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# Accuracy of the London Atlas, Haavikko's Method and Cameriere's European Formula of dental age estimation in Turkish children

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ABSTRACT

Age estimation is a mandatory procedure when the chronological age is unknown or uncertain. Dental development is the preferred characteristic for estimating a child's age. There are many methods for dental age estimation, but their reliability can differ between populations. This study compared the accuracy of three of these methods—the London Atlas (LA), Haavikko's method (HM), and Cameriere's European formula (CF)—in Turkish children living in northwestern Turkey. Panoramic radiographs of 980 children from northwestern Turkey aged between 6.00 and 14.99 years were examined for the whole study group and separately for different ages and sexes by all three methods. Statistical differences between chronological age and dental age were tested using the paired sample *t*-test and the Wilcoxon signed-rank test. The LA, HM, and CF accuracies were determined based on the mean absolute error. Spearman's rank correlation coefficient showed that the correlation between chronological age and dental age for both sexes was linear for all methods. The LA overestimated the chronological age by 0.09 years, while HM and CF underestimated it by 0.49 and 0.11 years, respectively. The difference between dental age and chronological age was significant in all samples, for all methods, except for the LA in boys. When boys, girls, and the total sample were evaluated, values with the lowest mean absolute error were obtained by HM and were statistically significant in all three groups. Therefore, HM is more accurate than the LA and CF for dental age estimation in Turkish children living in northwestern Turkey.

## 1. Introduction

Age estimation is a mandatory procedure when the chronological age (CA) is unknown or uncertain; for example, in the determination of whether the child has reached the age of criminal responsibility in judicial cases, and to clarify the status of leave-in matters, such as marriage, immigration, adoption, and employment when a valid age certificate is missing [1]. Within the scope of forensic sciences, age estimation is also used in cases where the deceased become unidentified and for the age determination of skeletal remains [2,3]. Clinically, the findings can be used to support treatment planning in pediatric dentistry, orthodontics, and oral pathology [4].

Dental development is the preferred characteristic for estimating a child's age. Except for the third molars, this process covers a period that ends around 15 years of age [5,6]. Various techniques have been developed for CA estimation, including physical, mental, and radiographic methods or their combinations [7]. While the somatic development of children is affected by genetic, nutritional, and environmental factors, the teeth are affected relatively less by these conditions. Therefore, the development of primary and permanent teeth in children can be evaluated by various methods, especially radiographic methods, and dental age (DA) can be estimated [6]. Age estimation methods based on radiographs can be classified as those using an atlas, scoring system, or measurement-based formula [6,8–10].

The London Atlas (LA) includes diagrams representing tooth development and eruption stages starting from *in utero*. Since it was first introduced in 2010 by AlQahtani *et al.* [10], the LA has been adapted to different languages and made available on the web. Haavikko's method (HM), named after its principal creator [11] and derived from a panoramic radiograph evaluation of 885 Finnish children aged 2–13 years [12] was based on assessing one of 12 radiological stages of four permanent teeth in which different teeth were used for children aged under and above 10 years, respectively. This scoring-type method is of particular benefit in cases of tooth agenesis [13]. Cameriere's European

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formula (CF), established in 2007 by Cameriere *et al.* [14] using data from seven European countries, estimates the DA of children by measurement of apical apertures and tooth lengths. The formula, which is an improved version of the traditional Cameriere's formula [15], has been suggested for use in European children.

Although there are studies where different DA estimation methods are used in different populations and geographical regions, to the best of our knowledge, there is no study in which the LA, HM, and CF methods were evaluated together and comparatively. Therefore, the aim of this study was to compare the accuracy of the LA, HM, and CF methods for DA estimation in Turkish children living in northwestern Turkey. The null hypothesis tested was that LA, HM, and CF would predict the DA with the same accuracy.

