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Comparitive Assessment of The Stages Of Midpalatal Suture Maturation And Circum-Maxillary Suture Maturation- A Cone Beam Computed Tomography Study

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ABSTRACT

AIM: The aim of this study is to assess the comparison between the stages of maturation of Mid-palatal suture and Circum-maxillary sutures. **OBJECTIVE**: 1) To assess the comparison between the stages of maturation of Mid-palatal suture and Circum-maxillary suture in growing individuals, 2) To check if Circum-maxillary sutures follows the ossification pattern of either spheno-occiptal synchondrosis or mid-palatal suture, 3) To establish the age group for each stages of maturation of Mid palatal suture To check if there is any difference in maturational stages of Mid-palatal suture between males and females. 4) To check the co-relation between mid-palatal maturation stage and CVMI staging. **MATERIAL AND METHODOLOGY**: This study is designed as descriptive correlation study which in which the aim is to assess the comparison between the stages of maturation of Mid-palatal suture and Circum-maxillary sutures using full skull Cone beam computed tomography. Dicom files of CBCT samples will be taken and divided into 5 groups based on the stages of maturation of MPS. The stage of maturation of MPS with that of the different Circum-maxillary sutures is done to see if there is any corelation between stages of maturation. CVMI stages of all the samples and check if there is any corelation between the CVMI staging and the midpalatal suture maturation stages. **CONCLUSION**: In conclusion, the findings of this study provide compelling evidence for the strong and synchronized maturation patterns of the midpalatal suture (MPS), circum-maxillary sutures, and the cervical vertebral maturation index (CVMI), reaffirming their interrelated roles in craniofacial development. The high correlation coefficients observed—particularly for the frontomaxillary ($\rho = 0.94$) and nasomaxillary sutures ($\rho = 0.93$), and CVMI ($\rho = 0.92$)—demonstrate that MPS maturation reliably parallels both circum-maxillary suture fusion and overall skeletal growth.

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1. INTRODUCTION

Rapid maxillary expansion is a routine orthopedic procedure performed in cases with maxillary constriction and maxillary protraction therapy to separate the Mid-palatal suture (MPS) and Circum-maxillary sutures to aid in transverse correction and to loosen the Circum-maxillary sutures to facilitate maxillary protraction therapy.[1] The Alt-RAMEC protocol was introduced by Liou it enables sutural mobilization with the opening and closing of the RME screw for 7–9 consecutive weeks without unnecessary expansion . Its rationale is similar to that of simple tooth extraction in which we repeatedly rock the tooth buccally and lingually until the tooth is “disarticulated” out of the alveolar socket.[2]

It is evident from current literature, that Alt-RAMEC protocol is most commonly used as a prerequisite for maxillary protraction therapy with the impression that if mid palatal sutures are fused, so will be the Circum-maxillary sutures.[3] Since there is no clear evidence in literature establishing correlation between the maturation of Midpalatal suture with that of Circum-maxillary sutures, Alt-RAMEC protocol is performed as a standard operating protocol for maxillary protraction.

For assessing the possibility and need for maxillary arch expansion, most orthodontists use the patient’s chronological age as the guide to address the maxillary arch constriction. This indicator might not properly show the true maturational stage of the Mid palatal suture and Circum-maxillary sutures as chronological age is not an optimal parameter to access the extent of growth and extent of maturation of mid palatal and Circum-maxillary sutures. So the determination of Mid palatal suture and Circum-maxillary sutures maturation exclusively based on chronologic age may not be a proper method to access the extent of maturation of Mid palatal and Circum-maxillary sutures.

Among only a few methods available, some clinicians use occlusal radiographs to evaluate the extent of Mid palatal suture maturation, but suture closure in occlusal radiograph does not necessarily indicate the stage and the extent of sutural closure due to superimposition of other anatomical structures. The gold standard to estimate the extent of maturation is the assessment of stages of maturation using the CBCT images.[3] Stages of mid palatal suture maturation was given by Fernanda Angelieri which includes 5 stages of mid palatal suture maturation. Studies show that the circum maxillary sutures also similar stages of maturation and hence it can be used to define the stage of maturation of circum maxillary suture.[3]

