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Time of mineralization of permanent teeth in children and adolescents in Gaborone, Botswana

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ABSTRACT

The mineralization sequence of permanent dentition can be used to assess the stage of development and age of individuals. The most commonly used methods are based on the assessment of developmental stages of target groups of teeth on one side of the lower jaw. When compared with the rest of the world, fewer studies have been done on dental age in Sub-Saharan Africa, particularly in the region of Southern Africa.

The aim of this study was to determine the chronology of mineralization of permanent teeth by the evaluation of developmental stages according to the Demirjian's method from 1973 and to evaluate dental age by using sex-specific self-weighted scores for dental stages and 50th percentile conversion tables of total maturity scores of seven mandibular teeth. We used a sample of panoramic radiographs (OPTs) of black African children and adolescents from the city of Gaborone, Botswana, with the aim of forming an appropriate sample to evaluate the development of the teeth in this socio-geographic environment.

The final sample consisted of 1760 OPTs (807 males and 953 females) of individuals aged 6–23 years. The developmental stages of the all permanent teeth in the left side of the maxilla and the mandible were evaluated.

Comparing the maxilla and the mandible, we found similar development within different stages for most of the teeth. In comparison to the average age at each stage of development, including the third molars between males and females, it is evident that females are slightly faster in developing permanent teeth, but without statistical significance for most of the developmental stages.

Applying 50th percentile conversion tables for calculating the dental age for the first seven mandibular teeth, 616 OPTs of the children (299 males and 317 females), aged 6.08–16.80 years, were evaluated and their dental age was calculated. Mean dental age was overestimated in comparison to chronological age by 1.25 ± 1.11 years and 0.72 ± 1.02 years for males and females, respectively ($p < 0.001$).

These findings indicate that Demirjian's method from 1973 is not suitable for routine use and that there is a need for establishing specific standards for Botswana children of black African origin for dental age estimation.

1. Introduction

Amongst many anatomical systems, teeth provide abundant information related to growth and development of the whole body. They change in two sequences, first as a deciduous and then as permanent dentition, so that these changes cover the time span from birth until the end of adolescence. The possibility of insight into these changes, either by clinical examination or certain radiographic procedures, creates the opportunity to estimate the biological age of a person by analyzing their teeth. When compared to other body systems in children, in particular the skeletal system, which can also be evaluated by radiography, the development of teeth is considered to be more reliable (Feijoo et al., 2012; Krailassiri et al., 2002; Uysal et al., 2004). Most of the studies on dental development evaluated dental age (DA) by

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using specific radiographic methods on a total number of selected teeth. These methods analyze the degree of tooth mineralization attained or the size of open apices on radiographic records, mostly panoramic (OPTs) (Cameriere et al., 2006a; Demirjian et al., 1973; Moorrees et al., 1963; Nolla, 1960). The most common method for DA estimation in children was introduced by Demirjian et al. in 1973 (Demirjian and Goldstein, 1976; Demirjian et al., 1973). The authors divided single and multi-rooted tooth development into eight formation stages. Formation stages were also illustrated by diagrams and radiographic pictures of incisors, canines, bicuspids and molars (Demirjian et al., 1973). In the majority of studies of dental development, mandibular teeth were predominantly studied, because of smaller distortion, when compared to maxillary teeth which have greater tendency of malposition, rotation or crowding (Demirjian and Goldstein, 1976; Demirjian et al., 1973; Haavikko, 1974; Liversidge, 2011, 2012). However, several recent studies in different populations studied permanent teeth in both jaws (Feijoo et al., 2012; Lee et al., 2008).

After initially studying 14 teeth from the upper and the lower left quadrants, only the system using seven teeth from the left side was further investigated, because of the high degree of correlation between the upper and lower jaw and the single side system that gives almost the same estimation as the one using all 14 teeth (Demirjian et al., 1973). Then, each of formation stages of the seven permanent teeth from the mandible were given a specific score of development, similarly to the approach by Tanner, Whitehouse and Healy, who scored development according to each bone of the hand and wrist (Tanner et al., 1962). The scores on all the seven teeth are then calculated together to give a total maturity score. Separate tables of 50th percentile dental maturity score based on French–Canadian males and females were used to convert total dental maturity scores into dental age (Demirjian et al., 1973). The Demirjian method and tables have been extensively used in different populations. Some studies suggested that French–Canadian standards were appropriate but most studies demonstrated that population-specific standards were necessary because of the difference between calculated dental age and chronological age (CA) (Cunha et al., 2009; Feijoo et al., 2012; Galić et al., 2010; Nyström et al., 1986; Sen Tunc and Koyuturk, 2008; Willems et al., 2001). According to our literature search, there are no previous studies on dental development in Botswana's children and adolescents of black African origin.

The aim of this study has been to explain the age within Demirjian stages of dental development of all permanent teeth from the left side on a sample of Botswana's children and adolescents of African origin and to build a reference database for studying dental development of subjects of specific ethnical and geographic backgrounds.

2. Materials and methods

In a cross-sectional study, we investigated OPT radiographs of children and adolescents aged 6–23 years who visited two private orthodontic practices from 2001 to 2015, located in the city of Gaborone, in the Republic of Botswana. The study was conducted in accordance to the ethical standards laid down by the Declaration of Helsinki (World Medical Association, 2013). Approval for the study was granted by the HRDC (Human Research and Development Committee) of the Ministry of Health in Botswana. All available OPTs from the sample were evaluated and only black African subjects up to 23 years of age were included in the study because of few available OPTs of Caucasians and Asians. Also, we found no evidence of the development of permanent teeth in older individuals. OPTs without accompanying subject's full dental records, lack of birth date and date when the OPTs were taken, as well as those OPTs of children with proven hereditary or systematic illnesses, malnutrition, severe destruction, extraction, or hypodontia of permanent teeth, and where the third molars were missing, were excluded from the study. In total, 1760 OPTs, 807 males and 953 females, were evaluated (Table 1).

Table 1
Chronological age group distribution of panoramic radiographs of black African children from the city of Gaborone, in the Republic of Botswana.

