Dental age estimation in Somali children using the Willems et al. model

Metsäniitty, Mari

2018-11

Metsäniitty , M , Waltimo-Siren , J , Ranta , H , Fieuws , S & Thevissen , P 2018 , ' Dental age estimation in Somali children using the Willems et al. model ' , International Journal of Legal Medicine , vol. 132 , no. 6 , pp. 1779-1786 . https://doi.org/10.1007/s00414-018-1926-1

http://hdl.handle.net/10138/260564
https://doi.org/10.1007/s00414-018-1926-1

publishedVersion

International Journal of Legal Medicine (2018) 132:1779–1786
https://doi.org/10.1007/s00414-018-1926-1

ORIGINAL ARTICLE

Dental age estimation in Somali children using the Willems et al. model

Mari Metsäniitty [1] · Janna Waltimo-Sirén [2] · Helena Ranta [1] · Steffen Fieuws [3] · Patrick Thevissen [4]

Received: 31 January 2018 / Accepted: 23 August 2018 / Published online: 1 September 2018

Abstract

Aim The aim of the current study was to retrospectively collect dental panoramic radiographs from Somali children living in Finland, to use the radiographic data to develop a new age estimation model based on the model established by Willems et al. (J Forensic Sci 46(4):893–895, 2001), and to compare the age prediction performances of the Willems et al. model (WM) and the newly developed model.

Material and methods Dental panoramic radiographs from 808 healthy Somalis born in Finland were selected. The development of the seven left mandibular permanent teeth, from the central incisor to the second molar, was staged according to Demirjian et al. (Hum Biol 45(2):211–227, 1973). Radiographs with all listed permanent teeth completely developed were excluded. The studied sample consisted of 635 subjects (311 females, 324 males) ranging in age from 4 to 18 years. Kappa and weighted Kappa statistics were used to quantify intra- and inter-observer agreement in stage allocation. The collected dataset was used to validate the WM, constructed on a Belgian Caucasian reference sample, and to establish a Somali-specific age estimation model (SM) based on the WM. Both models were validated and their age prediction performances quantified using mean error (ME), mean absolute error (MAE) and root mean squared error (RMSE).

Results The SM resulted in a slight underestimation of age when the sex groups were analysed separately or combined, with ME varying between 0.04 (standard deviation (SD) 1.01) and 0.05 (SD 1.04) years, MAE between 0.77 and 0.80 years and RMSE between 1.01 and 1.04 years. The WM statistically significantly underestimated the age of females, with an ME of 0.20 (SD 1.01) years ($p = 0.0006$). For males, and for females and males combined, no statistically significant ME was observed.

Conclusion The WM and SM were similar in their age prediction performances, and the use of the WM in dental age assessment in the Somali population is justified.

Keywords Forensic age estimation · Dental development · Asylum seeker · Somali · Willems model

Introduction

Dental maturity can be registered and used to indicate dental age. Dental maturity status is widely used in forensics to estimate chronological age [1], as well as in orthodontics and paediatric dentistry for treatment planning and as a diagnostic tool [2]. In orthodontics, the assessment of dental age is beneficial for optimising the onset of treatment with fixed appliances, although it has been shown that dental age, like chronological age, is a poor predictor of pubertal growth spurt timing, which is generally assessed for optimising treatment with functional appliances [3, 4].

In forensics, dental age is commonly assessed for victim profiling in identification and to estimate the age of young individuals with uncertain identity. The latter use being most commonly employed for asylum seekers. In Finland, forensic age assessment data from 2015 revealed that unaccompanied asylum seekers coming from Afghanistan (56%), Iraq (19%)

✉ Mari Metsäniitty
mari.metsaniitty@helsinki.fi

[1] Department of Forensic Medicine, University of Helsinki, P.O. Box 40, Kytösuontie 11, 00014 University of Helsinki, Finland

[2] Department of Oral and Maxillofacial Diseases, University of Helsinki and Helsinki University Hospital, P.O. Box 41, Mannerheimintie 172, 00014 University of Helsinki, Finland

[3] Leuven Biostatistics and Statistical Bioinformatics Centre (L-BioStat), University of Leuven, Kapucijnenvoer 35, BE-3000 Leuven, Belgium

[4] Department of Imaging and Pathology, Forensic Odontology, KU Leuven Campus Saint- Raphael, Kapucijnenvoer 7, Block A, box 7001, BE-3000 Leuven, Belgium

and Somalia (17%) were most often investigated [5]. The first Somali asylum seekers arrived in Finland in the early 1990s following the mayhem of the civil war in Somalia. In 2016, there were 19,059 first- and second-generation Somalis in Finland [6].

The lack of African reference data, in particular from the Somali population, has been considered problematic in the legal age estimation context [7]. Although, scientifically, increasing evidence exists that ethnic differences are negligible in age estimations based on tooth development [8, 9], more confirmatory proof, especially related to comparisons including black populations, is needed. In fact, few studies of tooth development have been performed among sub-Saharan African populations [10–15]. Only Davidson and Rodd [16] have compared dental age and chronological age between Somali and Caucasian children.

