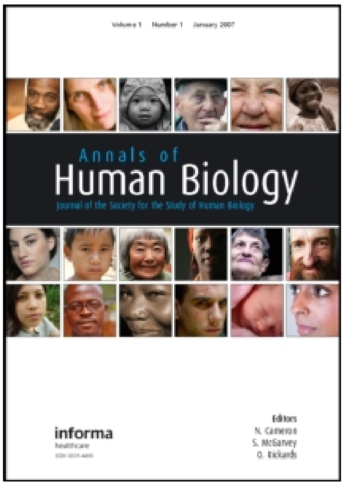

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Timing of human mandibular third molar formation

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ORIGINAL ARTICLE

Timing of human mandibular third molar formation

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Abstract

Background: Population differences in tooth formation using radiographs can be determined if the entire developmental sequence of a single tooth is studied. The only developing tooth visible radiographically from initiation to root completion is the third molar or wisdom tooth.

Aim: The timing of mandibular third molar formation was documented for two groups of children in England and two in South Africa.

Subjects and methods: Panoramic radiographs of White and Bangladeshi children from London and Black African and Cape Coloured children from South Africa were examined (age 5–24). Mean age of entering third molar stages (crypt appearance to root completion) was calculated using logistic regression and compared between sex and group using a *t*-test.

Results: Average age of third molar stages was significantly ($p < 0.001$) later in three groups for almost all stages of the third molar compared to Black children. The average age of entering initial mineralization ranged from 7.97 to 9.74 years while average age of apex closed was 19.27–20.88.

Conclusion: These results show for the first time a significant difference in the timing of maturation of the mandibular third molar between groups with South African Black children being earlier than other groups.

Keywords: *Third molar crown, root, radiograph*

Introduction

The existence of population differences in tooth formation between worldwide groups has long been speculated upon. The evidence that modern humans arose and migrated out of Africa has focused particular interest on the comparative maturation of Black African and European children (Tompkins 1996). Recent histological findings show that molar crowns in humans, including these groups, take a remarkably similar time to form (Reid and Dean 2006). Assuming this to be so and that the rate of odontogenesis is consistent, differences between individuals and groups can be explained by differences in the timing of earliest mineralization, in the rate of odontoblast differentiation/root extension or by differences in

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root length. In order to identify a difference in the timing of initial mineralization between groups, the entire developmental sequence of a tooth must be documented. The third permanent molar is usually the only tooth visible from crypt appearance to apex completion on radiographs of children and young adults who attend dental teaching hospitals. The aim of this study was to describe the timing of mandibular third molar formation from radiographs in two groups of children in UK and two groups in South Africa. These are the first results from an ongoing worldwide study of human tooth formation using archived dental radiographs.

Material and methods

Radiographic data were collected from two groups in London, UK and two groups in South Africa. This was a convenience sample, made up mostly of panoramic radiographs, with occasional supplementary peri-apical radiographs. All radiographs had previously been taken in the course of diagnosis and treatment. Radiographs were selected from archived collections and of White and Bangladeshi patients attending the Dental Institute of Barts and The London School of Medicine and Dentistry, London, UK. Radiographs of Black and Cape Coloured children from South Africa were selected from patient records of the Dental School (University of Witwatersrand) in Johannesburg, Medunsa Oral Science Department (now part of University of Limpopo) in Pretoria and archived radiographs from the collection of Professor C. J. Nortjé, Department of Dental Radiology, Dental School, Tygerburg, Cape (University of Stellenbosch, now University of the Western Cape). Data were treated as cross-sectional, although a proportion of children from each group was represented by more than one radiograph. This proportion was 34% for the Cape sample and 6%, 8% and 4% for the White, Bangladeshi and Black groups, respectively. Age and sex distribution of the groups are shown in Table I. For the Black children, 31 were of unrecorded sex and data from these children were included for analysis for combined sex. For a large group of Black children ($n = 431$), age was recorded in years only and the age for these individuals was assumed to be on the half year. For example, a seven year old child was assigned an age of 7.50 years.

The mandibular third molar was staged according to Moorrees et al. (1963) with some additional descriptive criteria shown in Figure 1. Radiographs of individuals with gross pathology or developmental anomalies including hypodontia of the left M_3 or other teeth were excluded as well as third molars with abnormally short roots, dysmorphology or asymmetric root formation between left and right side. The left third molar was assessed unless it was unclear or if only the right side was X-rayed. Intra-observer error of stage assessment was calculated using double readings of 100 radiographs. Cohen's Kappa was 0.77 indicating excellent agreement. Age was converted to a decimal value using Eveleth and Tanner (1990, pp. 6–7). Data were converted to binary by asking the question, had the child reached or passed the specific stage. The mean age of entering each stage (when half the children at that age had reached or passed the stage) was calculated by logistic regression for each stage, for boys and girls separately as well as combined sex. In addition, descriptives of age of children in-stage were also calculated. Difference in mean age between boys and girls within and between groups was compared using *t*-tests.

Table I. Age and sex distribution. Age 5+ indicates all children aged 5.00–5.99 years, etc.

	White Caucasian UK		Bangladeshi UK		Black African SA		Cape Coloured SA†	
Age	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
5+	19	25	20	19	6	10	8	5
6+	21	18	23	24	12	8	9	14
7+	26	22	27	28	24	17	18	17
8+	31	34	29	21	25	11	26	15
9+	38	23	23	22	25	17	33	25
10+	22	21	23	20	21	28	32	18
11+	20	25	22	21	17	26	21	33
12+	26	26	20	14	18	13	21	23
13+	25	15	16	23	26	25	19	32
14+	21	29	19	16	16	18	17	17
15+	27	22	28	26	18	23	25	19
16+	26	29	26	16	18	19	10	16
17+	23	37	24	23	24	23	17	15
18+	26	26	21	22	30	27	9	21
19+	25	37	16	34	27	22	12	38
20+	27	35	20	23	25	15	4	16
21+	22	39	15	11	19	10	16	36
22+	16	19	12	14	16	1	6	13
23+	14	22	16	12	23	22	16	28
Total	455	504	400	389	390	335	319	401
Total	959		789		725 + 31 = 756*		720	

*Includes 31 children of unknown sex.
†Mixed longitudinal sample, total number of radiographs per age group.

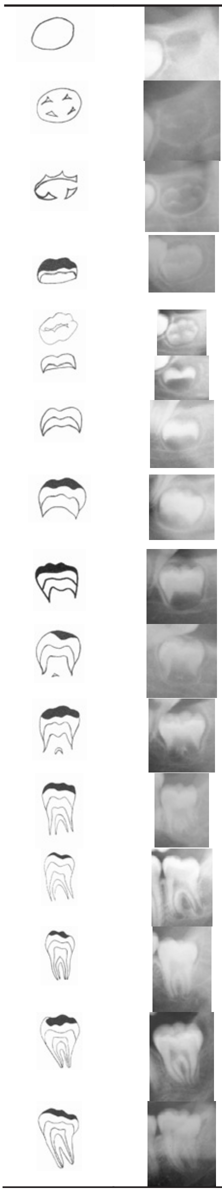
Results

1. Mean age of entering third molar formation stages – between boys and girls

Thirty-five out of 45 comparisons in the average timing of entering mandibular third molar formation stages between girls and boys within each group were not significantly different (Figure 2). The average timing of six stages was significantly difference in White boys and girls (Table II) including 'crypt' (0.51 years later in girls compared to boys) and for stage R1/2 and subsequent root stages up to stage Ac. The sex difference increased with stage from 0.7 to 1.6 years for stage Ac with mean age in girls being later. No significant sex differences were seen in the timing of third molar formation in Bangladeshi children (Table III), although mean age in girls was slightly later than boys for almost all stages. In contrast, mean age was slightly earlier for almost all stages in Black girls compared to boys. The sex difference was significantly different for only one stage (crown complete) where boys were 0.73 year later than girls (Table IV). The mean timing in Cape girls was earlier for all crown stages and Ri. The sex difference in the timing of third molar formation in Cape children was not significantly different except for three stages – Cco, Rc and Ac (Table V). Girls were 0.7 year earlier than boys for stage Cco while the two root stages differed by 0.7 and 1.25 year, being earlier in boys.

2. Mean age of entering third molar formation stages – between groups

The difference in mean age between Black children and other groups was significant ($p < 0.001$) in 44 out of 45 comparisons for combined sex (shown in Tables VI–VIII),



M_3 stage		Descriptive criteria
Cr	Crypt	Radioluscent area visible within alveolar bone.
Ci	Cusp tip initiation	One or more separate cusp tip(s) visible within crypt.
Cco	Cusp coalescence	Two or more cusp tips coalesced.
Coc	Crown outline	Crown outline, including marginal ridges. Enamel and dentine but less intense radio-opacity than fullT thickness.
C½	Crown one half	Thicker enamel of the crown occlusal surface radio-opaque with some dentine visible. Flat inferior dentine border.
C¾	Crown three quarters	Full thickness occlusal enamel with considerable aproximal dentine at the contact points. Curved inferior border.
Cc	Crown complete	Aproximal enamel complete to neck of tooth. Roof of pulp chamber visible.
Ri	Root initial	Some root visible aproximally, but less than half crown height.
Rcl	Cleft	Beginning of root furcation visible as a dot or line.
R¼	Root one quarter	Clear semilunar furcation visible. If taurodont, aproximal root length about half of crown height.
R½	Root one half	Root bifurcation more extensive. Aproximal root length equal to crown height. Distal root canal walls diverge with sharp edges.
R¾	Root three quarters	Root length considerably more than crown height and root canal walls diverge.
Rc	Root complete	Walls of the distal root canal are parallel and full length with rounded/blunt edges.
A½	Apex half closed	Apex of distal root partially open. Periodontal ligament slightly wider at distal apex.
Ac	Apex closed	Distal apex appears closed, with uniform periodontal ligament width.

