ORIGINAL ARTICLE

Oral Biosciences

Reliability and validity of five radiographic dental-age estimation methods in a population of Malaysian children

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Keywords
accuracy, dental age, Malaysia, radiograph, reliability.

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Received 11 August 2013; accepted 3 May 2014.

doi: 10.1111/jicd.12116

Abstract

Objective: To evaluate the reliability and validity of Demirjian's, Willems, Nolla's, Haavikko's, and Cameriere's radiographic methods of dental-age estimation in a population of Malaysian children.

Methods: A total of 426 dental panoramic radiographs of 5–15-year-old Malaysian children were included in the study. The mean age error and absolute age error for all the methods were calculated and their usability analyzed.

Results: The Nolla, Willems. and Demirjian methods overestimated the dental age with a mean of 0.97, 0.54, and 0.54 years, respectively, while the Cameriere and Haavikko methods underestimated by 0.41 and 1.31 years, respectively. The Cameriere method was highly precise and accurate in the population of Malaysian children, whereas the Haavikko and Demirjian methods were the least precise and accurate.

Conclusions: The Cameriere method of dental-age estimation is highly valid and reliable for Malaysian population, followed by the Willems and Nolla methods.

Introduction

Dental-age estimation is considered most an accurate, reliable, and fast method of age determination, especially in growing children,[1] and is considered very important in many fields of study.[2] Dental-age assessment is very critical for orthodontists in planning the treatment of different types of malocclusion in relation to maxillofacial growth[3] and pedodontists may be particularly interested in knowing whether the dental maturity of a child with a particular disease has been delayed or advanced.[4] Age estimation is also of importance in forensic science, not only for identification purpose of the victims, but also for medico-legal purposes.[5] Age estimation is also valuable in human anthropology and bioarchaeology as it can provide considerable information with regards to past population.[1]

There are two different concepts of age estimation in children using teeth: one is based on assessing tooth eruption in the mouth and the other on observing the mineralization of crowns and roots on radiographs of deciduous and permanent teeth.[6] However, age estimation by tooth formation is considered as a more reliable indicator of dental maturity than that by tooth eruption.[4]

Over the years, several radiographic methods of dental-age estimation have been proposed. Essentially, these methods define the stages of mineralization of teeth observed in radiographs and code them according to the available tables published by various authors. Among these methods, that devised by Nolla[7] in 1960 is one of the oldest and most commonly used in teaching and clinical practice.[8] The original paper reveals the stages of development of the left side of the upper and lower arches. A scale graded 0–10 for the development of each tooth was formed and a method based on the calcification of teeth for the dental-age estimation was presented based on a study conducted on 25 boys and 25 girls between 2 and 17 years old.[3,7]

Methods in which a few selected teeth were chosen from both the arches to represent the whole dentition

have been applied. Haavikko[9] suggested adopting an age-estimation method based on determination of one of 12 radiographic stages of four permanent teeth. This method was based on radiographic evaluation of all permanent teeth in 855 Finnish children aged 2–13 years.[6,10] An advantage of this method is that it can be used when some permanent teeth are missing and using reduced groups of teeth leads to a lower cost in time,[8,11] but a disadvantage is that the increased number of stages of teeth development may lead to less precision and accuracy.

In 1973, Demirjian *et al.*, proposed a dental-age assessment method[3] based on the eight stages of tooth development on permanent teeth from the left side of the mandible in panoramic radiographs, which represent the progressive mineralization of the crown and root up to the apical closure. Demirjian's method assigns a score to each stage of development based on individual teeth. The scores are summed up to obtain the dental maturity score, which can be directly converted into dental age by using a series of tables and percentile curves.[12] The adopted tables and percentile curves were based on evaluation of 4756 radiographs of French-Canadian children. The advantage of this method includes the objective criteria describing stages of tooth development, which are clearly illustrated by line diagrams and radiographic images. However, the method has a disadvantage in that the steps involved in conversion of the maturity score to dental age is rather complicated, and also time-consuming for clinical work.[1]

Recent studies have reported changes in the timing of tooth development for contemporary children compared to children who lived more than 30 years earlier, in that theres is a positive secular trend in growth and development.[1] Today's children are maturing earlier than they did 30 years ago and, moreover, they are growing faster than their grandparents.[13] This indeed led Willems *et al.*[14] to propose a modification of Demirjian's method, whereby they provided new tables for the scores that could be directly expressed in years, thereby avoiding the cumbersome steps in Demirjian's method. This method was validated and resulted in more accurate dental-age estimation in a Belgian Caucasian population.

