Applicability of London atlas of tooth development and eruption for dental age estimation in children of the Malaysian population using maxillofacial imaging

Radhadevi Kuppusamy[1], Norhayati Jaffar[2], Raja Zarina Raja Shahardin [3], Hemlatha Pandey [1], Scheila Mânica[1]

[1]Centre of Forensic and Legal Medicine and Dentistry, University of Dundee, United Kingdom.
[2]Dental Forensic Unit, Department of Oral Medicine and Maxillofacial, Hospital Kuala Lumpur, Malaysia.
[3]Department of Paediatric Dentistry, Hospital Tunku Azizah, Malaysia

Corresponding author:
radhadevi@moh.gov.my

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KEYWORDS

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ABSTRACT

In forensics, dental age estimation is crucial, and literature has many methods for estimating dental age. London Atlas of Human Tooth Development and eruption method was developed on British and Bangladeshi populations in 2010, and there are likely to be differences between other populations.

Malaysian children have not yet been extensively tested for the method's applicability despite its universal acceptance and reliability. This research aimed to test the applicability of The London Atlas of human tooth development and eruption in children of the Malaysian population aged 4 to 16.99 years old. The study sample included 523 panoramic radiographs of healthy patients who had attended the Dental Paediatrics Department Hospital Tunku Azizah, Malaysia, between May 2019 and December 2019. The intra- and inter-observer errors were analysed by taking 53 radiographs and evaluating them over 14 days using the interclass correlation and Cohen's Kappa index. A paired t-test was used to compare chronological and estimated age ANOVA F-tests were used to establish if the difference is statistically significant between chronological and estimated age. The range of age estimation fell within a year due to the mean absolute difference of 0.60 years. The mean age for estimated age was 9.31±3.18 for the overall sample, 9.06±3.09 for males, and 9.60±3.27 for females. Paired t-test analysis showed the mean difference between chronological and estimated age of -0.0365 and was not statistically significant (p=0.240). The result also showed no statistically significant difference between the sexes. The difference between the chronological and estimated age was underestimated within minimal range, 0.002 years in males and 0.08 years in females. The London Atlas of human tooth development and eruption showed high accuracy in Malaysian children.

INTRODUCTION

Dental age estimation is vital for individuals lacking identification documents, especially in legal contexts involving refugees, asylum seekers, victims of human trafficking, suspects or victims in criminal cases, as well as in forensic identification.[1] Forensic Age Estimation (FAE), an expertise in forensic medicine, aims to estimate the chronological age of individuals involved in judicial and legal proceedings, utilizing various biological methods such as hand-wrist bone ossification,

pubic symphysis changes, dental maturity, cranial suture fusion, dental maturity, and somatic indicators. There is considerable heterogeneity among these measures, often affected by genetic and environmental factors.[2] The incremental formation and periodic mineralization of dental maturation surpasses other techniques in reliability.[3]

Legal documentation solidifies an individual's identity and establishes their rightful place in society. Birth registrations serve as irrefutable proof of one's existence, laying the foundation for all legal rights and responsibilities that accompany citizenship. Without this vital record, individuals are left vulnerable, their very identity called into question, and their access to essential services and opportunities jeopardized. In Malaysia, civil registration is mandatory for births, deaths, adoptions, marriages, and divorces at the National Registration Department under the Ministry of Home Affairs, with penalties for non-compliance.[4] Failure to register a birth can result in statelessness, depriving individuals of citizenship rights such as education and healthcare. However, certain groups of people like refugees and asylum seekers, victims of human trafficking, homeless individuals, undocumented immigrants, marginalized communities, children born in remote areas, and some elderly individuals may not have legal documentation as proof of their age.

Dental age estimation in children and adolescents relies on techniques like radiographic assessment and dental and skeletal development evaluation. The London Atlas of Human Tooth Development and Eruption, published in 2010, includes dental growth and eruption sequences from the 30th week of pregnancy to the age of 23 years.[5-6] The atlas illustrates 31 diagrams of tooth development and eruption at the midpoint of the chronological age and the development stages. It is the only one that has covered the sequence at the midpoint and is well-recognized for being comprehensive, well-developed, and frequently used for dental age estimation.[5-7] It is worthwhile to try this method with non-European groups, including Malaysians, given that research is being conducted using it among European populations, and it is very adaptable and reliable.[8-10] As the original study was centred on the Bangladeshi and British populations, it is anticipated that different patterns of tooth growth and eruption will exist across other demographic groups.[6]

The applicability of this atlas to the diverse Malaysian population still needs to be explored. Given Malaysia's multiethnic population, genetic and dietary variables, and other environmental factors, this study on Malaysian children aged 4 to 16.99 years aims to assess the suitability of the London Atlas for this population, potentially enhancing age estimation practices.

