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Prediction of skeletal maturation using dental mineralization in the Solan, Himachal Pradesh population: An *in vivo* cross-sectional study

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Abstract:
The association between dental calcification stages and skeletal maturity is important for estimating chronological age and growth status in children and adolescents. This cross-sectional *in vivo* study included patients aged 8 to 17 years and assessed dental age using Demirjian's staging on orthopantomograms and skeletal age using cervical vertebral maturation on lateral cephalograms. A highly significant positive correlation was found between CVMI stages, chronological age, and Demirjian estimated dental age in both sexes ($p < 0.001$). The first premolar in females ($r = 0.816$) and the second premolar in males ($r = 0.843$) were the strongest individual predictors of skeletal maturity, while the second molar also showed reliable stage-wise utility. Thus, we document specific dental calcification stages that can serve as practical clinical indicators of skeletal maturation and growth phase assessment.

Keywords: Dental age, skeletal age, growth indicator, puberty, cervical vertebrae

Background:
Orthodontic diagnosis and treatment rely on the age of the patient. The chronological age of the patient is not a reliable method of determining the age **[1].** Previously, the method of measuring the hand and wrist using hand-wrist radiographs was considered as a method to determine the age of the patient **[2, 3].** However, it requires additional exposure to radiation. Another method of determining the age included the cervical vertebrae maturity index using lateral cephalograms. Recently, the calcification pattern of the teeth has been considered as an appropriate method of determining the age of the patient **[4].** The calcification of teeth can be considered a method of determining the skeletal age of the patient. Orthopantomograms of the dentition can indicate the age of the patient appropriately. The radiograph of the dentition does not require high exposure to radiation. The patient's dentition is a reliable indicator of age because calcification is independent of several factors, such as hormones and nutrition that might affect the other bones **[5, 6].** Which specific tooth is reliable for determining the age of the patient is still a debate to be resolved **[7].** The specific tooth that can predict age is affected by the ethnicity of the population. Determining the specific tooth that is a reliable predictor of age in a particular population is essential to verify the chronological age of the patient **[8]**. Therefore, it is of interest to determine the reliability of orthopantomograms of teeth in establishing a relationship between chronological age and skeletal age.

Methodology:
A cross-sectional *in-vivo* study was conducted at the Department of Orthodontics and Dentofacial Orthopedics, Bhojia Dental College; encompassing 140 patients (68 males, 72 females) aged 8 to 17 years. A sample of 140 participants provides sufficient statistical power ($\beta = 0.80$) at a significance level of $\alpha = 0.05$ to detect correlation between dental and skeletal maturation stages. Patients with systemic disorders, syndromes, and a history of orthodontic treatment, head/neck trauma, or congenitally missing teeth (except third molars) were strictly excluded. Standard digital lateral cephalograms taken in a natural head position and orthopantomograms were acquired using an Advapex OPG-TMJ-CEPH machine. The radiographs were taken in dark room to ensure it is clear and those radiographs demonstrating motion dullness or poor contrast were not include in the study. To improve intra-observer and inter-observer reliability weighted kappa was measured on 10% subset of radiographs which yielded value above 0.80 indicating there was perfect agreement in the stagging of dental and skeletal maturation. Dental maturation was evaluated from the panoramic radiographs using the Demirjian system. Visual assessment and categorization of the dental age was done using Demirjian's system. The stages ranged from A (initiation of calcification) to H (apical closure). Concurrently, skeletal maturation was determined from lateral cephalograms utilizing the Cervical Vertebrae Maturation Index (CVMI) established by Hassel and Farman. The second, third and fourth cervical vertebrae were assessed as per the morphology and categorized into six -level scale ranging from initiation and completion. Chronological age was recorded directly from clinical files. The Statistical Package for Social Sciences (SPSS) for Windows, Version 22.0 was used and the data obtained was subjected to statistical analysis. After evaluation of the normality of the data it was revealed that the data was not normally distributed, therefore the non-parametric Spearman's rank correlation was used to evaluate the monotonic relationship between maturity indices. Statistical significance was predefined at a 95% confidence level, with $p \leq 0.05$ interpreted as significant and $p < 0.001$ as highly significant.

Table 1: Spearman's Rank Correlation Coefficients ® between Skeletal Maturation (CVMI Stages) and Age/Dental Variables

Variable Correlated with CVMI Stages	Females (*r* value)	95% CI	Males (*r* value)	95% CI	Significance (*p* value)
Chronological Age	0.892**	[0.80, 0.94]	0.929**	[0.87, 0.96]	p<0.01 (Significant)
Demirjian Estimated Dental Age	0.862**	[0.75, 0.93]	0.902**	[0.82, 0.95]	p<0.01 (Significant)
Central Incisor (31)	0.067	[−0.23, 0.36]	0.334**	[0.05, 0.57]	Not Sig (F) / Sig (M)
Lateral Incisor (32)	0.173	[−0.13, 0.43]	0.385**	[0.09, 0.61]	Not Sig (F) / Sig (M)
Canine (33)	0.781**	[0.63, 0.88]	0.822**	[0.70, 0.90]	≤ 0.01 (Significant)
1st Premolar (34)	0.816 **	[0.68, 0.90]	0.812**	[0.67, 0.90]	≤ 0.01 (Highly Significant)