Age group	Males	Females	Total
6.0–6.9	22	21	43
7.0–7.9	23	20	43
8.0–8.9	26	22	48
9.0–9.9	21	29	50
10.0–10.9	27	32	59
11.0–11.9	50	50	100
12.0–12.9	56	67	123
13.0–13.9	49	59	108
14.0–14.9	59	56	115
15.0–15.9	48	69	117
16.0–16.9	69	71	140
17.0–17.9	53	68	121
18.0–18.9	45	69	114
19.0–19.9	50	74	124
20.0–20.9	47	57	104
21.0–21.9	60	64	124
22.0–22.9	55	64	119
22.0–22.9	47	61	108
Total	807	953	1760

The chronological age (CA) of children was calculated as the difference between the date the OPT was taken and birth date (rounded off to two decimal places), with age groups based on one year increments. The developmental stages, alphabetically abbreviated (A–H) according to the method of Demirjian et al. (Demirjian et al., 1973) of all permanent teeth in the left side of the maxilla and mandible, were evaluated by the first author (JC). Additionally, the crypt stage of the third molars, abbreviated as zero (0), was also evaluated. The average age within each stage in all permanent teeth from the left side was calculated separately for males and females. An independent sample *t*-test was used to compare the means of chronological age across developmental stages between the antagonistic teeth, as well as between sexes. The next step was to evaluate the usefulness of the original French–Canadian self-weighted scores for dental stages and tables for conversion to dental age in children as described by Demirjian et al. (1973). All children who had not completed mineralization of at least one of the seven permanent teeth from the mandible, excluding third molars, were evaluated and dental age (DA) was calculated. More specifically, stages of the seven left mandibular teeth were converted to specific values for each stage by using sex-specific tables of self-weighted scores for dental stages from Demirjian et al. (1973). These self-weighted, sex specific scores, for each tooth were based on the mathematical balancing of tooth development across stages on a French–Canadian sample of 2928 males and females age 2–20 years (Demirjian et al., 1973). The values of scores of all seven teeth were summed as dental total maturity scores and expressed as percentages. Then the 50th percentile dental maturity score was converted to dental age by using sex-specific tables from Demirjian et al. (1973).

In total, 616 OPTs of children (317 females) aged 6.08–16.80 years were included in the dental age estimation using the Demirjian 1973 method. Paired sample *t*-tests were used to compare DA and CA. Mean absolute error (MAE) of time distance from real age of children was also calculated. Evaluation of 100 randomly selected OPTs was conducted by JC for the second time, 2 months following initial evaluation, as well as by IG. Based on these 100 OPTs, intra- and inter-rater agreement of mineralization stages were calculated using kappa scores and intra- and inter-rater agreement of dental age by Demirjian et al. (1973) was calculated

Table 2
Kappa scores for mineralization stages, according to Demirjian's method, for permanent teeth from the left side of the maxilla and mandible, based on an evaluation of 100 randomly selected panoramic radiographs.

Tooth	21	22	23	24	25	26	27	28	31	32	33	34	35	36	37	38
Intra-rater kappa	0.82	0.84	0.89	0.78	0.84	0.76	0.83	0.84	0.88	0.86	0.92	0.88	0.88	0.77	0.82	0.83
Inter-rater kappa	0.72	0.88	0.84	0.80	0.83	0.78	0.72	0.74	0.76	0.88	0.80	0.80	0.79	0.81	0.74	0.78

using an intra-class correlation coefficient (ICC) (Ferrante and Cameriere, 2009). Statistical significance was set to 0.05. For data management and statistical analysis we used MS Excel 2010 (Microsoft Office 2010, Microsoft, and Redmond, WA) and SPSS Statistics 17.0 for Windows (SPSS Inc., Chicago, IL).

3. Results

The final sample comprised a total of 1760 OPTs of 807 males and 953 females, ages 6.08–23.96 years. The mean age in males and females were 16.11 ± 4.65 years and 16.45 ± 4.56 years respectively ($p > 0.05$).

Table 1 shows a distribution of subjects across age groups.

The average kappa coefficients for determining intra-rater and inter-rater agreement were 0.84 ($p < 0.05$) and 0.79 ($p < 0.05$) respectively, indicating a high level of concordance, Table 2.

Average Kappa values were somewhat better for mandibular teeth than for maxillary teeth, both for intra-rater and inter-rater agreement, but without statistical significance. ICCs of intra- and inter-rater agreement of dental age calculated by Demirjian's method were 0.96 and 0.98 respectively. The ages within different stages of development according to Demirjian were shown for all permanent teeth from the left side of the maxilla and the mandible (Tables 3 and 4). For stage H, only minimal age was recorded (Liversidge et al., 2006).

A comparison of the mean age within specific developmental stages was performed in the total sample between the antagonistic teeth. It was found that the mandibular teeth were slightly more advanced in the development in relation to the maxillary teeth in both sexes, without significant differences in most stages. In males, the significant difference in advanced development of mandibular teeth was found only for stage G between the central incisors, stages E and G between lateral incisors and stage G between first molars while significantly advanced development of maxillary teeth was found in stage G in second premolars (Table 3).

In females, the significant difference in advanced development of mandibular teeth was only found in stage G between antagonists of both incisors, stage E of the second incisor, stage E in the second premolars and stage G in the first molars. Significantly, advanced development of maxillary teeth was only found for stage G in the second premolar (Table 4).

Comparing sexes, mean ages within the same developmental stage (Tables 3 and 4), the studied sample showed that permanent dentition similarly develops with a significant difference in development of few teeth. In the maxilla, dental development in males was significantly earlier at stage F for the central incisor and stage F for the third molar while in females only for stage F for the second molars and stage D for the third molars. In the mandible, dental development in females was significantly earlier at stage G for the canines, stage E for the second premolar and stage F for the second molars. There was no statistically significant difference in the mean age within the developmental stage of lower third molars between sexes. The crypt stage was only found and evaluated in the third molars. Mean ages within crypt stage were 7.42 ± 0.22 and 7.49 ± 0.91 years in maxillary and 7.18 ± 0.90 and 7.54 ± 1.08 years in mandibular third molars in males and females, respectively (Tables 3 and 4). The development of the third molars completed in a wide time period from 14.67 to 22.51 years and 14.74–23.72 years in maxillary and 14.67–22.60 years and 15.30–23.07 years in mandibular teeth in males and females respectively (Tables 3 and 4).

