

Age estimation based on Willems method versus new country specific method in South African black children.

Guy Willems¹, Sang Seob², Andre Uys³, Herman Bernitz³, Maria Cadenas de Llano-Pérula¹, Steffen Fieuws⁴, Patrick Thevissen⁵

1. Department of Oral Health Sciences - Orthodontics, KU Leuven & Dentistry, University Hospitals Leuven, Leuven, Belgium

2. Medical Examiner's Office, National Forensic Service, Wonju, Korea

3. Department of Oral Pathology and Oral Biology, School of Dentistry, University of Pretoria, Private bag X20, Hatfield 0028, South Africa

4. Interuniversity Institute for Biostatistics and Statistical Bioinformatics, KU Leuven and University Hasselt, Leuven, Belgium

5. Department of Oral Health Sciences - Forensic Dentistry, KU Leuven & Dentistry, University Hospitals Leuven, Leuven, Belgium

Corresponding Author:

Prof Dr Guy Willems
guy.willems@kuleuven.be
+32 16 33.27.50

Abstract

Aim To develop new maturity scores for dental age estimation in South African black children according to Willems method, which was developed based on Belgian Caucasian (BC) reference data [Willems G, Van Olmen A, Spiessens B, Carels C (2001) *Dental age estimation in Belgian children: Demirjian's technique revisited. J Forensic Sci* 46 (4):893-895] and to compare age prediction performance of both methods.

Subjects and Methods A total of 986 panoramic radiographs of healthy South African black (SAB) children (493 males and 493 females) in the age range of 4.14 to 14.99 yrs (mean age 10.06 yrs) were selected for obtaining developmental staging scores [according to Demirjian A, Goldstein H, Tanner JM (1973) *A new system of dental age assessment. Hum Biol* 45 (2):211-227]. Willems BC methodology was applied to develop new country specific maturity scores (Willems SAB). Age prediction performance of Willems BC and Willems SAB were compared.

Results On average Willems BC renders acceptable results with an overestimation of chronological age of 0.06 yrs (SD 0.88 yrs) in SAB children. Compared to Willems SAB the overall mean absolute error was slightly higher with Willems BC (0.62 yrs and 0.68 yrs, respectively), but this was not significant in males. Also the root mean squared error was marginally higher in Willems BC.

Conclusion The new age prediction method developed in South African black children was found to be better compared to Willems BC, although the difference seems to be small and clinically not relevant, especially in males.

Keywords

Age Determination by Teeth, Child, South Africa

Introduction

Human age estimation has been a topic of interest since recorded history and many parameters of the developing human body have been studied and related to chronological age in living individuals. Only since second half of last century, a scientific approach to the matter was initiated, leading to a plethora of reported age estimation methods, concentrating on either children or subadults. [1,2] The reason is that growth and development offer a wealth of relatively quickly changing age related parameters in children at different locations in the human body. In adults these parameters are less obvious and generating much larger confidence intervals. [3]

In children, the most well known and extensively studied age estimation methods are based on the development of the hand and wrist bones [4,5] and the teeth. Both have the advantage covering a fairly wide time range in life span, namely from birth till early adulthood. It has been reported that long bones are particularly sensitive to environmental and nutritional conditions which might be reflected in their development. [6] In contrast, tooth development seems to be less easily disturbed and mainly genetically controlled, rendering teeth as more reliable identifiers of chronological age. [6-9] Among the available dental age estimation methods, the most frequently and widely employed was described by Demirjian et al. [10] These authors designed a scientific tooth development staging technique and a related age estimation method based on the development of the first seven left mandibular permanent teeth. However the method was found to be prone to consistent under- or overestimation of individuals' chronological age based on numerous validation studies in a large number of nationalities. Willems et al revised the Demirjian et al [10] age estimation method using a large sample of the Belgian Caucasian population (Willems BC). [11] The revised method was found to provide better age prediction performances, validated in and compared with different nationalities and ethnicities, if seven developing teeth are available. [12-22]

With recent world migration issues in mind, human age estimation is triggering interest of contemporary society, expressing the need for alternative documentation of the chronological age i.e. in case of unaccompanied minor fugitives. This concerns providing answers to both the issue of classifying subadults as minor or major, as well as chronological age estimation in children. Contemporary society requires such age information, both in civil and criminal law, as well as for socioeconomic and administrative purposes.