## 2. Materials and methods

### 2.1. Study design, sample population and sampling criteria

This cross-sectional, retrospective study was approved by the Çanakkale Onsekiz Mart University, Faculty of Medicine, Clinical Research Ethical Committee (protocol no. 2021/04–11). The digital panoramic radiographs that were taken within the appropriate indication of Turkish children aged between 6.00 and 14.99 years living in northwestern Turkey were randomly selected. The digital panoramic radiographs were captured using a Planmeca Promax 2D (Planmeca Oy, Helsinki, Finland) with an exposure period of 14 s at 60–64 kV and 5 mA.

The evaluation of all panoramic radiographs complied with the UK National Radiological Protection Board criteria [16]. According to these criteria, Grade 1 radiographs are diagnostically excellent with no exposure/positioning/processing errors, Grade 2 radiographs are diagnostically acceptable with some minor exposure/positioning/processing errors, and Grade 3 radiographs are diagnostically unacceptable with major errors [16]. For this reason, Grade 1 and 2 radiographs, of which at least 70% [16] were Grade 1, were included in the study. Radiographs of patients with any developmental disease, syndrome, and/or anomaly, history of dental trauma and/or endodontic/orthodontic treatment, or presence of dental anomalies in their medical and dental records were excluded from the study. In addition, radiographs that showed jaw cysts and tumors, the presence of periodontal/endodontic lesions that may affect tooth development, and hypodontia/oligodontia in the mandible, except for third molars, in the radiological evaluation were also excluded from the study.

### 2.2. Chronological age calculation and dental age estimation

The patients' CA was determined using the decimal system and the equation ''[(the date when the panoramic radiograph was obtained) – (the documented birth date)] / 365.25″ in Microsoft Excel 2013 (Microsoft, Redmond, WA, USA).

Three different methods for DA estimation were assessed, including one atlas (LA), one scoring (HM), and one measurement-based formula (CF) method. In the LA, the observer chose the closest reference image to the patient's panoramic radiograph. According to the LA, the root resorption of primary teeth and their position in the jaws are evaluated along with the root and crown formation and mineralization of permanent teeth and compared with the existing panoramic radiographs [10]. In the HM, teeth 47, 46, (16), 44, and 41 in individuals with a CA up to 10 years, and teeth 47, 44, 13, and 43 in individuals with a CA of over 10 years were analyzed according to the mineralization stage. After that, the estimated mean age for the tooth was positioned in the table previously created by Haavikko [11]. Finally, the values obtained from each evaluated tooth were summed and divided by the number of permanent teeth, resulting in a mean of DA. When using the CF, seven teeth in the left mandibular quadrant are evaluated by measuring their apical openings and tooth lengths. The DA of the individual is determined by placing the measurements and other variables into the formula [14]. Radiographic images were transferred to ImageJ 1.49v software (U.S. National Institutes of Health, Bethesda, Maryland, USA) for measurements. The distance between the inner surfaces of the apical opening was measured in teeth with one root ($A_i$, $i = 1, \ldots, 5$). The values obtained by measuring each apical opening in molar teeth ($A_i$, $i = 6, 7$) were summed. To eliminate possible angulation and magnification errors from the radiograph, the measurements are divided by tooth length ($L_i$, $i = 1, \ldots, 7$). The number of teeth with completed root development ($N_0$), the value obtained by dividing the distance between the inner surfaces of the apical opening of the second premolar tooth by the tooth length ($x_5$), the sum of all $A_i/L_i$ ratios ($s$), and the sex coefficient ($g$) are inserted into the formula: $DA = 8.387 + 0.282.g - 1.692.x_5 + 0.835.N_0 - 0.116.s - 0.139.s.N_0$

### 2.3. Reproducibility of measurements

Two experienced and well-trained pediatric dentists (BS, BÇ) evaluated the panoramic radiographs by the three different DA estimation methods. Before beginning the study, 150 randomly selected radiographs were evaluated twice at different times by each examiner to calibrate the methods and examiners. In addition, 80 radiographs randomly selected 1 month after the initial evaluation were assessed by both examiners twice, 2 weeks apart. The interclass correlation coefficient (ICC) was used to determine the inter-and intra-examiner agreements.

