

Dental age assessment on panoramic radiographs: Comparison between two generations of young Finnish subjects

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Abstract

Objective: To analyse the accuracy of a meta-analysis-based dental age assessment (DAA) method in Finnish paediatric patients and to compare the dental development between two generations of Finnish children.

Methods: Panoramic radiographs of Finnish Caucasian healthy children from two generations (early: born 1981–1984; subsequent: born 1996–2008) were analysed. All developing teeth on the left maxilla and mandible as well as the third permanent molars were analysed following Demirjian's classification. For each patient, dental age was calculated and compared with chronological age. Dental maturation patterns between the two groups were compared.

Results: The study included 200 Finnish Caucasian healthy children from two generations (early: aged 7–13 years; subsequent: aged 6–15 years). In the early generation, DAA underestimated the chronological age by a mean of 3.15 years. The underestimation was only 0.11 years in

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patients < 10 years, but 3.86 years in patients \geq 10 years. In the subsequent generation, the dental age was overestimated by a mean of 0.34 years; by 0.40 years in patients < 10 years and by 0.08 years in patients \geq 10 years.

Conclusions: The present DAA method is applicable to current Finnish children. Differences in dental development between two generations of Finnish children were detected.

Keywords

Age determination by teeth, radiography, panoramic, growth and development, cohort effect

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Introduction

Methods of age assessment are used in a variety of legal and forensic situations, as well as for research purposes and clinical work.^{1,2} Indicators for age estimation include skeletal maturity, body height and weight, sexual development, tooth development and eruption. Age estimation based on dental development stages in growing subjects correlates better with chronological age than other techniques.^{3,4} Developing teeth are used as maturation indicators because they are less affected by endocrine diseases and environmental damage than other body tissues.² Dental age assessment (DAA) has been established as a reliable method for estimating age.⁵ A DAA method developed in 1973 by Demirjian et al.,⁶ based on a sample of French-Canadian subjects, was found to be accurate.^{7,8} Demirjian's method, which has been tested and applied on various population groups, classifies the development stages of mandibular crowns and roots.⁹

The Dental Age Research London Information Group (DARLInG) established in 2008 a dental age reference database of British Caucasian subjects.¹⁰ They assessed upper left and lower left teeth, as well as all four wisdom teeth using Demirjian's method and used a meta-analysis approach to estimate a subject's dental age by taking into account the developmental stage of each

assessed tooth.¹⁰ This method enabled them to accurately estimate the age of young subjects around different age thresholds.^{11–13}

The DARLInG method has been tested in children of different ethnic backgrounds showing that it is applicable for children of Swiss⁸ and northern Chinese¹⁴ origin, but is not ideally suited for children of either southern Chinese¹⁵ or Australian descent.¹⁶

Furthermore, current generations of children seem to show different maturation patterns compared with earlier generations of children.¹⁷ The term 'secular trend' describes 'marked changes in growth and development of successive generations of human populations living in the same territories'.¹⁸ A secular trend in the development and maturation of permanent teeth has been documented mainly in European and European-origin populations in the last 100–200 years.^{18–21} Dental age is of interest to paediatric dentists and orthodontists for diagnosis and treatment planning,² and the potential existence of a secular trend in dental development and maturation may have an influence on daily practice and research. In terms of DAA, the existence of a secular trend in dental maturation would call for a constant updating of the reference set used for the calculation of dental age.

Therefore, the first aim of this study was to analyse the accuracy of DAA using the DARLInG meta-analysis method in a

contemporary Finnish population of children. The second aim was to detect potential differences in maturation between two generations of children, i.e. find traces of a secular trend in dental development.

Patients and methods

Materials

This retrospective study selected good quality anonymized panoramic radiographs based on their quality from the pre-treatment records of patients with conventional orthodontic problems with no syndromes or clefts from the Department of Oral Development and Orthodontics, University of Oulu, Oulu, Finland. Written informed consent was obtained from the patients and their parents prior to treatment to allow the use of their data for research purposes. Some of the records have been used in previous investigations.^{22,23} As the radiographs were anonymized, under Swiss law (Human Research Act HRA, Art 2 §2c), the research project did not require ethical approval. Exclusion criteria were a history of previous orthodontic treatment, syndromes or clefts and poor-quality radiographs.

