International Journal of Legal Medicine (2019) 133:189–195
https://doi.org/10.1007/s00414-018-1808-6

ORIGINAL ARTICLE

Comparison of the accuracy of the London atlas and Smith method in dental age estimation in 5–15.99-year-old Iranians using the panoramic view

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Received: 22 April 2017 / Accepted: 21 February 2018 / Published online: 7 March 2018

Abstract

Tooth development is widely used for age estimation and staging physical maturity. It is of great importance in dental age estimation in forensic dentistry, orthodontic treatment planning, and pediatric endocrinology. This study aimed to compare the accuracy of two age estimation methods, i.e., the London Atlas and Smith's method, using the panoramic view of developing teeth. In this descriptive-analytic study, panoramic radiographs of 339 healthy individuals, including 145 boys and 194 girls, were assessed. The participants aged between 5.00 and 15.99 years. Dental age of the subjects was determined by the London Atlas of Human Tooth Development and Eruption and Smith's method. The collected information was entered in the SPSS software (Ver.18). Differences and correlations between chronological and dental age were assessed by paired *t* tests and Pearson's correlation analysis. In all analyzes, the significance level was considered less than 0.05. The mean chronological age of the subjects was 10.13 ± 2.92 years. The mean ages estimated by the London Atlas and Smith's method were 10.29 ± 2.91 and 9.89 ± 2.84 years, respectively. Paired *t* test showed that the differences between the mean chronological age and mean estimated ages using the London Atlas and Smith's method were not significant ($P = 0.15$ and 0.16, respectively). Our findings showed that both methods had high accuracy for age estimation, but the London Atlas is easier to use.

Keywords Age determination by teeth dental · Age · Forensic · Forensic dentistry

Introduction

Due to the growing trend of international migration, forensic medical centers are facing an increasing need for age determination of unidentified persons. Age determination is also essential for the identification of individuals in crime scenes, terrorist incidents, and natural disasters [1]. Moreover, pediatric endocrinology and orthodontic treatment planning would require exact age determination [2]. Since identification of human remains is required for a variety of personal, legal, and social purposes, determination of age at death is also of high significance. Identification of individuals might be necessary in business activities, arrangement of contracts, and even marriage [3].

Physiological age, and thus the chronological age, is assessed based on certain developmental stages of a system or organ [4]. In a particular tissue system, a sequence of one or more irreversible events indicates the maturation of each tissue [5].

While several methods, including the use of height, weight, secondary sexual characteristics, biomarkers, and bone and dental development, have been proposed for age determination, most available techniques are costly and inaccurate. Therefore, teeth examination is currently regarded as the most widely used technique for age determination [6]. Among the various imaging methods used in age determination, panoramic dental X-ray is commonly used as a simple and inexpensive method for providing a general view of dental maturity [7].

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Humans develop two sets of teeth, i.e., primary and permanent teeth, during one third of their life. Dental development stages can be easily detected even long after death. Moreover, these stages are not largely affected by environmental changes, socioeconomic conditions, diet, and hormonal changes. Assessment of dental development stages can thus be regarded as one of the most appropriate methods of age determination [8]. However, tooth eruption can be seriously affected by numerous factors including adequate space in the dental arch, early extraction of primary teeth, and tooth tipping or impaction [9].

Various methods are utilized to determine the chronological age based on dental development stages. In one of the most recent studies in Iran, Javadinejad et al. [10] compared Demirjian's [11], Cameriere's [2], Willem's [12], and Smith's [13] methods and identified Smith's method as the most appropriate method of age estimation. Smith's method is actually the modified version of a method originally introduced by Moorrees et al. which estimates the chronological age based on 14 developmental stages of eight mandibular teeth on the left side [13].

Atlas of Tooth Development and Eruption (the London Atlas) is a novel, accurate, and fast method of age determination. This method, developed by Alqahtani et al. in 2010, utilizes an atlas and a software program to estimate the chronological age by assessing the developmental and eruption stages of all maxillary and mandibular teeth on the right side [14]. The aim of this study was to use panoramic radiographs of 5.00–15.99-year-old Iranians in order to compare the accuracy of age estimations based on Smith's method and the London Atlas.

