Original Article

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Relationships among chronological age, dental age, and bone age in Thai prepubertal females

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Objectives: The purpose of this study was to investigate the relationships between dental age, skeletal age, and chronological age in Thai girls during the prepubertal period, and to identify dental indicators for assessing advanced bone age.

Materials and Methods: This retrospective study examined panoramic and hand-wrist radiographs of Thai girls aged 8-10 years, with images taken within a 3-month interval. Dental age was assessed using Demirjian *et al.* 's method by two calibrated dentists. Bone age was determined using BoneXpert® software based on the Greulich & Pyle Atlas. Spearman correlation analyzed relationships among chronological age, skeletal age, and dental age. Subjects were categorized as normal, advanced, or delayed based on dental or bone age relative to chronological age. Chi-square test analyzed the relationship between bone age and dental age groups. Descriptive analysis identified potential tooth indicators for bone age assessment.

Results: Significant positive correlations were found among chronological age, dental age, and bone age ($p < 0.01$). Correlation coefficients were 0.597 between chronological and dental age, 0.570 between chronological and bone age, and 0.560 between dental and bone age. Chi-square tests revealed a significant association between bone age groups and dental age groups ($p = 0.001$). Subjects with advanced bone age demonstrated higher percentages of advanced second molar development compared to those with normal bone age.

Conclusions: This study demonstrated positive correlations among chronological age, dental age, and bone age in Thai prepubertal females, with the correlation between dental age and bone age being rated as moderate. Advanced bone age was associated with accelerated second molar development, suggesting its potential as an indicator for skeletal maturity assessment.

Keywords: bone age, children, chronological age, dental age, prepuberty, skeletal maturity

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Introduction

Age is a fundamental factor that influences every aspect of life, serving as a key determinant in physical maturation, cognitive development, and physiological functions. Individual age can be assessed through multiple parameters, including chronological, biological, skeletal, dental, behavioral, and mental ages. Each method of age estimation aims to align as closely as possible with chronological age. However, these parameters often show varying degrees of correlation due to individual developmental patterns [1]. These variations arise from multiple factors,

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including genetic makeup, environmental influences, nutritional status, and health conditions that can accelerate or delay specific aspects of development. Understanding these discrepancies is crucial for accurate assessment and appropriate intervention planning.

Skeletal development is a key indicator of physical maturation in children. Bone age assessment plays a valuable role in both dentistry and pediatrics. In dentistry, particularly orthodontics and pediatric dentistry, understanding skeletal maturity guides treatment planning, as certain interventions are most effective during specific growth stages [2]. In pediatrics, bone age assessment serves as a diagnostic tool for identifying growth abnormalities and potential endocrine disorders, especially when significantly advanced compared to chronological age [3]. Various skeletal areas can be used to assess maturity, with hand-wrist radiographs being the most widely used method due to their multiple ossification centers and ease of examination. Two primary methods are used to evaluate bone age: the Greulich & Pyle (GP) atlas and the Tanner-Whitehouse (TW) system [4, 5].

Dental age represents another significant measure of physical development, with tooth formation stages providing more reliable assessment than eruption patterns [6]. In dentistry, dental age assessment plays a crucial role in diagnosis and treatment planning. This biological indicator complements other physical maturity measures, offering dentists and healthcare providers additional tools for evaluating overall development. The assessment primarily relies on radiographic examination, particularly panoramic radiographs, for evaluating developmental stages. Various methods have been developed to assess dental age [7], with the Demirjian *et al.* method being widely accepted due to its standardized approach and reliability in evaluating tooth formation stages [8].

Studies have shown that correlations between chronological age and developmental ages—both bone and dental-vary significantly across different populations. For bone age, the study of Ontell *et al.* reported significant differences from chronological age in black adolescent girls [9], while Korean studies found significant correlations between these measures [10]. In Thai girls aged 8-9 years, Benjavongkulchai & Pittayapat found no statistically significant differences [11]. Similarly, dental age correlations using the Demirjian *et al.* method vary across populations. Spanish studies found dental age exceeded chronological age by 0.853 years [12], while Venezuelan studies reported a difference of 0.62 years [13]. In Nepalese children, significant differences were found in the 12-16 age group but not in the 7-11 age group [14].

