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ORIGINAL ARTICLE

The timing of mandibular tooth formation in two African groups

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ABSTRACT

Background: Ethnic differences in the timing of human tooth development are unclear.

Aim: To describe similarities and differences in the timing of tooth formation in two groups of Sudanese children and young adults.

Subjects and methods: The sample consisted of healthy individuals from Khartoum, Sudan, aged 2–23 years. The Northern group was of Arab origin (848 males, 802 females) and the Western group was of African origin (846 males, 402 females). Each mandibular left permanent tooth from first incisor to third molar was assessed from dental radiographs into one of 15 development stages. Mean ages at entry for 306 tooth stages were calculated using probit regression in males/females in each group and compared using a *t*-test.

Results: Mean ages were not significantly different in most tooth stage comparisons *between* ethnic groups for both males (61/75) and females (56/76), despite a tendency of earlier mean ages in the Western group. Mean ages for most tooth stage comparisons between males and females (137/155) were not significantly different *within* ethnic groups suggesting low sexual dimorphism.

Conclusion: The mean ages of most mandibular tooth formation stages were generally not significantly different between ethnic groups or between males and females in this study.

Abbreviations: I1: mandibular central incisor; I2: mandibular lateral incisor; C: mandibular canine; P1: mandibular first premolar; P2: mandibular second premolar; M1: mandibular first molar; M2: mandibular second molar; M3: mandibular third molar; Cr: crypt; Ci: initial cusp formation; Cco: coalescence on cusps; Coc: crown outline complete; C1/2: crown half complete; C3/4: crown three quarters complete; Cc: crown complete; Ri: initial root formation; Rcl: root cleft formation; R1/4: root length one quarter; R1/2: root length one half; R3/4: root length three quarters; Rc: root length complete; A1/2: apex half closed; Ac: apex closed

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Ethnic origin; tooth formation; sexual dimorphism; individual variation; group differences

Introduction

Human teeth grow in a highly organised sequence in relation to each other prior to their eruption into the oral cavity. Teeth appear in maxillary and mandibular bones as individual units and follow a sequence of development until all teeth are fully formed. Tooth formation from crown tip to root apex follows a predictable morphological path. How this relates to the timing of consecutive stage formation between human groups is less clear. Understanding the effects of biological factors on the timing of tooth formation is important in human biology, forensic anthropology, evolutionary, medical and anthropologic fields.

Maturing teeth are regulated by complex biological clocks in their trajectory to full maturity (Papagerakis et al., 2014). This is particularly evident in crown formation (Antoine et al., 2009). Children vary considerably with respect to maturing teeth in relation to chronological age by a number of years, but are still considered biologically normal (Demirjian & Levesque, 1980; Levesque et al., 1981; Liversidge, 2011; Liversidge et al., 2006; Nystrom et al., 2007).

In light of the large age variation between individuals, the precise effect of biological factors such as sex and ethnicity on the timing of dental maturity events needs to be explored in large groups or populations across world regions. The effect of biological factors on the complex and lengthy process of forming teeth requires particular attention to methods of sampling and analysis [illegible] et al., 1991). Some of the methods of analysis claiming differences between groups have been called into question (Liversidge, 2012; Liversidge et al., 1999). In addition, there is evidence to indicate the overall timing of tooth formation is relatively unaffected by severe biological insults such as malnutrition, despite affecting skeletal and somatic growth (Elamin & Liversidge, 2013; Garn et al., 1965). The mechanisms that insulate the forming teeth from severe environmental pressures such as malnutrition are not clear. Other evidence suggests that biological factors such as sex and ethn[illegible] formation than previously [illegible] Liversidge, 2011).

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Table 1. Radiographic studies that describe timing of individual permanent tooth maturation.

Country	Authors	*n* male, female	Age range	Teeth*	Statistics	Dispersion
Canada	Anderson et al. (1976)	121, 111	3–20	1	mean age L	SD
	Thompson et al. (1975)	121, 111	3–20	2	mean age L	—
	Demirjian & Levesque (1980)	2705, 2732	2–19	3	% smoothed curves	—
	Levesque et al. (1981)	2278, 2367	7–25	8	% smoothed curves	—
China	Zhao et al. (1990)	465, 438	3–16	3	50th percentile	—
Finland	Haavikko (1970)	615, 547	2–21	2	50th percentile	10th, 90th percentile
	Nyström et al. (2007)	966, 1004	0–25	2	50th percentile	—
South Africa, UK	Liversidge (2008)	390, 335	5–23	8	mean, logistic regression	SD†, SE
UK	Liversidge & Speechly (2001)	263, 258	4–9	3	mean, probit regression	SD
	Liversidge (2011)	529, 521	2–22	2	mean, logistic regression	SD†, SE
USA	Garn et al. (1958)	255	0–15	6	mean age L	—
	Garn et al. (1959)	255	0–15	5	50th percentile	10th, 90th percentile
	Fanning (1961)	48, 51	3–12	3, 7	mean age L	SD‡
	Fanning & Brown (1971)	151, 139	0–22	4	mean age L	10th, 90th percentile
	Moorrees et al. (1963)	184, 161	0–22	2, 7	mean age L	SD‡
Various	Liversidge et al. (2006)	4522, 4480	2–16	3	mean, logistic regression	SE

Age range in years.
*1, all maxillary and mandibular; 2, all mandibular; 3, all mandibular except M_3; 4, mandibular C, P_1, P_2, M_1, M_2, M_3; 5, m[illegible]lar P_1, P_2, M_1, M_2; 7, maxillary incisors; 8, M_3; L, longitudinal; SD, standard deviation; SE, standard error.
† needs correcting factor, ‡ illustrated as error bar.

number of methodological factors. Most studies on the timing of tooth formation have samples of limited age ranges, small numbers, and used non-cumulative statistical approaches. Samples that contain limited age ranges allow only a few tooth stages to be investigated and statistically significant differences may not necessarily amount to biological importance in light of the inherent variation seen between individuals (Bennett et al., 1991). Part of the difficulty is due to maturation of the tooth being divided into many stages (usually 8–15). This reduces the number of children per stage, despite a large sample size and wide age range. Another challenge is that teeth mature over a long period of time in relation to other body systems, developing from prior to birth into early adulthood when individuals undergo marked morphologic and skeletal change with genetic and other environmental factors playing a role.

Only a handful of studies describe the timing of individual tooth stages using appropriate statistical methods and dispersion parameters across age and these are listed in Table 1 (Anderson et al., 1976; Demirjian & Levesque, 1980; Fanning & Brown, 1971; Garn et al., 1959; Haavikko, 1970; Levesque et al., 1981; Liversidge, 2008, 2011; Liversidge & Speechly, 2001; Liversidge et al., 2006; Moorrees et al., 1963; Nyström et al., 2007; Thompson et al., 1975; Zhao et al., 1990). Some directly compare ethnic/regional groups (Liversidge, 2008, 2011; Liversidge et al., 2006), one notes differences for the third molar (Liversidge, 2008), whilst others showed similarities (Liversidge, 2011; Liversidge et al., 2006) in formation times. Most of these studies describe tooth formation in children of European origin and there are gaps in the literature describing the timing of tooth formation in other world groups, particularly those in Africa. The timing of formation of the mandibular third molar in South African Blacks (Liversidge, 2008) is the only tooth documented in this way from an African population.

The aim of our study was to investigate the effect of ethnic group and sex on the timing of mandibular tooth formation in two groups of dental patients in Sudan, with a wide age range using well-defined ethnic grouping, age structure and statistical analysis.