The calculated dental age using the Demirjian's method showed an overestimation in relation to chronological age in both sexes. When compared to real age, an overestimation was statistically significant ($p < 0.05$) in almost all age groups except in the last one of 16 years, with the mean overestimation of an average of 1.25 ± 1.11 years and 0.72 ± 1.02 years in males and females, respectively (Table 5 and Fig. 1).

4. Discussion

This is the first study of the development and mineralization of all permanent teeth in children and adolescents of black African origin in Botswana. We descriptively evaluated the time of mineralization of all teeth from the left side of maxilla and mandible according to the Demirjian's method (Demirjian et al., 1973). We demonstrated that mean ages within the Demirjian stages were generally lower in Botswana females than males and that a significant difference was only found in a few teeth and their stages. A lower mean age in females indicates that the development of mandibular permanent dentition in females is slightly faster compared to males. These findings are in line with many previous studies (Lee et al., 2008; Liversidge et al., 2006). When compared to mean ages within stages in the study by Liversidge et al. (2006), which included the data of mandibular teeth from Australia, Belgium, Canada, England, Finland, France, South Korea and Sweden, mandibular teeth in Botswana subjects are generally faster in maturation. There are very few studies that have evaluated the maxillary dentition and compared them to the mandibular (Feijoo et al., 2012). This is mostly because of clearer visibility and less superimposition of the roots and distortion of the teeth in the mandible. The mean age within stages in this study is comparable with the results obtained by Lee et al. (2008) on the Korean sample of subjects aged 1–20 years. The results from a similar study by Feijoo et al. (2012), which analyzed permanent teeth from all four quadrants in subjects between 2 and 16 years and calculated mean age of onset in specific stages, were not comparable to mean age within stages calculated in this study (Liversidge, 2008c).

The Demirjian system, by using eight stages of development, explains in detail and describes the continuum of mineralization from the beginning of mineralization to apex closure in permanent teeth (Demirjian et al., 1973). According to Lee et al. (2008), methods based on fractioning more stages of the crown and root can result in less precision and more difficult assessment. Therefore, the Demirjian approach was recommended because of the good reproducibility of developmental stages and their thorough explanation (Dhanjal et al., 2006). Excellent average Kappa scores of the intra-rater and inter-rater agreement showed high concordance between observations, which is in line with many similar studies (Djukic et al., 2013; Galić et al., 2010). Mandibular teeth showed some better Kappa values of agreement for developmental stages which can be attributed to their better visibility and lower distortion on OPTs when compared to maxillary (Demirjian et al., 1973; Liversidge, 2012). Information and insight into the time of development of permanent teeth has importance in different fields. In clinical medicine, particularly in pediatrics, it can be used as an

Table 3
Tooth stage data of chronological age (years) for the left maxillary and mandibular teeth in males according to Demirjian's method.

