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Original Article

Enhanced CBCT Assessment of Midpalatal Suture Maturation: A Retrospective Comparison of Axial and Coronal Approaches

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ABSTRACT

Determining the most suitable technique for maxillary expansion hinges heavily on the developmental stage of the midpalatal suture. A CBCT-based classification proposed by Angelieri *et al*. shifted the focus away from chronological age toward the evaluation of individual morphology. Yet questions have been raised about the diagnostic reliability of relying solely on axial CBCT sections, owing to inter-examiner inconsistency and the inherent challenge of judging intermediate stages (C and D). By revealing morphological features that a single-plane assessment might miss, the addition of standardized coronal sections to the conventional axial evaluation could heighten diagnostic fidelity—especially in uncertain cases—and this study sets out to examine that possibility. existing CBCT scans were subjected to retrospective review. Two approaches were employed to assess each midpalatal suture: the established axial-plane method outlined by Angelieri and a coronal-plane analysis performed over three standardized cuts (anterior, middle, posterior). The work prioritized measuring agreement between the two viewing planes, locating regional mismatches, and characterizing patterns of ossification, with a specific focus on intermediate maturational stages. Axial and coronal readings matched fully in 23 of the 34 examined cases, a finding that upholds the overall robustness of the axial perspective. Divergences, however, were clustered notably in stage C, which accounted for 8 of the 11 mismatched instances. In the majority of these, ossification appeared more advanced on at least one coronal section than what the axial view indicated. In addition, a small subset of cases showed an atypical anterior-to-posterior direction of ossification. Rather than disputing the broad legitimacy of Angelieri's staging, our data point to a potential pitfall of viewing only the axial plane: it may, on occasion, underrate how far suture maturation has progressed. Bringing coronal slices into the evaluation can refine diagnostic detail during transitional phases, furnishing a clearer depiction of the suture's three-dimensional architecture. Adopting this multimodal perspective could help temper subjective judgment and perhaps narrow the gap between different examiners' interpretations.

Keywords: Angelieri's classification, Assessment, Cone-beam computed tomography (CBCT), Coronal slices evaluation, Diagnosis, maxillary expansion

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Introduction

Skeletal narrowing of the maxilla represents a frequent craniofacial disorder regularly seen in orthodontic settings [1].

Multiple etiological contributors underlie this malocclusion, most notably enduring childhood habits such as mouth breathing, deviant swallowing patterns, and continued thumb or pacifier use. These aberrant behaviors upset the proper resting posture of the tongue, give rise to lip incompetence, and disturb the equilibrium of the circumoral muscles, collectively interfering with the normal growth and spontaneous widening of the maxillary arch [2–5].

Conventional management of transverse maxillary deficiency relies on palatal expansion modalities,

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among them Rapid Maxillary Expansion (RME), Slow Maxillary Expansion (SME), Surgically Assisted Rapid Maxillary Expansion (SARME), and Miniscrew-Assisted Rapid Palatal Expansion (MARPE). Each of these techniques works by delivering orthopedic loads that separate the midpalatal suture, promoting elongation of collagen fibers, osteoclastic activity, and eventual deposition of new bone to render the achieved expansion permanent [6].

As growth proceeds, the midpalatal suture undergoes continuous remodeling. Obliteration commonly begins somewhere between the ages of 15 and 18, and total fusion may be reached between 25 and 35 years. Still, the timeline of this ossification varies widely from person to person, so chronological age alone is an unreliable gauge of sutural maturity [7–9].

As the suture becomes more ossified, its resistance to expansion increases, requiring adjustments in both the magnitude and the character of the forces delivered during treatment.

Choosing an unsuitable expansion strategy without accounting for how mature the suture is can trigger a range of unwanted consequences: Periodontal damage [10, 11], Buccal tipping of the teeth or devices serving as anchorage [3, 12–14], Osseous trauma [12], Pain [13], Tooth-borne movement substituting the desired skeletal expansion [3, 7, 15], Root resorption [3, 10], Soft-tissue ulceration [3, 15, 16].

Historically, decisions about which palatal expansion method to use were predominantly shaped by the patient's age, on the assumption that a given chronological bracket corresponded reliably to a specific maturational stage, thereby demarcating protocols for preadolescents, adolescents, young adults, and adults [3]. Yet more recent evidence indicates that chronological age is not a reliable indicator of midpalatal suture status. In fact, wide inter-individual differences in the fusion sequence of the median palatine suture have been documented, even when gender is taken into account [7, 17–19]. Beyond that, the literature offers no unified stance on the age threshold for performing SARME [20–22].

Efforts to gauge suture maturation using methods such as histological workup, occlusal radiography, and animal-based CT research have yielded inconsistent results and offer only limited diagnostic utility [22–27]. Hoping to fill the gap left by the shortage of reliable clinical markers, Angelieri *et al*. proposed a CBCT-based protocol in 2013 to assess midpalatal suture maturity. The technique inspects the suture in axial cross-sections and classifies its morphology into five stages labeled A through E [7, 15], and it currently serves as a principal diagnostic benchmark.