Since third molars are the only teeth in development in the age range around 18 years it is not surprising that these have been extensively studied in numerous populations and according to varying methods. [23-26] At present the

work of Thevissen et al has been able to provide a reasonable answer on the age of majority issue by creating a very large and standardized radiographic database of third molars assembled in many different country specific populations. [23]

In children often a need for age estimation exists for different kinds of reasons such as human trafficking, child pornography, adoption of children lacking birth certificates, competitive sports etc. The revised method described by Willems et al [11] was frequently applied for this purpose. However, one of the main criticisms of that method is that it has never been validated on a Sub-Saharan sample. In order to overcome this limitation the aim of the present study was twofold. First to establish a new country specific age estimation method according to Willems BC method [11] using a South African Black reference sample with known chronological age (Willems SAB method), and second, to compare the age prediction performances of Willems SAB method with that of the original Willems BC method.

Materials and methods

Ethical approval was granted by the Faculty of Health Sciences Research Ethics Committee, University of Pretoria (number 122/2014 20.06.2014). The electronic radiographic database of the School of Dentistry, University of Pretoria, was retrospectively searched for digital dental panoramic radiographs. They were included in the present study if they belonged to healthy black South African children with registered birth certificates proving their exact birth dates. All radiographs were taken within the School of Dentistry, University of Pretoria using Orthopantomograph®/Orthoceph® (OP200D/OC200D, Instrumentarium, Tuusula, Finland) and stored as digital images in jpg format using the original Cliniview 10.1 software (Instrumentarium, Finland).

In the age range between 6.00 and 15.99 year, it was aimed to select 50 female (F) and 50 male (M) subjects in each age category of one year. In the age categories 4.00-4.99 and 5.00-5.99 year only 22 (12 F, 10 M) and 64 (31 F, 33 M) subjects could be collected, respectively. It was noted that all subjects (n=99) in the 15.00-15.99 age cohort showed complete tooth development of all seven left permanent mandibular teeth. Therefore, this age cohort was omitted from the present analysis.

Panoramic radiographs with poor image and diagnostic quality were excluded from the study. Radiographs showing agenesis of at least two bilateral corresponding teeth in the mandible (except third molars) and

radiographs of cleft lip and palate patients as well as patients with craniofacial deformities that were apparent on the images, were not selected.

Table 1 displays the sex distribution of the study sample by age categories of 1 year.

All seven left permanent mandibular teeth (except third molar) were staged and according to the Demirjian et al staging technique. [10] These scores were used to estimate age based on the Willems BC method. [11] Specific regression coefficients were obtained for South African Black children from a fit of the model on the full black South African dataset according to the Willems BC method. [11] Next, the dataset was split into a training and test dataset stratified on sex and age category (Table 2). A model was fitted on the subjects of the training dataset and this model was validated on the test dataset. Note that 4 female subjects in the test dataset had scores which did not appear in the training dataset, hence no prediction could be obtained. Therefore these 4 cases were removed from the test dataset, yielding 484 test cases in total (244 males and 240 females). The bias and accuracy of both approaches (Willems BC method versus Willems SAB method) was evaluated in general and by sex and age categories. The mean difference between estimated dental age and chronological age (mean error, i.e. bias), the mean absolute error (MAE) and the root mean squared error (RMSE) were compared using Wilcoxon signed rank tests. A McNemar test was used to compare the proportion of children with a $MAE \leq 1$ year. It is generally reasonable, when faced with alternative point estimators for age, to use the estimator with the smallest RMSE or smallest MAE.

Inter- and intraobserver error of the Demirjian et al staging technique was not specifically re-evaluated in the present study since throughout the last decennia it has been shown repeatedly that good inter and intra-observer agreement was obtained. [25,27,28] All statistical analyses were performed using SAS statistical software package (SAS Institute, Cary, NC, USA).

Results

Table 3 shows the frequency of the obtained developmental staging scores according to Demirjian et al [10] and categorized by age. A total of 7595 scores were generated for the present South African Black population sample.

Table 1: Total number of included subjects (n=986), their sex distribution and age descriptives (in years) per one year age cohort.