Research has also explored the relationships between bone and dental age, demonstrating positive correlations and potential clinical applications. Studies in Turkish girls found correlations ranging from 0.490 to 0.826 between dental and skeletal age, with second molars showing the strongest correlation [15]. Chaudhry *et al.* demonstrated highly significant correlations among dental, skeletal, and chronological ages in both urban and rural female children [16]. Research has also shown that tooth calcification stages could serve as a preliminary diagnostic tool for estimating pubertal growth spurt timing [17].

Nowadays, the prevalence of bone age advancement in females is increasing, and some of them develop precocious puberty [18]. Early onset of puberty before the typical age of 10 can result in premature epiphyseal closure, decreased final height, and psychological stress. Thus, an early detection of the sign of abnormal growth is very crucial for timely effective treatment. Dentist might detect the early signs of growth abnormalities by assessing the dental age from panoramic dental radiographs.

Given the limited research in Thai prepubertal females, this study aimed to evaluate the relationships among dental age, skeletal age, and chronological age in Thai prepubertal females aged 8-10 years, and to identify potential tooth indicators for assessing advanced bone age.

Materials and Methods

This retrospective study was approved by the Institutional Review Board of the Faculty of Dentistry/ Faculty of Pharmacy, Mahidol University (COA. No.MU-DT/PY-IRB 2020/069.0411) and received permission from the director of the Dental Hospital.

Sample size calculation and recruitment

The sample size was calculated based on the study by Krailassiri *et al.* [17]. The null correlation coefficient was set at 0.50, and the alternative correlation coefficient was 0.65. The power of this study was set at 95% ($\beta = 0.05$), with $\alpha = 0.05$ as the statistical significance level. Therefore, the sample size was at least 257 individuals.

The subjects were recruited from the lists of patients taking radiographs at the Oral and Maxillofacial Radiology Clinic, Dental Hospital, Mahidol University. The inclusion criteria were healthy Thai girls aged 8 to 10 years who had panoramic and left-hand wrist radiographs taken and had never received orthodontic treatment, as well as no history of permanent tooth extraction, surgical removal, or endodontic treatment, and no previous traumatic injury or surgery related to the left hand. Both radiographs were obtained either simultaneously or within a three-month interval. This three-month timeframe was established to provide sufficient flexibility for clinical data collection while ensuring that developmental changes remained minimal, thereby maintaining scientific validity. The subjects whose panoramic radiographs showed missing teeth, pathology, or any bony lesion in the left lower quadrant were excluded. The study also excluded subjects with poor quality of the radiographs. The subjects' medical history, dental history, and date of birth were reviewed from the medical chart by a dentist.

Dental age and bone age assessment

The study assessed the subject's dental age by evaluating dental development stages from the panoramic radiograph. Two calibrated examiners reviewed the panoramic radiographs and rated the dental development stage of the left lower permanent teeth, except the third molar, from A to H according to Demirjian *et al.* 's calcification stage (Table 1) [8]. The stage of tooth development was converted to the score, then summed and converted to the dental age using Demirjian *et al.* 's tables.

Table 1 Dental formation stages according to Demirjian *et al.* [8]

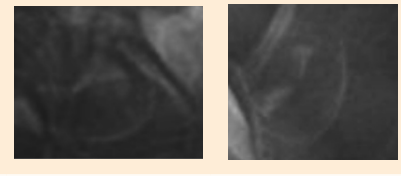
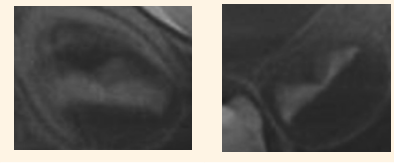
Stage 0	No sign of calcification. The crypt formation is not taken into consideration	
Stage A	In both uniradicular and multiradicular teeth, a beginning of calcification is seen at the superior level of the crypt in the form of an inverted cone or cones. There is no fusion of these calcified points.	
Stage B	Fusion of the calcified points forms one or several cusps which unite to give a regularly outlined occlusal surface.	