	Maxillary teeth									Mandibular teeth										
	Tooth	*N*	M ± SD	SE	Min	Q1	Med	Q3	Max	Tooth	*N*	M ± SD	SE	Min	Q1	Med	Q3	Max	*t*(df)	*p*[a]
Stage																				
E	**21**	2	6.40 ± 0.36	0.25	6.14		6.40		6.65	**31**										
F		27	6.80 ± 0.54	0.10	6.10	6.41	6.61	7.26	8.13		5	6.78 ± 0.37	0.17	6.46	6.53	6.61	7.11	7.41	0.10 (7.60)	0.92
G		30	8.39 ± 0.78	0.14	6.59	8.10	8.54	8.89	10.10		18	6.90 ± 0.70	0.16	6.14	6.41	6.71	7.46	8.58	6.84 (39.06)	<0.001
H		748	7.45								784			6.10						
D	**22**	2	6.40 ± 0.36	0.26	6.14		6.40		6.65	**32**										
E		21	6.97 ± 0.73	0.16	6.10	6.41	6.61	7.50	8.38		10	6.63 ± 0.40	0.13	6.14	6.41	6.44	6.92	7.41	1.67 (28.23)	0.11
F		34	8.07 ± 1.20	0.21	6.46	6.77	8.21	8.82	11.18		12	6.72 ± 0.42	0.12	6.21	6.54	6.61	6.77	7.60	5.65 (43.99)	<0.001
G		32	9.15 ± 1.09	0.19	7.45	8.38	9.16	10.00	11.14		24	7.83 ± 0.94	0.19	6.10	7.17	7.86	8.57	9.63	4.85 (52.88)	<0.001
H		718			7.87						761			7.45						
D	**23**									**33**	10	6.71 ± 0.62	0.20	6.41	6.41	6.51	6.66	8.44		
E		37	7.07 ± 0.89	0.15	6.10	6.43	6.77	7.51	9.46		33	7.37 ± 0.93	0.16	6.10	6.59	7.26	8.03	9.29	−1.37 (66.30)	0.17
F		76	9.38 ± 1.37	0.16	7.35	8.39	9.13	10.33	12.58		66	9.42 ± 1.33	0.16	7.35	8.43	9.16	10.25	12.51	−0.18 (138.25)	0.86
G		68	11.86 ± 1.12	0.14	8.73	11.13	11.87	12.68	14.16		56	11.77 ± 1.13	0.15	8.73	10.98	11.83	12.47	14.16	0.44 (117.88)	0.66
H		626			10.28						642			9.55						
D	**24**	23	6.75 ± 0.58	0.12	6.14	6.41	6.61	6.82	8.89	**34**	14	6.89 ± 0.62	0.17	6.41	6.41	6.55	7.25	8.44	−0.68 (26.15)	0.501
E		48	8.27 ± 0.96	0.14	6.10	7.59	8.34	8.89	10.21		54	7.88 ± 1.06	0.14	6.10	7.10	7.86	8.61	10.80	1.95 (99.96)	0.054
F		45	10.10 ± 1.33	0.20	7.45	9.06	10.09	11.16	12.58		44	9.93 ± 1.19	0.18	7.53	9.03	9.83	11.04	12.19	0.64 (86.33)	0.53
G		56	11.77 ± 1.12	0.15	8.32	11.13	11.80	12.43	14.16		68	11.95 ± 1.05	0.13	9.50	11.28	11.88	12.65	14.16	−0.92 (114.28)	0.36
H		635			10.28						627			10.25						
C	**25**	2	6.64 ± 0.25	0.18	6.46		6.64		6.82	**35**										
D		41	7.29 ± 0.85	0.13	6.14	6.57	7.21	7.86	9.29		37	7.08 ± 0.76	0.13	6.10	6.44	6.77	7.59	8.89	1.15 (76.00)	0.25
E		50	8.98 ± 1.13	0.16	6.10	8.36	8.92	9.65	11.42		39	8.65 ± 1.02	0.16	6.59	7.86	8.58	9.23	11.14	1.44 (85.10)	0.15
F		35	10.92 ± 1.18	0.20	7.53	10.09	10.98	11.87	12.68		59	10.61 ± 1.40	0.18	7.53	9.50	10.87	11.70	13.89	1.15 (81.27)	0.25
G		68	11.94 ± 0.99	0.12	8.32	11.58	11.92	12.56	13.91		92	12.43 ± 1.15	0.12	9.55	11.65	12.35	13.15	14.61	−2.89 (154.29)	0.004
H		611			10.83						580			11.04						
F	**26**	13	6.57 ± 0.41	0.11	6.14	6.31	6.41	6.62	7.42	**36**	14	6.80 ± 0.58	0.16	6.14	6.41	6.63	6.93	8.38	−1.20 (23.41)	0.24
G		75	8.45 ± 1.18	0.14	6.10	7.58	8.56	9.29	11.06		55	8.04 ± 1.11	0.15	6.10	7.21	8.13	8.86	10.21	2.03 (120.30)	0.045
H		719			7.45						738				7.45					
D	**27**	46	7.19 ± 0.78	0.11	6.10	6.54	7.14	7.86	8.89	**37**	50	7.35 ± 0.97	0.14	6.10	6.55	7.24	7.88	10.21	−0.89 (92.39)	0.37
E		73	9.61 ± 1.25	0.15	7.45	8.77	9.46	10.31	12.53		57	9.29 ± 1.00	0.13	7.45	8.57	9.16	10.04	11.42	1.62 (127.91)	0.11
F		37	11.90 ± 0.78	0.13	10.56	11.31	11.87	12.53	13.51		59	11.87 ± 0.93	0.12	9.55	11.27	11.83	12.53	14.16	0.17 (86.25)	0.87
G		136	13.00 ± 1.17	0.10	10.28	12.12	12.98	13.93	16.58		133	13.13 ± 1.23	0.11	10.28	12.20	13.07	14.12	16.20	−0.89 (265.61)	0.38
H		515			12.24						508			12.48						
0[b]	**28**	2	7.42 ± 0.22	0.16	7.26		7.42		7.58	**38**	23	7.18 ± 0.90	0.19	6.10	6.41	6.82	7.60	8.89	0.98 (5.49)	0.37
A		8	7.88 ± 0.90	0.32	6.46	7.02	8.00	8.75	8.94		16	7.64 ± 0.93	0.23	6.55	6.77	7.45	8.71	8.94	0.61 (14.54)	0.55
B		26	8.41 ± 1.53	0.30	6.55	7.35	8.15	8.93	12.51		15	8.80 ± 1.59	0.41	7.14	7.35	8.20	10.10	12.24	−0.77 (28.41)	0.45
C		56	9.82 ± 1.26	0.17	7.53	9.01	9.72	10.83	12.58		54	9.96 ± 1.19	0.16	7.87	9.09	9.83	10.95	12.34	−0.60 (107.95)	0.55
D		137	12.75 ± 1.56	0.13	9.90	11.73	12.44	13.59	19.49		150	12.69 ± 1.44	0.12	8.82	11.73	12.51	13.67	17.60	0.34 (276.95)	0.41
E		120	14.74 ± 1.62	0.14	11.04	13.61	14.54	15.90	18.81		115	15.03 ± 1.48	0.14	11.73	13.90	14.92	16.11	18.81	−1.43 (232.47)	0.15
F		84	16.37 ± 1.28	0.14	14.34	15.37	16.22	17.03	20.52		74	16.60 ± 1.56	0.18	14.35	15.38	16.45	17.12	20.75	−1.00 (141.49)	0.32
G		89	18.40 ± 1.59	0.17	14.67	17.14	18.41	19.30	22.51		94	18.30 ± 1.57	0.16	14.67	17.15	18.13	19.18	22.60	0.43 (180.18)	0.67
H		256			15.72						251			15.72						

[a] Independent samples *t*-test.
[b] Crypt stage for the third molar; *N*, number of individuals; *M*, mean age; SD, standard deviation; SE, standard error of the mean age; Min, minimum age; Max, maximum age; *t*, value of the independent samples *t*-test; df, degree of freedom; *p*, statistically significant if $p < 0.05$.

Table 4
Tooth stage data of chronological age (years) for the left maxillary and mandibular teeth in females according to Demirjian's method.