Figure 1. Third molar formation stages and descriptive criteria. Based on Moorrees et al. (1963).

suggesting that average timing of third molar stages was significantly delayed in White, Bangladeshi and Cape groups compared to Black children. Mean age entering crypt formation stage was earliest in Black children at 7.16 years followed by Bangladeshi children over a year later. Mean age for both White and Cape children was 9.06 years. Mean age of initiation and early crown stages differed significantly between Bangladeshi/White groups with mean age of White children being later. The cumulative distribution curves of stages

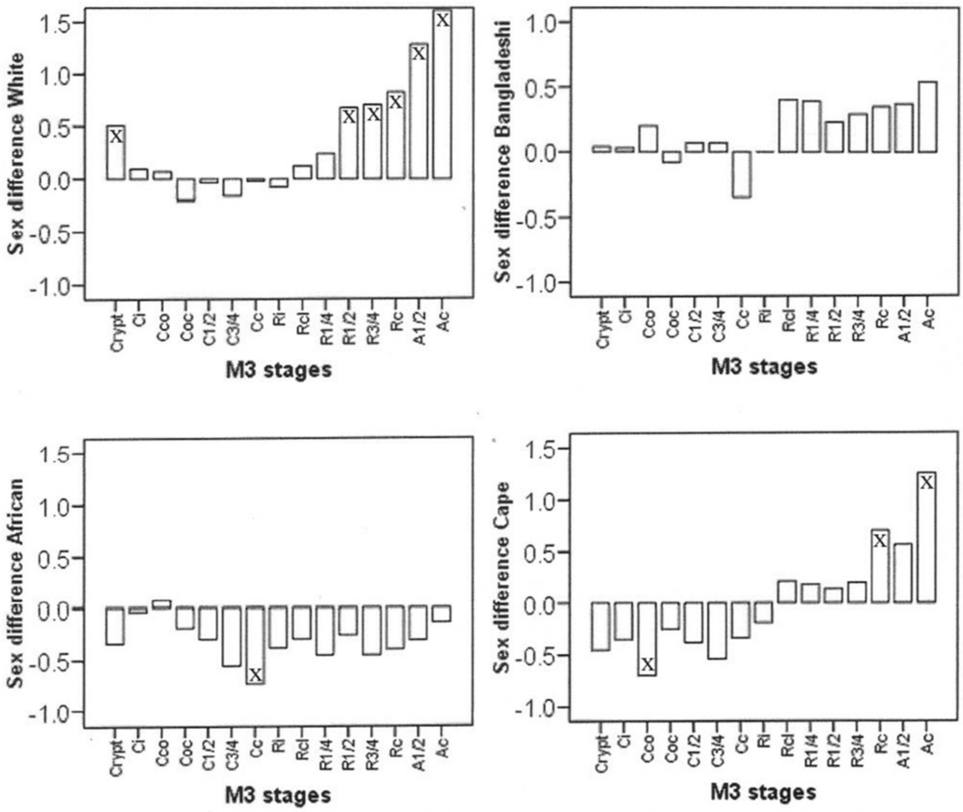


Figure 2. Difference in the average age (in years) of entering a tooth formation stage of boys and girls. A negative difference indicates (boys are older) girls are earlier than boys and vice versa. x indicates significant differences. See Tables II, III and IV for significance levels.

Table II. Mean age in years of entering mandibular third molars stage in Africans.

	Boys			Girls				Sexes combined		
M_3 stage	Mean	SE	SD	Mean	SE	SD	Sex diff.	Mean	SE	SD
Crypt	7.33	0.242	0.89	6.99	0.302	0.93	NS	7.16	0.191	0.96
Ci	7.92	0.209	0.85	7.88	0.258	0.86	NS	7.97	0.156	0.86
Cco	8.78	0.199	0.89	8.86	0.216	0.74	NS	8.82	0.142	0.82
Coc	9.81	0.184	0.71	9.62	0.205	0.72	NS	9.78	0.123	0.70
C1/2	10.32	0.187	0.73	10.02	0.197	0.75	NS	10.21	0.126	0.72
C3/4	11.75	0.215	0.86	11.20	0.210	0.94	NS	11.45	0.140	0.90
Cc	13.38	0.192	0.78	12.65	0.198	0.84	$p < 0.01$	12.97	0.142	0.84
Ri	13.73	0.201	0.74	13.35	0.226	1.04	NS	13.54	0.143	0.89
Rcl	14.28	0.219	0.88	13.98	0.222	1.05	NS	14.09	0.153	0.95
R1/4	14.59	0.200	0.77	14.14	0.224	1.05	NS	14.33	0.148	0.92
R1/2	15.77	0.215	0.89	15.51	0.213	0.96	NS	15.63	0.147	0.94
R3/4	16.89	0.214	0.99	16.44	0.215	0.92	NS	16.70	0.146	0.98
Rc	17.84	0.218	1.07	17.44	0.193	0.76	NS	17.67	0.144	0.95
A1/2	18.62	0.209	1.04	18.31	0.229	0.99	NS	18.51	0.150	1.04
Ac	19.31	0.195	1.00	19.17	0.228	0.98	NS	19.27	0.145	0.99

Table III. Mean age of children entering a stage of M_3 for Cape Coloured children.

	Boys			Girls				Sexes combined		
M_3 stage	Mean	SE	SD	Mean	SE	SD	Sex. diff	Mean	SE	SD
Crypt	9.26	0.233	1.24	8.81	0.244	1.01	NS	9.06	0.166	1.13
Ci	9.89	0.222	1.16	9.54	0.208	0.87	NS	9.71	0.148	1.02
Cco	10.52	0.192	0.99	9.82	0.200	0.86	$p<0.05$	10.20	0.138	0.92
Coc	10.98	0.188	0.92	10.73	0.180	0.79	NS	10.85	0.129	0.85
C1/2	11.49	0.199	0.96	11.11	0.174	0.73	NS	11.27	0.131	0.85
C3/4	12.69	0.215	0.99	12.15	0.189	0.86	NS	12.39	0.137	0.93
Cc	13.95	0.233	1.03	13.61	0.207	1.01	NS	13.78	0.158	1.02
Ri	14.67	0.239	1.02	14.48	0.231	1.18	NS	14.56	0.170	1.12
Rcl	15.08	0.237	1.02	15.29	0.245	1.22	NS	15.19	0.175	1.14
R1/4	15.19	0.243	1.00	15.37	0.245	1.21	NS	15.30	0.167	1.13
R1/2	16.52	0.254	1.01	16.65	0.250	1.28	NS	16.63	0.179	1.18
R3/4	17.83	0.259	0.83	18.02	0.236	1.22	NS	18.00	0.173	1.09
Rc	18.14	0.267	0.82	18.84	0.224	1.18	$p<0.05$	18.63	0.171	1.09
A1/2	18.97	0.252	0.82	19.53	0.219	1.15	NS	19.39	0.169	1.05
Ac	20.06	0.28	0.88	21.31	0.30	1.53	$p<0.01$	20.88	0.195	1.30

Table IV. Mean age of entering stage (in years) of Bangladeshi children in London, $n=789$ (400 boys, 389 girls).

	Boys			Girls				Sexes combined		
M_3 stage	Mean	SE	SD	Mean	SE	SD	Sex diff.	Mean	SE	SD
Crypt	8.22	0.150	0.69	8.26	0.178	0.98	NS	8.24	0.117	0.85
Ci	8.92	0.155	0.77	8.95	0.172	0.88	NS	8.93	0.116	0.83
Cco	9.56	0.154	0.68	9.76	0.159	0.75	NS	9.66	0.107	0.72
Coc	10.69	0.170	0.81	10.61	0.156	0.69	NS	10.62	0.115	0.75
C1/2	11.13	0.176	0.77	11.20	0.162	0.73	NS	11.17	0.122	0.75
C3/4	12.48	0.207	0.97	12.55	0.177	0.80	NS	12.51	0.134	0.89
Cc	13.77	0.209	1.02	13.42	0.187	0.84	NS	13.59	0.142	0.94
Ri	14.02	0.207	0.98	14.02	0.198	0.94	NS	14.03	0.139	0.96
Rcl	14.43	0.202	1.01	14.83	0.206	1.10	NS	14.64	0.149	1.06
R1/4	15.16	0.194	0.99	15.55	0.207	1.09	NS	15.34	0.141	1.05
R1/2	16.53	0.193	1.05	16.76	0.242	1.43	NS	16.65	0.155	1.26
R3/4	17.44	0.201	1.09	17.73	0.225	1.21	NS	17.60	0.150	1.16
Rc	18.06	0.214	1.02	18.41	0.224	1.25	NS	18.25	0.158	1.15
A1/2	18.72	0.220	1.04	19.09	0.223	1.27	NS	18.94	0.156	1.16
Ac	19.53	0.237	1.08	20.07	0.236	1.18	NS	19.82	0.156	1.14

Ci, Ri, R1/2 and Ac for each group (combined sex) are shown in Figure 3. These represent smoothed curves of the proportion of children for each age group that have reached or passed the specific stage. The average of entering a stage is the age when half the children for an age group have reached that stage. Stage Ci is visible between the 6th and 13th year and by age 14, all children have reached or passed this stage. The average age for combined sex of entering stage Ci ranged from 7.97 to 9.74 years. Stage Ri is seen from the 10th year and almost all third molars have reached or passed this stage by age 18. Average of Ri ranged from 13.54 to 14.70. Stage R1/2 is seen from age 11 and by 21 all third molars have reached or passed this stage with average values from 15.65 to 16.65. Early maturing children

Table V. Mean age of entering stage (in years) of white children in London, $n = 1126$ (524 boys, 602 girls).