Table 1 Dental formation stages according to Demirjian *et al.* [8] (continued)

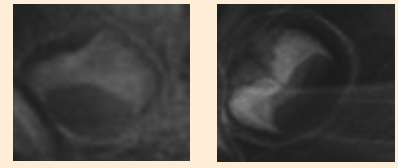
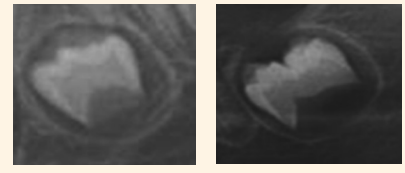
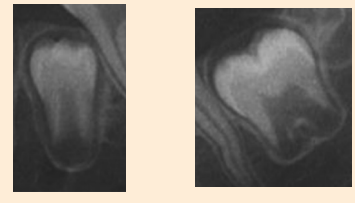
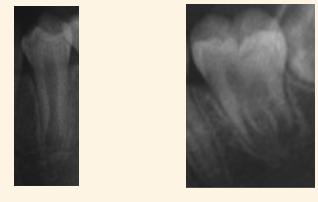
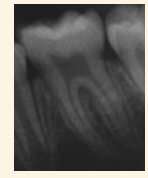
Stage C	a. Enamel formation is complete at the occlusal surface. Its extension and convergence towards the cervical region is seen. b. The beginning of a dentinal deposit is seen. c. The outline of the pulp chamber has a curved shape at the occlusal border.	
Stage D	a. The crown formation is completed down to the cementoenamel junction. b. The superior border of the pulp chamber in the uniradicular teeth has a definite curved form, being concave towards the cervical region, The projection of the pulp horns if present, gives an outline shaped like an umbrella top. In molars the pulp chamber has a trapezoidal form. c. Beginning of root formation is seen in the form of a spicule.	
Stage E	Uniradicular teeth: a. The walls of the pulp chamber now form straight lines, whose continuity is broken by the presence of the pulp horn, which is larger than in the previous stage. b. The root length is less than the crown height. Molars: a. Initial formation of the radicular bifurcation is seen in the form of either a calcified point or a semi-lunar shape. b. The root length is still less than the crown height.	
Stage F	Uniradicular teeth: a. The walls of the pulp chamber now form a more or less isosceles triangle. The apex ends in a funnel shape. b. The root length is equal to or greater than the crown height. Molars: a. The calcified region of the bifurcation has developed further down from its semi-lunar stage to give the roots a more definite and distinct outline with funnel shaped endings. b. The root length is equal to or greater than the crown height.	

Table 1 Dental formation stages according to Demirjian *et al.* [8] (continued)

Stage G	The walls of the root canal are now parallel, and its apical end is still partially open. In molars, only the distal root is rated.		
Stage H	a. The apical end of the root canal is completely closed (distal root in molars). b. The periodontal membrane has a uniform width around the root and the apex.		

Before beginning the research procedure, examiners' intra- and inter-examiner reliability were tested using duplicate examinations of 15 panoramic radiographs two weeks apart until the kappa values of inter and intra-reliability reached ≥ 0.8. Both examiners were blinded to the samples' chronological age. During the research procedure, the intra- and inter-examiner reliability were reassessed from 10% of radiographs and obtained 0.80 inter-examiner reliability, and 0.82 intra-examiner reliability.

The hand-wrist radiographs were analyzed using BoneXpert® Software (Visiana, Holte, Denmark) to determine bone age [19, 20]. The assessment was based on the Greulich & Pyle Atlas [4], which provides standardized reference images of 30 bones, including phalanges, metacarpals, carpals, and distal radius and ulna from healthy children aged 3 months to 18 years. BoneXpert® is an automated artificial intelligence-based system that digitally assesses skeletal maturity by analyzing the same 30 bones traditionally evaluated in the Greulich & Pyle Atlas. The software provides objective bone age measurements within minutes while eliminating inter-observer variability associated with manual assessment methods [19, 20]. All radiographs were processed using the software's standard protocols, and bone age was automatically calculated and recorded in decimal years.

