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The accuracy of three methods of age estimation using radiographic measurements of developing teeth

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Abstract

The accuracy of age estimation using three quantitative methods of developing permanent teeth was investigated. These were Mörnstad et al. [Scand. J. Dent. Res. 102 (1994) 137], Liversidge and Molleson [J. For. Sci. 44 (1999) 917] and Carels et al. [J. Biol. Bucc. 19 (1991) 297]. The sample consisted of 145 white Caucasian children (75 girls, 70 boys) aged between 8 and 13 years. Tooth length and apex width of mandibular canine, premolars and first and second molars were measured from orthopantomographs using a digitiser. These data were substituted into equations from the three methods and estimated age was calculated and compared to chronological age. Age was under-estimated in boys and girls using all the three methods; the mean difference between chronological and estimated ages for method I was -0.83 (standard deviation ±0.96) years for boys and -0.67 (±0.76) years for girls; method II -0.79 (±0.93) and -0.63 (±0.92); method III -1.03 (±1.48) and -1.35 (±1.11) for boys and girls, respectively. Further analysis of age cohorts, found the most accurate method to be method I for the age group 8.00–8.99 years where age could be predicted to 0.14 ± 0.44 years (boys) and 0.10 ± 0.32 years (girls). Accuracy was greater for younger children compared to older children and this decreased with age.

Keywords: Forensic odontology; Permanent tooth length; Tooth apex width; Radiographs; Age estimation

1. Introduction

Tooth development is frequently used to estimate age or maturation. The most widely used methods are usually based on subjective assessment of crown and root formation stage, however, an alternate approach is to use measurements of the developing tooth. The aim of this study was to test the accuracy of three methods of age estimation using tooth parameters digitised from radiographs of a group of children aged between 8 and 13 years of age. The methods are Mörnstad, Staaf and Welander [1], Liversidge and Molleson [2] and Carels, Kuijpers-Jagtman, Van der Linden and Van't Hof [3].

2. Method

This study was a retrospective study of rotational pantomographs (using Panelipse®) from 75 girls and 70 boys between 8.00 and 12.99 years of age (Table 1). These children were healthy white Caucasian patients attending the Paediatric and Orthodontic Departments of the Medical and Dental School of St. Bartholomew's and the Royal London Hospital and whose radiographs were taken as part of the routine treatment between 1992 and 1997.

Parameters on each radiograph were recorded by means of a digitiser attached to an X-ray viewer. Thirty-one points from five mandibular teeth were identified (Fig. 1) and co-ordinates registered using a digitiser (Geotech®, USA) with a resolution set at 0.3 mm. Each radiograph was digitised twice; data were only recorded if the 31 data points were within the selected resolution. A computer programme was written so that tooth parameters were substituted into equations from the three methods to calculate estimated age,

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Table 1
Age and sex distribution of sample studied

Age group	Boys	Girls	Total
>8	18	17	35
>9	17	18	35
>10	16	19	35
>11	4	14	18
>12	15	7	22
All	70	75	145

Age group >8 indicates age from 8.00 to 8.99 years.

allowing for the 1.19 × magnification. Chronological age for each subject was calculated using date of birth and date of X-ray [4]. Chronological age was subtracted from estimated age: a positive result represented an over-estimation; a negative result represented an under-estimation. Estimated age was compared to chronological age using *t*-test. For methods II and III, additional analysis of accuracy by tooth type was carried out.