Though tissue biopsy remains the definitive standard for assessing midpalatal suture (MPS) maturation, performing it on live patients is impractical. Serial occlusal radiographs, on the other hand, suffer from compromised diagnostic value because neighboring anatomic structures are superimposed [7, 28]. A non-invasive modality like CBCT sidesteps this issue by rendering the maxillofacial region in three dimensions, free of superimpositions, while also exposing the patient to less radiation than standard medical CT.

That said, even with its broad acceptance, the method has drawn fire for the interpretive slant it demands, sparking concerns about consistency across observers [28, 29].

Although the classification is widely used, its trustworthiness is frequently called into question precisely because of this built-in subjectivity [28, 29]. Adding to the concern, individuals continue to exhibit markedly different responses to treatment, underscoring the potential of supplementing current diagnostic tools with additional modalities to sharpen both accuracy and reliability in staging suture maturation.

With this in mind, the present study sets out to build on Angelieri's axial-view framework by folding in findings from three supplementary coronal CBCT cuts: posterior, central, and anterior. Expanding the dimensional lens through which the suture is examined should equip practitioners with a richer, more impartial template for appraising the degree of ossification and selecting the most suitable expansion approach.

The objectives of the protocol are:

- To check how closely the maturational stages seen in the axial plane align with those detected in the coronal slices, while taking the suture's full thickness into account.
- To investigate the posterior-to-anterior sequence of ossification, which the literature describes as the standard progression.
- To spotlight any diagnostic gaps between the two viewing modes and to determine whether those gaps stem from greater or lesser degrees of ossification.

Materials and Methods

This retrospective observational study was carried out within the Department of Dentistry at San Raffaele Hospital, spanning 2019 to 2024. It conformed to the tenets of the Declaration of Helsinki and was sanctioned by the Ethics Committee of Vita-Salute San Raffaele University (approval code DIG-RETRO-1/2021).

Patient selection

CBCT volumes obtained for clinical diagnostic purposes were retrospectively reviewed. Criteria for inclusion were: age equal to or above 5 years regardless of sex, absence of significant medical conditions, presence of transverse maxillary constriction, and provision of signed informed consent. Exclusions applied when scans showed systemic illness, craniofacial malformations or syndromes, a history of orthodontic care, or substandard image quality.

To structure the analysis, the individuals were divided into four age brackets anchored to developmental phases commonly cited in the literature: Group 1 (5 to < 11 years), Group 2 (11 to < 14 years), Group 3 (14–18 years), and Group 4 (> 18 years). Grouping in this fashion was intended to map the distribution of midpalatal suture maturational stages across different ages and to detect any trends associated with craniofacial growth. The chosen age boundaries correspond to key transitional windows in skeletal and dental maturation, enabling a more nuanced analysis of ossification patterns across successive developmental stages.

CBCT acquisition and standardization

The Sirona Orthophos XG-3D platform served as the imaging device for all CBCT examinations, with exposure parameters guided by ALARA principles. Settings included a restricted field of view measuring 8 × 8 cm, scan cycles lasting 8.9-14 seconds, and a spatial resolution of 0.1–0.2 mm. Patient positioning for each scan required the Frankfurt horizontal plane to be parallel to the floor. Two dedicated operators, unchanged throughout the study, jointly handled every acquisition procedure.

Post-scan review took place within the Real-Guide® software platform.

To uphold analytical consistency and measurement fidelity across the dataset, skull orientation was rigorously normalized for every case before any readings began:

- In the axial projection, the median plane was defined by drawing a line through the anterior and posterior nasal spines, thereby standardizing the rotational alignment.
- In the coronal projection, the software's upright reference marker was centered precisely over the skull's midsagittal division.
- In the sagittal projection, the skull's tilt was adjusted until the palate's postero-anterior course ran as near to parallel with the software's horizontal reference as achievable.

Assessment of midpalatal suture maturation

The median palatine suture was inspected on uniformly oriented axial cuts **(Figure 1)** and categorized into one of five progressive maturational grades (A through E) based on the scheme published by Angelieri *et al*. [7], with grading performed by two examiners of considerable experience. When anatomical complexity arose—particularly in palates displaying deep curvature or increased thickness—a pair of central axial slices (one anterior, one posterior) was evaluated, as originally advocated by Angelieri *et al*. [7, 15]. The conclusive axial stage for each subject was settled by mutual agreement following a shared review of the case.

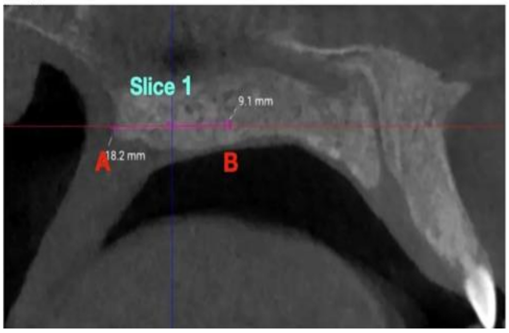
Figure 1. Identification of the anatomical reference points along the palatal midline used for standardized coronal slice positioning. Point A: posterior edge of the palatine bone; point B: transverse palatine suture; point C: posterior border of the incisive foramen. Points were identified in the sagittal view and referenced along the palatal midline.