	Maxillary teeth									Mandibular teeth										
	Tooth	*N*	Mean	SE	Min	Q1	Median	Q3	Max	Tooth	*N*	Mean	SE	Min	Q1	Med	Q3	Max	t(df)	p[a]
Stage																				
D	**21**	2	6.34 ± 0.12	0.08	6.25		6.34		6.42	**31**										
E		9	6.70 ± 0.29	0.10	6.35	6.37	6.77	6.97	7.09		10	6.58 ± 0.27	0.09	6.25	6.35	6.49	6.84	6.97	0.93 (16.45)	0.36
F		17	7.46 ± 1.07	0.26	6.52	6.70	7.28	7.62	10.62		6	7.25 ± 0.37	0.15	6.74	6.87	7.31	7.58	7.70	0.70 (20.97)	0.49
G		33	8.02 ± 0.86	0.15	6.08	7.64	8.23	8.60	9.36		12	7.20 ± 0.47	0.14	6.52	6.89	7.22	7.46	8.27	4.06 (35.83)	0.0003
H		892			7.22						925			6.08						
C	**22**	2	6.34 ± 0.19	0.08	6.25		6.34		6.62	**32**										
D		5	6.74 ± 0.25	0.12	6.40	6.48	6.80	6.97	6.97		2	6.48 ± 0.12	0.08	6.40		6.48		6.57	1.85 (4.26)	0.13
E		17	7.45 ± 1.09	0.26	6.35	6.75	7.28	7.62	10.62		12	6.81 ± 0.46	0.13	6.25	6.36	6.78	6.97	7.70	2.16 (22.97)	0.04
F		28	7.78 ± 0.78	0.15	6.25	7.19	7.98	8.40	8.77		13	7.32 ± 1.14	0.32	6.25	6.54	7.22	7.46	10.62	1.32 (17.42)	0.20
G		26	8.91 ± 1.37	0.27	6.08	7.95	9.20	9.68	11.10		15	7.72 ± 0.79	0.20	6.65	7.15	7.64	8.31	9.49	3.53 (38.99)	0.001
H		875			8.22						911			6.08						
D	**23**	5	6.68 ± 0.33	0.15	6.25	6.34	6.80	6.97	6.97	**33**	8	6.62 ± 0.27	0.10	6.25	6.41	6.56	6.93	6.97	0.34 (7.32)	0.74
E		28	7.06 ± 0.66	0.12	6.25	6.56	6.95	7.46	9.24		26	7.26 ± 0.78	0.15	6.25	6.66	7.12	7.73	9.24	−1.01 (49.17)	0.32
F		66	9.18 ± 1.33	0.16	6.08	8.25	9.16	9.90	12.47		65	9.14 ± 1.34	0.17	6.08	8.22	9.18	10.29	12.15	0.17 (128.93)	0.86
G		83	11.54 ± 1.14	0.13	8.22	10.70	11.57	12.23	13.90		72	11.37 ± 0.94	0.11	9.00	10.70	11.54	12.02	12.89	1.04 (152.97)	0.30
H		771			9.83						782			9.63						
D	**24**	17	6.68 ± 0.28	0.07	6.25	6.41	6.66	6.94	7.28	**34**	12	6.68 ± 0.43	0.13	6.25	6.36	6.56	6.93	7.83	0 (17.49)	1.00
E		49	7.91 ± 0.85	0.12	6.08	7.35	8.05	8.44	9.89		54	7.83 ± 0.94	0.13	6.08	7.20	7.75	8.38	10.62	0.45 (100)	0.65
F		57	10.42 ± 1.02	0.13	8.21	9.60	10.38	11.06	12.47		52	10.39 ± 1.15	0.16	8.22	9.51	10.33	11.08	14.10	0.14 (101.6)	0.89
G		57	11.79 ± 1.09	0.14	9.25	10.95	11.68	12.64	14.10		66	11.65 ± 0.94	0.12	9.49	10.87	11.66	12.47	13.43	0.80 (115.92)	0.43
H		773			9.83						769			9.83						
C	**25**	2	6.33 ± 0.12	0.08	6.25		6.34		6.42	**35**	2	6.34 ± 0.12	0.08	6.25		6.34		6.42	−0.08 (2)	0.94
D		34	7.20 ± 0.78	0.13	6.25	6.63	6.99	7.58	9.24		23	7.17 ± 0.59	0.12	6.35	6.74	7.15	7.54	8.27	0.17 (54.23)	0.87
E		46	8.66 ± 1.04	0.15	6.08	8.09	8.60	9.26	10.70		46	8.09 ± 1.10	0.16	6.08	7.30	8.23	8.73	10.70	2.55 (89.72)	0.01
F		50	10.89 ± 1.12	0.16	8.22	10.04	10.80	11.68	14.10		74	10.88 ± 1.12	0.13	8.76	9.89	10.79	11.67	14.10	0.05 (112.24)	0.96
G		71	11.93 ± 1.03	0.12	9.63	11.24	11.98	12.66	14.01		96	12.32 ± 1.16	0.12	9.49	11.49	12.54	13.26	14.63	−2.33 (161.09)	0.02
H		750			10.69						712			11.23						
F	**26**	13	6.59 ± 0.24	0.07	6.25	6.37	6.57	6.78	6.97	**36**	8	6.76 ± 0.66	0.23	6.25	6.35	6.58	6.87	8.27	−0.70 (8.15)	0.50
G		71	8.53 ± 1.22	0.15	6.25	7.47	8.34	9.49	11.10		53	7.81 ± 1.01	0.14	6.25	7.04	7.65	8.44	10.62	3.59 (120.64)	0.0005
H		869			6.08						892			6.08						
C	**27**	4	6.58 ± 0.30	0.15	6.25	6.29	6.58	6.87	6.91	**37**	2	6.34 ± 0.13	0.08	6.25		6.34		6.42	1.36 (3.99)	0.24
D		45	7.37 ± 0.71	0.11	6.25	6.78	7.30	7.85	9.24		47	7.44 ± 0.80	0.12	6.25	6.77	7.30	8.23	9.21	−0.44 (89.50)	0.66
E		59	9.60 ± 1.15	0.15	6.08	8.92	9.53	10.40	12.15		55	9.42 ± 1.23	0.17	6.08	8.64	9.49	10.32	12.15	0.81 (109.91)	0.42
F		49	11.37 ± 0.99	0.14	9.62	10.70	11.33	12.00	14.10		55	11.51 ± 0.99	0.13	9.63	10.74	11.50	12.02	13.98	−0.76 (101.95)	0.45
G		156	13.01 ± 1.13	0.09	10.69	12.17	12.90	13.88	16.16		158	13.07 ± 1.29	0.10	10.10	12.14	13.06	13.89	16.80	−0.44 (305.54)	0.66
H		640			11.73						636			11.35						
0[b]	**28**	10	7.49 ± 0.91	0.29	6.52	6.66	7.31	8.30	9.24	**38**	18	7.54 ± 1.08	0.25	6.55	6.88	7.15	7.84	11.14	−0.13 (21.60)	0.90
A		11	7.96 ± 1.46	0.44	6.25	7.09	7.64	8.34	11.14		14	7.76 ± 1.37	0.37	6.25	6.55	7.29	8.72	10.70	0.35 (20.92)	0.73
B		13	8.06 ± 0.84	0.23	6.55	7.38	8.10	8.57	9.60		25	8.57 ± 1.27	0.25	7.29	7.71	8.25	8.99	13.22	−1.48 (33.69)	0.14
C		42	10.27 ± 1.62	0.25	7.82	9.21	9.86	10.97	14.52		41	10.29 ± 1.19	0.19	8.22	9.33	9.90	11.05	12.69	−0.06 (75.28)	0.95
D		147	12.24 ± 1.78	0.15	6.08	11.21	12.06	13.15	18.21		159	12.41 ± 1.73	0.14	6.08	11.39	12.22	13.27	17.68	−0.85 (300.55)	0.40
E		170	14.65 ± 1.92	0.15	10.70	13.32	14.49	15.92	21.30		153	14.79 ± 1.69	0.14	11.23	13.59	14.67	15.93	20.70	−0.70 (320.85)	0.49
F		113	16.91 ± 1.54	0.14	13.71	15.80	16.85	17.99	22.21		102	16.89 ± 1.55	0.15	14.20	15.70	16.73	17.56	22.16	0.10 (210.48)	0.92
G		125	18.71 ± 1.85	0.17	14.74	17.23	18.54	19.86	23.72		120	18.45 ± 1.53	0.14	15.30	17.20	18.30	19.39	23.07	0.21 (0.55)	0.89
H		288			15.11						300			15.11						