In 2006, Cameriere *et al.*,[15] published a new concept of estimating chronological age in children by measuring the open apices in seven mandibular teeth on radiographs, which gave reliable estimates of the age in 455 Italian Caucasian children.

Although the various dental-age assessment methods produce high degrees of accuracy and precision, indigenous differences between various population groups were found to affect the reliability, resulting in under- or over-estimation of the dental age. Since various studies have been conducted predominantly on the Western population and a similar assessment was found to underestimate in Malaysian children, which included a multiracial population, this study was undertaken.

The aim of this study was to evaluate the precision and accuracy for the five above-mentioned methods of age estimation using radiographs of developing teeth in a population of Malaysian children.

Materials and methods

Study design

The design of this study was a retrospective cross-sectional study of panoramic radiographs taken by Orthopantomograph OP200 (Instrumentarium Dental Inc., Tuusula, Finland). These were good quality radiographs taken in the course of diagnosis and treatment at the Pediatric Clinic of AIMST University Dental Hospital, Malaysia. Ethical approval was granted by the Institution Ethical Committee (Reference: AUHAEC 77/ FOD/ 2012).

Study sample

The sample included 627 Malaysian children of known chronological age and gender. The radiographs of healthy children were randomly selected from patients attending the Pediatric Clinic of University Dental Hospital between 2009 and 2011 and their ages ranged from 5 to 16 years. The sample included patients from all the three ethnic groups of the Malaysian population. The criteria for inclusion in the sample were the availability of a panoramic radiograph of adequate quality in their clinical records, and no history of any medical conditions, syndromes or surgical treatments that could affect the development and eruption of permanent teeth. Children who were of Malaysian origin of at least two generations were included in the study. Exclusion criteria included: radiographs of poor quality affecting permanent tooth visualization, genetic or congenital anomalies, or history of orthodontic treatment.

Imaging of panoramic radiographs

All the panoramic radiographs included in the study were digitalized using a HP Scanjet G4050 Backlight scanner and the images were stored as computer JPEG files and processed by a computer-aided drafting program (Adobe Photoshop Version 7). To ensure independent and unbiased results, the observers were blind to the actual age of patients during the analyses. All the labels on radiographs containing information about the patient were covered up prior to digitalizing the radiographs.

Methodology and dental-age estimation methods

The digitalized radiographs were evaluated by three observers and assessed in order to determine the developmental stages of the teeth according to the methods of Nolla, Haavikko, Demirjian, Willems, and Cameriere.

Nolla method
The degree of calcification is estimated for all seven mandibular permanent teeth excluding the third molar.[7] The degree of calcification is based on 10 stages of maturity ranging from Stage 0, which indicates the absence of a tooth germ, Stage 1 for no sign of calcification, but presence of crypts, and so on till Stage 10 which indicates the completed apical end of a developing tooth. As the process of calcification is continuous, the accuracy of the estimation can be increased using decimal divisions in those cases where calcification is between two correlative stages. The stages scored are summed and matched to a normality table for boys or girls devised by Nolla that reflects the dental age of the patient.

Haavikko method
Age estimation is dependent on four reference permanent teeth, which are the determinants of one of the 12 radiographic stages.[10] These stages are then equated to dental age using a table, and chronological age is enumerated as the mean of all the estimates. Different reference teeth are used for children under and over 10 years of age: the lower right first molar, lower right first premolar, lower right canine, and upper right central incisor in children younger than 10 years; the lower right second molar, lower right first premolar, lower right canine, and upper right canine in subjects older than 10 years.

Demirjian method
Age estimation is based on the development of the seven left permanent mandibular teeth.[3] Tooth formation is scored into eight stages from A to H and criteria for the stages are explained for each tooth in detailed written description and line diagrams. Each stage of the teeth is assigned a biologically weighted score, and the sum of these scores provides an estimate of the patients' dental maturity, measured on a scale from 0 to 100. Finally the overall maturity score is converted to a dental age by using available standard tables for each gender.

Willems method
This is a modification of Demirjian's method, where each tooth is scored according to Demirjian's tooth development stages.[14] These maturity scores are then converted to fractions of dental age using published conversion tables and are then summed to obtain dental age.