There is very limited to no evidence in literature regarding the maturation of Circum-maxillary sutures and its correlation with the maturation of Midpalatal suture. And hence the maturation of Midpalatal suture is considered as the indicator for assessment of maturation of Circum- maxillary sutures and hence the Alt-RAMEC protocol is employed to loosen the Circum- maxillary as a standard operating procedure before maxillary protraction therapy. In a study conducted by Jae-Hee Yang et al, shows that the age groups of different stages of synchondrosis maturation with respect to timing and pattern of the fusion of the Spheno occipital sychondrosis is slightly different from that of maturation of Mid palatal suture. Hence there is no clear evidence in literature which states that, the pattern and timing of maturation of Circum-maxillary sutures follows the pattern and timing of Mid palatal suture or the Speno occipital synchondrosis.[4]

It is of great importance to determine and co-relate if the fusion of Mid palatal sutures follows the maturation pattern of Circum-maxillary sutures which dictates the need for Alt- RAMEC. The purpose of this study is to check the if there is a positive or no correlation and also degree of correlation between the maturation of Mid-palatal suture and maturation of Circum-maxillary suture based on the assessment of several stages of maturation of sutures with the help of CBCT images.

MATERIALS AND METHDOLOGY

CBCT of subjects was collected from Department of Oral Medicine and Radiology, Dayananda Sagar College of Dental sciences, Bengaluru, which will be taken for diagnosis and treatment planning of orthodontic and other specialty needs.

The CBCT records in DICOM format of the full skull of different samples are taken and observed with CS 3D imaging software. The images are looked for the patency and stage of maturation of Mid-palatal suture by 2 different observers at different interval of time for identification of the stage of maturation of Mid palatal suture and to allot each sample in to different groups based on the stage of mid palatal suture maturation. These samples will be divided in to 5 groups based on the stages of maturation of the mid palatal suture as given by Fernanda Angileri et al .

Once all the samples are divided between 5 groups, the average of each group will be established by intra group comparison using the measure of central tendency. The averages of each stages will be used for inter group comparison with mid palatal suture maturation stage. The stage of maturation of MPS with that of the different Circum-maxillary sutures is done to see if there is any correlation between stages of maturation. The study also aims at estimation of the age group in which the 5 different groups fall in to, to establish the age group for each stage of maturation of Mid palatal suture, which will fulfil the primary objective of the study.

For studying the secondary objective, since we now have the stages of maturation of both MPS and the stages of maturation of Circum-maxillary suture and literature supporting the stages of maturation of speno-occipital synchondrosis, the maturation of Circum-maxillary sutures is compared with the stages and age of maturation of these both sutures to study the resemblance of pattern of maturation of Circum-maxillary sutures with MPS and speno-occipital synchondrosis

To study another secondary objective, we will study the CVMI stages of all the samples and check if there is any corelation between the CVMI staging and the midpalatal suture maturation stages which is already recorded.

The assessment of the maturation stage is done by two observers separately. If the assessment done by both the observers coincides then the stage of maturation is assessed If the assessment done by two observers is different then a third observer is involved to avoid interobserver bias Intraexaminer and interexaminer reliability will be checked using kappa statistics bias during the procedure.

2. RESULTS

The purpose of this study was to assess the comparison between the stages of maturation of Mid-palatal suture and Circum-maxillary sutures using full skull Cone beam computed tomography. A total of 30 samples of full skull CBCTs were obtained with FOV of 16X17 in the age group of 8-18 years of age group. The samples were divided into 5 groups based on stage of mid palatal suture maturation and circummaxillary sutures of all the samples were assessed and compared for correlation. As the secondary objective, CVMI stages were also assessed. The following shows the results obtained

Distribution of Maturation Stages for CVMI and Circum-Maxillary Sutures in MPS Stage A (Table 1)

Suture	Stage I	Stage II	Stage III	Stage IV	Stage V	Stage VI
CVMI	4 (57.1%)	2 (28.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
FZ	5 (71.4%)	2 (28.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
FM	6 (85.7%)	1 (14.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
ZM	5 (71.4%)	2 (28.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
ZT	0 (0.0%)	7 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
PTM	6 (85.7%)	1 (14.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
FN	4 (57.1%)	1 (14.3%)	1 (14.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
NM	7 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
IM	5 (71.4%)	2 (28.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)

Interpretation:
In **MPS Stage A**, the majority of patients exhibit **early maturation** of both skeletal (CVMI) and circum-maxillary sutures. Specifically:

- **CVMI** is predominantly in **Stage I**, indicating early skeletal development.
- Most sutures like **FM, PTM, NM**, and **IM** show **Stage I dominance**, reflecting a high degree of suture patency.
- **ZT** stands out with all subjects in **Stage II**, showing slight advancement compared to other sutures.
- No subjects presented with maturation beyond **Stage III** in any suture.

