Clinical Oral Investigations (2022) 26:5773–5784
https://doi.org/10.1007/s00784-022-04534-6

ORIGINAL ARTICLE

Dental age estimation with fewer than mandibular seven teeth: An accuracy study of Bedek models in Turkish children

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Received: 30 November 2021 / Accepted: 3 May 2022 / Published online: 13 May 2022
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Abstract

Objectives One or more missing teeth, such as hypodontia, make it difficult to obtain accurate results in age estimation methods. This paper aims to test the accuracy of the models developed by Bedek et al. that can estimate age with fewer than seven teeth for Turkish children.

Materials and methods Panoramic radiographs of 1118 children (540 girls and 578 boys) aged between 6 and 16 years were evaluated using the Willems method and Bedek models for the entire sample and for different ages and sexes. Differences between dental age (DA) and chronological age (CA) calculated for all methods for each sex and all age groups were analyzed the paired sample *t*-test and Wilcoxon signed rank test. The accuracy of the DA estimation methods was determined by the proximity of DA to CA by calculating mean absolute error (MAE).

Results While all Bedek models underestimated CA by 0.2 to 0.1 years, the Willems method overestimated CA by 0.3 years. DA-CA difference in the total sample and girls was statistically significant in all methods. In the total sample, the seven- and four-teeth models had the lowest MAE, while the one-tooth model had the highest MAE.

Conclusions Seven- and four-teeth models were the most suitable for age estimation, and all models except the one-tooth model were found to be more accurate than the Willems method in northwestern Turkish children.

Clinical relevance Especially in children with hypodontia, it may be possible to estimate DA with the use of Bedek models.

Keywords Age estimation · Bedek models · Dental age · Panoramic radiographs · Willems method

Introduction

Estimation of dental age (DA) can provide additional information in determining the identity of a deceased individual and is becoming increasingly important for living individuals in judicial cases such as criminal liability or illegal immigration [1]. Moreover, DA estimation is used in treatment planning in pediatric dentistry, orthodontics, orthopedics, and pediatric endocrinology [2]. The development of the individual with chronological age (CA) may not always be consistent. DA is thought to reliably predict CA because dental tissues are less affected by local, systemic, and hormonal variables than other tissues [3]. Therefore, one of the most convenient methods of determining age is considered to be the assessment of the stages of tooth development [4]. Most methods developed for DA estimation evaluate tooth development stages radiographically [5]. Demirjian's method, which uses tooth calcification stages, is accepted as the oldest and most commonly used radiographical method for estimating DA [6]. In this method, seven left mandibular permanent teeth (from central incisor to second left permanent molar) are evaluated in eight developmental stages (A to H). Studies showed that Demirjian's method overestimated CA in different populations, except French Canadians [7, 8]. Due to the low accuracy of Demirjian's method in different populations, Willems et al. [9] created new score tables and removed the conversion of maturity score to DA, making its use more practical. According to a meta-analysis [10] of the use of the Willems method in DA estimation, predicted DA by approximately 6 months (−0.04 and −0.02 years) more accurately than the Demirjian's method.

Despite the validity of the Willems method in different populations and geographic regions, and its relatively simple and easy-to-apply system, the most important disadvantage

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of the method is that it cannot be used in the case of missing one or more teeth due to hypodontia or incomplete human remains in the mandible. For this reason, with the idea that a more precise identification method should be established, Bedek et al. [11] developed new models for new DA prediction based on combinations of one to seven mandibular teeth as a result of their regression analyzes, in 2019. When seven different models developed by Bedek et al. [11] with different tooth combinations were compared with the Willems method, it was stated that the new models measured age more accurately. In addition, new models such as the Willems method were simple and practical to use. It is known that the Willems method is suitable for age estimation in the Turkish population [12–17]. However, as far as we know, the accuracy of the new DA estimation models developed by Bedek et al. [11] has been tested only in South Indian children [18], and there is no study in the literature about the use in the Turkish population. Therefore, the aim of the study was to test the accuracy of Bedek models in DA estimation in northwestern Turkish children and to compare their accuracies with the Willems method. The first null hypothesis tested was that the Willems method and all Bedek models would predict DA with the same accuracy.

Material and methods

Study design and samples

Ethical approval for this study was provided by the Çanakkale Onsekiz Mart University, School of Medicine, Clinical Research Ethic Board (Protocol no. 18920478–050.01.04–2100054264), and the study was conducted in accordance with all the principles stated in the Declaration of Helsinki. Panoramic radiographs taken for radiological diagnostics between 2018 and 2020 were randomly selected for the study. Radiographs were obtained with Promax 2D (Planmeca Oy, Helsinki, Finland, 60–64 kV, 5 mA, and 14 s exposure period). The UK National Radiological Protection Board (NRPB) criteria [19] describe three grades of radiograph quality based on the clinical value of the image. They assign the grades as excellent, diagnostically acceptable, and unacceptable. Accordingly, grade 1 radiographs, defined as excellent, describe radiographs that do not contain errors in patient preparation, positioning, exposure, rendering, or film processing. Accordingly, in our study, only grade 1 radiographs were evaluated in order to maximize the evaluation accuracy. In addition, the presence of all teeth on the left side of the lower jaw except third molars was also among the inclusion criteria. Children who had a systemic disease or syndrome that affects hard tissue metabolism; missing, excess, or deep caries in the teeth; with pathological lesions such as cysts or tumors in the mandible; previous dental trauma; and children who received endodontic and/or orthodontic treatment or had dental anomalies were not included in the study. Children's CAs were calculated according to the difference between the date of radiology and the day they were born using the decimal system. The sexes of the children were recorded along with their CAs.

Sample size calculation

G*Power 3.0.10 statistical software (v.3.1.9.7, Universitat Kiel, Kiel, Germany) was used to calculate sample size. Based on the data from Sheriff et al. [18], which showed that the DA-CA values of the Willems method were 12.1 ± 2.6 compared to the Bedek one-tooth model which was 11.3 ± 2.6 in the 7–15 age range in boys, a sample size of 790 was calculated to be enough to achieve power of 98% with a significance level (α) set at 0.01.

