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Panoramic radiography with lateral cephalometry for age and gender estimation

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Abstract:
Accurate age and sex estimation remains a challenge in forensic science and clinical dentistry, as the reliability of commonly used radiographic indicators varies across populations. Therefore, it is of interest to evaluate the 100 healthy individuals aged 10–20 years using lateral cephalograms and orthopantomograms to compare dental age, cervical vertebral maturation and gonial angle measurements. Dental age and CVMI showed strong positive correlations with chronological age, while gonial angle was a weaker predictor despite age-related variation. Thus, data show that dental age and cervical vertebral maturation are more reliable for age estimation and orthopantomograms may better detect subtle sex-related differences in gonial angle than lateral cephalograms.

Keywords: Gender determination, age estimation**,** cervical vertebral maturation (CVM), chronological age, skeletal maturity

Background:
The mandible is the largest, strongest and most resilient bone of the facial skeleton, showing clear sexual dimorphism **[1]**. Among its anatomical landmarks, the gonial angle holds special significance as it is influenced by gender, age and dental status **[2]**. Its value has also been explored for estimating age in both dentate and edentulous individuals **[3]**. Consequently, in forensic sciences and related investigations, the gonial angle is often considered a parameter for both gender determination and age estimation **[4]**. Dental age estimation techniques can be categorized into morphologic, radiologic, biochemical and histological approaches **[5]**. Radiological methods are simple, cost-effective, non-destructive and applicable to both living and dead individuals. They estimate age using dental development, eruption status, open apices and pulp-to-tooth ratio **[6]**. Demirjian *et al.* developed a radiographic age estimation method that scores seven left mandibular teeth using an eight-stage tooth development classification system **[7]**. Demirjian's method has gained widespread global acceptance for age estimation across diverse populations because it is simple and practical, features well-defined stages and offers better inter observer reliability **[8]**. Traditionally, hand–wrist radiographs were considered the most reliable method for assessing biological maturity, but their drawback was the need for an additional radiograph **[9]**. To address this, Lamparski (1972) introduced the cervical vertebral maturation (CVM) method, later refined by Hassel and Farman in 1995. This technique offered the benefit of reducing unnecessary radiation, as lateral cephalograms are already routinely taken for diagnostic and treatment purposes **[10]**. Therefore, it is of interest to assess the potential limitations and challenges in using these radiographs for age and gender determination for forensic investigations and clinical dentistry.

Materials and Methods:
Study design:
This cross-sectional study was conducted on 100 healthy individuals (50 males and 50 females), aged 10–20 years, who reported to the Department of Dentistry, Government Gandhi Medical College, Bhopal, Madhya Pradesh, India for diagnostic and treatment purposes. All participants underwent lateral cephalogram and orthopantomogram imaging.

Study duration:
The study was conducted over a period of 9 months.

Study population:
The study population comprised healthy adolescents of both sexes aged 10–20 years attending the Department of Dentistry during the study period.

Sample size calculation:
The sample size was calculated using the standard formula for cross-sectional studies. Considering a 95% confidence level, 80% power and allowable error based on previous studies, the minimum required sample size was approximately 96 subjects. Hence, a total of 100 subjects (50 males and 50 females) were included to ensure adequate statistical power and gender-wise comparison.

Methodology:
The gonial angle was measured on both orthopantomograms (OPGs) and lateral cephalograms using manual tracing for sex determination by a single trained orthodontist. Tracing acetate is placed over the film and landmarks are traced using a sharp 4H pencil on an illuminated tracing board. The bilateral gonial angle was measured by drawing one tangent along the lower border of the mandible and another along the posterior border of the ramus and condyle and the angle was measured by using a "D" Head Protractor. Later, a bilateral gonial angle was calculated. In lateral cephalometric radiographs, the mean gonial angle was determined from the superimposed images. Manual angular measurements show inherent examiner-related variability (±0.5°–1°) **[11]**. Lateral cephalograms and orthopantomograms, due to their two-dimensional nature, are affected by magnification and distortion, which may influence measurement accuracy **[12]**. In the present study, these aforesaid parameters are considered and statistical analysis was performed accordingly. Dental age was estimated from OPGs using Demirjian's method **[7]** assesses dental age using eight developmental stages (A–H) of mandibular 2nd permanent molar, ranging from initial cusp calcification to complete root apex closure. Skeletal age was evaluated using the cervical vertebral maturation index **[10]** (CVMI), a six-stage index based on morphological changes in the C2–C4 cervical vertebrae observed on lateral cephalograms.