Demirjian's dental age estimation method [17], constructed on a French-Canadian reference sample, is a widely used method to estimate age in children. After staging the development of the seven left mandibular permanent teeth (FDI 31–37), maturity scores are summed up and compared to reference tables or graphs. The age prediction performances of Demirjian's method have been validated in different populations and have resulted in the overestimation of chronological age [13, 18–20]. Willems et al. [18] adapted Demirjian's method using a large Belgian Caucasian reference sample and avoided calculating maturity scores. The Willems et al. model (WM) has been validated in multiple populations (Bangladeshi, Belgian Caucasian, Bosnian-Herzegovian, British Caucasian, Chinese, Former Yugoslav Republic of Macedonian, Malaysian, Serbian, Turkish) and proved to perform better than Demirjian's method [8, 18–19, 21–27]. Over- and underestimations have been reported within a mean error range of − 0.58 to 0.39 years. Therefore, the WM was selected for use in the current research.

The aim of the current study was to investigate the age prediction performances of the WM validated on Somali children. An additional purpose was to create a new Somali-specific age estimation model based on the WM and developed on a reference sample of Somali children born and living in Finland. The age prediction performances of the WM and the newly developed Somali model (SM) were compared.

Material and methods

Ethical approval was granted by the Research Ethics Committee of the Hjelt Institute, University of Helsinki (number 02/2010). All individuals eligible to be included in the current study were born in Finland after 1 January 1980. Both of an individual's parents had to be born in Somalia, their mother tongue had to be listed as Somali and their permanent address is Helsinki. According to the Finnish Population Register Centre, 2115 persons fulfilled the above criteria. The research permit was received from the division of Oral Health Care of the Department of Social Services and Health Care in Helsinki (HEL 2015-010918). Retrospectively, 1231 dental panoramic radiographs, used for diagnostic and treatment planning purposes, of 811 criteria-fitting Somali persons were collected from the dental files at the Department of Social Services and Health Care's division of Oral Health Care in Helsinki. Only one dental panoramic radiograph per person was included in the study. Subjects were excluded from the study if they were found to have any medical abnormalities affecting dental development (reducing the sample to 808 persons).

The development of the seven left mandibular permanent teeth (FDI 31 to 37) was staged according to Demirjian et al. [17]. In cases with one or more missing index teeth, the contra-lateral homologous teeth were used instead. When all the permanent teeth (31 to 37) were found to be mature (Demirjian stage H, $N = 120$), or when staging could not be performed due to bilaterally missing teeth ($N = 53$), the radiograph was excluded. Therefore, the final studied sample included 635 subjects (311 females, 324 males) in the age range of 4 to 18 years (Table 1).

To test the inter- and intra-observer agreement of the Demirjian staging, 37 panoramic radiographs were re-examined by the principal investigator and a second examiner after 2 months. Kappa and weighted Kappa statistics were used to quantify their agreement.

The Somali sample was used to validate the WM and to establish a Somali-specific age estimation model (SM) based on the WM. The SM was validated using leave-one-out cross-validation. Both models were analysed and compared on their

Table 1 Age and sex distribution of the Somali sample

Age/years	Female (%)	Male (%)	Total
4–4.99	1 (0.32)	3 (0.93)	4
5–5.99	6 (1.93)	7 (2.16)	13
6–6.99	20 (6.43)	19 (5.86)	39
7–7.99	46 (14.79)	33 (10.19)	79
8–8.99	48 (15.43)	42 (12.96)	90
9–9.99	47 (15.11)	50 (15.43)	97
10–10.99	34 (10.93)	48 (14.81)	82
11–11.99	35 (11.25)	41 (12.65)	76
12–12.99	25 (8.04)	35 (10.80)	60
13–13.99	25 (8.04)	23 (7.10)	48
14–14.99	12 (3.86)	12 (3.70)	24
15–15.99	11 (3.54)	6 (1.85)	17
16–16.99	0 (0.00)	3 (0.93)	3
17–17.99	1 (0.32)	2 (0.62)	3
Total	311	324	635

Table 2 Mean error (true age minus predicted age), mean absolute error and root mean squared error validating the Willems et al. model [18] on the collected Somali sample and the Somali model using leave-one-out cross-validation

		Willems model			Somali model		
Sex	*N*	ME (SD)	MAE (SD)	RMSE (95% CI)	ME (SD)	MAE (SD)	RMSE (95% CI)
F	307	0.20 (1.01)	0.78 (0.67)	1.02 (0.94;1.10)	0.04 (1.01)	0.77 (0.66)	1.01 (0.93;1.09)
M	321	− 0.02 (1.00)	0.77 (0.63)	0.99 (0.92;1.07)	0.05 (1.04)	0.80 (0.67)	1.04 (0.96;1.12)
F + M	628	0.09 (1.01)	0.78 (0.65)	1.01 (0.95;1.06)	0.04 (1.03)	0.79 (0.66)	1.03 (0.97;1.08)

All reported ME, MAE and RMSE values are expressed in years. *F*, female; *M*, male; *ME*, mean error; *SD*, standard deviation; *MAE*, mean absolute error; *RMSE*, root mean square error and *CI*, confidence interval

age prediction performances, calculating the difference between true age and the predicted age. The mean error (ME) presented over- or underestimations (i.e., bias), the mean absolute error (MAE) and root mean squared error (RMSE) quantified the magnitude of the errors (i.e., accuracy). Note that the MAE and RMSE reflect bias as well as lack of precision. The bias and the discrepancy between the age predictions of the WM and SM were evaluated using Wilcoxon signed rank tests. Spearman correlation between true age and the error in age estimation was used to evaluate if the direction and the magnitude of the difference depended on age. All statistical analyses were performed using SAS software, version 9.4 of the SAS System for Windows.