Dental age estimation

In all panoramic radiographs, seven left mandibular permanent teeth (from central incisor to second left permanent molar) were scored from A to H according to the developmental stages of the Demirjian method [6]. The developmental stages of teeth according to the Demirjian method are described in Fig. 1.

According to the Willems method, the DA was calculated by summing the scores given for the developmental stage of each tooth (from A to H according to the developmental stages of the Demirjian method) in the sex-specific tables [9]. In the Bedek models, seven different DA estimation methods were developed for each sex, the coefficients of which vary according to the tooth combination [11]. Data obtained in DA estimation studies should be analyzed using appropriate statistical methods [2]. In this context, regression formulas, which suggest that the standard error of the sample group can be used to determine the accuracy of the method, are the most frequently used statistical analysis form in DA estimation studies [2, 20, 21]. Bedek et al. [11] used univariate regression analysis for age estimation based on a single tooth, followed by forward and backward elimination regression analysis to select the best combination for models applied to 2–6 teeth. As a result, it has been determined which teeth will be used in the DA estimation method in different sexes from 1-tooth model to 7-teeth model. DA was obtained by calculating the intercept value generated for each model and the sum of the coefficients assigned to the sex-specific tooth development stages (from A to H according to the developmental stages of the Demirjian method)

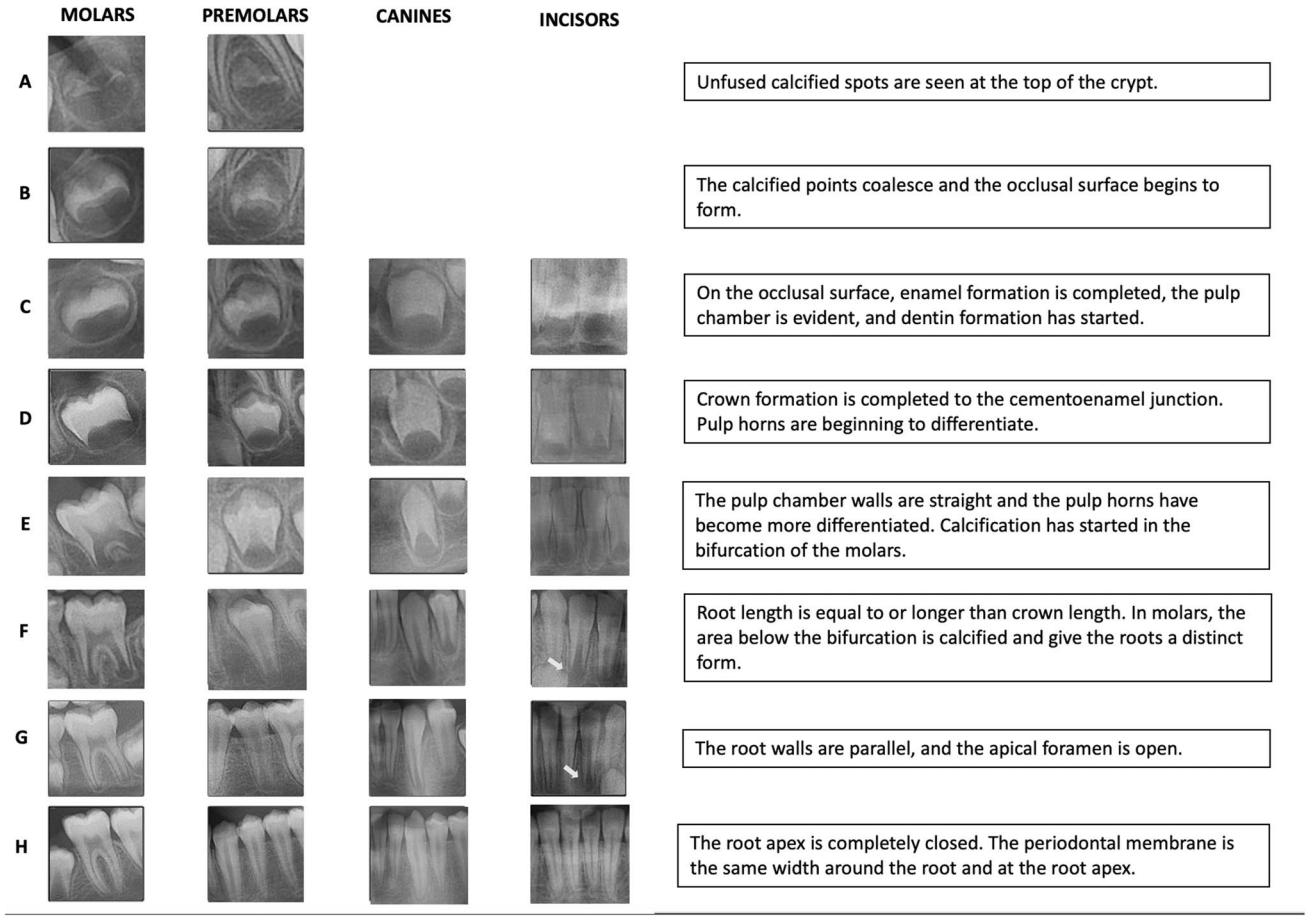


Fig. 1 Radiographic representation of the eight stages of tooth development of the Demirjian classification

Table 1 The intercept values and the combination of the left mandibular teeth of the Bedek models for both sexes

Sex	Bedek models	Intercept value	Combination of mandibular teeth[†]
Boy	Seven-teeth model	4.396	31 32 33 34 35 36 37
	Six-teeth model	4.544	31 33 34 35 36 37
	Five-teeth model	4.664	31 33 34 36 37
	Four-teeth model	5.451	31 33 34 37
	Three-teeth model	6.069	33 34 37
	Two-teeth model	5.370	34 37
	One-tooth model	5.828	34
Girl	Seven-teeth model	5.095	31 32 33 34 35 36 37
	Six-teeth model	5.077	32 33 34 35 36 37
	Five-teeth model	5.079	32 33 34 36 37
	Four-teeth model	5.112	32 33 34 37
	Three-teeth model	5.350	32 34 37
	Two-teeth model	5.350	34 37
	One-tooth model	5.771	37

[†]FDI notation system

in the model. Table 1 presents the intercept values and the combination of the left mandibular teeth of the Bedek models for both sexes.