Cameriere method
Dental age is estimated based on the following linear regression formula:[16]

$$\text{Age} = 8.387 + 0.282g - 1.692X_5 + 0.835N_0 - 0.116s - 0.139s \times N_0$$

where g is 1 for males and 0 for females, N_0 is the number of teeth with the apical ends completely closed, s is the sum of A:L ratio for every tooth with an open apex, and A is the distance between the inner sides of the open apex for the single rooted teeth. For teeth with two roots, the sum of the distances between the inner sides of the two open apices is measured on the radiograph. L is the radiographic tooth length, and A/L ratios are considered to manipulate the accountable differences in magnification and angulation during radiographic imaging. X_5 is the A/L ratio of tooth 5. The chronological age of each patient was calculated by subtracting the date of the radiograph from the date of birth after converting them to decimal divisions according to Eveleth and Tanner.[17]

Data processing

All the details collected from the patient's dental records were entered in an Microsoft Excel file. Dental age was estimated on each included radiograph based on the five methods of age estimation and entered in the Excel file. Dental-age estimation through each method was compared with the chronological age for each subject. The dental age was subtracted from the chronological age, and the dental-age error was estimated. A positive result indicated an overestimation and negative figure an underestimation.

Interobserver and intraobserver reliability
The three observers involved in calibrating the radiographs were well trained in each age estimation methods. In order to check the interobserver reliability, before initiating the original study, 40 randomly selected radiographs were evaluated by all the observers through the adapted five estimation methods and interobserver reliability was tested by an intraclass correlation coefficient.

Precision and accuracy
A method with high precision and high accuracy is considered as the most reliable age estimation method in a particular population. Precision or reliability reflects a small error or the degree to which further measurements give the same or similar results.[6,18] Hence, precision can be measured as the mean absolute error. Accuracy of age estimation reveals how closely the chronological age could be predicted.[19] Hence, a more accurate the method means smaller difference between dental age and chronological

age. Accuracy can be evaluated numerically as the mean of age errors.

Statistical analysis

These data were transformed to a SPSS Version 7 statistical program to perform the statistical analysis. The significance of the difference between chronological and dental age was tested using Student's *t*-test. A *P*-value of < 0.05 was considered as statistically significant. One-way ANOVA and Duncan post-hoc analyses were used to compare the mean age errors and absolute age errors of the different age-estimation methods.

Results

Only 426 radiographs (67.9%) satisfied the inclusive criteria and hence were included in the study. Table 1 shows the distribution of panoramic radiographs by gender, age, and ethnic group.

Assessment of intra- and interobservers reliability

The intraclass correlation coefficient analysis for inter- and intraobserver reliability (*r* value) ranged from 0.900 to 0.999 at the 95% confidence level. Since the *r*-value is significant it showed that the data are highly associated, with good reliability of the observers (Table 2).

Comparison of the dental age and chronological age using different age-estimation methods in Malaysian children

Table 3 summarizes the mean chronological and dental age in conjunction with the statistical data for Malaysian children. The results showed overestimation of mean age by Nolla's, Willems' and Demirjian's and underestimation by Haavikko's and Cameriere's methods (Figure 1). The mean absolute error, which served as a measure for the precision of the methods compared, revealed that Cameriere's and Willem's methods were very precise when applied to the Malaysian population, followed by Nolla's and Demirjian's methods, whereas Haavikko's method was least precise (Table 4). The accuracy that is given by mean age error was highest with Cameriere's followed by Willems', Nolla's and Demirjian's methods, while Haavikko's method was the least accurate. In all these methods statistically significant differences were observed.

Table 1. Age, gender and ethnic distribution of the sample studied

	Malay		Chinese		Indian	
	M	F	M	F	M	F
5–7	12	13	11	11	8	10
7–9	15	19	6	14	7	11
9–11	11	12	10	8	11	13
11–13	10	13	9	12	15	15
13–15	14	39	19	31	21	26
Subtotals	62	96	55	76	62	75
	158		131		137	

Total study population 426.

Table 5 summarizes the accuracy and precision of different radiographic age-estimation methods among the three ethnic groups of the population of Malaysian children. The results suggest that Cameriere's and Willems' methods were consistent in accuracy and precision in all the ethnic groups, whereas Haavikko's method was the least accurate and precise.

In addition to the accuracy and precision, an attempt was made to assess the usability (simplicity) of the different age-estimation methods and requirements of the equipment, such as negatoscope or X-ray scanner. These factors are summarized in Table 6.