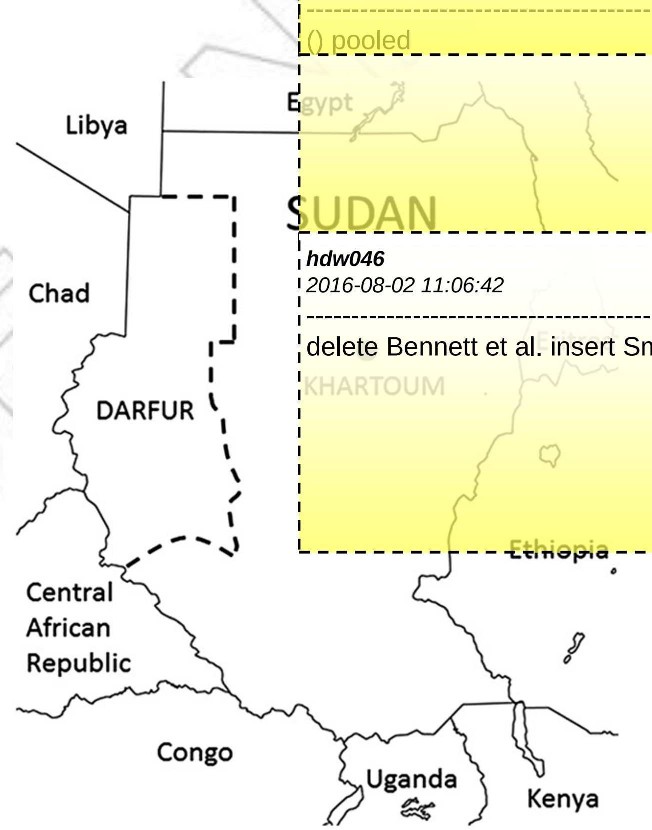

Figure 1. Map of Sudan, pre-cessation into two countries in 2011, where the study was conducted.

Materials and methods

The subjects (2.83–23.96 years, *n* ¼ 2898) for this investigation were part of a population survey that considered tooth formation, anomalies and disease in Khartoum, Sudan (Elamin, 2011). Sample selection followed the design from the Strengthening and The Reporting of Observational Studies in Epidemiology guidelines (STROBE) (von Elm et al., 2007). Arab tribes from the North of Sudan (Jaali, Mahasi, Shaigi, Bedairi, Halfawi and Dongalawi groups) and Western Sudanese tribes of African origin, namely Fur and Zagawa, were studied (Figure 1).

Table 2. Age and sex distribution of study sample. The Northern group was of Arab origin and the Western group was of African origin.

	North group			West group		
Age	F	M	Total	F	M	Total
2þ	1	4	5	—	—	—
3þ	31	37	68	4	4	8
4þ	28	32	60	4	6	10
5þ	31	47	78	30	21	51
6þ	71	68	139	23	54	77
7þ	62	56	118	22	61	83
8þ	60	32	92	28	35	63
9þ	45	35	80	52	45	97
10þ	30	30	60	25	49	74
11þ	20	29	49	57	150	207
12þ	28	19	47	52	130	182
13þ	18	41	59	26	113	139
14þ	30	50	80	14	86	100
15þ	31	34	65	16	43	59
16þ	37	36	73	12	21	33
17þ	61	52	113	6	7	13
18þ	55	65	120	4	3	7
19þ	34	48	82	9	11	20
20þ	35	41	76	5	4	9
21þ	34	39	73	9	2	11
22þ	41	31	72	3	1	4
23þ	19	22	41	—	—	—
Total	802	848	1650	402	846	1248

M, male; F, female; 2þ, includes individual aged from 2.00–2.99 years, etc.

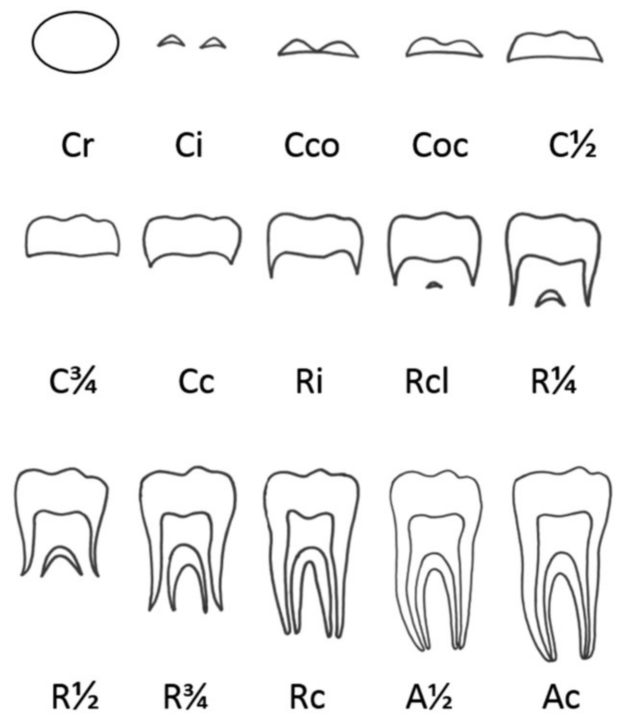

Figure 2. Mandibular tooth formation stages after Moorrees et al. (1963), with the addition of crypt stage for molars.

Subjects from the Northern group were randomly selected from pre-schools, Khalwas (religious schools), main-stream schools and universities between January 2007 and May 2012 and stratified by school, using a cluster sampling method (Bennett et al., 1991). Schools, pre-schools, Khalwas and universities in the three localities (Bahri, Umdurman and Khartoum City) in Khartoum were chosen from a list of schools in these localities obtained from the Ministry of Education and sampled where safety permitted. The Western group were drawn from schools and Khalwas located in and around camps for the internally displaced in Khartoum. Children were excluded if the date of birth was unknown or if they had craniofacial anomalies. The age and sex distribution of the group is shown in Table 2. For practical reasons, radiographs were limited to individuals rv3 years and older. Ethical approval was granted by the Ethics committee at El Razi Dental School prior to the study (01/11/2006). Verbal and written consent were obtained from individuals and from parents of minors. A dental examination was carried out and, where appropriate, a dental panoramic radiograph taken (Orthophos Model: D3200, Siemens, Germany). The same machine was used in this study but was moved between two locations, a dental school in southern Khartoum and a dental hospital in the northern part. The radiograph involved taking a standard view with the head in the Frankfort plane. The film was manually developed by experienced dental staff in preparation for clinical use.

The radiographs were digitised, decoded and randomised for blind scoring by a person other than the investigator. Age of each subject was converted to decimal age. Permanent mandibular left teeth were staged by the first author (FE) from the radiographs using the 14 crown and root stages after Moorrees et al. (1963) in addition to staging the crypt of the third molar, i.e. 120 stages (Figure 2). We only assessed mandibular teeth as maxillary teeth are less clearly visualised on panoramic radiographs due to superimposition of the hard palate. Intra-examiner reliability of stage assessment from 90 panoramic radiographs was assessed by Cohen's Kappa, showing excellent agreement (j ¼ 0.91). SPSS, Release Version 17.0 (#SPSS, Inc., 2009, Chicago IL) was used to analyse data. Probit regression was used to calculate the cumulative mean age at entry or transition into tooth stages, where at least 10 individuals per year of age were available.

A total of 309 mean ages at entry were available to compare from a total of 420 possible comparisons in four groups of different ethnic origin and sex (male–female groups from North and West; male–male and female–female groups from both regions). Missing data in Tables 3–9 are the tooth stages that develop before the third birthday, prior to the minimum age in our sample. Most tooth stages were observed across a wide age range and for most calculations at least 10 individuals were present in consecutive year age groups.

The number of available comparisons is shown in summary in Tables 3 and 4: 75 and 76 comparisons of Northern-Western males and females, respectively, 80 comparisons of Northern male–female and 75 Western male–female groups. The mean age of stage attainment for each tooth stage was compared between male (North/West) and female (North/West) groups of different ethnicity. Sex comparisons were carried out within ethnic groups using a *t*-test, with a significance level of $p < 0.05$.