Coronal slice acquisition

From each subject, three coronal cross-sections were extracted at predetermined anatomical landmarks **(Figure 1):**

- Slice 1 (Posterior): centered on the midpoint spanning the posterior rim of the palatine bone (point A) and the transverse palatine suture (point B). **(Figure 2)**
- Slice 2 (Central): centered on the midpoint between point B and the rear margin of the incisive foramen (point C). **(Figure 3)**
- Slice 3 (Anterior): positioned 3 mm behind point C **(Figure 4)**

All anatomical reference points were first located on the sagittal projection and subsequently traced along the palatal midline.



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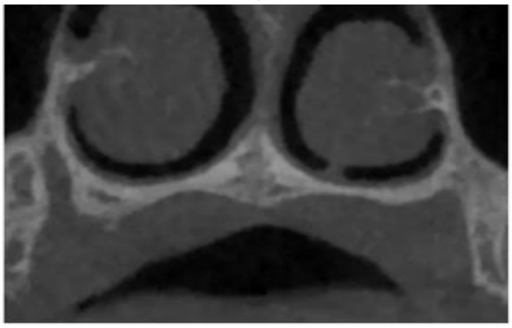

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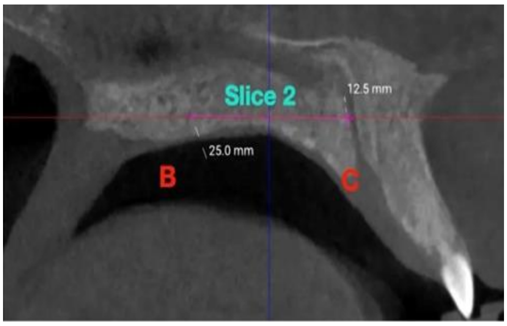
Figure 2. Coronal slice 1 (posterior) location. The slice was obtained at the midpoint between point A (posterior edge of the palatine bone) and point B (transverse palatine suture), along the palatal midline.



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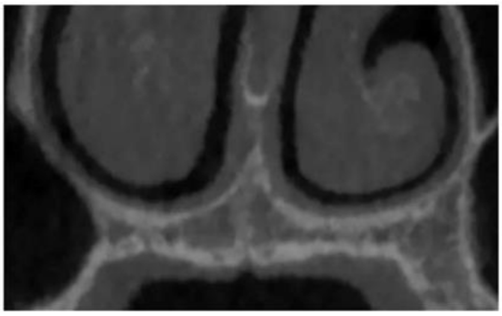
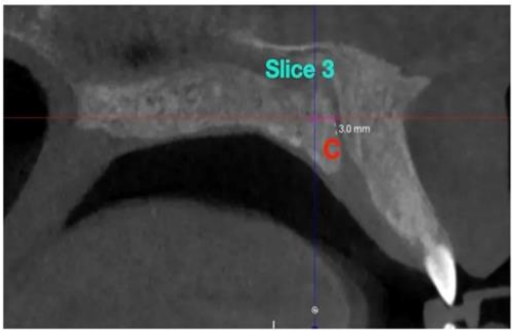


b)

Figure 3. Coronal slice 2 (central) location. The slice was obtained at the midpoint between point B (transverse palatine suture) and point C (posterior border of the incisive foramen), along the palatal midline.



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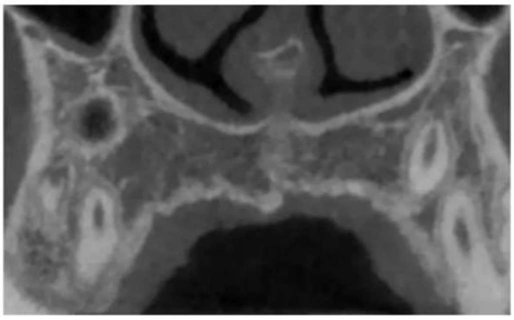

b)

Figure 4. Coronal slice 3 (anterior) location. The slice was obtained 3 mm posterior to point C (posterior border of the incisive foramen), along the palatal midline.

Data collection and analysis

All collected information was entered into a Microsoft Excel spreadsheet. For each participant, the midpalatal suture as visualized on the axial slice was directly compared against its presentation on the three coronal cuts (S1, S2, and S3).

Two seasoned examiners scrutinized the CBCT volumes in accordance with a uniform protocol covering both image alignment and interpretative criteria. Examination was collaborative throughout, and conclusive decisions regarding axial staging and the degree of coronal agreement were reached through joint discussion of each scan.

The dataset was then systematically arranged across four dedicated tables, each designed to illuminate a separate dimension of how the axial and coronal perspectives related to one another:

- General concordance table: This table presents, on a subject-by-subject basis, the axial maturational stage assigned under Angelieri's system (Stages A through E) together with the number of coronal slices—whether 0, 1, 2, or all 3—whose staging corresponded with the axial determination.
- Single concordance table: For the subset of cases in which merely a single coronal slice aligned with the axial stage, this table records which specific slice (S1, S2, or S3) was in agreement.