MATERIALS AND METHODS

A total of 1029 orthopantomograms (OPG) retrieved from the Dental Paediatric Department, Hospital Tunku Azizah Malaysia database from May 2019 to December 2021 were analyzed. Ethical approval was received National Medical Research Register (NMRR) Malaysia ethics committee (NMRR ID-22-01089-T58 (IIR)).

The overall sample included images of healthy Malaysian children population aged 4 to 16.99 years.Poor quality images, the presence of artifacts, subjects with any systemic diseases, developmental problems, and abnormal dental development, including the presence of other conditions such as the presence of gross pathology related to the jaw or teeth, gross caries, periapical pathosis, and extensive restorations or crowns, indication of trauma during the tooth development period, impacted or embedded tooth were excluded. A total of 529 radiographs (279 males and 244 females) adhered to the inclusion criteria.

The sample's complete information was anonymized by a code and collated into a Microsoft Excel 2021 (Redmond, WA, USA) with variables such as a)the subject's sexes, b) the date of birth, and c) the date when the radiograph was taken. The chronological age was calculated by subtracting the date of birth (a) from the date when the radiograph was taken (b) using decimal age. Thirteen groups have been created to classify the subjects based on their age range, as shown in Table 1. A single observer (principal author) used the London Atlas of Human Tooth Development and Eruption Software available on the Queen Mary University of London website (https://www.qmul.ac.uk/dentistry/atlas/software-app/) to estimate dental age. Development and eruption stages were assessed on the right mandible and right maxilla of each subject; however, if there is a presence of the exclusion criteria on the right side, the left side of the mandible and maxilla were assessed. There is no statistically significant

difference between dental age assessment on the left and right sides of the mouth. However, the London Atlas of human tooth development and the eruption were typically analyzed from the right.

Table 1. Number of subjects distributed according to age group.

Age group	Female	Male
4.00 - 4.99	12	12
5.00 - 5.99	28	35
6.00-6.99	24	33
7.00 - 7.99	33	40
8.00 -8.99	29	38
9.00 - 9.99	23	31
10.00 - 10.99	17	19
11.00 -11.99	14	14
12.00 - 12.99	12	15
13.00 - 13.99	15	16
14.00 -14.99	14	10
15.00 - 15.99	18	13
16.00 - 16.99	5	3
	244	279

The dental age estimation was defined as how closely chronological age could be predicted, measured as the difference between chronological age and the estimated age for each subject. A paired subject t-test was used to study the variation between the chronological age and estimated age. The chronological age was subtracted from the dental age and a positive result shows an overestimation and a negative result shows an underestimation. One-way ANOVA's F-tests were performed to establish whether the discrepancy between chronological age and estimated age was statistically significant. A significance level of 5% ($p < 0.001$) was used, and all statistical tests were performed with IBM Statistical Package of the Social Sciences (SPSS) Statistics software v29 (SPSS Inc., Chicago IL). A re-evaluation of 10% of the overall sample was carried out 14 days after the first author's original evaluation and a certified forensic odontologist evaluated the same 10% of the data for inter-rater reliability. An intraclass correlation (ICC) and Cohen's Kappa were performed to assess the variances between and among examiners.

RESULTS

Results showed that the intraclass correlation coefficient (ICC 2.1, absolute) produced a reasonable degree of agreement, with 0.992 and 0.976, respectively, from the intra-examiner and inter-examiner. A significant agreement is shown by Cohen's Kappa scores of 0.769 for intra-examiner and 0.693 for inter-examiner.