Materials and methods

This cross-sectional descriptive-analytic study evaluated the panoramic radiographs of healthy Iranian children aged between 5.00 and 15.99 years and had no medical history of systemic diseases/disorders. Of the 450 selected participants in the current study, 339 children, including 145 boys (43%) and 194 girls (57%), were eligible. The participants were categorized in 11 age groups (Table 1).

At baseline, the purpose of the study was explained to each parent participants; written consent of each of them was obtained. Then, the radiographs were collected from the Oral and Maxillofacial Radiology Clinic of Azad University, Isfahan, Iran. The radiographs were obtained for diagnostic and treatment planning purposes. The participants' gender and birth date, along with the radiograph date, were recorded in a questionnaire. Unclear radiographs, as well as those belonging to children with dental anomalies, fractures, previous orthodontic treatments, or severe malocclusion, were excluded.

Table 1 The frequency distribution of the participants in different age and sex groups

Age (years)	Boys		Girls		Total	
	n	%	*n*	%	*n*	%
5	10	6.9	14	7.2	24	7.1
6	18	12.4	15	7.7	33	9.7
7	19	13.1	20	10.3	39	11.5
8	20	13.8	20	10.3	40	11.8
9	20	13.8	20	10.3	40	11.8
10	17	11.7	20	10.3	37	10.9
11	10	6.9	12	6.2	22	6.5
12	9	6.2	20	10.3	29	8.6
13	12	8.3	20	10.3	32	9.4
14	6	4.1	20	10.3	26	7.7
15	4	2.8	13	6.7	17	5.0
Total	145	100.0	194	100.0	339	100.0

All panoramic radiographs were obtained by a PCH-2500 X-ray system (Vatech Co., Gyeonggi-do, Korea) via a charge-coupled device (CCD) and saved as JPEG files. A single trained examiner unaware of the participants' characteristics estimated their ages using Windows Picture and Fax Viewer and with the naked eye.

To estimate the age with London Atlas method, radiographs were assessed to identify developmental and growth stages for all teeth (including primary and permanent teeth) on the right side of both lower and upper jaws. Then, we estimated the age of individual referring specific figures and tables of this method or using available software on the website: http://www.atlas.dentistry.qmul.ac.uk [14]. Also, we used developmental stages of teeth provided by Moorrees et al. for Smith's method [10, 13]. These fourteen stages specify eight permanent teeth on the left side of mandible. According to Smith's tables categorized by sex, developmental stages for each tooth indicated as a point estimate specific dental age. In this method, we considered no score for the stage of closed apex. Ultimately, a dental age was estimated using this method taking account of mean dental age of all developing teeth [13].

The chronological age of subjects was determined by subtracting their birth date from the date on which radiographs were taken.

In order to measure intra-examiner reproducibility, 50 radiographs were reexamined at a 2-week interval and the Kappa values were 0.90 and 0.98 for the London Atlas and Smith's method, respectively (combined 0.96), indicating excellent agreement.

It should be considered that coding was applied for all subjects, and the examiner was blinded to their characteristics

as well. Their sex was made available for the examiner at the time of assessment.

Finally, the collected data was entered into the Statistical Package for the Social Sciences (version 18.0; SPSS Inc., Chicago, Ill., USA) and was represented by frequency (percent) or mean ± SD. According to the results of the Kolmogorov-Smirnov test indicating the normality of data distribution, paired sample *t* test and Pearson's correlation were used. In all analyzes, the significance level was considered less than 0.05.