The study compared two generations of Finnish Caucasian healthy children with developing teeth. The patients in the early group were born between 21 January 1981 and 27 December 1984. The patients in the subsequent group were born between 18 June 1996 and 29 March 2008. The 1980s' panoramic radiographs were taken on a conventional panoramic unit (Planmeca PM 2002 CC; Planmeca OY, Helsinki, Finland), and the more recent radiographs were taken on a digital unit (Planmeca PM 2002 Proline CM; Planmeca OY).

Preview Version 8.0 (Apple, Cupertino, CA, USA) was used to view and analyse the digitized images on a portable computer (MacBook Pro 13" 2.5 GHz Intel Core i5;

Apple). Image manipulations (zoom, sharpening, brightness, contrast and gamma adjustments) to facilitate image analysis were done when necessary.

Methods

One examiner (F.A.B.) was trained and calibrated on panoramic radiographs as described in a previous publication.⁸ All developing teeth on the left-hand side (quadrants two and three) as well as all third permanent molars were assessed¹⁰ using the Demirjian classification,⁶ which divides tooth development into eight stages from A to H.

The age and sex of each patient were blinded to the examiner when assessing tooth development stages. When the tooth anatomy was difficult to see or when a tooth was missing, the contralateral tooth was assessed. If the latter was not interpretable, the tooth was excluded from the analysis.

Chronological age for each patient was calculated by subtracting the date of birth from the date of the X-ray. Each tooth was assigned a developmental stage according to its root development. Using the DARLInG meta-analysis method with random effects¹⁰ (reference sample based on sex specific data obtained from British Caucasian subjects between 2003 and 2010), each individual's dental age was calculated from the information gathered on his/her assessed teeth. The dental age was then compared with the patient's chronological age.

Statistical analyses

The sample size planned in this study was 100 patients for each generation. Assuming a standard deviation of 0.85 effects¹⁰ for the difference between dental and chronological age and a two-sided type 1 error of 0.05, the statistical power is 80% to detect

a mean difference between dental and chronological age of 0.25 years.

To test the intra-rater agreement, 20% of the radiographs in each group were randomly chosen from a sequence generated by random.org (Random Integer Set Generator) and re-examined after an interval of 2 weeks. The index of agreement was calculated using Cohen's Kappa. The categories published by Landis and Koch²⁴ were used to indicate the degree of agreement.

Dental age was calculated using the meta-analytic approach with random effects proposed previously.¹⁰ Meta-analysis is a quantitative procedure used in statistical methodology to combine and summarize the results of several studies addressing a particular research hypothesis. In the context of DAA, the meta-analysis approach allows the computation of a subject's dental age by calculating a weighted mean of the mean values of the stages of tooth development.¹⁰

In each group of patients, the calculated dental age was compared with the gold standard, namely chronological age, by calculating the prediction error (dental age minus chronological age). A Student's *t*-test for paired data was used to test the null hypothesis that the mean prediction error is 0. Other comparisons of the means were conducted using Student's *t*-test. To compare the magnitude of the prediction error between the early and subsequent groups, a multivariable linear regression was used. The dependent variable was the prediction error and the main independent variable was the group (early versus subsequent). Interaction terms between groups and sex and between groups and chronological age (< 10 versus \geq 10 years) were introduced to investigate if sex and chronological age modified the difference in prediction error between early and subsequent groups.

All statistical analyses were performed using R version 3.3.1 (R Core Team; R: A

language and environment for statistical computing; R Foundation for Statistical Computing, Vienna, Austria; 2010). The significance threshold was set at 0.05 and all statistical tests were two-sided.