Results

The intra-observer agreement was excellent, with Kappa and weighted Kappa values equal to 0.95 (95% confidence interval (CI) 0.92 to 0.98) and 0.98 (95% CI 0.96 to 0.99), respectively. The inter-observer agreement was also excellent, with Kappa and weighted Kappa values equal to 0.97 (95% CI 0.95 to 1.00) and 0.99 (95% CI 0.98 to 1.00), respectively.

The validated WM overestimated age for males with an ME of − 0.02 years and underestimated age in the total sample (females + males) with an ME of 0.09 years, but these ME values were not significant ($p = 0.27$ and $p = 0.11$, respectively). The WM significantly underestimated the age of females, with an ME of 0.20 years ($p = 0.0006$). The MAE was 0.78 years in females, 0.77 years in males and 0.78 years in females and males combined. The RMSE was 1.02, 0.99, and 1.01 years for females, males and females and males combined, respectively (Table 2).

Validation of the SM resulted in a slight underestimation of age in the three respective sex groups, with MEs varying between 0.04 and 0.05 years, MAEs between 0.77 and 0.80 years and RMSEs between 1.01 and 1.04 years (Table 2).

Comparison between the performance of the WM and the SM revealed statistically significant differences ($p < 0.0001$) in ME 0.16 years in females and − 0.07 years in males. The MAE differed 0.01 years in females ($p > 0.05$) and 0.03 years in males ($p < 0.05$) (Table 3). Figures 1, 2 and 3 present the differences in ME and MAE in years by age categories in females, in males and in females and males combined. The RMSE values from the validated WM and SM were not constant over age and varied between the one-year age-categories (Table 4). The direction of the error (ME) depended on the true age: at younger ages, there was a tendency of overestimation, and at older ages, there was a tendency of underestimation (Spearman correlation between true age and the error in age estimation equalled 0.36, $p < 0.0001$).

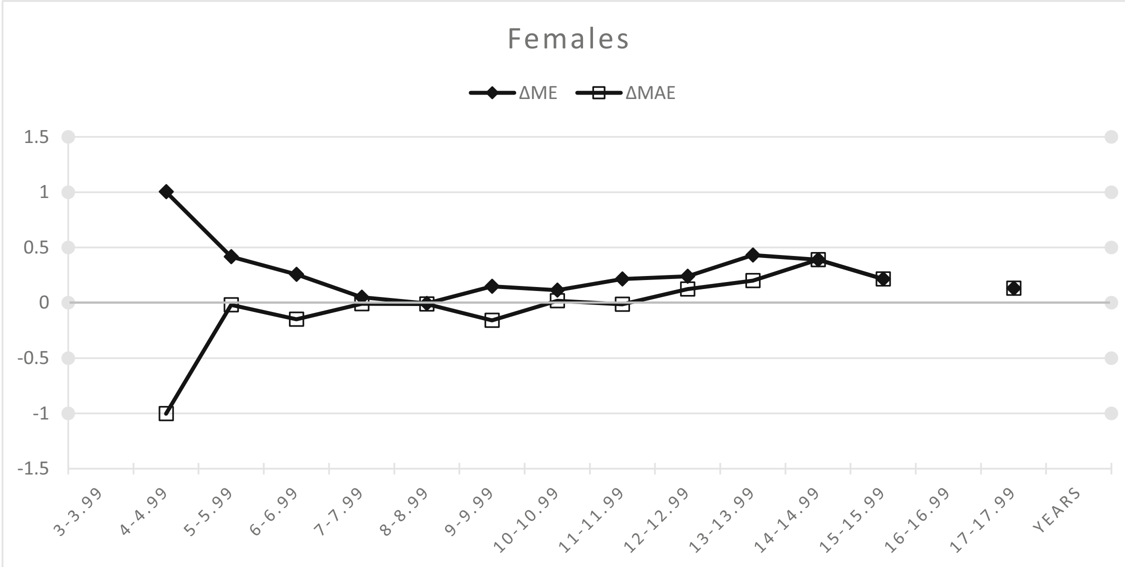
Discussion

The present study on the dental development of Somalis was undertaken to add to the few studies investigating dental development and age-related estimations in sub-Saharan Africans. In our study setting, it was possible to gather reliable data on individuals of ascertained ethnic background and chronological age, which may not necessarily apply to studies

Table 3 Differences in mean error (true age minus predicted age), mean absolute error and root mean square error between the validated Willems et al. model and the Somali model

	Difference bias		Difference accuracy		
Sex	ΔME	*p* value	ΔMAE	ΔRMSE	*p* value
F	0.16	< 0.0001	0.01	0.01	0.97
M	− 0.07	< 0.0001	− 0.03	− 0.05	0.0418
F + M	0.05	< 0.0059	− 0.01	− 0.02	0.18