The mean for chronological age was 9.27 for the overall sample, 9.05 and 9.53 for males and females, respectively. Meanwhile, the mean age for estimated age was 9.31 for both sexes, 9.06 for males, and 9. 60 for females (Table 2). The paired t-test revealed that -0.0365 was not statistically significant ($p=0.240$), showing a clear distinction between chronological age and estimated age. (Table 3). It can be seen in Table 2 of the results that the range of age estimations fell within a year because of the mean absolute difference of 0.60 years of estimations.

Table 2. The mean for CA and EA and mean absolute error between CA and EA

	CA		EA		MAE	
	MEAN	SD	MEAN	SD	MAE	SD
Male	9.05	3.08	9.06	3.09	0.5821	0.3931
Female	9.53	3,41	9.60	3.27	0.6030	0.3889
Overall sample	9.27	3.24	9.31	3.18	0.5937	0.3909

Table 3. Comparison of CA and EA using paired t-test.

Age	Sex	N	CA		EA		CA-EA		95% CI	
			Mean	SD	Mean	SD	Mean	SD	Lower	Upper
4 – 4.99	M	12	4.53	0.28	4.33	0.39	0.20	0.38	0.44	0.44
	F	12	4.53	0.28	5.17	0.49	-0.63	0.31	-0.43	-0.83
5 – 5.99	M	35	5.45	0.28	5.64	0.65	-0.20	0.51	-0.37	-0.02
	F	28	5.50	0.30	5.96	0.51	-0.46	0.48	-0.65	-0.27
6 – 6.99	M	33	6.5	0.27	6.74	0.56	-0.25	0.48	-0.42	-0.08
	F	24	6.38	0.31	6.5	0.51	-0.12	0.10	-.033	0.09
7 – 7.99	M	40	7.45	0.29	7.45	0.55	0.01	0.52	-0.16	0.17
	F	33	7.46	0.27	7.43	0.70	0.02	0.64	-0.20	0.23
8 – 8.99	M	38	8.45	0.28	8.42	0.82	0.03	0.69	-0.19	0.25
	F	29	8.46	0.28	8.60	0.86	-0.15	0.80	-0.45	0.16
9 – 9.99	M	31	9.41	0.28	9.24	0.89	0.17	0.74	-0.10	0.44
	F	23	9.38	0.30	9.54	0.88	-0.16	0.86	-0.54	0.21
10 – 10.99	M	19	10.47	0.25	10.08	0.61	0.39	0.58	0.11	0.68
	F	17	10.53	0.26	10.21	0.85	0.32	0.83	-0.10	0.75
11 – 11.99	M	14	11.56	0.25	11.42	0.73	0.14	0.70	-0.27	0.54
	F	14	11.53	0.30	11.79	0.73	-0.26	0.64	-0.62	0.11
12 – 12.99	M	15	12.38	0.21	12.97	0.83	-0.59	0.90	-1.09	-0.09
	F	12	12.40	0.34	12.58	0.90	-0.18	0.69	-0.62	0.25
13 – 13.99	M	16	13.42	0.30	13.5	1.03	-0.08	0.88	-0.55	0.39
	F	15	13.46	0.28	13.63	0.64	-0.17	0.58	-0.49	0.15
14 – 14.99	M	10	14.42	0.33	15.00	0.85	-0.58	0.87	-1.21	0.05
	F	14	14.53	0.29	14.29	0.70	0.24	0.66	-0.14	0.63
15 – 15.99	M	13	15.43	0.28	14.73	0.73	0.70	0.75	0.24	1.16
	F	18	15.47	0.28	14.72	0.55	0.75	0.14	0.45	1.04
16 – 16.99	M	3	16.43	0.32	15.50	0.00	0.93	0.32	0.13	1.73
	F	5	16.54	0.18	16.9	0.55	-0.36	0.42	-0.88	0.16