Data analysis

Data were analyzed using SPSS software version 21 for MAC OS (SPSS Inc., Chicago, USA). Descriptive statistics were used to analyze subjects' demographic data, chronological age, dental age according to Demirjian *et al.* 's method, and bone age based on the Greulich & Pyle Atlas. The Spearman rank order correlation coefficient was applied to measure the relationship among chronological age, dental age, and bone age. Subjects were categorized as normal, advanced, or delayed based on dental or bone age relative to chronological age. The Chi-squared test was performed to assess the relationship between bone age and dental age groups. The *p*-value of less than 0.05 was considered statistically significant.

Results

Three hundred and six females aged 8 to 10 years old who had hand-wrist and panoramic radiographs taken at the same period were recruited. However, 29 subjects were excluded because twelve of them were missing at least one permanent tooth in the left lower arch, one had poor quality panoramic radiographs, and sixteen had poor quality hand-wrist radiographs. Therefore, two hundred and seventy-seven subjects were considered eligible for analysis.

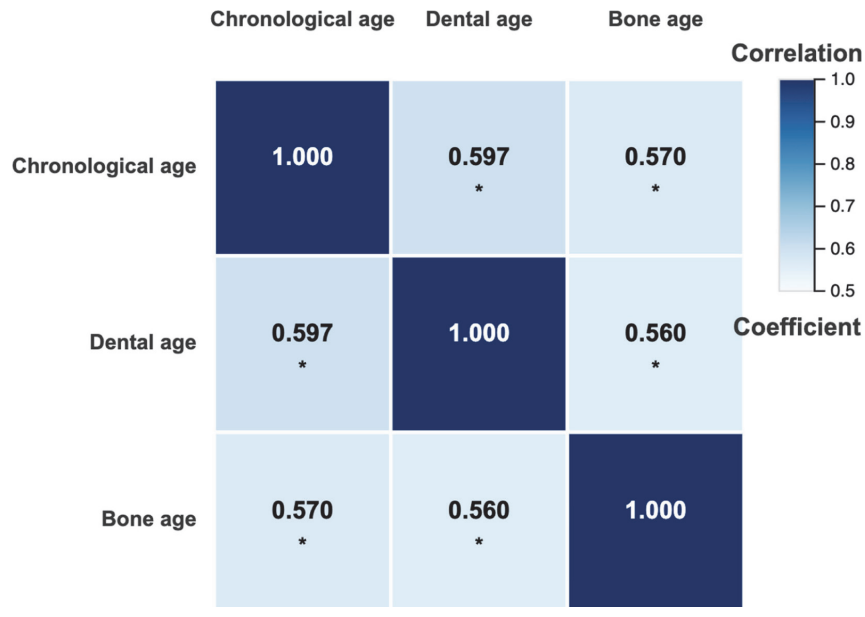
The mean (standard deviation; SD), median (Min-Max) chronological age of subjects were 9.82 (0.75) years old, 9.96 years old with a range of 8.00 to 10.97. Forty-seven percent of subjects were 10 years old. The distribution of subjects in each age and the average chronological age, dental age, and bone age were presented in Table 2. The mean or median of chronological ages were comparable to those of dental ages and bone ages.

The correlation coefficients among chronological age, dental age, and bone age were presented in Figure 1. In overall, the correlation coefficients among chronological age, dental age, and bone age were 0.560 – 0.597 and were statistically significant among aged parameters ($p < 0.01$).

Table 3 presents the relationship between dental age and bone age. Subjects were categorized into three groups based on their dental or bone age relative to chronological age: normal, advanced, and delayed. Normal age was defined as dental/bone age within one year of chronological age. Advanced age was defined as dental/bone age at least one year ahead of chronological age, while delayed age was at least one year behind chronological age. Of all subjects, 59.6% showed normal dental age, while 27.1% and 13.3% exhibited advanced and delayed dental age, respectively. Among subjects with delayed dental age, 39.5% showed delayed bone age, 36.8% showed normal bone age, and 23.7% showed advanced bone age. In the normal dental age group, the majority (56.4%) demonstrated normal bone age development, while 23.6% and 20% showed advanced bone age and delayed bone age, respectively. Notably, in the advanced dental age group, while 52.7% had normal bone age development, a considerable proportion (40.5%) showed advanced bone age.