Results

This retrospective study compared two generations of Finnish Caucasian healthy children with developing teeth. The early group (50 males and 50 females) were born between 21 January 1981 and 27 December 1984 (age range, 7–13 years); and the subsequent group (53 males and 47 females) were born between 18 June 1996 and 29 March 2008 (age range, 6–15 years). The age distributions are shown in Figures 1a and 1b. Among the 200 patients, a total of 2917 teeth were evaluated for this analysis. In the early group, 363 teeth were missing; and in the subsequent group, 320 teeth were missing. Due to unreadable pictures, 45 teeth (nine in the early group, 36 in the subsequent group) could not be evaluated. Cohen's Kappa coefficient for the intra-rater agreement was at 0.953 for the 20% of re-evaluated pictures.

The mean chronological age was higher in the early group than in the subsequent group (Table 1). Within each group, the age difference between males and females was similar. The proportion of patients < 10 years was inverted in the two groups; with 19 of 100 (19%) patients < 10 years in the early group compared with 81 of 100 (81%) patients < 10 years in the subsequent group. In the early group, the mean dental age was lower than the mean chronological age except for patients < 10 years, for whom the mean dental age (7.59 years) corresponded well with the mean chronological age (7.70 years). In the subsequent group, mean dental age and mean chronological age were similar.

Calculation of the prediction error (dental age minus chronological age)

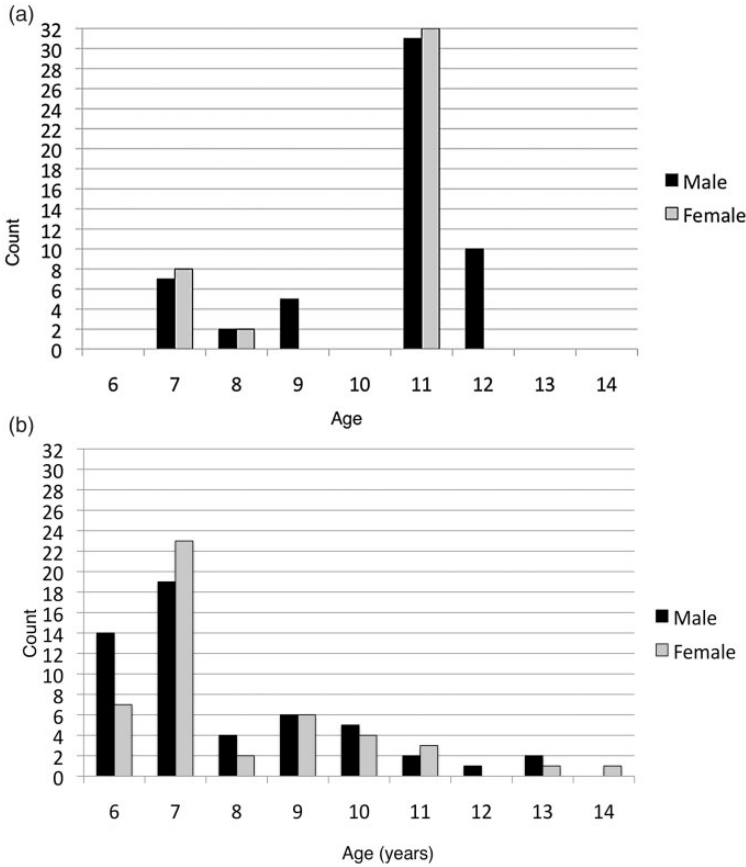


Figure 1. Chronological age distribution of each group of patients: early group (Figure 1a, $n = 100$) and subsequent group (Figure 1b, $n = 100$). The age categories include ages in the range of 0.00–0.99 for each age (e.g. age category 6 indicates an age range of 6.00–6.99).