Age	Total	F	M	mean	SD	median	min	max	Q1	Q3
4-5	22	12	10	4.61	0.27	4.61	4.14	4.97	4.40	4.88
5-6	64	31	33	5.55	0.30	5.62	5.02	5.99	5.33	5.82
6-7	100	50	50	6.54	0.29	6.57	6.00	6.99	6.29	6.81
7-8	100	50	50	7.56	0.28	7.61	7.01	7.99	7.31	7.77
8-9	101	51	50	8.49	0.29	8.45	8.00	9.00	8.27	8.75
9-10	100	49	51	9.44	0.27	9.44	9.01	10.00	9.22	9.65
10-11	99	50	49	10.48	0.28	10.47	10.00	10.99	10.25	10.75
11-12	101	50	51	11.56	0.27	11.53	11.02	12.00	11.34	11.79
12-13	100	51	49	12.53	0.28	12.51	12.00	13.00	12.30	12.78
13-14	99	49	50	13.49	0.30	13.50	13.01	14.00	13.23	13.74
14-15	100	50	50	14.50	0.29	14.48	14.01	15.00	14.24	14.73

A total number of 986 panoramic radiographs were selected from 986 children (mean age 10.06y; standard deviation 2.88y; median 10.04y; range 4.14y - 14.99y; Quartile1 7.67y; Quartile3 12.54y). including 493 males (mean age 10.07y; standard deviation 2.88y; median 10.01y; range 4.23y - 14.99y; Quartile1 7.64y; Quartile3 12.47y) and 493 females (mean age 10.05y; standard deviation 2.89y; median 10.06y; range 4.14y - 14.99y; Quartile1 7.71y; Quartile3 12.57y).

Age: age groups of one year (i.e. 4.00-4.99 and so on); Total: total number of subjects per age category; F: total number of female subjects per age category; M: total number of male subjects per age category; Descriptive statistics per age category of one year: mean age and standard deviation (SD), median age, minimum age, maximum age, and ages at percentile 25 (Q1) and percentile 75 (Q3)

Table 2: Total number of included subjects for the training and test dataset stratified on sex and age.

	Training data	Test data	Total data
Sex			
F	249	244*	493
M	249	244	493
Total	498	488	986
Age			
4-5	11	11*	22
5-6	33	31	64
6-7	50	50	100
7-8	50	50	100
8-9	51	50	101
9-10	51	49	100
10-11	50	49	99
11-12	51	50	101
12-13	51	49	100
13-14	50	49	99
14-15	50	50	100
Total	498	488	986

Age: age groups of one year (i.e. 4.00-4.99 and so on)

(*) 4 females of age category 4-5 years had a score C on *t32*, a score which did not occur in the training set. As such, no prediction based on Willems SAB could be obtained.

Table 3: Frequency of Demirjian et al [10] developmental staging scores of all seven permanent left mandibular teeth by sex and age category

<i>Demirjian score</i>	<i>Sex</i>	<i>Age</i>												<i>Total</i>
		<i>4-5</i>	<i>5-6</i>	<i>6-7</i>	<i>7-8</i>	<i>8-9</i>	<i>9-10</i>	<i>10-11</i>	<i>11-12</i>	<i>12-13</i>	<i>13-14</i>	<i>14-15</i>	<i>15-16</i>	
<i>B</i>	<i>F</i>	16	3	1	0	0	0	0	0	0	0	0	0	20
	<i>M</i>	8	7	0	0	0	0	0	0	0	0	0	0	15
<i>C</i>	<i>F</i>	21	64	24	1	0	0	0	0	0	0	0	0	110
	<i>M</i>	32	72	38	2	0	1	0	0	0	0	0	0	145
<i>D</i>	<i>F</i>	16	54	84	46	16	7	2	0	0	0	0	0	225
	<i>M</i>	15	57	81	74	37	24	5	0	0	0	0	0	293
<i>E</i>	<i>F</i>	25	66	96	121	115	51	15	3	0	0	0	0	492
	<i>M</i>	15	60	105	121	108	82	44	10	3	0	0	0	548
<i>F</i>	<i>F</i>	6	30	90	60	74	128	136	84	50	21	3	0	682
	<i>M</i>	0	32	91	77	68	97	137	139	69	33	8	0	751
<i>G</i>	<i>F</i>	0	0	55	106	74	26	38	78	93	80	50	0	600
	<i>M</i>	0	3	35	71	80	59	20	49	87	105	63	0	572
<i>H</i>	<i>F</i>	0	0	0	16	78	131	159	185	214	242	297	0	1322
	<i>M</i>	0	0	0	5	57	94	137	159	184	212	279	0	1127
<i>Total</i>	<i>F</i>	84	217	350	350	357	343	350	350	357	343	350	0	3451
	<i>M</i>	70	231	350	350	350	357	343	357	343	350	350	0	3451

