A radiographic study of the mandibular third molar root development in different ethnic groups

Helen M.Liversidge[1]
Kalaiarasu Peariasamy[2]
Morenike Oluwatoyin Folayan[3]
Abiola Adetokunbo Adeniyi[4],
Papa Ibrahima Ngom[5]
Yuko Mikami[6]
Yukie Shimada[7]
Kazuto Kuroe[8]
Ingun F.Tvete[9]
Sigrid I. Kvaal[10]

[1] Institute of Dentistry, Queen Mary University of London, Barts and The London School of Medicine and Dentistry, London, United Kingdom

Department of Paediatric Dentistry, Sungai Buloh Hospital, Selangor, Malaysia

Department of Child Dental Health, Obafemi Awolowo University, Osogbo, Nigeria

Department of Preventive Dentistry, Lagos State University Teaching Hospital, Lagos, Nigeria

Department of Dentistry, University Cheikh Anta Diop, Dakar, Senegal

Community & Global Health, Graduate School of Medicine, University of Tokyo, Japan

Department of Pediatric Dentistry, Showa University, School of Dentistry, Tokyo, Japan

Kuroe Orthodontic Practice, Kagoshima, Japan

Norwegian Computing Center, Oslo, Norway

Institute of Clinical Dentistry, University of Oslo, Oslo, Norway

Corresponding author:
h.m.liversidge@qmul.ac.uk

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ABSTRACT

Background: The nature of differences in the timing of tooth formation between ethnic groups is important when estimating age.

Aim: To calculate age of transition of the mandibular third (M3) molar tooth stages from archived dental radiographs from sub-Saharan Africa, Malaysia, Japan and two groups from London UK (Whites and Bangladeshi).

Materials and methods: The number of radiographs was 4555 (2028 males, 2527 females) with an age range 10-25 years. The left M3 was staged into Moorrees stages. A probit model was fitted to calculate mean ages for transitions between stages for males and females and each ethnic group separately. The estimated age distributions given each M3 stage was calculated. To assess differences in timing of M3 between ethnic groups, three models were proposed: a separate model for each ethnic group, a joint model and a third model combining some aspects across groups. The best model fit was tested using Bayesian and Akaikes information criteria (BIC and AIC) and log likelihood ratio test.

Results: Differences in mean ages of M3 root stages were found between ethnic groups, however all groups showed large standard deviation values. The AIC and log likelihood ratio test indicated that a separate model for each ethnic group was best. Small differences were also noted between timing of M3 between males and females, with the exception of the Malaysian group. These findings suggests that features of a reference data set (wide age range and uniform age distribution) and a Bayesian statistical approach are more important than population specific convenience samples to estimate age of an individual using M3.

Conclusion: Some group differences were evident in M3 timing, however, this has some impact on the confidence interval of estimated age in females and little impact in males because of the large variation in age.

INTRODUCTION

Developing teeth are frequently used to estimate age and a number of methods are available (see review by Liversidge).[1] Most of these divide the growth and development of a tooth into discrete crown and root stages. Once a tooth formation stage has been identified, dental age can be calculated from a selected reference data.

Studies show that females on average, are earlier in dental development of most teeth with the exception of root stages of

the third molar[2-4] and this means that sex-specific reference data are appropriate.[1] Many studies report differences in the timing of tooth development in various parts of the world and these have been interpreted as regional and ethnic differences,[5-17] although this has been questioned because of differences in sample structure, sample size and most importantly, statistical analyses.[18-20] Newer approaches to calculating the probability of age, given a tooth stage are considered more appropriate than mean age of individuals within a tooth stage.[21-24]
Recommendation from the Study Group on Forensic Age Diagnostics for age estimation in the living[25] state that data on the reference population regarding genetic/geographic origin should be provided, as it is still unclear if ancestry/region impact on estimated age. The aims of this study were (1) to compare regional and sex differences in root development of the mandibular third molar (M3) for given ages; (2) to derive age distributions for given stages of root development of M3; and (3) to consider the possibility of an individual being at least/older than 18 years at given stages of root development of M3.