showed that the approach used to calculate the dental age performed differently in the early and subsequent groups (Table 2). In the early group, dental age underestimated chronological age by a mean of 3.15 years. The prediction interval (–6.2 to –0.1 years) showed that the underestimation varied widely between the patients in the early group. Whereas the mean prediction error was not associated with sex, it was associated with age: the difference between dental age and chronological age in patients <10 years of age was smaller (mean

underestimation of 0.11 years) than in patients ≥ 10 years of age (mean underestimation of 3.86 years, $P < 0.0001$). The mean prediction error was significantly different for patients <10 years and those ≥ 10 years ($P < 0.0001$, Student’s t -test). In addition, the prediction error varied approximately from –1.2 to 1.0 years for patients <10 years, whereas the range of prediction error was wider in patients ≥ 10 years (–4.9 to –2.8 years). The distribution of the prediction errors is shown in Figure 2 and the individual prediction

Table 1. Demographic, chronological age and dental age data for two groups of paediatric patients with dental radiography images from the 1980s (early group) and 1990s (subsequent group).

	n	Chronological age, years			Dental age, years ^a		
		Mean ± SD	Median (Q1, Q3) (min, max)		Mean ± SD	Median (Q1, Q3) (min, max)	
Early group							
All	100	10.97 ± 1.62	11.61 (11.26, 11.91) (7.18, 12.71)		7.82 ± 0.58	7.73 (7.45, 8.09) (6.65, 10.93)	
Female	50	10.81 ± 1.70	11.53 (11.19, 11.77) (7.18, 12.25)		7.71 ± 0.61	7.65 (7.25, 8.00) (6.92, 10.39)	
Male	50	11.13 ± 1.54	11.78 (11.46, 11.94) (7.58, 12.71)		7.93 ± 0.53	7.85 (7.60, 8.11) (6.65, 9.11)	
Chronological age < 10 years	19	7.70 ± 0.39	7.70 (7.37, 7.91) (7.18, 8.71)		7.59 ± 0.47	7.66 (7.22, 7.81) (6.65, 8.53)	
Chronological age ≥ 10 years	81	11.74 ± 0.31	11.72 (11.54, 11.97) (11.17, 12.71)		7.87 ± 0.59	7.80 (7.49, 8.15) (6.96, 10.39)	
Subsequent group							
All	100	8.37 ± 1.82	7.64 (7.18, 9.26) (6.13, 14.50)		8.71 ± 1.80	7.91 (7.47, 9.40) (6.33, 13.23)	
Female	47	8.46 ± 1.81	7.65 (7.29, 9.49) (6.24, 14.50)		8.74 ± 1.89	7.70 (7.46, 9.86) (6.86, 13.21)	
Male	53	8.28 ± 1.85	7.63 (6.97, 9.20) (6.13, 13.72)		8.68 ± 1.73	8.00 (7.59, 9.36) (6.33, 13.23)	
Chronological age < 10 years	81	7.63 ± 11.49	7.42 (6.99, 7.93) (6.13, 9.78)		8.04 ± 1.09	7.68 (7.44, 8.26) (6.33, 12.23)	
Chronological age ≥ 10 years	19	11.49 ± 1.32	11.08 (10.61, 12.15) (10.04, 14.50)		11.57 ± 1.35	12.05 (10.68, 12.62) (8.56, 13.23)	

^aDental age was the age predicted using the model with mixed effects.

Table 2. Description of the prediction error that was calculated as the difference between dental age and chronological age.