Before evaluating all panoramic radiographs, researchers (B.Ç. and B.S.) were calibrated according to the Demirjian method using 150 randomly selected radiographs, blinded for CA and sex information. To avoid researcher bias, all radiographs were counterchecked by an experienced and independent dentist after an interval of 2 weeks.

After four weeks, intra- and inter-observer agreement tests were performed to assess the reproducibility of DA estimation methods. Eighty randomly selected radiographs were re-evaluated and the intraclass correlation coefficient (ICC) between both measurements was calculated.

Statistical analysis

The data was analyzed by SPSS version 20.0 (IBM Corp., Chicago, IL, USA) separately and collectively for each sex and age group. To test for normality, the Kolmogorov–Smirnov test was used, and data with a normal

distribution were assessed using the paired *t*-test, while data with a non-normal distribution were assessed using the Wilcoxon signed-rank test. *p* values less than 0.05 were accepted as the significant level in all evaluations. The mean of the difference between DA and CA calculated in all methods for each sex and all age groups showed over– or underestimation. The proximity of DA to CA, percentages of accuracy for absolute difference values, and mean absolute error (MAE) are used to determine the accuracy of DA estimation methods [22]. MAE is an effective factor in determining the accuracy of DA estimation methods. A lower MAE indicates that the method is more accurate [23]. Therefore, in this study, the accuracy of the DA estimation method was determined by the proximity of DA to CA by calculating MAE. In all methods, the relationship between DA and CA for both sexes and the total sample was analyzed using the Pearson correlation coefficient. The absolute value of DA-CA and the percentage of DA relative to CA were calculated to determine the accuracy of all methods over a 1-year period.

Results

Intra-observer Kappa values for all DA estimation methods ranged from 0.93 to 0.97, and inter-observer Kappa values ranged from 0.81 to 0.86. For the Willems method, seven-teeth model, six-teeth model, five-teeth model, four-teeth model, three-teeth model, two-teeth model, and one-tooth model of Bedek; the intra-observer ICC values were found to be 0.97, 0.94, 0.99, 0.96, 0.94, 0.98, 0.94, and 0.93, respectively. The inter-observer ICC values were found to be 0.86, 0.87, 0.86, 0.88, 0.89, 0.87, 0.85, and 0.85, respectively. All measurements were considered to be good correlated and reliable.

The study included 1277 panoramic radiographs obtained from northwestern Turkish children, aged between 6 and 15.9 years. Forty-five of the total panoramic radiographs were excluded because they were not of grade 1 quality. Radiographs of 22 children with congenital missing teeth on the left side of the lower jaw, 15 children with systemic disease or syndrome, 36 children with tooth loss, 8 children with pathological lesions in the mandible, and 33 children with dental trauma and orthodontic and/or endodontic history were excluded from the study. A total of 1118 (540 girls and 578 boys) panoramic radiographs were included in the study for DA estimation.

In the total sample, all models of Bedek underestimated age (0.2 to 0.1 years), but Willems method overestimated age (0.3 years). The MAE was 0.6 years for Willems method in both sexes, while it was the smallest MAE for seven- and six-teeth models (0.5 years) for boys and four-teeth model for girls (0.5 years). It was found to be the greatest MAE for two-teeth model for boys and the one-tooth model for girls (0.7 years). MAE was less than 1 in both sexes and in the total sample, Willems method and all models of Bedek (Table 2).

DA-CA difference in total sample and girls was statistically significant in all methods. In boys, the DA-CA difference was significant in one- and two-teeth models and Willems method. In the total sample, the smallest difference was shown by one-tooth model (-0.1 ± 1.1 years), the greatest difference by Willems method (0.3 ± 0.8 years). In boys, the smallest difference was shown by three-teeth model (0 ± 0.9 years), the greatest difference by Willems method (0.4 ± 0.7 years). In girls, the smallest difference was shown by three-teeth model (-0.1 ± 0.9 years), the greatest difference by one-tooth model (-0.3 ± 0.7 years). In all Bedek models, except for the one-tooth model in boys, the CA was underestimated (Table 2).

In boys, Willems method overestimated age at all ages, but underestimated age at only 13 years (-0.1 ± 0.9 years). For all models of Bedek, CA was overestimated at the ages of 6, 8, 9, 10, and 11 years, and underestimated the age range from 13 to 15.9 years (Table 3).

In girls, Willems method underestimated the age range from 14 to 15.9 years and overestimated the age range from 6 to 13.9 years. The age range for all models of the Bedek is underestimated, from 12 to 15.9 years. Between the ages of 8 and 10.9, all the Bedek models overestimated the age, while only one-tooth model underestimated age (Table 4).

Pearson correlation analysis was used in all DA methods to show the relationship between DA and CA in both sexes and the entire sample. The results showed that good linear correlations (between 0.921 and 0.969) were statistically significant for all methods ($p < 0.001$) (Table 5).

Accuracy percentages were calculated for the absolute difference values for the methods. Among the Bedek models, better accuracy percentages in the total sample within ± 1 year were found to be 80.6% in the seven-teeth model for boys, 79.1% in the four–teeth model for girls, and 79.7% in the seven-teeth model for total sample. The lowest accuracy percentages were found in the one-tooth model in both sexes and the total sample (around 61%) (Table 6).

Discussion

The validity and reliability of DA estimation methods may decrease in years. Insufficient results in age estimation revealed the necessity of revising the Demirjian method, and the Willems method was developed. In a meta-analysis [24], it was stated that Willems method is suitable for DA estimation, with the method overestimated age in different populations (0.26 and 0.29 years for boys and girls, respectively). It has been stated that studies conducted in the Turkish population have also shown similar results [12–16]. In

Table 2 Comparison of Willems method and Bedek models dental age and chronological age in total sample