Age: age groups of one year (i.e. 4.00-4.99 and so on)

In general results show that the use of the Willems BC method [11] is able to render acceptable age estimations based on the present South African Black population database. Based on the total sample, the mean age estimations for males and females together did not differ significantly from the mean chronological age, hence there was no evidence for any difference between chronological and estimated age (bias). On average the predicted age is 0.06 yrs (SD=0.86) lower than the chronological age. This difference in age was not statistically significant. Also for males there was no bias present, but for females there was a small, yet significant difference between predicted age and chronological age, the predicted age being on average 0.11 years (SD=0.88) lower (Table 4). The mean absolute error equaled 0.69 years and was comparable for males and females (0.68 year in males and 0.69 year in females) yielding a mean RMSE for the total sample of 0.86 years. (Table 5)

New dental maturity scores were developed for all seven permanent left mandibular teeth in the South African black males and females of the total dataset, based on a weighted ANOVA following the Willems BC methodology. [11] Regression coefficients of this approach are reported in Table 6 for both males and females. Missing values correspond to developmental staging scores which did not appear in the training dataset.

The performance of the Willems BC method [11] as well as the newly created Willems SAB method were validated in the test dataset. Mean difference (error), mean absolute difference and the proportion of subjects with predicted age within 1 year of the chronological age are shown for both methods in Tables 7-8. Comparison of the mean RMSE of both approaches is reported in Table 9. Overall, the bias of both approaches did not differ significantly. For females however, the bias was slightly higher with the Willems BC method, whereas for males the bias was lower. The overall MAE was slightly higher with the Willems BC method (0.68 years compared to 0.62 years for the Willems SAB method). Also for females, the MAE was higher with the Willems BC method compared to the Willems SAB method. For males, the small difference in MAE between both methods was not significant.

Discussion

Human age estimation is currently in the spotlight of our society. Scientific literature points at dental age estimation as the most practicable methodology in children and subadults rendering the best age prediction performances. [14] The most important reason is the high correlation between tooth development and age. Moreover the developmental status of diverse tooth positions (seven left mandibular teeth) can be used as age predictors and

Table 4: Descriptive statistics on error and absolute error for age estimation in South African Black children categorized by sex based on the Willems BC method. [11]

	Sex	N	Mean	SD	Median	Min	Max	Q1	Q3	P
Chronological Age	M+F	986	10.05	2.88	10.04	4.14	15.00	7.66	12.55	.
Estimated Age	M+F	986	9.99	2.69	10.03	3.84	16.03	8.02	12.07	.
Error	M+F	986	0.06	0.86	0.00	-2.67	2.57	-0.53	0.62	0.1408
Absolute Error	M+F	986	0.69	0.52	0.57	0.00	2.67	0.27	1.03	
Chronological Age	M	493	10.06	2.87	10.01	4.23	14.95	7.64	12.45	.
Estimated age	M	493	10.05	2.68	10.12	4.52	16.03	8.02	12.30	.
Error	M	493	0.01	0.84	-0.02	-2.18	2.17	-0.58	0.54	0.8750
Absolute Error	M	493	0.68	0.50	0.56	0.00	2.18	0.28	1.02	
Chronological Age	F	493	10.05	2.89	10.06	4.14	15.00	7.71	12.57	.
Estimated Age	F	493	9.94	2.70	10.03	3.84	15.79	8.10	12.07	.
Error	F	493	0.11	0.88	0.02	-2.67	2.57	-0.43	0.67	0.0305
Absolute Error	F	493	0.69	0.55	0.58	0.00	2.67	0.25	1.03	

M: total number of male subjects; F: total number of female subjects; mean age and standard deviation (SD), median age, minimum age, maximum age, and ages at percentile 25 (Q1) and percentile 75 (Q3); P= p-value from Wilcoxon signed rank test comparing age and estimated age based on Willems et al. [11]; error = difference between estimated age and chronological age.