Distribution of Maturation Stages for CVMI and Circum-Maxillary Sutures in MPS Stage B (Table 2)

Suture	Stage I	Stage II	Stage III	Stage IV	Stage V	Stage VI
CVMI	3 (42.9%)	3 (42.9%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
FZ	2 (28.6%)	5 (71.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
FM	3 (42.9%)	3 (42.9%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
ZM	3 (42.9%)	3 (42.9%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
ZT	4 (57.1%)	2 (28.6%)	1 (14.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
PTM	3 (42.9%)	3 (42.9%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
FN	5 (71.4%)	0 (0.0%)	2 (28.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
NM	7 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
IM	4 (57.1%)	2 (28.6%)	1 (14.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)

Interpretation:

In **MPS Stage B**, there is a **slight maturation progression** compared to Stage A, but most sutures still remain in early developmental stages:

- **CVMI** remains primarily in Stages I and II, suggesting continued skeletal immaturity.
- **FZ, FM, ZM, PTM** are evenly split between Stages I and II, indicating gradual suture development.
- **ZT** shows some advancement with one subject in **Stage III**, suggesting it may begin fusing earlier than others.
- **FN and IM** show mild variation, with **FN** beginning to shift into **Stage III**.
- **NM** is consistently in **Stage I**, indicating it remains the most delayed in maturation.

Distribution of Maturation Stages for CVMI and Circum-Maxillary Sutures in MPS Stage C (Table 3)

Suture	Stage I	Stage II	Stage III	Stage IV	Stage V	Stage VI
CVMI	0 (0.0%)	1 (14.3%)	2 (28.6%)	3 (42.9%)	0 (0.0%)	0 (0.0%)
FZ	0 (0.0%)	6 (85.7%)	1 (14.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
FM	0 (0.0%)	2 (28.6%)	5 (71.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
ZM	0 (0.0%)	6 (85.7%)	1 (14.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
ZT	0 (0.0%)	1 (14.3%)	6 (85.7%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
PTM	1 (14.3%)	1 (14.3%)	5 (71.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
FN	0 (0.0%)	1 (14.3%)	5 (71.4%)	1 (14.3%)	0 (0.0%)	0 (0.0%)
NM	0 (0.0%)	7 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
IM	0 (0.0%)	5 (71.4%)	2 (28.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)

Interpretation:

In **MPS Stage C**, the data reveals a **transitional phase** of skeletal and suture maturation:

- **CVMI** advances, with a notable presence in **Stages III and IV**, suggesting mid-pubertal skeletal growth.
- Circum-maxillary sutures like **FM, ZT, PTM, FN** are predominantly in **Stage III**, showing active fusion beginning.
- **FZ and ZM** remain largely in **Stage II**, suggesting they lag slightly behind FM and ZT.
- **NM** continues to show delayed maturation, with 100% in **Stage II**, reinforcing its known slower development.
- Overall, more variation emerges across sutures, and higher stage appearances (like Stage IV for CVMI, FN) begin.

Distribution of Maturation Stages for CVMI and Circum-Maxillary Sutures in MPS Stage D (Table 4)

Suture	Stage I	Stage II	Stage III	Stage IV	Stage V	Stage VI
CVMI	0 (0.0%)	0 (0.0%)	1 (14.3%)	3 (42.9%)	2 (28.6%)	0 (0.0%)
FZ	0 (0.0%)	1 (14.3%)	2 (28.6%)	4 (57.1%)	0 (0.0%)	0 (0.0%)
FM	0 (0.0%)	0 (0.0%)	1 (14.3%)	6 (85.7%)	0 (0.0%)	0 (0.0%)
ZM	0 (0.0%)	0 (0.0%)	4 (57.1%)	2 (28.6%)	1 (14.3%)	0 (0.0%)
ZT	0 (0.0%)	0 (0.0%)	2 (28.6%)	2 (28.6%)	2 (28.6%)	0 (0.0%)
PTM	0 (0.0%)	1 (14.3%)	2 (28.6%)	2 (28.6%)	1 (14.3%)	0 (0.0%)
FN	0 (0.0%)	0 (0.0%)	1 (14.3%)	5 (71.4%)	0 (0.0%)	0 (0.0%)
NM	0 (0.0%)	1 (14.3%)	4 (57.1%)	2 (28.6%)	0 (0.0%)	0 (0.0%)
IM	0 (0.0%)	0 (0.0%)	3 (42.9%)	3 (42.9%)	0 (0.0%)	0 (0.0%)

Interpretation:

In **MPS Stage D**, the sutures show **significant progression** in maturation, reflecting late pubertal or post-pubertal development:

- **CVMI** shifts strongly to **Stages IV and V**, indicating advanced skeletal maturation.
- Most circum-maxillary sutures (**FM, FN, ZM, IM**) now have a high proportion in **Stage III or IV**, and some (e.g., **ZT, PTM**) begin reaching **Stage V**, indicating early fusion.
- **FM** stands out with **85.7% in Stage IV**, suggesting it's one of the first sutures to progress toward fusion.

