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Original Research Article

Generation and validation of a new linear regression equation of mandibular first permanent molar and its comparative evaluation for predictive accuracy with already established regression equation of cervical vertebrae: a radiographic study

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ABSTRACT

Background: Accurate skeletal age estimation is essential for orthodontic treatment planning and forensic identification. This study aimed to generate a new linear regression equation for age estimation using the pulp chamber crown trunk height ratio (PCTHR) of the permanent mandibular first molar and to compare its accuracy with the established cervical vertebral maturation index (CVMI) regression equation.

Methods: This observational analytical cohort study included 305 subjects aged 9–14 years. Orthopantomograms (OPGs) and lateral cephalograms were obtained. Pulp chamber height (PCH) and crown root trunk height (CRTH) of the mandibular first molar was measured using Image J 1.46r software, and PCTHR was calculated. Cervical vertebral bone age was calculated using the Mito et al regression equation: Cervical vertebral bone age (years)=−0.20 +6.20×(AH3/AP3) + 5.90×(AH4/AP4) + 4.74×(AH4/PH4). A linear regression equation for age estimation using PCTHR was derived from 305 subjects and validated on a subset of 90 subjects (15 per age group). Accuracy was compared using correlation coefficient (R), R^2, mean absolute error (MAE), and root mean square error (RMSE). Statistical analysis was performed using statistical package for the social sciences (SPSS) version 25.0 (IBM Corp., Armonk, NY, USA).

Results: The mean age of the 305 subjects was 12.01±1.634 years. PCH showed a weak negative correlation with age (r=–0.110). The derived regression equation was: predicted age (9–14 years) =11.362–(0.456×PCH) + (0.222×CRTH). The model explained 75% of the variance (R^2=0.750, R=0.866) with MAE 0.719 years and RMSE 0.854 years. The CVMI model showed stronger correlation (R=0.895, R^2=0.800) with lower error (MAE 0.599 years, RMSE 0.763 years).

Conclusions: Both PCTHR and CVMI methods are effective for skeletal age estimation in Indian children aged 9–14 years. CVMI demonstrated superior accuracy, but the PCTHR method offers a useful non-invasive alternative using routine OPGs without additional radiation.

Keywords: Age estimation, Mandibular first molar, Pulp chamber height, Cervical vertebral maturation, Forensic dentistry, Orthodontics

INTRODUCTION

The assessment of skeletal maturation is crucial for orthodontic treatment planning and outcomes, as face growth often does not progress in a linear manner. The timing of treatment initiation is crucial in influencing the outcomes of orthodontic therapy. Additionally, evaluating skeletal maturation is essential for monitoring, assessing, and appropriately scheduling treatment in young patients with growth disorders or endocrine conditions.[1,2]

There are various indicators and parameters for assessment of skeletal age maturation such as body mass index, bisexual characteristics, hand wrist radiography (most commonly used), cervical vertebral maturation indicator (CVMI), use of frontal sinus from lateral cephalogram, dental eruption and dental calcification stages.[3]

Hand wrist radiography is considered the most reliable method for assessing skeletal age. However, it involves additional radiation exposure, which raises safety concerns. According to the as low as reasonably achievable principle (ALARA), routinely using hand radiographs is being reconsidered to minimize unnecessary radiation, especially in growing children.[1,4] The British Orthodontic Society recommendations advise against the use of hand and wrist radiography for orthodontic purposes in anticipating the commencement of the pubertal growth spurt.[3] There is growing emphasis on assessing cervical vertebrae to minimize radiation exposure to patients. Lateral cephalometric radiographs, which are routinely taken in orthodontics, naturally capture the cervical vertebrae. Studies have shown that noticeable morphological changes occur in the C2, C3, and C4 vertebral bodies during growth, making them useful indicators of skeletal development.[5]

Due to the deposition of secondary dentin, dental pulp gradually loses size with time, making it a useful indication of age. Even in people above 25, this constant change can be utilized to accurately predict age.[6] The use of tooth radiographs is a nonionizing and simple process. One way of estimating skeletal maturity is use of regression equation. The maxillary canine, which fully grows at age 17, has a regression equation that has already been determined. This regression equation was unable to assess population ages under 17.[7,8] Considering need for age prediction method for age group below 17 years a new regression equation needs to be developed for permanent mandibular first molar which completes its development at the age of 12 years so that the age of the population below 17 years could be analysed by using dental pulp as indicator.[8]