MATERIALS AND METHODS

Data were collected from archived dental radiographs of patients attending dental schools or private clinics during 2003-2015. The sample consisted of panoramic or lateral radiographs of 4555 individuals aged 10-25 years. Inclusion criteria were clear image of M2 and M3, recorded date of birth and date of radiograph. Chronological age was calculated as the time from date of birth to the date of radiographs. In 29% of cases from Nigeria, South Africa, and Senegal, only year of birth was available. In these cases, age was assumed to be half way into their year i.e. if the age was 14 years then age was assumed to be 14.5 years old. Health status and socio-economic status were not recorded.

The following regional groups were considered:

1. Sub-Saharan African (Nigeria, Senegal and South Africa)
2. Japanese
3. Malaysian
4. White/European UK
5. Bangladeshi UK

The age distribution for the different regional groups for male and females is shown in Table 1. The development of mandibular left third molar (M3) was scored by the first author based on Moorrees et al.[2] (illustrated in Figure 1) following descriptive criteria.[26] Tooth stages of M3 in the Malaysian radiographs were scored by the second author and inter-observer reliability was calculated from 20 radiographs (Kappa 0.81). Data from South Africa and UK groups have been analysed in previous reports of M3 development and age estimation.[26-28]

Figure 1: Molar crown and root stages after Moorrees. (Ri = initial root, Rcl = root cleft, R¼ = root quarter, R½ = root half, R¾ = root three quarters, Rc = root complete, A½ = apex half closed, Ac = apex closed)

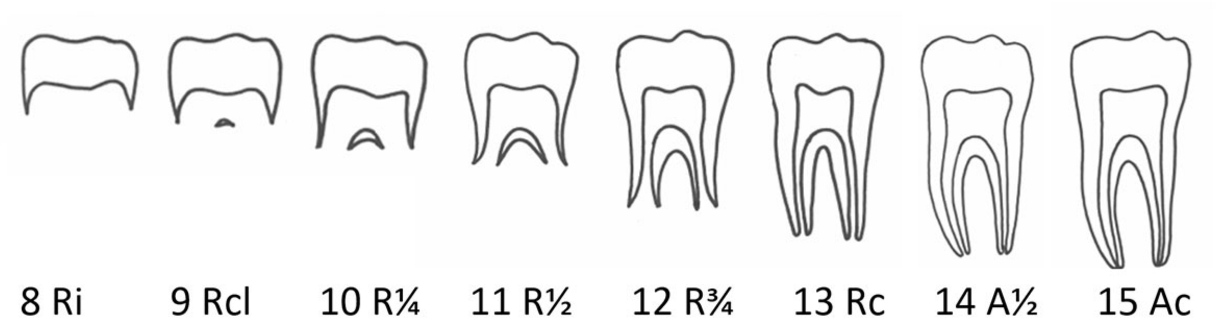


Table 1: The age and sex distribution from the different regional groups, 2028 males, 2527 females. (Age in years, M = male, F = female)

Age	Regional group									
	Sub-Saharan African		Japanese		Malaysian		White/UK		Bangladeshi/UK	
	M	F	M	F	M	F	M	F	M	F
10	69	87	53	57	42	29	42	35	27	23
11	71	85	49	52	38	60	38	47	19	13
12	84	77	27	30	62	63	41	34	21	16
13	69	65	12	21	49	68	35	34	23	24
14	51	68	14	22	40	63	26	46	23	11
15	54	52	14	23	41	71	28	34	33	31
16	29	43	9	25	29	64	28	39	29	14
17	33	39	7	26	23	36	27	51	21	20
18	37	42	9	18	13	27	35	42	20	29
19	33	35	5	10	17	24	29	62	13	30
20	32	27	6	16	14	15	35	52	15	35
21	27	20	7	13	17	12	22	57	17	7
22	24	9	2	9	16	17	19	36	18	21
23	13	18	0	8	1	3	9	19	19	8
24	13	34	5	2	0	0	8	10	17	10
25	14	20	0	5	0	0	8	7	9	4
Total	653	721	219	337	402	552	430	605	324	310

We have taken a transition analysis approach (as described in Boldsen et al.)[29] that is a parametric method for "modelling the passage of individuals from a given developmental stage to the next higher stage in an ordered sequence." [18] We assumed a distributional form for the transitions between maturity stages, and fitted this model by maximum likelihood estimation.[18] We then derived the age distribution conditional on stage through a Bayesian estimation procedure (further information in supplementary methods). Hence, this is two-step modelling approach; 1) fit a probit model for estimating the mean age of transition between the stages and the estimated common standard deviation for transitions (on log scale) and 2) use the estimates from step 1 to derive the age distributions for each stage.