	Prediction error, years ^a			Statistical significance ^b	
	n	Mean ± SD	Median (Q1, Q3) (min, max)	H ₀ : mean error = 0	Prediction interval, years ^c
Early group					
All	100	-3.15 ± 1.58	-3.73 (-4.17, -3.06) (-4.91, 0.81)	P < 0.0001	-6.24, -0.06
Female	50	-3.09 ± 1.67	-3.85 (-4.15, -3.11) (-4.67, 0.81)	P < 0.0001	-6.37, 0.18
Male	50	-3.20 ± 1.49	-3.64 (-4.18, -3.07) (-4.91, 0.63)	P < 0.0001	-6.12, -0.29
Chronological age < 10 years	19	-0.11 ± 0.57	-0.06 (-0.48, 0.37) (-1.25, 0.81)	NS	-1.23, 1.01
Chronological age ≥ 10 years	81	-3.86 ± 0.54	-3.91 (-4.22, -3.58) (-4.91, -1.86)	P < 0.0001	-4.92, -2.80
Subsequent group					
All	100	0.34 ± 0.87	0.32 (-0.17, 0.83) (-2.42, 3.17)	P = 0.0001	-1.36, 2.04
Female	47	0.28 ± 1.02	0.21 (-0.23, 0.82) (-2.42, 3.17)	NS	-1.72, 2.28
Male	53	0.40 ± 0.71	0.34 (-0.05, 0.86) (-1.38, 1.90)	P = 0.0001	-0.99, 1.79
Chronological age < 10 years	81	0.40 ± 0.71	0.31 (-0.03, 0.82) (-1.02, 3.17)	P < 0.0001	-0.98, 1.79
Chronological age ≥ 10 years	19	0.08 ± 1.36	0.56 (-0.98, 1.16) (-2.42, 1.78)	NS	-2.58, 2.74

^aA positive mean prediction error means that the predicted dental age is higher than the chronological age.

^bStudent's t-test for the (null) hypothesis that the mean prediction error is null; NS, no significant difference (P ≥ 0.05).

^cThe prediction interval is defined by mean prediction error +/- 1.96 SD of the prediction error. For approximately 95% of patients, the prediction error falls in this interval.

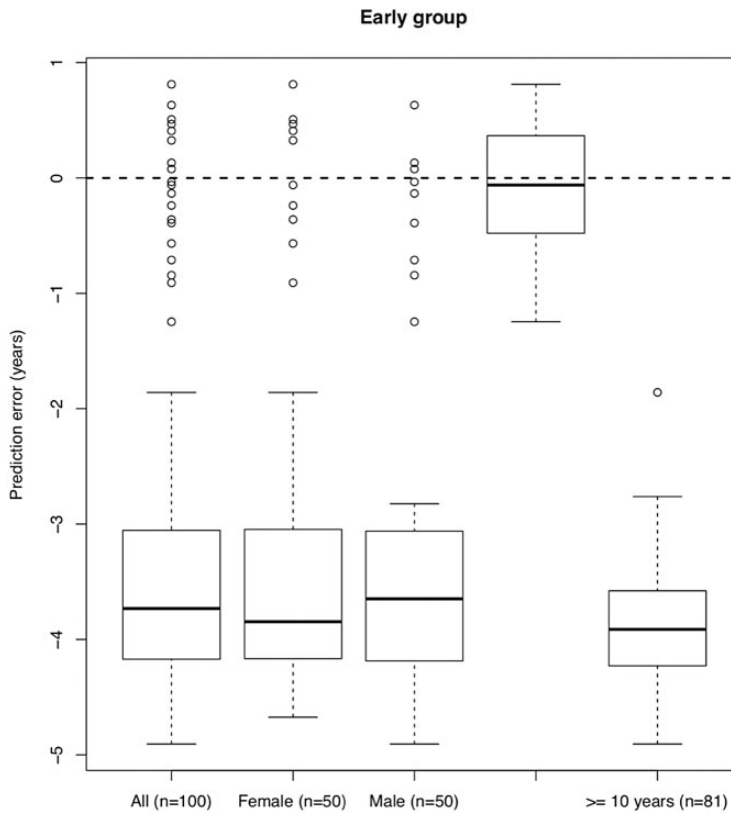


Figure 2. Box-whisker plots representing the distribution of the individual errors in predicting chronological age in the early group and by subgroups (sex and age). The central black horizontal line represents the median, the extremities of the box are the 25th and 75th percentiles, the error bars represent the minimum and maximum outliers and the circles above the upper error bar represent extreme outliers. The size of each group is reported in parentheses. The dashed horizontal line is shown as a reference line representing a perfect prediction of chronological age.

errors are represented against the chronological age in Figure 3.