Clinical studies have shown that functional appliances are most effective during the pubertal growth spurt, when mandibular growth reaches its peak. One of the main challenges in treating class II patients is determining the optimal timing for starting functional appliance therapy. To address this, clinicians need to accurately assess the patient's mandibular growth potential during the growth phase.[3,9,10]

Additionally, dental tissues are more resilient to thermal, chemical, and mechanical influences compared to other tissues like connective, muscle, and epithelial tissues. Therefore, teeth serve as a distinct and reliable indicator for estimating skeletal age.[11] Today, they are widely used as a valuable tool for age estimation in both living and deceased individuals, especially in medico legal contexts.[12-14]

This study aims to develop and validate a new linear regression equation for age estimation using the permanent mandibular first molar and to assess its accuracy by comparing it with an existing regression equation based on cervical vertebrae analysis.

METHODS

Study design and setting

Observational analytical cohort study conducted in the Department of Orthodontics and Department of Oral Medicine and Radiology, VSPM'S Ranjeet Deshmukh Dental College and Research centre Nagpur, India. The study was conducted from March 2023 to August 2024.

Study population

Patients of the Department of Orthodontics and Dentofacial Orthopedics within the age group of 9 to 14 years.

Sample size derivation

Level of significance (α error) =5%, power=80%, type of test=two sided. Formula is given as follows.

$$n = (Z_1)^2[P(1P)]/d^2$$

Assuming all factors, minimum sample size came to 289 subjects. A total of 305 subjects were included. A subset of 90 subjects (15 per age group from 9 to 14 years) was used for validation and comparison.

Sampling technique

Convenience sampling was employed.

Inclusion criteria

OPGs and lateral cephalograms of subjects between age group of 9 to 14 years, OPG and lateral cephalogram of orthodontic patients who already have both the X rays for treatment planning and diagnosis for orthodontic treatment, the mandibular first molar should be completely erupted into the oral cavity, the mandibular first molar root should be fully formed and C3, C4 cervical vertebrae should be clearly visible in lateral cephalogram were included.

Exclusion criteria

Mandibular first molar with any pathology, such as attrition, caries or periodontitis or periapical lesions, which would alter the surface area of the tooth, maligned or impacted mandibular first molar, mandibular first molar with any restorative filling or any prosthetic fittings, patient having any bone diseases or deformity, traumatic lesions or malformations associated with cervical vertebrae or jaw bone and patient having history of hormonal disorders / syndromic patients were excluded.

Methodology

Age evaluation by pulp chamber crown trunk height ratio (PCTHR)

Orthopantomograms (OPG) were obtained for 305 subjects in digital format using Carestream CS 8100 X ray machine. Image J 1.46r software was utilized to mark the points and record linear measurements. According to Mathew et al, the pulp crown trunk height ratio (PCTHR) of a mandibular first molar was calculated by dividing the pulp chamber height (PCH) by the crown root trunk height (CRTH). Points were marked on the highest point on the root furcation and the central fossa, and a line was drawn connecting these points.

The points on the roof and floor of pulp chamber were also marked and connected. CRTH measured the separation between the central fossa and the highest point on the root furcation, while PCH measured the separation between the pulp chamber's floor and roof points. A linear regression equation was obtained from the study group using PCTHR. The accuracy of age estimation was evaluated by applying the derived linear regression equation to the test group (n=90).

Figure 1: Colour plate I: (left) Carestream CS 8100 X-ray machine used for image acquisition; (right) digitised orthopantomogram showing mandibular first molars.