Results

Overall, in the current study, the mean chronological age calculated as 10.13 ± 2.92 years whereas it was estimated by two methods of London Atlas and Smith as 10.29 ± 2.91 and 9.89 ± 2.84 years, respectively. As a result, the mean chronological age and the mean ages estimated by the London Atlas were not significantly different in boys ($P = 0.196$), girls ($P = 0.203$), or the whole study sample ($P = 0.150$). Likewise, there were no significant differences between the mean chronological age and the mean ages estimated using Smith's method in boys ($P = 0.204$), girls ($P = 0.200$), or the whole study sample ($P = 0.160$).

On the other hand, the absolute difference between the mean chronological age and the age estimated by the London Atlas method (0.60 ± 0.57 years) was statistically significantly higher than the absolute difference between the mean chronological age and the age estimated by Smith's method (0.70 ± 0.57 years) ($P = 0.008$). It should be noted that absolute differences are used to express variation without bias (Table 2).

According to Fig. 1, the estimated age by the London Atlas method for all age ranges from 6 to 15.99 years (except 5 years) was lower than the chronological age of individual and in contrast, by London Atlas method, and for all age ranges (except 15 years), the estimated age was higher than the chronological age. On the other hand, the means of absolute differences in age ranges of 8 to 13 years estimated by these two methods were different and the London Atlas method showed higher accuracy than Smith's method (P value < 0.05).

The frequency distribution of deviations of ages estimated by the London Atlas and Smith's method from the chronological age categorized by age and sex suggested that in both groups, more than 70% of age estimations were between − 1 and + 1 year. Moreover, while the London Atlas overestimated age in about 15% of the cases, the age of 16.8% of the participants was underestimated by Smith's method, although deviations between different age ranges categorized by sex were not significant (P value > 0.05) (Table 3).

As Fig. 2 shows, Pearson's correlation coefficients suggested strong linear correlations between the chronological age and ages estimated by the London Atlas ($P < 0.001$; $r = 0.96$) and Smith's method ($P < 0.001$; $r = 0.955$). Although the accuracy and correlation coefficient of the London Atlas were slightly higher than those of Smith's method, no significant difference was detected between the two methods.

Discussion

Age estimation is one of the major issues in forensic medicine to introduce the treatment and identify patient rights and is of vital importance for many forensic medicine events to be faired and stated confidently. Although there are various methods to estimate the age, a scientific, noninvasive, and quick method is not proven in this respect so far. One of the applied methods to this estimation is dental age. The dental age is a type of developmental ages which is fairly well associated with real age of individual and due to ease of use, it is a common practice. Among common methods to estimate dental age, dental radiology provides a wide range of facilities for investigators. Dental radiology can be used in living individuals as well as forensic cases and skeletal remains as it is easy, low cost, and reliable. The present study compared the London Atlas (a novel dental age estimation technique introduced by Alqahtani et al. [14]) with Smith's method [13].

Smith's method in 1991 in fact is a modified version of the method which was first introduced by Moorrees et al. [13]. It describes each tooth separately and provides an average from all teeth that are developing. This method can be introduced as a prediction tool with a measure of dispersion values which is easy to use. In comparison, London Atlas method developed by Alquhtani et al. is considered as a widely used method designed for age prediction as well [15]. It provides 31 age categories based on tooth development and eruption.

The London Atlas was assessed among the Bengali and white British residents of England by Alqahtani et al. [6, 15] and in Saudi Arabian children by Alshihri et al. [16]. Numerous studies in Iran have also focused on dental age estimation. Javadinejad et al. compared Demirjian's, Smith's, Cameriere's, and Willem's methods in Isfahan (Iran) and identified Smith's method as the most appropriate method of age estimation [10]. Since the present research was also conducted on children in Isfahan, Smith's method was compared with the London Atlas to determine the best method of age estimation in the Iranian population. To the best of our knowledge, no previous study in the country has compared the accuracy of these two methods.

The mean chronological age of the participants was 10.13 ± 2.92 years (9.60 in boys and 10.50 in girls). The mean ages estimated by the London Atlas and Smith's method were 10.29 ± 2.91 and 9.89 ± 2.84 years, respectively.