[a] Independent samples *t*-test.
[b] Crypt stage for the third molar; *N*, number of individuals; *M*, mean age; SD, standard deviation; SE, standard error of the mean age; Min, minimum age; Max, maximum age; *t*, value of the independent samples *t*-test; df, degree of freedom; *p*, statistically significant if $p < 0.05$.

Table 5
Comparison of chronological age (CA) and dental age (DA) (years) according to Demirjian's 1973 method of 299 males and 317 females of black African origin from the city of Gaborone, in the Republic of Botswana.

Age groups	*N*	Gender	CA ± SD	DA ± SD	(DA−CA) ± SD	SEM	*L*	*U*	MAE ± SD	*t*(df)	[a]*p*
6.0–6.9	22	M	6.45 ± 0.22	7.77 ± 0.39	1.33 ± 0.44	0.09	1.13	1.52	1.33 ± 0.44	14.12 (21)	<0.001
	21	F	6.56 ± 0.26	7.55 ± 0.96	0.99 ± 1.07	0.23	0.50	1.48	1.00 ± 1.06	4.25 (20)	<0.001
7.0–7.9	23	M	7.55 ± 0.25	8.82 ± 0.91	1.26 ± 0.85	0.18	0.89	1.63	1.26 ± 0.85	7.09 (22)	<0.001
	20	F	7.46 ± 0.25	8.21 ± 0.62	0.75 ± 0.57	0.13	0.49	1.02	0.78 ± 0.53	5.92 (19)	<0.001
8.0–8.9	26	M	8.57 ± 0.25	9.62 ± 1.03	1.05 ± 1.00	0.20	0.64	1.45	1.18 ± 0.83	5.35 (25)	<0.001
	22	F	8.40 ± 0.24	9.10 ± 0.69	0.70 ± 0.65	0.14	0.41	0.98	0.77 ± 0.56	5.01 (21)	<0.001
9.0–9.9	21	M	9.41 ± 0.29	10.66 ± 1.05	1.25 ± 1.00	0.22	0.80	1.70	1.29 ± 0.94	5.75 (20)	<0.001
	29	F	9.50 ± 0.28	10.64 ± 1.02	1.15 ± 0.93	0.17	0.80	1.50	1.23 ± 0.80	6.67 (28)	<0.001
10.0–10.9	27	M	10.51 ± 0.34	12.00 ± 1.19	1.49 ± 1.10	0.21	1.05	1.92	1.56 ± 0.98	8.14 (49)	<0.001
	32	F	10.56 ± 0.24	11.56 ± 1.03	1.00 ± 1.06	0.19	0.62	1.38	1.14 ± 0.90	5.35 (31)	<0.001
11.0–11.9	50	M	11.59 ± 0.27	13.13 ± 1.36	1.54 ± 1.34	0.19	1.16	1.92	1.60 ± 1.27	7.03 (26)	<0.001
	48	F	11.50 ± 0.27	12.61 ± 1.12	1.10 ± 1.11	0.16	0.78	1.43	1.18 ± 1.03	6.87 (47)	<0.001
12.0–12.9	52	M	12.48 ± 0.26	14.01 ± 1.30	1.54 ± 1.27	0.18	1.18	1.89	1.66 ± 1.10	8.71 (51)	<0.001
	61	F	12.46 ± 0.29	13.19 ± 1.14	0.73 ± 1.10	0.14	0.45	1.02	1.11 ± 0.71	5.21 (60)	<0.001
13.0–13.9	38	M	13.47 ± 0.34	14.50 ± 1.14	1.03 ± 1.12	0.18	0.67	1.40	1.32 ± 0.74	5.70 (37)	<0.001
	46	F	13.46 ± 0.27	14.04 ± 0.54	0.58 ± 0.66	0.10	0.39	0.77	0.68 ± 0.55	6.00 (45)	<0.001
14.0–14.9	34	M	14.39 ± 0.26	15.12 ± 0.77	0.73 ± 0.76	0.13	0.47	1.00	0.91 ± 0.54	5.59 (33)	<0.001
	28	F	14.42 ± 0.28	14.40 ± 0.49	−0.02 ± 0.47	0.09	−0.20	0.16	0.32 ± 0.33	−0.23 (27)	0.814
15.0–15.9	5	M	15.49 ± 0.31	15.60 ± 0.00	0.11 ± 0.31	0.14	−0.27	0.50	0.25 ± 0.19	5.59 (33)	0.459
	7	F	15.54 ± 0.37	14.60 ± 0.00	−0.94 ± 0.37	0.14	−1.28	−0.60	0.93 ± 0.37	−6.69 (6)	0.001
16.0–16.0	1	M	16.20	15.60	–	–	–	–	–	–	–
	3	F	16.56 ± 0.22	14.60 ± 0.00	−1.96 ± 0.22	0.13	−2.50	−1.42	1.96 ± 0.22	−15.55 (2)	0.004
Total	299	M	11.18 ± 2.48	12.43 ± 2.61	1.25 ± 1.11	0.06	1.12	1.37	1.36 ± 0.96	19.50 (298)	<0.001
	317	F	11.28 ± 2.43	12.01 ± 2.34	0.72 ± 1.02	0.06	0.61	0.83	0.96 ± 0.80	12.58 (316)	<0.001

