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SHORT COMMUNICATION

Accuracy of Cameriere, Haavikko, and Willems radiographic methods on age estimation on Bosnian–Herzegovian children age groups 6–13

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Abstract The aim of this cross-sectional study was to compare the accuracy of the Cameriere European formula (Cameriere), adopted Haavikko method from 1974 (Haavikko), and revisited Demirjian method by Willems (Willems) for age estimation on orthopantomograms (OPGs) of Bosnian–Herzegovian (BH) children age groups 6–13 years. The accuracy was determined as difference between estimated dental age (DA) and chronological age (CA) and the absolute accuracy (absolute difference) was assessed by analyzing OPGs of 591 girls and 498 boys. The Cameriere method overestimated the mean age by 0.09 year for girls and underestimated by −0.02 year for boys. The Haavikko method underestimated the mean age by −0.29 year for girls and −0.09 year for boys. The Willems method overestimated the mean age by 0.24 year in girls and by 0.42 year in boys. The absolute accuracies were 0.53 year for girls and 0.55 year for boys for Cameriere method; for Haavikko method, 0.59 year for girls and 0.62 year for boys; and for Willems method 0.69 year for girls and 0.67 year for boys. In conclusion, Cameriere method is the most accurate for estimating the age of BH children age groups 6–13 years using OPGs, following adopted Haavikko method and Willems method.

Keywords Forensic dentistry · Age estimation · Bosnia and Herzegovina · Cameriere method · Haavikko method · Willems method

Introduction

Estimation of chronological age (CA) using morphological and radiological analysis on teeth has importance in forensic dentistry, human anthropology, and bioarchaeology. Two

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different concepts of age estimation in children using teeth are present; assessing teeth eruption in mouth and observation of mineralization of crowns and roots on radiographs of deciduous and permanent teeth [1]. In order to quantify continuous process from first traces of cusps mineralization until root apex closure, many authors suggested different number of radiographic stages, from three stages by Hunt and Glasser [2] to possible 40 stages suggested by Nolla [3]. The most widely used method was introduced by Demirjian [4] in 1973. This method was based on Tanner et al. [5] system for estimating the maturity of the hand and wrist. Demirjian's method is related on evaluation of one from eight appropriate radiographic stages (A to H) of crown and root development on permanent teeth from left side of mandible, excluding third molar. Adopted Demirjian's tables and percentile curves were based on evaluation of 4,756 OPGs of French–Canadian children [6]. Few papers showed that French–Canadian standards were not appropriate for age estimations on children from different regions in Europe and world with general trend of overestimation of dental age (DA) comparing to chronological age in children. Demirjian's method is also inappropriate to evaluate differences among populations in dental maturity [7]. Haavikko et al. [8] suggested to adopt an age estimation method based on determination of one of 12 radiographic stages of four permanent teeth; different teeth were used for children under and after 10 years of age. Method was based on previous radiographic evaluation of all permanent teeth on 885 Finnish children ages 2 to 13 years and is useful when some permanent teeth are missing [9].

Cameriere et al. [10] introduced a new concept of estimating chronological age in children by measuring the open apices in seven mandibular teeth on radiographs of Italian children. Accuracy of Cameriere's method was tested on greater sample of OPGs taken from 1,100 Italian, Kosovan, and Slovenian children [11]. Analysis of covariance showed that belonging to various European regions did not have significant influence on age estimation. To establish a more general formula, Cameriere et al. [12] presented a European formula, as a result of regression analysis of OPGs taken from 1,270 girls and 1,382 boys from Croatia, Germany, Kosovo, Italy, Slovenia, Spain, and United Kingdom.

Few recent papers were related to evaluation of precision and accuracy of different radiographic methods using developing teeth [13–15]. Precision or reliability means small error or small average deviation or the degree to which further measurements or calculations give the same or similar results. More accurate or more valid method means smaller difference between dental age and chronological age or smaller bias [16].