Table 2 The mean chronological age and ages estimated by the London Atlas and Smith's method in boys and girls

Age (years)	Boys		Girls		Total	
	Mean	SD	Mean	SD	Mean	SD
Chronological age	9.61	2.64	10.51	3.06	10.13	2.92
Age estimated by the London Atlas	9.70	2.74	10.73	2.97	10.29	2.91
Age estimated by Smith's method	9.52	2.63	10.16	2.97	9.89	2.84
Abs. Chronological age - London Atlas method	0.59	0.56	0.63	0.58	0.60	0.57
Abs. Chronological age - Smith's method	0.65	0.53	0.73	0.59	0.70	0.57
P_1	0.196		0.203		0.150	
P_2	0.204		0.200		0.160	
P_3	0.132		0.028		0.008	

P_1: The significance level provided by comparison between the mean chronological age and the mean age estimated by the London Atlas method

P_2: The significance level provided by comparison between the mean chronological age and the mean age estimated by Smith's method

P_3: The significance level provided by comparison of the mean absolute difference between the chronological age and the age estimated by London Atlas method with the mean absolute difference between the chronological age and the age estimated by Smith's method

Abs. Absolute

Comparisons between the participants' chronological age and ages estimated using the London Atlas showed that this method slightly overestimated the age of boys, girls, and all subjects in total. On the contrary, Smith's method tended to

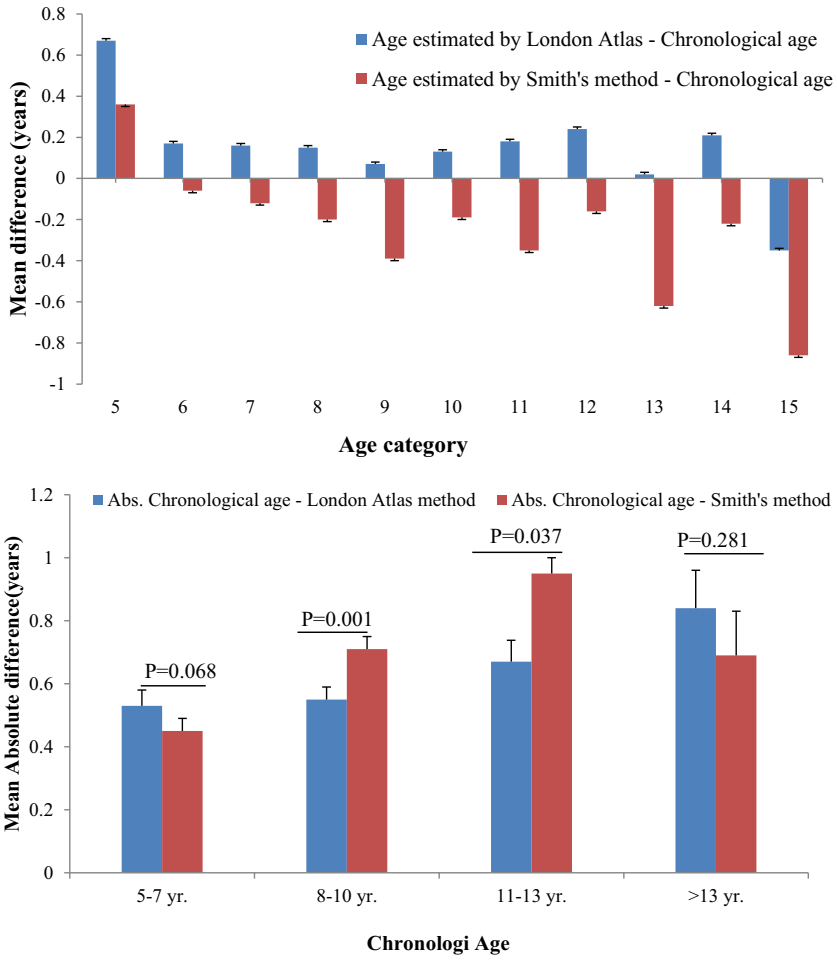

Fig. 1 Bar charts of the mean difference and mean absolute difference in years between ages estimated by the London Atlas and Smith's method with the chronological ages for each age category