- Moderate concordance table: Where concordance was observed in two out of the three coronal slices, this table documents the particular combination of matching slices.
- Table of increased or reduced ossification: Restricted to the moderate concordance category, this table assesses whether the one coronal slice that diverged from the axial reference exhibited signs of relatively heightened or relatively diminished ossification. The analysis was confined to moderate concordance cases because the dataset contained only one instance of single concordance, which is described independently.

Statistical analysis

Subjects were divided into five groups matching Angelieri's five-tiered classification. The Kolmogorov–Smirnov test was used to determine whether continuous variables followed a Gaussian distribution. Consequently, continuous data were summarized using mean ± standard deviation (M ± SD) alongside median (interquartile range), whereas categorical endpoints were reported as counts and associated percentages (%). A suite of nonparametric tools was deployed to probe group-level differences. Specifically, the Kruskal–Wallis rank-sum test for independent samples was used to compare continuous measures across groups.

In contrast, either the Chi-square or Fisher's exact test was used for categorical outcomes. A contingency framework evaluated using Fisher's exact test was used to assess whether the male-to-female split varied meaningfully across age brackets. The degree of alignment between Angelieri staging and the findings from coronal slices was scrutinized through a contingency table examined via Fisher's exact test, to flag any statistically notable departures. To bring into relief any sex-related differences in how Angelieri stages were apportioned within each age band, another contingency table was interrogated with Fisher's exact test. Two further contingency arrangements were devised to expose statistically meaningful patterns in concordance distribution between Angelieri's categories and the coronal cuts under study: the first aimed to identify the particular coronal slice position where matching occurred, while the second confined the analysis strictly to the "Moderate" concordance tier. Lastly, the question of whether the tendency toward overestimation or underestimation in coronal slices relative to Angelieri's reference stage carried statistical weight was examined with a contingency table analyzed through Fisher's exact test.

Results and Discussion

An initial set of 44 CBCT volumes, acquired on clinical grounds, was screened for suitability. After a quality audit, 10 scans were removed owing to subpar imaging characteristics—motion streaks and lack of sharpness among the reasons. The final cohort, therefore, numbered 34 participants (25 female, 9 male), whose ages ranged from 9.2 to 52.1 years, and all were orthodontic treatment-naïve. **Table 1** lays out how sex was distributed within each age stratum.

Table 1. Sex distribution according to age groups.

Description parameters	Age groups (years)				
	5 to < 11	11 to < 14	14–18	> 18 years	P
Female	2 (50.00)	12 (85.70)	5 (83.30)	6 (60.00)	0.28
Male	2 (50.00)	2 (14.30)	1 (16.70)	4 (40.00)	

All data are categorical and shown as n (%).
Fisher's exact test was used.

How the maturational stages of the midpalatal suture—grouped per Angelieri *et al*. [7]—were apportioned across the sample is shown graphically in **Figure 5.** Stage A accounted for 1 individual (2.94%), stage B for 2 (5.88%), stage C for 17 (50%), stage D for 7 (20.59%), and stage E for another 7 (20.59%).

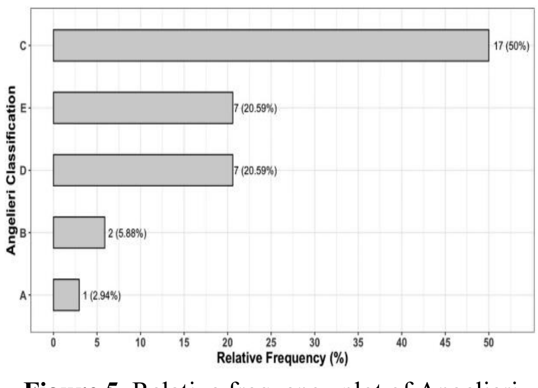

Figure 5. Relative frequency plot of Angelieri classification.

To further disentangle the links among suture maturation, chronological age, and sex, the material was fractionated further. **Tables 2 and 3** document the incidence of each maturational stage within the four age-defined groups, with sex-segregated tabulations supplied alongside.

Table 2. Description of the whole sample according to Angelieri's classification.