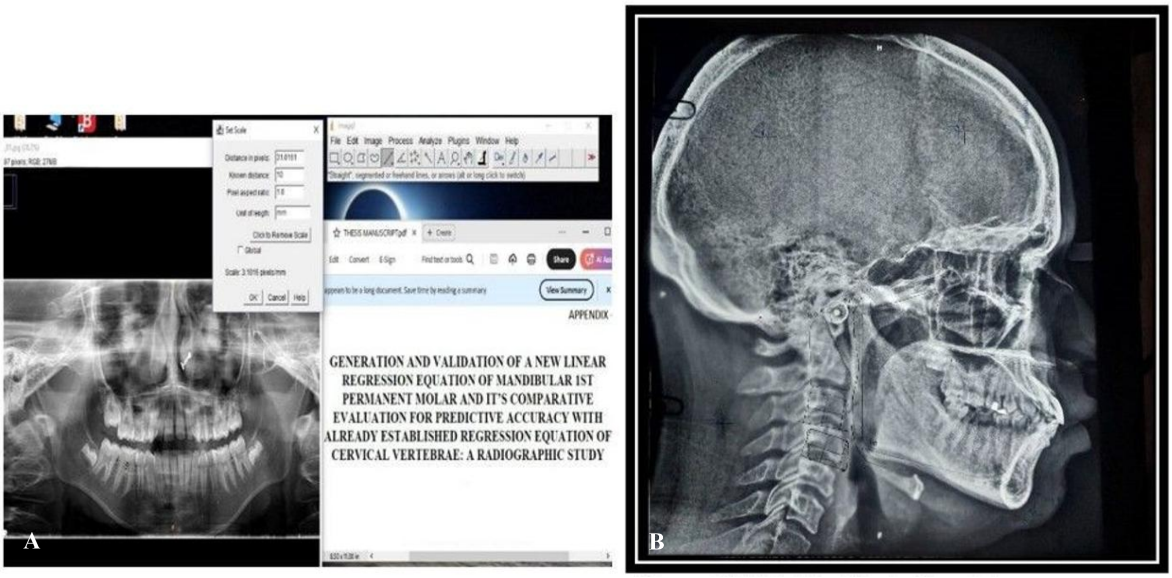

Figure 2: Colour plate II: (left) ImageJ 1.46r software interface with measurement tools; (right) digitised lateral cephalogram with cervical vertebrae (C2, C3, C4) visible.

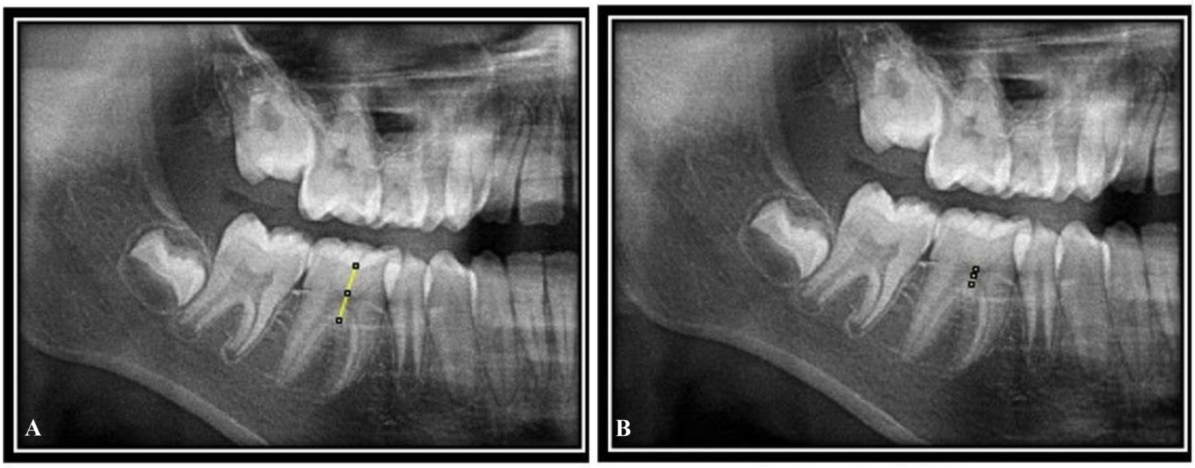

Figure 3: Colour plate III: (A) crown root trunk height measurement on mandibular first molar – line from central fossa to root furcation; (B) pulp chamber height measurement – line from pulp chamber roof to floor.