Table 2 Mean and median (min–max) values of chronological age, dental age, and bone age of the subjects.

Age group	N(%)	Chronological age	Dental age	Bone age
8 (8.00-8.99)	43 (15.1%) Mean (SD)	8.53±0.26	8.76±0.99	8.45±1.28
	Median (Min-Max)	8.57 (8.00-8.94)	8.50 (7.30-11.30)	8.35 (5.18-11.04)
9 (9.00-9.99)	99 (34.7%) Mean (SD)	9.55±0.30	9.64±1.17	9.47±1.34
	Median (Min-Max)	9.60 (9.00-9.99)	9.40 (8.00-12.50)	9.59 (6.31-12.48)
10 (10.00-10.99)	135(47.4%) Mean (SD)	10.44±0.28	10.92±1.43	10.89±1.32
	Median (Min-Max)	10.41 (10.00 – 10.97)	11.00 (8.20-15.40)	10.95 (7.55 – 13.67)
Total	277 (100%) Mean (SD)	9.82±0.75	10.13±1.52	10.00±1.61
	Median (Min-Max)	9.96 (8.00-10.97)	9.90 (7.30-15.40)	9.91 (5.18-13.67)



*Spearman rank order correlation test was used. Correlation is significant at $p < 0.01$ level (2-tailed)

Figure 1 The correlation coefficients between chronological age, dental age, and bone age

Table 3 Bone age development on subjects with delayed, normal, and advanced dental age

	Dental age			
	Delayed	Normal	Advanced	*p-value*
Delayed bone age	15(39.5%)	33 (20.0%)	5 (6.8%)	0.001
Normal bone age	14 (36.8%)	93 (56.4%)	39 (52.7%)	
Advanced bone age	9 (23.7%)	39 (23.6%)	30 (40.5%)	
	38 (100%)	165 (100%)	74 (100%)	

Figure 2 compares tooth developmental stages among subjects with delayed, normal, and advanced bone age. At age 8, 70% of subjects with delayed bone age showed second molars at stage D, while the normal bone age group exhibited a similar distribution between stages D (46.2%) and E (53.8%). In contrast, subjects with advanced bone age predominantly showed second molars at stage E (71.4%). Additionally, all subjects in the advanced bone age group demonstrated canine development at stage F. At age 9, 72.7% of subjects with advanced bone age showed second premolars at stage F. In the normal bone age group, 41.2% and 58.8% of subjects had second premolars at stages E and F, respectively. The percentage of second molars at stage F was highest in the advanced bone age group (54.5%), compared to normal (27.5%) and delayed bone age groups (11.5%). At age 10, stage F of second premolars was predominant across all groups, with distribution exceeding 80% in delayed (88.2%), normal (82.6%), and advanced (81.6%) bone age groups. In the advanced bone age group, 71.4% and 14.3% of subjects showed second molars at stages F and G, respectively, while in the delayed bone age group, 41.2% and 52.9% showed second molars at stages E and F, respectively.



Figure 2 Distribution of tooth developmental stages among subjects with delayed, normal, and advanced bone age

Discussion

In dentistry, panoramic radiographs serve as essential tools for screening, diagnosis, and treatment of oral diseases. The American Academy of Pediatric Dentistry recommends panoramic radiographs in the transitional dentition to evaluate both dental disease and development [21]. Since dental and bone development are primarily governed by genetic factors and hormonal regulation, unusual patterns in dental development might indicate underlying bone development abnormalities.

This study evaluated relationships among chronological age, dental age, and bone age in Thai girls aged 8-10 years, with particular focus on identifying tooth indicators for assessing advanced bone age. This age group was selected due to the increasing prevalence of advanced bone age in girls and the importance of timely intervention to prevent precocious puberty.

