RESEARCH ARTICLE

Correlation of Cervical Vertebrae (CVMI) with Skeletal Maturity Index (SMI) and Modified MP3

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ABSTRACT

Background: Assessment of skeletal maturity is important for proper timing of orthodontic treatment. Chronological age is unreliable, while hand-wrist radiographs involve additional radiation. Cervical Vertebral Maturation Index (CVMI) method offers simpler alternatives.

Aim: To evaluate the correlation of Cervical Vertebral Maturation Index (CVMI) with Fishman's Skeletal Maturity Indicators (SMI) and modified MP3 stages.

Materials and Methods: A cross-sectional study was conducted on 45 subjects aged 10–18 years. Skeletal maturity was assessed using CVMI, SMI, and modified MP3 methods. Correlation was evaluated using Spearman's rank correlation coefficient, with $p<0.05$ considered significant.

Results: CVMI Stage 1 was most common (37.78%), followed by Stage 3 (26.67%) and Stage 2 (17.78%). A strong positive and statistically significant correlation was observed among CVMI, SMI, and modified MP3 stages.

Conclusion: CVMI showed strong correlation with SMI and modified MP3 and can be used as a reliable and radiation-sparing method for skeletal maturity assessment without requiring an additional hand-wrist radiograph.

Keywords: Cervical Vertebral Maturation Index (CVMI); Skeletal Maturity Indicators (SMI); Modified MP3; Skeletal Maturity; Growth Assessment; Pubertal Growth Spurt; Orthodontic Treatment Timing; Lateral Cephalogram; Hand-Wrist Radiograph.

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INTRODUCTION

Malocclusion may involve dental, skeletal, or combined discrepancies. Dental malocclusion can usually be corrected by orthodontic tooth movement, whereas skeletal malocclusion may require growth modification when sufficient growth remains. Successful treatment of skeletal discrepancies depends on proper timing. Therefore, accurate assessment of skeletal maturity and identification of the pubertal growth spurt are essential for diagnosis, treatment planning, and selecting the appropriate time for orthopaedic treatment.[1]

Chronological age alone is not a reliable indicator of skeletal maturation because individuals of the same age may show variations in growth and development. Therefore, biological maturity indicators are preferred for assessing developmental status and the pubertal growth spurt treatment.[2]

Several skeletal maturity indicators are available, including dental development, secondary sexual characteristics, hand-wrist maturation, cervical vertebral maturation, and phalangeal maturation. Among these, hand-wrist, cervical vertebral, and middle phalanx of the third finger (MP3) assessments are widely used in orthodontics.[3]

Lateral cephalography is routinely used to evaluate craniofacial morphology, skeletal relationships, and growth patterns. As cervical vertebrae are visible on lateral cephalograms, their morphological changes can be used to assess skeletal maturity without an additional radiograph**.** Recent advances have introduced artificial intelligence and machine-learning techniques for cervical vertebral

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Table 1. Frequency and Percentage Distribution by CVMI Stage

CVMI Stage	Clinical Description	Frequency (n)	Percentage (%)
Stage 1	Initiation	17	37.78%
Stage 2	Acceleration	8	17.78%
Stage 3	Transition	12	26.67%
Stage 4	Deceleration	2	4.44%
Stage 5	Maturation	5	11.11%
Stage 6	Completion	1	2.22%
Total		45	100.00%

Table 2. Frequency and Percentage Distribution by MP3 Stage

MP3 Stage	Epiphyseal-Diaphyseal Status	Frequency (n)	Percentage (%)
MP3-F	Start of pubertal growth spurt	18	40.00%
MP3-FG	Acceleration of growth spurt	8	17.78%
MP3-G	Maximum point of growth spurt	12	26.67%
MP3-H	Deceleration of growth spurt	1	2.22%
MP3- HI	Maturation of growth spurt	6	13.33%
Total		45	100%

Table 3. Correlation - CVMI vs. Modified MP3

	MP3-F	MP-FG	MP3-G	MP3-H	MP3-HI	Total
CVMI1	17	0	0	0	0	17
CVMI2	1	7	0	0	0	8
CVMI3	0	1	11	0	0	12
CVMI4	0	0	1	1	0	2
CVMI5	0	0	0	0	5	5
CVMI6	0	0	0	0	1	1
Total	18	8	12	1	6	45