Discussion

An in-depth knowledge about the development and maturity of permanent dentition is highly applicable for clinical, medico-legal, and forensic purposes. The surveillance of different morphological stages of tooth formation in radiographs serves to be the most reliable element in dental-age estimation.[7,9,20] Various dental-age estimation methods have been proposed in the past are highly applicable to a Western population. With all of the possible differences in environmental factors, dietary habits, growth rate, and ethnicity, such methods may not be readily applicableto the Malaysian population, which is an aspect that has not been exclusively studied in the recent past. In addition, recent studies have shown acceleration in tooth development and eruption in contemporary children when compared with those children who lived 30 years ago,[13] which implies that the older methods of dental-age estimation may not be suitable for the present population of children. For this reason, in this study we validated the five methods of dental-age estimation most frequently used, ranging from the earliest method developed some decades previously, to the latest. However, reliability and validity of an age-estimation method for a particular population largely depends on its accuracy and precision level.[21] Therefore this study is a genuine effort to evaluate available age-estimation methods based on these criteria.

Nolla's method

Nolla's method, being one the first age estimation method to evaluate the tooth formation longitudinally, has proven itself to be a time-tested method. Our result affirms that

Table 2. Intraclass correlation coefficient of inter- and intraobserver reliability

	Method				
Reliability	Demirjian	Willems	Nolla	Haavikko	Cameriere
Intraobserver (*r* value)	0.901–0.919*	0.922–0.936*	0.991–0.999*	0.910–0.951*	0.944–0.950*
Interobserver (*r* value)	0.900–0.914*	0.911–0.951*	0.907–0.951*	0.933–0.954*	0.926–0.943*

*$P = 0.05$.

Table 3. Comparison of the dental age and chronological age using different radiographic methods for Malaysian children

		Mean (SD)					
Method	Sex	Chronological age	Dental age	Mean Age error	Mean absolute error	95% CI of age difference	*P*-value*
Demirjian	M	11.93 (2.76)	12.91 (3.16)	0.98 (1.29)	1.25	0.79, 1.17	0.000
	F	12.65 (2.63)	13.62 (2.86)	0.97 (1.12)	1.23	0.83, 1.11	0.000
	Total	12.35 (2.70)	13.32 (3.00)	0.97 (1.19)	1.24	0.86, 1.09	0.000
Willems	M	11.93 (2.76)	12.48 (3.12)	0.55 (1.40)	1.03	0.35, 0.76	0.000
	F	12.65 (2.63)	13.17 (2.98)	0.53 (1.20)	0.96	0.38, 0.67	0.000
	Total	12.35 (2.70)	12.88 (3.05)	0.54 (1.28)	0.99	0.41, 0.66	0.000
Nolla	M	11.93 (2.76)	12.44 (3.24)	0.50 (1.31)	1.1	0.31, 0.69	0.000
	F	12.65 (2.63)	13.21 (3.10)	0.57 (1.31)	1.1	0.41, 0.73	0.000
	Total	12.35 (2.70)	12.89 (3.18)	0.54 (1.31)	1.1	0.42, 0.67	0.000
Haavikko	M	11.93 (2.76)	10.99 (2.44)	−0.94 (1.03)	1.13	−1.09, −0.79	0.000
	F	12.65 (2.63)	11.06 (1.97)	−1.59 (1.08)	1.69	−1.72, −1.45	0.000
	Total	12.35 (2.70)	11.03 (2.18)	−1.31 (1.10)	1.45	−1.42, −1.21	0.000
Cameriere	M	11.93 (2.76)	11.49 (2.51)	−0.44 (1.14)	0.95	−0.61, −0.28	0.000
	F	12.65 (2.63)	12.26 (2.25)	−0.39 (1.03)	0.85	−0.51, −0.26	0.000
	Total	12.35 (2.70)	11.94 (2.39)	−0.41 (1.08)	0.89	−0.51, −0.31	0.000

M = 179; F = 247; total = 426; SD, standard deviation; CI, confidence interval.
*$P < 0.05$.

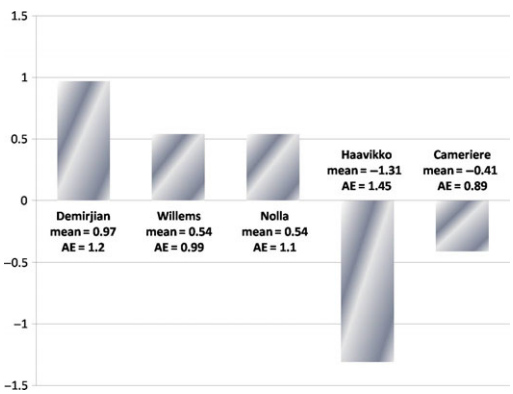

Figure 1. The mean age error and its absolute error (AE) associated with the five age-estimation methods.