Description parameters	Group A		Group B		Group C		Group D		Group E		P
	Mean ± SD	Median (iqr)	Mean ± SD	Median (iqr)	Mean ± SD	Median (iqr)	Mean ± SD	Median (iqr)	Mean ± SD	Median (iqr)	
Proportions [n (%)]	1 (2.90)		2 (5.90)		17 (50.00)		7 (20.60)		7 (20.6)		
Concordance (n)	3 ± NA	3 (0)	2.5 ± 0.707	2.5 (0.5)	2.471 ± 0.624	3 (1)	2.714 ± 0.488	3 (0.5)	3 ± 0	3 (0)	0.22
Age (years)	9.20 ± NA	9.20 (0)	20.65 ± 15.486	20.65 (10.95)	13.472 ± 2.748	13 (1.8)	16.929 ± 6.32	14 (6.65)	31.917 ± 16.989	25.1 (30.1)	**< 0.01**
Age group											
5 to < 11 years	1 (100.00)		1 (50.00)		2 (11.80)		–		–		**< 0.01**
11 to < 14 years	–		–		11 (64.70)		3 (42.90)		–		
14–18 years	–		–		2 (11.80)		2 (28.60)		2 (28.60)		
> 18 years	–		1 (50.00)		2 (11.80)		2 (28.60)		5 (71.40)		
Sex											
Female	–		1 (50.00)		13 (76.50)		5 (71.40)		6 (85.70)		0.45
Male	1 (100.00)		1 (50.00)		4 (23.50)		2 (28.60)		1 (14.30)		

All data are shown as Mean ± SD, median (IQR) for continuous variables and as n (%) for categorical ones.
Wilcoxon rank sum test for continuous variables and Fisher's exact test for categorical ones.

Table 3. Contingency table of sex and Angelieri classification according to age group.

Angelieri's stage	**5 to < 11 years**		
	F	**M**	**P**
A	0 (0)	1 (2.94)	0.13
B	0 (0)	1 (2.94)	
C	2 (5.88)	0 (0)	
D	0 (0)	0 (0)	
E	0 (0)	0 (0)	
	11 to < 14 years		
	F	M	
A	0 (0)	0 (0)	0.99
B	0 (0)	0 (0)	
C	9 (26.47)	2 (5.88)	
D	3 (8.82)	0 (0)	
E	0 (0)	0 (0)	
	14–18 years		
	F	M	
A	0 (0)	0 (0)	0.30
B	0 (0)	0 (0)	
C	2 (5.88)	0 (0)	
D	1 (2.94)	1 (2.94)	
E	2 (5.88)	0 (0)	
	>18 years		

	F	M	
A	0 (0)	0 (0)	0.20
B	1 (2.94)	0 (0)	
C	0 (0)	2 (5.88)	
D	1 (2.94)	1 (2.94)	
E	4 (11.76)	1 (2.94)	

Fisher's exact test.

Coronal view agreement with Angelieri staging

Table 4 catalogs the extent of consistency between axial morphologic staging (Angelieri's framework) and the corresponding readings derived from the three standardized coronal cross-sections. The outcomes are summarized stage by stage below:

- Stage A: The sole subject classified here was in step with all three coronal cuts.
- Stage B: One of the two patients displayed unanimous agreement across slices; the other fell into the moderate concordance category, matching on two of the three.
- Stage C: Across the 17 members, a single individual had only one matching coronal slice, 7 secured matches on two slices, and the remaining 9 attained complete agreement.
- Stage D: Five of the 7 cases were concordant on every slice, whereas 2 landed in the moderate concordance group.
- Stage E: All 7 instances documented perfect agreement between the axial designation and all three coronal views.

Table 4. Contingency table of coronal slices (CS) concordance with Angelieri's classification. All data are categorical variables.

Angelieri's stage	0 CS	1 CS	2 CS	ALL CS	*p*
A	–	–	–	1 (4.30)	0.35
B	–	–	1 (10.00)	1 (4.30)	
C	–	1 (100.00)	7 (70.00)	9 (39.10)	
D	–	–	2 (20.00)	5 (21.70)	
E	–	–	–	7 (30.40)	

Fisher's exact test was used.

Table 5 zooms in exclusively on instances of partial concordance—where just a single coronal slice squared with Angelieri's stage—and specifies whether that matching slice was S1, S2, or S3.

Table 5. Specifies in which one of the three coronal slices (S1, S2, or S3) there was concordance with Angelieri's stage.

Angelieri's stage	S1	S2	S3	*p*
A	0	0	0	0.99
B	0	0	0	
C	0	0	1 (100.00)	
D	0	0	0	
E	0	0	0	

Fisher's exact test was used.

That single partially concordant midpalatal suture coincided with Angelieri's Stage C only when inspected on Coronal Slice 3. Across Coronal Slices 2 and 3, the ossification front had moved so far forward that the suture itself had become untraceable.

Table 6 concentrates strictly on the Moderate Concordance subset (cases where exactly two of three coronal slices aligned with Angelieri's stage) and identifies the specific slice pairings involved.

- Stage A: No suture at stage A departed from full concordance.
- Stage B: The sole stage B instance falling in the moderate range matched on slices 2 and 3.
- Stage C: Two of these cases matched Angelieri's stage on slices 1 and 2. Another two matched on slices 1 and 3, while three others did so on slices 2 and 3.
- Stage D: One individual showed alignment on slices 1 and 3, and a second on slices 2 and 3.
- Stage E: No coronal evaluation for a stage E suture ever diverged from perfect concordance.

Table 6. Specifies which two coronal sections were in agreement with Angelieri's stage, exclusively for cases of Moderate Concordance.