Evaluation of dental age of children of particular regional groups in Europe was of little interest until now [15]. Bosnia and Herzegovina has been affected by recent war from 1992 to 1995 including civilian victims, displacement of people and refugees, still missing people including children [17–20]. Cunha et al. [21], in their review about problem of aging human remains and living individuals which exposed the experience of the authors working in the Forensic Anthropology Society of Europe subsection of the International Academy of Legal Medicine, suggested that age estimation should be brought up to date on the usage of known methods provided by literature and development of new methods and to more precisely discuss the results in the specific population in order to use the most adequate technique.

Therefore, the aim of this study was to evaluate the applicability of three different radiographic methods using developing teeth on age estimation on Bosnian–Herzegovian (BH) children ages 6–13 years.

Materials and methods

Study population

OPGs of 1,089 children, 591 girls and 498 boys, dated after year 2000, were selected at random basis from patients from School of Dental Medicine University of Sarajevo and regional community dental clinics from Banja Luka, Čitluk, Ljubuški, Mostar, Orašje, Posušje, and Zenica, and private dental practices in Bihać and Čapljina in order to include Bosnian, Croatian, and Serbian children. These three nations form the major population in Bosnia and Herzegovina.

Exclusion criteria were evident systemic diseases and congenital anomalies, premature birth, hypodontia of permanent teeth except third molars.

Personal data for patients except date of birth, date of radiograph, and gender were not collected and their parents or tutors had signed agreement with dental institutions that dental records and radiographs could be used only for research and educational purposes without possibility of personal identification. Ethical approval for this study was obtained by the Ethics Committee of the School of Dental Medicine, University of Zagreb, Croatia.

OPGs were digitalized using a Kodak EasyShare Z812-IS Digital Camera. The computer images were stored in and examined using Corel Draw (Corel Draw software package v.12.0, 2003, Corel Corporation, Ottawa, Canada).

The Cameriere European formula, adopted Haavikko and Willems radiographic methods on developing teeth were used for age estimation.

The Cameriere method is explained in detail in Cameriere et al. [12]. European linear regression formula was used, available also as MS Excel template at website of Istituto di

Medicina Legale, Universita′ Degli Studi Macerata: AgEstimation project. http://agestimation.unimc.it:

$$\text{Age} = 8.387 + 0.282g - 1.692 \times 5 + 0.835N_0 - 0.116s - 0.139s \cdot N_{0,}$$

where g is a variable—equal to 1 for males and 0 for females.

The adopted Haavikko method was explained in detail in Haavikko et al. [8].

The Willems method, based on revisited Demirjian method using adopted scores, was explained in Willems et al. [22].

Statistical analysis and data management

Analyses were made for each gender and age cohort (i.e., children between 8.00 and 8.99 years of age were included in the 8-years cohort and so on). MedCalc (MedCalc, Version 10.2.0.0, Mariakerke, Belgium) and MS Excel (Microsoft Office) were used for statistical analysis and data management.

Intra-observer repeatability of this study was tested by re-examining 10% (N=110) of OPGs. The weighted Cohen's Kappa was used to measure the repeatability of the number of closed apices for Cameriere's method as well as Demirjian's and Haavikko's stages for all selected teeth. Intra-observer reliability of two observations of dental age was tested by applying concordance correlation coefficient [16].

Difference between the chronological ages of girls and boys was tested using independent samples t test. Accuracy of each method was determined by mean difference between dental age and chronological age (DA–CA) for girls and boys, and age cohorts separately. Absolute accuracy was determined by means of the absolute differences of DA–CA for girls and boys and age cohorts separately. Paired samples t test was applied to assess the significances of the difference between DA and CA for each method, genders and age cohort and absolute accuracy between methods for both genders. Non-parametric Wilcoxon signed-rank test was also applied to assess the significances of the difference between CA and DA because sample size was small and having non-normal distribution in some age groups. An independent sample t test was used to compare absolute accuracy between genders for each method.

When the p value was less than 0.05, the results were considered statistically significant.

Results

Age and gender distribution of the BH children were presented in Table 1.