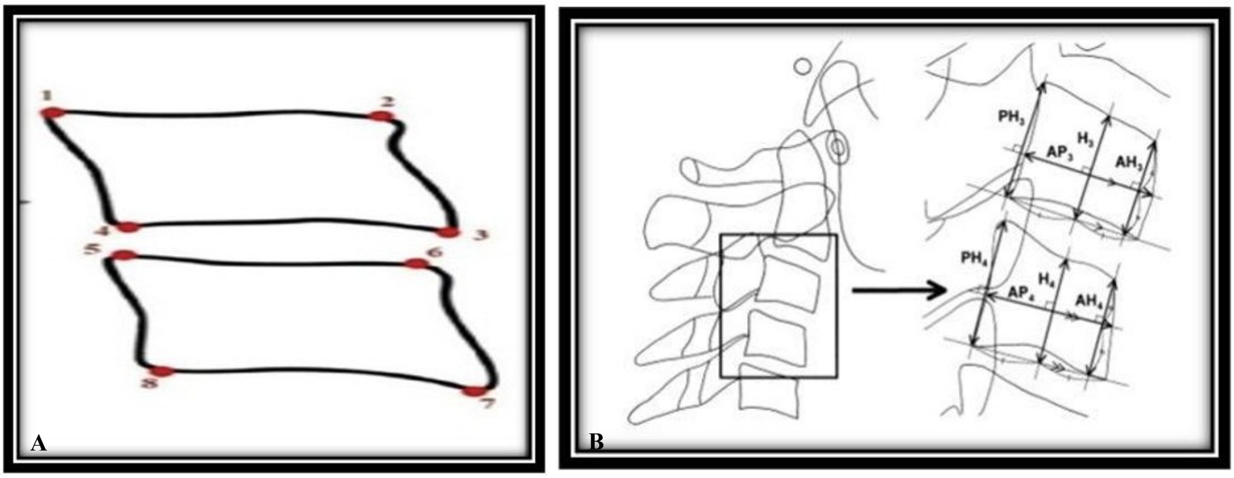

Figure 4: (A) Landmarks on vertebral bodies C2 and C3: AH (anterior height), AP (anteroposterior length), PH (posterior height); (B): Reference lines drawn on vertebral bodies C2 and C3 for geometric measurement according to Mito et al method.

Method of age estimation by cervical vertebrae using regression equation

Lateral cephalograms were traced on Image J 1.46r software. Following landmarks were located on vertebral bodies C3 and C4 as per Mito et al.[15] Parameters measured: AH3 (anterior height of C3), AP3 (anteroposterior length of C3), PH3 (posterior height of C3), AH4, AP4, PH4. Cervical vertebral bone age was calculated as follows.[9,15]

$$Cervical\ vertebral\ bone\ age\ (years) = -0.20 + 6.20 \times (AH3/AP3) + 5.90 \times (AH4/AP4) + 4.74 \times (AH4/PH4)$$

Comparison

Both regression equations were compared to check the accuracy for age estimation using correlation coefficient (R), R^2, mean absolute error (MAE), and root mean square error (RMSE).

Statistical analysis

Data were analyzed using statistical package for the social sciences (SPSS) version 25.0 (IBM Corp., Armonk, NY, USA). Pearson correlation, linear regression, ANOVA, and descriptive statistics were used. A p value <0.05 was considered statistically significant.

Ethical approval

The study was conducted in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments. Approval was obtained from the Institutional Ethics Committee of the institute. Written informed consent was obtained from the parents/legal guardians of all participants.

RESULTS

Descriptive statistics (total sample, n=305)

The mean chronological age of the study participants was 12.01±1.634 years. The mean pulp chamber height (PCH) was 2.4624±0.56059, while the mean crown root trunk height (CRTH) was 7.9758±0.87906 (Table 1).

Table 1: Descriptive statistics.

Variable	Mean	SD	N
Age (9-14 years)	12.01	1.634	305
PCH	2.4624	0.56059	305
CRTH	7.9758	0.87906	305

Correlations

PCH showed a weak negative correlation with chronological age (r=−0.110), indicating a reduction in pulp chamber height with increasing age. A moderate positive correlation was observed between PCH and CRTH (r=0.390, p<0.01) (Table 2).

Table 2: Correlations.

Variables	Age (9-14)	PCH	CRTH
Age (9-14)	1.000	-0.110	-0.059
PCH	-0.110	1.000	0.390**
CRTH	-0.059	0.390**	1.000

**p<0.01

Regression model for PCTHR

The regression model demonstrated a correlation coefficient (R) of 0.156 with an R^2 value of 0.024, indicating that the included variables explained a small proportion of age variability (Table 3).