Angelieri's stage	S1–S2	S1–S3	S2–S3	*p*
A	0	0	0	0.99
B	0	0	1 (20.00)	
C	2 (100.00)	2 (66.70)	3 (60.00)	
D	0	1 (33.30)	1 (20.00)	
E	0	0	0	

Fisher's exact test was used.

Table 7 captures the direction of disagreement within the moderate concordance subset, recording whether the non-matching coronal slice (S1, S2, or S3) showed signs of relatively accelerated or relatively delayed ossification of the midpalatal suture when benchmarked against the axial stage derived through Angelieri *et al.*'s protocol.

- S1: Greater ossification was evident on slice 1 in a single case where the axial reference was stage B and in three cases assigned to stage C axially; conversely, one case staged as D on axial view appeared less ossified on this slice.
- S2: Slice 2 revealed more extensive ossification in two-stage C cases as well as in one-stage D cases.
- S3: Slice 3 displayed comparatively heavier ossification in two-stage C cases.

Table 7. Description of the ossification seen in the discordant coronal slice relative to the axial reference stage.

Angelieri's stage	S1		
	Increased ossification	**Reduced ossification**	**P**
A	0 (0.00)	0 (0.00)	0.40
B	1 (25.00)	0 (0.00)	
C	3 (75.00)	0 (0.00)	
D	0 (0.00)	1 (100.00)	
E	0 (0.00)	0 (0.00)	
	S2		
	Increased	Reduced	P
A	0 (0.00)	0 (0.00)	0.40
B	0 (0.00)	0 (0.00)	
C	2 (66.70)	0 (0.00)	
D	1 (33.30)	0 (0.00)	
E	0 (0.00)	0 (0.00)	
	S3		
	Increased	Reduced	P
A	0 (0.00)	0 (0.00)	0.99
B	0 (0.00)	0 (0.00)	
C	2 (100.00)	0 (0.00)	
D	0 (0.00)	0 (0.00)	
E	0 (0.00)	0 (0.00)	

Fisher's exact test was used.

Axial assessment compared to coronal slices analysis

A growing body of contemporary work has stressed that chronological age provides a poor basis for predicting how far the midpalatal suture has matured and, by extension, for shaping orthodontic treatment decisions [7, 23].

The histological series published by Persson and Thilander [23] reported full obliteration of the posterior palatal suture in quite young individuals (a 15-year-old girl and a 21-year-old man), yet found entirely unfused sutures in subjects of advanced age (27, 32, 54, and one as old as 71 years). These tissue-level observations stand at odds with classical teachings—epitomized by the publications of Haas [30] and Melsen [31]—which have long maintained that rapid maxillary expansion (RME) loses much of its effect after the age of 25.

Given the unreliability of chronological age as a yardstick, Revelo and Fishman [27] shifted toward an individualized appraisal of the midpalatal suture using occlusal radiographs. Wehrbein and Yildizhan [25] then demonstrated histologically that occlusal films cannot be relied on to detect suture closure, largely because the vomer, along with other regional anatomy, projects into the same area.

The breakthrough came in 2013, when Angelieri *et al*. [7] championed CBCT as a novel diagnostic window into midpalatal suture maturation, noting the wide dispersion of maturational stages across different chronological brackets. Crucially, their data showed that each ossification stage could be encountered as early as age 11. The implication is clear: chronological age grows ever less pertinent both to establishing a diagnosis and to selecting an orthodontic course of action.

Angelieri consequently underlines the indispensability of individualized radiographic evaluation of the suture, performed specifically via CBCT.

That being said, earlier investigations have highlighted notable inter-examiner divergence in labeling maturational stages, particularly for sutures caught in transition between two categories. Such diagnostic ambiguity can lead to discordant clinical judgments and treatment decisions, thereby eroding the method's standardization and repeatability [32].

Neither Angelieri's original classification nor the multimodal refinement explored in this work can escape the influence of interindividual variation. This variation stems from multiple overlapping causes: 1) innate anatomical dissimilarities among individuals [29]—encompassing differences in sutural contour, bone mineralization, and the intricacy of interdigitation—any of which can modify the radiographic signature of the suture; 2) the element of personal judgment involved in deciphering CBCT greyscale gradients, particularly at intermediate stages where scattered ossification islands may be confused with adjoining anatomy [32]; and 3) the degree of operator experience, which powerfully shapes one's ability to correctly align volumetric images, follow the suture's trajectory, and detect faint morphological indicators [28, 32]. These forces, magnified by potential scanning artifacts or unit-to-unit differences in voxel size and contrast resolution, fuel diagnostic inconsistency even where protocols are tightly standardized. Taking stock of these sources of variability reinforces the logic behind supplementing the evaluative process with coronal slices, since viewing the suture from multiple angles can curb the impact of subjective interpretation and sharpen diagnostic reliability, most notably when a case straddles two stages.

Contributing further to these hurdles are the sheer quality of the radiographic record (which dictates anatomical visibility), the demand for considerable skill in navigating diagnostic software, and the particular background of the person interpreting the images. Faults in axial-plane orientation or misreading of sutural features can increase the likelihood of an incorrect diagnosis.