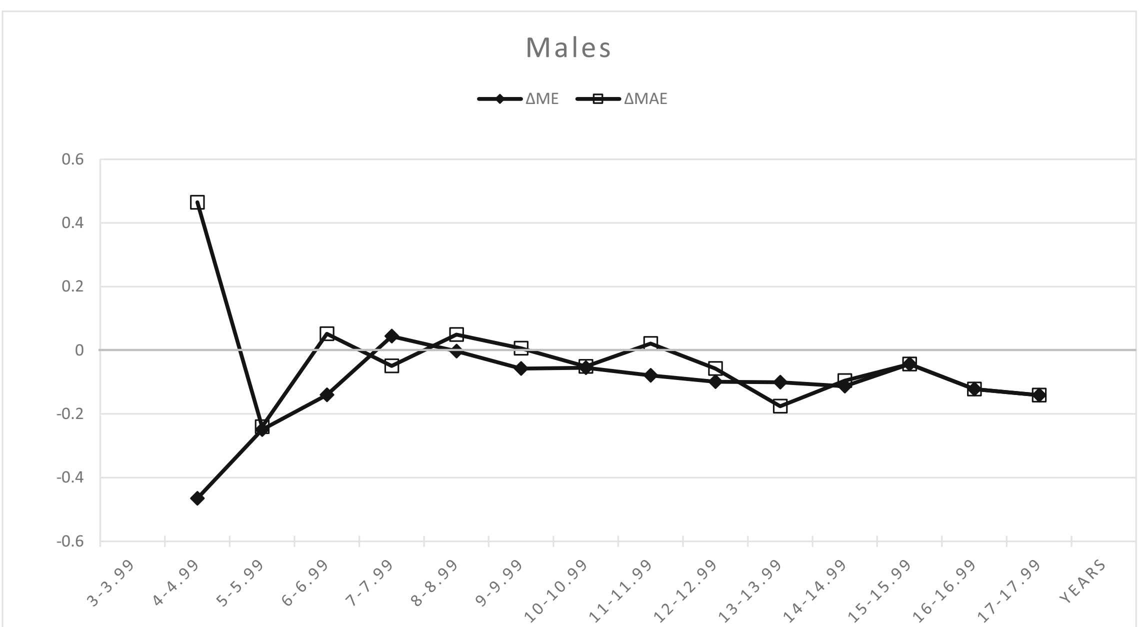
All reported ME, MAE and RMSE values are expressed in years. *F*, female; *M*, male; *ΔME*, difference in mean error; *ΔMAE*, difference in mean absolute error; *ΔRMSE*, difference in root mean square error; *p value*, *P* value from Wilcoxon signed rank test comparing the differences in true age and predicted age between the two models



ΔME difference in mean errors and ΔMAE difference in mean absolute errors. ME and MAE values are expressed in years

Fig. 1 Differences in mean errors and mean absolute errors obtained from the validated Willems et al. model and the Somali model in females, per age category of 1 year

performed locally. Phillips and van Wyk Kotze [11] constructed dental age-related tables in children of White and Coloured in South Africa ($N = 1006$), Indian ($N = 234$) and Black origin ($N = 236$; 171 Zulu and 65 Xhosa). The age range of the children they studied was 7 to 16 years. They showed differences in tooth development between the different ethnic groups, but the comparison results were difficult to interpret due to notable differences in the sample sizes and unequal age distributions within the samples. The sexes were not studied separately, and the size of the Black origin group was small. Davidson and Rodd [16] compared dental age with chronological age in Somali ($N = 81$) and Caucasian ($N = 81$) children under 16 years of age, resident in Sheffield, UK. Using Demirjian's method [17] to assess dental age, Somali children were significantly more advanced in dental development than the Caucasian children. The usefulness of the result is questionable, however, since it is unclear whether the exact age of Somali children was known, the Somali sample size was small



ΔME difference in mean errors and ΔMAE difference in mean absolute errors. ME and MAE values are expressed in years

Fig. 2 Differences in mean errors and mean absolute errors obtained from the validated Willems et al. model and the Somali model in males, per age category of 1 year