The ANOVA results showed that the regression model was statistically significant (p=0.025), suggesting that the predictor variables collectively contributed to age estimation (Table 4).

Regression analysis demonstrated that PCH had a negative association with age, whereas CRTH showed a positive association. Based on these findings, a regression equation was derived for predicting chronological age (Table 5).

Derived linear regression equation

$$Predicted\ age\ (9-14\ years) = 11.362 - (0.456 \times PCH) + (0.222 \times CRTH)$$

Comparison of PCTHR and CVMI models (validation on 90 subjects).

Comparative evaluation revealed that the CVMI model demonstrated higher predictive accuracy than the PCTHR model, with higher correlation and R^2 values along with lower MAE and RMSE values (Table 6).

Age wise distribution of CVMI age and PCTHR age (from validation data, n=90).

Age 9 years

Mean CVMI age range 8.28–10.99 years; mean PCTHR age range 10.36–11.35 years.

Age 10 years

Mean CVMI age range 9.09–11.23 years; mean PCTHR age range 10.35–11.75 years.

Age 11 years

Mean CVMI age range 10.44–13.16 years; mean PCTHR age range 11.62–12.44 years.

Age 12 years

Mean CVMI age range 10.40–15.65 years; mean PCTHR age range 11.36–12.26 years.

Age 13 years

Mean CVMI age range 11.35–14.79 years; mean PCTHR age range 12.64–14.78 years.

Age 14 years

Mean CVMI age range 13.11–15.68 years; mean PCTHR age range 12.10–13.39 years.

Table 3: Model summary.

Model	R	R square	Adjusted R square	Std. error of estimate
1	0.156	0.024	-0.018	1.620
Predictors: (constant), CRTH, PCH				

Table 4: ANOVA.

Model	Sum of squares	df	Mean square	F	Sig.
Regression	19.637	2	9.819	3.743	0.025
Residual	792.310	302	2.624		
Total	811.948	304			

Table 5: Coefficients.

Model	Unstandardized B	Std. error	Standardized beta	t	Sig.
(Constant)	11.362	0.852		14.196	0.000
PCH	-0.456	0.180	0.033	0.295	0.769
CRTH	-0.222	0.115	-0.122	-1.088	0.279

Table 6: Comparative summary.

Metric	PCTHR model	CVMI model	Difference	Better model
R	0.866	0.895	0.029	CVMI
R^2	0.750	0.800	0.050	CVMI
MAE	0.719	0.599	-0.120	CVMI
RMSE	0.854	0.763	-0.091	CVMI

DISCUSSION

A complex interplay between shape and function is reflected in the human face's growth and development.[9] Correcting skeletal discrepancies through repositioning of the apical bases necessitates a thorough understanding of craniofacial growth patterns. Assessing a child's growth status is particularly crucial when planning orthodontic treatment that involves growth modification using myofunctional or orthopedic appliances. These appliances are most effective when used during the pubertal growth spurt.[15-24] Growth phases have been evaluated using a variety of physiological markers, including body weight, sexual maturation features, dental development, peak growth velocity in standing height, and chronological age.[25,26] However, these methods are often insufficient. Therefore, several biological indicators, including hand wrist radiographs, cervical vertebral morphology, and changes in the middle phalanx of the third finger, have been explored as more reliable markers for evaluating an individual's peak growth period.[16-34]

The analysis of hand wrist radiographs is the most traditional and widely used method for estimating skeletal age, with its accuracy and reliability well established through numerous studies.[22,23] However, these techniques demand expert interpretation and can be time consuming. In recent years, growing attention has been directed toward evaluating skeletal maturation through changes in the size and shape of cervical vertebrae in developing individuals.[33-35] Because cervical vertebrae can be analyzed on lateral cephalograms, which are frequently used in orthodontic diagnosis, and because hand wrist radiographs require additional radiation exposure, this method is becoming more common.[5-37]

Hassel and Farman developed the CVMI by analyzing the concavities along the lower borders of the second, third, and fourth cervical vertebrae.[18] Their study revealed a strong correlation between CVMI and hand wrist skeletal maturation methods. Franchi et al validated the use of CVMI stages as reliable biological markers for assessing both mandibular and overall skeletal maturity.[16]

In this study, the cervical vertebral bone age for each young subject was calculated by measuring the geometric dimensions of the third (C3) and fourth (C4) cervical vertebral bodies and inserting these values into the designated formula.[15]