Table 1 Age groups and gender distribution of the panoramic radiographs of the Bosnian–Herzegovian children

Chronological age	Girls	Boys	Total
6.00–6.99	19	22	41
7.00–7.99	55	34	89
8.00–8.99	99	72	171
9.00–9.99	132	104	236
10.00–10.99	101	100	201
11.00–11.99	95	84	179
12.00–12.99	66	63	129
13.00–13.99	24	19	43
All	591	498	1,089

Results of weighted Cohen Kappa score for repeatability of number of closed apices for Cameriere method was 1.00. Cohen Kappa for repeatability of radiographic stages for Haavikko method was 0.854 and for Willems method was 0.811. Concordance correlation coefficients were 0.968 for the Cameriere method, 0.983 for the Haavikko method and 0.969 for the Willems method. There were no statistically significant differences between chronological age of girls and boys (p=0.253).

For girls, the mean (standard deviation) CA was 10.03 years (1.73 years). The mean DA was 10.13 years (1.67 years) according to the Cameriere method, 9.81 years (1.78 years) according to the Haavikko method and 10.28 years (1.98 years) according to the Willems method.

For boys, the mean CA was 10.16 years (1.74 years). The mean DA was 10.14 years (1.67 years) according to the Cameriere method, 10.16 years (1.74 years) according to the Haavikko method and 10.58 years (1.86 years) according to the Willems method.

Results comparing accuracy by the all three methods for girls and boys are shown in Table 2 and Fig. 1 and distribution of the results into the age cohorts for girls and boys separately are given in Electronic supplementary materials, Tables S1 and S2, and Figs. 2 and 3.

The DA was found to be overestimated according to the Cameriere method with a mean difference of 0.10 years for girls. The difference between the DA and the CA for girls was significant from zero (p<0.001), while it was underestimated but was not statistically significant (p=0.630) for boys with a mean accuracy of −0.02 year. The DA was found to be underestimated according to the Haavikko method with a mean difference of −0.23 year for girls and −0.09 year for boys. The difference between the DA and the CA for both genders was statistically significant (p<0.001). The DA was found to be overestimated according to the Willems method with a mean difference of 0.25 year for girls and 0.42 year for boys. The difference between the DA and the CA for both genders was

Table 2 Summary of mean differences in years (DA–CA) between the dental age (DA) and the chronological age (CA) and absolute difference (AD) for each radiographic method for girls and boys

Method	Gender	*N*	CA(SD)	DA(SD)	DA–CA (SD)	95% CI of DA–CA	(DA–CA)[a]	AD	AD[a]	*t* Statistics[b] (d.f.)	p^b	p^c
Cam	Girls	591	10.03 (1.73)	10.13 (1.67)	0.10 (0.71)	0.04 to 0.16	0.09	0.53	0.39	3.46(590)	0.001	0.001
Haa				9.81 (1.78)	−0.23 (0.73)	−0.28 to −0.16	−0.23	0.59	0.48	−7.38(590)	<0.001	<0.001
Will				10.28 (1.98)	0.25 (0.89)	0.18 to 0.32	0.15	0.69	0.52	6.80(590)	<0.001	<0.001
Cam	Boys	498	10.16 (1.74)	10.14 (1.67)	−0.02 (0.71)	−0.05 to 0.08	−0.04	0.55	0.42	−0.48(497)	0.629	0.544
Haa				10.06 (2.00)	−0.09 (0.79)	−0.16 to −0.02	−0.14	0.62	0.51	−2.61(497)	0.009	0.002
Will				10.58 (1.86)	0.42 (0.77)	0.35 to 0.49	0.34	0.67	0.52	12.22(497)	<0.001	<0.001

Cam Cameriere, *Haa* Haavikko, *Will* Willems, *CI* confidence interval, *SD* standard deviation