In the subsequent group, the mean prediction error was positive (0.34 years; $P=0.0001$) because, overall, the dental age was higher than the chronological age. The prediction interval (from -1.4 to 2.0 years) showed that dental age can underestimate chronological age by 1.4 years for some patients and overestimate it by 2.0 years for others. The mean prediction error was not associated with sex or chronological age. Distribution of the prediction errors is shown in Figure 4 and the

individual prediction errors are represented against chronological age in Figure 3.

When comparing the early to the subsequent group, the mean prediction error was more important in the early group than in the subsequent group (-3.15 years versus 0.34 years, respectively; $P<0.0001$). In a multivariate linear regression model, the sex of the children did not modify the magnitude of the difference in the prediction error between the early and subsequent groups. In contrast, the magnitude of the difference in the prediction error between the early and subsequent groups was more important in

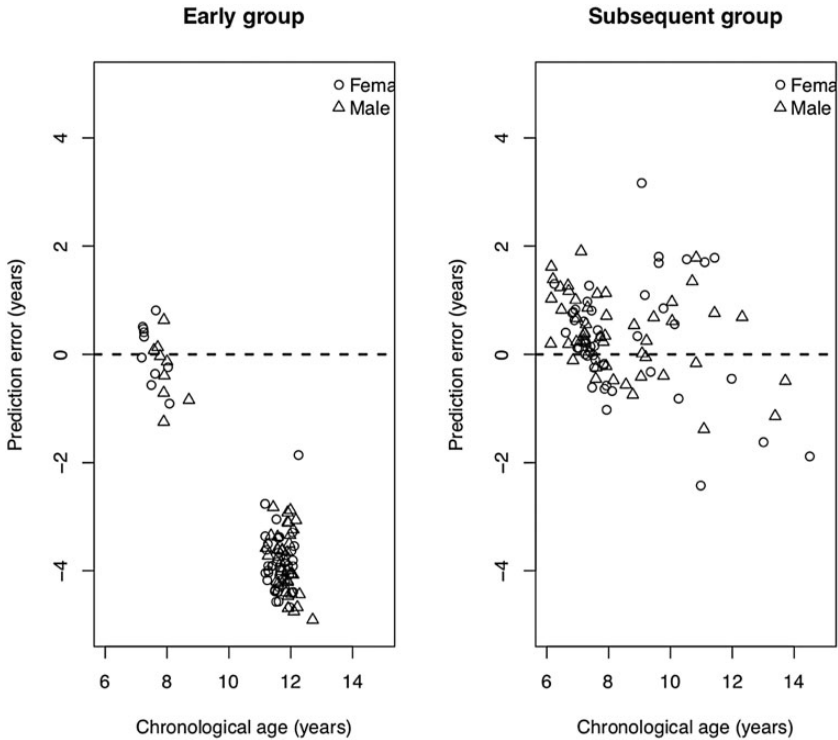


Figure 3. Scatter plots representing the joint distribution of the individual errors in predicting chronological age and the subject's chronological age in the early group (left panel) and in the subsequent group (right panel). Circles represent females and triangles males. The dashed horizontal line is shown as a reference line representing a perfect prediction of chronological age.

patients < 10 years of age than in patients \geq 10 years ($P < 0.0001$) (Figure 5).

Discussion

Radiological evaluation of dental maturity is a simple, non-invasive and reliable method to determine age in children.²⁵ Demirjian's age assessment technique evaluates the development of seven lower left teeth, from the first incisor to the second molar.⁶ It is therefore limited to the age at which these teeth are fully calcified, which is usually at around 16 years of age.⁹ To extend the use of dental age assessment and increase accuracy, the DARLInG research team also included upper left

teeth as well as all four wisdom teeth into their technique.¹⁰ Our earlier research has shown that Demirjian's staging method allows precise repeated staging of maxillary and mandibular teeth.⁸ In the current study, the Kappa values for intra-rater agreement were at 0.953, classified by Landis and Koch as 'almost perfect agreement'.²⁴