	Boys			Girls				Sexes combined		
M_3 stage	Mean	SE	SD	Mean	SE	SD	Sex diff.	Mean	SE	SD
Crypt	8.80	0.156	0.95	9.31	0.183	1.22	$p<0.05$	9.06	0.121	1.10
Ci	9.69	0.168	1.01	9.78	0.179	1.10	NS	9.74	0.121	1.06
Cco	10.34	0.170	0.96	10.41	0.165	0.87	NS	10.38	0.119	0.92
Coc	11.37	0.175	0.93	11.17	0.171	0.83	NS	11.28	0.122	0.88
C1/2	11.85	0.177	0.91	11.81	0.172	0.81	NS	11.84	0.124	0.86
C3/4	13.18	0.190	0.97	13.02	0.179	0.82	NS	13.10	0.130	0.90
Cc	14.23	0.171	0.78	14.21	0.185	0.94	NS	14.22	0.122	0.87
Ri	14.72	0.175	0.78	14.64	0.194	1.04	NS	14.70	0.131	0.93
Rcl	15.09	0.174	0.82	15.21	0.191	1.05	NS	15.16	0.134	0.95
R1/4	15.38	0.179	0.81	15.62	0.185	1.05	NS	15.52	0.128	0.95
R1/2	16.29	0.160	0.70	16.97	0.204	1.22	$p<0.01$	16.66	0.133	1.03
R3/4	16.99	0.165	0.74	17.70	0.187	1.15	$p<0.01$	17.38	0.128	1.01
Rc	17.92	0.165	0.80	18.75	0.187	1.11	$p<0.01$	18.39	0.136	1.01
A1/2	18.33	0.263	0.77	19.62	0.195	1.28	$p<0.001$	19.04	0.140	1.12
Ac	19.26	0.18	0.87	20.88	0.208	1.31	$p<0.01$	20.16	0.143	1.19

Table VI. Comparison of mean age of entering formation stages between groups (combined sex).

M_3 stage	Cape *vs.* African, $p<$	Cape *vs.* Bangladeshi, $p<$	Cape *vs.* White, $p<$	African *vs.* Bangladeshi, $p<$	African *vs.* White, $p<$	Bangladeshi *vs.* White, $p<$
Crypt	0.001	0.001	NS	0.001	0.001	0.001
Ci	0.001	0.001	NS	0.001	0.001	0.001
Cco	0.001	0.01	NS	0.001	0.001	0.001
Coc	0.001	NS	0.05	0.001	0.001	0.001
C1/2	0.001	NS	0.01	0.001	0.001	0.001
C3/4	0.001	NS	0.001	0.001	0.001	0.01
Cc	0.001	NS	0.05	0.05	0.001	0.001
Ri	0.001	0.05	NS	0.05	0.001	0.001
Rcl	0.001	0.05	NS	0.01	0.001	0.01
R1/4	0.001	NS	NS	0.001	0.001	NS
R1/2	0.001	NS	NS	0.001	0.001	NS
R3/4	0.001	NS	0.01	0.001	0.001	NS
Rc	0.001	NS	NS	0.05	0.01	NS
A1/2	0.001	NS	NS	NS	0.01	NS
Ac	0.001	0.001	0.01	0.01	0.001	NS

reach stage Ac at the earliest during the 13th year and by 24 all third molars are mature. The average age for combined sex of entering stage Ac was 19.27–20.88 years for these groups, with the earliest seen in Black children.

Comparison of mean age by sex showed that the difference between mean age of third molar formation between Black boys and boys of other groups was significant in 30 out of 45 comparisons including early crown stages up to stage C3/4. Cape/White and Cape/Bangladeshi boys were most similar. The mean age in White boys were significantly different compared to Bangladeshi boys for crown stages and stage Rcl. Black girls and girls of other groups were significant in mean age for all 45 comparisons. Cape/Bangladeshi and

Table VII. Comparison of mean age of entering formation stages between groups (boys).

M_3 stage	Cape *vs.* African, *p*<	Cape *vs.* Bangladeshi, *p*<	Cape *vs.* White, *p*<	African *vs.* Bangladeshi, *p*<	African *vs.* White, *p*<	Bangladeshi *vs.* White, *p*<
Crypt	0.001	0.001	NS	0.01	0.001	0.01
Ci	0.001	0.001	NS	0.001	0.001	0.01
Cco	0.001	0.01	NS	0.001	0.001	0.05
Coc	0.001	NS	NS	0.001	0.001	0.01
C1/2	0.001	NS	NS	0.01	0.001	0.01
C3/4	0.01	NS	NS	0.05	0.001	0.05
Cc	NS	NS	0.001	NS	0.01	NS
Ri	0.01	NS	NS	0.01	0.001	NS
Rcl	0.01	0.05	NS	NS	0.01	0.05
R1/4	NS	NS	NS	0.05	0.01	NS
R1/2	0.05	NS	NS	0.01	NS	NS
R3/4	0.01	NS	NS	NS	NS	NS
Rc	NS	NS	NS	NS	NS	NS
A1/2	NS	NS	NS	NS	NS	NS
Ac	0.05	NS	0.05	NS	NS	NS

Table VIII. Comparison of mean age of entering formation stages between groups (girls).

M_3 stage	Cape *vs.* African, *p*<	Cape *vs.* Bangladeshi, *p*<	Cape *vs.* White, *p*<	African *vs.* Bangladeshi, *p*<	African *vs.* White, *p*<	Bangladeshi *vs.* White, *p*<
Crypt	0.001	NS	NS	0.001	0.001	0.001
Ci	0.001	0.05	NS	0.001	0.001	0.001
Cco	0.001	NS	0.05	0.01	0.001	0.001
Coc	0.001	NS	NS	0.001	0.001	0.05
C1/2	0.001	NS	0.01	0.001	0.001	0.05
C3/4	0.001	NS	0.001	0.001	0.001	NS
Cc	0.001	NS	0.05	0.01	0.001	0.01
Ri	0.001	NS	NS	0.001	0.001	NS
Rcl	0.001	NS	NS	0.01	0.001	NS
R1/4	0.001	NS	NS	0.001	0.001	NS
R1/2	0.001	NS	NS	0.001	0.001	NS
R3/4	0.001	NS	NS	0.001	0.001	NS
Rc	0.001	NS	NS	0.01	0.001	NS
A1/2	0.001	NS	NS	0.05	0.001	NS
Ac	0.01	0.01	NS	0.05	0.05	0.05

Cape/White girls were most similar. The Bangladeshi/White comparisons were significantly different from crypt up to C1/2 stage.

Cumulative frequency distribution of all stages for Black South Africans in this study are shown in Figure 4 and two particular stages (Rcl and A1/2) show peculiarities. The slope of 'Rcl' is far steeper compared to other stages. The lines for stage A1/2 in Africans almost overlap Rc, suggesting that A1/2 might not be a useful separate stage for this group, however the lines, although close, do not overlap for the three other groups in this study.

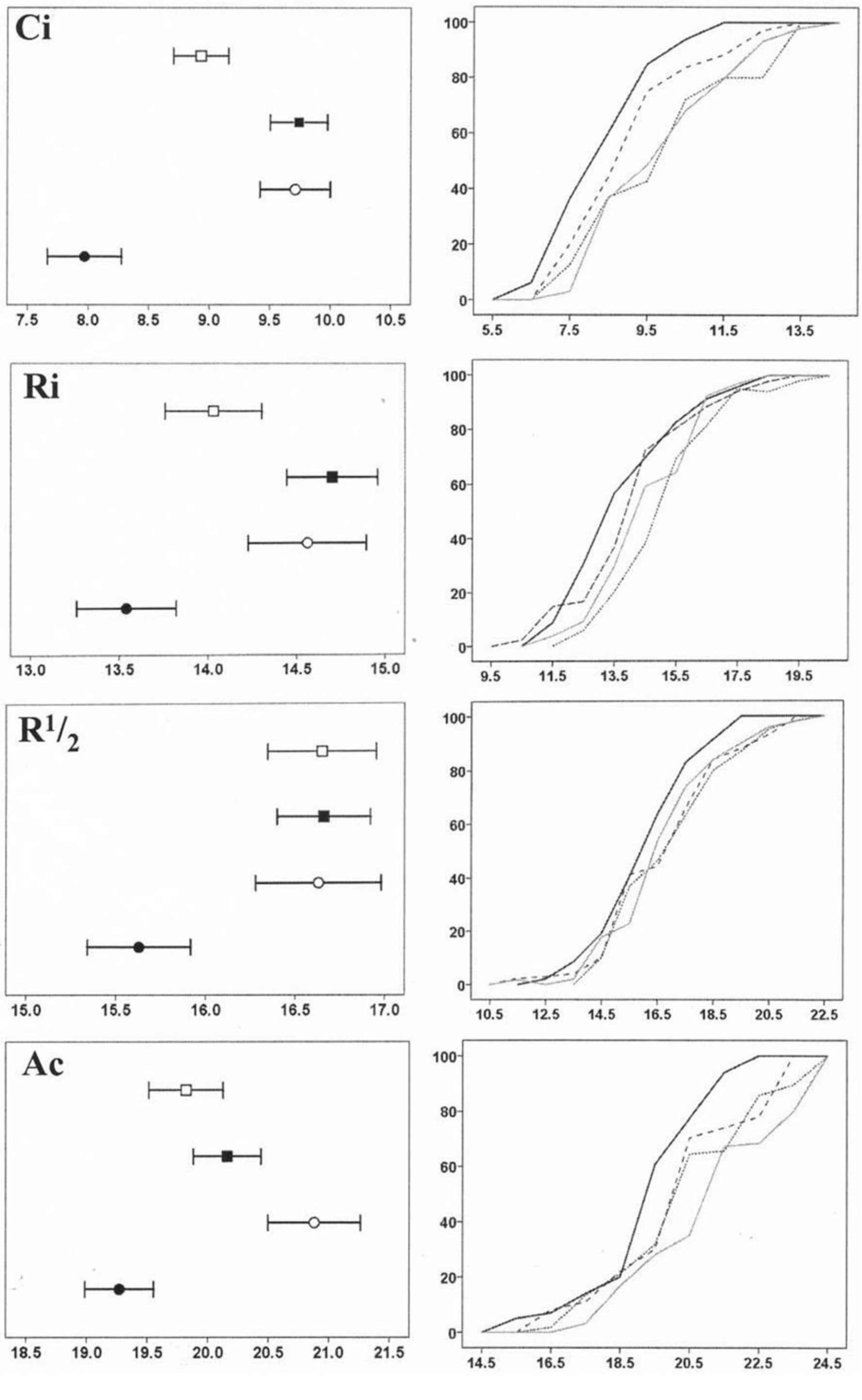


Figure 3. The 95% confidence interval of mean age and cumulative distribution curves (percentage of children who have reached or passed a stage plotted against age groups). From top: Stage cusp tip initiation Ci, initial root formation Ri, root half R1/2, apex closed Ac. Data are for combined sex and have been smoothed. Solid line, Black; dotted line, White; dashed line, Bangladeshi; grey line, Cape.