These methods are as follows. Method I: This method is based on regression equations using a number of parameters of crown height, root length and apex width of different teeth and age based on orthopantomographs of Swedish children [1]. Age- and sex-specific regression equations for several age groups between 6 and 14 years are given; all of these calculate a single age from a combination of parameters. The present study tests the sex-specific equations for 8–13-year-old boys and girls. Method II: The regression equations tested for this method are based on tooth length data from an excavated 18th century coffin buried population at Spitalfields, London [2]. This is based on direct measurement as well as radiographic measurement for each tooth type; age was estimated from canine, both premolars and second molar tooth length and an average of all available teeth for each subject. Data from boys and girls were combined. Method III: This method is adapted from tooth length for age charts for a group of Dutch children [3]. These are sex-specific regression equations. Estimated age was calculated from the canine, both premolars and second molar tooth length and an average calculated for each subject. All readings were completed by the second author after a period of calibration and training. Intra-examiner reproducibility was calculated using paired *t*-test after re-examination of 17 radiographs. The mean difference between estimated age on the first and second readings was not significant (0.01 ± 0.16 years).

3. Results

Results are shown in Tables 2–5. All three methods significantly under-estimated age; methods I and II were similar in magnitude and girls were marginally more accurately aged than boys whilst method III under-estimated age by more than a year. Further breakdown of data into age cohorts are shown in Figs. 2–4 showing median and interquartile range. The accuracy was best for the youngest age group (>8 indicating age range from 8 to 8.99 years) using methods I and III and this decreased with age. Accuracy for method III was similar for age cohorts but was the least for the oldest age group. Analysis comparing accuracy by tooth type for methods II and III is illustrated in Figs. 5 and 6. The accuracy of method II ranged from −0.28 to −1.05 years; for method III it was between −2.00 and −2.64 years. Accuracy was similar for boys and girls. The most accurate tooth was the canine using method II. An unusual observation was the variation between age groups for this tooth shown in Fig. 7; other individual teeth showed little variation.

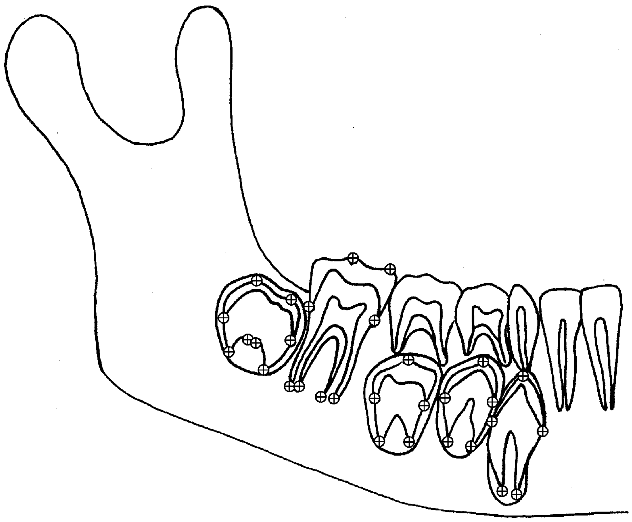

Fig. 1. Co-ordinates measured in digitising programme.

Table 2
Mean difference (*d*) in years between chronological and estimated ages, standard error of mean difference (SE*d*), 95% confidence interval of mean difference (95% CI*d*), standard deviation of mean difference (SD*d*) and 95% confidence interval of individual age (95% CIi)

Method	Sex	*N*	*d*	SE*d*	95% CI*d*	SD*d*	95% CIi
I	Boys	70	−0.83	0.11	−1.06, −0.61	0.96	−2.75, 1.09
	Girls	75	−0.67	0.09	−0.76, −0.58	0.76	−2.19, 0.85
II	Boys	70	−0.79	0.11	−1.01, −0.57	0.93	−2.65, 1.07
	Girls	75	−0.63	0.11	−0.84, −0.42	0.92	−2.47, 1.21
II	Boys	70	−1.03	0.18	−1.38, −0.68	1.48	−3.99, 1.93
	Girls	75	−1.35	0.13	−1.60, −1.10	1.11	−3.57, 0.87

Table 3
Mean difference (±standard deviation) in years between chronological age and estimated age for each age cohort