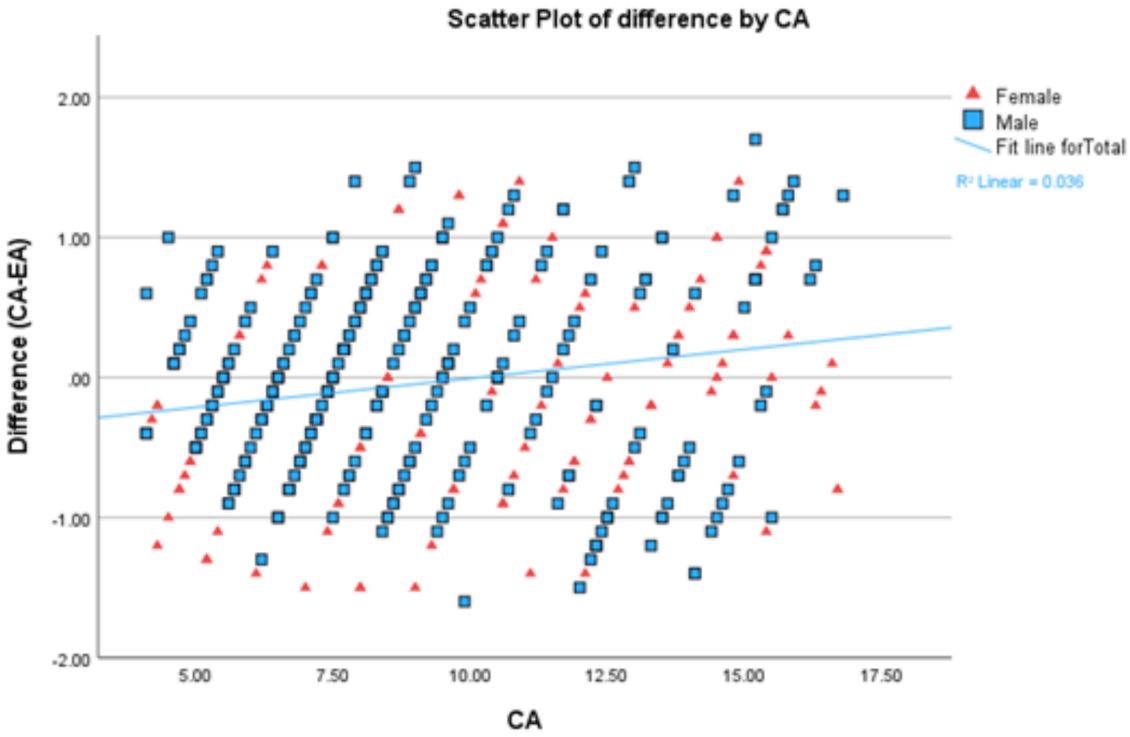
A significant difference in chronological age and estimated age appears between sexes in the age groups of 12-12.99 and 15-15.99 for males and 5-5.99, 10-10.99, and 15-15.99 for females. Similarities were found in both sexes in the age group of 15-15.99. Comparisons among the chronological age and estimated age were insignificant in most age groups, with the p-value less than 0.001 ($p<0.0001$). The most significant difference was seen in the female age group of 4-4.99 years, showing disparities of-0.63 ± 0.31, and the minor disparities were seen in the male age group of 16-16.99 with a difference of -0.08±0.88. The estimated age is remarkably close compared to chronological age in the age group of 7-7.99 for both sexes, with 0.01±0.52 and 0.02±0.69 in males and females, respectively. Age estimation reliability varies by sexes and age group, with some groups showing more excellent reliability than others, as shown in Table 4.

Table 4. Frequency of estimated age from real age deviation range by sex and age group

Age group	Sex	Age deviation range			total
		>-1	-1 to +1	>1	
4 – 4.99	M	0	12	0	12
	F	1	11	0	12
5 – 5.99	M	0	35	0	35
	F	F	24	0	28
6 – 6.99	M	1	32	0	33
	F	1	23	0	24
7 – 7.99	M	1	38	1	40
	F	2	31	0	33
8 – 8.99	M	1	36	1	38
	F	2	25	2	29
9 – 9.99	M	2	27	2	31
	F	2	18	3	23
10 – 10.99	M	0	17	2	19
	F	0	12	5	17
11 – 11.99	M	0	12	2	14
	F	1	13	0	14
12 – 12.99	M	6	8	1	15
	F	1	11	0	12
13 – 13.99	M	1	14	1	16
	F	0	15	0	15
14 – 14.99	M	3	6	1	10
	F	0	13	1	14
15 – 15.99	M	0	8	5	13
	F	1	12	5	18
16 – 16.99	M	0	2	1	3
	F	0	5	0	5