The current study presents an augmented diagnostic framework that combines the axial-plane appraisal described by Angelieri with an inspection of three coronal sections at predefined landmarks.

Tables 2 and 3—laid out in keeping with the template offered by Angelieri *et al*. [7]—chart the frequency distribution of midpalatal suture maturational stages within our own sample. The scarcity of stages A and B can plausibly be explained by the fact that these early-stage presentations typically occur in the earliest years of life, when a clinical rationale for CBCT imaging is rarely encountered.

The figures reveal a pronounced heterogeneity in maturational staging that cuts across age groups. These observations buttress the argument that chronological age may have some ancillary utility but must not be mistaken for a faithful surrogate of the midpalatal suture's ossification status [7, 23].

A range of other variables has been widely discussed in the published literature as influencing the tempo of midpalatal suture ossification and interdigitation. Moving past chronological age—now regarded as a flimsy criterion—two further decisive elements are the patient's biological sex and the restraining force exerted by circummaxillary sutures on expansion.

A recurring finding across multiple studies is that, in general, suture ossification occurs earlier in females than in males [26, 30, 33]. Having said that, both Angelieri [7] and Persson and Thilander [23] documented remarkable scatter in how maturational stages were apportioned across the two sexes and the various age brackets. Hence, while sex and age carry some informative weight, neither can stand alone as a sufficient parameter for building a patient's diagnostic picture or for choosing among therapeutic pathways.

Within our own dataset, when looking at the pediatric and adolescent strata, female subjects were overrepresented in stages C (2 females versus 0 males in the 5 to < 11-year bracket, and 9 females versus 2 males in the 11 to < 14-year bracket) and D (3 females versus 0 males in the 11 to < 14-year bracket) of suture maturation. This pattern aligns with the body of work, indicating that ossification tends to commence earlier in females than in males. A caveat worth underlining, however, is the female-skewed composition of our sample, which may have introduced a confound and thus tempers the strength of this finding as a conclusive marker.

Given the sparse number of subjects falling into stages A and B within the cohort, and since stage E exhibited unanimous alignment between axial and coronal readings, the discussion that follows will center solely on the mismatches and matches (between axial and coronal planes) about stages C and D. Homing in on these two stages holds particular clinical relevance, as they frequently constitute pivotal decision points, depicting a suture caught in the middle of interdigitation and progressive ossification. Examining the 34 cases enrolled in this study has yielded meaningful insights into midpalatal suture maturation, enriching the understanding of its ossification trajectory and the diagnostic pitfalls it poses.

Full agreement among all three coronal cuts and the Angelieri axial stage was recorded in 23 of the 34 cases. This substantial proportion supports the broad diagnostic soundness of the axial approach, especially for clearly demarcated maturational poles such as A, B, and E. The data drawn from our cohort lack the statistical power to cast doubt on the overall validity of Angelieri's staging framework. While our results indicate a generally satisfactory level of concordance between the two techniques, they also highlight a degree of fluctuation—most pronounced in intermediate stages—that could indicate situations where supplementing the axial view with additional planes of section might be advantageous.

Stage C was the most challenging category from a diagnostic standpoint, accounting for 7 of the 10 moderate-concordance cases. The fluid, morphologically patchy character of this stage may well account for the mismatches observed, since rapid ossification activity can yield inconsistent appearances depending on the section plane and the exact subregion being inspected.

Across the 10 cases classified as moderate concordance (where the axial stage matched two of the three coronal slices), the non-matching coronal cut predominantly displayed evidence of more extensive ossification than the axial view would suggest **(Table 7).** To be precise:

- On slice 1 (posterior position), four instances exhibited heavier ossification of the suture, while one showed lighter ossification (judged against the axial reference stage).
- On slice 2 (central position), all three mismatched cases pointed toward surplus ossification.
- In both instances where the disagreement lay with slice 3 (anterior position), the suture again appeared more ossified than the axial reference indicated.

This recurring trend suggests a tangible risk of underestimating the true maturational stage when interpretation relies solely on axial imaging.

Strikingly, four cases displayed a more heavily ossified anterior region, coupled with a less advanced posterior region, resulting in a reversal of the canonical posterior-to-anterior maturational sequence widely cited in textbooks. Although these findings are at an early stage, they invite deeper investigation into the anatomical or biological drivers that may guide ossification.

Table 4 lays out the cross-tabulation between Angelieri stages and the number of coronal slices found to be concordant. Fisher's exact test was employed to probe the strength of association between axial staging and coronal slice findings. Stage C, while representing the largest single category, also showed the greatest spread in coronal slice agreement, with 8 of its 17 cases diverging from full concordance. Despite this observation, the computed p-value (0.35) falls short of statistical significance, suggesting that the discordant findings are not of a magnitude to invalidate Angelieri's method. Nonetheless, the mere presence of these non-matching cases bolsters the argument for introducing complementary diagnostic tools—coronal slice assessment among them—especially when confronting borderline or transitional stages.