### 2.4. Statistical analyses

The data acquired from all DA estimation methods were analyzed independently and collectively for each sex and age group. After checking the normality assumption of the data by the Kolmogorov – Smirnov and Shapiro – Wilk tests, data with normal distribution were evaluated by the paired *t*-test, and data without normal distribution were evaluated by the Wilcoxon signed-rank test. For each sex and age group, the mean difference between CA and DA was computed. The lack of bias, mean or median absolute difference, and a high percentage of age within six months are all approaches to assess the quality of a DA estimation technique [17]. Liversidge *et al.* [18] stated that the most important is the lack of error including the smallest mean absolute error (MAE). Therefore, the LA, HM, and CF accuracies were determined using the MAE. Spearman's rank correlation coefficient was used to investigate the correlation between CA and DA for both sexes in the three DA estimation methods. The IBM Statistical Package for Social Sciences (SPSS) version 20.0 (IBM Corp., Chicago, IL, USA) software was used for all statistical analyses, and statistical significance was set at $p < 0.05$ for all the tests.

## 3. Results

The inter-and intra-examiner agreements had ICC values of 0.94 and 0.98, respectively. There was no statistically significant difference, and the values were considered to be exceptionally good and dependable.

A total of 1080 digital panoramic radiographs of Turkish children living in northwestern Turkey were evaluated in terms of meeting the inclusion criteria. Radiographs were excluded that belonged to a child with systemic disease and/or syndrome ($n = 7$), showed the presence of a periapical lesion on index teeth ($n = 33$), and indicated index tooth loss for any reason ($n = 19$). Of the 1,021 radiographs that remained, a further 41 were excluded because they were Grade 3 quality. As a result, 980 panoramic radiographs were evaluated for DA estimation.

Table 1 shows the distribution of panoramic radiographs by the age groups and sex and the mean and standard deviations of the CA, DA, DA – CA, MAE, and *p*-values for the DA estimation calculated by each method. While the LA underestimated the CA of boys aged 6, 7, 9, 13, and 14 (−0.16, −0.11, −0.15, −0.08, and −0.21, respectively), it

**Table 1**
Distribution and percentage of the sample size according to age groups and sexes, and comparison of dental age and chronological age according to the London Atlas, Haavikko's method, and Cameriere's European formula among both sexes.