Sex	N	CA Mean (SD)	Method	DA	DA-CA Mean (SD)	MAE	*p* value
Boy	578	11.1 (2.8)	Willems	11.4 (2.8)	0.4 (0.7)	0.6 (0.5)	**< 0.001**
			Seven-teeth model	11 (2.5)	0 (0.8)	0.5 (0.4)	0.500
			Six-teeth model	11.1 (2.5)	0 (0.8)	0.5 (0.4)	0.743
			Five-teeth model	11 (2.6)	− 0.1 (0.8)	0.5 (0.4)	0.071
			Four-teeth model	11 (2.5)	0 (0.9)	0.5 (0.4)	0.612
			Three-teeth model	11.1 (2.5)	0 (0.9)	0.6 (0.4)	0.996
			Two-teeth model	10.9 (2.6)	− 0.2 (1.1)	0.7 (0.5)	**< 0.001**
			One-tooth model	11.2 (2.4)	0.2 (1.1)	0.6 (0.3)	**0.001**
Girl	540	10.8 (3)	Willems	10.9 (3)	0.1 (0.8)	0.6 (0.4)	**< 0.001**
			Seven-teeth model	10.7 (2.6)	− 0.2 (0.8)	0.6 (0.4)	**< 0.001**
			Six-teeth model	10.6 (2.7)	− 0.2 (0.8)	0.6 (0.4)	**< 0.001**
			Five-teeth model	10.6 (2.7)	− 0.3 (0.8)	0.6 (0.4)	**< 0.001**
			Four-teeth model	10.7 (2.6)	− 0.1 (0.8)	0.5 (0.4)	**< 0.001**
			Three-teeth model	10.6 (2.7)	− 0.2 (0.8)	0.6 (0.4)	**< 0.001**
			Two-teeth model	10.7 (2.6)	− 0.1 (0.9)	0.6 (0.4)	**0.001**
			One-tooth model	10.5 (2.7)	− 0.3 (1.1)	0.7 (0.5)	**< 0.001**
Total	1118	10.9 (2.9)	Willems	11.2 (2.9)	0.3 (0.8)	0.6 (0.4)	**< 0.001**
			Seven-teeth model	10.9 (2.6)	− 0.1 (0.8)	0.5 (0.4)	**< 0.001**
			Six-teeth model	10.8 (2.6)	− 0.1 (0.8)	0.5 (0.4)	**< 0.001**
			Five-teeth model	10.8 (2.6)	− 0.2 (0.8)	0.6 (0.4)	**< 0.001**
			Four-teeth model	10.9 (2.6)	− 0.1 (0.9)	0.5 (0.4)	**0.003**
			Three-teeth model	10.8 (2.6)	− 0.1 (0.9)	0.6 (0.4)	**< 0.001**
			Two-teeth model	10.8 (2.6)	− 0.2 (1)	0.6 (0.5)	**< 0.001**
			One–tooth model	10.9 (2.6)	− 0.1 (1.1)	0.7 (0.4)	**0.027**

All values marked in bold are statistically significant ($p < 0.05$)

DA dental age, *CA* chronological age, *SD* standard deviation, *MAE* mean absolute error, *Std* standard

line with these findings, the Willems method was also found to be suitable for age estimation and overestimated the age in this study (0.4 years for boys and 0.1 years for girls).

However, in order to use the Willems method, all teeth must be present in the left side of the lower jaw. If any tooth is missing in this quadrant, it is recommended to evaluate the symmetrical tooth on the right [6, 9]. Appropriate age estimation cannot be made if there are missing teeth on both sides due to hypodontia/oligodontia and/or tooth loss due to reasons such as trauma and caries. For this reason, the Willems method is insufficient for DA estimation in such cases. In a meta-analysis [24], it has been reported that the congenital permanent tooth agenesis rate between 0.15% and 16.18%, excluding third molars. In parallel with the studies in the literature, non-syndromic tooth agenesis was found to be 7.25% in a study conducted in Turkey [25], and it was indicated that the most frequently missing teeth were the left mandibular second premolar.

Missing teeth are one of the exclusionary factors in DA estimation methods [26]. Just like the Willems method, most DA estimation methods require all seven teeth to be in the mandibular quadrant. Since it is difficult to estimate the age in cases of hypodontia, researchers have also conducted studies in which less than seven teeth were evaluated for age estimation. According to Haavikko's method published in 1974, teeth numbered 47, 46, (16), 44, and 41 are evaluated for reference in children up to the age of 10, while teeth numbered 47, 44, 13, and 43 are evaluated in children older than 10 years old [27]. In a meta-analysis of the Haavikko's method, it overestimated the mean age by − 0.89 years for girls and − 0.66 years for boys [28]. Although the Haavikko method may be acceptable in some populations [29, 30] and it may seem advantageous not to include mandibular second premolars in the age estimation, a meta-analysis [28] found the Haavikko's method to be less accurate than the Willems method.

Demirjian and Goldstein developed two different four-teeth methods in 1976 that could predict DA with few teeth [31]. In the first method, the first and second permanent molars and the first and second premolars were used, in the second method, the second permanent molars, the first and second premolars and the permanent central incisors were

Table 3 Comparison of dental age and chronological age in boys by age groups with Willems method and Bedek models