No previous investigation has examined the applicability of the DARLInG dental age assessment method in a Finnish population. Several reports show an influence of the studied population on the accuracy of DAA.^{1,16,26} In a previous investigation, we showed that the DARLInG method is applicable to Swiss subjects younger than 12 years of age.⁸ On the other hand,

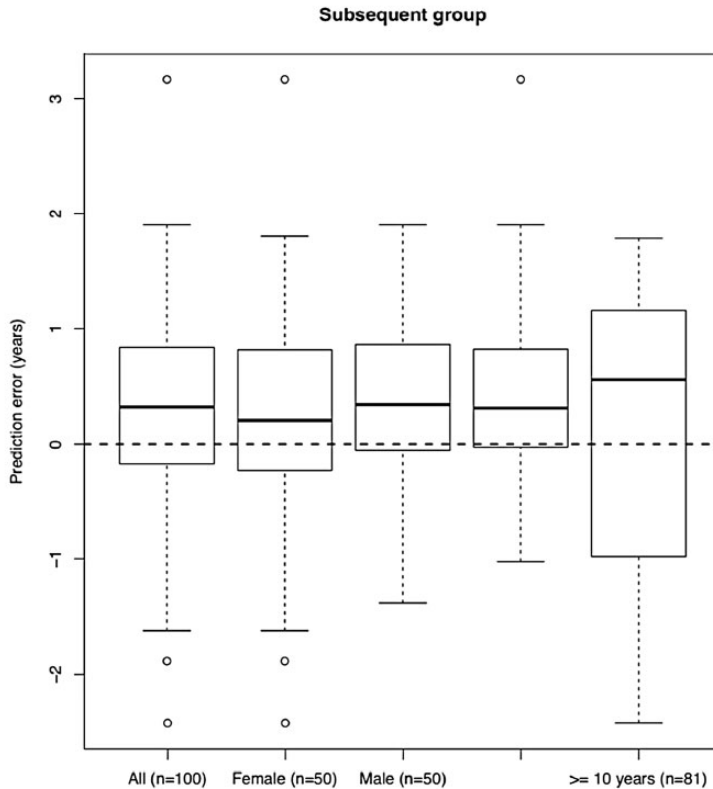


Figure 4. Box-whisker plots representing the distribution of the individual errors in predicting chronological age in the subsequent group and by subgroups (sex and age). The central black horizontal line represents the median, the extremities of the box are the 25th and 75th percentiles, the error bars represent the minimum and maximum outliers and the circles above the upper error bar represent extreme outliers. The size of each group is reported in parentheses. The dashed horizontal line is shown as a reference line representing a perfect prediction of chronological age.

another study found the need for an ethnic specific reference dataset for southern Chinese children.¹⁵ In 1988, a study reported that, even within Finland, differences were found in dental maturity charts when southern Finnish children were compared with children living in the northeastern part of the country.²⁷ The present study suggests that the DARLInG method seems to be applicable to the current generation of northern Finnish children, especially to those older than 10 years of age and of female sex.

This present study followed a retrospective design and no radiographs were taken purposely for this investigation. Therefore, it was not possible to perfectly fit the sex distribution among the two groups since the chosen radiographs had to comply to a certain standard to be evaluable. Each of the two groups was made up of a sample of 100 children of northern Finnish origin. The early group comprised 50 boys and 50 girls; and the subsequent group included 53 boys and 47 girls. For DAA, sex specific data were used because the timing in tooth