Table 3. Ethnic group comparisons. Summary of 75 comparisons of mean age entering mandibular tooth stages in North-West males and 76 in North-West females showing predominant similarity between ethnic groups. Missing tooth stages occurred at a younger age than our sample and could not be calculated.

Comparisons*	I1	I2	C	P1	P2	M1	M2	M3
Male								
Cr								NS
Ci								"
Cco								NS
Coc					NS		NS	NS
C1/2					NS		NS	NS
C3/4				NS	NS		NS	#
Cc			NS	NS	"		NS	NS
Ri			NS	"	#	NS	NS	NS
Rcl			—	—	—	NS	NS	NS
R1/4	NS	NS	NS	"	NS	NS	"	NS
R1/2	NS	NS	NS	NS	#	NS	NS	NS
R3/4	NS	NS	NS	#	NS	NS	NS	NS
Rc	NS	"	NS	NS	NS	NS	NS	NS
A1/2	NS	"	#	#	NS	NS	NS	NS
Ac	NS	"	NS	NS	NS	NS	NS	NS
Female								
Cr								NS
Ci								NS
Cco							NS	NS
Coc					NS		NS	NS
C1/2					NS		NS	NS
C3/4				NS	NS		NS	NS
Cc			NS	NS	NS		NS	NS
Ri		NS	NS	NS	NS		"	NS
Rcl		—	—	—	—	NS	"	NS
R1/4	NS	NS	NS	#	#	NS	NS	NS
R1/2	NS	NS	NS	#	#	NS	"	NS
R3/4	NS	NS	NS	#	#	NS	"	NS
Rc	NS	NS	#	NS	NS	NS	NS	"
A1/2	NS	NS	NS	#	#	NS	NS	"
Ac	NS	NS	#	#	#	#	NS	"

*Significant difference in mean age entering tooth stage ($p < 0.05$).
" Significant advance in mean age for Western group (Northern group is reference).
Significant delay in mean age for Western group (Northern group is reference).
NS, Non-significant differences ($p > 0.05$); —, No cleft stage for anterior teeth.

Table 4. Male–female comparisons. Summary of 80 comparisons of mean age entering mandibular tooth stages in North male–female and 75 West male–female groups showing predominant similarity between males and females. Missing tooth stages occurred at a younger age than our sample and could not be calculated.

Comparisons*	I1	I2	C	P1	P2	M1	M2	M3
North								
Cr								NS
Ci							NS	NS
Cco					NS		NS	NS
Coc					NS		NS	NS
C1/2				NS	NS		NS	NS
C3/4				NS	NS		NS	NS
Cc			NS	NS	#		NS	NS
Ri		NS	NS	NS	#	NS	NS	NS
Rcl		—	—	—	—	NS	NS	NS
R1/4	NS	NS	"	NS	NS	NS	NS	NS
R1/2	NS	NS	"	NS	NS	NS	NS	NS
R3/4	NS	NS	"	NS	NS	NS	NS	NS
Rc	NS	NS	NS	NS	NS	NS	NS	NS
A1/2	NS	"	"	"	"	NS	NS	NS
Ac	NS	"	NS	NS	NS	NS	NS	#
West								
Cr								NS
Ci								NS
Cco							NS	NS
Coc					NS		NS	NS
C1/2					NS		NS	"
C3/4				NS	NS		NS	"
Cc			NS	NS	NS		NS	"
Ri			NS	NS	NS		"	NS
Rcl			—	—	—	NS	NS	NS
R1/4	NS	NS	NS	NS	NS	"	NS	NS
R1/2	NS	NS	NS	NS	NS	NS	NS	NS
R3/4	NS	NS	"	NS	NS	NS	NS	NS
Rc	NS	NS	NS	NS	NS	NS	NS	NS
A1/2	NS	NS	NS	NS	NS	NS	NS	NS
Ac	NS	NS	"	NS	NS	NS	NS	NS

*Significant difference in mean age entering tooth stage ($p < 0.05$).
" Significant advance in mean age for females (Males are reference group).
Significant delay in mean age for females (Males are reference group).
NS, Non-significant differences ($p > 0.05$); —, No cleft stage for anterior teeth.

Results

A summary of significant/non-significant comparisons for all available mandibular tooth stages between ethnic groups and male/female groups is shown in Table 3 and 4, respectively. Results for M3 are shown in Table 5, M2 in Table 6, M1 in Table 7, P2 in Table 8, P1 in Table 9, canine in Table 10, I2 in Table 11 and I1 in Table 12. Figures 3–8 show mean age at entry with 95% confidence interval of mean for stages of M3, M2 and C, comparing means in Northern and Western male groups and Northern male and female groups.

Other results of individual tooth stages including average age of individuals within a tooth stage and minimum and maximum age for tooth stages are available in Elamin (2011), although some root stages were re-assessed and ages checked subsequently for this paper. The reported standard deviation values for mean age at entry in this paper require a multiplication correction factor of p/�, as mean ages were calculated using logistic regression (Greene & Hensher, 2010).

Ethnic comparisons

A high percentage of tooth stage comparisons of mandibular teeth were not significantly different. In males, 61 out of 75 tooth stages (81%) were not significantly different. Of the 14 stages that were significant, mean age was earlier for eight stages in the Western males compared to the Northern males. In females, 56 out of 76 tooth stages (74%) were not significantly different. Of the 20 stages that were significant, mean age was earlier for seven stages in the Western group. The tooth stages involved were the lateral incisor apical root stages in males and premolars in both sexes. Mean ages of most root stages of both premolars in the Western females were later compared to Northern females. The reason for this is unclear. The Western female group was considerably smaller than other groups and late root stages of M3 are based on small numbers. These results are summarised in Table 3 and illustrated in Figures 3, 5 and 7 for M3, M2 and C, respectively.

Sex comparisons

Most tooth stage comparisons of eight mandibular teeth were not significantly different. In the Northern groups, 69 out of 80 tooth stages (86%) were not significantly different. Of the 11 stages that were significant, mean age was earlier for eight stages in females compared to males. In the Western group, 68 out of 75 tooth stages (91%) were not significantly different. Mean age was earlier in the females for

Table 5. Comparison of mean age in years, standard deviation (SD), 95% confidence interval (95% CI) for entering mandibular M3 stages in Northern and Western Sudanese groups.