Table 4. The accuracy and precision of different radiographic age-estimation methods in Malaysian children

	Accuracy (mean age error) (Mean ± SE)*	Precision (mean absolute error) (Mean ± SE)*
Demirjian	0.97 ± 0.057^{c}	1.242 ± 0.077^{c}
Willems	0.54 ± 0.062^{b}	$0.991 \pm 0.081^{a,b}$
Nolla	0.54 ± 0.063^{b}	1.101 ± 0.064^{b}
Haavikko	-1.31 ± 0.053^{d}	1.456 ± 0.061^{d}
Cameriere	-0.41 ± 0.052^{a}	0.894 ± 0.057^{a}

SE, standard error.
*Each value is the mean and standard error of 426 observations. Mean values bearing different superscripts are statistically different ($P < 0.05$).

Nolla's method consistently overestimates dental age in the Malaysian population, with a mean age error of 0.54 years. Our result was in concordance with Rai and Anand, who stated that Nolla's method overestimated the dental age in Indian children.[22] However, Kirzioglu and Ceyhan and Maber *et al.* reported an underestimation by Nolla's method in their population of children.[2,21] In our study, Nolla's method reflected a moderate precision score, which is in agreement with Maber *et al.*, who stated that the increased the number of stages in Nolla's method of age estimation could moderately decrease the precision of the method.[21] Furthermore, this method had a moderate accuracy among the population of Malaysian children, which is consistent with the previous studies reported by

Table 5. The accuracy and precision of different radiographic age estimation methods among the three ethnic groups of Malaysian children population

	Accuracy (mean age error)			Precision (mean absolute age error)		
Method	Malay	Chinese	Indian	Malay	Chinese	Indian
Demirjian	0.74^{c}	1.03^{d}	1.19^{c}	1.08^{c}	1.34^{c}	1.31^{c}
Willems	$0.25^{a,b}$	0.62^{b}	$0.78^{b,c}$	0.87^{a}	1.09^{b}	$1.04^{a,b}$
Nolla	0.16^{a}	0.85^{c}	0.69^{b}	0.95^{b}	$1.17^{b,c}$	1.2^{b}
Haavikko	-1.16^{d}	-1.57^{d}	-1.25^{d}	1.34^{d}	1.65^{d}	1.4^{d}
Cameriere	-0.34^{b}	-0.46^{a}	-0.44^{a}	0.88^{a}	0.9^{a}	0.9^{a}

Mean values bearing different superscripts are statistically different ($P < 0.05$).

Demirjian's *et al.*[3] and Moorrees *et al.*,[20] in their study population. On evaluating individual ethnic groups of the population of Malaysian children, Nolla's method was found to be highly accurate in Malay children but had a moderate accuracy and precision in other ethnic groups.

Haavikko's method

The convenience factor of Haavikko's method involving few selected teeth from both the jaws has been documented by several researches. In our study, Haavikko's method was found to highly underestimate the dental age with a mean of 1.31 years. Our results were consistent with Butti *et al.*, Kirzioglu *et al.*, Maber *et al.*, Mornstad *et al.*, Staaf *et al.*, and Nystrom *et al.*, who also recognized an underestimation in Italian, Turkish, Bangladesh: British Caucasian, Swedish, Scandinavian, and Finnish children respectively.[2,21,23–25] Our results also substantiate that this method has the least precision and accuracy among all the methods considered for all the population of Malaysian children, which is in contrast to Rai and Anand, Mornstad *et al.*, and Staaf *et al.*[22,24,25] Haavikko"s method also has the least accuracy and precision when evaluated individually for all the three ethnic groups.