- The continued variability across sutures highlights that **maturation is not uniform**, and some sutures (like **NM**) lag slightly.

Distribution of Maturation Stages for CVMI and Circum-Maxillary Sutures in MPS Stage E (Table 5)

Suture	Stage I	Stage II	Stage III	Stage IV	Stage V	Stage VI
CVMI	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	5 (71.4%)	1 (14.3%)
FZ	0 (0.0%)	0 (0.0%)	0 (0.0%)	6 (85.7%)	1 (14.3%)	0 (0.0%)
FM	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	7 (100.0%)	0 (0.0%)
ZM	0 (0.0%)	0 (0.0%)	0 (0.0%)	6 (85.7%)	1 (14.3%)	0 (0.0%)
ZT	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (28.6%)	5 (71.4%)	0 (0.0%)
PTM	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (28.6%)	5 (71.4%)	0 (0.0%)
FN	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (28.6%)	5 (71.4%)	0 (0.0%)
NM	0 (0.0%)	0 (0.0%)	1 (14.3%)	6 (85.7%)	0 (0.0%)	0 (0.0%)
IM	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (14.3%)	6 (85.7%)	0 (0.0%)

Interpretation:
In **MPS Stage E**, the data reflects the **most advanced stage of skeletal and suture maturation**, marking near or complete fusion:

- **CVMI** shows **71.4% in Stage V** and one subject in **Stage VI**, signifying skeletal maturity.
- **FM** stands out with all subjects in **Stage V (100%)**, suggesting complete fusion.
- Most circum-maxillary sutures (e.g., **FZ, ZM, ZT, PTM, FN, IM**) are concentrated in **Stages IV and V**, confirming substantial structural maturation.

Notably, **NM**, previously the most delayed, now shows **85.7% in Stage IV**, with one case in Stage III, indicating it is catching up but still slightly behind others

MPS Stage A
Interpretation:
- CVMI predominantly lies in **Stage I (57.1%)**, indicating very early skeletal development.
- Sutures like **FM (85.7%)**, **PTM (85.7%)**, and **NM (100%)** are dominantly in Stage I, reflecting high suture patency and lack of fusion.
- **ZT** is unique with **100% in Stage II**, indicating slightly faster maturation than others.
- No suture exceeds **Stage II**, confirming early stage of skeletal and suture maturation.

MPS Stage B
Interpretation:
- A gradual shift in CVMI with subjects now split between **Stage I and II** equally.
- Most sutures (e.g., **FZ, FM, ZM, PTM**) show balanced distribution between **Stage I and II**, reflecting minor maturation.
- **ZT** shows a singular presence in **Stage III**, suggesting early onset of fusion in some cases.
- **NM** remains in **Stage I**, indicating slowest maturation among all sutures.

MPS Stage C
Interpretation:
- CVMI exhibits notable advancement with 71.5% spread across **Stages III and IV**, indicating mid-pubertal skeletal growth.
- Sutures like **FM (71.4%)** and **ZT (85.7%)** are heavily concentrated in **Stage III**, showing active fusion phases.
- **FZ** and **ZM** remain mostly in **Stage II**, suggesting lag in ossification compared to FM and ZT.
- **NM** remains behind, though slightly improved, now fully in **Stage II**.

MPS Stage D
Interpretation:
- CVMI mostly in **Stages IV (42.9%) and V (28.6%)**, marking substantial skeletal maturation.
- Sutures such as **FM (85.7%)**, **FN (71.4%)**, and **IM (42.9% in both III and IV)** reflect advanced fusion.
- **ZT** and **PTM** start showing cases in **Stage V**, reinforcing their readiness for final fusion.
- **NM** still lags slightly with the majority in **Stage III (57.1%)**, but is progressing steadily.