[a] Median

[b] Paired samples *t* test

[c] Wilcoxon signed-rank test

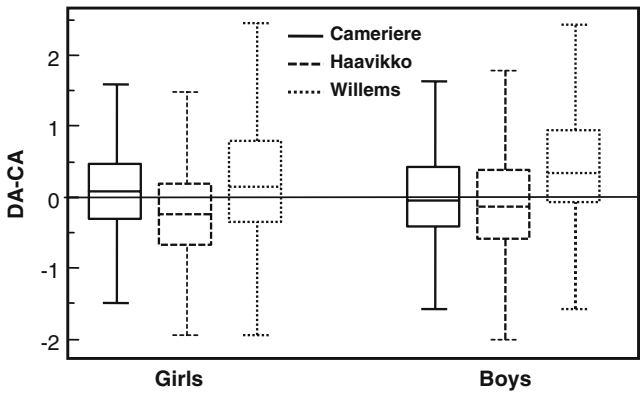

Fig. 1 Boxplot of the difference between the dental age and the chronological age (DA–CA) for girls and boys according to the Cameriere, Haavikko and Willems methods. *Boxplots* shows median and interquartile range, *whiskers* indicate the range

statistically significant ($p<0.001$). For both genders, the Cameriere method was the most accurate, followed by the Haavikko and Willems.

Mean differences (SD—standard deviation) in years between the DA and the CA for age cohorts were shown for girls in Electronic supplementary materials, Table S1 and for boys in Electronic supplementary materials, Table S2. The differences between the mean estimated DA and the CA for both genders and age cohort for all three methods were less than a year except for the girls for the age group of 13 years for the Haavikko method. The standard deviations were less than a year for both genders, except for Haavikko 6-year-old group for girls.

Summary of the mean values of absolute differences for all three methods are presented in Table 2. For the Cameriere method, the absolute differences were 0.53 year for girls and 0.55 year for boys. Although absolute accuracy was better for girls than for boys, the difference between the two mean absolute differences was not

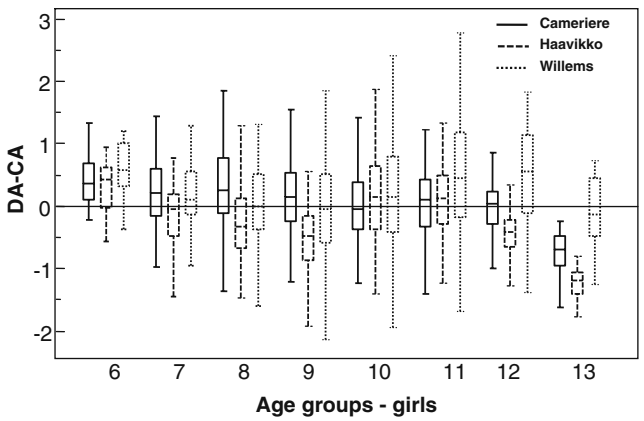

Fig. 2 Girls—boxplot of the differences between the dental age and the chronological age (DA–CA) for 6–13-year age groups according to the Cameriere, Haavikko, and Willems methods. *Boxplot* shows median and interquartile range, *whiskers* indicate the range

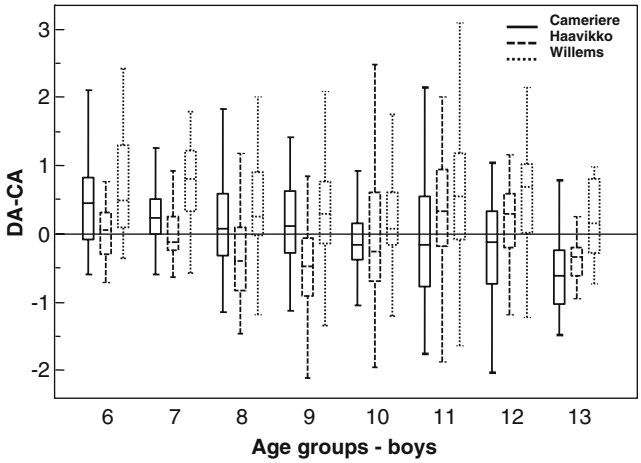

Fig. 3 Boys—boxplot of differences between the dental age and the chronological age (DA–CA) for 6–13-year age groups according to the Cameriere, Haavikko, and Willems methods. *Boxplot* shows median and interquartile range, *whiskers* indicate the range

statistically significant (p=0.500). For the Haavikko method the mean absolute differences were 0.59 year for girls and 0.62 year for boys, without statistically significance between genders (p=0.250). The absolute differences for Willems method were 0.69 year for girls and 0.67 year for boys, respectively (p=0.625). The absolute accuracy for Haavikko method for both genders was better than Willems method (p=0.0004) but was significantly less accurate than for Cameriere method (p=0.0011). Mean absolute differences and standard error of absolute difference for age cohort for girls and boys are presented in Electronic supplementary materials, Table S3.