Age group	Sex	*N*	Method I	Method II	Method III
>8	Boys	18	0.14 (±0.44)	−0.52 (±0.70)	−0.67 (±1.03)
	Girls	17	0.10 (±0.32)	−0.38 (±0.66)	−0.17 (±0.85)
>9	Boys	17	−0.49 (±0.44)	−0.49 (±0.84)	−0.61 (±0.75)
	Girls	18	−0.37 (±0.60)	−0.60 (±1.00)	−0.93 (±0.64)
>10	Boys	16	−0.87 (±0.48)	−0.63 (±1.06)	−1.39 (±0.59)
	Girls	19	−0.78 (±0.55)	−0.76 (±0.80)	−1.72 (±0.55)
>11	Boys	4	−1.18 (±0.52)	−0.84 (±1.45)	−2.03 (±0.38)
	Girls	14	−1.22 (±0.46)	−1.08 (±0.82)	−2.16 (±0.96)
>12	Boys	15	−2.25 (±0.49)	−1.66 (±0.86)	−2.89 (±0.60)
	Girls	7	−1.87 (±0.37)	−1.54 (±0.73)	−2.74 (±0.64)

Age group >8 indicates 8.00 to 8.99 years of age.

Table 4
Mean difference (±SD) in years between chronological and estimated age: method II by tooth type for each age cohort

Age group	Sex	*N*	C	P1	P2	M2
>8	Boys + girls	34	0.11 (±1.44)	−1.00 (±0.86)	−0.82 (±0.80)	−0.62 (±0.58)
>9	Boys + girls	34	−0.33 (±1.02)	−1.08 (±1.24)	−0.72 (±1.37)	−1.04 (±0.76)
>10	Boys + girls	35	−0.10 (±0.79)	−0.56 (±1.28)	−0.39 (±1.54)	−1.11 (±0.87)
>11	Boys + girls	18	−0.73 (±0.37)	−0.56 (±1.15)	−0.31 (±2.05)	−1.32 (±1.36)
>12	Boys + girls	22	−1.72 (±1.16)	−1.42 (±1.13)	−0.57 (±1.38)	−1.44 (±1.49)
All		143	−0.28 (±1.25)	−0.92 (±1.17)	−0.58 (±1.40)	−1.05 (±1.01)

Table 5
Mean difference (±SD) in years between chronological and estimated age: method III by tooth type for each age cohort

Age group	Sex	*N*	C	P1	P2	M2
>8	Boys + girls	34	−1.73 (±0.87)	−1.96 (±0.81)	−2.76 (±0.70)	−1.63 (±0.59)
>9	Boys + girls	34	−2.02 (±0.78)	−2.13 (±1.10)	−2.19 (±1.13)	−2.00 (±0.76)
>10	Boys + girls	35	−2.36 (±0.92)	−1.83 (±1.03)	−2.12 (±1.15)	−2.09 (±0.76)
>11	Boys + girls	18	−3.04 (±0.57)	−2.03 (±0.87)	−2.35 (±1.51)	−2.51 (±0.99)
>12	Boys + girls	22	−3.96 (±1.13)	−2.94 (±0.89)	−2.82 (±0.95)	−2.84 (±0.92)
All	Boys	70	−2.64 (±1.20)	−2.26 (±1.06)	−2.31 (±1.07)	−2.13 (±0.89)
	Girls	73	−2.29 (±1.07)	−2.00 (±0.96)	−2.23 (±1.12)	−2.13 (±0.85)