| Age | Boys N(%) | CA mean (SD) | Method | Mean (SD) DA | DA-CA | MAE | *p*-value | Girls N(%) | CA mean (SD) | Method | Mean (SD) DA | DA-CA | MAE | *p*-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **6–6.99** | 45 (4.59) | 6.48 (0.27) | **LA** | 6.32 (0.58) | − 0.16 (0.51) | 0.41 (0.4) | **0.038** | 65 (6.63) | 6.43 (0.32) | **LA** | 6.42 (0.44) | 0 (0.44) | 0.26 (0.36) | 0.930 |
| | | | **HM** | 6.67 (0.52) | 0.18 (0.44) | 0.43 (0.29) | **0.007** | | | **HM** | 6.45 (0.51) | 0.03 (0.38) | 0.4 (0.31) | 0.591 |
| | | | **CF** | 7.57 (0.17) | 1.09 (0.27) | 0.14 (0.1) | **<0.001** | | | **CF** | 7.35 (0.14) | 0.92 (0.29) | 0.1 (0.09) | **<0.001** |
| **7–7.99** | 68 (6.94) | 7.36 (0.26) | **LA** | 7.25 (0.68) | − 0.11 (0.58) | 0.56 (0.38) | 0.133 | 67 (6.84) | 7.47 (0.28) | **LA** | 7.59 (0.77) | 0.12 (0.68) | 0.5 (0.59) | 0.160 |
| | | | **HM** | 7.27 (0.39) | − 0.08 (0.37) | 0.27 (0.28) | 0.069 | | | **HM** | 7.2 (0.39) | − 0.27 (0.37) | 0.25 (0.3) | **<0.001** |
| | | | **CF** | 7.7 (0.16) | 0.35 (0.27) | 0.12 (0.1) | **<0.001** | | | **CF** | 7.51 (0.21) | 0.03 (0.28) | 0.16 (0.14) | 0.335 |
| **8–8.99** | 64 (6.53) | 8.47 (0.3) | **LA** | 8.66 (0.51) | 0.18 (0.53) | 0.37 (0.35) | **0.008** | 59 (6.02) | 8.43 (0.26) | **LA** | 8.79 (0.62) | 0.36 (0.65) | 0.51 (0.35) | **<0.001** |
| | | | **HM** | 8.11 (0.57) | − 0.36 (0.52) | 0.46 (0.34) | **<0.001** | | | **HM** | 8.05 (0.59) | − 0.38 (0.5) | 0.48 (0.34) | **<0.001** |
| | | | **CF** | 8.54 (0.68) | 0.07 (0.59) | 0.54 (0.41) | 0.378 | | | **CF** | 8.6 (0.73) | 0.17 (0.61) | 0.58 (0.44) | **0.037** |
| **9–9.99** | 49 (5.00) | 9.53 (0.29) | **LA** | 9.38 (0.48) | − 0.15 (0.36) | 0.32 (0.36) | **0.006** | 45 (4.59) | 9.52 (0.31) | **LA** | 9.63 (0.94) | 0.11 (0.8) | 0.66 (0.67) | 0.360 |
| | | | **HM** | 9.04 (0.71) | − 0.48 (0.67) | 0.59 (0.37) | **<0.001** | | | **HM** | 8.93 (0.55) | − 0.6 (0.56) | 0.43 (0.33) | **<0.001** |
| | | | **CF** | 9.98 (0.57) | 0.46 (0.53) | 0.48 (0.3) | **<0.001** | | | **CF** | 9.84 (0.55) | 0.32 (0.61) | 0.44 (0.33) | **0.001** |
| **10–10.99** | 69 (7.04) | 10.51 (0.28) | **LA** | 10.79 (0.69) | 0.28 (0.56) | 0.6 (0.35) | **<0.001** | 68 (6.94) | 10.46 (0.28) | **LA** | 10.85 (0.66) | 0.39 (0.66) | 0.58 (0.31) | **<0.001** |
| | | | **HM** | 11.06 (0.55) | 0.55 (0.47) | 0.43 (0.33) | **<0.001** | | | **HM** | 10.34 (0.36) | − 0.12 (0.43) | 0.29 (0.22) | **0.027** |
| | | | **CF** | 10.45 (0.28) | − 0.06 (0.32) | 0.19 (0.2) | 0.154 | | | **CF** | 10.23 (0.44) | − 0.23 (0.49) | 0.2 (0.39) | **<0.001** |
| **11–11.99** | 62 (6.33) | 11.44 (0.29) | **LA** | 11.65 (0.44) | 0.2 (0.4) | 0.31 (0.31) | **<0.001** | 55 (5.61) | 11.47 (0.27) | **LA** | 11.66 (0.42) | 0.2 (0.45) | 0.3 (0.29) | **0.002** |
| | | | **HM** | 11.62 (0.48) | 0.17 (0.45) | 0.34 (0.33) | **0.003** | | | **HM** | 10.91 (0.31) | − 0.55 (0.36) | 0.27 (0.15) | **<0.001** |
| | | | **CF** | 10.93 (0.59) | − 0.51 (0.55) | 0.4 (0.42) | **<0.001** | | | **CF** | 10.97 (0.61) | − 0.5 (0.59) | 0.52 (0.3) | **<0.001** |
| **12–12.99** | 55 (5.61) | 12.52 (0.3) | **LA** | 12.59 (0.48) | 0.07 (0.46) | 0.26 (0.4) | 0.256 | 39 (3.98) | 12.42 (0.31) | **LA** | 12.45 (0.65) | 0.03 (0.55) | 0.44 (0.47) | 0.752 |
| | | | **HM** | 12.03 (0.3) | − 0.49 (0.34) | 0.23 (0.2) | **<0.001** | | | **HM** | 11.13 (0.24) | − 1.29 (0.33) | 0.2 (0.15) | **<0.001** |
| | | | **CF** | 11.62 (0.87) | − 0.9 (0.85) | 0.73 (0.46) | **<0.001** | | | **CF** | 11.86 (1.07) | − 0.57 (0.94) | 0.92 (0.53) | **0.001** |
| **13–13.99** | 72 (7.35) | 13.48 (0.28) | **LA** | 13.4 (0.56) | − 0.08 (0.58) | 0.36 (0.43) | 0.235 | 63 (6.43) | 13.52 (0.29) | **LA** | 13.56 (0.44) | 0.05 (0.41) | 0.24 (0.37) | 0.357 |
| | | | **HM** | 12.19 (0.27) | − 1.29 (0.35) | 0.25 (0.24) | **<0.001** | | | **HM** | 11.35 (0.21) | − 2.16 (0.36) | 0.12 (0.18) | **<0.001** |
| | | | **CF** | 12.42 (1.11) | − 1.07 (1.07) | 0.97 (0.54) | **<0.001** | | | **CF** | 12.86 (0.9) | − 0.66 (0.83) | 0.74 (0.5) | **<0.001** |
| **14–14.99** | 19 (1.94) | 14.24 (0.18) | **LA** | 14.03 (0.51) | − 0.21 (0.6) | 0.5 (0.03) | 0.142 | 16 (1.63) | 14.2 (0.19) | **LA** | 13.94 (0.51) | − 0.26 (0.47) | 0.49 (0.06) | **0.044** |
| | | | **HM** | 12.45 (0.26) | − 1.78 (0.27) | 0.22 (0.13) | **<0.001** | | | **HM** | 11.5 (0.26) | − 2.7 (0.32) | 0.24 (0.1) | **<0.001** |
| | | | **CF** | 13.63 (0.66) | − 0.6 (0.61) | 0.39 (0.53) | **<0.001** | | | **CF** | 13.31 (0.82) | − 0.89 (0.79) | 0.63 (0.5) | **<0.001** |