Table 4. Correlation - CVMI vs. SMI

	SMI1-2	SMI3-4	SMI5-6	SMI7-8	SMI9-10	SMI11	Total
CVMI1	17	0	0	0	0	0	17
CVMI2	1	7	0	0	0	0	8
CVMI3	0	1	11	0	0	0	12
CVMI4	0	0	1	1	0	0	2
CVMI5	0	0	0	0	5	0	5
CVMI6	0	0	0	0	0	1	1

maturation (CVM) assessment. Although these methods show promising results, their diagnostic performance may vary according to the maturation stage and methodology used radiograph**.**

Recent quantitative and AI-assisted CVM methods emphasize the need to establish the validity and reliability of CVM by comparing it with established skeletal maturity indicators.[4]

Therefore, the present study aims to evaluate the correlation of Cervical Vertebral Maturation Index (CVMI) with Skeletal Index (SMI) and modified MP3 stages in subjects with skeletal and dental malocclusion, thereby assessing their usefulness in determining skeletal maturity and optimal timing for orthodontic treatment.[5-7]

MATERIALS AND METHODS

This cross-sectional study was conducted in the Department of Orthodontics and Dentofacial Orthopaedics. A total of 45 subjects in the age group of 10–18 years were selected by simple random sampling. The sample size was calculated using the formula for correlation studies at 95% confidence interval and 80% power.

Methodology

Table 5. Spearman's Rank Correlation Matrix

Pairwise Comparison	Correlation Coefficient (rS)	p-value	Significance Level
CVMI vs. SMI (Hand-Wrist)	0.9736	$p < 0.0001$	Highly significant
CVMI vs. Modified MP3	0.9791	$p < 0.0001$	Highly significant

Lateral cephalograms obtained in natural head position using a cephalostat. Cervical vertebral maturation was assessed from lateral cephalograms, while skeletal maturity was evaluated using Fishman's Skeletal Maturity Indicators and modified MP3 method from hand-wrist radiographs. Tracings were carried out on matte acetate paper using a 3H pencil and illuminated tracing table.

Materials used

Cephalostat, Lateral cephalometric X-ray machine, Hand-wrist radiographs, Matte acetate tracing paper**,**3H pencil**,** Illuminated tracing table**,** Adhesive tape.

RESULTS

The study included 45 subjects aged 10–18 years and evaluated skeletal maturity using CVMI, SMI, and modified MP3. Descriptive statistics and Spearman's rank correlation were used, with $p<0.05$ considered significant. CVMI assessment was based on morphological changes in C2, C3, and C4 vertebrae.CVMI Stage 1 was the most commonly observed stage, indicating that a large proportion of subjects were in the early phase of skeletal maturation.

The majority of subjects were in CVMI Stage 1 (37.78%), followed by Stage 3 (26.67%) and Stage 2 (17.78%). Stages 4 and 6 were least represented. CVMI showed high diagnostic reliability (97.36%) and assessed skeletal maturity without additional radiation exposure as shown in Table 1.

Modified MP3 analysis showed MP3-F as the most common stage (40%), followed by MP3-G (26.67%) and MP3-FG (17.78%). MP3-H was the least common (2.22%). These findings indicate that most subjects were in the active pubertal growth phase as shown in Table 2.

CVMI showed a strong positive correlation with both Modified MP3 and SMI. The correlation between CVMI and Modified MP3 was near-perfect ($r_s = 0.9791$, $p < 0.0001$). CVMI stages also closely corresponded with SMI stages, indicating that CVMI can reliably assess skeletal maturity while avoiding additional hand-wrist radiographic exposure as shown in Table 3.

CVMI showed a strong positive correlation with SMI, with high agreement across most stages.

Minor differences occurred mainly between adjacent stages. Thus, CVMI is a reliable alternative to hand-wrist assessment and can reduce additional radiographic exposure as shown in Table 4.

Spearman's analysis showed a very strong positive correlation of CVMI with SMI ($r_s = 0.9736$) and Modified MP3 ($r_s = 0.9791$), both $p< 0.0001$. Thus, CVMI is a reliable method for skeletal maturity assessment and can reduce additional radiographic exposure as shown in Table 5.