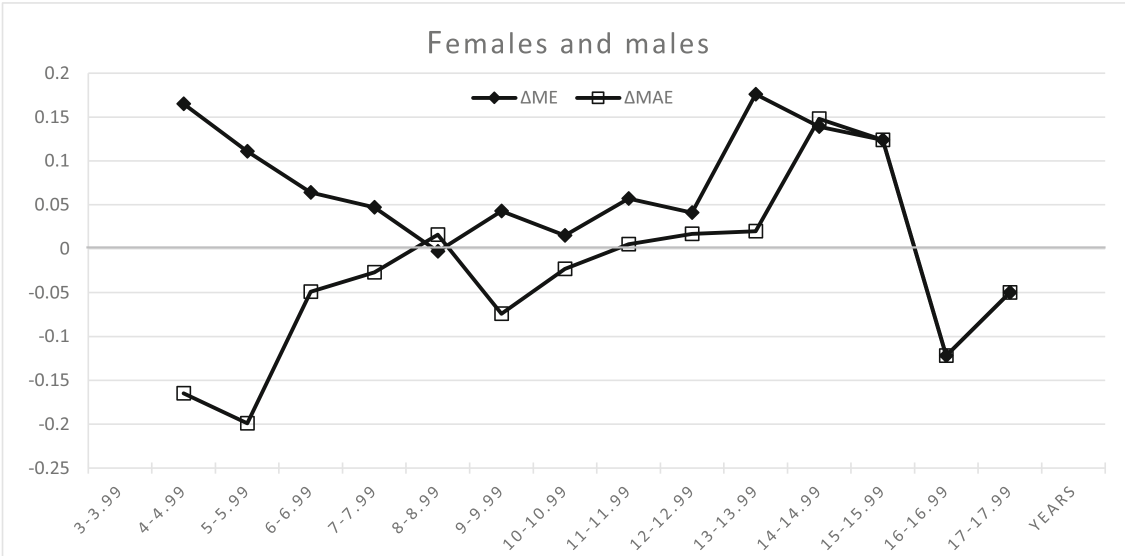


Fig. 3 Differences in mean errors and mean absolute errors obtained from the validated Willems et al. model and the Somali model in females and males combined, per age category of 1 year

($N = 81$), and precise information regarding the age distribution of the sample was lacking. The timing of mandibular tooth formation in two African groups was compared in a study by Elamin et al. [14]. The sample consisted of Sudanese children and young adults of Arab (802 females, 848 males) and African origin (402 females, 846 males) between 2 and 23 years old. Tooth development was radiographically assessed from each mandibular left permanent tooth using the Moorrees et al. [28] staging technique. Mean ages entering tooth stage were calculated using probit regression and compared using *t* tests. In general, the mean entering ages of most mandibular tooth formation stages were not significantly different between both ethnic groups or between females and males. Cavrić et al. [13] validated Demirjian's method [17] on children of African origin aged between 6.08 and 16.80 years in Gaborone, Botswana, using panoramic radiographs of 616 individuals (317 females, 299 males). The mean dental age was overestimated by 1.25 years ± 1.11 for males and 0.72 years ± 1.02 for females. A recent study by Willems et al. [15] validated the Willems model (WM) [18] on South African black children and a constructed WM-based South African-specific age estimation model. Small but clinically insignificant differences were found in validating the two models. These results were in concordance with the present study. Comparisons between these discussed results are possible, but are hampered by the varying study setups in the current study and the cited publications, except for the latter.

Indeed, a number of previous studies indicate that the ethnic influence on dental age estimation is not distinct [9, 19]. Vissen Thevissen et al. [29] performed their study on the third molars of nine country-specific populations (Belgium, China, Japan, Korea, Poland, Thailand, Turkey, Saudi Arabia and South India) and Maber et al. [19] on seven mandibular teeth (FDI 31 to 37) of Bangladeshi and British Caucasian origin individuals. In the present study, a trend similar to these studies was observed. The WM was validated on the collected Somali sample, and the calculated ME for females indicated a significant underestimation of 0.21 years (77 days), but an insignificant overestimation of − 0.02 years (7 days) for males and an underestimation of 0.09 years (33 days) for females and males combined (Table 2). Since the difference in actual value was small and clinically irrelevant, the WM is the age estimation method that can be used if a Somali-specific model (SM) is lacking. Moreover, the comparison between the WM and the developed SM revealed significant but small differences in biases of age predictions (Table 3): for females 0.16 years (58 days), for males − 0.07 years (26 days) and for females and males combined 0.05 years (18 days). In accuracy, there was a significant difference only for males: MAE 0.03 years (11 days) and RMSE 0.05 years (18 days) ($p = 0.0418$).

Because the analysed SM dataset was too small to split into a powerful enough training and test dataset, it was validated using the leave-one-out cross-validation. Therefore, only one subject was used as a test set, and a model was built on all the remaining subjects. The error was evaluated on the single subject that was held out and the procedure repeated for all subjects; next, all the obtained errors were averaged. A disadvantage was that if a tested subject had a score which did not appear in the training dataset, no prediction could be obtained for that subject when their score was entered as a categorical predictor into the model on the training dataset. To obtain fair comparisons between the validation results of the WM and SM models, a sample with only subjects able to be validated in both models was used. Due to the described disadvantage of the leave-one-out cross-validation, the original sample size

Table 4 Root mean squared error calculated for females and males from the validated Willems et al. and the Somali models per age category of 1 year. Individuals with stage H were excluded