Inclusion criteria:
[1] Healthy males and females aged 10–20 years.
[2] Availability of good-quality OPG and lateral cephalogram.

[3] Presence of mandibular teeth is required for Demirjian's method.
[4] No systemic disease affecting growth or development.

Exclusion criteria:
[1] History of trauma, surgery, or orthodontic treatment affecting the mandible.
[2] Craniofacial anomalies, missing teeth needed for assessment, or systemic disorders influencing maturation.

Ethical approval:
The research was approved by the Institutional Ethical Committee of Gandhi Medical College Bhopal, Madhya Pradesh, India with approval number IEC Protocol No. 314 IEC/2025

Consent:
All those patients who satisfied the inclusion criteria received detailed information regarding the study and further only those patients were included who signed an informed consent ensuring their confidentiality**.** In case of participants below 18 years of age, consent was obtained from their parents or guardians. The purpose and procedure of the study were explained in detail; confidentiality of all collected data was strictly maintained.

Statistical analysis:
All data were compiled and analyzed using IBM SPSS Statistics for Windows, Version 30.0 (IBMCorp., Armonk, NY, USA). Descriptive statistics were calculated for all variables, with continuous data expressed as mean ± standard deviation (SD) and categorical data as frequency and percentage. Normality of data distribution was assessed using the Shapiro–Wilk test. Gender-wise comparisons of chronological age, dental age and gonial angle measurements obtained from lateral cephalogram and orthopantomogram were performed using the independent samples t-test and effect size was calculated using Cohen's d. Association between gender and cervical vertebral maturation index (CVMI) stages were evaluated using the Chi-square test.

Results:
Table 1 summarizes the baseline demographic characteristics of the study participants. The study included 100 subjects with equal gender distribution (50 males and 50 females). Most participants were aged 15–17 years (47%), followed by 12–14 years (35%) and ≥18 years (18%). The mean chronological age of the total sample was 15.62 ± 2.22 years, with comparable mean ages observed between males (15.60 ± 2.24 years) and females (15.64 ± 2.23 years). Gender-wise comparison showed no significant difference in chronological age between males and females (p = 0.929). Gonial angle values from lateral cephalograms were similar across genders (p = 0.098), whereas orthopantomograms showed significant gender differences on both sides, with higher mean values in females (p = 0.019 and p = 0.018). Dental age by Demirjian's method and cervical vertebral maturation stages **(Figure 1)** showed no gender differences (p = 1.000). Overall, orthopantomograms were more sensitive than lateral Cephalograms in identifying gender-related differences. Age-group comparison showed significant differences in gonial angle measurements on both lateral cephalograms and orthopantomograms, with the highest mean values in the 15–17-year group. Chronological age showed a strong positive correlation with dental age (r = 0.891) and CVMI stage (r = 0.789) also show in **Figure 2 and Figure 3**. In contrast, gonial angles showed weak and non-significant correlations with chronological age despite age-related variation. Overall, dental age and cervical vertebral maturation were more reliable indicators of chronological age than gonial angle measurements **(Table 2, 3)**. **Table 4 and Figure 4** present the descriptive statistics of gonial angle measurements obtained from lateral cephalograms and orthopantomograms (right and left sides) according to gender. On lateral cephalometric radiographs, females showed a slightly higher mean gonial angle (123.92 ± 3.95°) compared to males (122.54 ± 4.30°); however, this difference was not statistically significant (p = 0.098), indicating comparable gonial angle values between genders when measured on lateral cephalograms. In contrast, gonial angle measurements obtained from orthopantomograms showed statistically significant gender differences. Females exhibited significantly higher mean gonial angles on both the right side (123.72 ± 3.71°) and the left side (123.58 ± 3.67°) compared to males (121.70 ± 4.71° on the right and 121.50 ± 4.88° on the left), with p-values of 0.019 and 0.018, respectively. The observed mean differences suggest a consistent pattern of higher gonial angle values in females on OPG measurements. Overall, these findings indicate that while lateral cephalogram-based gonial angle measurements do not differ significantly between males and females, orthopantomogram-based measurements reveal significant gender-related differences, with females showing higher gonial angle values bilaterally. This suggests that OPG may be more sensitive in detecting subtle gender-related variations in gonial angle measurements.