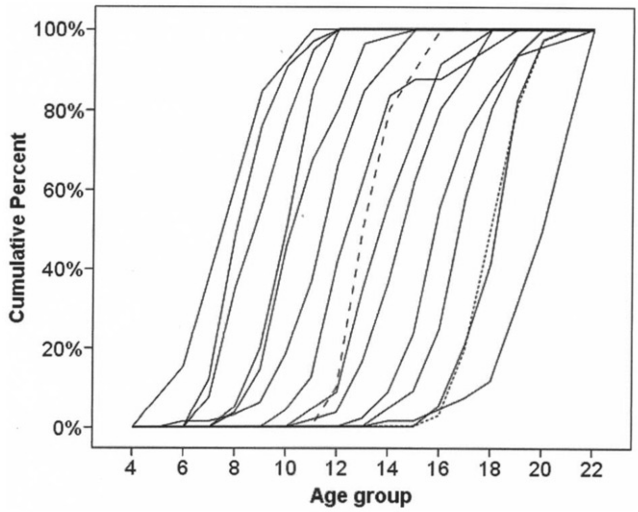


Figure 4. Cumulative distribution curves (percentage of children who have reached or passed a stage plotted against age groups in years) for South African Blacks, sexes combined. Dotted line, root cleft (Rcl); dashed line, apex half closed (A1/2). Stage Ac smoothed.

3. Mean age of children 'in a stage' – between boys and girls

Average age for most stages in boys and girls, shown in Tables IX–XII, was similar. The stages that were significantly different include R1/4, Rc ($p < 0.01$) and A1/2 ($p < 0.05$) between White boys and girls. Mean age for most stages between Bangladeshi boys and girls was similar except for crypt ($p < 0.05$) and R1/4 ($p < 0.01$). In Black boys and girls, the mean age was similar except for R3/4 ($p < 0.05$). This was due to three boys with delayed third molar formation (older than 20 years of age) and comparison of mean age excluding these from the group resulted in no sex difference. No difference in mean age midstage for third molars was noted in Cape boys and girls.

4. Mean age of children 'in a stage' – between groups

Comparisons between groups for combined sex (Table XIII) show that a large proportion of stages were significantly different in Black children compared to the other three groups ($p < 0.001$). For the combined sex comparisons, the mean age in Cape/White and Bangladeshi/White were not significantly different for 13 out of 14 comparisons. The mean age between Black children and other groups were significantly different for 30 out of 42 tooth stages, including all initial crypt stage comparisons. For boys (Table XIV), mean age in Cape/Bangladeshi and Bangladeshi/White children did not differ, while Cape/White differed significantly for only one crown stage. Cape/African and African/White comparisons differed significantly for the first four and five stages, respectively and one 'root cleft' comparison, although the sample size for this stage is small. Other root stages were not significantly different between groups. For girls (Table XV), no significant differences were noted between Cape/White, while Bangladeshi/White and Cape/Bangladeshi were significant for one and two stages out of 14, respectively. Cape/African and African/White comparisons differed significantly for around half of the comparisons, most of which were root stages.

Table IX. Mean age of children 'in a stage' of M_3 – Africans, $n=756$ (390 boys, 335 girls and 31 unknown sex). For 431 individuals, age was recorded in years only and was assumed to be on the half year – minimum/maximum age must be interpreted with this in mind. Stage 12 R3/4 significantly different: Girls earlier than boys, all others NS.

	Boys						Girls						Combined sex					
M_3	Mean	SE	SD	*n*	Min.	Max.	Mean	SE	SD	*n*	Min.	Max.	Mean	SE	SD	*n*	Min.	Max.
Crypt	7.91	0.40	1.32	11	6.40	10.87	7.74	0.55	1.83	11	4.85	10.50	7.78	0.29	1.46	26	4.85	10.87
Ci	8.65	0.23	1.00	19	7.10	11.18	8.41	0.40	1.49	14	6.50	11.50	8.55	0.21	1.22	33	6.50	11.50
Cco	8.92	0.23	1.12	23	6.50	11.50	9.52	0.31	1.10	13	7.50	11.50	9.15	0.19	1.20	40	6.50	11.50
Coc	10.03	0.39	1.29	11	7.50	11.70	10.27	0.49	1.39	8	8.50	12.50	10.13	0.30	1.30	19	7.50	12.50
C1/2	11.18	0.33	1.76	28	7.64	14.62	11.11	0.24	1.21	26	9.06	13.50	11.17	0.20	1.50	55	7.64	14.62
C3/4	12.47	0.28	1.58	32	9.50	15.50	11.71	0.31	1.73	31	6.49	15.50	12.08	0.21	1.68	65	6.49	15.50
Cc	13.27	0.39	1.04	7	11.63	14.50	13.83	0.76	2.84	14	10.50	18.56	13.50	0.46	2.26	24	10.50	18.56
Ri	14.67	0.57	1.80	10	12.50	18.50	13.72	0.53	1.92	13	11.00	17.50	14.13	0.39	1.89	23	11.00	18.50
Rcl	13.50	0.26	0.68	7	12.51	14.53	14.22	0.72	1.25	3	13.50	15.66	13.72	0.28	0.88	10	12.51	15.66
R1/4	15.53	0.39	1.89	23	12.50	18.50	14.65	0.27	1.45	28	11.24	17.51	15.06	0.23	1.68	55	11.24	18.50
R1/2	16.82	0.31	1.53	24	13.50	19.91	15.95	0.36	1.60	20	12.80	19.09	16.41	0.24	1.68	47	12.80	19.91
R3/4	17.84	0.37	1.75	22	14.89	22.50	16.59	0.27	1.29	22	13.50	18.82	17.22	0.24	1.62	45	13.50	22.50
Rc	18.26	0.27	1.18	19	15.50	20.30	18.42	0.29	1.26	19	15.69	20.59	18.34	0.19	1.19	39	15.50	20.59
A12	18.78	0.26	1.05	17	16.72	20.29	18.40	0.28	1.17	18	16.50	20.73	18.56	0.19	1.11	36	16.50	20.73
Ac				102	13.98					71	13.50					176	13.50	

Table X. Mean age of children ‘in a stage’ of M_3 – Cape Coloured children, $n = 720$ (319 boys, 401 girls). NS sex differences in mean age midstage.

	Boys						Girls						Combined sex					
M_3	Mean	SE	SD	*n*	Min.	Max.	Mean	SE	SD	*n*	Min.	Max.	Mean	SE	SD	*n*	Min.	Max.
Crypt	9.52	0.36	1.38	15	7.33	11.32	9.03	0.44	1.58	13	6.33	11.38	9.29	0.28	1.47	28	6.33	11.38
Ci	9.59	0.30	1.21	16	7.68	12.10	9.84	0.40	0.98	6	8.87	11.67	9.66	0.24	1.13	22	7.68	12.10
Cco	10.29	0.52	1.79	12	8.46	15.33	10.32	0.30	1.35	20	8.46	12.60	10.31	0.27	1.50	32	8.46	15.33
Coc	11.27	0.46	1.58	12	9.21	15.33	10.77	0.44	1.33	9	8.68	12.85	11.06	0.32	1.46	21	8.68	15.33
C1/2	11.91	0.31	1.64	27	9.23	15.33	11.97	0.30	1.54	27	8.52	15.58	11.94	0.21	1.58	54	8.52	15.58
C3/4	13.20	0.35	1.76	26	10.32	18.04	13.05	0.27	1.61	36	9.74	16.85	13.11	0.21	1.66	62	9.74	18.04
Cc	14.07	0.34	1.28	14	12.63	16.50	14.54	0.68	2.96	19	11.36	23.98	14.34	0.41	2.38	33	11.36	23.98
Ri	14.54	0.46	1.31	8	12.02	15.91	14.83	0.54	2.24	17	11.39	19.41	14.74	0.39	1.97	25	11.39	19.41
Rcl	14.43	0.58	0.82	2	13.85	15.01	14.93	0.63	0.89	2	14.30	15.56	14.68	0.38	0.76	4	13.85	15.56
R1/4	15.51	0.47	2.25	23	9.85	20.84	16.22	0.46	2.35	26	12.23	20.26	15.89	0.33	2.31	49	9.85	20.84
R1/2	16.40	0.48	2.14	20	9.51	19.82	17.36	0.47	2.52	29	11.58	23.72	16.97	0.34	2.40	49	9.51	23.72
R3/4	17.60	0.64	1.28	4	16.64	19.39	18.50	0.35	1.54	19	14.39	20.55	18.34	0.32	1.51	23	14.39	20.55
Rc	18.27	0.38	1.19	10	16.13	20.16	19.16	0.40	1.67	17	16.32	23.30	18.83	0.30	1.55	27	16.13	23.30
A12	19.49	0.67	2.33	12	17.17	24.80	20.62	0.28	1.75	39	15.81	23.63	20.36	0.27	1.94	51	15.81	24.80
Ac				43	18.62					68	14.64						14.64	

Table XI. Mean age of children 'in a stage' of M_3 – Bangladeshi children, $n = 789$ (400 boys, 389 girls). Crypt stage $p < 0.05$ and R1/4 $p < 0.01$ sex differences in mean age midstage.

