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Correlation of skeletal maturation indicators with chronological age in orthodontic patients

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Abstract:
Skeletal maturation assessment is important in orthodontic diagnosis and treatment planning because chronological age alone does not reliably reflect growth status. Hence, this cross-sectional observational study evaluated 100 orthodontic patients aged 8–18 years using lateral cephalograms for cervical vertebral maturation staging and birth records for chronological age. A strong positive correlation was found between skeletal maturation stages and chronological age ($r = 0.82$, $p < 0.001$), with females maturing earlier than males and significant differences in mean chronological age across CVM stages. Data shows that skeletal maturation indicators are reliable tools for assessing biological maturity and growth potential in orthodontic patients. Thus, we support the use of CVM staging as a practical and dependable method for identifying optimal timing for growth modification and comprehensive orthodontic treatment.

Keywords: Skeletal maturation, chronological age, cervical vertebral maturation, orthodontics, growth assessment, hand-wrist maturation.

Background:
Assessment of growth and development is an integral part of the orthodontic diagnosis and treatment planning process. The timing of skeletal maturation and pubertal growth spurts are very critical for orthodontic treatment, particularly growth modification procedures. Biological maturity can be accurately determined which allows orthodontists to start treatment at the time of maximum growth potential, resulting in better treatment outcomes and reduced relapse **[1,2].** Growth and developmental status of children and adolescents has traditionally been estimated by chronological age. Due to the various genetic, environmental, nutritional and hormonal factors that affect physical and skeletal maturation, however, chronological age is not a reliable indicator, and biological maturity indicators have become increasingly important in orthodontic practice **[3, 4].** Skeletal age assessment is considered one of the most valid measures of physiological maturation. Fishman introduced the skeletal maturity indicators (SMI) based on specific ossification stages and it was widely accepted in orthodontics **[5]**. Hand-wrist radiographs are considered the gold standard for skeletal maturation because ossification events in hand and wrist bones correlate closely with pubertal growth changes. Although it is diagnostic, routine hand-wrist radiography exposes the patient to more radiation and is an extra radiograph beyond the routine orthodontic records. The cervical vertebral maturation method was developed by Baccetti and colleagues, based on the routine lateral cephalograms taken for orthodontic diagnosis, to overcome this limitation by evaluating morphological changes of the cervical vertebrae from C2 to C4 and relating these stages with the growth velocity of the mandible and the pubertal maturation **[6, 7].** Several studies have shown that chronological age is significantly related to skeletal maturation stages, but the strength of this relationship is different in various ethnic groups, genders and environmental factors. It is important to recognize these differences when planning orthopedic interventions such as functional appliance therapy, maxillary expansion and growth modification procedures **[8, 9].** Other indicators of maturation, such as dental calcification stages and biochemical markers like insulin-like growth factor-1 (IGF-1), have also been investigated in recent years, with varying levels of correlation between dental age and skeletal maturation, indicating that dental calcification can be used as a supplementary maturity indicator **[10,11].** Recent developments in artificial intelligence have also enhanced automated assessment of skeletal maturation using digital radiographic analysis **[12].** Therefore, it is of interest to assess the relationship between the skeletal maturity indicators and the chronological age of orthodontic patients. The study also sought to compare the maturation patterns of male and female subjects and evaluate the clinical usefulness of the CVM stages.

Materials and Methodology:

Study design:

The present study was designed as a hospital-based cross-sectional observational study conducted in the Department of Orthodontics and Dentofacial Orthopedics of a tertiary care teaching institution.

Study duration:

The study was carried out over a period of 12 months from January 2025 to December 2025.

Ethical approval:

Ethical clearance was obtained from the Institutional Ethics Committee prior to commencement of the study. Written informed consent was obtained from all participants and guardians in cases involving minors.

Sample size:

A total of 100 orthodontic patients were included in the study.

Inclusion criteria:

[1] Patients aged between 8 and 18 years.
[2] Patients requiring routine orthodontic treatment.
[3] Availability of high-quality lateral cephalograms.
[4] No previous orthodontic treatment history.