Table 5: Root mean squared error and 95% confidence intervals for estimated age in black South African children based on the Willems BC method. [11]

	RMSE (95%CI)
M+F	0.8608 (0.823;0.899)
F	0.8811 (0.826;0.936)
M	0.8400 (0.787;0.893)

M: male; F: female; RMSE: root mean squared error; 95%CI: 95% confidence intervals for RMSE.

Table 6: Country specific regression coefficients for males and females separately obtained from a fit of the model on the full South African Black dataset according to the Willems BC method. [11]

M	Tooth	B	C	D	E	F	G	H
	31	.	.	4.178	4.687	5.055	5.058	5.628
	32	.	0.000	0.270	0.164	0.403	1.044	1.465
	33	.	0.000	-0.281	-0.154	-0.063	0.355	0.773
	34	.	0.000	0.055	0.046	0.427	1.293	1.842
	35	0.000	0.081	0.400	0.349	0.584	0.857	1.536
	36	.	.	0.000	0.317	0.813	0.970	1.629
	37	0.000	0.051	0.768	0.727	1.387	1.365	1.797

F	Tooth	B	C	D	E	F	G	H
	31	.	.	4.279	4.689	4.847	5.017	5.569
	32	.	0.000	0.536	0.524	0.572	0.988	1.569
	33	.	0.000	-0.380	-0.527	-0.649	-0.284	0.214
	34	.	0.000	-0.075	0.068	0.058	0.918	1.251
	35	0.000	0.572	1.113	1.229	1.792	2.483	3.241
	36	.	.	0.000	-0.228	0.002	0.471	0.917
	37	0.000	0.167	0.493	0.530	0.934	1.146	1.878

combined. Further on a strong genetically coordinated dental maturation and an insignificant effect of possible environmental influences make tooth development a solid age predictor. Tooth maturation is registered according to different staging techniques. [23] The most well known and widely applied is the technique described by Demirjian et al. [10] The technique was developed on a French-Canadian reference sample to establish age related maturity curves or tables. Numerous studies have been and still are reporting on its validation in specific populations [29-32] while others adapted the used methodology. One of the latter is the Willems BC method. [11] In the recent decennium it was validated in different populations. When comparing different dental age estimation methods several authors even found the Willems BC method to perform best. [12-22] One of the main reasons for this is the larger reference database used of Belgian Caucasian subjects (2116 panoramic radiographs of children between 3 and 18 years) with more or less equal sex and age distribution. Moreover the method calculates the dental maturity scores directly in years avoiding maturity-to-age conversions. To our knowledge the Willems BC method [11] was never extensively validated in a large database of black Subsaharan children, nor was the method used to establish black Subsaharan population specific age prediction models. It was expected the Willems BC method to perform equally well in a black population since literature [33] and more specifically the work of Thevissen et al [23,34,35], who used third molar development for the age of majority determination, showed that a large Belgian Caucasian database outperforming many country specific data sets. Recent reported findings confirm the appropriateness for the use of Willems BC method in population samples from, among others, Japan [35], United Arab Emirates [36], and Brazil.[28] Also in Malay children [37] it was found that, although a small overestimation of chronological age by the Willems BC method was noted, both Willems BC method and the newly developed country specific Malay model (developed based on the Willems BC methodology [11]) predicted age with equal magnitude and variance in error.

The present investigation in this South African Black population sample, however, shows a small but significant overestimation of chronological age by the Willems BC method [11] in female subjects only (Table 4). The South African Black database was split into a training - and test dataset of approximately equal numbers. The total training dataset was used to construct a new country specific age prediction model based on Willems BC methodology [11] generating new maturity scores expressed directly in years (Table 6). It can be seen from Table 3 that the present SAB population sample did not contain any teeth showing developmental stage A according to