	Boys						Girls						Combined sex					
M_3	Mean	SE	SD	*n*	Min.	Max.	Mean	SE	SD	*n*	Min.	Max.	Mean	SE	SD	*n*	Min.	Max.
Crypt	8.86	0.25	1.12	20	7.22	11.37	7.92	0.27	0.97	13	6.52	9.96	8.49	0.20	1.15	33	6.52	11.37
Ci	8.86	0.24	0.99	17	6.20	10.97	8.92	0.30	1.26	18	6.40	11.27	8.89	0.19	1.12	35	6.20	11.57
Cco	10.08	0.27	1.22	21	8.02	12.44	10.55	0.43	1.79	17	8.22	13.92	10.29	0.24	1.50	38	8.02	13.92
Coc	10.17	0.32	1.02	10	8.63	11.98	11.00	0.32	1.15	13	9.28	12.58	10.64	0.24	1.15	23	8.63	12.58
C1/2	12.07	0.37	1.94	28	9.08	16.98	11.73	0.24	1.19	25	9.89	13.71	11.91	0.22	1.62	53	9.08	16.98
C3/4	13.06	0.37	1.97	28	9.24	17.41	12.53	0.38	1.47	15	9.06	14.57	12.88	0.28	1.81	43	9.06	17.41
Cc	13.70	1.51	2.61	3	11.27	16.46	14.39	0.35	1.30	14	11.74	16.76	14.27	0.37	1.51	17	11.27	16.76
Ri	14.57	0.80	2.40	9	11.51	17.89	15.11	0.59	2.66	20	10.05	20.44	14.94	0.47	2.55	29	10.05	20.44
Rcl	14.93	0.43	1.77	17	11.94	18.44	15.88	0.43	1.37	10	13.56	17.54	15.29	0.31	1.65	28	11.94	18.44
R1/4	15.76	0.27	1.50	32	11.72	19.11	17.29	0.39	2.01	26	13.61	20.82	16.39	0.25	1.93	59	11.72	20.82
R1/2	17.05	0.53	2.37	20	12.91	22.84	16.38	0.38	1.82	23	11.32	19.20	16.64	0.31	2.06	45	11.32	22.84
R3/4	17.32	0.33	1.27	15	15.68	19.72	18.38	0.50	1.92	15	15.14	22.37	17.85	0.30	1.66	31	15.14	22.37
Rc	18.20	0.49	1.90	15	15.08	21.48	18.48	0.67	2.58	15	13.11	22.26	18.33	0.38	2.16	32	13.11	22.26
A12	19.21	0.41	1.53	14	17.26	22.25	19.41	0.34	1.57	22	15.80	22.78	19.36	0.24	1.49	39	15.80	22.78
Ac				72	16.76					60	16.45					140	16.45	

Table XII. Mean age of children 'in a stage' of M_3 – White children, $n = 959$ (455 boys, 504 girls). Stage R1/4 and Rc $p < 0.01$, A1/2 $p < 0.05$ sex differences in mean age midstage.

	Boys						Girls						Combined sex					
M_3	Mean	SE	SD	*n*	Min.	Max.	Mean	SE	SD	*n*	Min.	Max.	Mean	SE	SD	*n*	Min.	Max.
Crypt	9.54	0.32	1.58	25	7.39	12.47	8.63	0.39	1.17	9	6.63	10.53	9.30	0.26	1.52	34	6.63	12.47
Ci	9.49	0.31	1.15	14	7.75	12.12	9.11	0.21	0.96	20	7.47	11.39	9.27	0.18	1.04	34	7.47	12.12
Cco	10.30	0.32	1.71	29	7.46	13.58	10.28	0.37	1.38	14	8.23	12.32	10.29	0.24	1.59	43	7.46	13.58
Coc	11.09	0.30	1.05	12	8.99	12.94	11.66	0.57	1.88	11	9.07	15.92	11.36	0.31	1.49	23	8.99	15.92
C1/2	12.54	0.30	1.60	29	9.32	15.14	11.97	0.31	1.62	28	8.31	17.20	12.26	0.21	1.62	57	8.31	17.20
C3/4	12.80	0.35	1.67	23	9.74	15.51	13.79	0.36	1.98	30	9.60	17.18	13.36	0.26	1.90	53	9.60	17.18
Cc	14.49	0.43	1.62	14	12.39	19.07	15.42	0.74	2.58	12	12.84	20.35	14.92	0.42	2.12	26	12.39	20.35
Ri	15.16	0.36	1.14	10	13.45	17.01	15.43	0.53	1.84	12	12.38	17.76	15.31	0.33	1.53	22	12.38	17.76
Rcl	15.02	0.51	1.24	6	13.48	16.45	15.92	0.71	2.14	9	14.39	20.75	15.56	0.47	1.84	15	13.48	20.75
R1/4	15.39	0.30	1.42	23	12.86	17.55	16.90	0.31	1.95	39	13.01	21.56	16.34	0.24	1.90	62	12.86	21.56
R1/2	16.87	0.37	1.47	16	15.13	20.81	17.08	0.41	1.90	22	14.41	21.78	16.99	0.28	1.72	38	14.41	21.78
R3/4	17.62	0.30	1.43	23	15.79	21.28	18.39	0.35	1.98	32	14.17	22.99	18.07	0.24	1.80	55	14.17	22.99
Rc	17.73	0.45	1.55	12	15.38	20.02	19.71	0.38	2.06	29	15.13	23.46	19.13	0.33	2.11	41	15.13	23.46
A12	19.02	0.26	1.26	24	16.74	21.62	19.94	0.27	1.58	35	16.39	22.42	19.56	0.19	1.50	60	16.39	22.42
Ac				95	17.13					88	16.28					184	16.28	

Table XIII. Comparison of mean age M_3 midstage between groups (combined sex).

M_3 stage	Cape *vs.* African, *p*<	Cape *vs.* Bangladeshi, *p*<	Cape *vs.* White, *p*<	African *vs.* Bangladeshi, *p*<	African *vs.* White, *p*<	Bangladeshi *vs.* White, *p*<
Crypt	0.001	0.05	NS	0.05	0.001	0.05
Ci	0.001	0.05	NS	NS	0.05	NS
Cco	0.001	NS	NS	0.001	0.001	NS
Coc	0.05	NS	NS	NS	0.001	NS
C1/2	0.01	NS	NS	0.05	0.001	NS
C3/4	0.001	NS	NS	0.05	0.001	NS
Cc	NS	NS	NS	NS	0.05	NS
Ri	NS	NS	NS	NS	0.05	NS
Rcl	NS	NS	NS	0.001	0.001	NS
R1/4	0.05	NS	NS	0.001	0.001	NS
R1/2	NS	NS	NS	NS	NS	NS
R3/4	0.01	NS	NS	NS	0.05	NS
Rc	NS	NS	NS	NS	0.05	NS
A1/2	0.001	0.01	0.05	0.05	0.001	NS

Table XIV. Comparison of mean age M_3 midstage between groups (boys).

M_3 stage	Cape *vs.* African, *p*<	Cape *vs.* Bangladeshi, *p*<	Cape *vs.* White, *p*<	African *vs.* Bangladeshi, *p*<	African *vs.* White, *p*<	Bangladeshi *vs.* White, *p*<
Crypt	0.01	NS	NS	NS	0.01	NS
Ci	0.05	NS	NS	NS	0.05	NS
Cco	0.05	NS	NS	0.01	0.001	NS
Coc	0.05	NS	NS	NS	0.05	NS
C1/2	NS	NS	0.05	NS	0.01	NS
C3/4	NS	NS	NS	NS	NS	NS
Cc	NS	NS	NS	NS	NS	NS
Ri	NS	NS	NS	NS	NS	NS
Rcl	NS	NS	NS	0.01	0.05	NS
R1/4	NS	NS	NS	NS	NS	NS
R1/2	NS	NS	NS	NS	NS	NS
R3/4	NS	NS	NS	NS	NS	NS
Rc	NS	NS	NS	NS	NS	NS
A1/2	NS	NS	NS	NS	NS	NS

Discussion

The existence of population differences in human tooth maturation are presented here for the first time. The mandibular third molar initiates and completes maturation significantly earlier in Black children from South Africa compared to White and Bangladeshi in London and Cape Coloured in Cape Town. This difference is evident for all 15 stages of tooth formation from crypt appearance to apex closure, suggesting a shift in the timing of initiation. The duration of molar amelogenesis is similar between groups (Reid and Dean 2006). If the *initial* timing of cusp tip mineralization differs, then the timing of all subsequent crown and root stages will also differ. It becomes clear how important it is to document the whole developmental course and in particular age of initiation, in order to demonstrate this

Table XV. Comparison of mean age M_3 midstage between groups (girls).