MPS Stage E
Interpretation:

- CVMI heavily weighted in **Stage V (71.4%)**, with some in **Stage VI**, indicating nearly complete skeletal maturity.
- **FM** achieves full maturity with **100% in Stage V**.
- Most sutures, including **FZ, ZM, ZT, PTM, FN, and IM**, are dominantly in **Stage IV and V**, confirming extensive fusion.
- **NM**, though previously delayed, shows **85.7% in Stage IV**, showing it is catching up

Distribution of Cervical Vertebral Maturation Index (CVMI) Stages Across Age Groups with Percentages and Statistical Significance (Table 6)

CVMI Stage	<10	10–12	12–14	14–16	16–18	18+
Stage I	100.0% (2/2)	57.1% (4/7)	42.9% (3/7)	0.0% (0/5)	0.0% (0/5)	0.0% (0/5)
Stage II	0.0% (0/2)	42.9% (3/7)	42.9% (3/7)	20.0% (1/5)	0.0% (0/5)	0.0% (0/5)
Stage III	0.0% (0/2)	0.0% (0/7)	0.0% (0/7)	40.0% (2/5)	20.0% (1/5)	0.0% (0/5)
Stage IV	0.0% (0/2)	0.0% (0/7)	14.3% (1/7)	40.0% (2/5)	40.0% (2/5)	0.0% (0/5)
Stage V	0.0% (0/2)	0.0% (0/7)	0.0% (0/7)	0.0% (0/5)	40.0% (2/5)	80.0% (4/5)
Stage VI	0.0% (0/2)	0.0% (0/7)	0.0% (0/7)	0.0% (0/5)	0.0% (0/5)	20.0% (1/5)
p-value	<0.001					

Interpretation: The distribution of CVMI stages across age groups demonstrates a clear age-driven progression in skeletal maturity. In the <10 years group, 100% of patients are in Stage I, indicating early skeletal development typical of pre-pubertal stages. The 10–12 and 12–14 years groups show a mix of Stages I and II (57.1% and 42.9%, respectively), reflecting the onset of pubertal growth. The 14–16 years group transitions to Stages III (40%) and IV (40%), marking mid-pubertal skeletal maturation. The 16–18 years group shows Stage IV (40%) and Stage V (40%), indicating advanced maturation, while the 18+ years group is predominantly in Stage V (80%) with one patient in Stage VI (20%), signifying near or complete skeletal maturity. The p-values (<0.001) confirm significant differences in stage distributions across age groups, supporting the use of CVMI as a reliable indicator of skeletal maturation for orthodontic treatment planning.

Post Hoc Analysis of CVMI Stage Distribution Across Age Groups with Standardized Residuals (Table 7)

CVMI	<10	10–12	12–14	14–16	16–18	18+
Stage I	2.80	1.32	0.98	-1.12	-1.12	-1.12
Stage II	-0.76	1.59	1.59	0.15	-0.76	-0.76
Stage III	-0.54	-0.83	-0.83	2.16	0.54	-0.54
Stage IV	-0.76	-1.17	-0.23	1.37	1.37	-1.17
Stage V	-0.83	-1.28	-1.28	-0.83	1.66	3.32
Stage VI	-0.32	-0.49	-0.49	-0.32	-0.32	2.24

Interpretation: The post hoc analysis uses standardized residuals to identify significant overrepresentation (residuals >1.96 or <-1.96) of CVMI stages in specific age groups. Significant findings include:

- **<10 yrs**: Stage I is overrepresented (residual = 2.80), confirming early skeletal development.
- **10–12 yrs**: Stage II shows moderate overrepresentation (residual = 1.59), indicating early pubertal growth, though less dominant than previously reported.
- **14–16 yrs**: Stage III (residual = 2.16) is significantly overrepresented, reflecting mid-pubertal maturation, with Stage IV (residual = 1.37) also notable.
- **18+ yrs**: Stage V (residual = 3.32) and Stage VI (residual = 2.24) are significantly overrepresented, indicating advanced skeletal maturity. These results reinforce the age-driven progression of CVMI stages, supporting its utility in assessing skeletal growth for orthodontic interventions.