[a] Paired *t*-test between DA and CA; DA−CA, difference between dental and chronological age; MAE, mean absolute error between dental and chronological age; *L*, lower interval; *U*, upper interval of 95% Confidence Interval of DA–CA; SD, standard deviation; df, degrees of freedom, statistically significant if $p < 0.05$.

indicator of maturity or for showing improvement or side effects of specific therapy (Bagattoni et al., 2014; Simmons, 1999). In clinical dentistry, such as orthodontics, it can be used in combination with other skeletal methods to compare different patterns or to estimate the exact time of starting or finishing an intervention (Cameriere et al., 2006b; Cameriere et al., 2015; Celikoglu et al., 2011). Dental age estimation procedures are most commonly used to compare with other biological systems of the human body in relation to legal

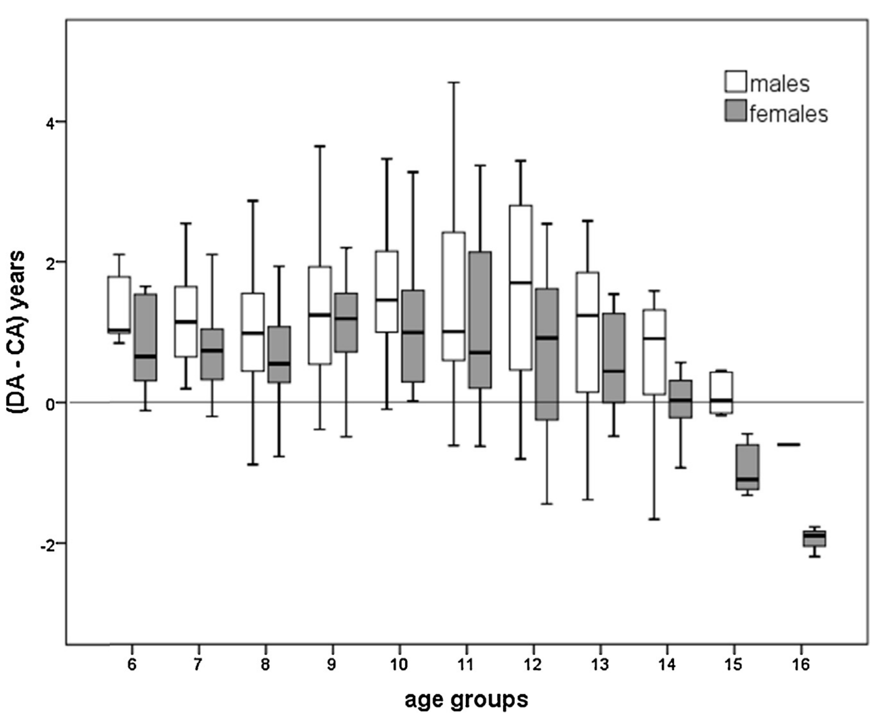

Fig. 1. Boxplot of the differences (DA–CA), the dental age (DA) and chronological age (CA) according to the Demirjian's method from1973 for the participants between six and 16 years of age from Gaborone, Botswana. Boxplot shows median and interquartile range, while the whiskers indicate the range.

matters and criminal investigations when the date of birth of individual is not known (Cunha et al., 2009). Previous studies showed that there is no difference in the dental development between the left and right side of the arches, so analysis of only the left side of both jaws is representative for target populations (Demirjian et al., 1973; Feijoo et al., 2012; Haavikko, 1974; Lee et al., 2008).

There are two main approaches to the evaluation of dental development of permanent teeth: (1) evaluation of eruption and (2) evaluation of mineralization on panoramic radiographs (Nuzzolese et al., 2009; Willems, 2001). Eruption is mostly influenced by dental development and mineralization, but also by local factors including alveolar space, previous local trauma of deciduous teeth, environmental and nutritional variations (Ulijaszek et al., 1998). Methods using OPTs are more appropriate because it is possible to evaluate the development of the whole dentition, pre- and post-eruption, in contrast to the insight into the number of teeth that are located in the mouth. Most approaches to dental age estimation differentiate variance in the time span of the first seven teeth, which generally mature between 12 and 14 years, and the third molars that could mature as late as 20–23 years of age (Ambarkova et al., 2014; Cameriere, 2014; Galic et al., 2011; Galić et al., 2010; Thevissen et al., 2010b, 2013). Most dental methods in children are based on evaluating seven teeth, like the methods of Demirjian (Demirjian and Goldstein, 1976; Demirjian et al., 1973), Haavikko (1970) and Cameriere et al. (2006a), or on evaluating at least four mandibular teeth (Demirjian and Goldstein, 1976; Haavikko, 1974). Demirjian's 1973 method weighs the development of selected teeth into a single maturity score. It is based on Tanner's approach to maturity assessment where specific maturity events were accessed, weighted and totally scored and finally expressed as biological age (Liversidge, 2012). Maturity score is a percentage of maturity which indicates the relative position of an individual person in the development from the start to the end of maturation (Liversidge, 2012). Dental age corresponds to the 50th percentile of the maturity score, so obtained dental age comparing to chronological age show whether a participant is advanced or delayed compared to standards (Liversidge, 2012).

The calculated dental age in the Botswana sample was significantly advanced in most age groups, both in males and females. An overestimation was higher in males (1.25 ± 1.11) then in females (0.72 ± 1.02). These finding indicate that the Demirjian 1973 method is not suitable for age estimation. There is a need to evaluate other methods or establish specific standards for Botswana children of black African origin for dental age calculation.