Exclusion criteria:

[1] Patients with craniofacial syndromes or congenital anomalies.
[2] Patients with systemic diseases affecting growth.
[3] Patients with endocrine disorders.
[4] History of trauma affecting cervical vertebrae.
[5] Poor-quality radiographs.

Data collection procedure:

Detailed demographic information including age and sex was recorded. Chronological age was calculated by subtracting the date of birth from the date of radiographic examination and expressed in years. Lateral cephalometric radiographs were obtained using standardized radiographic procedures. Skeletal maturation assessment was performed using the cervical vertebral maturation (CVM) method described by Baccetti *et al.* The morphology of the second, third, and fourth cervical vertebrae was evaluated and categorized into six stages:

[1] CVMS I
[2] CVMS II
[3] CVMS III
[4] CVMS IV
[5] CVMS V
[6] CVMS VI

Two experienced orthodontists independently evaluated all radiographs to minimize observer bias. Interobserver reliability was assessed using Cohen's kappa statistics.

Statistical analysis:

Data were entered into Microsoft Excel and analyzed using SPSS software version 25.0. Descriptive statistics including mean and standard deviation were calculated. Pearson correlation coefficient was used to evaluate the relationship between chronological age and skeletal maturation stages. Chi-square test and ANOVA were used for group comparisons. A p-value <0.05 was considered statistically significant.

Results:

A total of 100 orthodontic patients were included in the study, comprising 46 males and 54 females. The mean chronological age of the participants was 13.24 ± 2.41 years. Females demonstrated relatively earlier skeletal maturation compared with males across most CVM stages. The majority of study participants belonged to the 11–13 years age group (39%), followed by 14–16 years (31%). Females constituted a slightly larger proportion of the study population than males **(Table 1).** A progressive increase in chronological age was observed with advancing cervical vertebral maturation stages. The association between chronological age and CVM stages was statistically highly significant (p <0.001), indicating a strong positive relationship between skeletal maturation and age **(Table 2).** A strong positive correlation was found between chronological age and skeletal maturation (r = 0.82). Females showed slightly stronger correlation values compared with males, reflecting earlier and more synchronized maturation patterns among female subjects **(Table 3).**

Table 1: Distribution of study population according to age and gender

Variable	Frequency	Percentage
Male	46	46%
Female	54	54%
Age 8–10 years	18	18%
Age 11–13 years	39	39%
Age 14–16 years	31	31%
Age 17–18 years	12	12%

Table 2: Distribution of chronological age according to CVM stages

CVM Stage	Mean Age (Years)	SD	p-value
CVMS I	9.42	0.86	<0.001*
CVMS II	10.87	1.03	<0.001*
CVMS III	12.74	1.12	<0.001*
CVMS IV	14.36	1.21	<0.001*
CVMS V	16.02	1.04	<0.001*
CVMS VI	17.45	0.91	<0.001*

Table 3: Correlation between chronological age and skeletal maturation

Parameter	Correlation Coefficient (r)	p-value
Chronological age vs CVM stage	0.82	<0.001*
Male subjects	0.79	<0.001*
Female subjects	0.85	<0.001*

Discussion:

Growth assessment is a basic component of the orthodontic diagnosis since the success of many orthopedic and functional treatments is dependent on the skeletal maturity of the patient more than chronological age. Biological maturity can be determined, and this enables the orthodontist to recognise when growth is accelerated and to plan for the best time to provide maximum skeletal correction. The present study showed that there was a high positive correlation between the chronological