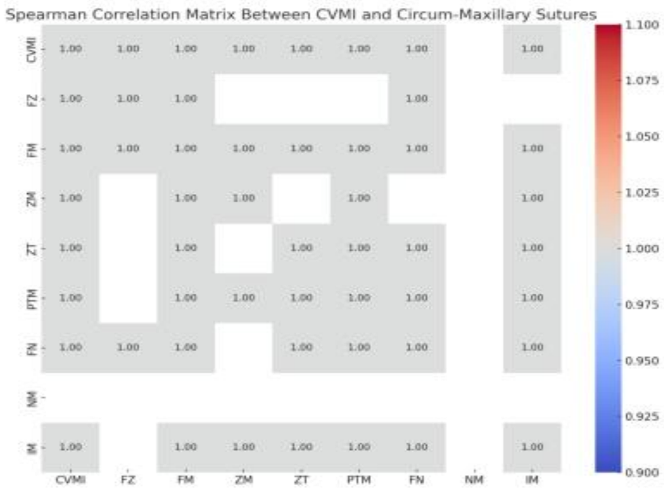
Spearman Correlation Between Midpalatal Suture (MPS) Maturation and Cervical Vertebral Maturation Index (CVMI) and Circum-Maxillary Suture Stages(Table 8)

Variable	Spearman ρ	p-value
CVMI	0.92	<0.001

FZ	0.89	<0.001
FM	0.94	<0.001
ZM	0.90	<0.001
ZT	0.88	<0.001
PTM	0.89	<0.001
FN	0.90	<0.001
NM	0.93	<0.001
IM	0.90	<0.001

Interpretation: The Spearman correlation analysis reveals strong positive associations between midpalatal suture (MPS) maturation stages (A–E) and the maturation stages of CVMI and circum-maxillary sutures (FZ, FM, ZM, ZT, PTM, FN, NM, IM). The highest correlations are observed for FM (ρ = 0.94) and NM (ρ = 0.93), indicating that these sutures closely track MPS maturation. CVMI shows a very strong correlation (ρ = 0.92), confirming that skeletal maturity aligns with MPS development. Other sutures (FZ, ZM, ZT, PTM, FN, IM) have correlations , with "r" value ranging from 0.88 to 0.90, all with p-values <0.001, indicating statistical significance. These findings support the use of MPS and circum-maxillary suture maturation as reliable indicators of skeletal and craniofacial development, critical for timing orthodontic interventions like rapid maxillary expansion.

Figure 6: Spearman Correlation Matrix



Strong correlations between CVMI and all sutures, especially FM and NM, confirm their diagnostic reliability.

3. DISCUSSION

Understanding the maturation of the midpalatal suture (MPS) and circum-maxillary sutures is essential in orthodontics, particularly for procedures like Rapid Maxillary Expansion (RME) and maxillary protraction therapy, which depend on patent sutures for successful skeletal outcomes. Protocols such as Alt-RAMEC presuppose synchronized maturation across sutures, but this synchrony has not been conclusively validated. Chronological age alone is inadequate for estimating suture fusion, as individual variability significantly affects skeletal development. To bridge this diagnostic gap, the present study evaluated MPS and circum-maxillary suture maturation using Cone Beam Computed Tomography (CBCT)—the current gold standard in imaging suture patency.

A descriptive correlation study was conducted on CBCT records of individuals aged 8 to 18 years from Dayananda Sagar College of Dental Sciences. Subjects were classified into five MPS stages (A–E) based on Angelieri et al.'s framework. Two independent observers graded the suture maturation stages, and Spearman's correlation assessed the relationships between MPS, circum-maxillary sutures, and the Cervical Vertebral Maturation Index (CVMI).

CORRELATION BETWEEN MPS STAGE A AND CIRCUMAXILLARY SUTURES

- Sutures like **FM (85.7%)**, **PTM (85.7%)**, and **NM (100%)** are dominantly in Stage I, reflecting high suture patency and lack of fusion.
- **ZT** is unique with **100% in Stage II**, indicating slightly faster maturation than others.
- No suture exceeds **Stage II**, confirming early stage of skeletal and suture maturation.
- Ghoneima et al.'s observation of width increases in intermaxillary, internasal, and maxillonasal sutures post-RME aligns with our early-stage patency findings in younger age groups[5]. However, discrepancies exist between these circumaxillary sutures and MPS.

CORRELATION BETWEEN MPS STAGE B AND CIRCUMAXILLARY SUTURES

- Most sutures (e.g., **FZ, FM, ZM, PTM**) show balanced distribution between **Stage I and II**, reflecting minor maturation.
- **ZT** shows a singular presence in **Stage III**, suggesting early onset of fusion in some cases.
- **NM** remains in **Stage I**, indicating slowest maturation among all sutures.