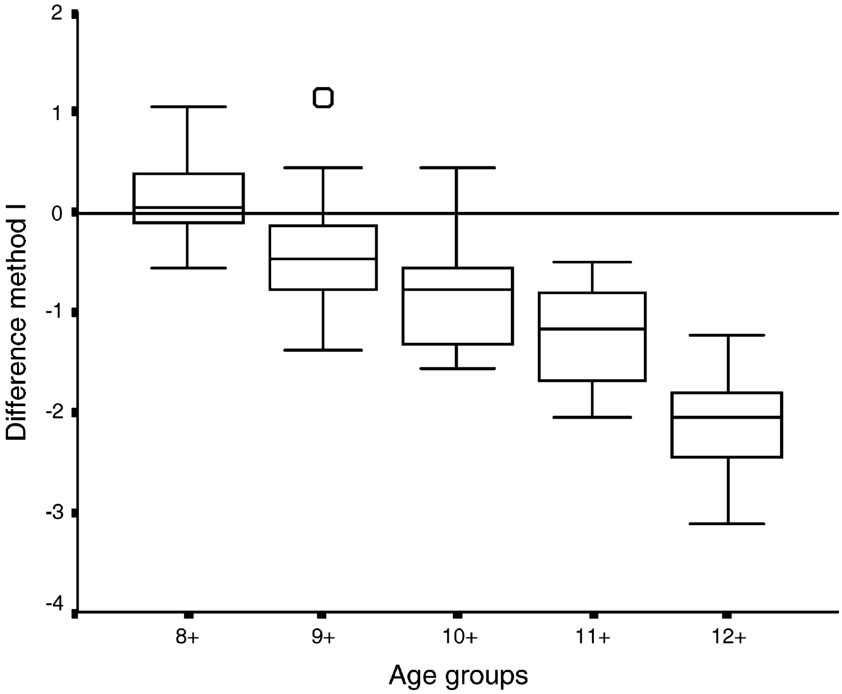

Fig. 2. Boxplot of difference between estimated and real age method I for age groups. Boxplot shows median and interquartile range, whiskers indicate the range.

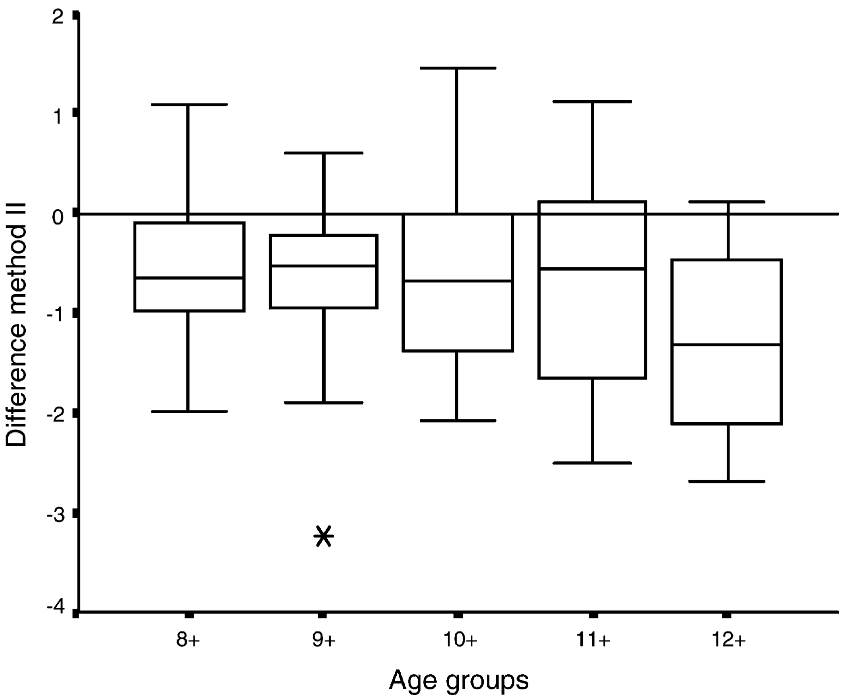

Fig. 3. Boxplot of difference between estimated and real age method II for age groups.