From the overall sample size, 460 subjects (87.95%) were estimated within -1 to +1 years, signifying a greater degree of reliability. Meanwhile, 30 subjects (5.73%) were overestimated, indicating age estimated more than one year, and 33 subjects (6.31%) were underestimated below one year from the chronological age. The male group had a more significant percentage of 53.7% age estimated between -1 and +1 compared to the female group with 46.3%. Meanwhile, the percentage of underestimation was slightly higher in the male group, and the distribution for overestimation was equal for both sexes. The percentage of prediction accuracy is shown in Figure 1, where equal distribution is seen in both sexes for overestimation of more than one year and underestimation of less than one year. Overall, the outcome shows very equivalent performance. The comparison pattern between chronological age and estimated age with chronological ageis demonstrated in Fig.1.

Figure 1.



The paired sample t-test results show no significant difference between chronological age and estimatedage; hence, the estimation based on the London Atlas of Human Tooth Development and Eruption reflects a precise estimation of the subjects. Table 5 shows that the mean difference between the chronological age and estimated age for both male and female groups was underestimated within an exceedingly small range of 0.002 years for males and 0.08 years for females. It can be concluded that the London Atlas has a low margin of error and provides a consistent estimation for both male and female subjects.

Table 5. Summary of comparison of CA and EA

Sex	N	CA	DA	CA-EA	T	One-sided P	Two-sided P
M	279	9.05±3.08	9.06±3.09	-0.002±0.70	-0.05	0.48	0.96
F	244	9.53±3.41	9.60±3.27	-0.08±0.72	-1.65	0.50	0.10

DISCUSSION

Despite improved dental age estimation techniques, a significant gap remains in population-specific studies for Malaysian children aged 4 to 16.99 years. Accurate age estimation is vital for immigration and medico-legal matters in this age group. Current dental age estimate techniques often exhibit specificity to the Malaysian population, limiting their applicability and accuracy.[11] This study aims to assess the suitability of the London Atlas Human Tooth Development and Eruption method for Malaysian children aged 4 to 16.99 years, utilizing the London Atlas' online software program, which provides graphical and textual information on tooth growth and eruption.[7]

The intra-observer value in this study was more significant than the original study by AlQahtani (2010), which has an ICC of 0.879;[6] however, it has similar ICCs in the study on the Chinese population by Jianxin et al.(2023), which has an ICC of 0.98,[12] and the study by Pavloic *et al.* (2017), on Portuguese population which has an ICC of 0.988[8] and study by Sharma and Wadhwan on Indian children which has an ICC of 0.997.[13]

A primary factor in deciding if the method is applicable is the mean difference between estimated and chronological ages. This study showed that the difference between estimated and chronological ages differs statistically significantly when estimating Malaysian children's ages using the London Atas of Tooth Development and Eruption. In this population, the mean difference was 0.365 years, indicating a propensity for overestimation by 3.7 months so this information should be factored in any report. The mean absolute error between them represents accuracy independent of bias.[6] The mean absolute error for the overall group, male group, and female group were lower, with 0.59, 0.58, and 0.60, respectively.

It has been reported that a difference of one year between chronological age and estimated age has been found in several studies assessing the applicability of London Atlas of Tooth Development and Eruption.[8,14] However, this study found a discrepancy of 0.93 years, indicating better accuracy when applied to Malaysian children. Approximately 87% of estimates were within one year of chronological age. The highest discrepancies for underestimation were in the male group aged 16-19.99, with a mean difference of 0.93, followed by the male and female groups aged 15-15.99, with 1.70 and 1.75, respectively. Overestimation discrepancies were more prominent in the female group aged 4-4.99, with a mean difference of -0.63. Similar trends were observed in Saudi Arabian studies by Alshiri *et al.*(2015), where 65% were estimated within a year of chronological age, with a discrepancy of 7 months at 13-15 years of age.[14] Ghafari *et al.* (2019), compared the London Atlas with the Smith method in 339 Iranian children, reporting similar accuracy and practical applicability of the London Atlas on the population. They found that 77.6% of subjects were underestimated within one year, 16.8% were overestimated over one year, and 6.8% were underestimated over one year.[15] The original study by AlQahtani *et al.* (2012), reported 53% estimated accurately, with 23% and 24% overestimation and underestimation, respectively, based on Bangladeshi and British Caucasian populations.[7]

This study revealed significant differences in chronological age and estimated age between males and females in the age groups 15-15.99 and 16-16.99, with differences of 0.70, 0.75, and 0.93, respectively, indicating overestimation. This contrasts with Ismail et al.'s study, which found an underestimation in the 15-year-old age group. Ismail *et al.* (2018) study only examined Malay ethnicity.[5] Estimating age for this group was solely based on third molar development, which reaches complete root formation at about 25 years old.[16-18] Age estimation based on a single tooth may result in underestimation or overestimation due to variations in angles, formation, and morphology.