	Age/ years	*N*	RMSE		ΔRMSE
			Willems et al. model	Somali model	
F	4–4.99	1	− 0.19 (− 1.89, 1.51)	1.19 (− 9.53, 11.91)	− 1.38
	5–5.99	3	0.69 (0.20, 1.17)	0.67 (− 0.20, 1.55)	0.02
	6–6.99	19	0.45 (0.30, 0.60)	0.61 (0.40, 0.82)	− 0.16
	7–7.99	46	0.66 (0.52, 0.80)	0.66 (0.52, 0.79)	0.00
	8–8.99	48	0.82 (0.65, 0.99)	0.82 (0.65, 0.99)	− 0.00
	9–9.99	47	0.84 (0.66, 1.01)	1.08 (0.85, 1.30)	− 0.24
	10–10.99	34	0.93 (0.70, 1.16)	1.00 (0.75, 1.24)	− 0.07
	11–11.99	35	1.05 (0.80, 1.31)	1.12 (0.85, 1.39)	− 0.07
	12–12.99	25	1.05 (0.74, 1.35)	0.95 (0.67, 1.22)	0.10
	13–13.99	25	1.29 (0.92, 1.67)	1.03 (0.73, 1.33)	0.26
	14–14.99	12	1.77 (0.98, 2.56)	1.35 (0.75, 1.95)	0.42
	15–15.99	11	1.95 (1.03, 2.86)	1.76 (0.93, 2.58)	0.19
	17–17.99	1	4.12 (32.88, 41.11)	3.99 (− 31.83, 39.80)	0.13
M	4–4.99	1	0.62 (− 0.19, 1.42)	− 0.14 (− 1.41, 1.13)	0.76
	5–5.99	7	0.98 (0.36, 1.59)	1.09 (0.40, 1.77)	− 0.11
	6–6.99	18	0.80 (0.53, 1.07)	0.79 (0.51, 1.06)	0.01
	7–7.99	33	0.80 (0.60, 1.00)	0.83 (0.62, 1.04)	− 0.03
	8–8.99	42	0.72 (0.56, 0.88)	0.67 (0.52, 0.81)	0.05
	9–9.99	50	0.86 (0.69, 1.04)	0.90 (0.72, 1.08)	− 0.04
	10–10.99	48	0.98 (0.78, 1.18)	1.02 (0.81, 1.23)	− 0.04
	11–11.99	41	0.93 (0.73, 1.14)	0.93 (0.72, 1.14)	0.00
	12–12.99	35	1.24 (0.94, 1.55)	1.34 (1.02, 1.67)	− 0.10
	13–13.99	23	1.03 (0.72, 1.35)	1.19 (0.83, 1.55)	− 0.16
	14–14.99	12	0.88 (0.49, 1.27)	1.03 (0.57, 1.48)	− 0.15
	15–15.99	6	1.78 (0.52, 3.04)	1.85 (0.54, 3.16)	− 0.07
	16–16.99	3	2.12 (− 0.63, 4.87)	2.24 (− 0.68, 5.14)	− 0.12
	17–17.99	2	2.86 (− 3.29, 9.00)	3.00 (− 3.45, 9.44)	− 0.14

F, females; *M,* males; *RMSE,* root mean squared error; Δ*RMSE,* difference in root mean square error. 95% confidence intervals for the RMSE are given between brackets

was reduced for this comparison from 635 (Table 1) to 628 (Table 2) subjects.

The good performance of validating the WM on the collected Somali children could partially be explained by the larger number of subjects in the Belgian Caucasian reference sample (WM, $N = 2116$, SM, $N = 635$) [18]. Larger samples tend to be a more accurate reflection of the population; hence, their sample means are more likely to be closer to the population mean. Even a small change in the number of subjects included in the considered sample can affect the outcome. To obtain an equal number of females in the comparison of error in age prediction between the WM and SM, in the current study, the validation sample was reduced from 311 to 307 subjects, increasing the ME of the WM from 0.20 to 0.21 years.

The age prediction performances were not constant over age (Table 4). The higher the true age, the larger the absolute error was (rho = 0.30, $p < 0.0001$). The direction of the error depended on the true age: at younger ages, there was a tendency of overestimation and at older ages a tendency of underestimation (Spearman correlation between true age and the error in age estimation equalled 0.36, $p < 0.0001$). This is a classical finding in the application of regression models [30].

Since the present study was considering Somali children living in Finland and not in their home country, a possible influence of environmental factors might have an effect on dental maturity. Related to nutrition, Jääsaari et al. [31] longitudinally studied the association between dental maturity and body mass index (BMI) in an unselected group of Finnish children at the ages of 6 and 12 years. Tooth development was registered according to Demirjian et al. [17] from the seven left mandibular permanent teeth (FDI 31–37) on 108 dental panoramic radiographs. Groups of delayed, average and advanced dental development were established and compared with normal and high BMI groups; energy intake was also studied with food records. They found no significant difference in BMI between delayed, normal or advanced dental maturity groups. However, the dental age in the advanced dental maturity group was advanced by 0.6 to 1.0 years when compared with the chronological age, and this group of children had a higher energy intake when compared with the average and delayed dental maturity groups ($p = 0.004$). They conclude that there might be an association between advanced dental maturity and BMI. A previous study has also reported advanced dental development in overweight or obese children [32]. Converse results demonstrating a delay of dental development in underweight children have not, to the best of our knowledge, been published. Elamin and Liversidge [33] studied dental development in malnourished and normal BMI groups of young Arabs in Sudan. The subjects ($N =$ 2115) were between 2 and 22 years old. No significant difference in tooth formation was detected between the two groups. This study showed that teeth have substantial biological stability and are insulated from nutritional deprivation.