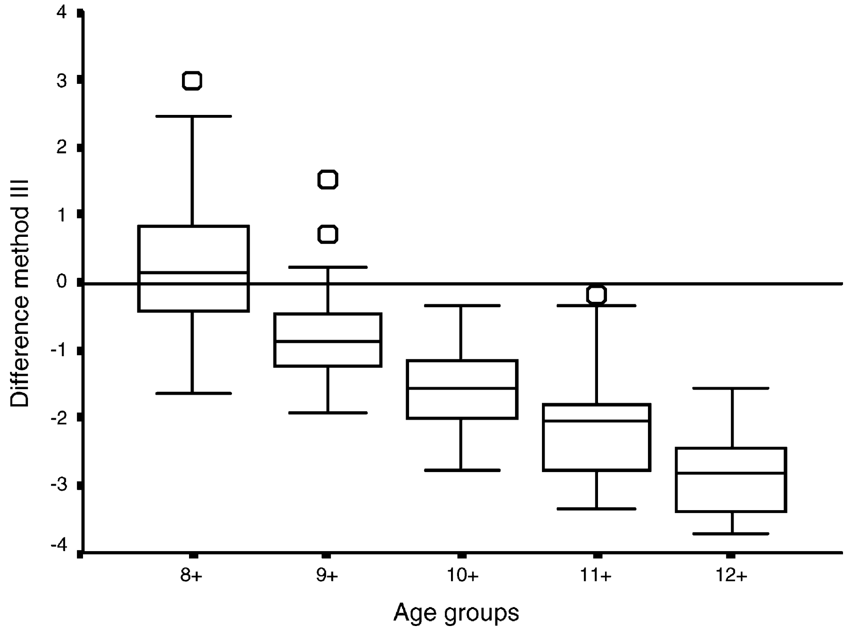

Fig. 4. Boxplot of difference between estimated and real age method III for age groups.

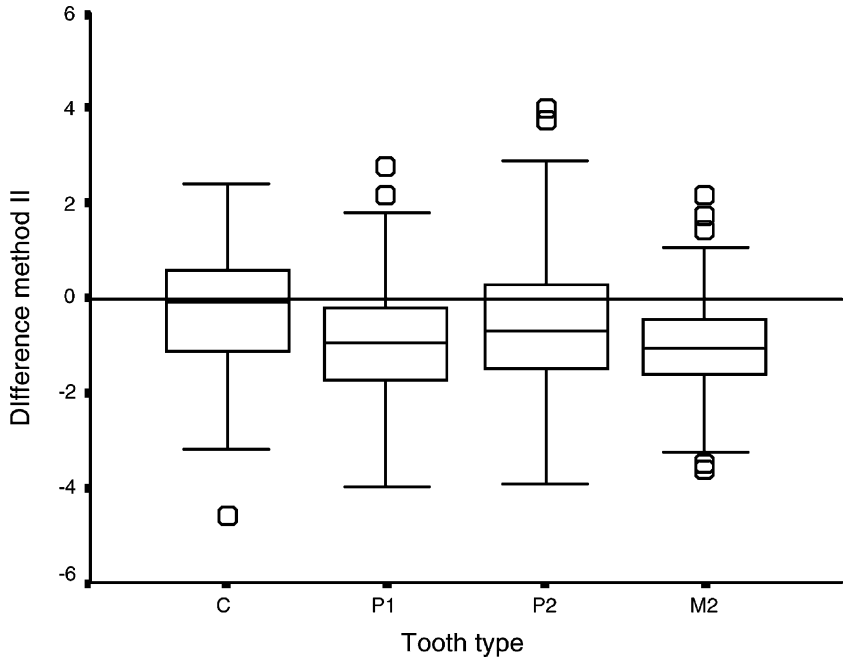

Fig. 5. Boxplot of difference between estimated and real age method II by tooth type.