	North females (*n* ¼ 802)		West females (*n* ¼ 401)		North males (*n* ¼ 848)		West males (*n* ¼ 846)	
Stage	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI
Cr	8.19, 1.41	7.95–8.45	8.23, 1.68	7.28–9.18	8.49, 2.05	7.75–9.23	8.35, 2.66	8.01–8.68
Ci	8.88, 1.18	8.65–9.14	8.75, 2.06	8.34–9.16	9.54, 3.76	9.08–10.01	8.45, 1.45	8.02–8.89
Cco	9.28, 1.19	9.04–9.59	9.50, 1.32	9.13–9.87	9.72, 2.06	9.21–10.23	9.45, 1.36	9.17–9.73
Coc	9.77, 1.26	9.50–10.10	10.11, 1.54	9.79–10.44	10.17, 2.12	9.72–10.62	10.29, 1.50	10.05–10.53
C1/2	10.71, 1.57	10.11–11.49	11.23, 1.48	10.95–11.51	11.14, 1.74	10.80–11.47	11.55, 1.63	11.36–11.74
C3/4	12.27, 1.81	11.79–12.71	12.26, 1.18	12.02–12.51	12.44, 1.86	12.09–12.79	13.30, 1.41	13.12–13.48
Cc	13.56, 1.96	13.11–13.97	13.04, 1.45	12.71–13.36	13.72, 1.72	13.40–14.05	14.04, 1.25	13.85–14.23
Ri	14.47, 1.87	14.06–14.85	14.23, 1.23	13.86–14.59	14.76, 1.29	14.48–15.03	14.58, 1.18	14.37–14.80
Rcl	14.95, 1.77	14.56–15.31	15.25, 1.47	14.80–15.71	15.10, 1.36	14.83–15.37	14.91, 1.12	14.71–15.12
R1/4	15.70, 2.14	15.34–16.06	15.49, 1.21	15.07–15.92	15.66, 1.38	15.39–15.93	15.49, 1.36	15.19–15.79
R1/2	16.69, 2.50	16.34–17.05	16.27, 1.12	15.82–16.72	16.62, 1.77	16.32–16.91	17.26, 1.63	16.64–17.87
R3/4	18.06, 2.73	17.68–18.45	17.28, 0.85	16.70–17.86	17.64, 2.03	17.33–17.95	18.01, 1.36	17.26–18.74
Rc	19.16, 2.39	18.78–19.54	18.11, 1.00	17.55–18.66	18.51, 1.86	18.21–18.81	18.63, 1.19	18.01–19.25
A1/2	19.57, 2.28	19.21–19.93	18.44, 0.80	17.95–18.93	18.89, 1.70	18.55–19.22	19.05, 0.98	18.44–19.66
Ac	20.61, 1.94	20.24–20.99	19.43, 1.34	18.72–20.14	19.70, 1.54	19.41–20.00	20.17, 1.47	19.33–21.00

n, Number of individuals in the group.

Table 6. Comparison of mean age in years for entering mandibular M2 stages in Northern and Western Sudanese groups.

	North females (*n* ¼ 802)		West females (*n* ¼ 402)		North males (*n* ¼ 848)		West males (*n* ¼ 846)	
Stage	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI
Ci	3.48, 0.22	3.25–3.71			3.03, 0.94	2.59–3.47		
Cco	3.78, 0.56	3.56–3.99	3.90, 0.52	3.36–4.44	3.44, 0.94	3.12–3.76		
Coc	3.98, 0.69	3.76–4.21	4.19, 0.33	3.81–4.57	3.86, 0.76	3.62–4.10	4.13, 0.54	3.67–4.60
C1/2	4.34, 0.98	4.07–4.61	4.66, 0.96	4.15–5.17	4.23, 0.96	3.97–4.49	4.79, 0.89	4.29–5.28
C3/4	5.63, 0.89	5.41–5.86	5.58, 1.14	5.39–5.76	5.40, 1.18	5.15–5.65	5.88, 1.07	5.52–6.23
Cc	7.61, 1.50	7.32–7.90	7.52, 1.14	7.14–7.90	7.33, 1.83	7.00–7.65	7.59, 1.19	7.33–7.85
Ri	9.71, 1.38	9.44–9.98	9.00, 0.81	8.76–9.25	9.76, 1.52	9.47–10.04	9.44, 0.63	9.29–9.58
Rcl	10.49, 1.30	10.24–10.74	9.84, 0.65	9.65–10.02	10.29, 1.25	10.04–10.54	10.14, 0.67	9.98–10.29
R1/4	11.24, 1.61	10.95–11.53	10.79, 0.72	10.62–10.95	11.23, 1.21	10.99–11.47	10.83, 0.62	10.72–10.93
R1/2	12.07, 1.19	11.81–12.33	11.60, 0.49	11.45–11.75	11.79, 1.12	11.53–12.05	11.82, 0.65	11.73–11.92
R3/4	12.87, 1.23	12.60–13.14	12.33, 0.63	12.17–12.49	12.54, 1.18	12.27–12.80	12.49, 0.60	12.39–12.59
Rc	13.44, 1.18	13.18–13.69	13.09, 0.56	12.89–13.28	13.50, 1.09	13.27–13.74	13.29, 0.76	13.19–13.39
A1/2	14.01, 1.12	13.74–14.29	14.30, 1.12	13.93–14.67	14.29, 1.03	14.04–14.55	14.08, 1.01	13.92–14.23
Ac	15.55, 1.67	15.24–15.85	15.62, 1.09	15.19–16.06	15.32, 1.00	15.10–15.53	15.57, 1.27	15.28–15.86

Abbreviations, see Table 5.

Table 7. Comparison of mean age in years entering mandibular M1 stages in Northern and Western Sudanese groups.

	North females (*n* ¼ 802)		West females (*n* ¼ 402)		North males (*n* ¼ 848)		West males (*n* ¼ 846)	
Stage	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI
Cc	2.97, 0.57	2.30–3.65						
Ri	4.07, 0.23	3.90–4.25			4.18, 0.42	3.95–4.41	4.10, 0.18	3.71–4.32
Rcl	4.20, 0.21	4.04–4.37	4.33, 0.50	3.71–4.96	4.51, 0.34	4.31–4.71	4.58, 0.41	4.10–5.07
R1/4	5.22, 0.31	5.03–5.41	4.86, 0.32	4.53–5.19	5.23, 0.32	5.06–5.41	5.39, 0.13	5.20–5.57
R1/2	6.00, 0.41	5.80–6.20	6.09, 0.15	5.92–6.27	6.08, 0.47	5.88–6.27	6.12, 0.23	5.94–6.30
R3/4	6.47, 0.97	5.76–6.91	6.80, 0.31	6.51–7.09	7.06, 0.47	6.84–7.28	6.81, 0.57	6.55–7.08
Rc	7.34, 0.88	6.92–7.77	7.18, 0.81	6.89–7.45	7.27, 0.89	6.27–8.26	7.03, 1.31	5.84–7.86
A1/2	7.60, 0.71	6.45–9.02	8.31, 1.23	7.36–8.88	7.89, 1.07	7.29–8.69	8.29, 1.27	8.04–8.52
Ac	8.08, 0.58	7.94–8.24	9.71, 1.09	9.45–9.96	8.99, 1.30	8.18–10.14	9.50, 1.07	8.95–9.95

Abbreviations, see Table 5.

all seven tooth stages that were significant in this group. These results are summarised in Table 4 and illustrated in Figures 4, 6 and 8 for M3, M2 and C, respectively.

Discussion

Our results show that the timing of tooth formation is not significantly different in the vast majority of the 306 tooth stage comparisons. There was no clear pattern, i.e. the stages that were significant were not specific to crown stage, root stage or tooth type, although mean ages in a number of root stages of successional teeth (canine and premolars) were delayed in the Western group compared to the Northern group. Mean ages were earlier in the Western group compared to the Northern group in around one third of comparisons.

Comparison between Northern and Western groups

Our main finding was that most mandibular tooth stages were not significantly different in timing in the two ethnic groups in Khartoum. Around 83% of comparisons in our

Table 8. Comparison of mean age in years entering mandibular P2 stages in Northern and Western Sudanese groups.