Age	N	CA Mean (SD)	Method	DA	DA-CA Mean (SD)	MAE	*p* value
6–6.9	41	6.5 (0.3)	Willems	7 (0.7)	0.5 (0.6)	0.6 (0.4)	**< 0.001**
			Seven-teeth model	6.8 (0.6)	0.2 (0.5)	0.5 (0.4)	**0.005**
			Six-teeth model	6.7 (0.6)	0.2 (0.5)	0.4 (0.3)	0.071
			Five-teeth model	6.6 (0.6)	0.1 (0.6)	0.5 (0.4)	0.272
			Four-teeth model	6.6 (0.5)	0.1 (0.5)	0.4 (0.2)	0.245
			Three-teeth model	6.6 (0.7)	0.1 (0.6)	0.6 (0.3)	0.527
			Two-teeth model	6.6 (0.6)	0.1 (0.5)	0.5 (0.2)	0.221
			One-tooth model	7.1 (0.9)	0.6 (0.8)	0.8 (0.2)	**< 0.001**
7–7.9	66	7.4 (0.3)	Willems	7.9 (0.5)	0.5 (0.4)	0.3 (0.3)	**< 0.001**
			Seven-teeth model	7.4 (0.5)	0.1 (0.5)	0.4 (0.3)	0.165
			Six-teeth model	7.3 (0.6)	0 (0.6)	0.5 (0.4)	0.773
			Five-teeth model	7.3 (0.6)	− 0.1 (0.5)	0.5 (0.3)	0.164
			Four-teeth model	7.3 (0.7)	− 0.1 (0.6)	0.6 (0.4)	0.532
			Three-teeth model	7.6 (0.9)	0.2 (0.9)	0.8 (0.5)	**0.031**
			Two-teeth model	7.2 (0.7)	− 0.1 (0.6)	0.4 (0.5)	0.093
			One-tooth model	8 (0.9)	0.6 (0.8)	0.6 (0.7)	**< 0.001**
8–8.9	62	8.5 (0.3)	Willems	9 (0.8)	0.5 (0.7)	0.6 (0.5)	**< 0.001**
			Seven-teeth model	8.9 (1.1)	0.4 (1)	0.8 (0.7)	**0.004**
			Six-teeth model	9 (1.1)	0.5 (1)	0.8 (0.6)	**< 0.001**
			Five-teeth model	8.9 (1.1)	0.4 (1)	0.9 (0.6)	**0.002**
			Four-teeth model	9.2 (1.2)	0.7 (1.1)	1 (0.7)	**< 0.001**
			Three-teeth model	9.2 (1.1)	0.7 (1.1)	1 (0.6)	**< 0.001**
			Two-teeth model	8.7 (1.3)	0.2 (1.3)	1.2 (0.6)	0.274
			One-tooth model	9.4 (1.3)	0.9 (1.2)	1.2 (0.2)	**< 0.001**
9–9.9	47	9.5 (0.3)	Willems	10.1 (0.8)	0.5 (0.8)	0.7 (0.5)	**< 0.001**
			Seven-teeth model	10.3 (0.8)	0.7 (0.7)	0.6 (0.4)	**< 0.001**
			Six-teeth model	10.4 (0.7)	0.8 (0.7)	0.6 (0.4)	**< 0.001**
			Five-teeth model	10.3 (0.8)	0.7 (0.7)	0.6 (0.5)	**< 0.001**
			Four-teeth model	10.4 (0.7)	0.9 (0.6)	0.5 (0.4)	**< 0.001**
			Three-teeth model	10.2 (0.9)	0.7 (0.8)	0.7 (0.5)	**< 0.001**
			Two-teeth model	9.9 (1.1)	0.4 (1)	0.9 (0.6)	**0.014**
			One-tooth model	10.4 (1)	0.8 (0.9)	0.6 (0.7)	**< 0.001**
10–10.9	68	10.5 (0.3)	Willems	11.1 (0.8)	0.6 (0.7)	1.1 (0.7)	**< 0.001**
			Seven-teeth model	11 (0.5)	0.5 (0.4)	0.3 (0.3)	**< 0.001**
			Six-teeth model	11 (0.4)	0.5 (0.4)	0.3 (0.3)	**< 0.001**
			Five-teeth model	11 (0.5)	0.5 (0.4)	0.4 (0.3)	**< 0.001**
			Four-teeth model	11 (0.4)	0.5 (0.4)	0.3 (0.2)	**< 0.001**
			Three-teeth model	11 (0.5)	0.4 (0.5)	0.4 (0.3)	**< 0.001**
			Two-teeth model	10.8 (0.6)	0.3 (0.5)	0.4 (0.4)	**< 0.001**
			One-tooth model	11 (0.5)	0.5 (0.4)	0.5 (0.1)	**< 0.001**
11–11.9	62	11.4 (0.3)	Willems	11.9 (0.6)	0.5 (0.5)	0.4 (0.4)	**< 0.001**
			Seven-teeth model	11.6 (0.5)	0.2 (0.5)	0.4 (0.3)	**0.012**
			Six-teeth model	11.6 (0.5)	0.2 (0.5)	0.4 (0.3)	**0.009**
			Five-teeth model	11.5 (0.5)	0.1 (0.5)	0.4 (0.3)	**0.032**
			Four-teeth model	11.6 (0.5)	0.1 (0.5)	0.4 (0.3)	**0.015**
			Three-teeth model	11.6 (0.5)	0.2 (0.5)	0.4 (0.3)	**0.009**
			Two-teeth model	11.5 (0.7)	0.1 (0.6)	0.5 (0.4)	0.160
			One-tooth model	11.7 (0.9)	0.3 (0.8)	0.5 (0.7)	**0.007**

Table 3 (continued)

Age	N	CA Mean (SD)	Method	DA	DA-CA Mean (SD)	MAE	*p* value
12–12.9	56	12.5 (0.3)	Willems	12.8 (0.7)	0.3 (0.7)	0.5 (0.4)	**0.003**
			Seven-teeth model	12.5 (0.6)	0 (0.6)	0.6 (0.3)	0.643
			Six-teeth model	12.5 (0.6)	0 (0.6)	0.6 (0.3)	0.648
			Five-teeth model	12.5 (0.6)	−0.1 (0.6)	0.6 (0.3)	0.553
			Four-teeth model	12.5 (0.6)	−0.1 (0.6)	0.6 (0.3)	0.551
			Three-teeth model	12.5 (0.6)	−0.1 (0.6)	0.6 (0.3)	0.585
			Two-teeth model	12.5 (0.7)	0 (0.7)	0.7 (0.3)	0.883
			One-tooth model	12.7 (1.2)	0.2 (1.1)	1.2 (0.2)	0.297
13–13.9	71	13.5 (0.3)	Willems	13.4 (0.9)	−0.1 (0.9)	0.8 (0.5)	0.408
			Seven-teeth model	13 (0.7)	−0.5 (0.7)	0.6 (0.4)	**< 0.001**
			Six-teeth model	13 (0.7)	−0.5 (0.7)	0.6 (0.4)	**< 0.001**
			Five-teeth model	13 (0.8)	−0.5 (0.8)	0.6 (0.4)	**< 0.001**
			Four-teeth model	13 (0.7)	−0.5 (0.7)	0.6 (0.4)	**< 0.001**
			Three-teeth model	13 (0.7)	−0.5 (0.7)	0.6 (0.4)	**< 0.001**
			Two-teeth model	12.9 (0.7)	−0.6 (0.7)	0.5 (0.4)	**< 0.001**
			One-tooth model	13.4 (1)	−0.1 (1)	0.9 (0.5)	0.267
14–14.9	46	14.5 (0.3)	Willems	14.8 (1)	0.3 (1)	0.9 (0.5)	0.065
			Seven-teeth model	13.9 (0.6)	−0.6 (0.6)	0.5 (0.3)	**< 0.001**
			Six-teeth model	13.9 (0.6)	−0.6 (0.6)	0.5 (0.3)	**< 0.001**
			Five-teeth model	13.9 (0.6)	−0.6 (0.6)	0.6 (0.3)	**< 0.001**
			Four-teeth model	13.9 (0.6)	−0.6 (0.6)	0.6 (0.3)	**< 0.001**
			Three-teeth model	13.9 (0.6)	−0.6 (0.6)	0.6 (0.3)	**< 0.001**
			Two-teeth model	13.8 (0.7)	−0.7 (0.7)	0.7 (0.2)	**< 0.001**
			One-tooth model	14 (0)	−0.5 (0.3)	0 (0)	**< 0.001**
15–15.9	59	15.5 (0.3)	Willems	15.6 (0.7)	0.1 (0.7)	0.6 (0.4)	0.287
			Seven-teeth model	14.5 (0.5)	−1.1 (0.5)	0.4 (0.3)	**< 0.001**
			Six-teeth model	14.5 (0.5)	−1.1 (0.5)	0.4 (0.3)	**< 0.001**
			Five-teeth model	14.4 (0.5)	−1.1 (0.5)	0.4 (0.3)	**< 0.001**
			Four-teeth model	14.4 (0.5)	−1.1 (0.5)	0.4 (0.3)	**< 0.001**
			Three-teeth model	14.4 (0.5)	−1.1 (0.5)	0.4 (0.3)	**< 0.001**
			Two-teeth model	14.1 (2)	−1.4 (2)	0.9 (1.8)	**< 0.001**
			One-tooth model	14 (0)	−1.6 (0.3)	0 (0)	**< 0.001**