N: Number; SD: Standard Deviation; CA: Chronological Age; DA: Dental Age; MAE: Mean Absolute Error; LA: London Atlas; HM: Haavikko's Method; CF: Cameriere's European Formula.Bold values mean statistically significant ($p < 0.05$).

underestimated only the CA of 14 for girls (−0.26). For the HM, there was an overestimation of CA for age groups 6, 10, and 11 in boys (0.18, 0.55, and 0.17, respectively) and the 6-year-old group in girls (0.03), but an underestimation of all other age groups in both sexes. For the CF, an overestimation was observed in the 6.00–9.99 age range in boys (1.09, 0.35, 0.07, and 0.46, respectively) and girls (0.92, 0.03, 0.17, and 0.32, respectively), and an underestimation in the 10.00–14.99 age range.

In the total sample (Table 2), the mean difference between the DA and CA was significant in all DA estimation methods, except for the LA in boys ($p = 0.189$). When girls, boys, and the total sample group were evaluated, the HM with the lowest MAE was revealed as statistically significant in all three groups (MAE mean: 0.36 for boys, 0.3 for girls, and 0.33 for the total sample; all $p$-values $< 0.001$).

For both the sex and total study sample, the Spearman correlation coefficient test was performed to analyze the DA − CA. As shown in Table 3, all DA estimation methods had a good linear correlation (range from 0.953 to 0.979), which was statistically significant ($p < 0.001$). Fig. 1 illustrates the DA − CA relationship and the various DA estimation methods in boys and girls of all age groups.