	North females (n ¼ 802)		West females (n ¼ 402)		North males (n ¼ 848)		West males (n ¼ 846)	
Stage	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI
Cco	3.40, 0.70	2.85–3.96			3.66, 0.50	2.99–3.72		
Coc	3.98, 0.52	3.66–4.30	4.02, 0.79	2.61–4.55	3.57, 0.40	3.30–3.82	4.15, 0.39	3.69–4.60
C1/2	4.26, 0.56	3.95–4.57	4.43, 0.66	3.34–4.85	4.15, 0.45	3.90–4.40	4.20, 0.47	3.51–4.89
C3/4	5.25, 0.59	4.99–5.52	5.18, 0.61	4.52–5.44	5.21, 0.94	4.97–5.42	5.16, 0.65	4.64–5.68
Cc	6.50, 0.71	6.24–6.76	6.48, 1.10	6.12–6.80	5.95, 1.18	5.66–6.12	6.85, 0.61	6.58–7.12
Ri	8.73, 0.97	8.42–9.04	8.16, 0.67	7.80–8.53	7.91, 1.56	7.63–8.22	8.45, 0.50	8.24–8.66
R1/4	9.00, 1.20	8.77–9.25	9.54, 0.54	9.32–9.96	9.33, 1.26	9.05–9.64	9.78, 0.54	9.61–9.96
R1/2	9.83, 1.41	9.55–10.14	10.58, 0.58	10.37–10.80	10.18, 0.63	9.97–10.40	10.79, 0.53	10.64–10.94
R3/4	11.02, 1.33	10.71–11.37	11.80, 0.43	11.61–11.99	11.43, 1.64	11.07–11.77	11.82, 0.64	11.68–11.96
Rc	12.18, 1.45	11.44–12.90	12.70, 0.46	12.48–12.92	12.66, 1.33	12.33–12.96	12.87, 0.60	12.73–13.02
A1/2	12.96, 1.38	12.60–13.31	14.27, 0.78	13.95–14.61	13.77, 1.13	13.50–14.03	14.50, 0.60	13.90–14.20
Ac	14.19, 1.54	13.82–14.56	15.30, 1.32	14.88–15.83	14.29, 0.78	12.75–15.39	14.82, 1.03	14.40–15.38

Abbreviations, see Table 5.

Table 9. Comparison of mean ages in years for entering mandibular P1 stages in Northern and Western Sudanese groups.

	North females (n ¼ 802)		West females (n ¼ 402)		North males (n ¼ 848)		West males (n ¼ 846)	
Stage	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI
C1/2	2.99, 1.18	2.31–3.68						
C3/4	4.20, 0.91	3.93–4.46	3.66, 1.21	2.51–4.80	4.14–0.86	3.58–4.5[illegible]	[illegible]	[illegible]
Cc	5.47, 0.80	5.26–5.69	4.97, 1.41	4.41–5.52	5.23–0.90	5.00–5.4[illegible]	[illegible]	[illegible]
Ri	6.54, 1.16	6.30–6.78	6.82, 1.18	6.43–7.20	6.04–1.47	5.32–6.5[illegible]	[illegible]	[illegible]
R1/4	7.76, 0.92	7.58–7.95	8.32, 1.16	7.97–8.66	8.03– 1.30	7.78–8.3[illegible]	[illegible]	[illegible]
R1/2	8.69, 1.07	8.19–9.30	9.70, 0.98	9.49–9.91	9.68–1.23	9.26–10[illegible]	10.00–0.92	9.82–10.18
R3/4	9.63, 1.65	9.14–10.28	10.82, 1.00	10.63–11.01	10.53–0.87	10.26–10.79	10.97–1.01	10.83–11.12
Rc	10.92, 1.46	10.12–11.89	11.97, 0.72	11.77–12.16	11.61–0.41	10.69–12.38	12.07–1.12	11.93–12.21
A1/2	11.88, 1.35	11.54–12.24	12.95, 0.92	12.72–13.17	12.62–1.37	12.30–12.92	13.13–1.09	12.98–13.28
Ac	12.76, 1.31	12.41–13.14	13.94, 0.96	13.61–14.26	13.46–1.36	12.52–14.17	13.90–0.87	13.75–14.05

Abbreviations, see Table 5.

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Table 10. Comparison of mean ages in years for entering mandibular C stages in Northern Sudanese and Western Sudanese groups.

	North females (n ¼ 802)		West females (n ¼ 402)		North males (n ¼ 848)		West males (n ¼ 846)	
Stage	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI
C3/4					2.97–0.89	2.52–3.4[illegible]	[illegible]	[illegible]
Cc	3.93, 1.00	3.62–4.24	4.19, 0.74	3.10–4.67	4.05, 1.21	3.73–4.3[illegible]	[illegible]	[illegible]
Ri	5.18, 0.87	4.95–5.41	5.08, 1.34	4.57–5.58	5.21, 1.10	4.96–5.4[illegible]	[illegible]	[illegible]
R1/4	6.69, 1.43	6.42–6.96	6.90, 0.92	6.54–7.25	7.33, 1.52	7.04–7.6[illegible]	[illegible]	[illegible]
R1/2	8.04, 1.13	7.67–8.44	8.19, 1.09	7.39–8.89	8.77, 0.24	8.52–9.0[illegible]	[illegible]	[illegible]
R3/4	8.91, 1.03	8.70–9.14	8.89, 1.18	8.54–9.24	9.76, 1.47	9.25–10[illegible]	9.99–0.92	9.83–10.15
Rc	10.24, 1.25	9.96–10.54	10.83, 1.00	10.64–11.02	10.98, 0.98	10.33–11.[illegible]	[illegible]	[illegible]
A1/2	11.13, 1.30	10.83–11.47	12.47, 0.63	12.30–12.66	11.96, 1.27	11.64–12.26	12.98–0.83	12.48–13.61
Ac	12.11, 1.24	11.78–12.46	12.97, 0.49	12.81–13.17	12.65, 0.97	11.36–13.64	13.51–0.39	13.42–13.60

Abbreviations, see Table 5.

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study were not significantly different and there was no clear pattern in the tooth stages that were different. This finding is in agreement with two previous reports comparing the timing of age at entry of individual mandibular teeth between groups. The first study compared mean age entering Demirjian stages in children from Australia, Belgium, Canada, England, Finland, France, South Korea and Sweden (Liversidge et al., 2006). About 13% of comparisons were significantly different between groups with no clear pattern. The second (Liversidge et al. 2006) noted few differences between Whites and Bangladeshi groups in London (Liversidge, 2011). Comparing our results with the London groups show some stages in the Sudanese groups to be earlier (particularly incisors) and some later. Incisor stages assessment in some of the radiographs of the younger children in our study was difficult due to occasional poor image quality and this may have influenced our results.

Mean ages of M3 tooth stages were slightly later than one previous study of third molars in South African Blacks (Liversidge, 2008). Sub-Saharan African groups are known to have extensive genetic diversity (Tishkoff et al., 2009) and future studies on tooth formation in Africa are needed.

Several studies use non-cumulative methods of analyses and report ethnic differences. Two studies compare timing of tooth formation directly. Harris and McKee (1990) describe mean age using Moorrees stages aged 3–13 years, reporting earlier mean ages in middle southern US black children compared to Whites. Another study in South African children found Blacks earlier than other groups (Phillips & van Wyk Kotze, 2009). Earlier mean/median age of third molars was reported in Black individuals in the US (Blankenship et al., 2007; Harris, 2007; Mincer et al., 1993) and in South Africans (Olze et al., 2004). Other studies compared mean age of third molars in Germany and Japan (Olze et al., 2007) and first

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Table 11. Comparison of mean ages in years for entering mandibular I2 stages in Northern and Western Sudanese groups.

	North females (n ¼ 802)		West females (n ¼ 402)		North males (n ¼ 848)		West males (n ¼ 846)	
Stage	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI
Ri	3.61, 0.83	3.29–3.93	3.83, 0.62	3.19–4.47	3.27, 1.18	2.84–3.70		
R1/4	4.80, 0.89	4.56–5.04	4.63, 0.72	4.17–5.09	4.78, 1.07	4.52–5.03	4.77, 0.91	4.27–5.28
R1/2	5.97, 0.92	5.75–6.19	5.88, 0.83	5.58–6.18	5.90, 1.14	5.63–6.16	5.40, 1.25	4.95–5.86
R3/4	7.16, 1.29	6.90–7.42	7.09, 0.74	6.76–7.43	7.00, 0.95	6.80–7.20	6.70, 1.10	6.42–6.98
Rc	7.37, 0.84	7.20–7.54	8.25, 1.05	6.98–7.59	7.54, 1.00	7.33–7.76	7.12, 0.96	6.90–7.32
A1/2	7.68, 0.84	7.21–8.18	7.94, 1.25	7.60–8.25	8.52, 1.42	8.21–8.84	7.81, 1.19	7.57–8.05
Ac	8.07, 0.86	7.89–8.26	8.31, 1.27	7.98–8.60	9.12, 1.37	8.82–9.48	8.31, 1.08	8.08–8.54

Abbreviations, see Table 5.