DISCUSSION

Assessment of skeletal maturity is essential for proper timing of orthodontic treatment, especially growth modification. Since chronological age does not accurately represent skeletal development, CVMI, SMI, and Modified MP3 are useful maturity indicators.[8,9]

In this study, 45 subjects aged 10–18 years were assessed, and the correlation between CVMI, SMI, and Modified MP3 was evaluated.

Distribution according to CVMI

Most subjects were in the active growth period, with CVMI Stage 2 (Acceleration) being most common, followed by Stage 3 (Transition). These stages indicate significant remaining growth and are favorable for growth-modification treatment. Stages 4–6 were less frequent, probably due to the relatively younger age distribution of the study sample.[10]

Distribution according to Modified MP3

MP3-FG was the most common stage, followed by MP3-H and MP3-I. Its distribution was comparable with CVMI, indicating a close association between the two maturity indicators.[11]

Correlation between CVMI and SMI

A strong positive correlation was found between CVMI and SMI. As CVMI stage increased, SMI also increased, suggesting that CVMI can reliably assess skeletal maturity without an additional hand-wrist radiograph.[12]

Correlation between CVMI and Modified MP3

A strong positive correlation was found; early MP3 stages corresponded with early CVMI stages and advanced stages with advanced CVMI stages.[8-12]

Correlation between SMI and Modified MP3

A positive correlation was observed, confirming that both methods similarly assess skeletal maturation.[11]

Comparison with previous studies

The findings agree with previous studies showing a strong association between CVMI, SMI, and MP3 in assessing skeletal maturity.[8]

Similarly, previous studies have shown that hand-wrist skeletal maturity indicators are closely related to pubertal growth changes. Therefore, the findings of the present study further support the use of CVMI and Modified MP3 as reliable methods for skeletal maturity assessment.[10-12]

CONCLUSION

CVMI is a reliable method for assessing skeletal maturity and shows a strong correlation with SMI and Modified MP3 stages. It effectively identifies different phases of pubertal growth. Since CVMI can be assessed from routinely taken lateral cephalograms, it can reduce the need for additional hand-wrist radiographs, minimizing radiation exposure and improving orthodontic diagnosis and treatment planning.

REFERENCES

1. Sarrafan Sadeghi T, Ourang SAH, Sohrabniya F, Sadr S, Shobeiri P, Motamedian SR. Performance of artificial intelligence on cervical vertebral maturation assessment: BMC Oral Health. 2025.
2. Kazimierczak W, Jedliński M, Issa J, et al. Accuracy of Artificial Intelligence for Cervical Vertebral Maturation Assessment—A Systematic Review. J Clin Med. 2024.
3. Rana SS, Nath B, Chaudhari PK, Vichare S. Cervical Vertebral Maturation Assessment using various Machine Learning techniques on Lateral cephalogram: A systematic literature review. J Oral Biol Craniofac Res. 2023.
4. Hassan F, Ayub A, Hussain N, et al. Comparison of Cervical Vertebral Maturation with Fishman's Skeletal Maturity Index Method in Assessment of Growth Status. Pak J Health Sci. 2022.
5. San Roman P, Palma JC, Oteo MD, Nevado E. Skeletal maturation determined by cervical vertebrae development. Eur J Orthod. 2002 ;24(3):303-311.
6. Baccetti T, Franchi L, McNamara JA Jr. Semin Orthod. 2005;11:119-129.
7. Fishman LS. Angle Orthod. 1982;52:88-112.
8. Fishman LS. Radiographic evaluation of skeletal maturation: a clinically oriented method based on hand-wrist radiographs. Angle Orthod. 1982;52(2):88–112.
9. Lamparski DG. Skeletal age assessment utilizing cervical vertebrae. University of Pittsburgh; 1972.

10. Hassel B, Farman AG. Skeletal maturation evaluation using cervical vertebrae. Am J Orthod Dentofacial Orthop. 1995;107(1):58–66.
11. Rajagopal R, Kansal S. A comparison of modified MP3 stages and the cervical vertebrae as growth indicators. J Clin Orthod. 2002;36(7):398–406.
12. Prasad M, Ganji VSK, George SA, Talapaneni AK, Shetty SK. A comparison between cervical vertebrae and modified MP3 stages for the assessment of skeletal maturity. J Nat Sci Biol Med. 2013;4(1):74.