All values marked in bold are statistically significant ($p < 0.05$)

DA dental age, *CA* chronological age, *SD* standard deviation, *MAE* mean absolute error, *Std* standard

used. Age was overestimated in studies performed with both four-teeth methods and was not found to be accurate for age estimation [15, 32, 33]. In addition, the inclusion of second premolars in the estimation of DA in both methods of Demirjian may limit its use in cases of hypodontia.

Given the high prevalence of hypodontia and the frequency of children with early permanent tooth loss, to address the lack of methods to predict DA with few teeth, Bedek et al. [11] developed new models based on Croatian children for DA estimation based on fewer than seven teeth. In their study, more precise results were found in DA estimation than the Willems method in all models except the one-tooth model. The seven-teeth model was the most accurate predictor of age. Sheriff et al. [18] also tested Bedek models in South Indian children and found that seven-teeth models best predicted age and that all models developed were more accurate than the Willems method. The models that best predicted age were seven- and four-teeth models, and all models were found to be more accurate than the Willems method, except for the one-tooth model, in this study. Therefore, the

Table 4 Comparison of dental age and chronological age in girls by age groups with Willems method and Bedek models

Age	*N*	CA Mean (SD)	Method	DA	DA-CA Mean (SD)	MAE	*p* value
6–6.9	64	6.4 (0.3)	Willems	6.6 (0.8)	0.2 (0.6)	0.6 (0.5)	**0.034**
			Seven-teeth model	6.8 (0.8)	0.3 (0.6)	0.6 (0.5)	**< 0.001**
			Six-teeth model	6.4 (0.9)	− 0.1 (0.7)	0.8 (0.4)	0.383
			Five-teeth model	6.4 (0.9)	0 (0.7)	0.8 (0.4)	0.735
			Four-teeth model	6.9 (0.6)	0.4 (0.4)	0.5 (0.3)	**< 0.001**
			Three-teeth model	6.7 (0.6)	0.2 (0.4)	0.5 (0.3)	**< 0.001**
			Two-teeth model	6.8 (0.6)	0.3 (0.5)	0.5 (0.4)	**< 0.001**
			One-tooth model	7 (0.6)	0.5 (0.6)	0.5 (0.4)	**< 0.001**
7–7.9	65	7.5 (0.3)	Willems	7.6 (0.7)	0.2 (0.6)	0.5 (0.4)	**0.026**
			Seven-teeth model	7.5 (0.5)	0.1 (0.4)	0.4 (0.3)	0.219
			Six-teeth model	7.4 (0.6)	− 0.1 (0.5)	0.4 (0.4)	0.308
			Five-teeth model	7.4 (0.6)	− 0.1 (0.5)	0.5 (0.4)	0.242
			Four-teeth model	7.7 (0.6)	0.2 (0.5)	0.5 (0.4)	**0.002**
			Three-teeth model	7.4 (0.6)	− 0.1 (0.5)	0.5 (0.4)	0.376
			Two-teeth model	7.7 (0.9)	0.3 (0.8)	0.7 (0.6)	**0.014**
			One-tooth model	7.5 (0.5)	0 (0.6)	0.3 (0.5)	0.701
8–8.9	56	8.4 (0.3)	Willems	8.7 (0.7)	0.3 (0.6)	0.6 (0.5)	**0.001**
			Seven-teeth model	8.7 (0.8)	0.2 (0.7)	0.6 (0.5)	**0.015**
			Six-teeth model	8.7 (0.8)	0.2 (0.7)	0.6 (0.5)	**0.019**
			Five-teeth model	8.7 (0.8)	0.2 (0.7)	0.6 (0.5)	**0.011**
			Four-teeth model	8.9 (0.8)	0.5 (0.7)	0.6 (0.5)	**< 0.001**
			Three-teeth model	8.7 (0.9)	0.3 (0.8)	0.7 (0.6)	**0.015**
			Two-teeth model	8.8 (1)	0.4 (0.9)	0.9 (0.5)	**0.005**
			One-tooth model	7.9 (0.8)	− 0.5 (0.8)	0.8 (0.2)	**< 0.001**
9–9.9	41	9.5 (0.3)	Willems	9.9 (0.7)	0.3 (0.7)	0.6 (0.4)	**0.004**
			Seven-teeth model	10 (0.7)	0.4 (0.7)	0.6 (0.4)	**< 0.001**
			Six-teeth model	10 (0.7)	0.4 (0.7)	0.6 (0.4)	**< 0.001**
			Five-teeth model	9.9 (0.6)	0.3 (0.7)	0.5 (0.4)	**0.002**
			Four-teeth model	10 (0.6)	0.4 (0.6)	0.5 (0.3)	**< 0.001**
			Three-teeth model	9.9 (0.6)	0.3 (0.7)	0.5 (0.4)	**0.002**
			Two-teeth model	10 (0.6)	0.4 (0.6)	0.4 (0.4)	**< 0.001**
			One-tooth model	9.1 (1.3)	− 0.4 (1.2)	0.9 (0.9)	**0.030**
10–10.9	64	10.5 (0.3)	Willems	10.5 (0.5)	0.1 (0.5)	0.4 (0.3)	0.142
			Seven-teeth model	10.6 (0.4)	0.1 (0.4)	0.3 (0.2)	**0.006**
			Six-teeth model	10.6 (0.4)	0.1 (0.4)	0.3 (0.2)	**0.010**
			Five-teeth model	10.5 (0.4)	0 (0.4)	0.3 (0.2)	0.625
			Four-teeth model	10.5 (0.4)	0 (0.4)	0.4 (0.3)	0.945
			Three-teeth model	10.5 (0.5)	0 (0.5)	0.4 (0.3)	0.565
			Two-teeth model	10.6 (0.4)	0.1 (0.4)	0.4 (0.3)	**0.030**
			One-tooth model	10.5 (1.1)	0 (1)	1 (0.4)	0.959
11–11.9	51	11.5 (0.3)	Willems	11.7 (0.7)	0.2 (0.6)	0.6 (0.3)	**0.010**
			Seven-teeth model	11.3 (0.6)	− 0.1 (0.6)	0.5 (0.3)	0.080
			Six-teeth model	11.3 (0.6)	− 0.1 (0.6)	0.5 (0.3)	0.080
			Five-teeth model	11.4 (0.6)	− 0.1 (0.6)	0.5 (0.3)	0.399
			Four-teeth model	11.4 (0.6)	− 0.1 (0.6)	0.5 (0.3)	0.378
			Three-teeth model	11.5 (0.7)	0.1 (0.7)	0.5 (0.5)	0.440
			Two-teeth model	11.5 (0.7)	0.1 (0.7)	0.5 (0.5)	0.445
			One-tooth model	12 (0.8)	0.5 (0.8)	0.8 (0.1)	**< 0.001**