M_3 stage	Cape *vs.* African, *p*<	Cape *vs.* Bangladeshi, *p*<	Cape *vs.* White, *p*<	African *vs.* Bangladeshi, *p*<	African *vs.* White, *p*<	Bangladeshi *vs.* White, *p*<
Crypt	NS	0.05	NS	NS	NS	NS
Ci	0.05	NS	NS	NS	NS	NS
Cco	NS	NS	NS	NS	NS	NS
Coc	NS	NS	NS	NS	NS	NS
C1/2	0.05	NS	NS	NS	0.05	NS
C3/4	0.01	NS	NS	NS	0.001	0.05
Cc	NS	NS	NS	NS	NS	NS
Ri	NS	NS	NS	NS	0.05	NS
Rcl	NS	NS	NS	NS	NS	NS
R1/4	0.01	NS	NS	0.001	0.001	NS
R1/2	0.05	NS	NS	NS	0.05	NS
R3/4	0.01	NS	NS	0.01	0.001	NS
Rc	NS	NS	NS	NS	0.01	NS
A1/2	0.001	0.01	NS	0.05	0.001	NS

shift in timing. Other permanent teeth begin to mineralize around birth (first molar), during the first year (incisors, canines) or during the third or fourth year (premolars and second molar). Dental radiographs of very young children are not taken routinely, thus the permanent third molar is the only tooth that can be studied for the whole developmental sequence if archived cross-sectional dental radiographs of living children are used.

Previous studies of third molar maturation

A number of third molar formation studies have documented the mean age of third molar maturation (Garn et al. 1962; Moorrees et al. 1963; Haavikko 1970; Fanning 1971; Anderson et al. 1976; Levesque et al. 1981; Nyström et al. 2007). Three used the Fels longitudinal growth study (Garn et al. 1962; Moorrees et al. 1963; Fanning 1971) and Garn et al. (1962) reported on both formation and eruption stages. Moorrees et al. (1963) defined 14 stages from a longitudinal study from birth up to age 25 (tabulated by Harris and Buck 2002). Fanning (1971) reported four stages of third molar formation including 3rd and 97th percentiles from the same material. One cross-sectional study from Finland described timing of most third molar stages (Haavikko 1970). Anderson et al. (1976) using longitudinal radiographs from Burlington, Canada reported on both maxillary and teeth. Both these studies included few older individuals which may have biased the results of the last maturational stage. Two studies that did include older individuals are those of Levesque et al. (1981) from Canada and Nyström et al. (2007) from Finland who used the eight stages of maturation defined by Demirjian. Ten published studies have tabulated sufficient data to calculate mean age of entry (plus standard error) of some third molar stages (Banks and Banks 1934; Clow 1984; Gonzelaz and Del Rosario 1990; Gorgani et al. 1990; Gravely 1965; Legović et al. 1997; Nortjé 1983; Rozkovcová et al. 2004; Sarnat et al. 2003; Trisović et al. 1977; Uzamiş et al. 2000). In this paper, mean age at entry has been calculated for their data using probit regression to enable comparison with the results from this study (see Table XVI, Figure 5). Numerous other studies report part of the developmental sequence of this tooth, although only a few measure maturation.

Table XVI. Studies that provide sufficient data to calculate mean age entering M_3 stage (+ standard error) crypt and initial mineralization. *n* for combined sex, age range in years, data for lower left M_3 except Gorgani et al. (combined left and right). Gorgani et al. only documents percentage and estimates have been used.

Reference	Region	*n*	Age (years)	Comments
Banks and Banks (1934)	Colorado, USA (longitudinal)	1000	6–22	
Gravely (1965)	Leeds England	550	6–15	
Nortjé (1983)	Cape Coloured, South Africa	500	15–21	
Trisović et al. (1977)	Belgrade, Yugoslavia	3852	4–14	
Gorgani et al. (1990)	Nebraska, USA	229 Black 221 White	6–14	%, estimated 12 or 13 per year of age
Gonzáles (1990)	Mexico City	500	7–18	All quadrants combined
Menzies Clow (1984)	Motherwell, England	1154	6–15	
Uzamiş et al. (2000)	Hacettepe, Turkey	400	6–13	
Sarnat et al. (2003)	Tel Aviv, Israel	639	7–16	Both jaws combined
Rozkovcová et al. (2004)	Prague, Czech Republic	1700	5–21	

Age of third molar crypt formation

Comparison of mandibular third molar crypt formation from published studies showed the mean age as eight or nine with a wide range from about 6 (although this is often the minimum age) up to 14 (see Figure 5). The earliest mean age reported for crypt formation was 7.16 Black children from South Africa in this study followed by 7.8 from one early study (Banks and Banks 1934) and 8.04 for Black children from USA (Gorgani et al. 1990). Other mean ages from Table XIV are 10.11 (Clow 1984), 10.25 (Gravely 1965), 10.02 (Rozkovcová et al. 2004) and 10.33 (Uzamiş et al. 2000). Legović et al. (1997) presented sufficient data to calculate mean age of crypt formation from two regions of Croatia – Istria at 9.05 and Slovania at 10.59. The progression from small to full size crypt is reported in two studies. The longitudinal study (Garn et al. 1962) reported small crypt at 8.6 and full size crypt at 9.1 years, while Trisović et al. (1977) reported average age of small crypt at 9.39 and full size crypt almost a year later at 10.35 in their cross-sectional study. Growth of the crypt, therefore, probably takes 6 months or more before cusp tips are visible and this might partly explain the large variation in timing of mean age shown in Figure 5.

Age of third molar cusp tip initiation

The mean age of initial mineralization of cusp tips has been consistently reported as during the ninth year. Garn et al. (1962) reported 9.4, Moorrees et al. (1963) 9.2 and 9.6, Fanning (1971) 8.95 and 9.09 for boys and girls, respectively, while Anderson et al. (1976) reported 9.4 for both sexes. Haavikko (1970) reported 9.8 and 9.6, Levesque et al. (1981) 9.7 and 9.8, while Nyström et al. (2007) reported 9.26 and 9.47 for boys and girls, respectively. Standard deviation of about 1 year is available from the one longitudinal study (Moorrees et al. 1963, see Harris and Buck 2002). Cumulative curves for this stage calculated from published data (Figure 5) show that the earliest age is 6 but that it can be as late as 14. The earliest mean age was 7.97 in Black children from South Africa followed by Bangladeshi children from the present study at 8.93 years. Other mean values were 9.67 (Banks and Banks 1934), 10.13 for data of maxillary and mandibular

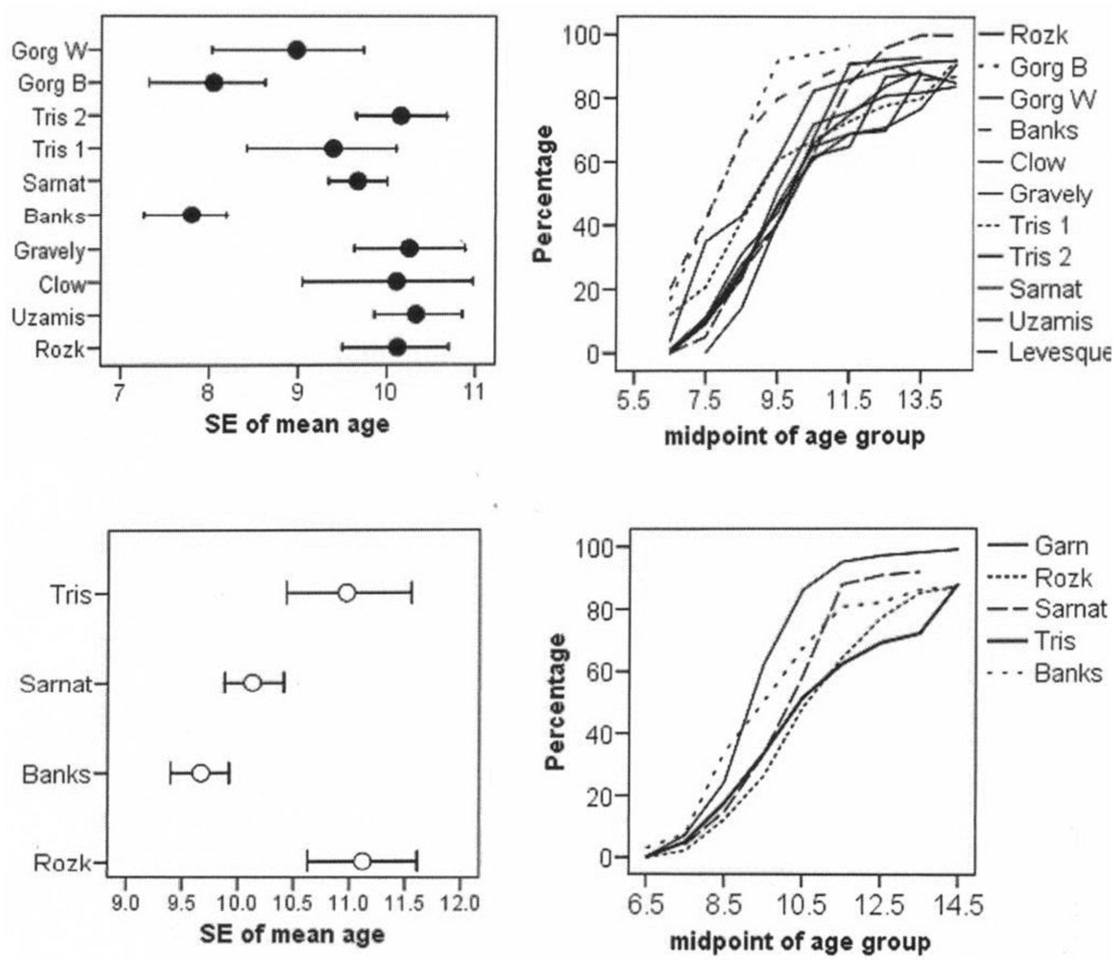


Figure 5. Mean age ± standard error and cumulative distribution curves of third molar crypt (top) and initial mineralization (bottom) for girls. Left, mean age and standard error, right, percentage of grouped data. See Table XVI for references.

third molars (Sarnat et al. 2003), 10.91 (Trisović et al. 1977) and 11.12 years (Rozkovcová et al. 2004).