Table 3 The frequency distribution of deviations of ages estimated by the London Atlas and Smith's method from the chronological age

Chronological age	Gender	London Atlas			Smith's method		
		> 1 year	− 1 to + 1 year	< − 1 year	> 1 year	− 1 to + 1 year	< − 1 year
5–7 years	Boy	1 (2.1%)	42 (89.4%)	4 (8.5%)	2 (4.3%)	42 (89.4%)	3 (6.4%)
	Girl	2 (4.1%)	37 (75.5%)	10 (20.4%)	1 (2.0%)	47 (95.9%)	1 (2.0%)
8–10 years	Boy	8 (14%)	43 (75.5%)	6 (10.5%)	10 (17.5%)	44 (77.2%)	3 (5.3%)
	Girl	1 (1.7%)	50 (83.3%)	9 (15%)	18 (30.0%)	40 (66.7%)	2 (3.3%)
11–13 years	Boy	2 (6.5%)	25 (80.6%)	4 (12.9%)	6 (19.4%)	21 (67.7%)	4 (12.9%)
	Girl	3 (5.8%)	37 (71.2%)	12 (23.1%)	14 (26.9%)	34 (65.4%)	4 (7.7%)
>13 years	Boy	1 (10.0%)	6 (60.0%)	3 (30.0%)	1 (10.0%)	7 (70.0%)	2 (20.0%)
	Girl	6 (18.2%)	22 (66.7%)	5 (15.2%)	7 (21.2%)	25 (75.8%)	1 (3.0%)
Total	Boy	12 (8.3%)	116 (80.0%)	17 (11.7%)	19 (13.1%)	114 (78.6%)	12 (8.3%)
	Girl	12 (6.2%)	146 (75.3%)	36 (18.6%)	40 (20.6%)	146 (75.3%)	8 (4.1%)

underestimate age in boys, girls, and the whole study sample. However, the differences between the chronological and estimated ages were not significant and there were strong linear correlations between the chronological age and ages estimated by both the London Atlas and Smith's method.

An earlier study evaluated the accuracy of four common age estimation methods among 3.9–14.5-year-old individuals and reported no significant difference between the participants' chronological age and the age estimated by Smith's method [9]. They calculated the mean difference between the chronological age and age estimated by Smith's method as 0.06 ± 0.63 while in the current study, it was calculated as 0.70 ± 0.57. Although this difference shows a higher value in our study, this value can be influenced by the age of subjects which was on average about 2 years higher in our study.

Corral et al. assessed the accuracy of six age estimation methods among a Colombian population and found the chronological age to have the greatest correlations with ages estimated by Moorrees's, Fanning and Hunt's, and Smith's methods [17]. Moreover, they calculated the ratio of the chronological age to the estimated age. If the obtained ratio for each method was larger than one, the method overestimated age. Otherwise, it underestimated age. Unlike our findings, Smith's method was reported to overestimate age in both girls

