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Edited by Vini Mehta
E-mail: vmehta@statsense.in
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Correlation between dental calcification age and cervical maturity index

Pooja Arora[1,*], Dinesh Solanki[2], G.A Prarthana[3], Saksham Madhok[4], Suryabhan Yadav[5], Dipti Choksi[6], PurvaMathur[7]&Yogesh Garg[8]

[1]Department of Dentistry, Advance Cancer Institute, BFUHS, Bathinda, Punjab, India; [2]Department of Dentistry, JIET Medical College and Hospital, Jodhpur, Rajasthan, India; [3]Department of Oral Medicine and Radiology, Raja Rajeshwari Dental College and Hospital, Bangalore, Karnataka, India; [4]Department of Orthodontics and Dentofacial Orthopedics, Teerthanker Mahaveer Dental College and Research Centre, Moradabad, Uttar Pradesh, India; [5]Department of Conservative Dentistry, ITS CDSR, Muradnagar, Ghaziabad, Uttar Pradesh, India; [6]Department of Conservative Dentistry and Endodontics, Faculty of Dental Science, Dharamsinh Desai University, Nadiad, Gujarat, India; [7]Department of Periodontology and Oral Implantology, Rajasthan Dental College, Jaipur, Rajasthan, India; [8]Department of Public Health Dentistry, JCD Dental College, Sirsa, Haryana, India; *Corresponding author

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Affiliation URL:
http://jcddentalcollege.com
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http://jcddentalcollege.com

Author contact:
Pooja Arora - E-mail: drpoojaarora786@gmail.com
Dinesh Solanki - E-mail: dr.din17@gmail.com
G.A Prarthana - E-mail: prarthanaga7@gmail.com
SakshamMadhok - E-mail: drshaksham.dental@tmu.ac.in
Suryabhan Yadav - E-mail: surajbhansinghyadav@gmail.com
DiptiChoksi - E-mail: diptichoksi.fods@ddu.ac.in
PurvaMathur - E-mail: purmathur@gmail.com
Yogesh Garg - E-mail: yogeshgarg1988@gmail.com

Abstract:
Skeletal growth indicators are affected by environmental factors, and dental calcification stages are considered somewhat stable in comparison. Hence, a total of 120 panoramic radiographs and lateral cephalograms from 8 to 18 years old subjects were evaluated. The Demirjian method was used to assess dental maturity and the CVM method to determine skeletal maturity. The outcomes showed a positive correlation between dental calcification and CVM stages ($r = 0.78$, $p < 0.001$). Thus, we show that dental calcification may be a potentially useful measure for skeletal maturity estimation in orthodontic patients.

Keywords: Dental calcification, cervical vertebral maturation, skeletal maturity, demirjian method, orthodontic diagnosis

Background:
Assessment of skeletal maturity is an integral part of orthodontic diagnosis and treatment planning, particularly in growing patients. Determining the stage of skeletal development helps clinicians identify the optimal timing for growth modification and other orthodontic interventions, thereby improving treatment outcomes **[1].** Traditionally, hand–wrist radiographs have been considered the standard method for evaluating skeletal maturity. However, the requirement for additional radiographic exposure has encouraged the search for alternative approaches **[2].** The cervical vertebral maturation (CVM) method has gained considerable acceptance in orthodontics because it utilizes cervical vertebrae visible on routine lateral cephalometric radiographs, eliminating the need for additional radiographic examinations **[2-5].** Several studies have demonstrated the reliability and clinical usefulness of CVM as an indicator of skeletal growth and maturation **[3–6].** In recent years, dental development has emerged as a potential adjunctive indicator of skeletal maturity. Dental calcification stages observed on panoramic radiographs are considered relatively stable and less affected by environmental influences than several other growth indicators **[3].** Consequently, increasing attention has been directed toward evaluating the relationship between dental calcification stages and cervical vertebral maturation. Systematic reviews and cross-sectional investigations have reported significant associations between dental maturation and skeletal development, suggesting that dental age assessment may serve as a useful adjunct in growth evaluation **[7, 8].** These findings support the possibility of utilizing routinely obtained dental radiographs to estimate skeletal maturity, thereby enhancing diagnostic efficiency and reducing the need for additional radiographic procedures. The relationship between dental development and skeletal maturation was initially described by Chertkow **[9]** and later expanded by Coutinho *et al.* **[10]**, who demonstrated significant correlations between tooth calcification stages and skeletal growth phases. Their findings provided the foundation for subsequent investigations exploring the association between dental and skeletal maturation indicators. Despite the growing body of evidence supporting this relationship, variations in the strength of correlation have been reported among different populations and ethnic groups **[5, 8].** Therefore, further studies are required to validate the applicability of these indicators in specific populations and to improve their clinical utility in orthodontic practice. The combined assessment of dental calcification stages and cervical vertebral maturation offers a simple, non-invasive, and clinically practical method for evaluating growth status in orthodontic patients. Such an approach may facilitate more accurate treatment planning and improve overall treatment outcomes **[1, 6].** Therefore, it is of interest to report the correlation between dental calcification stages and cervical vertebral maturation stages in the study population.