Discussion

Age determination of individuals using all available scientific methods is common part of forensic practice. Forensic dentistry uses different clinical, morphological, and radiological methods on the teeth to determine the dental age on living persons and after death [23]. Dental age of children is commonly determined by radiological evaluation of development of crown and root of growing teeth [21].

Better method demonstrates the accuracy or smaller difference between dental age and chronological age and the reproducibility or the extent to which estimated ages remain consistent over repeated measurements of the same individual [13].

The most used Demirjian's technique and French–Canadian standards have proven to overestimate age both in males and females, and most studies suggested that the method needs an adaptation for every specific population. However, well-defined and reproducible stages of dental development of seven mandibular teeth and great number of different population on which the method was applied makes Demirjian's method suitable for age estimation [21]. Willems adopted and simplified Demirjian's method by analysis of OPGs of Belgian children [22]. According to Liversidge, revisited Demirjian's method by Willems was the best as regards average difference and median absolute difference between the dental age and chronological age [15].

In this study, we tested the repeatability and accuracy of the three dental age radiographic methods and evaluated which method is more useful for BH children by determining mean difference for each gender and age cohort separately.

For girls, the mean DA was overestimated for 0.10 year according to the Cameriere method by the range of differences of −0.80 to 0.60 year for all age groups. The DA was underestimated for −0.23 year according to the Haavikko method by the range of differences of −1.22 to 0.50 year for all age groups, whereas it was overestimated 0.25 year for the Willems method by the range of differences of 0.01 to 0.78 year, except for 13-year-old group, which was underestimated of −0.12 year. For the age of the 13 years old, the underestimation was more than a year using the Haavikko method.

For boys, the mean DA was underestimated for −0.02 according to the Cameriere method by the mean of differences of −0.60 to 0.09 year for the 10-, 11-, 12- and 13-year-old groups, whereas it was overestimated by the mean differences of 0.09 to 0.45 year for the age groups of 6, 7, 8 and 9 years old. The DA was underestimated for −0.09 according to the Haavikko method by the mean differences for −0.37 to −0.08 year for 8-, 9-, 10- and 13-year age groups, and it was overestimated for the 6-, 7-, 11- and 12-year-age groups by the mean differences of 0.06 to 0.34 year. The DA was overestimated for 0.42 year according to the Willems method by the mean differences of 0.20 to 0.78 year, for all age groups.

In this study, sample represents general population and includes all main ethnic communities in Bosnia and Herzegovina. It was drawn from the School of Dental Medicine University of Sarajevo, community dental clinics and private practices in Bosnia and Herzegovina.

The War in Bosnia and Herzegovina between 1992 and 1995 caused hundreds of thousands of BH civilian casualties including dead and missing children [20]. Different scientific methods are used in cases where the age may play an important task in cases for identification [21, 24]. The War also caused exodus of civilians inside the country, in the neighboring countries, European Union, USA and many other parts of the World. BH is still a country in postwar reconstruction and transition which could still bring some of BH children into the situation to

emigrate or to travel in a foreign country illegally or without identification papers. It is the civil right of a person in a modern society to determine the correct age because persons under the boundary age have the right to be treated as children or minors. Norwegian approach to young asylum seeker, for example, includes usually usage of two different tables or methods (e.g., Haavikko) in teeth under development when age has to be determined [25, 26].

According to literature, there are no other published articles about estimating age on growing teeth on Bosnian–Herzegovian children, except previous study using Demirjian's standards from 1976 [27]. Demirjian's DA was overestimated by the mean differences of 0.60–2.17 years for girls and 0.63–2.60 years for boys in age groups range 5–14 years. The differences were statistically significant for most age groups for both genders. Those overestimations were in concordance with many previous studies of applicability of Demirjian's method on different European and children from India, China, Brazil, Iran, Northern Turkey [28–32].