Demirjian et al [10], which could be an indication of advanced dental maturity. On the other hand the age inclusion criteria (4 - 16 years) could also explain this. In addition Table 3 also shows no teeth present with incomplete tooth development in the 15.00-15.99 age category, which could also be an indication of a possibly more advanced dental maturity in relation to chronological age. Identical findings were reported earlier in another sample. [38] When comparing performances of Willems BC method with Willems SAB method, a small but statistically significant difference in overall MAE (-0.06 yrs (SD 0.42); Table 8) and RMSE (-0.06; Table 9) for the total database (M+F) was found. The overall MAE when using the Willems BC method is about 22 days larger compared to the Willems SAB method. The difference for females was 29 days and significant, for males only 15 days (not significant). In addition, one can wonder whether the differences found in females are clinically relevant in view of the magnitude of the imprecision of the age estimation. On average, one could argue that the present results fall well into the expected range of performance of the methodology under investigation since earlier studies have reported dental development of children originating from different countries such as Australia, Belgium, Canada, Finland, France, South Korea and Sweden not to show major differences [39], apparently also not within two ethnic groups from Sudan. [40]

The timing of dental development in children of subsaharan descent has not been studied at large. Some reports were based on datasets of all permanent teeth either including or excluding third molars or on third molars only. [32,41] Other research also studied tooth eruption in relation to chronological age and added to the confusion and error rate since eruption is much more dependent on local intra-oral environmental factors. [42,43] Therefore age estimation methods employing tooth eruption stages for chronological age estimation should be cautiously used with those aspects in mind.

In the present population sample we seem to notice a somewhat faster tooth development, especially when the 15.00-15.99 age cohort is looked at. The lack of subjects with developing permanent teeth except third molars in this age cohort might indicate a more advanced tooth development in the South African Black population sample. It certainly contrasts with the database used in Willems BC where for this specific age cohort 11 out of 68 patients were found with incomplete lower left second molar root formation. [unpublished data] From the results of our analysis however, this aspect doesn't seem to have a big influence on the prediction performances since both the Willems BC method and the Willems SAB model seem to deliver slightly different but approximately the same results. This

Table 7: Performance for estimating chronological age stratified by sex and age group following the Willems BC method [11] and the new Willems SAB method.