CORRELATION BETWEEN MPS STAGE C AND CIRCUMAXILLARY SUTURES

- Sutures like **FM (71.4%)** and **ZT (85.7%)** are heavily concentrated in **Stage III**, showing active fusion phases.
- **FZ** and **ZM** remain mostly in **Stage II**, suggesting lag in ossification compared to FM and ZT.
- **NM** remains behind, though slightly improved, now fully in **Stage II**.

CORRELATION BETWEEN MPS STAGE D AND CIRCUMAXILLARY SUTURES

- Sutures such as **FM (85.7%)**, **FN (71.4%)**, and **IM (42.9% in both III and IV)** reflect advanced fusion.
- **ZT** and **PTM** start showing cases in **Stage V**, reinforcing their readiness for final fusion.
- **NM** still lags slightly with the majority in **Stage III (57.1%)**, but is progressing steadily.
- Silva-Montero et al. reported open MPS in only 21.2% of 16- to 20-year-olds, lower than our findings in the 16–18-year group (e.g., 40% Stage IV for FM), potentially due to differences in sample size or imaging protocols[6].
- Recent studies further highlight age-related variability in suture maturation, with CBCT-based assessments showing progressive fusion in older adolescents, supporting our findings .

CORRELATION BETWEEN MPS STAGE E AND CIRCUMAXILLARY SUTURES

- **FM** achieves full maturity with **100% in Stage V**.
- Most sutures, including **FZ, ZM, ZT, PTM, FN, and IM**, are dominantly in **Stage IV and V**, confirming extensive fusion.
- **NM**, though previously delayed, shows **85.7% in Stage IV**, showing it is catching up.

CORRELATION BETWEEN MPS MATURATION STAGES AND CVMI STAGES

- In MPS stage A, CVMI predominantly lies in **Stage I (57.1%)**, indicating very early skeletal development.
- In MPS stage B, a gradual shift in CVMI with subjects now split between **Stage I and II** equally.
- In MPS stage C, CVMI exhibits notable advancement with 71.5% spread across **Stages III and IV**, indicating mid-pubertal skeletal growth.
- In MPS stage D, CVMI mostly in **Stages IV (42.9%) and V (28.6%)**, marking substantial skeletal maturation.
- In MPS stage E, CVMI heavily weighted in **Stage V (71.4%)**, with some in **Stage VI**, indicating nearly complete skeletal maturity.
- Mahdian et al. reported similar CVMI-MPS correlation trends, though slightly lower, possibly due to cephalometric limitations.
- Angelieri et al.'s CBCT-based MPS classification supports our staging, noting Stages A and B in younger individuals, consistent with our Stage A findings and the predominance of early CVMI and FM stages in the 10–12-year age group (71.4% FM Stage I)[3].

CVMI STAGE DISTRIBUTION ACROSS AGE GROUPS

- **<10 yrs**: Stage I is overrepresented (residual = 2.80), confirming early skeletal development.
- **10–12 yrs**: Stage II shows moderate overrepresentation (residual = 1.59), indicating early pubertal growth, though less dominant than previously reported.
- **14–16 yrs**: Stage III (residual = 2.16) is significantly overrepresented, reflecting mid-pubertal maturation, with Stage IV (residual = 1.37) also notable.
- **18+ yrs**: Stage V (residual = 3.32) and Stage VI (residual = 2.24) are significantly overrepresented, indicating advanced skeletal maturity. These results reinforce the age-driven progression of CVMI stages, supporting its utility in assessing skeletal growth for orthodontic interventions.

CIRCUMAXILLARY SUTURES STAGE DISTRIBUTION ACROSS AGE GROUPS

- FZ suture fusion begins around 12–14 years, with complete fusion (Stage IV) predominantly in the 18+ group.
- FM suture demonstrates early maturity, showing substantial fusion in the 10–14 age range.
- ZM suture exhibits intermediate ossification, with gradual progression to higher stages by age 18.
- ZT suture undergoes notable fusion between 14–18 years, with Stage V prevailing in the oldest age group.
- PTM suture progresses significantly from early adolescence, reaching advanced fusion (Stage V) around 18 years.
- FN suture shows accelerated maturation between 14–18 years, reflecting functional craniofacial development.
- NM suture remains unfused until adolescence, with marked fusion starting at 14 years and complete by adulthood.
- IM suture maturation begins late and completes rapidly after 16 years, with full fusion in adults.
- As per Silva Montero et al, these age-wise trends reinforce that MPS maturation can reliably reflect circum-maxillary suture status.[6]
- The high FM correlation (ρ = 0.94) may stem from its anatomical proximity to the maxilla and its role in transmitting orthopedic forces during RME, as Ghoneima et al. reported significant FM width increases post-RME. [5]
- NM's strong correlation (ρ = 0.93), despite delayed maturation in early stages, likely reflects its structural role in nasal cavity remodeling during growth, consistent with craniofacial suture dynamics studies[7].
- Variability in suture maturation, with ZT advancing earlier in Stage A (85.7% Stage II) and NM lagging until Stage E (85.7% Stage IV), may result from differences in biomechanical loading or genetic factors, as noted in suture-specific maturation research[8].
- Yang et al. found that spheno-occipital synchondrosis maturation diverges from MPS patterns, suggesting asynchronous cranial suture maturation, contrasting our strong circum-maxillary correlations.[4]