As a relative limitation of the study, the subjects included here had undergone dental panoramic radiography for valid clinical reasons related to dental health and deviations from normal occlusal development. Except for some longitudinal studies [31, 34, 35], this is typical for most, if not all, recent studies, making them comparable with each other. Poor dental health that leads to precocious extractions of primary teeth has been shown to speed up the eruption and alter the crown-to-root ratio of the succedaneous permanent teeth [36, 37]. Nevertheless, dental developmental status is less affected than eruption status in subjects suffering from the premature loss of primary teeth [17]. Many of the children forming the material of the present study are likely to have exhibited malocclusion, since 95% of dental panoramic radiographs taken of children aged 7–12 years in the municipal healthcare centres in the City of Helsinki are taken for reasons related to orthodontics [38]. Although the study subjects were not analysed here for the presence or type of orthodontic problems, it is worth noting that individuals with discrepancies in jaw size have been shown to display advanced dental maturity in comparison to children with non-skeletal orthodontic problems; the difference reaches statistical significance in girls with mandibular prognathism [2].

Conclusion

The small differences in age prediction performances of the WM and the constructed SM reflect the usefulness of the Belgian population as a reference for forensic age predictions in Somali children living in Finland. The study also provides further support for the universal application of the WM to estimate age.

Funding information The Department of Oral and Maxillofacial Diseases, University of Helsinki, Finland funded the search of the sample from the Finnish Population Register Centre. The study was supported by a grant from the Association of Finnish Female Dentists. The authors are grateful to Senior Dental Officer Marja Noponen, DDS, PhD, and the personnel in the Unit for Specialised Oral Care in the Metropolitan Area and Kirkkonummi for arranging facilities for the study of radiographs and patient files. We thank Tuomo Maisala, DDS, in Oral Health Care, Helsinki, Finland for the search of the sample.

Compliance with ethical standards

Ethical approval was granted by the Research Ethics Committee of the Hjelt Institute, University of Helsinki (number 02/2010).

Conflicts of interest The authors declare that they have no conflicts of interest.

References

1. Schmeling A, Dettmeyer R, Rudolf E, Vieth V, Geserick G (2016) Forensic age estimation: methods, certainty, and the law. www.aerzteblatt-international.de/ref0416
2. Celikoglu M, Erdem A, Dane A, Demirci T (2011) Dental age assessment in orthodontic patients with and without skeletal malocclusions. Orthod Craniofacial Res 14(2):58–62. https://doi.org/10.1111/j.1601-6343.2011.01508.x
3. DuPlessis E, Araujo E, Behrents R, Kim K (2016) Relationship between body mass and dental and skeletal development in children and adolescents. Am J Orthod Dentofac Orthop 150(2):268–273. https://doi.org/10.1016/j.ajodo.2015.12.031
4. Litsas G, Lucchese A (2016) Dental and chronological ages as determinants of peak growth period and its relationship with dental calcification stages. Open Dent J 10:99–108. https://doi.org/10.2174/1874210601610010099
5. Metsäniitty M, Varkkola O, Waltimo-Sirén J, Ranta H (2017) Forensic age assessment of asylum seekers in Finland. Int J Legal Med 131:243–250. https://doi.org/10.1007/s00414-016-1498-x
6. Statistics Finland. Statistics Finland's PX-Web databases. Population 31.12. by region, language, age, sex and year. http://www.stat.fi/tup/suoluk/suoluk_vaesto_en.html
7. Gunawardena S, Liyanage U, Weeratna J, Mendis N, Perera H, Jayasekara R, Fernando R (2017) Forensic age estimation in anti-piracy trials in Seychelles: experiences and challenges faced. Forensic Sci Int 270:278.e1–278.e7. https://doi.org/10.1016/j.forsciint.2016.11.010
8. Liversidge H, Smith B, Maber M (2010) Bias and accuracy of age estimation using developing teeth in 946 children. Am J Phys Anthropol 143:545–554. https://doi.org/10.1002/ajpa.21349
9. Thevissen P, Alqerban A, Asaumi J, Kahveci F, Kaur J, Kim YK, Pittaypat P, Van Vlierberghe M, Zhang Y, Fieuws S, Willems G (2010) Human dental age estimation using third molar developmental stages: accuracy of age predictions not using country specific information. Forensic Sci Int 201:106–111
10. Olze A, van Niekerk P, Schmidt S, Wernecke K-D, Rösing F, Geserick G, Schmeling A (2006) Studies on the progress of third-