Table 1: Distribution of study participants according to gender and age group with descriptive statistics of chronological age (n = 100)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	50	50.0
	Female	50	50.0
Age Groups	12–14 years	35	35.0
	15–17 years	47	47.0
	≥18 years	18	18.0
(years) (Mean ± SD)	Male	15.60 ± 2.24	–
	Female	15.64 ± 2.23	–
	Total	15.62 ± 2.22	–

Table 2: Gender-wise comparison of chronological age, dental age, gonadal angle measurements and skeletal maturity (CVMI) (n = 100)

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Parameter	Male(n= 50) Mean± SD	Female (n= 50) Mean ± SD	Test statistic	P	Effect size/ Association (Cohen's d)
Chronological age (years)	15.60 ± 2.24	15.64 ± 2.23	t = −0.089	0.929	−0.02
Dental age (Demirjian)	15.06 ± 1.86	15.06 ± 1.86	t = 0.000	1.000	0.00
Gonial angle–Lateral cephalogram (°)	122.54 ± 4.30	123.92 ± 3.95	t = −1.671	0.098 (NS)	−0.33
Gonial angle–OPG (Right) (°)	121.70 ± 4.71	123.72 ± 3.71	t = −2.383	0.019*	−0.48
Gonial angle–OPG (Left) (°)	121.50 ± 4.88	123.58 ± 3.67	t = −2.410	0.018*	−0.48
CVMI stage distribution	–	–	χ^2=0.000	1.000	No gender association

Table 3: Age-wise comparison and correlation of gonial angle measurements, dental age and skeletal maturity with chronological age (n = 100)

Parameter	12–14 years(n =35) Mean±SD	15–17 years(n =47) Mean±SD	≥18years(n=18) Mean± SD	p-value (ANOVA)	Correlation with Age (r,95%CI)
Gonialangle–Lateral cephalogram (°)	122.06±4.24	124.47±4.11	122.28±3.38	0.018*	0.110 (−0.088,0.300)
Gonialangle–OPG (Right) (°)	121.86±4.55	124.13±3.99	120.67±3.71	0.005*	0.008 (−0.188,0.204)
Gonialangle–OPG (Left) (°)	121.54±4.60	124.09±4.07	120.44±3.62	0.002*	0.025 (−0.172,0.221)
Dentalage (Demirjian)	–	–	–	–	0.891 (0.842,0.926)
CVMI stage	–	–	–	–	0.789 (0.702,0.854)

*Statistically significant

Table 4: Descriptive statistics of gonadal angle measurements on lateral cephalogram and orthopantomogram according to gender (n = 100)

Gender	N	Lateral Cephalogram Mean ± SD	Mean Difference	p-value	OPG (Right) Mean ± SD	Mean Difference	p-value*	OPG (Left) Mean ± SD	Mean Difference	p-value
Male	50	122.54 ± 4.30	−1.38	0.098	121.70 ± 4.71	−2.02	0.019*	121.50 ± 4.88	−2.08	0.018*
Female	50	123.92 ± 3.95		(NS)	123.72 ± 3.71			123.58 ± 3.67		(S)
Total	100	123.23 ± 4.17			122.71 ± 4.34			122.54 ± 4.42		

*Statistically significant, NS- not significant

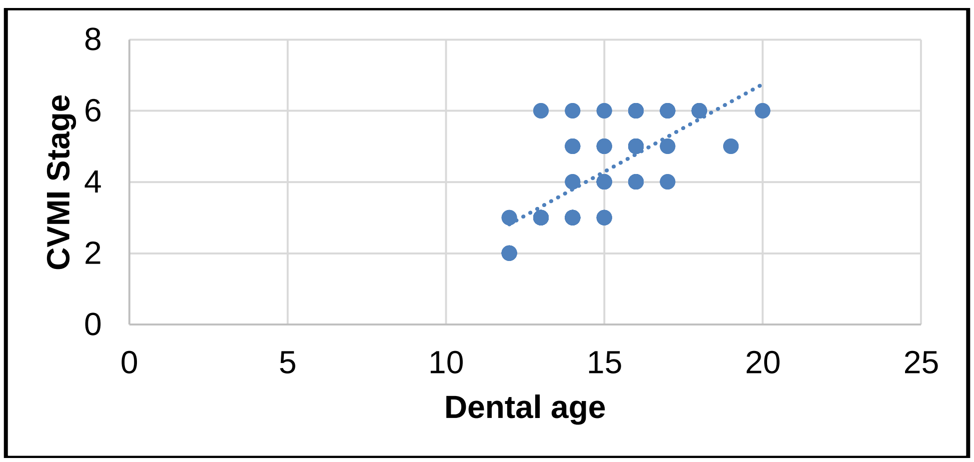

Figure 1: Scatter plot depicting the correlation between dental age and CVMI stage