In the second step in the age estimation procedure, we considered the estimates obtained from the probit model obtained in step one as given, without considering estimate uncertainty in step one. This was done for simplicity, reducing the complexity of step two. Hence, the estimated age distributions given molar stage represent the age distribution from the fitted probit model, given that the estimated mean age of transition between the stages and the estimated common standard deviation for

transitions is the most likely age distribution. This does not take account of the uncertainty in the fitted probit model and this might increase the size of the uncertainty intervals for age, a point that warrants further investigation.
For an introduction in the Bayesian way of thinking in biological anthropology, see Konigsberg and Frankenberg.[20] Taking this Bayesian approach in the last step we obtained 2500 age samples for each molar and stage. The Bayesian equivalence of a confidence interval is a credibility interval, and a 95% interval is given by the 2.5 and 97.5 percentiles in the distribution of the 2500 samples. Further statistical information is provided in Supplemental Methods.

RESULTS

The distribution of tooth formation stages of M3 and chronological age for males and females is shown in the scatterplots in Figures 2 and 3. Only tooth stages that begin after age 10 (the minimum age of our sample) are included in these illustrations (root three quarters to apex closed).

Figure 2: Third molar root stage versus chronological age in years in males. Stages see Figure 1

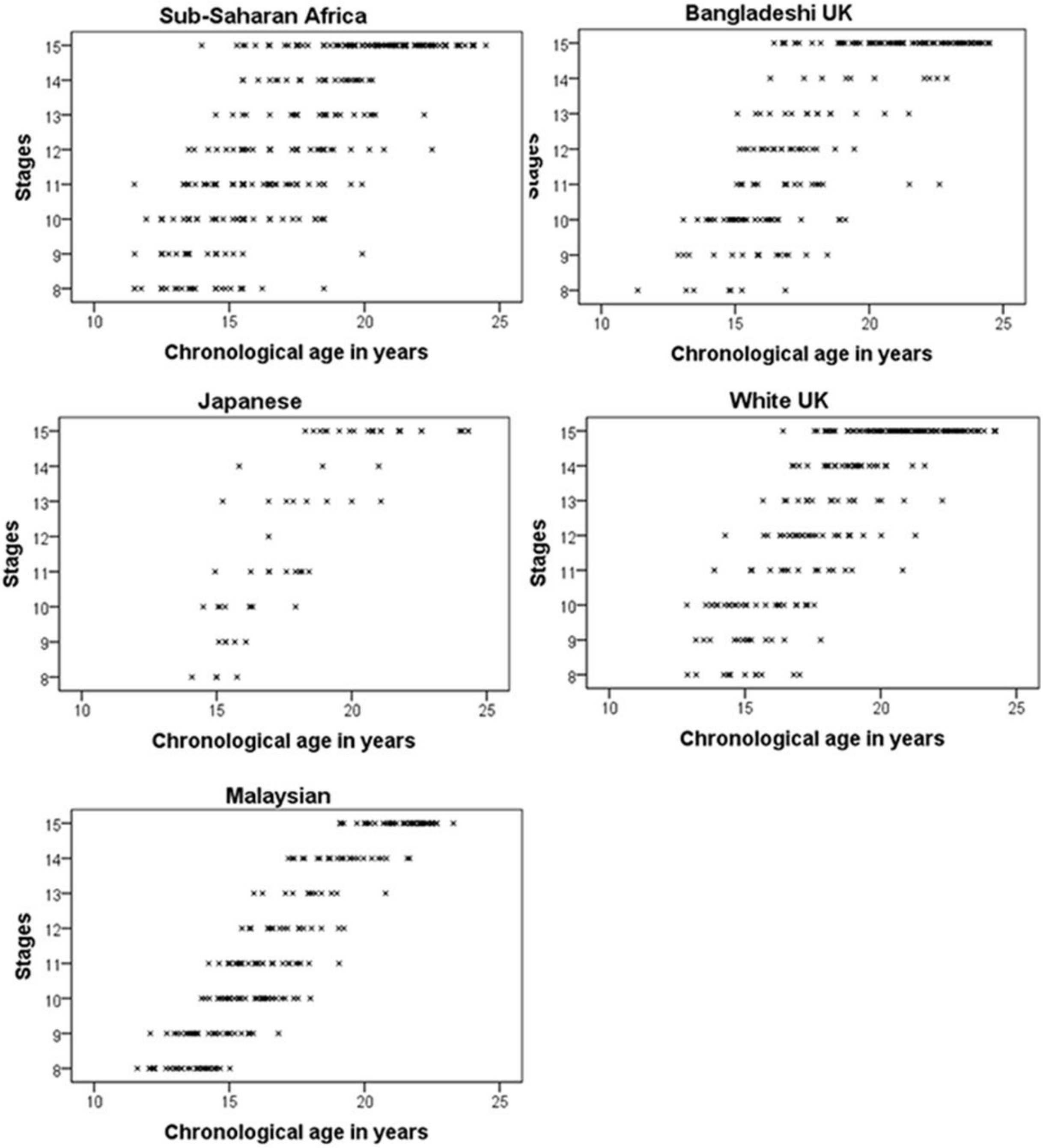
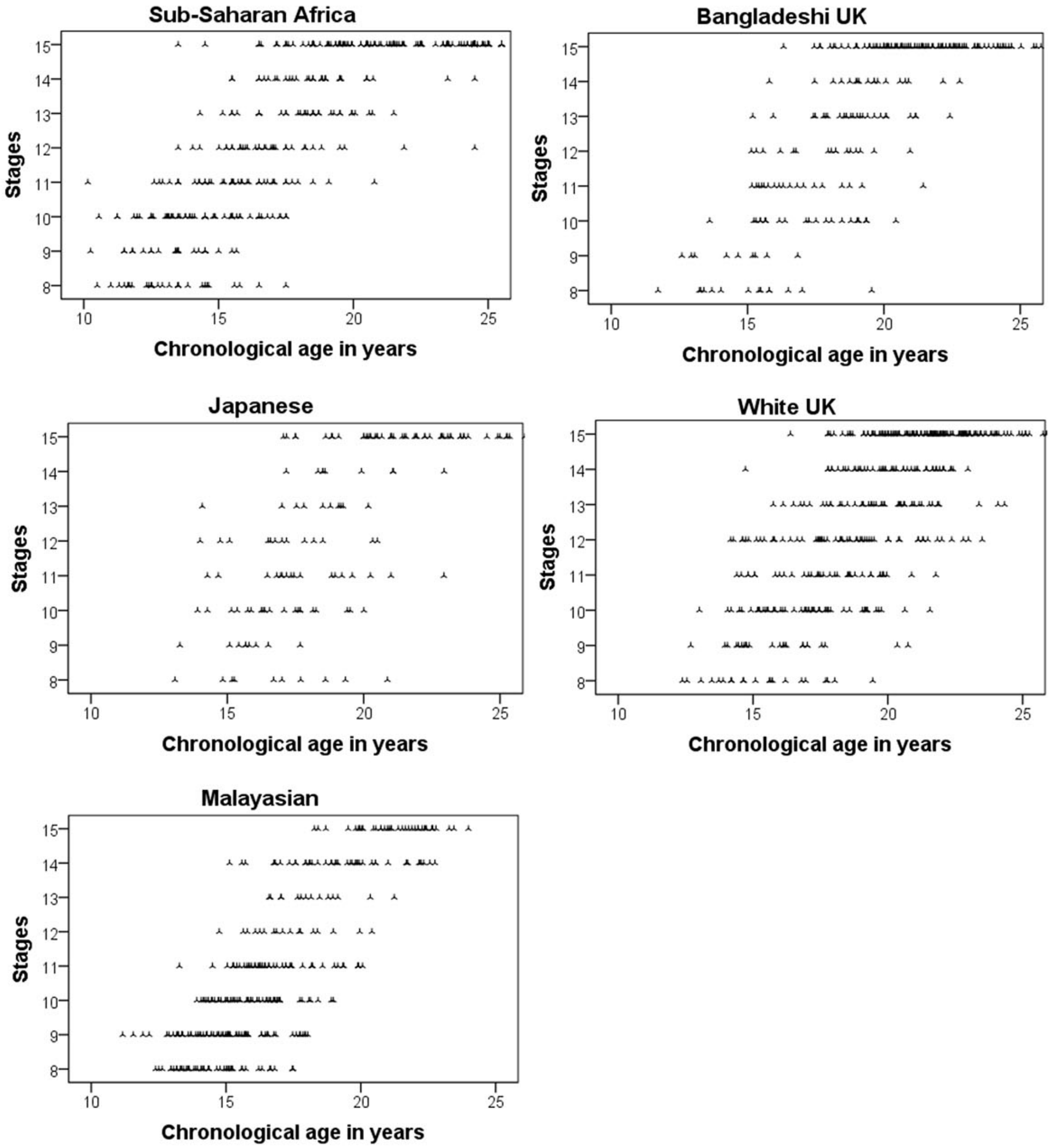