This study found no significant sex difference in third molar development, consistent with findings in the Bangladeshi population.[19] However, some studies have reported that males' third molar develop earlier than females.[20] Both males and females in this study had advanced stages of third molar development compared to the London Atlas of Human Tooth Development and Eruption software.[16-17] Dhamo et al. found that a higher percentage of the Asian population had faster dental development in contrast to the European population, which exhibited a delayed development.[21]

Using the London Atlas software, this study showed no significant difference between males and females in most age groups, which was

similar with the Hispanic population,[9] the Saudi Arabian population,[22] and the American population.[23] The London Atlas software did not reveal significant sexes differences in most age groups in the Malaysian population. However, it's essential to remain cautious about sexes differences, as they may result from variations in sample size or the small number of subjects since orthopantomograms (OPGs) are less common with young children.

Various methods have been tested in Malaysian children, including Demerjian's,[11,24-25] Willem's,[11,24,26] Nolla's,[11] Haavikko's,[11] and Cameriere's,[11] with varying results, but Willem's method was deemed to be most suitable.[23,26] In each study, there was a level of advancement in females than males at a certain age; however, there was no significant difference in overestimation or underestimation between the age groups. Mani et al. *(2008)*, reported overestimation in males was seen in 10-12 years and 9-11 years in the female group,[24] and Nik-Hussein *et al.* (2011) reported a more significant difference was identified in the age group of 5-6.9 and underestimation in the age group of 14-15.9 in both sexes. In this study, the trend for overestimation shows a higher number than underestimation in the older age group, which is from 10 years old in both sexes. The study demonstrates heightened age overestimation almost before pubertal changes, likely due to a rapid surge in dental tissue and overall growth. This was ascribed by Mani *et al.* (2008) to the irregular and uneven dental development process, which is related to changes in para-pubertal pace.[24]

Malaysian neighboring countries have tested the applicability of the London Atlas of Human Tooth Development and Eruption.Using the Thai population, Namwong and Manica (2022) found a maximum discrepancy of 1.3 years without a significant sexes effect. Thailand's population aged 7 to 15 years was also tested by P. Duangto *et al.* (2022) who reported the mean absolute error consistent with the current study. A comparison of the London Atlas of Human Tooth Development and Eruption with the Demerjian method was conducted on the East China population, and the mean error was less than one year for both methods.[8,27]

In cases of dental profiling for unidentified remains, the London Atlas of Human Tooth Development and Eruption method can be used confidently, as the study did not analyze different ethnicities separately.[28] Ethnicity may not be a reliable alternative to genetic heritage, given substantial genetic diversity within and among ethnic groups.[19]

However, it's important to acknowledge the limitations of atlas-based methods, as they may not account for all variations in tooth development and emergence stages. Additionally, estimating dental age based on eruption or emergence is influenced by various factors, including missing teeth, misalignment, impacted teeth, and early extraction, which can affect the eruption phase.[29-30] Recommendations have been made to address these issues by identifying which teeth tend to be more stable during development.[31]

CONCLUSION

The London Atlas method produced excellent results for age estimation in Malaysian children aged 4 to 16.99, with most age groups showing disparities of less than two years. Caution is advised for age groups with developing third molars, therefore, multiple methods are recommended for age estimation. Sexes had no significant impact, making this method universally applicable. This marks the first large-scale study on Malaysian children, indicating strong reliability as a reference method.

Future research should include larger, standardized sample sizes for improved accuracy and comparability. Even though sex differences were not significant in this study, large samples may provide more insight. In addition, it would be valuable to assess accuracy and reliability across Malaysia's three major ethnic groups (Malays, Chinese, and Indians).

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