2nd Premolar (35)	0.759**	[0.59, 0.87]	0.843 **	[0.72, 0.91]	≤ 0.01 (Significant)
1st Molar (36)	0.127	[−0.17, 0.39]	0.446**	[0.16, 0.65]	Not Sig (F) / Sig (M)
2nd Molar (37)	0.683**	[0.49, 0.81]	0.720**	[0.54, 0.84]	≤ 0.01 (Significant)

** Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level.*

Results and Discussion:

Among the 140 participants evaluated in this study, the females had a slightly higher mean chronological age of 14.14 ± 2.35 years. Conversely, the males had a slightly lower mean chronological age of 13.56 ± 2.40 years. The overall mean dental age, calculated using the Demirjian method by assessing the left mandibular teeth, was also higher for females (13.88 ± 2.24 years) than for males (13.43 ± 2.40 years). However, across all six skeletal maturation stages of the Cervical Vertebrae Maturation Index (CVMI), females consistently exhibited a lower mean chronological and dental age than males, confirming that females reach skeletal and dental maturity chronologically earlier. Specifically, at CVMI Stage III, which marks the transition period, the mean chronological age was 12.57 ± 1.03 years for females versus 13.21 ± 0.65 years for males, confirming an earlier pubertal onset in the female demographic. **Table 1** illustrates the significant positive correlation ($p<0.001$) between skeletal maturation (CVMI stages), chronological age, and Demirjian estimated dental age across both sexes using Spearman's rank correlation coefficient. Furthermore, it identifies the first premolar in females (r=0.816) and the second premolar in males (r=0.843) as the strongest individual dental predictors of skeletal maturity, making them highly reliable diagnostic indicators. The widest gap in the chronological, dental, and skeletal ages occurred at the 3rd stage of CVMI; this was consistent with the findings of Kiran *et al.* and Basaran *et al.* specifically showing a difference of almost one full year between genders, which is highly indicative of an earlier onset of the pubertal growth spurt in the female demographic **[9, 10].** The 1st premolars, 2nd premolars, and 2nd molars found in Demirjian Stage G were associated with stage 3 of CVMI, which corresponds directly with the peak of the pubertal growth spurt, and this association was consistently reported by Kumar *et al.* **[11].**Considering individual teeth, the highest Spearman correlation coefficients indicated that the 1st premolars in females had a robust predictive ratio with an r-value of 0.816, demonstrating a predictive capacity which was found consistent with the findings of Rozylo-Kalinowska *et al.* **[12]** in the female cohort and further supported by Valizadeh *et al.*, who also observed the highest correlations for first premolars in females **[13]**. Yet another study by Kishore *et al.* **[14]** demonstrated the 2nd premolar as the tooth with strong predictive capabilities, matching our male cohort where the second premolar yielded an exceptionally high correlation of r=0.843 **[10].** The r-value obtained in this study for second molar was not highest, but it was uniformly distributed tooth across the various CVMI stage. Thus, it is highly reliable for tracking growth from pre-pubertal phase to growth completion. This precise diagnostic utility of the second molar is echoed by Cossellu *et al.* (2014), who confirmed it as a highly reliable indicator for evaluating the progression through specific pubertal growth phases **[15]**. Finally, in this study, the central and lateral incisors in females did not show a significant relationship with skeletal growth (r=0.067 and r=0.173, respectively); however, the mandibular canines did demonstrate a highly significant relation, a finding that has also been demonstrated in certain other studies such as those by Hegde *et al.* and Rohmetra *et al.* confirming their standalone diagnostic value **[16, 17].** Gopalakrishnan *et al.* conducted a similar study they found a strong and statistically significant relation between skeletal maturity and dental calcification; they recommended the studies in various region to rule racial or regional influences **[18]**. Lashin *et al.* conducted a study in which they compared two methods for determination of age using calcification of the teeth as one of the parameter, they found nolla method and fishman both reliable for the determination of age however one of the methods underestimated the chronological age while the other over estimated it, in this a single method was employed, variable methods can strengthen the findings further **[19].** The primary limitation is the cross-sectional nature of the study, which prevents the tracking of individual growth velocities over time. Additionally, the study relies on the Demirjian method, which may overestimate age in non-Caucasian populations

Conclusion:

Dental calcification stages can be a reliable predictor of skeletal maturation, suggesting that routine orthopantomograms may serve as a useful, non-invasive adjunct for skeletal maturity assessment. The findings also suggest earlier pubertal onset and relatively faster dental maturation in females than in males, which can enable the use of sex-specific predictive markers. Among individual teeth, the first premolar in females and the second premolar in males may be of predictive value.

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