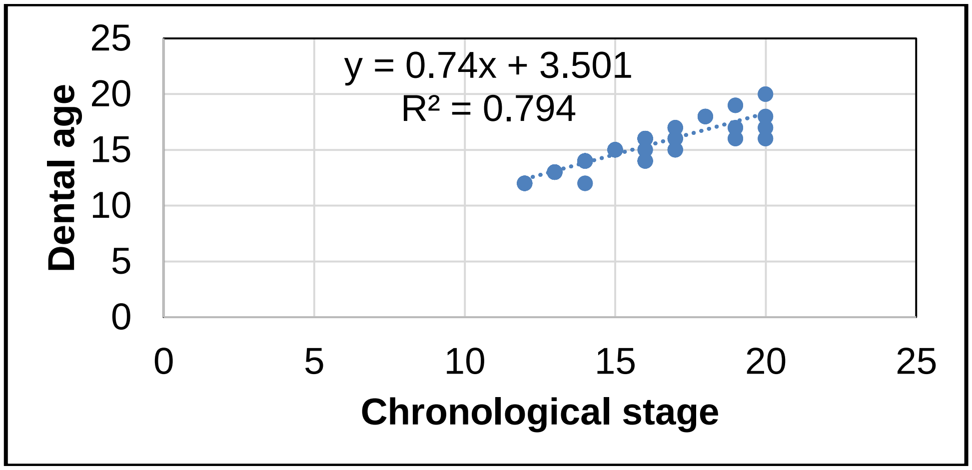

Figure 2: Scatter plot showing correlation between chronological age and dental age

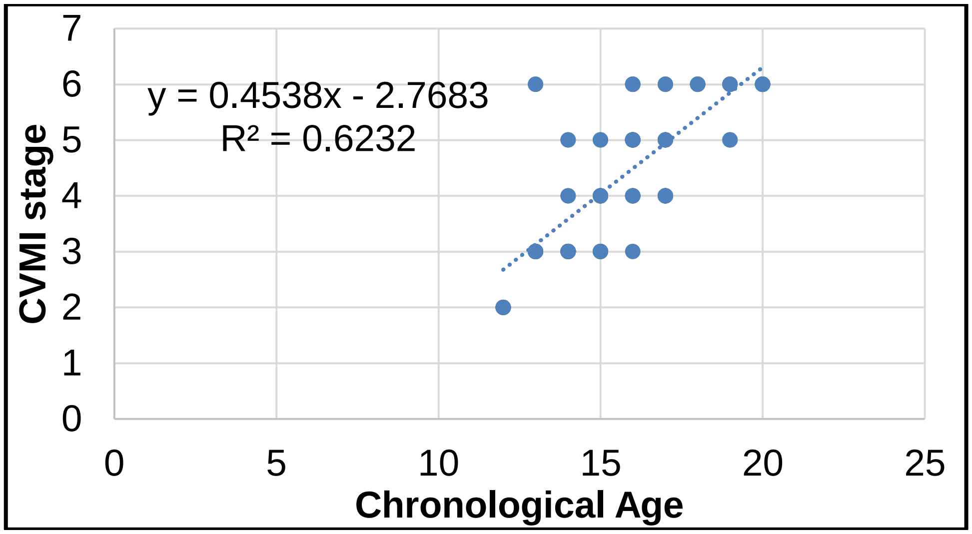

Figure 3: Scatter plot showing the relationship between chronological age and CVMI stage

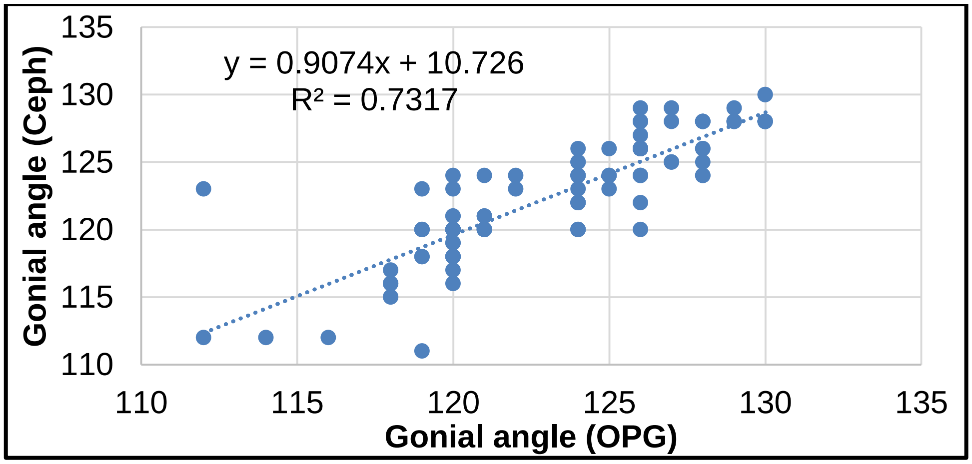

Figure 4: Scatter plot showing agreement between gonial angle measurements obtained from lateral cephalogram and orthopantomogram