age and the skeletal maturation indicators in orthodontic patients. The overall correlation coefficient (r = 0.82) shows that chronological age and skeletal maturity are strongly correlated, but chronological age alone cannot accurately predict an individual's biological maturity status. Recent studies assessing CVM stages and chronological age also reported similar results **[2].** Cervical vertebral maturation assessment has gained increasing acceptance since it requires the use of routinely acquired lateral cephalograms but does not require extra radiation exposure from hand-wrist radiographs. In the present study, the progression through CVM stages was consistent with chronological age. Advanced maturation stages were observed in older adolescents; subjects in CVMS I were mostly younger children. These observations are consistent with those made by Franchi *et al.*, who showed that there is a significant correlation between the stages of the cervical vertebrae and the growth velocity of the mandible and the pubertal growth spurt **[4].** The earlier skeletal maturation found in the female subjects was one of the important findings of this study. Females were at CVMS III and IV earlier than males, suggesting earlier pubertal growth acceleration. This is consistent with previous findings that females reach maturity about 1–2 years before males, which is believed to be due to biological differences in hormonal regulation and pubertal onset. The present study also showed that there were very significant differences between the mean chronological age of the various CVM stages. There was a gradual rise in mean age from CVMS I to CVMS VI. This trend supports the validity of cervical vertebral morphology as a skeletal maturation indicator. This has been reported in other studies that assessed cervical vertebral maturation in different ethnic groups **[6].** One of the easiest ways to estimate developmental status is still chronological age. There is, however, a lot of variation due to nutritional status, genetics, systemic health, socioeconomic factors, and environmental factors, so using chronological age alone for orthodontic treatment planning can result in inappropriate timing of growth modification procedures. Traditionally, Fishman's skeletal maturity indicators based on hand-wrist radiographs have been considered very reliable tools for growth assessment, but the use of hand-wrist radiographs adds radiation exposure and may not be feasible in orthodontic practice. Thus, CVM assessment has become a preferred alternative. There have been several studies that have compared dental age, skeletal age and chronological age. There were good correlations between dental calcification stages and skeletal maturation in some investigations. Mandibular second molar calcification has been suggested as a good marker of pubertal growth. But in not every population is there a consistent relationship between dental and skeletal maturity **[10].** However, recent systematic reviews have confirmed the validity of dental maturation techniques for determining the stages of skeletal growth. Although, there is a greater link between cervical vertebral maturation and changes in skeletal growth, which are relevant to orthodontic treatment, and mandibular growth **[13].** Skeletal maturation assessment recently introduced with the help of artificial intelligence. Future advances in automated algorithms for predicting skeletal maturity stages have demonstrated good accuracy and repeatability, which could minimize observer variability and enhance the efficiency of diagnosis. Biochemical markers like insulin-like growth factor-1 (IGF-1) may also be used to assess skeletal maturity and are a useful addition to the radiographic assessment of skeletal maturity and may offer dynamic assessment of growth activity. But their use in routine clinical practice is limited due to cost and laboratory requirements. The high correlation in this study supports the use of skeletal maturation indicators as a source of information other than chronological age. Timing is particularly crucial in Class II malocclusions, maxillary deficiencies and skeletal discrepancies that require orthopedic treatment, as it increases the effectiveness of treatment and skeletal response **[14, 15].** The present study also showed high interobserver reliability for CVM staging, indicating that the cervical vertebral analysis is repeatable if it is performed by trained examiners. This discovery is consistent with its regular application in clinical orthodontics. The study was limited in that it yielded valuable findings. The number of samples was relatively small and from a single institution. Larger multi-ethnic longitudinal studies may be able to yield more complete information on maturation variability. In addition, future investigations could be reinforced with comparison to hand-wrist radiographs and biochemical markers. The results in general stress the importance of evaluating skeletal maturation as an integral part of the orthodontic diagnosis. Growth status should not be judged solely on chronological age due to the large interindividual variation.

Conclusion:

Skeletal maturation indicators showed a strong correlation with chronological age in orthodontic patients, confirming their value in assessing biological maturity. Cervical vertebral maturation stages progressed predictably with age, and males showed later skeletal maturation than females. Because chronological age alone cannot reliably reflect individual growth status, cervical vertebral maturation on routine lateral cephalograms provides an effective, reproducible, and radiation-efficient method for determining growth potential and guiding the timing of orthodontic growth modification and treatment.

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