4. Discussion

Accuracy of any age prediction method (the closeness of estimated age to chronological age) is influenced by several factors. Precision (the closeness of repeated measurements) of this quantitative method (here a digitiser linked to a radiograph) is high provided radiographs are selected for clear images in the area of landmarks. Several studies show that vertical dimensional measurements can be reliably made in panoramic radiography provided a correction is

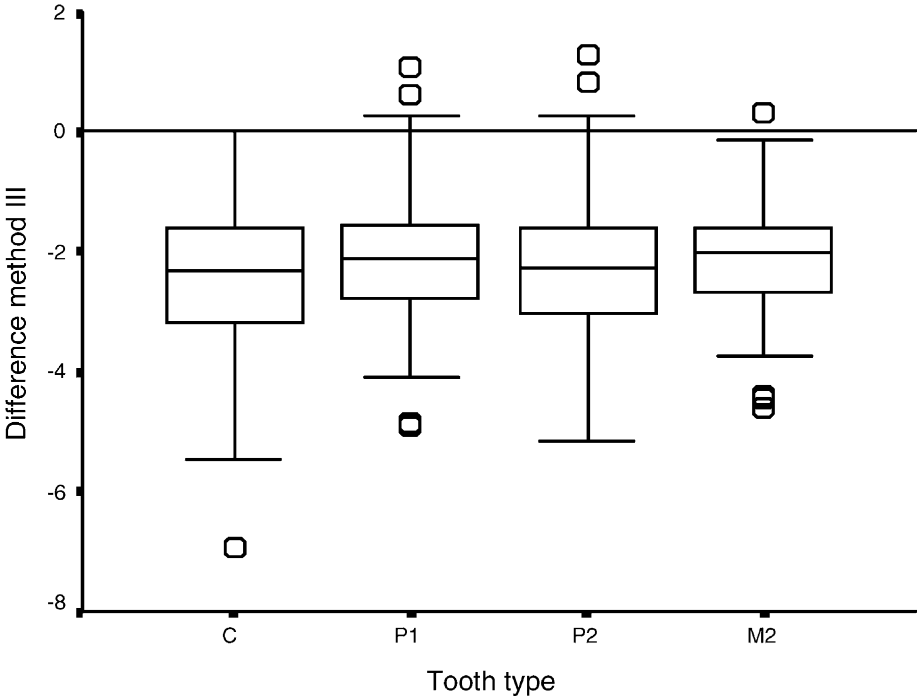

Fig. 6. Boxplot of difference between estimated and real age method III by tooth type.

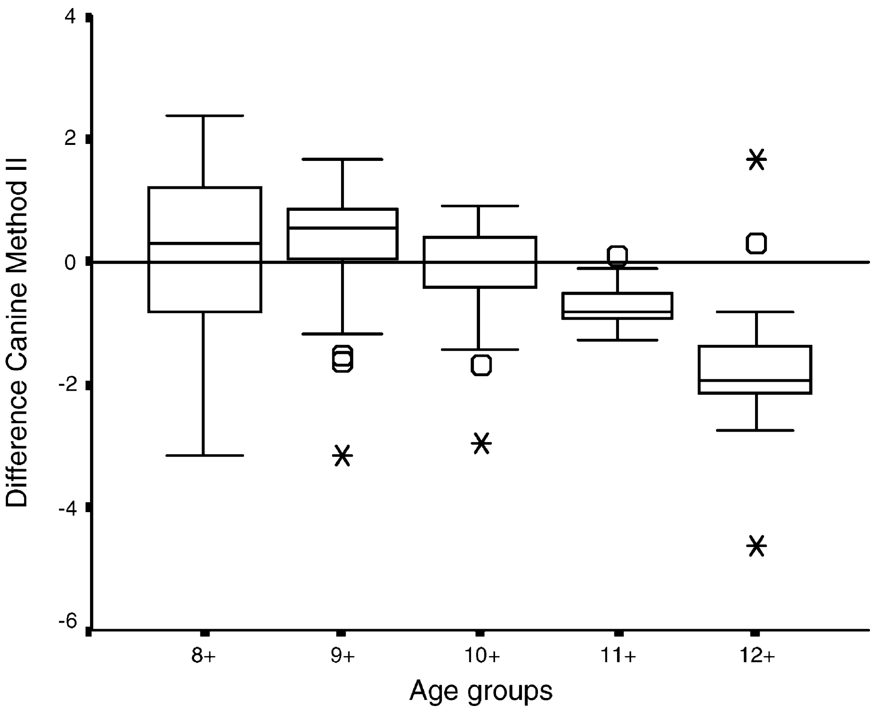

Fig. 7. Boxplot of difference between estimated and real age canine method II for age groups.

