an extensive sample that encompasses a broader spectrum of age groups in order to thoroughly examine the relationship between the level of ossification and the process of ageing, which in turn helps in accurate orthodontic treatment planning and also in forensic anthropology.

A CBCT study conducted in Iran, shows highest ossification noted in stage C of 40.4%, followed by stage D of 26.4%, and stages B and E show similar frequencies, whereas in our study, the highest ossification noted in stage C of 31.3%, followed by stage B and D showing similar frequency of 21.1% and 21.8%. Also, in contrast to the findings of Vahdat et al. (2020), our study demonstrates a prevalence of 10.2% in stage A, while Vahdat et al. (2020) reported a prevalence of 0% in the same stage (CSL STYLE ERROR: reference with no printed form). This variation may be due to different ethnic populations, socioeconomic differences, and dietary habits. Studies claimed that the relative progress and the formation of the mid-palatal suture is contingent upon the masticatory pressures exerted on the maxillary bone over an individual's lifetime. Unlike other cranial sutures, ossification process and suture morphology are affected by mechanical forces like the forces of mastication. Research has established a correlation between the presence of an open suture in adults and a decline in the functional strength of muscles as a result of ageing and tooth loss, or the use of a softer diet due to poor health (Katsaros et al., 2006; N'Guyen et al., 2008).

The study carried out by Ghasemi and Nguyen found statistically insignificant differences within the ossification stages and gender. Similarly, our analysis showed statistical insignificance among ossification stages and gender (Vahdat et al., 2020; N'Guyen et al., 2008). As a result, age or gender is not a reliable indicator of the suture's developmental stage; instead, factors such as hormonal, genetic, and mechanical influences should be taken into account in addition to age. Haghanifar stated that gender did not have a major impact on the level of ossification of the suture. However, a noteworthy rise in ossification was seen in women compared to men after a decade, which is in accordance with the present study (Haghanifar et al. 2017).

A study conducted by Knaup found a strong correlation between the ossification of the midpalatal suture and age. Specifically, individuals below the age of 25 had a wider suture compared to those over the age of 25. Additionally, the study observed the highest bone density in individuals between the ages of 18 and 63, which aligns with our own findings (Knaup et al., 2004). In the evaluation of 200 CBCT scans of people aged 11 to 50, Katti et al. (2020) discovered that stages A and B were common in the 11-20 age range, which is in line with our study. In our study, it was noted that on stage C, the prevalence was 51.1%, which is the highest across all age groups (10-29), whereas Katti et al. (2020) found that the stage C prevalence was 60% in those aged 21-30 years and 40% in those aged 31-40 years. For stage D, Vahdat et al. (2020) found that stage D started at the age group of 20-29 whereas Katti et al. (2020) started at 21-30 years, which is in accordance with our study with the highest frequency in 50-59 years. In relation to stage E, which signifies the fusion of the maxillary bones occurring after the age of 40, this finding aligns with the research conducted by Angelieri et al. (2013). They examined 78 CBCT scans of persons aged 18-66 and observed that the prevalence of stage E rose after the age of 30.

Palatal bone height is an essential factor in various dental procedures, including basal implant placements and orthodontic treatments. The literature suggests that the height of the palatal bone varies depending on the location and the individual's age and gender (Gibas-Stanek et al., 2023). It is advisable to position palatal micro-implants near the midpalatal suture to reduce the likelihood of incisor root injury (Wilmes et al., 2016). Nevertheless, it is advisable to refrain from using this particular region for implantation in infants and adolescents due to its potential interference with maxillary bone formation. Furthermore, when the suture is not fully mineralized, it might negatively impact the stability of micro-implants and raise the risk of miniscrew loss (Bernhart et al., 2000). However, in the present study, the connection between ossification stages and palatal bone height is statistically negligible.

The midpalatal suture plays a pivotal role in craniofacial development and orthodontic care by facilitating the growth and manipulation of the palatal shelves during the embryonic stages. Previously, it was thought to fully ossify during early adulthood, but recent studies reveal considerable variability in ossification timing, with some individuals retaining partial ossification into later stages of life. Research suggests a link between the expression of FGFR1-2 genes and the formation of midfacial bones, indicating that mutations in these genes may lead to abnormalities in midfacial tissue growth. These findings have clinical implications, particularly in syndromic disorders like Crouzon, Apert, and Pfeiffer syndromes, where midfacial hypoplasia can result in ocular, respiratory, and dental complications such as severe crowding (Bachler and Neubüser, 2001; Britto et al., 2001).

Additionally, the flexibility of the midpalatal suture remains crucial throughout an individual's lifespan to accommodate changes in the oral cavity. Orthodontic procedures such as rapid maxillary expansion rely on the integrity of this suture for successful outcomes. Neglecting midfacial hypoplasia can worsen dental crowding and contribute to malocclusion, highlighting the importance of early intervention and personalized orthodontic approaches. Understanding the molecular mechanisms underlying suture ossification enhances clinical strategies, emphasizing the importance of proactive management to address associated issues. In summary, the midpalatal suture's dynamic nature underscores its critical role

in craniofacial development, orthodontic care, and long-term oral health.

CONCLUSION

The midpalatal suture is a vital component in the craniofacial complex, and the success and timing of maxillary expansion depend on how well it matures and ossifies. The ossification process and the suture's morphology are greatly influenced by the mechanical forces of mastication, even though age and gender are important considerations. Therefore, a combination of methods is recommended for clinical decision-making regarding the development and maturation of the MPS before maxillary expansion. The level of initiation and ossification stages of the mid-palatal suture can be accurately assessed using CBCT due to its high-resolution. Additionally, in forensic anthropology, the stage of ossification of the mid-palatal suture can provide valuable information for estimating the age of individuals, particularly in cases involving skeletal remains. Further research is needed to establish a reliable and standardised method for assessing MPS maturation. Overall, the ossification of the midpalatal suture represents an important aspect of craniofacial development and serves as a marker of skeletal maturation in both clinical and forensic contexts. To our understanding, this is the first study that analyses ossification stages and palatal bone thickness.

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