Figure 3: Third molar root stage versus chronological age in years in females. Stages see Figure 1

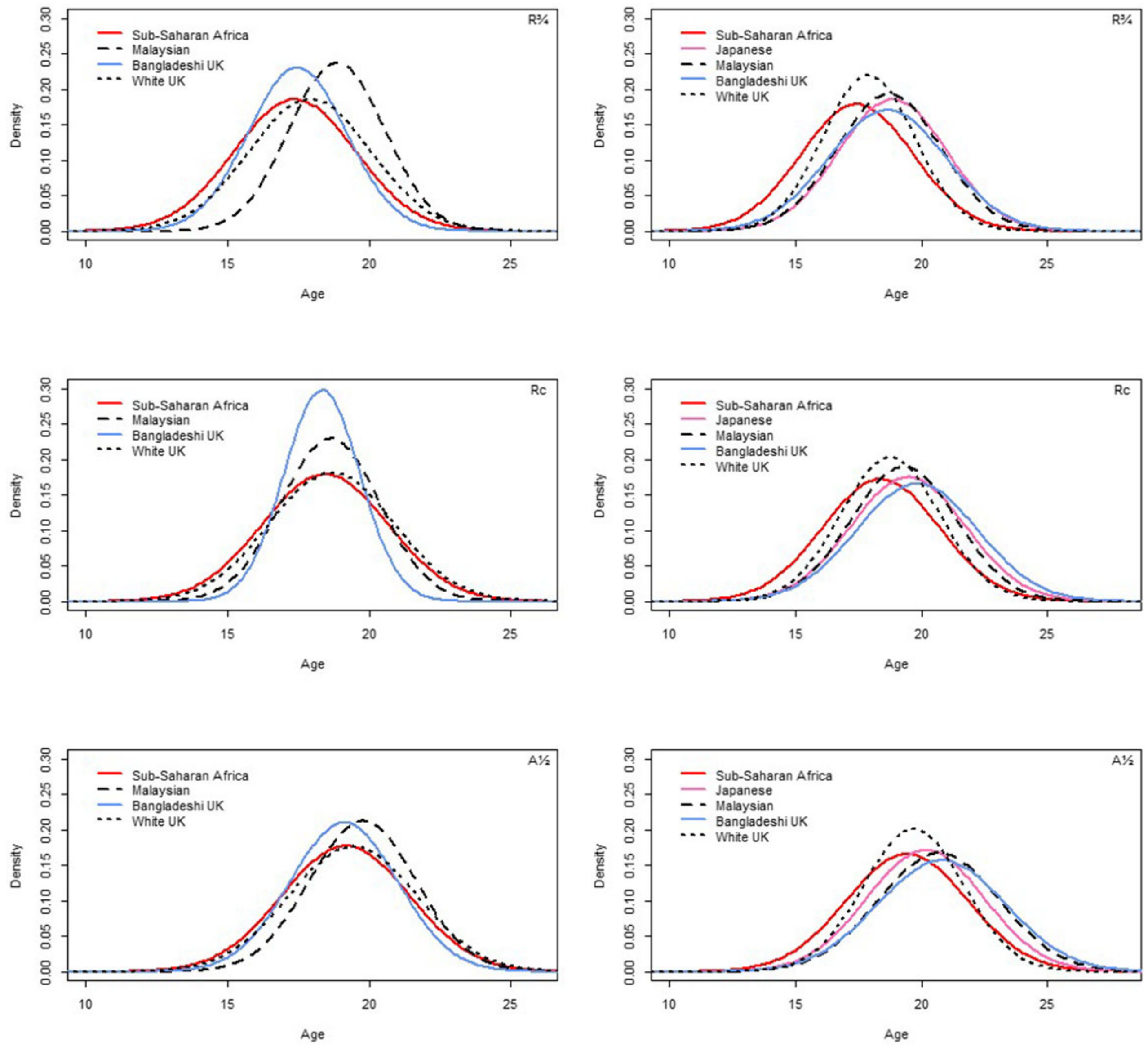


These figures show that each stage occurs over a wide age range and that each age group has a wide variation in scores. From Figure 2 we can see that there are relatively few individuals younger than 15 years in Japanese males and consequently this regional group was not included in further analyses. The plots demonstrate a greater variation in tooth stages in females than in males for all regional groups. Malaysian, both males and females, seem to show least age variation within each stage.

The estimated age density plots for some late root stages of M3 (stages R¾ to $A_{1/2}$) are shown in Figure 4.

The mean age for M3 stages from initial root (Ri) to apex half closed (A½), standard deviation (SD)

Figure 4: Estimated age density plots for M3 stages in males (left) and females (right). (R¾ = root three quarters, Rc = root complete, A½ = apex half closed)



and 95% credibility interval (95% CI) for each ethnic group are shown in Table 3. These estimates of mean age, given a root stage, show very little variation between males in different regional groups. The SD varies between 1.33 for the Malaysian males (stage Ri) and increase with stages of root growth to 2.26 years for Bangladeshi UK males (stage A½). All groups have a mean age older than 18 years for stage Rc, but 18 years could not be excluded from any of the groups (R_i- $A_{1/2}$) with 95% confidence.