Table 12. Comparison of mean age in years entering mandibular I1 stages in Northern and Western Sudanese groups.

	North females (n ¼ 802)		West females (n ¼ 402)		North males (n ¼ 848)		West males (n ¼ 846)	
Stage	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI	Mean, SD	95% CI
R1/4	4.00, 0.43	3.75–4.24	3.83, 0.34	3.19–4.47	3.58, 0.72	3.18–3.98	3.46, 0.75	2.24–4.68
R1/2	5.15, 0.48	4.92–5.38	4.83, 0.29	3.02–6.63	5.02, 0.57	4.77–5.27	4.77, 0.50	4.27–5.28
R3/4	6.17, 0.61	5.93–6.41	5.88, 0.46	5.58–6.18	6.16, 0.64	5.92–6.39	5.40, 0.69	4.95–5.86
Rc	6.75, 0.91	6.56–6.94	6.59, 0.77	6.32–6.86	6.54, 0.43	6.42–6.67	6.18, 1.15	4.38–6.74
A1/2	7.07, 0.91	6.62–7.48	7.03, 0.94	6.73–7.32	6.67, 0.56	6.52–6.81	6.85, 1.00	6.60–7.07
Ac	7.36, 0.86	7.19–7.54	7.42, 1.14	7.09–7.72	7.20, 0.89	7.02–7.40	6.87, 0.97	6.63–7.09

Abbreviations, see Table 5.

nation people in Canada (Olze et al., 2010). Forensic age estimation from third molars in the living is reviewed by Olze et al. (2004), who compare descriptive data in German, Japanese, and South African groups. They note that mean ages of some root stages in South Africans were earlier than Germans and mean ages in Japanese were later than Germans and they recommend population-specific reference data. The use of mean/median ages to estimate age has been questioned and age of transition into maturity stages (including probit regression analysis) is now seen as more appropriate to estimate age and to compare groups (Boldsen et al., 2002; Konigsberg & Frankenberg, 2002; Konigsberg et al., 2008).

Comparison between male–female within groups

Our study found few statistical differences between mean ages of mandibular tooth stages in the Northern male–female group and Western male–female group. The results from this study differ from previous findings of an advancement in root formation in females compared to males (Anderson et al., 1976; Garn et al., 1958; Haavikko, 1970; Liversidge, 2012; Liversidge et al., 2006; Moorrees et al., 1963; Nystrom et al., 2007; Thompson et al., 1975). Numerous previous studies report sexual dimorphism in timing between males and females in some teeth, particularly canines and third molar root stages (Anderson et al., 1976; Demirjian & Levesque, 1980; Garn et al., 1959; Haavikko, 1970; Levesque et al., 1981; Liversidge, 2008; Liversidge et al., 2006; Moorrees et al., 1963; Nystrom et al., 2007; Thompson et al., 1975).

The reason for the lack of significant difference in the timing of tooth formation in males and females in our study is unclear. The size of the Western female group was considerably smaller than other groups. Sampling is possibly a factor when numbers are small; however, the cumulative statistical approach partly overcomes this difficulty.

This lack of significant difference in timing of tooth formation supports a recent histological study reconstructing longitudinal growth in enamel and dentine that reports no clear difference in modern male and female canine formation rates (Dean et al., 2014).

Strengths and limitations

A major strength of our study, which addresses some of the limitations of previous studies, was the structured design and statistical analysis to compare mandibular tooth formation at the population level in the Northern group. The stratified structured sampling strategy enabled comparisons to be representative. The study design included a large number of children per age group (3–23 years) selected to represent the Northern group. The age distribution of children in our sample was spread across a wide age range from as young as was practical up to dental maturity of the third molar. In order to assess the entire dentition, large sample sizes from very young to fully mature are required to validate the conclusions of effects of biological factors on the timing of tooth formation. This was accomplished for the Northern group.

Most tooth stages are ob[illegible] individuals in a given populat[illegible] this, a sample has to ensure sufficient child[illegible] range and a cumulative appr[illegible]oid reporting differences that may have been influenced by the large variation in age that is seen between individuals or small groups.

The mean age entering a t[illegible] age at which 50% of childre[illegible] particular stage. This cumulative statist[illegible] calculation of mean age of ea[illegible] stage uses all individuals who have reached or passed each specific tooth stage in consecutive age categories. For example, to calculate mean age entering stage X, the proportion of individuals who have

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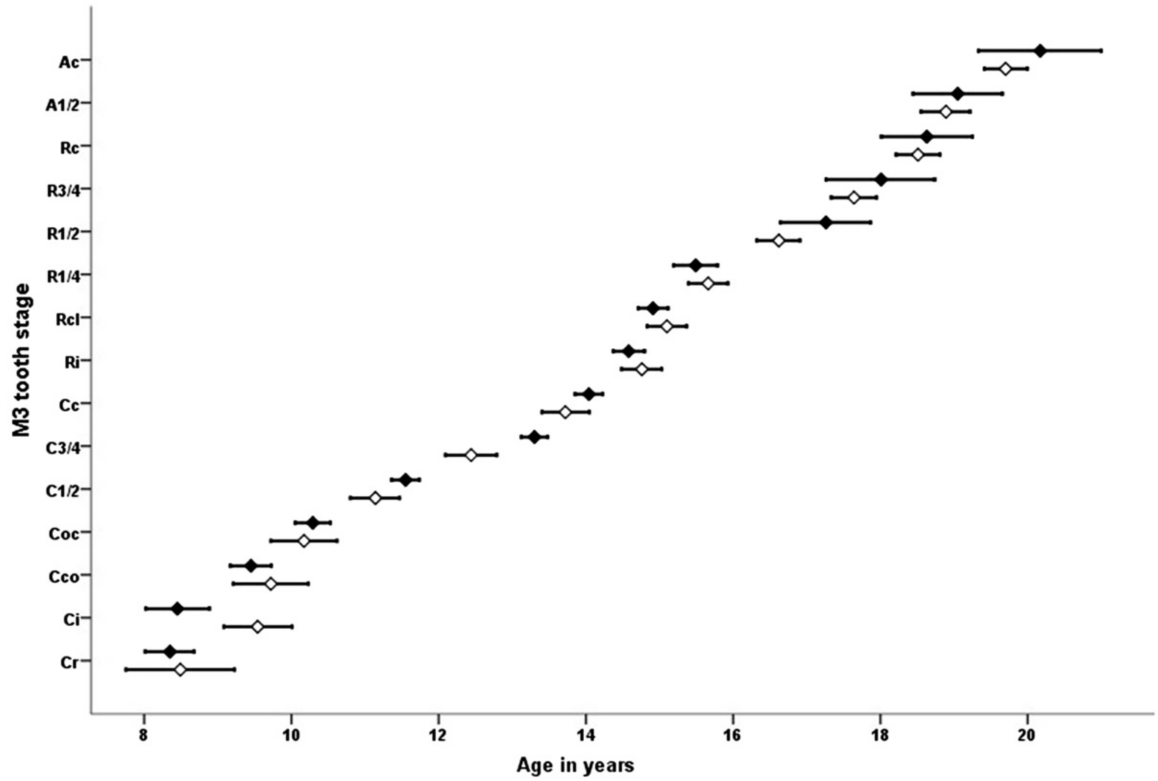

Figure 3. North-West male mean age comparisons for mandibular third molar (M3) stages across the age span of the developing tooth showing similarity between the groups. black diamond, north; unfilled diamond, west.