**Table 2**
Comparison of dental age and chronological age for different dental age estimation methods in boys, girls, and the total sample

| Sex | CA mean (SD) | Method | DA mean (SD) | DA-CA mean (SD) | MAE mean (SD) | *p*-value |
|---|---|---|---|---|---|---|
| **Boys** | 10.27 (2.41) | **LA** | 10.3 (2.48) | 0.03 (0.54) | 0.41 (0.33) | 0.189 |
| | | **HM** | 9.97 (2.15) | − 0.3 (0.77) | 0.36 (0.28) | **<0.001** |
| | | **CF** | 10.12 (1.92) | − 0.15 (0.9) | 0.44 (0.34) | **<0.001** |
| **Girls** | 9.96 (2.46) | **LA** | 10.11 (2.5) | 0.15 (0.6) | 0.44 (0.39) | **<0.001** |
| | | **HM** | 9.26 (1.88) | − 0.7 (0.88) | 0.30 (0.23) | **<0.001** |
| | | **CF** | 9.89 (2.08) | − 0.07 (0.79) | 0.48 (0.36) | **0.050** |
| **Total** | 10.12 (2.43) | **LA** | 10.21 (2.49) | 0.09 (0.57) | 0.43 (0.36) | **<0.001** |
| | | **HM** | 9.62 (2.05) | − 0.49 (0.85) | 0.33 (0.26) | **<0.001** |
| | | **CF** | 10.01 (2) | − 0.11 (0.85) | 0.46 (0.35) | **<0.001** |

SD: Standard Deviation; CA: Chronolocigal Age; DA: Dental Age; MAE: Mean Absolute Error; LA: London Atlas; HM: Haavikko's Method; CF: Cameriere's European Formula.
Bold values mean statistically significant ($p < 0.05$).

**Table 3**
Correlation between dental age and chronological age according to Spearman's correlation test for different dental age estimation methods in boys, girls, and the total sample.

| Method | r/p values | Sex | | |
|---|---|---|---|---|
| | | Boys | Girls | Total |
| **London Atlas** | **r-values** | 0.979 | 0.971 | 0.975 |
| | ***p*-values** | **<0.001** | **<0.001** | **<0.001** |
| **Haavikko's Method** | **r-values** | 0.960 | 0.968 | 0.964 |
| | ***p*-values** | **<0.001** | **<0.001** | **<0.001** |
| **Cameriere's European Formula** | **r-values** | 0.953 | 0.962 | 0.956 |
| | ***p*-values** | **<0.001** | **<0.001** | **<0.001** |

r-value: Spearman's rank correlation coefficient.
Bold values mean statistically significant ($p < 0.05$).

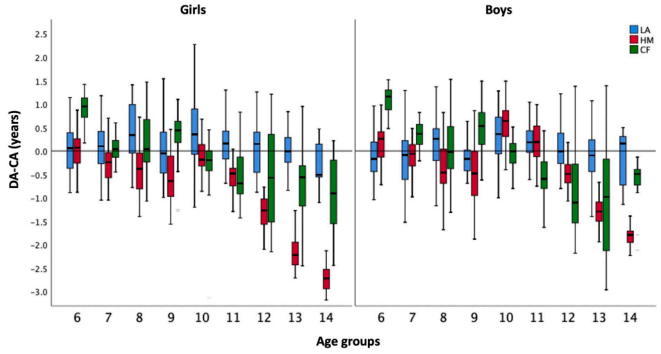



**Fig. 1.** The relationship between the dental age and chronological age, and the various dental age estimation methods in girls and boys *(DA: Dental Age; CA: Chronological Age; LA: London Atlas; HM: Haavikko's Method; CF: Cameriere's European Formula)*.

## 4. Discussion

In forensic dentistry, teeth can be used to estimate age. DA estimation also provides important information for diagnosis and treatment planning, especially for pediatric dentists and orthodontists. Different morphological, clinical, and radiographic techniques are used in estimating DA [19,20]. Radiographic approaches are the most frequently used among these methods because they are simple, reproducible, and reliable [20]. Although the Demirjian method is the most known and used radiographic method for DA estimation, many studies have shown it is inaccurate in some geographical regions and populations [19,21–23]. For this reason, many different radiographic DA estimation methods have been developed to accurately determine the CA of individuals of different races living in different countries. Current radiographic approaches include visual assessment, metric measurement, or scoring systems. The three methods adopted in this study were the LA in which visual evaluation is compared with the images of primary and permanent teeth of individuals of different ages; the HM in which the developmental stages of different teeth are scored; and the CF, a measurement-based approach in which the ratio of the distance between the apical openings of the teeth with an open apex to the length of the tooth is calculated.