Discussion:

Gender determination is crucial for forensic investigations as well as for understanding regional variation and population history. Along with this, accurate dental age determination has become an essential responsibility of dental medicolegal officers due to the rising incidence of crime **[13]**. The present study showed a statistically significant gender-based difference in gonial angle measurements (p=0.929), with females exhibiting higher values compared to males. These findings are consistent with previous studies by Sikaria *et al.* **[2]**. Previous studies by Sikaria *et al.* **[2]**, the present study findings are in agreement with Girdhar *et al.* **[14]** and Dogan *et al.* **[15]**, who reported significant gender-related variations in gonial angle measurements. Similar to the present study, females showed higher gonial angle values compared with males, suggesting the presence of sexual dimorphism in mandibular morphology. However, Mohrana *et al.* [16] reported no significant association between gender and gonial angle, contrasting with the present results. Conversely, some researchers have observed higher mean gonial angle values in males compared to females **[17]**, which is also in direct contrast to the findings of this study. The variations in gonial angle reported across studies may be due to differences in population characteristics, age groups and sample sizes, as well as the imaging modalities and measurement techniques used. Genetic and developmental factors, along with observer variability, may also contribute to these contrasting findings. No statistically significant gender differences were observed in chronological age, dental age assessed using Demirjian's method, or the distribution of cervical vertebral maturation index (CVMI) stages in the present study. Previous studies have also reported a high level of agreement between dental and skeletal maturation in both sexes, indicating similar maturation patterns with only minor variations in timing **[18]**. The accuracy of age estimation by OPG was 93.8% and by lateral cephalogram was 79.7%. In accordance with the present study, OPG showed better overall reliability for gonial angle-based gender assessment, whereas both OPG and lateral cephalograms exhibited comparable performance for age estimation **[19].** Correlation analysis in the present study demonstrated a strong positive relationship between chronological age and dental age. These findings are consistent with earlier reports by Gandhi *et al.* **[20]** who observed significant positive correlations between skeletal maturity and permanent dentition. However, Poulsen and Sonnesen **[21]** reported no significant association between skeletal and dental maturation, which contrasts with the present results. In the present study, gonial angle measurements obtained from lateral cephalograms showed no significant gender differences, whereas orthopantomograms showed significantly higher bilateral gonial angle values in females, suggesting that OPG is more effective in detecting subtle gender-related variations. Panoramic radiography is advantageous for gonial angle assessment as the right and left angles can be measured separately without superimposition of anatomical landmarks, a limitation commonly encountered in lateral cephalograms stated by Tashkandi *et al.* **[22].** However, Bhullar *et al.* **[23]** show **no gender differences in gonial angles** on either cephalograms or OPGs, supporting equivalence of modalities. The present study has certain limitations, including a relatively small sample size and single-center design, which may limit the generalizability of the findings. The study relied on two-dimensional imaging (lateral cephalogram and OPG) and three-dimensional imaging modalities such as CT/CBCT were not used, which may limit measurement accuracy due to inherent limitations of 2D imaging. CT/CBCT was not used due to higher radiation exposure, cost constraints and limited availability, particularly in routine clinical settings.

Conclusion:

OPG measurements of the gonial angle showed greater sensitivity than lateral cephalograms in detecting gender-related differences, while both imaging modalities were equally effective in assessing age-related variations. Bilateral superimposition in lateral cephalograms limits accurate assessment of individual tooth development stages, making OPG the preferred modality for dental age estimation. The significant positive correlation among dental age, chronological age and CVMI validates their combined application for accurate age estimation.

Advancement to knowledge:

This study provides a comparative evaluation of dental age, cervical vertebral maturation and gonial angle measurements for age estimation in adolescents and young adults using both lateral cephalograms and orthopantomograms. It demonstrates that dental age and cervical vertebral maturation are more reliable indicators of chronological age than gonial angle. The findings also suggest that orthopantomograms may be more sensitive than lateral cephalograms in detecting subtle sex-related differences in gonial angle, offering additional guidance for forensic and clinical age assessment.

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