Age of third molar crown completion and initial root formation

The mean age of completion of the third molar crown is during the 12th or 13th year. Garn et al. (1962) reported this at 13.9 for sexes combined, Moorrees et al. (1963) 12.0 and 12.3, Haavikko (1970) 13.7 and 13.3, Fanning (1971) 12.27 and 11.79, Anderson et al. (1976) 13.3 and 12.8 for boys and girls, respectively. Mean age of initial root occurred about a year later at 14.8 (Garn et al. 1962), 12.7 and 12.9 (Moorrees et al. 1963) and 14.1 and 13.7 (Anderson et al. 1976) for boys and girls, respectively. Standard deviation is around

1.3 years (Moorrees et al. 1963, see Harris and Buck 2002), i.e. about 10% of the mean for both these stages.

Age of third molar root cleft formation

The mean age of root cleft formation is from mid thirteenth to the beginning of the fifteenth year. Moorrees et al. (1963) reported 13.6 and 13.5 with standard deviation of 1.4 years; Anderson et al. (1976) reported 14.8 and 14.5 for boys and girls, respectively. Demirjian's stage E (that includes root cleft and root quarter) is reported as 14.5 by Levesque et al. (1981) and 15.05 for boys and 15.06 for girls (Nyström et al. 2007). Tabulated data of Japanese individuals from Olze et al. (2004) was calculated as 15.4 for combined sex.

Age of third molar root length one half

Mean age of root half occurred during the 15th or 16th year. Garn et al. (1962) reported mean age as 16.9, Moorrees et al. (1963) as 15.1 and 15.8, Haavikko (1970) as 16.7 and 15.8, Fanning (1971) as 15.35 and 15.86, Anderson et al. (1976) as 16.1 and 15.4 for boys and girls, respectively, with a standard deviation of about 1.5 years (Moorrees et al. 1963). Demirjian's stage F mean age is reported as during the 16th year. Levesque et al. (1981) reports mean age as 16.3, while Nyström et al. (2007) reported 16.73 for boys and 16.51 for girls. Mean age from Spanish and Japanese individuals has been calculated from Prieto et al. (2005) as 15.73 (95% interval 15.18–16.18) for Spanish and 17.06 for Japanese (Olze et al. 2004) although this was not significantly different.

Age of third molar root length complete and apex half closed

Mean age for Demirjian's stage G was reported as occurring during late 17th or 18th year. Levesque et al. (1981) reported 17.6 and 18.3 while Nyström et al. (2007) reported 18.03 and 18.84 for boys and girls, respectively. Similarly mean age calculated from a Spanish group from Prieto et al. (2005) was 18.75 [95% interval 18.53–19.01] and 19.48 for Japanese from Olze et al. (2004). These were not significantly different. Maximum age for this stage was reported as 22 in boys and 24 in girls from Turkey (Sisman et al. 2007). Mean age of root length complete in Black South Africans from the present study occurred during the 17th year, while for other groups mean age was during 18th year. This is later than the 16.3 and 17 reported by Moorrees et al. (1963) and 17.4 and 17.7 (Anderson et al. 1976) but similar to Haavikko (1970) at 18.4 and 18.7 for boys and girls, respectively. Moorrees et al. (1963) report a standard deviation of around 1.7 years, again approximately 10% of the mean value. Average age from the present study for apex half closed was 18.5–19.5, slightly later than 17.6 for boys and 18 for girls from Moorrees et al. (1963) and 18.2 from Anderson et al. (1976).

Age of third molar apex closed

Results from the present study for mean age entering apex closed was during the 19th or 20th year with a standard deviation of 1 year or just over, but with a sex difference of more than a year. These findings are similar to some previously published mean age 20.1 and 19.2 (Moorrees et al. 1963), 19.2 and 20.7 (Levesque et al. 1981), 20.31 and 20.5 (Nyström et al. 2007) for boys and girls, respectively, but later than those lacking older individuals (Garn et al. 1962; Haavikko 1970; Fanning 1971; Anderson et al. 1976). Cape children reached apex closure on average at age 19.6 (calculated from Nortjé 1983), significantly earlier than the results from the present study, although both lack large numbers of older individuals. Standard deviation from the present study was considerably less than the 2 years reported from the longitudinal study of Moorrees et al. (1963, see Harris and Buck 2002). A delay in late root stages in girls is illustrated in Levesque et al. (1981) where only 90% of girls aged 24 had reached full maturity of this tooth. Nyström et al. (2007) also detailed the age 97th percentile of in-stage age in girls as 24.18 years. This has important implications for design study relating to the maximum age of a sample, for description or as a test sample to determine accuracy of age estimation.

Sex differences in timing of third molar stages

An unusual finding in this study is that Black girls are on average earlier than Black boys for almost all stages of third molar formation and Cape girls are earlier than Cape boys for crown stages, although few of these comparisons were significant. Previous reports have shown no significant sex difference in average timing of maturation of this tooth (Garn et al. 1962), in contrast to other permanent teeth where boys are significantly later on average for tooth formation except for early stages (Thompson et al. 1975). Most studies report mean age earlier in boys compared to girls for all or most stages (Garn et al. 1962; Moorrees et al. 1963; Haavikko 1970; Nyström et al. 2007) but this is not a consistent finding (Anderson et al. 1976; Levesque et al. 1981). A delay in late root formation of third molars in girls has been noted; all boys had reached this stage by the maximum age of 24, but not all girls (Levesque et al. 1981). This delay in late root formation was also apparent in the non-African groups in the present study, although additional information from histological investigation on dentine formation might help to explain this variation.

Methodological issues

Measuring tooth formation presents several methodological challenges (see Smith 1991). The first concerns the choice of statistics and aim of a study – to either measure maturation or describe average age of individuals ‘in a stage’ up to the penultimate stage. Comparing maturational events, in this case tooth formation stages, is best done using cumulative distribution functions that describe the increasing proportion of an age group that has reached or passed a specific stage plotted against age groups. The average age of entering a stage is the age when 50% of the age group has attained or passed this stage. The third permanent molar is unique in being the most variable tooth in size, shape and formation time. Individual duration from crypt to apex closure of this tooth can only be determined from longitudinal radiographs and has been reported as between 10 and 12 years (Garn et al. 1962), however the age range for each stage can be 11 years, more than any other tooth. An early maturing child may begin to mineralize this tooth at age 6 and could finish root growth around 16 while a delayed individual may only begin formation around 13 finishing at 23. To document the variation of formation of this tooth from a cross-sectional study, a large sample with a wide age range is needed. The age range of any maturity study should include an age group younger than the minimum age of the first maturity event and extend up to the age when 100% of the age group has reached the final maturity stage. In this study the minimum age of third molar crypt was 4 and the maximum 12, that is slightly younger than 14 or 15 reported previously (see Banks and Banks 1934; Trisović et al. 1977; Rozkovcová et al. 2004). The end of crown stages and initial root stage age range is 10–20. Apex closed was first seen at age 13 and by 24 years 100% of all groups had reached this stage.

The second problem, that of an appropriate age range, becomes obvious if one is measuring maturation. The average age of entering a stage is not be confused with the median, 50th percentile or mean age in a specific stage. The average age of entering a stage is cumulative and determined from the whole sample, all children who have not yet reached the stage as well as all children who have reached or passed the stage. This is appropriate for qualitative maturity events. Average age within a stage is, by definition, a very much smaller sample size for each stage, and even large studies record less than 5 for some stages/groups (see Harris 2007). Average age in-stage does have some use in documenting minimum and maximum age of stages but comparisons are of little value without some knowledge of the variation of a maturity event. Average age within a stage can be biased if the maximum age of a sample is truncated for that stage. For instance, around half of 20-year-olds have reached full maturation of the third molar and if the maximum age of a study falls short by several years, the average in-stage age of late root stages will be biased. In this case, the 50th percentile will be very different to the age when 50% of individuals in *an age group* have attained that stage, illustrating the difference between measuring maturation and describing the average age in-stage of tooth formation. Studies using age truncated samples to describe average age of stages or accuracy of a method should be interpreted with this in mind (Elomaa and Elomaa 1973; Bolaños et al. 2003; Prieto et al. 2005; Orhan et al. 2006). Another difficulty is when tooth formation stages are assumed to have a numerical value and 'average stage' for third molars is calculated or used as a score to estimate age (Bolaños et al. 2003; Mesotten et al. 2003; Gunst et al. 2003; Olze et al. 2003; Sarnat et al. 2003; Olze et al. 2004; Olze et al. 2006; Daito et al. 1992). In-stage age for third molar formation was described from individuals from USA and Europe (Demisch and Wartmann 1956; Elomaa and Elomaa 1973; Engström et al. 1983; Köhler et al. 1994; Willershausen et al. 2001; Solari and Abramovitch 2002; Bolaños et al. 2003; Friedrich et al. 2003; De Salvia et al. 2004; Prieto et al. 2005; Meinl et al. 2007), Turkey (Orhan et al. 2006; Sisman et al. 2007), Blacks from South Africa (Olze et al. 2006), India (Bhat and Kamath 2007), Japan (Arany et al. 2004; Olze et al. 2004), and Korea (Choi and Kim 1991). A few of these gave sufficient information to compare results of the mandibular left third molar. Mean age of Demirjian root stages D, E and F were not significantly different between Japanese, Spanish and Austrians while mean age for stage G in Spanish was significantly earlier than Japanese and Austrians were significantly later than both (Arany et al. 2004; Prieto et al. 2005; Meinl et al. 2007). Both the studies from Japan and Austria include individuals up to age 24, while the Spanish sample maximum age was 20. Mean age (sexes combined) of stage Rc is not significantly different between Germans and Spanish (Willershausen et al. 2001; Bolaños et al. 2003) or results from this study. A few studies described in-stage age comparing Blacks and Whites from USA (Mincer et al. 1993; Harris 2007; Blankenship et al. 2007) and Germans and Japanese (Olze et al. 2003). Blacks were found to be significantly earlier and Japanese considerably later. This group from Japan (Olze et al. 2004) is curious and appears to differ from most other groups including another Japanese group (Arany et al. 2004). The raw data tabulated showed that only 28% of 20 years olds had reached apex closed and numerous individuals aged 24 and older showed immature apices. In-stage age of two regional Spanish groups and Magrebians in Cueta, North Africa did not differ in relation to estimating age using 18 year cut off point (De las Heras et al. 2008). To summarize, average age in stage comparisons can be seriously hampered by small sample size. Few population differences are apparent when data are compared, although direct comparison of groups show that Blacks in Tennessee and South Africa were earlier than Whites in Tennessee and some stages in one group of Japanese were later than Germans and South African Blacks.