In both criminal and civil law, it is critical to accurately assess an individual's age for legal reasons but also for other purposes, such as enrolling in school, getting married, recruiting, joining the army, and retirement. In the DA estimation methods used for this purpose, the obtained DA is evaluated as overestimated or underestimated according to the CA of the individual. The main parameter used in evaluating the success of a DA estimation method is that the MAE value is close to zero because the mean difference between DA and CA indicates bias, while the MAE between DA and CA is calculated to express accuracy regardless of bias [24,25]. When evaluated from this perspective, HM generated the lowest MAE value among the three methods tested in the boys (0.36 ± 0.28), girls (0.30 ± 0.23) and the total sample of the current study (0.33 ± 0.26), followed by the LA and CF, respectively (Table 2). When evaluated on the basis of age groups, HM was found to be successful, especially in the 12.00–14.99 age range for boys and 11.00–14.99 age range for girls (Table 1). The CF for the 6.00–7.99 age range in boys and girls, and the LA for the 8.00–9.99 age range in boys had the lowest MAE values (Table 1). While HM was determined as the most accurate method in the entire sample group included in the study, the CF was revealed to be the least accurate method.

HM has been used in many countries and populations since it was first introduced as a DA estimation method by Kaarina Haavikko in 1974 when evaluating panoramic radiographs for the development and eruption of teeth. Kırzıoğlu *et al.* [26] commented that HM was more accurate than the Nolla and Demirjian methods used on panoramic radiographs of 425 Turkish children. When the same researcher evaluated the same methods in a patient group with amelogenesis imperfecta, HM was also an acceptable method [20]. According to the radiographic findings of Wang *et al.* [27], HM had a high degree of accuracy and precision in estimating the age of 613 Chinese children. In an evaluation of the Demirjian, Nolla, Haavikko's, and Willems radiographic methods on 946 Bangladeshi and British Caucasian children, HM was found to be more accurate for individual teeth, first premolar teeth, and second molar teeth [28]. Considering the advantages of HM, especially in individuals with hypodontia/oligodontia, accuracy in reference teeth is of great importance [13]. However, in some studies comparing different populations and different DA estimation methods, accuracy was found to be lower for HM than other methods [29–31].

As indicated above, the LA, which was introduced more recently than the other two methods used in this study, ranked second for accuracy, based on the MAE values. Sousa *et al.* [32] reported that LA showed good evaluation performance in Brazilian children. In a study by Ghafari *et al.* [33], in which the LA and Smith methods were compared in Iranian

children, both methods had similar accuracies, but the LA was considered easier to apply. The result that the LA overestimated age for children of different sexes and the whole sample group in current study (0.03 for boys, 0.15 for girls, and 0.09 for the total sample) coincides with the findings of some previous studies [34,35].

As mentioned above, the CF was the least accurate among the three methods for estimating DA in current study. The original CF was proposed to be adaptable according to geographic region, race, and population [14]. Subsequent studies have tested and validated the applicability of this method in various subjects from a range of countries [36,37]. Although the accuracy of the CF method in DA estimation has been reported in Turkey [38], the current study results show that the formula can be modified for the northwestern Turkish population.

This study is the first to compare the LA, HM, and CF methods. Therefore, the results should be evaluated carefully. The limitation of the study was that the sample included patients from a certain location. Furthermore, dietary, socioeconomic, sociocultural, and environmental variables can impact the development of children in different geographical regions [39].

In this study, the DA estimates of children living in northwestern Turkey were found to be more accurate when evaluated by HM than by the LA and CF methods for both sexes and in the total sample group. Therefore, the null hypothesis of the study, which tested that the accuracy of the LA, HM, and CF was the same for all three methods, was rejected. Considering the importance of DA estimation in legal, forensic, and dental sciences, more studies using different methods in different races, populations, and geographical regions will pave the way for scientific progress in this area.

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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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