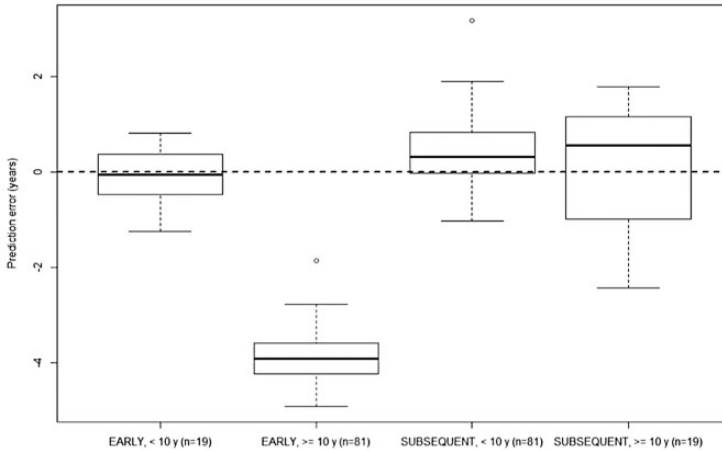


Figure 5. Box-whisker plots representing the distribution of the individual errors in predicting chronological age by group (early/subsequent) and by age ($</\geq$ 10 years). The central black horizontal line represents the median, the extremities of the box are the 25th and 75th percentiles, the error bars represent the minimum and maximum outliers and the circles above the upper error bar represent extreme outliers. The size of each group is reported in parentheses. The dashed horizontal line is shown as a reference line representing a perfect prediction of chronological age.

maturation differs between boys and girls.^{1,28} Nevertheless, this current investigation was not affected by the dissimilar sex distribution, since the statistical analysis showed that sex did not have a statistically significant impact on the prediction error.

Because of the retrospective nature of the current study, achieving a similar age distribution among the two groups was challenging. Eventually, in the early group, 81% of the patients were older than 10 years of age; and in the subsequent group, 81% were younger than 10 years of age. The chronological age of studied subjects impacts the accuracy of DAA, especially in younger subjects.^{7,8,29} The differences in mean age between the two assessed groups in the current study could be a confounding factor for the dissimilarities found in the prediction error, which was smaller in both groups for patients younger than 10 years of age. This fact might partially be explained by the overall better prediction error in the subsequent group, which included more patients younger than 10 years of age.

The overall prediction error (i.e. difference between dental age and chronological age) was statistically significant in both groups. In the early group, no statistically significant difference could be found between chronological age and dental age among patients younger than 10 years of age. In the subsequent group, no statistically significant difference in prediction error was found in females and in patients older than 10 years of age. In the subsequent group, a statistically significant difference in prediction error was found in males and patients younger than 10 years of age. The median prediction error for males was 0.34 years and was 0.56 years for patients older than 10 years, which raises the question whether the difference is clinically relevant. Previous research has found that a mean age difference of up to ± 1 year can be considered accurate for DAA.³⁰

Another possible explanation for differences in the accuracy of dental age assessment might be the considerable time gap between the capture of radiographs for

study and the reference samples.^{26,31} The DARLInG reference sample consisted of pictures taken between 2003 and 2010. In the current study, the pictures in the early group were taken between 1992–1997 and in the subsequent group between 2004–2014. The subsequent group therefore lies closer to the time frame of the reference sample. In 1998, a report described a trend towards earlier dental maturation in orthodontic patients between the 1970s and the 1990s.¹⁹ Another study showed that children in a modern sample were advanced in timing of root maturation compared with children in a historic sample and a time difference of 50 years.²⁰ Interestingly, there did not seem to be a difference in duration of root formation between the children of different generations.²⁰ In contrast, a recent study of Turkish children could not find significant positive secular trends in dental maturity from the 1980s through to the 2000s.²¹ These current findings showed a better accuracy of DAA in the subsequent group than in the early group. This could be due to a secular trend in dental development in Finnish children. To further investigate the issue, larger samples and more children from additional generations should be evaluated. In order to rule out different age distribution of the samples as a possible confounding factor for DAA, the subjects for further studies should have a more even age distribution. Pertinent questions for dental age assessment are how long a reference sample maintains its validity, and when to replace the underlying reference data in order to assess dental age as closely to chronological age as possible.

In conclusion, the DARLInG dental age assessment method based on data from British Caucasian children is applicable to the current generation of Finnish patients of both sexes older than 10 years of age as well as to female patients younger than 10 years. Differences in dental maturation between two generations of Finnish

children were detected. Whether the differences found in this current study reflect a secular trend in dental development needs to be addressed in further research on larger population samples of children from different ethnic groups and from different generations.

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Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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