made using the magnification factor of the machine [5–8]. Positioning the child patient may also influence magnification; however, both methods I and III are based on radiographic measurements of large groups of children and the variation inherent in these methods is similar to the present study. Another factor affecting accuracy is the applicability of the reference material. If possible, standards of tooth formation should be appropriate for the population tested.

In addition, standards should be of sound design (encompassing entire growth period of teeth used, adequate age distribution and appropriate statistics), as the method is only as good as the data upon which it is based. In this regard, method II is deficient; it is based on only a few individuals for this age group reflected by the large standard deviation found in this study. Perhaps the most important factor affecting accuracy is individual biological variability of tooth development, and younger children were more accurately aged than older children using all three methods tested in this study. These quantitative methods use tooth or root length to predict age; with apex width of some developing teeth contributing to method I. However, tooth length of any individual tooth varies between children of the same age; this variation may be small in fetal or early postnatal growth but increases with age [9–15] with a sex difference becoming apparent in the canine. The pattern of decreasing accuracy with age using methods I and III (Figs. 2 and 4) may be due to differences in tooth length. Comparison of the average crown height, root length and apex width for the canine of the present study with the figures of Swedish children in Mörnstad et al. [1] show few differences. However, average canine length for age in the present study was significantly shorter than Dutch children in Carels et al. [2]. Original data were no longer available from this mixed longitudinal study (Carels, personal communication). Another factor explaining this difference is a possible shift in the timing of root maturation and apex closure or even a difference in the rate of eruption between these population groups. Data on individual tooth formation is not well documented for different European children, apart from Finnish children [16], although some regional variation in dental maturation as a whole using Demirjian and co-workers' method [17,18] has been suggested [19–21]. Tooth length of mature, unworn teeth between Scandinavian, Japanese, Nigerian and Dutch adults suggest that some variation exists between ethnic groups [22–25]. However, none of these factors explain the poor accuracy for the older age groups and this is compounded by the very small sample size of children older than 11 years.

Accuracy of predicting age using tooth formation is better for younger children compared to older children because of the fast rate of development and the presence of many developing teeth. This is particularly true in fetal and early postnatal growth where average predicted age has been reported as 1–2 weeks [26–29]. In early childhood, the average predicted age using crown and root growth using the longitudinal dental growth studies from birth [30,31], is around 0.5 year (95% confidence interval around 1 year) [29,32]. Demirjian's method tested on Chinese children 5–7-year-olds found 95% CI of up to 1.3 years [33]; for Norwegian children, a confidence interval of around a year for 6- and 9-year-olds and ±2 years for 12-year-olds were found [21]. Results from the present study of methods I and II are similar to other reports of accuracy for the age group 9–13 years, despite the small sample size. Several studies have specifically investigating accuracy of a number of tooth formation methods [34,35]. In a group of 100 children (aged 9.5 and 12.5 years), accuracy using the three methods of crown and root growth was from −0.63 to 0.86 years with a confidence interval of ±1 to ±2 years [34]. Another study of 6–14-year-olds [35], found accuracy to be between −0.89 and 0.55 years with a similar confidence interval depending on method, sex and age group. The accuracy of predicting age in adolescent and young adults, using the third molar formation is around 1–2 years (under-estimated) with 95% CI of between ±2 and 4 years [36–38].

5. Conclusion

The method of Mörnstad et al. [1] is the most accurate for >8-year-old age group of the three methods tested. All methods were more accurate for younger children compared to older children. These findings suggest that appropriate quantitative methods, possibly population-specific, are as good as appropriate qualitative methods of tooth formation in accurately predicting age from the developing dentition.

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