molar mineralisation in a black African population. Homo 57:209–217

11. Phillips V, van Wyk Kotze T (2009) Dental age related tables for children of various ethnic groups in South Africa. J Forensic Odontostomatol 27:29–44
12. Cavrić J, Galić I, Vodanović M, Brkić H, Gregov J, Viva S, Rey L, Cameriere R (2016) Third molar maturity index (I3M) for assessing age of majority in a black African population in Botswana. Int J Legal Med 130:1109–1120. https://doi.org/10.1007/s00414-016-1344-1
13. Cavrić J, Vodanović M, Marušić A, Galić I (2016) Time of mineralization of permanent teeth in children and adolescents in Gaborone, Botswana. Ann Anat 203:24–32. https://doi.org/10.1016/j.aanat.2015.08.001
14. Elamin F, Hector M, Liversidge H (2017) The timing of mandibular tooth formation in two African groups. Ann Hum Biol 44(3):261–272. https://doi.org/10.1080/03014460.2016.1213313
15. Willems G, Lee S-S, Uys A, Bernitz H, Cadenas de Llano-Pérula M, Fieuws S, Thevissen P (2017) Age estimation based on Willems method versus new country-specific method in South African black children. Int J Legal Med. https://doi.org/10.1007/s00414-017-1686-3
16. Davidson L, Rodd H (2001) Interrelationships between dental age and chronological age in Somali children. Community Dent Health 18:27–30
17. Demirjian A, Goldstein H, Tanner J (1973) A new system of dental age assessment. Hum Biol 45:211–227
18. Willems G, Van Olmen A, Spiessens B, Carels C (2001) Dental age estimation in Belgian children: Demirjiani's technique revisited. J Forensic Sci 46:893–895
19. Maber M, Liversidge H, Hector M (2006) Accuracy of age estimation of radiographic methods using developing teeth. Forensic Sci Int 159S:S68–S73
20. Flood S, Franklin D, Turlach B, McGeachie J (2013) A comparison of Demirjian's four dental development methods for forensic age estimation in South Australian sub-adults. J Forensic Legal Med 20:875–883. https://doi.org/10.1016/j.jflm.2013.07.002
21. Galić I, Vodanović M, Cameriere R, Nakas E, Galić E, Selimović E, Brkić H (2011) Accuracy of Cameriere, Haavikko, and Willems radiographic methods on age estimation on Bosnian-Herzegovian children age groups 6-13. Int J Legal Med 125(2):315–321. https://doi.org/10.1007/s00414-010-0515-8
22. Ye X, Jiang F, Sheng X, Huang H, Shen X (2014) Dental age assessment in 7 - 14-year-old Chinese children: comparison of Demirjian and Willems methods. Forensic Sci Int 244:36–41. https://doi.org/10.1016/j.forsciint.2014.07.027
23. Ambarkova V, Galić I, Vodanović M, Biočina-Lukenda D, Brkić H (2014) Dental age estimation using Demirjian and Willems methods: cross sectional study on children from the Former Yugoslav Republic of Macedonia. Forensic Sci Int 234(187):e1–e7. https://doi.org/10.1016/j.forsciint.2013.10.024
24. Nik-Hussein N, Kee K, Gan P (2011) Validity of Demirjian and Willems methods for dental age estimation for Malaysian children aged 5-15 years old. Forensic Sci Int 204(1–3):208.e1–208.e6. https://doi.org/10.1016/j.forsciint.2010.08.020
25. Djukic K, Zelic K, Milenkovic P, Nedeljkovic N, Djuric M (2013) Dental age assessment validity of radiographic methods on Serbian children population. Forensic Sci Int 231:398.e1–398.e5. https://doi.org/10.1016/j.forsciint.2013.05.036
26. Onat Altan H, Altan A, Bilgiç F, Akıncı Sözer Ö, Damlar İ (2016) The applicability of Willems' method for age estimation in southern Turkish children: a preliminary study. J Forensic Legal Med 38:24–27. https://doi.org/10.1016/j.jflm.2015.11.015
27. Akkaya N, Yilanci H, Göksülük D (2015) Applicability of Demirjian's four methods and Willems method for age estimation in a sample of Turkish children. Legal Med 17:355–359. https://doi.org/10.1016/j.legalmed.2015.04.003
28. Moorrees C, Fanning E, Hunt EE (1963) Age variation of formation stages for ten permanent teeth. J Dent Res 42:1490–1502
29. Thevissen PW, Fieuws S, Willems G (2010) Human third molars development: comparison of 9 country specific populations. Forensic Sci Int 201(1–3):102–105. https://doi.org/10.1016/j.forsciint.2010.04.054
30. Aykroyd R, Lucy D, Pollard A, Solheim T (1997) Technical note: regression analysis in adult age estimation. Am J Phys Anthropol 104(2):259–265
31. Jääsaari P, Tolvanen M, Niinikoski H, Karjalainen S (2016) Advanced dental maturity of Finnish 6 to 12-yr- old children is associated with high energy intake. Eur J Oral Sci 124(5):465–471. https://doi.org/10.1111/eos.12292
32. Chehab DA, Tanbonliong T, Peyser J, Udin RT (2017) Association between body mass index and dental age in Hispanic children. Gen Dent 65(4):54–58
33. Elamin F, Liversidge H (2013) Malnutrition has no effect on the timing of human tooth formation. PLoS One 8(8):e72274. https://doi.org/10.1371/journal.pone.0072274
34. Nyström M, Kleemola-Kujala E, Evalahti M, Peck L, Kataja M (2001) Emergence of permanent teeth and dental age in a series of Finns. Acta Odontol Scand 59:49–56
35. Krekmanova L, Carlstedt-Duke J, Marcus C, Dahllöf G (1999) Dental maturity in children of short stature - a two-year longitudinal study of growth hormone substitution. Acta Odontol Scand 57(2):93–96
36. Brin I, Koyoumdijsky-Kaye E (1981) The influence of premature extractions of primary molars on the ultimate root length of their permanent successors. J Dent Res 60:962–965
37. Kim C, Hong Y, Han D, Hong H, Kim Y, Bae K (2011) A prospective cohort study on emergence of permanent teeth and caries experience in Korean children. Int J Paediatr Dent 21:254–260. https://doi.org/10.1111/j.1365-263X.2011.01114.x
38. Pakbaznejad Esmaeili E, Ekholm M, Haukka J, Waltimo-Sirén J (2016) Quality assessment of orthodontic radiography in children. Eur J Orthod 38:96–102