Teeth are considered dependable anatomical structures for forensic age estimation, as they are minimally affected by environmental factors.[11-14] Estimating age through radiographic analysis of secondary dentine deposition is a widely accepted and non-invasive technique, particularly effective in adults.[21-27] Several accurate age estimation equations based on secondary dentine deposition have been developed for Western populations.[28-30] However, when these are applied to Indian samples, they result in errors that are unacceptable for forensic purposes. Therefore, to improve the accuracy of age prediction, it is recommended to develop population specific formulas tailored to the Indian population.[19-31]

In our study, we developed a separate technique for estimating age by examining the mandibular first molars using orthopantomograms (OPG). The decrease in pulp chamber height was used as an indirect indicator of secondary dentine deposition. It has been observed that this deposition is not uniformly distributed throughout the pulp cavity. In molars, as age progresses, secondary dentine deposition takes place on the roof and floor of the pulp chamber, leading to reduction in its height rather than its width.[21,22] Drusini et al measured the coronal pulp chamber height in posterior teeth by calculating the distance between the highest point of the pulp horn and the cervical line.[6] However, we found this technique to be impractical, as the superimposition of adjacent pulp horns and the presence of a thin cemento enamel junction made it difficult to obtain accurate measurements.[22-47]

In our study, we introduced a new, simple method where we measured the height of the pulp chamber and the height of the crown root trunk, then calculated a ratio called PCTHR.[22] When we compared this ratio with the actual ages of the participants, we found a clear and statistically significant negative correlation ($r=-0.56$; $p=0.000$), meaning the ratio decreased as age increased. Our findings suggest that measuring the reduction in pulp chamber height in mandibular first molars is a more reliable indicator of age than measuring pulp area in front teeth. When we applied the regression equation based on PCTHR ratios to a test group, the estimated ages closely matched the actual ages, with no significant difference (p=0.639).[48-50]

In our study, there was no significant difference between the actual age and the estimated age for both male and female participants. This finding is consistent with results from other age estimation studies conducted on the Indian population.[28-49]

Comparison of both regression equations: Age showed a strong positive correlation with both CVMI age (r=0.895) and PCTHR age (r=0.866), meaning both methods estimate age well. PCH Length had a moderate negative correlation with age (r=–0.354), suggesting pulp chamber height decreases as age increases. There was a strong positive relationship between CVMI age and PCTHR age (difference=0.029), showing both estimate age in a similar way. The model shows a strong correlation (R=0.906) between the predictors and actual age. An R square of 0.821 means that about 82% of the variation in age is explained by the variables in the model. Among the predictors, PCTHR age and CVMI age have statistically significant effects, with p values of 0.000 and 0.002, respectively.

These results demonstrate the reliability and precision of the cervical vertebral bone age method in estimating skeletal age in India's expanding population. When Mito et al. compared the actual potential obtained through regression analysis with the predicted growth potential obtained using cervical vertebral age, chronological age, and bone age, they discovered that the difference between the actual and predicted potential was greatest when using chronological age, followed by cervical age and bone age.[15,22]

Caldas et al discovered that for both Brazilian boys and girls, the age of the cervical vertebrae and bone varied significantly with chronological age, which is similar to what we found.[39] Using cervical vertebral computerized analysis, Caldas et al observed no discernible difference between chronological age and cervical vertebral bone age in another investigation.[51] This is in contrast to our study since we had assumed that the age range was between 9 and 14 years, but their sample had a wider range distribution (7–16 years).[52] Because skeletal maturity methods cannot accurately identify changes in skeletal maturity when participants are either too far ahead of or too far past the pubertal growth spurt, a large age range in the sample may have an impact on the correlation result.[40-43]

CONCLUSION

This study validates CVMI as a reliable skeletal maturity indicator, explaining 82% of chronological age variance in Indian children aged 9–14 years. The novel PCTHR method using mandibular first molars on routine OPGs demonstrated a moderate negative correlation between pulp chamber height and age, offering a reproducible, non-invasive dental alternative for age estimation. While CVMI showed slightly superior accuracy, both methods agreed strongly with chronological age and showed no sex-based differences. Combined use of skeletal and dental indicators enhances precision in clinical orthodontics and forensic science.

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