Table 4 (continued)

Age	*N*	CA Mean (SD)	Method	DA	DA-CA Mean (SD)	MAE	*p* value
12–12.9	33	12.5 (0.3)	Willems	12.8 (0.9)	0.3 (0.8)	0.8 (0.5)	**0.042**
			Seven-teeth model	12.4 (0.8)	− 0.1 (0.7)	0.7 (0.4)	0.384
			Six-teeth model	12.4 (0.8)	− 0.1 (0.7)	0.7 (0.4)	0.384
			Five-teeth model	12.4 (0.8)	− 0.1 (0.7)	0.7 (0.4)	0.562
			Four-teeth model	12.4 (0.8)	− 0.1 (0.7)	0.7 (0.4)	0.527
			Three-teeth model	12.4 (0.8)	− 0.1 (0.8)	0.7 (0.3)	0.604
			Two-teeth model	12.4 (0.8)	− 0.1 (0.8)	0.7 (0.3)	0.606
			One-tooth model	12.5 (0.7)	0 (0.6)	0.4 (0.4)	0.922
13–13.9	58	13.5 (0.3)	Willems	13.6 (1)	0.1 (1)	0.7 (0.7)	0.497
			Seven-teeth model	13.1 (0.8)	− 0.5 (0.7)	0.5 (0.5)	**< 0.001**
			Six-teeth model	13.1 (0.8)	− 0.5 (0.7)	0.5 (0.5)	**< 0.001**
			Five-teeth model	13.1 (0.7)	− 0.5 (0.7)	0.4 (0.6)	**< 0.001**
			Four-teeth model	13.1 (0.7)	− 0.5 (0.7)	0.4 (0.6)	**< 0.001**
			Three-teeth model	13.1 (0.7)	− 0.5 (0.7)	0.3 (0.6)	**< 0.001**
			Two-teeth model	13 (0.7)	− 0.5 (0.8)	0.3 (0.6)	**< 0.001**
			One-tooth model	12.7 (1.1)	− 0.8 (1.2)	0.4 (1.1)	**< 0.001**
14–14.9	48	14.5 (0.3)	Willems	14.5 (1.1)	0 (1.1)	1 (0.4)	0.786
			Seven-teeth model	13.7 (0.8)	− 0.8 (0.8)	0.7 (0.3)	**< 0.001**
			Six-teeth model	13.7 (0.8)	− 0.8 (0.8)	0.7 (0.3)	**< 0.001**
			Five-teeth model	13.7 (0.8)	− 0.9 (0.8)	0.7 (0.2)	**< 0.001**
			Four-teeth model	13.7 (0.8)	− 0.9 (0.8)	0.8 (0.2)	**< 0.001**
			Three-teeth model	13.6 (0.8)	− 0.9 (0.9)	0.8 (0.2)	**< 0.001**
			Two-teeth model	13.6 (0.8)	− 0.9 (0.9)	0.8 (0.2)	**< 0.001**
			One-tooth model	13.4 (0.9)	− 1.1 (1)	0.9 (0.2)	**< 0.001**
15–15.9	60	15.5 (0.3)	Willems	15.3 (0.9)	− 0.2 (0.8)	0.7 (0.4)	0.087
			Seven-teeth model	14.3 (0.6)	− 1.2 (0.6)	0.5 (0.3)	**< 0.001**
			Six-teeth model	14.3 (0.6)	− 1.2 (0.6)	0.5 (0.3)	**< 0.001**
			Five-teeth model	14.2 (0.7)	− 1.3 (0.7)	0.6 (0.3)	**< 0.001**
			Four-teeth model	14.2 (0.7)	− 1.3 (0.7)	0.6 (0.3)	**< 0.001**
			Three-teeth model	14.2 (0.7)	− 1.3 (0.7)	0.6 (0.4)	**< 0.001**
			Two-teeth model	14.2 (0.7)	− 1.3 (0.7)	0.6 (0.4)	**< 0.001**
			One-tooth model	14.1 (0.8)	− 1.4 (0.8)	0.7 (0.4)	**< 0.001**

All values marked in bold are statistically significant ($p < 0.05$)

DA dental age, *CA* chronological age, *SD* standard deviation, *MAE* mean absolute error, *Std* standard

first null hypothesis to test that the Willems method and Bedek models were at the same accuracy, was rejected.