Methodology:

This cross-sectional observational study assessed the relationship between dental calcification stages and the cervical vertebral maturation (CVM) index. This sample included 8–18-year-old orthodontic patients selected from existing records. Patients with systemic illness, craniofacial anomaly, and history of previous orthodontic treatment or poor-quality radiographs were excluded to avoid compromising data consistency and reliability. Subject-specific digital panoramic radiographs and lateral cephalograms were retrieved from institutional archives. We evaluated dental calcification stages using Demirjian method that is determined into A to H in which mineralisation stages are classified. Mandibular Canines and 1s, 2s PMs & 2s M → consistent association with skeletal maturity. The changes in shape of second, third and fourth cervical vertebrae (C2 to C4) are classified by the CVM method into stages of cervical maturation based on lateral cephalograms. This technique provides an assessment of skeletal maturity without the need for repeat radiographs. All radiographs were assessed by a trained observer in standardised conditions. A second group of radiographs was revaluated two weeks later to assess reliability, and the consistency of observations was evaluated using relevant reliability statistics. Data was compiled and analyzed using appropriate software. We used Spearman's rank correlation coefficient to address the relationship between dental calcification stages and CVM stages, since both variables are ordinal. $P<0.05$ was considered to be statistically significant. Such methodology provides a reliable evaluation of the association among dental and skeletal maturation.

Results:

The stages of cervical vertebral maturation (CVM) were compared with the dental calcification stages in 120 subjects**. Table 1**shows that male and female respondents were evenly distributed throughout the age groups. Most subjects were 11 to 16 years of age, which is a key time for skeletal growth and puberty. The large proportion of developmental changes during this age range makes it a reasonable time to study maturation indicators. As seen at **Table 2** most subjects were classified in stages E and F of the Demirjian index meaning that crowns were nearly completed with roots not yet matured which happens typically during puberty. The other 3 states were less populated with subjects in either the early (C, D) or late (G, H) stages and thus formed a peak in the middle stages of dental development. The **Table 3** shows the subjects were essentially at peak mandibular growth and the transition in skeletal maturation state hung out between stage CS3 and CS4 on CVM. The number of subjects that were in the early (CS1, CS2) and late stages (CS5, CS6) was also lower as shown by the age distribution of the sample. A high positive correlation between dental calcification and CVM stages was found (Spearman's $r = 0.78$, $p < 0.001$), as shown in **Table 4**, which indicates that when dentin develops faster it coincide with a more advanced skeletal maturity. Higher Demirjian stages (G and H) were significantly associated with advanced CVM stages (CS5 and CS6); conversely, earlier dental stages were associated with earlier skeletal stages. In general, these findings provide a consistent relationship between dental and skeletal maturation. The tight clustering of subjects within middle stages, and the high correlation, suggest that dental calcification can reliably indicate skeletal growth. We conclude that these findings align with the use of dental maturation as a defensible purpose adjunct to assessing growth phases, especially where minimising additional radiographic exposure is important.