Previous studies which evaluated the first seven mandibular teeth by using the Demirjian 1973 method showed statistically significant overestimation when compared to the 50th percentile of Demirjian's French–Canadian standards across most age groups (Cunha et al., 2009; Feijoo et al., 2012; Galić et al., 2010; Lee et al., 2008; Leurs et al., 2005). Our findings on Botswana children are in agreement with most previous studies on European Caucasians (Cunha et al., 2009), South African Caucasians, mixed race, African and Asian children (Phillips and van Wyk Kotze, 2009), South Koreans(Lee et al., 2011) and South Americans (Franco et al., 2013; Maia et al., 2010). Although Liversidge (2012) argues that the reason why 50th percentile differs in most published results remains unidentified, a possible explanation could include the use of an inappropriate maturity curve, the sigmoid curve, or the manner in which the scores for chronological age were derived or the how tables were derived by manual smoothing and fitting (Liversidge, 2012).

The third molars were studied separately or excluded in most studies on permanent teeth (Brkic et al., 2011; Liversidge, 2008b, 2008c; Thevissen et al., 2010a, 2013). They have larger variability in the timing of initial formation and finished mineralization as well as having the most dispersed age range of formation and the highest level of agenesis (Liversidge, 2008c). Most of the first seven permanent teeth complete their mineralization between the ages of 12 and 14, when only the crown formation of the third molars is completed (Ambarkova et al., 2014; Cameriere et al., 2008; Galic et al., 2011, 2013; Liversidge, 2008a). However, the third molars are the only teeth that can be studied in the entire developmental range of stages from cross-sectional radiographic material (Liversidge, 2008c). In our study, there was no significant difference in mean ages at most of the developmental stages between maxillary and mandibular third molars. Statistically significant difference in mean ages was found only in the maxilla at D and F stages of maxillary third molars without a particular pattern. Mandibular third molars similarly develop in both sexes. Studies on the third molar mineralization on African–Zulu and Nguni populations and Cape coloureds (people from the western cape of mixed race) from South Africa showed that African females on average develop earlier than African males for almost all stages of third molar formation and Cape females earlier than Cape males for crown stage formation, although few of these comparisons were significant (Liversidge, 2008c). Contrary to these findings from Southern Africa, most previous studies on mandibular third molars reported earlier mean age within stage in males compared to females for most stages (Liversidge, 2008c). According to Kasper et al. (2009), the usefulness of the third molar stages alone for age prediction is low, however when combined with other skeletal and dental information, a more narrow range of predicted age is possible. Separate studies on the third molar development have been carried by the American Board of Forensic Odontologists (ABFO study) (Mincer et al., 1993) on American Caucasians. Kasper et al. (2009) compared the results from ABFO studies to Texan Hispanics. Texan Hispanic third molar development was 8–18 months earlier when compared to the sample from ABFO studies. In American Caucasians, maxillary third molar formation was slightly advanced over mandibular, and root formation occurred earlier in males than females (Mincer et al., 1993). In Texan Hispanics, all stages of development for the maxilla and mandible showed the mean ages for males to be less than female mean ages. Also the mean ages in the maxilla at each developmental stage were smaller than in mandible in both sexes, with the exceptions of stage C in females and stage D in males.

An important aspect of the third molar development is that they are the only teeth that may be used for age estimation in older age groups, even up to early 20s, because other permanent teeth have already finished their development (Ambarkova et al., 2014; Galic et al., 2011; Galić et al., 2010). The third molars may be used around 18 years for discriminating between adults (those who are 18 years of age or older) and minors (those who are younger than 18 years) (Cameriere et al., 2014; Galic et al., 2015). The sample of OPTs in our study was restricted to the age of 23 years because we did not find older individuals with open third molar apices. Similarities were found with some previous studies (Thevissen et al., 2010b, 2013). In order to record the time of the first radiographic evidence of mineralization of the third molars, the crypt stage of the third molars was also evaluated (Liversidge, 2008b). Mean ages within crypt stages in this study were lower in both sexes than in Africans from South Africa, which were reported as the group with the earliest crypt stage formation and final maturation of the third molars (Liversidge, 2008c).

The main limitation of this study is the fact that there were no available OPTs of younger individuals (only 3 OPTs of 5 year-olds were excluded from analysis). Only those age categories with an appropriate minimum number of subjects (more than ten) are representative according to Liversidge (2012). This is because there are no general dental or ethical orthodontic indications for performing OPTs at this specific age (Liversidge, 2012). Ethical considerations presume the use of radiographic techniques with minimal effective radiation doses for diagnostic purposes (Galic et al., 2015). The effective dose of OPTs is approximately three to four times greater than intraoral radiographs (Koch and Poulsen, 2009). Another problem of taking OPTs of very young children is that they need to stand still for up to 20 s to avoid movement errors in the images which are then useless for diagnostic analysis if they occur (Koch and Poulsen, 2009). As a result, the lower mineralization stages, including crypts, were unavailable for the study and appropriate numbers of individuals of a younger age were not attainable. This is a common limitation in age estimation studies using OPTs of children and adolescents (Ambarkova et al., 2014; Feijoo et al., 2012; Galic et al., 2011, 2013).

5. Conclusion

In the sample of black African children and adolescents, the antagonistic teeth showed similar development, with statistically significant difference in some stages of few teeth.

The advanced development of mandibular teeth was only found for Demirjian stage G between the central incisors, stages E and G between lateral incisors and stage G between first molars, while significantly advanced development of maxillary teeth was found in stage G in second premolars in males. The significant difference in advanced development of mandibular teeth was only found in stage G between antagonists of both incisors, stage E of the second incisor, stage E in the second premolars and stage G in the first molars and advanced development of maxillary teeth was only found for stage G in the second premolar in females. Difference in mean age within stage between sexes in maxillary teeth was found at stage F for the central incisors, stage F for the second molars and stages D and F for the third molars, while in the mandibular teeth it was found at stage G for the canines, stage E for the second premolars and stage F for the second molars.

An overestimation of dental age shows that the Demirjian 1973 method is not suitable for daily application. There is a need for establishing specific standards for Botswana children of black African origin.

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