Few papers have been published about comparing accuracy of age estimation of different radiographic methods using developing teeth. Staaf et al. [33] compared three radiographic methods including adopted Haavikko method on 541 Swedish children. For adopted Haavikko method, underestimation was 0.38 and 0.55 year for girls under and over 10 years of age and 0.28 and 0.53 year for boys under and over 10 years of age. Butti et al. [34] tested adopted Haavikko method on 500 Italian children. Dental age was also underestimated by −0.41 and −0.29 year for girls and boys, respectively. For adoption of her method, Haavikko tested nine selected teeth divided into six different groups. The greatest correlation coefficients between group of teeth and age groups were different for age groups up to 10 years of age and for the age groups 10 to 13 years. Haavikko also suggested using this method up to 13 years of age which is in concordance with our results for Haavikko method for girls [8]. Willems et al. [22] established method by adaptation of scoring system of Demirjian's radiographic stages on 2,116 OPGs of Belgian children by weighted ANOVA. Corresponding age scores are expressed directly in years for each of the seven left mandibular teeth in girls and boys separately. Method was tested on the second sample of 355 OPGs. Dental age was more accurate comparing with Demirjian method; mean overestimation was 0.2 year (SD:1.3, median: 0.2) for girls and 0.0 year (SD: 0.9, median: 0.1) for boys, respectively [22]. Mean dental age using Willems' method for BH girls is comparable with Willems' findings on Belgian children; BH boys were more overestimated comparing with Belgian boys. Maber et al. [14] compared the accuracy of several radiographic methods on sample of 946 Bangladeshi and British Caucasian children, including Willems method and Haavikko method from 1970 on all developing teeth [9]. Dental age for Willems method was underestimated for −0.20 and −0.05 year for girls and boys, respectively. Underestimation for Haavikko method was −0.57 and −0.39 year for girls and boys, respectively, but those findings for Haavikko were not comparable with our results because adopted Haavikko method was not used. Mani et al. [35] compared Demirjian and Willems methods on 428 Malay girls and boys. Willems method overestimated the age for 0.41 and 0.55 year for girls and boys, respectively, which was more accurate comparing to Demirjian method. Cameriere et al. [13] compared Demirjian method from 1973, Willems method and Cameriere method on open apices of teeth on OPGs from white Italian, Spanish, and Croatian children (401 girls and 355 boys). Median underestimation was −0.073 year for girls, and boys were overestimated for 0.247 year for Willems method. Cameriere method was more accurate, median underestimations were −0.081 and −0.036 year for girls and boys, respectively, which is in concordance with our results for Cameriere method using the European formula. Absolute difference in age estimation reports only the time distance from the true age and does not consider whether dental age is overestimated or underestimated [15]. Liversidge [15] studied data from Maber et al. [14] and calculated the absolute difference of different radiographic methods with the addition of several other methods. Median of absolute accuracy for Willems method for both genders was 0.52 year, which is in concordance with our results. Cameriere et al. [13] also compared the mean absolute differences or mean prediction errors for three methods including Willems et al. [22] and Cameriere et al. [10]. Mean absolute differences for Willems method was 0.93 year for both genders which was less accurate comparing with our results and for Cameriere method were 0.48 year for girls and 0.50 year for boys which is close to our results for Cameriere method using European formula.

Conclusion

Authors tried to verify which of the three radiographic methods is the most applicable and accurate to the studied population. All methods are applicable for dental age estimation on BH children. They are more accurate comparing with Demirjian's standards from 1976, which is comparable with many previous studies on other population. The Cameriere method using European formula is the most accurate for both genders, followed by the Haavikko method; the Willems method is least accurate. However, the Haavikko method is not appropriate for girls over 12 year-old group of age. Absolute accuracy is the

best for the Cameriere method using European formula, followed by the Haavikko and Willems methods.

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