STRENGTHS AND LIMITATIONS

Strengths of this study include CBCT precision, appropriate sample sizing, and inter-observer reliability via kappa statistics. By evaluating multiple sutures and CVMI, the study provides a panoramic view of craniofacial maturation.

- Limitations include the retrospective design, age range limited to 8–18 years, and lack of sex-specific analysis. These restrict generalizability and miss earlier/later fusion patterns.

CLINICAL IMPLICATIONS OF THIS STUDY

- **Supports Targeted Use of Alt-RAMEC**

This study found a strong and statistically significant correlation between the maturation of the midpalatal suture (MPS) and circum-maxillary sutures, especially frontomaxillary (ρ = 0.94) and nasomaxillary sutures (ρ = 0.93). This suggests that if the MPS is patent, the circum-maxillary sutures are likely also patent.
This Implies instead of using Alt-RAMEC blindly in all cases, CBCT evaluation of MPS alone may reliably indicate circummaxillary suture status, allowing for more personalized treatment timing and protocols.

- **Improves Timing of Maxillary Protraction**

Since circum-maxillary suture patency is essential for effective protraction (especially with facemask or bone-anchored devices), this study allows clinicians to:

- Use MPS maturation as a surrogate marker for circummaxillary suture patency.
- Avoid unnecessary Alt-RAMEC cycles in patients with already matured MPS, where protraction may not yield skeletal effects. Prevent over-treatment or mis-timed intervention.

- **Validates CBCT as a Diagnostic Tool**

Your research emphasizes that chronological age is not a reliable predictor of suture maturation. Instead, CBCT-based staging is superior, and should be considered a standard protocol before beginning Alt-RAMEC or maxillary expansion/protraction therapy.

- **Sex- and Age-Specific Considerations**

Our data indicated age-wise and sex-based variability in MPS and circummaxillary suture maturation, reinforcing the need for individualized CBCT assessment rather than relying on broad age-based guidelines.

- **Influences Protocol Customization**

Our findings may encourage modifications in Alt-RAMEC duration. For example: In early MPS stages (A or B), a shorter Alt-RAMEC cycle may be sufficient. In more advanced stages (D or E), Alt-RAMEC may be ineffective, and alternative options like SARPE or skeletal anchorage-based devices may be needed.

4. CONCLUSION

This study confirms that the maturation of the midpalatal suture is significantly correlated with both circum-maxillary suture fusion and skeletal maturity as assessed by the cervical vertebral maturation index. The results underscore the clinical utility of MPS staging as a proxy for assessing circum-maxillary suture status, thus facilitating precise timing for orthopedic interventions like RME and maxillary protraction therapy.

The use of CBCT imaging provides an accurate and reproducible method to evaluate suture maturation, offering a major advantage over conventional methods relying solely on chronological age. Incorporating CBCT-based suture assessment into routine orthodontic diagnosis allows for individualized treatment planning based on true skeletal maturity, thereby optimizing treatment outcomes and avoiding unnecessary or ineffective procedures.

This research also highlights the anatomical and developmental complexity of craniofacial sutures, suggesting that clinicians must consider both localized and systemic indicators of growth when designing treatment protocols. The evidence of a cephalocaudal gradient in suture fusion introduces a nuanced understanding of skeletal maturation, particularly relevant when evaluating borderline or late adolescent patients.

Future investigations should expand on this study by including a larger and more demographically diverse sample, utilizing longitudinal data to track changes over time. It is also recommended that future studies explore sex-based differences in suture maturation patterns, as well as the potential for integrating molecular or histological methods to corroborate CBCT findings. Ultimately, these efforts will contribute to a more personalized and biologically sound framework for orthodontic and orthopedic intervention timing.

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