Root morphology

Roots of third molars differ from those of other molars and stage definitions clearly need some refinement and flexibility to allow for differences in position of the root cleft relative to the enamel margin, shape of the root furcation, number of roots and whether they are fused. The beginning of cleft formation may appear as a dot or line that is visible before a good-sized spicule of aproximal dentine is visible. On the other hand, if the furcation is further from the crown margin (if a molar is taurodont), the cleft will form relatively later or stage R1/4 might be attained prior to root furcation. If the tooth has a single root or partly fused roots, a cleft may not be visible in the formation sequence. Root length relative to crown height is probably a more important descriptive criteria for early root assessment than cleft initiation. The proportion of mandibular third molars having fused or partly fused roots is greater than other molars and was reported as 18% in southern African Blacks and Indians (Shaw 1931; Onda et al. 1989) and 52% in Brazilians (Guerisoli et al. 1998). Root formation is associated with the eruptive phase and some evidence suggests earlier average age of emergence of this tooth in East Africa compared to USA (Chagula 1960; Fanning 1962). Average age of clinical eruption of the left mandibular third molar is between 16 and 20 with standard deviation of around 2 years (Adler and Adler-Hradecky 1962; Fanning 1962; Houpt et al. 1967; Malcolm 1970; Malcolm and Bue 1970; Sidhu and Gupta 1973; Nayak and Patel 1977; Brown 1978; Levesque et al. 1981; Hassanali and Odhiambo 1981; Yamada 1992; Yamada et al. 1992). One exception is an average age of 14.8 and 15.8 for boys and girls, respectively, from Lae, one of three groups in Papua New Guinea (Malcolm and Bue 1970). Mean ages of mandibular eruption for boys and girls have been calculated for this study from tabulated data using probit regression as 16.7 and 17.2 for Zulu in South Africa (from Suk 1919), 17.2 and 17.3 for Digo in Kenya (from MacKay and Martin 1952), 16.6 and 16.3 (from Ajmani and Jain 1984), 16.6 and 18.3 (Otuyemi et al. 1997) for Nigerians and mean age of any third molar (combined sex) 16.9 for Kenyans (from Carothers 1947).

Agenesis of third molars

The tooth that most commonly fails to develop in individuals with hypodontia is the third molar (Garn et al. 1963). Reporting this is complicated by inclusion of young children who have not yet formed this tooth, grouping skeletal with radiographic material, studies that fail to exclude previous extractions from the patient and combination of which jaw/side and number of missing third molars. The level of agenesis of the third molar, from studies that include radiographs, patient history, aged 14 and older, ranges from 6 to 23% in groups in Europe, USA, China and Japan (Banks and Banks 1934; Garn et al. 1963; Gravely 1965; Rantanen 1967; Elomaa and Elomaa 1973; Thompson et al. 1974; Clow 1984; Daito et al. 1992; Mok and Ho 1996; Baba-Kawano et al. 2002; Rozkovcová et al. 2004; Meinl et al. 2007). One study from Japan reports 33% of individuals having one or more missing third molars (Takahama and Otawa 1982). In contrast, less than 2% of South African Blacks had a missing third molar (Nortjé and Harris 1993). Delayed tooth formation has been noted with agenesis of one or more teeth (Garn et al. 1962; Uslenghi et al. 2005) and it seems possible that a high level of agenesis at a population level might be related to delayed third molar formation.

The age when a diagnosis of third molar agenesis can be confirmed is of great interest to paediatric dentists and orthodontists. Three longitudinal radiographic studies from USA and Japan suggest that 14 is the earliest age this can be confirmed (Banks and Banks 1934; Garn et al. 1962; Baba-Kawano et al. 2002). An observation of second molar formation from the present study, showed that when the mandibular third molar is in the crypt stage ($n = 125$), the adjacent second molar stage ranged from midcrown to R3/4. If R3/4 or more of the second molar has formed, the probability of agenesis of the wisdom tooth is 0.99. This pattern is similar to other studies that document formation of these teeth (Clow 1984; Choi and Kim 1991; Baba-Kawano et al. 2002) and suggests that second molar root formation is a better biological predictor than chronological age to confirm agenesis of the third molar.

Growth of the jaws and third molar development

The mandible itself may play a role in the timing of initiation of third molars but measuring the growing mandible is highly complex. Indirect measures such as ramus width and mandibular length from lateral cephalographs provide some information. More meaningful is the retromolar triangular space and the associated width of the ramus in the coronal plane. The growing mandibular corpus has been described as a growing 'V' shape (Enlow 1990) with a major growth site being the lingual tuberosity, which is not visible radiographically in the lateral view. The corpus lengthens posteriorly as each permanent molar crown develops and the ramus is displaced several centimetres by resorption of the anterior border and deposition at the posterior border. The distance between the most distally erupted tooth and the anterior border of the ramus increases as the crown of each molar forms. Sufficient distance has been shown to be associated with early eruption of the first mandibular molar in a small longitudinal study (Lin 1993). After the second molar crown is formed, the anlagen of the third molar begins to grow downwards from the alveolar surface – to lie within bone that then mechanically responds to growth of the tooth bud and later cap stages. The alveolar bone remodels around the tooth cap as the cusp tips mineralize and fuse forming the occlusal surface with establishment of crown volume. From the lateral view, the third molar crown usually forms in the ramus and the occlusal surface tilts anteriorly (Richardson et al. 1984).

In the young adult, sufficient buccolingual width of the alveolar shelf distal to the mandibular second molar (Willis 1966) and bi-ramal width allows unimpeded third molar eruption (Olive and Basford 1981). Local factors such as previous extraction of other permanent teeth also influence third molar formation; this appears to be associated with accelerated third molar eruption and formation (Fanning 1962; Yavuz et al. 2006). The mesial root of the third molar is reported to be significantly longer (Harris and Nortjé 1984) and less curved (Biçakçi et al. 2007) in individuals with prior previous extraction of the first or second molar.

The jaws, dentition and midface are thought to grow as a functional matrix. The mandible and maxillae, mid cranial fossa, muscles of mastication, tooth and arch size, occlusion as well as the soft tissues of lips and tongue all influence each other. Of these, architecture of the mandible has been most studied and differences in the width of the mandibular ramus and mandibular length in the sagittal plane occur between groups. A very broad ramus places the mandibular corpus in a protrusive position resulting in bimaxillary prognathism with possible proclination of anterior teeth (Enlow 1990). Bjork (1950) suggests that prognathism of Shona tribe compared to Swedes was due mainly to the size of the mandible. Prognathism has been noted in several other sub-Saharan African groups including Sotho-Tswana, Barundi, South African Blacks, Cape Coloureds in South Africa (Savage 1963; Jacobson and Oosthuizen 1970; Seedat 1983; Barter et al. 1995; Jacobson and Oosthuizen 1970). Width of the ramus is broader proportionate to the middle cranial fossa in North American Blacks compared to Whites (Harris et al. 1977). This study also noted a significantly longer mandibular length (gonion to pogonion) with wider ramal width in Blacks compared to Whites. Arch length (reflecting tooth size, spacing and crowding of teeth) is larger in North American Blacks compared to Whites (Burris and Harris 2000). Less crowding and more spacing between anterior teeth was noted in Tanzanian compared to Finnish children (Mugonzibwa et al. 2004). Is this associated with early initiation of third molars? If so, the pattern between the two London groups is less clear. Mandibular length (condylion and gonion to gnathion) is significantly smaller in Bangladeshi children in London compared to Whites (Gunasekera 1993). In addition, tooth size and arch length is also significantly smaller in this group of Bangladeshis (Ramaraj 1990). Does a larger mandible or structural differences in bony architecture play a role in the initiation of the third molar? Why does the third molar initiate early in some individuals and so late in others? Do the differences between groups in mandibular size and shape play any role? There is little doubt of the challenge analysing a complex three-dimensional structure such as the growing mandible. New methods such as two-dimensional warp of mandibular shape in world groups (Bastir et al. 2004) and three-dimensional analyses of mandibular growth in patient groups (Cevidanes et al. 2005) and baboons and great apes (Boughner and Dean 2004) are useful tools that may help to answer some of these questions.

Conclusions

Children from London (White and Bangladeshi) and Cape Town (Cape Coloured) were significantly delayed in the mean age of initiation and almost all subsequent formation stage of the permanent mandibular third molar compared to Black South African children. This delay was apparent for 14 out of 15 tooth formation stages and is the first evidence of a human population shift in dental formation from radiographic studies. The difference in timing of third molars between South African Black children and the three other groups is possibly related to mandibular growth around the age when the second permanent molar crown is complete. Factors that might play a role include mandibular architecture especially development of the retromolar space, midramal width and the incidence of hypodontia in different populations.

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