One of the biggest advantages of Bedek five-, four-, three-, two-, and one-tooth models is that it does not require mandibular second premolars for age estimation. In addition, easier, more practical, and more accurate results were obtained by using fewer teeth in age estimation compared to the Willems method. For all these reasons, it may be possible to make an accurate age estimation in both incomplete human remains with missing teeth and hypodontia with Bedek models. In this study, all models with fewer than six teeth (not including the mandibular second premolar) and more than six teeth determined the age accurately. With the success of Bedek models, the presence of missing teeth in the mandible is no longer an obstacle to age estimation. Although we assert that Bedek models with fewer teeth can be used to estimate DA in hypodontia cases, we used traditional panoramic radiograph evaluation indications since this study is the first to evaluate Bedek models in a Turkish population. Therefore, the fact that hypodontia cases were

Table 5 Correlation between dental age and chronological age in both sexes and total sample with Willems method and Bedek models according to Pearson correlation test

Method	Willems		Seven-teeth model		Six-teeth model		Five-teeth model		Four-teeth model		Three-teeth model		Two-teeth model		One-tooth model	
r/*p* values	*r* value	*p* value	*r* value	*p* value	*r* value	*p* value	*r* value	*p* value	*r* value	*p* value	*r* value	*p* value	*r* value	*p* value	*r* value	*p* value
Boys	0.965	**< 0.001**	0.961	**< 0.001**	0.959	**< 0.001**	0.959	**< 0.001**	0.955	**< 0.001**	0.951	**< 0.001**	0.921	**< 0.001**	0.925	**< 0.001**
Girls	0.968	**< 0.001**	0.969	**< 0.001**	0.967	**< 0.001**	0.966	**< 0.001**	0.968	**< 0.001**	0.965	**< 0.001**	0.958	**< 0.001**	0.935	**< 0.001**
Total	0.966	**< 0.001**	0.965	**< 0.001**	0.962	**< 0.001**	0.962	**< 0.001**	0.961	**< 0.001**	0.957	**< 0.001**	0.939	**< 0.001**	0.926	**< 0.001**

All values marked in bold are statistically significant ($p < 0.05$)

r Pearson's rho

not evaluated in the study is an important limitation, and we think that there is a need for studies on this subject. Furthermore, while researchers' calibration and correctness are maintained to the highest level possible, as is accuracy in radiograph evaluation, the potential bias risk in DA estimation studies is always a limitation. One of the strengths of the study is that the sample group is a homogeneous group from a city with a very low immigration rate, since its accuracy increases when DA estimation studies are performed on individuals from the same geographical region and ethnicity. In addition, the large number of samples and the fact that they were compatible in terms of sex and age also make the statistical analysis more reliable.

In all Bedek models and in both sexes, the DA-CA difference and MAE values were found to be higher in Sheriff et al.'s study [18] than in the current study. The high values of both DA-CA and MAE indicate that the Bedek models are more suitable for northwestern Turkish children than for South Indian children. The reasons for these differences can be explained by the ethnic and regional differences, nutrition, and socio-economic levels of the participants and the sample size of these studies [34].

In cases where it is necessary to determine the age in a short time, even in multiple missing teeth, for legal reasons or judicial cases, methods that give fast and accurate results meet the forensic requirements [35]. The new models developed by evaluating the panoramic radiographs of Croatian children have so far been tested only in South Indian children and have been found to be accurate and suitable for DA estimation. Similar results were found in northwestern Turkish children and it was seen that it gave more successful results than the Willems method. In addition, the age estimation models of Bedek et al. were simple, accurate, and produced maximum accuracy with fewer teeth, and were accepted in all populations studied so far.

Conclusions

In this study, although all of Bedek's age estimation models were found to be suitable for northwestern Turkish children, the more precise DA estimation was obtained in seven- and four-teeth models. It can be predicted that these models can be used in cases of missing teeth, tooth agenesis, and in forensic cases with incomplete human remains, thus filling the gap in the literature. In addition, simpler and more accurate results can be obtained in a shorter time by using fewer teeth than other methods that use seven teeth. More studies are needed to test the accuracy of newly developed models for age estimation in different populations and different geographic regions.

Table 6 Percentage accuracy of age estimation in both sexes and total sample using Willems method and Bedek models

Method	Boys %		Girls %		Total %	
	±0.5 years	±1 year	±0.5 years	±1 year	±0.5 years	±1 year
Willems	44.8	76.3	53.5	81.7	49	78.8
Seven-teeth model	45.3	80.6	47.2	78.7	46.2	79.7
Six-teeth model	44.3	78.7	46.5	78.5	45.3	78.6
Five-teeth model	44.6	79.2	46.7	78.5	45.6	78.9
Four-teeth model	45.2	76.6	47.6	79.1	46.3	77.8
Three-teeth model	44.3	73.5	48	78.1	46.1	75.8
Two-teeth model	44.1	73.9	46.5	74.3	45.2	74.1
One-tooth model	33.7	61.8	31.5	61.7	32.6	61.7

Author contribution Conceptualization: Burak Çarıkçıoğlu, Berkant Sezer; methodology: Burak Çarıkçıoğlu, Berkant Sezer; formal analysis and investigation: Burak Çarıkçıoğlu, Berkant Sezer; writing—original draft preparation: Burak Çarıkçıoğlu; writing—review and editing: Burak Çarıkçıoğlu, Berkant Sezer.

Declarations

Ethical approval Ethical approval for this study was provided by the Çanakkale Onsekiz Mart University, School of Medicine, Clinical Research Ethic Board (Protocol no. 18920478–050.01.04–2100054264), and the study was conducted in accordance with all the principles stated in the Declaration of Helsinki.

Informed consent Informed consent was not needed due to the retrospective design of the study.

Conflict of interest The authors declare no competing interests.

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