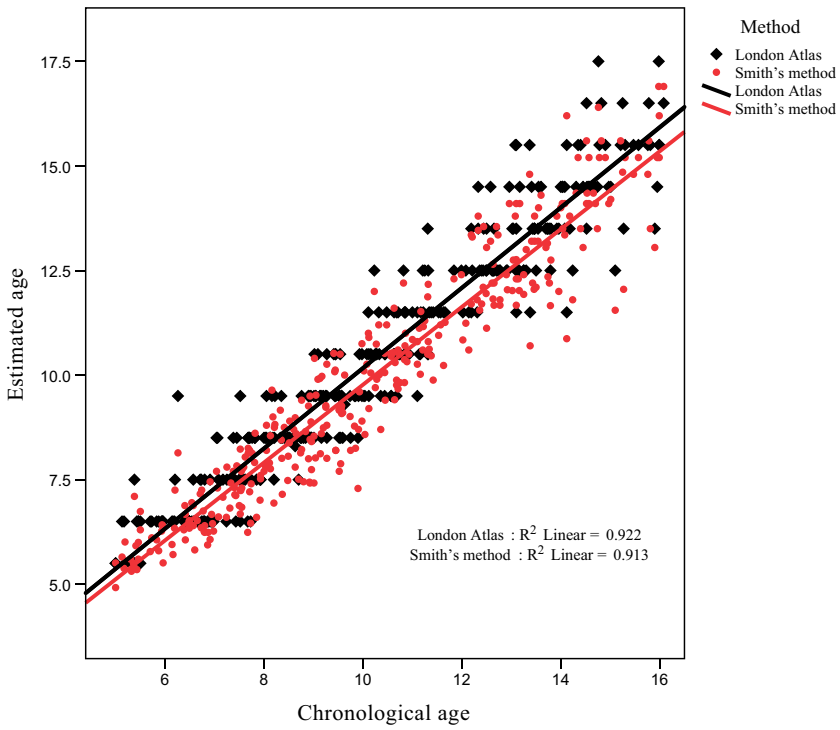

Fig. 2 Scatterplot of estimated age versus the chronological age of London Atlas (black diamonds) and Smith's method (red dots)

and boys. In 2002, Hernández and Sierra identified Smith's method as the best age estimation method among the Colombian population [18].

Alqahtani et al. used samples of known-age individuals (prenatal to 23 years) to compare the London Atlas with Schour and Massler's and Ubelaker's age estimation charts. While all three methods underestimated age, the London Atlas had the highest accuracy. For ages 3–16 years (i.e., ages close to the age range studied in the present research), the London Atlas slightly overestimated age, but the ages estimated by the two other methods were still lower than the chronological age [2]. These results are consistent with our findings.

Alshihri et al. utilized the London Atlas for dental age assessment in Western Saudi children and adolescents. Consistent with our findings, they found the atlas to slightly overestimate age [16].

In the current study, the London Atlas and Smith's method correctly (with a deviation of ± 1 year) estimated the chronological age of 77.6 and 78.2% of the participants, respectively. The Smith method underestimated the age of 16.8% of the participants with a deviation over 1 year and overestimated the age of 15% of the children with a deviation greater than 1 year. The corresponding values for the London Atlas were 6.8 and 5.6%, respectively.

It can be said that for forensic use, the London table cannot provide enough evidence, since the accuracy for an estimate of an individual case cannot be given. Just its best estimate is, e.g., 10.5 years. With Smith, a number of the accuracy can be given in the form of a std. dev. With the London table, there is always an inbuilt error of half a year, which may have practical implications in the younger ages.

In a study by Alshihri et al., the London Atlas correctly (with a deviation of 1 year) estimated the age of 65.5% of the subjects, underestimated the age of 19% of the participants with a deviation more than 1 year, and overestimated the age of 15.5% of the studied individuals with a deviation over 1 year [16]. According to Alqahtani et al., the ages estimated by the London Atlas were correct, higher than the chronological age, and lower than chronological age in 52.84, 23.12, and 24.04% of the cases, respectively [6]. Our findings were more similar to those reported by Alshihri et al. (probably due to the closer age range of the participants).

Finally, in the present research, the accuracy of both methods decreased at ages ≥ 12 years. This finding was actually expected since most teeth are fully developed at this age, i.e., fewer teeth can be used in age estimation and this increases the probability of error.

Based on the above-mentioned facts, the London Atlas and Smith's method are both suitable for accurate age estimation in the Iranian population.

Conclusion

Both the London Atlas and Smith's method can accurately estimate Iranian individuals' chronological age. While Smith's method requires more mathematical calculations, the London Atlas only involves the visual comparison of the panoramic view with the atlas. Furthermore, a free software program facilitates the use of the London Atlas. Therefore, the atlas is recommended as an easy-to-use and accurate method of age estimation.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

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