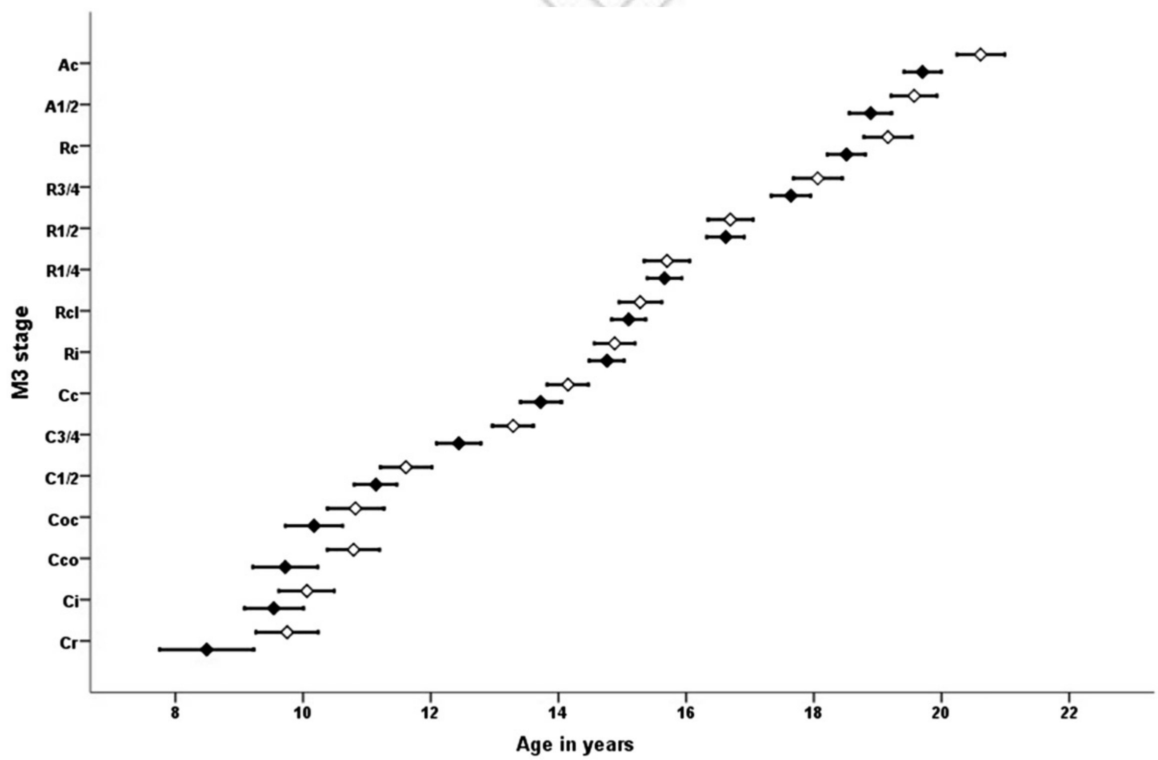

Figure 4. North male–female mean age comparisons for mandibular third molar (M3) stages across the age span of the developing tooth showing similarity between the groups. unfilled diamond, female; black diamond, male.

entered stage X (or later stages) is noted for consecutive age categories from the youngest to the age category where 99% of individuals have reached/passed stage X. This means that sufficient individuals are included in each analysis as the age range from 1–99% can include up to nine consecutive age categories (for late root stages of M3).

A limitation of the study was that a convenience sample of the Western group was necessary due to the ongoing civil

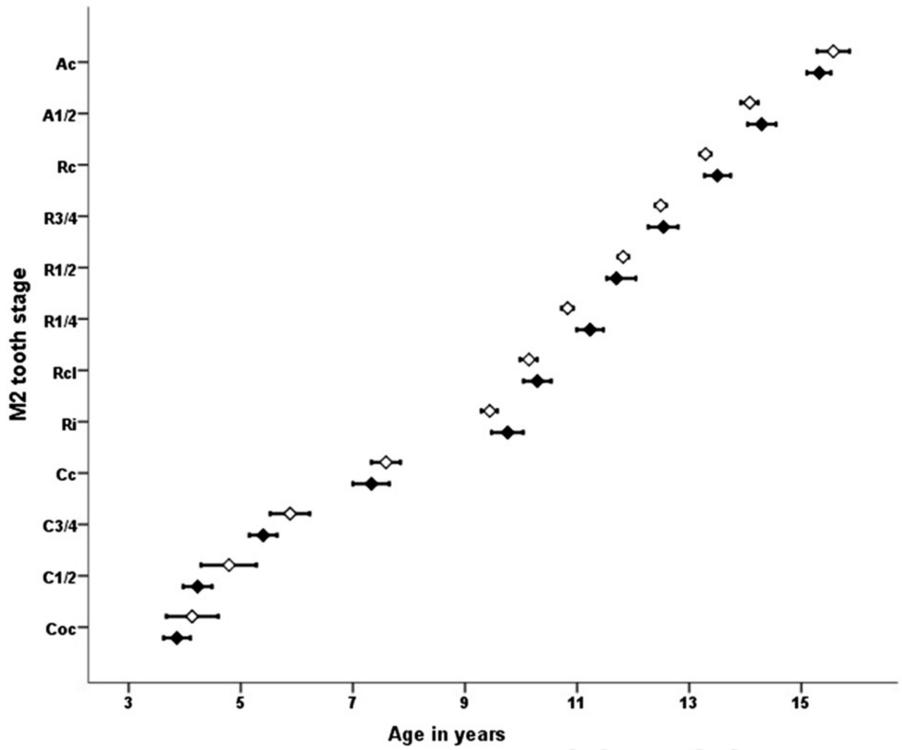

Figure 5. North-West male mean age comparisons for mandibular second molar (M2) stages across the age span of the developing tooth showing similarity between the groups. black diamond, north; unfilled diamond, west.

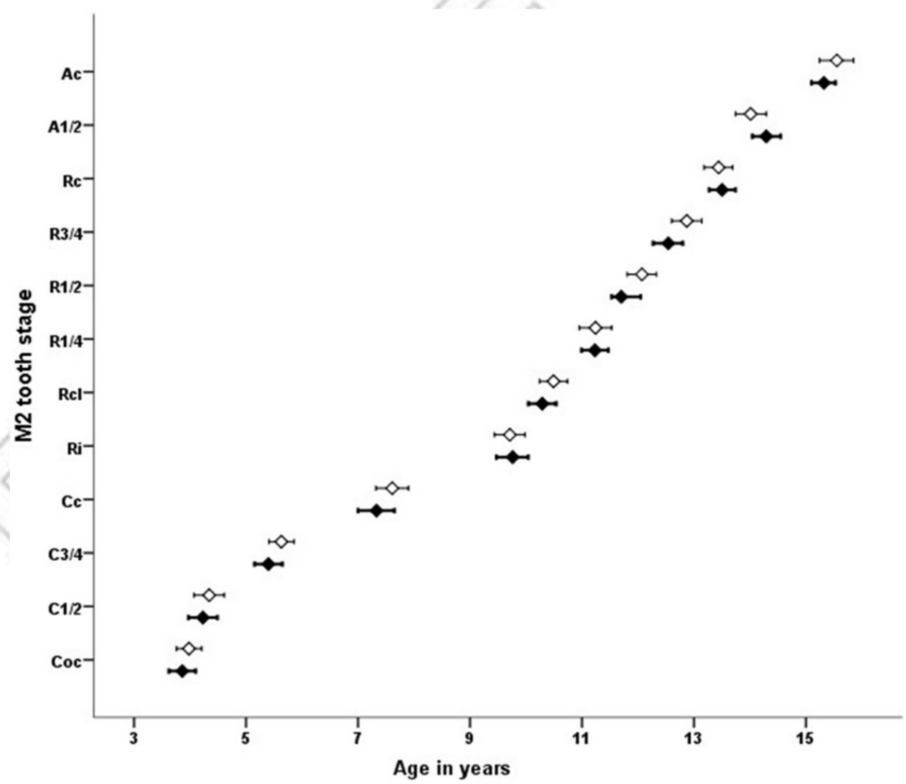

Figure 6. North male–female mean age comparisons for mandibular second molar (M2) stages across the age span of the developing tooth showing similarity between the groups. unfilled diamond, female; black diamond, male.