Demirjian's method

One of the simplest, most practical and frequently used methods, which was set as a benchmark with which other methods are compared to predict dental age, was proposed by Demirjian, based on a large sample of French-Canadian origin.[3] The author also reported the possibility that the standards they obtained may not be valid in other populations. This is also reflected in our study, where Demirjian's method consistently overestimated the dental age with a mean of 0.97 years. Our results are in accordance with Mani *et al.*[26] and Hussain *et al.*,[1] who reported an overestimation of a similar range in a population of Malaysian children. An overestimated age was also reported in children of South America, western European countries, North America, Bosnia-Herzegovenia, India, China, Brazil, Iran, and Turkey, with an average ranging from 0.02 to 3.04 years.[21] In evaluating the precision of Demirjian's method in Malaysian children, and furthermore among the three ethnic groups, it was noted that it had least precision and accuracy method among those tested, which is analogous to the study by Hussain *et al.* on Malaysian children[1] and Rai and Anand in Indian children.[22]

Willems' method

Willems' method gained wide acceptance because it was based on the Demirjian method but avoids the tedious

Table 6. Criteria for selecting an age estimation method in Malaysian children

	Accuracy (mean age error)*	Precision (mean absolute error)†	Usability‡	Measuring equipment
Demirjian	Low	Low	Moderate	Dental X-ray, negatoscope, Demirjian's original article
Willems	Moderate	High	High	Dental X-ray, negatoscope, Demirjian's teeth development stages, Willems' original article
Nolla	Moderate	Moderate	High	Dental X-ray, negatoscope, Nolla's original article
Haavikko	Low	Low	High	Dental X-ray, negatoscope, Haavikko's original article
Cameriere	High	High	Moderate	Digital X-ray or X-ray Scanner, Computer and basic knowledge about Photoshop Software, Cameriere original article

*The smaller the mean age error the higher the method's accuracy.

†The smaller the standard error the higher the method's precision.

‡Usability refers to the minimum number of measurements and formulas required per method.

lengthy steps involved in calculation. Alhough our result affirms an overestimation by Willems' method it was comparatively much less than Demirjian's method and the mean overestimation is 0.54 years. This confirms the previous results by Mani *et al.* who reported an overestimation of 0.41 years in a Malay population.[26] Similar results were noted among Indian, Egyptian, Belgian Caucasian children and in Bangladeshi boys.[14,21,22,27] In contrast, underestimation of dental age was established by Willems' method among Bangladeshi girls and British Caucasian children.[21,26] Our results also indicate that this method was very precise and moderately accurate in Malaysian children and among the three ethnic groups, which contradicts the previous result by Hussain *et al.*[1] and Rai and Anand,[22] who documented high accuracy of Willems' method among Indian children.

Cameriere's method

Cameriere's method, which was introduced recently, has been widely tested in different populations and claims to be more reliable and accurate in many ethnic groups. Our result reflects an underestimation by 0.41 years of dental age by Cameriere's method. Similar results were reported by Galic *et al.*[22] Cameriere's method proved to be the most precise and accurate age-estimation method in comparison with the other methods considered, in the population of Malaysian children. Cameriere's method also demonstrated high accuracy and precision in all the ethnic groups except Malay children, in which it was moderately accurate.

Criteria for selecting an age-estimation method for application to the Malaysian children population

Our results indicated that each dental-age estimation method provides a different combination of accuracy, precision, simplicity on execution and equipment requirements. However, accuracy and precision are of utmost importance when performing age estimation. Accordingly, Cameriere's method, although having moderate usability and equipment requirements, was found to be very accurate and precise for the population of Malaysian children, followed by Willems' and Nolla's methods, whereas Haavikko's and Demirjian's methods were least applicable to the population of Malaysian children. However, in circumstances where digital X-rays or an X-ray scanner is unavailable and knowledge about Photoshop software is insufficient, Willems' method, which requires only basic equipment, would be more reliable for the Malaysian children population.

Conclusions

After analyzing the data from our study of population of Malaysian children, the following conclusions were drawn:

(a) Nolla's, Willems', and Demirjian's methods consistently overestimated the dental age, whereas Cameriere's and Haavikko's methods underestimated the dental age;
(b) Cameriere's and Willems' methods of age estimation are highly precise, while Haavikko's and Demirjian's method's are less so;
(c) Cameriere's method was highly accurate, whereas Haavikko's and Demirjian's were the least accurate;
(d) Cameriere's method of dental-age estimation is highly applicable to the Malaysian population, followed by Willems and Nolla's methods, whereas, Haavikko's and Demirjian's methods have least applicability.

Acknowledgments

The authors would like to thank Professor Wihaskoro Sosroseno for his constant support throughout the study, and Dr Deivanai Subramanian and Dr. K. Marimuthu, Department of Biotechnology, AIMST University, for their statistical assistance; Dr Manikandan Natarajan, Senior Dental Officer, Faculty of Dentistry, AIMST University, for his computing assistance and Mr George Selvaraj, Dental Records Department, AIMST University for technical support.

Conflict of interest

The authors declare no conflict of interest.

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