Willems BC						Willems SAB			
Sex	Age	N	Error	Abs. error	%<1y	N	Error	Abs.error	%<1y
M+F	4-15	488	0.091 (0.858)	0.681 (0.529)	75%	484	0.089 (0.799)	0.624 (0.505)	81%
F	4-15	244	0.095 (0.859)	0.672 (0.543)	75%	240	0.035 (0.796)	0.597 (0.527)	81%
M	4-15	244	0.086 (0.858)	0.690 (0.515)	74%	244	0.141 (0.800)	0.652 (0.483)	80%
M+F	4-5	11	0.066 (0.553)	0.452 (0.293)	100%	7	0.047 (1.026)	0.691 (0.707)	86%
M+F	5-6	31	-0.067 (0.852)	0.688 (0.491)	77%	31	-0.230 (0.703)	0.498 (0.541)	84%
M+F	6-7	50	-0.355 (0.579)	0.510 (0.446)	84%	50	-0.058 (0.631)	0.510 (0.370)	90%
M+F	7-8	50	-0.404 (0.515)	0.526 (0.385)	88%	50	-0.177 (0.498)	0.423 (0.313)	90%
M+F	8-9	50	-0.373 (0.630)	0.577 (0.446)	84%	50	-0.264 (0.693)	0.594 (0.437)	86%
M+F	9-10	49	0.148 (0.812)	0.668 (0.476)	76%	49	0.030 (0.783)	0.622 (0.468)	84%
M+F	10-11	49	0.154 (0.605)	0.475 (0.400)	94%	49	0.199 (0.636)	0.544 (0.377)	90%
M+F	11-12	50	0.152 (0.913)	0.732 (0.558)	68%	50	0.039 (1.042)	0.848 (0.594)	64%
M+F	12-13	49	0.383 (0.963)	0.847 (0.587)	63%	49	0.068 (0.942)	0.742 (0.575)	71%
M+F	13-14	49	0.683 (0.805)	0.832 (0.647)	61%	49	0.512 (0.709)	0.647 (0.585)	86%
M+F	14-15	50	0.553 (1.036)	1.009 (0.589)	48%	50	0.662 (0.687)	0.761 (0.574)	62%
F	4-5	6	0.347 (0.492)	0.499 (0.295)	100%	2	-0.038 (0.427)	0.302 (0.054)	100%
F	5-6	15	0.068 (0.676)	0.577 (0.325)	87%	15	-0.047 (0.406)	0.291 (0.277)	100%
F	6-7	25	-0.395 (0.607)	0.506 (0.514)	80%	25	-0.304 (0.618)	0.551 (0.403)	88%
F	7-8	25	-0.528 (0.499)	0.581 (0.433)	84%	25	-0.353 (0.449)	0.462 (0.330)	88%
F	8-9	25	-0.266 (0.583)	0.502 (0.388)	88%	25	-0.133 (0.713)	0.550 (0.459)	84%
F	9-10	24	0.057 (0.914)	0.747 (0.505)	71%	24	-0.198 (0.807)	0.659 (0.490)	79%
F	10-11	25	0.062 (0.478)	0.353 (0.320)	96%	25	0.154 (0.533)	0.414 (0.361)	92%
F	11-12	25	0.113 (1.022)	0.819 (0.599)	60%	25	-0.095 (1.154)	0.966 (0.607)	52%
F	12-13	25	0.574 (0.836)	0.792 (0.623)	68%	25	0.232 (0.810)	0.582 (0.599)	80%
F	13-14	24	0.557 (0.944)	0.820 (0.716)	71%	24	0.399 (0.901)	0.667 (0.716)	83%
F	14-15	25	0.656 (0.995)	1.032 (0.572)	48%	25	0.676 (0.669)	0.730 (0.606)	68%
M	4-5	5	-0.271 (0.449)	0.395 (0.313)	100%	5	0.081 (1.237)	0.846 (0.802)	80%
M	5-6	16	-0.194 (0.995)	0.792 (0.600)	69%	16	-0.403 (0.876)	0.692 (0.656)	69%
M	6-7	25	-0.316 (0.560)	0.514 (0.377)	88%	25	0.188 (0.553)	0.469 (0.336)	92%
M	7-8	25	-0.279 (0.509)	0.472 (0.330)	92%	25	-0.001 (0.491)	0.384 (0.297)	92%
M	8-9	25	-0.479 (0.668)	0.652 (0.493)	80%	25	-0.395 (0.660)	0.637 (0.419)	88%
M	9-10	25	0.235 (0.709)	0.591 (0.442)	80%	25	0.248 (0.707)	0.586 (0.453)	88%
M	10-11	24	0.250 (0.712)	0.602 (0.440)	92%	24	0.245 (0.737)	0.680 (0.351)	88%
M	11-12	25	0.190 (0.810)	0.645 (0.510)	76%	25	0.173 (0.921)	0.731 (0.568)	76%
M	12-13	24	0.185 (1.061)	0.905 (0.553)	58%	24	-0.103 (1.052)	0.907 (0.508)	63%
M	13-14	25	0.803 (0.642)	0.843 (0.588)	52%	25	0.621 (0.450)	0.628 (0.439)	88%
M	14-15	25	0.450 (1.087)	0.986 (0.617)	48%	25	0.649 (0.718)	0.791 (0.550)	56%

Age: age groups of one year (i.e. 4.00-4.99 and so on); Willems BC: Demirjian et al method [10] adapted by Willems et al based on a Belgian Caucasian reference database and validated [11]; Willems SAB: newly constructed dental age estimation method using the Willems BC methodology on a South African Black Reference database and validated; Mean (Standard deviation) error (error and absolute error) for both approaches obtained on test dataset; %<1y: percentage of subjects with absolute error within 1 year; N: number of subjects in test dataset; Positive error: observed age higher than predicted age (underestimation).

Table 8: Comparison of the performance of the Willems BC method [11] and the Willems SAB method.