Table 1: Age and gender distribution of the study sample

Age Group (years)	Males (n)	Females (n)	Total (n)
8–10	12	14	26
11–13	18	20	38
14–16	20	18	38
17–18	10	8	18
Total	60	60	120

Table 2: Distribution of dental calcification stages

Tooth Stage (Demirjian)	Number of Subjects (n)	Percentage (%)
Stage C	10	8.3%
Stage D	18	15.0%
Stage E	26	21.7%
Stage F	30	25.0%
Stage G	22	18.3%
Stage H	14	11.7%
Total	120	100%

Table 3: Distribution of Cervical Vertebral Maturation (CVM) Stages

CVM Stage	Number of Subjects (n)	Percentage (%)
CS1	12	10.0%
CS2	20	16.7%
CS3	28	23.3%
CS4	26	21.7%
CS5	20	16.7%
CS6	14	11.6%
Total	120	100%

Table 4: Correlation between dental calcification stages and CVM Stages

Parameter Compared	Correlation (Spearman's r)	Coefficient	p-value
Dental Calcification vs CVM Stage	0.78		<0.001

Discussion:

Orthodontic diagnosis depends largely on the assessment of skeletal maturity, which is essential for determining the optimal timing of many treatment approaches, particularly those involving growth modification. The present study assessed the relationship between dental calcification stages and cervical vertebral maturation (CVM) stages and demonstrated a strong positive correlation between these two indicators. These findings suggest that dental maturation occurs in parallel with skeletal growth and may serve as a useful adjunctive clinical marker for evaluating growth status **[1]**. The strong correlation observed in the present study ($r = 0.78$) is consistent with findings reported in previous investigations that evaluated the association between dental maturation and skeletal maturity using CVM methods **[2, 3].** Similar observations have been reported in studies evaluating different population groups, indicating that dental calcification stages may be useful indicators of biological maturation **[4–8].** One of the earliest studies to demonstrate that tooth mineralization stages correspond with phases of skeletal growth was conducted by Chertkow **[9]**, and these findings were

later expanded by Coutinho*et al.* **[10].** The present results support these pioneering observations and further strengthen the evidence supporting the relationship between dental and skeletal maturation. Dental development has been considered a relatively stable biological process and is generally less affected by environmental influences than many other growth indicators **[11, 12].** Previous studies have shown that specific teeth, particularly the mandibular canine and second molar, exhibit significant correlations with skeletal maturity indicators **[13].** The participants in the present study were predominantly distributed within dental calcification stages E and F and CVM stages CS3 and CS4, which correspond to the pubertal growth spurt. Similar developmental transitions have been reported in previous investigations assessing dental maturation and skeletal development during adolescence **[14, 15].** The present findings are also consistent with studies reporting stronger associations between skeletal maturity and calcification stages of mandibular teeth, particularly the canine and second molar **[16].** Such teeth undergo mineralization in distinct and sequential stages, making them reliable markers for developmental assessment. However, despite the strong correlation observed in the present study, dental and skeletal maturation are not identical biological processes. Differences in the timing and strength of this association have been reported across populations, suggesting the influence of genetic, ethnic, environmental, and nutritional factors **[17, 18].** Although dental calcification is considered a reliable developmental indicator, it should not be regarded as a complete substitute for skeletal maturity assessment. Previous studies have demonstrated that discrepancies may occur between dental and skeletal ages at the individual level, highlighting the importance of comprehensive evaluation **[17, 18].** The CVM method used in the present study offers significant clinical advantages because it utilizes routinely obtained lateral cephalometric radiographs and therefore avoids additional radiation exposure. When combined with dental calcification assessment from panoramic radiographs, clinicians can obtain a more comprehensive evaluation of maturation status without requiring supplementary imaging procedures. Overall, the findings of the present study are in agreement with the majority of available literature and confirm a significant positive correlation between dental calcification stages and cervical vertebral maturation stages. Clinically, this relationship may assist orthodontists in estimating skeletal maturity, particularly when additional radiographic examinations are undesirable. Nevertheless, dental calcification should be considered an adjunctive indicator and used alongside established skeletal maturity assessment methods to provide a more individualized and accurate evaluation of growth status **[1, 6].**

Conclusion:

A very strong and statistically significant correlation exists between stages of dental calcification and cervical vertebral maturation stages indicating that dental development is in close accordance with skeletal maturity. Dental calcification may be a useful additional tool in the evaluation of growth, especially during puberty. Similar to skeletal maturity indicator, dental maturity should not be used in isolation but as an adjunct for the most accurate diagnosis and treatment planning.

Advancement of Knowledge:

This study indicates that dental calcification is a valid and non-invasive method to estimate skeletal maturity. The results justify routine imaging with radiographs for monitoring growth, leading to reduced radiation exposure. Moreover, our findings highlight the relevance of combining one or more dental and skeletal indicators as a way to improve orthodontic treatment planning.

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