Dental age estimation in this study was performed using the Demirjian *et al.* method [8], despite the availability of newer Thai-specific models developed by Duangto *et al.* [22, 23]. This methodological decision was based on our preliminary comparative analysis of different age estimation approaches conducted prior to the main study. We evaluated both the Demirjian *et al.* method and the Duangto *et al.* models (employing either seven or four permanent mandibular teeth) in our study population. The comparative analysis revealed that the correlations between dental ages derived from the Duangto *et al.* models and both chronological age and bone age were weaker than those obtained using the Demirjian *et al.* method in our population. This discrepancy can be attributed to regional population differences within Thailand, as the Duangto *et al.* models were developed using a northern Thai population, while our study examined children from central Thailand. Therefore, the Demirjian *et al.* method was selected for dental age analysis in this study due to its better performance in our specific population.

The results showed positive correlations between chronological age and dental/bone age, consistent with previous research. However, the correlations between chronological age and dental/bone age (0.597 and 0.570, respectively) indicated only moderate relationships, suggesting that these parameters are related but with sufficient variation to require careful interpretation in clinical practice. Given these findings, clinicians should select appropriate parameters based on their specific clinical objectives: skeletal age assessment provides valuable information for evaluating growth disorders and planning orthopedic interventions, while dental age offers more reliable data for restorative and orthodontic treatment planning.

These moderate correlations can be attributed to population-specific developmental patterns, as the reference standards—the Demirjian method for dental age [8] and the Greulich and Pyle method for bone age [4]—were developed from French-Canadian and Caucasian populations, respectively, whereas our study examined Asian subjects. The observed population differences highlight the importance of developing ethnicity-specific reference standards to improve age estimation accuracy and enhance the clinical utility of these assessment methods.

The correlation between dental and bone age in our study ($r = 0.560$) aligned with findings from Krailassiri *et al.*, who reported correlations ranging from 0.31 to 0.69 in Thai individuals aged 7-19 years [17]. When subjects were categorized into normal, advanced, and delayed dental and bone age groups, significant associations were found. In the normal dental age group, the majority demonstrated normal bone age development, with 23.6% showing advanced bone age. Interestingly, in the advanced dental age group,

40.5% of subjects exhibited advanced bone age, supporting Garn *et al.*'s finding that girls with advanced bone age tend to show advanced dental development [24].

Our study also attempted to investigate the tooth indicator for assessing advanced bone age and found that the distribution of second molars with a high stage of tooth development in subjects with advanced bone age was higher than that reported in subjects with normal bone age. The percent distribution of mandibular second molars at stage E in 8-year-old girls and stage F in both 9- and 10-year-old girls in the advanced group was approximately 20% higher than in the normal group. These were consistent with the previous studies. Lecca-Morales and Carruitero demonstrated that the highest correlation between calcification stages and hand wrist maturation stages is the second molar (r = 0.758, $p<0.01$) [25] as well as the study of Uysal *et al.,* the second molar showed the highest correlation for female subjects (r = 0.826, $p<0.01$) [15]. In addition, Kumar *et al.* also reported that the dental maturity stages of mandibular second molar are reliable indicators of skeletal maturity; there was a high correlation (r = 0.866, $p<0.01$ for females) between dental age by Demirjian index and skeletal age by cervical vertebrae maturation indicators [26]. Using the second molar for the analysis of bone maturation might provide an advantage over other teeth because it has a long development time until the closure of the apical apex around 16 years old [27].

However, this study employed the Demirjian method for evaluating dental age, which might not match well with this study's population. Therefore, further studies are needed to develop specific dental age evaluation models for the central Thai population. Moreover, the number of subjects with advanced dental age was limited in our study, and all recruited subjects were healthy individuals. A larger sample size is needed to improve the reliability of the results. Additionally, further research should be conducted to investigate this relationship in subjects with growth abnormalities compared to those without, as pathological conditions may demonstrate clear correlation patterns between dental age and bone age assessment.

Conclusion

This study demonstrated positive correlations among chronological age, dental age, and bone age in Thai prepubertal females, with the correlation between dental age and bone age being rated as moderate. Importantly, individuals with advanced bone age exhibited later stages of second molar development compared to those with age-appropriate bone development, suggesting that dental development patterns can serve as useful indicators for assessing skeletal maturity in this population.

Conflicts of interest

All authors declare no conflicts of interest

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