The repeated pattern in which mismatched cases skew toward greater ossification suggests that axial views alone may not fully capture how far maturation has actually progressed, particularly in stages C and D. Coronal slices can provide an added layer of perspective, one that becomes especially valuable when the axial picture looks hazy or teeters between two stages.

Limitations of the research

Several constraints within this study may temper the extent to which its conclusions can be extrapolated. To begin with, the dataset is built from 34 CBCT volumes, rigorously curated using strict entry and exclusion criteria. Broadening the participant pool in subsequent investigations would help corroborate these observations and widen their relevance to the general population, thereby amplifying their practical utility in clinical settings.

A further shortcoming is the paucity of midpalatal sutures captured at stages A and B, developmental phases predominantly encountered in the youngest cohorts. Yet, CBCT scanning is seldom warranted in such pediatric populations under current diagnostic justification and radiation safety standards. While the sparse coverage of these early maturational stages may color comparisons across the full spectrum of maturity levels, it remains consistent with prevailing clinical indication benchmarks and exposure-limiting guidelines.

Moreover, the analytical framework employed only three coronal cross-sections. In practice, however, the entire suture was surveyed using coronal views during the actual evaluation, then subsequently partitioned into three representative zones to facilitate interpretation. That said, mirroring Angelieri's own practice of inspecting the suture's full depth from the axial perspective [7, 15, 34], practitioners are counseled against confining their review to merely three coronal cuts. They should instead appraise the entire sutural architecture visible in the coronal CBCT projection.

An additional element meriting attention is the contribution of the circummaxillary sutures, which may meaningfully account for some of the documented variability. The mechanical impedance offered by these articulations during maxillary expansion can shape both the ossification trajectory of the midpalatal suture and the broader therapeutic response. Earlier contributions, including the work of Garib *et al*. [35], have drawn notice to circummaxillary sutures as sources of resistance during expansion, emphasizing their possible role in asymmetrical outcomes and fluctuations in treatment efficacy.

Within the confines of this investigation, the putative effect of circummaxillary sutures was not explicitly measured. Prospective work that integrates analysis of these structures into the evaluation of midpalatal suture maturation could yield a richer understanding of the observed heterogeneity and further hone both diagnostic and treatment algorithms.

Another weakness of the current work is the lack of a structured evaluation of inter-rater and intra-rater reliability. Although the CBCT datasets were read by two seasoned examiners who adhered to a tightly defined, standardized protocol for image alignment and interpretation—and although final staging decisions were settled by consensus—no independent or repeated scoring was undertaken to numerically assess observer agreement. As a result, how reproducible the proposed axial–coronal assessment framework proves when deployed by different raters remains an open question. Future research should integrate blinded independent readings and formal reliability testing to more robustly substantiate the coronal assessment method put forward here.

Towards personalized protocols

Embracing a dual-plane evaluation of the midpalatal suture—one that marries axial and coronal perspectives—can assist in formulating more individualized treatment plans, lowering the odds of complications that stem from partial or one-dimensional diagnostic workups.

Isfeld *et al*. [9] highlighted the shortcomings of current tools for gauging mid-palatal suture maturation, noting that no single imaging modality or staging taxonomy, including CBCT-based systems, has ever been corroborated against a histological gold standard. This absence of histological anchoring argues strongly for clinicians to pursue a multi-pronged diagnostic philosophy, weaving together varied imaging viewpoints and criteria to sharpen precision. In light of the diagnostic ambiguities that cling to intermediate stages, our data bolster the case for fusing axial and coronal CBCT perspectives to arrive at a fuller picture of suture maturity.

Chatwani *et al*. [32] reported sizable inter-examiner discrepancies, observable even among seasoned orthodontic professionals, when assigning maturational stages under Angelieri's scheme [7], highlighting the importance of examiner background and the irreducible subjectivity of the process. This inconsistency, especially pronounced in cases that straddle two stages or exhibit equivocal features, suggests that single-plane assessments may miss subtle diagnostic clues.

Layering multiple CBCT viewing angles—specifically, the axial and coronal—could reduce the subjectivity that plagues single-view readings, delivering a more robust and comprehensive visualization of sutural architecture.

Summing up, the present work brings several clinically relevant points into focus:

- Harnessing both axial and coronal CBCT views in tandem could raise the dependability of midpalatal suture staging, most notably within the diagnostically vexing intermediate categories C and D.
- The mismatches cataloged here—largely defined by coronal sections showing further-advanced ossification relative to their axial counterparts—imply that leaning solely on the axial perspective may, on occasion, cause an underassessment of suture maturation.
- The detection of non-uniform ossification sequences, among them atypical anterior-to-posterior progression, mirrors the inherent biological variability of the maturational journey and lends weight to the argument for a more customized diagnostic framework.

Even though the modest sample size limits the ability to draw definitive inferences, the regularity of certain trends in this analysis invites deeper exploration. Far from undermining Angelieri's method, our observations supplement and refine its application by illustrating the potential diagnostic gains of a multimodal CBCT strategy—particularly when confronting borderline cases—thereby advancing more precise and personalized treatment planning

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