war, resulting in a different sample structure of considerably smaller size. Despite a reasonable number of Western males and females for ages 5–16 (see Table 2), the younger and older age categories are not well represented. This resulted in some mandibular tooth stages containing small numbers in the unrepresented age categories. The number of individuals in the Western group over the age of 16 is small and similarity in the timing of later root stages of M3 between

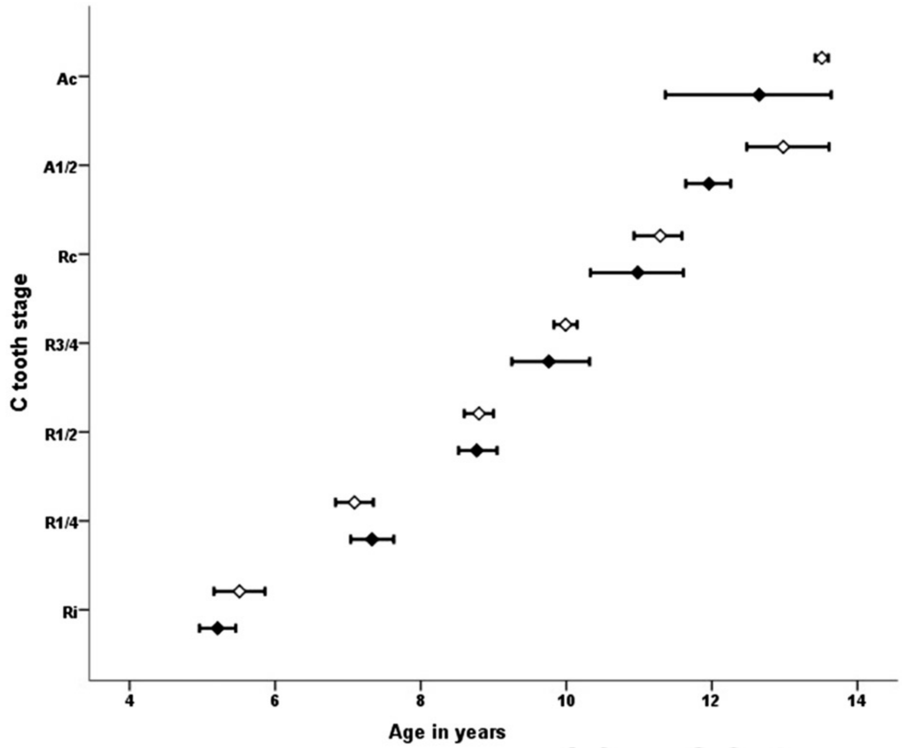

Figure 7. North-West male mean age comparisons for mandibular canine (C) stages across the age span of the developing tooth showing similarity between the groups. black diamonds, north; unfilled diamonds, west.

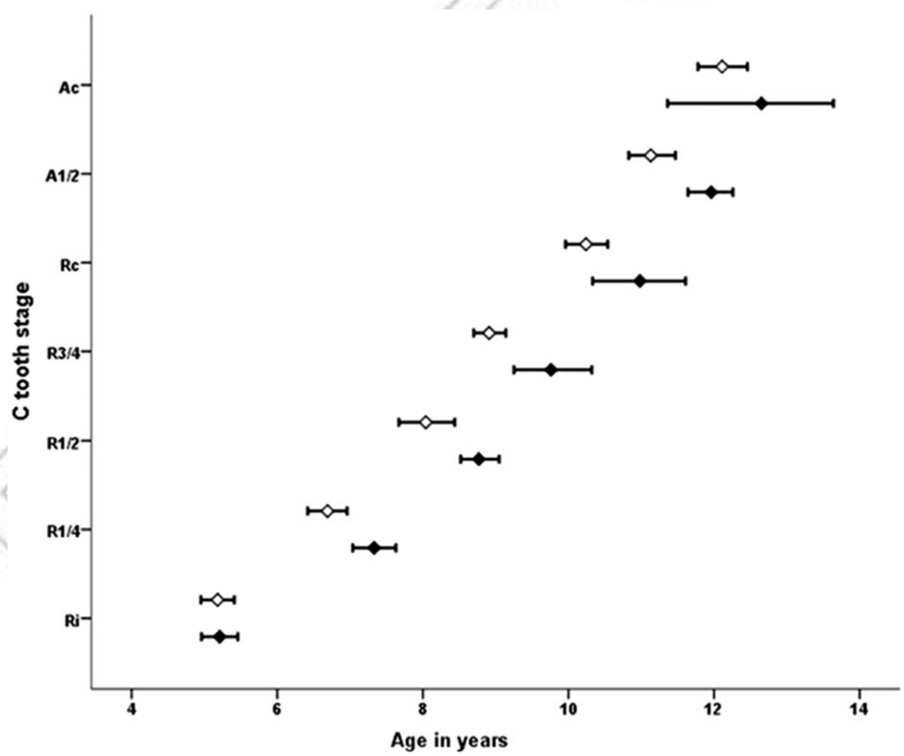

Figure 8. North male–female mean age comparisons for mandibular canine (C) stages across the age span of the developing tooth showing similarity between the groups. unfilled diamond, female; black diamond, male.

the sexes should be further investigated with larger numbers.

Another limitation, in common with many other studies using dental panoramic radiographs of living children, is the lack of very young children. The mean ages of most crown stages of permanent incisors, canines and first molars occur during the first 3 years.

A limitation of any maturity study is that maturation, a continuous process, is divided into arbitrarily selected, discreet stages that are not equally spaced in time. A tooth must be allocated to a crown or root stage and some tooth stages rely on subjective estimation of final crown and root lengths, for example $Cr\frac{3}{4}$ and $R\frac{3}{4}$ and these are more difficult to assign. Other difficulties include superimposition of the vertebral column with anterior teeth and the mandible not being correctly positioned in very young children. These influence the clarity of the radiographic image. Other factors such as individual variation in crown height and root length, as well as the duration of development of both crown and roots, may explain some inconsistencies in the pattern of differences in our results.

Conclusions

Mean ages of 23% of 151 tooth stage comparisons of mandibular teeth between 2–23 years of age were significantly different between Northern and Western males and Northern and Western females. The age variation within each group was considerably greater than the age variation between groups for all mandibular tooth stages we could assess in this study.

Mean ages of 12% of 155 tooth stage comparisons of mandibular teeth between 2–23 years of age were significantly different between males and females in both Northern and Western groups. A pattern of sexual dimorphism in tooth formation was not apparent in our results. This is in contrast to most previous radiographic studies that report a clear pattern with earlier mean ages of canine root stages and late M3 root stages in females compared to males.

This means that healthcare providers in the region can use these results of timing of mandibular teeth from the Northern group as a reference to assess dental maturity for dental treatment or to plan the timing of orthodontic treatment. More research is needed on the rate of tooth development, root proportions of mature teeth, as well as timing and root stage at tooth eruption in these and other African groups.

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Disclosure statement

The authors report no conflict of interest, financial or personal relations with other organisations or people who may influence the study findings inappropriately.

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