	N	Mean	SD	Med	Min	Max	Q1	Q3	P
M+F									
Error Willems BC	484	0.09	0.86	0.01	-2.67	2.57	-0.52	0.65	.
Error Willems SAB	484	0.09	0.80	0.09	-2.78	3.08	-0.46	0.53	.
Difference	484	0.00	0.47	-0.05	-1.96	2.06	-0.29	0.27	0.8817
Absolute error Willems BC	484	0.68	0.53	0.59	0.00	2.67	0.26	1.01	.
Absolute error Willems SAB	484	0.62	0.51	0.49	0.00	3.08	0.25	0.86	.
Difference	484	-0.06	0.42	-0.06	-1.18	2.06	-0.29	0.20	0.0086
F									
Error Willems BC	240	0.09	0.86	-0.01	-2.67	2.57	-0.46	0.65	.
Error Willems SAB	240	0.04	0.80	0.01	-2.78	3.08	-0.46	0.45	.
Difference	240	-0.05	0.46	-0.11	-1.16	1.09	-0.36	0.27	0.0495
Absolute error Willems BC	240	0.67	0.55	0.59	0.00	2.67	0.22	0.99	.
Absolute error Willems SAB	240	0.60	0.53	0.45	0.00	3.08	0.21	0.82	.
Difference	240	-0.08	0.42	-0.07	-1.16	1.03	-0.36	0.19	0.0279
M									
Error Willems BC	244	0.09	0.86	0.06	-2.18	2.17	-0.56	0.65	.
Error Willems SAB	244	0.14	0.80	0.16	-2.04	2.21	-0.45	0.62	.
Difference	244	0.05	0.47	0.10	-1.96	2.06	-0.18	0.27	0.0072
Absolute error Willems BC	244	0.69	0.52	0.58	0.00	2.18	0.29	1.02	.
Absolute error Willems SAB	244	0.65	0.48	0.54	0.01	2.21	0.30	0.89	.
Difference	244	-0.04	0.42	-0.06	-1.18	2.06	-0.26	0.20	0.1391

Willems BC: Demirjian et al method [10] adapted by Willems et al based on a Belgian Caucasian reference database and validated [11]; Willems SAB: newly constructed dental age estimation method using the Willems BC methodology on a South African Black Reference database and validated; Med: Median; Min: lowest value; Max: highest value; Q1: percentile 25; Q3: percentile 75; SD: standard deviation; P: p-value from Wilcoxon signed rank test comparing (Absolute) Error Willems BC and (Absolute) Error Willems SAB

Table 9: Comparison of mean RMSE between the Willems BC method [11] and the Willems SAB method.

Sex	N	Willems BC	Willems SAB
M+F	484	0.862 (0.81;0.92)	0.803 (0.75;0.85)
F	240	0.863 (0.79;0.94)	0.795 (0.72;0.87)
M	244	0.861 (0.78;0.94)	0.810 (0.74;0.88)

Willems BC: Demirjian et al method [10] adapted by Willems et al based on a Belgian Caucasian reference database and validated [11]; Willems SAB: newly constructed dental age estimation method using the Willems BC methodology on a South African Black Reference database and validated; M: males; F: females; RMSE: root mean squared error; 95% confidence intervals for the RMSE are given between brackets.

may reflect the usefulness of the method developed by Willems et al [11] in case country specific databases are lacking.

The performance of both the Willems BC and Willems SAB methods are additionally compared by analyzing their coverage, expressed as the percentage of correctly aged individuals within i.e. 1 year of their chronological age in a specific age cohort. Results show indeed differences between both methods although they are small and age cohort as well as sex dependent.

A limitation of the present research is that the performance of Willems BC which is based on a large reference database is compared with the performance of Willems SAB for which a smaller country specific database was used. The difference in size might explain the relatively successful results of Willems BC. In addition it must be pointed out that the current study focusses on the accuracy of point predictions and not on interval predictions. Future research might focus more explicitly on integrating both permanent teeth and third molars in the same model eventually giving rise to an age estimation model overcoming most of today's shortcomings, especially in the 15-16 year age range. Indeed this transition point between two age estimation approaches renders the largest error in age estimation at present because the number of useful age related parameters present is less. An other approach could possibly be to focus research on the use of multivariate Bayesian statistics [24] or the ad-hoc procedure based on conditional independence [26] which would overcome the disadvantages of regression analysis (i.e; attraction to the middle) and possibly render better age prediction performances.

Conclusion

The performance of the newly developed method using data of South African Black children was found to be better compared to the Willems BC method, developed based on a Belgian Caucasian reference sample [11], especially for females and for the total sample of male and female subjects together. However the difference in mean absolute error for age prediction between both methods is so small (29 days only) that it could be considered as clinically irrelevant. The difference in mean absolute error for males was statistically not significant.

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