Table 3 shows the estimated and observed percentage of individuals 18 years for the stages from initial root formation to apex half closed. This demonstrates that 68% to 82% of individuals are older than 18 years when the root development in M3 is in stage A½. The females are slightly later in development and 71% to 88 % were older than 18 years at stage A½.

The results comparing three model alternatives for M3 are shown in Table 4 for ethnic group comparisons for males and females. Interpreting BIC criteria, AIC and the log likelihood ratio test show some differences. The best model using BIC is the joint model (lowest BIC value) for both males and females. The best model using AIC suggest that a separate mode for each ethnic group l is best for both males and females (lowest AIC value). The log likelihood ratio test indicates that a separate model for each ethnic group.

Table 2: Estimated mean age, standard deviation (SD) and 95% credibility interval (95% CI) for the mandibular left third molar (M3) in years. (Ri = initial root, Rcl = root cleft, R¼ = root quarter, R½ = root half, R¾ = root three quarters, Rc = root complete, A½ = apex half closed)

Group		Males			Females		
	Stage	**Mean**	**SD**	**95% CI**	**Mean**	**SD**	**95% CI**
Sub-Saharan Africa	Ri	14.13	1.70	11.11, 17.74	13.71	1.74	10.59, 17.51
	Rcl	14.58	1.80	11.44, 18.39	14.18	1.76	11.06, 17.91
	R¼	15.26	1.86	11.95, 19.25	15.04	1.96	11.62, 19.25
	R½	16.46	2.00	12.81, 20.61	16.40	2.10	12.66, 20.88
	R¾	17.36	2.15	13.39, 21.89	17.43	2.23	13.41, 22.00
	Rc	18.43	2.23	14.37, 23.18	18.38	2.32	14.43, 23.29
	A½	19.16	2.25	15.17, 23.98	19.42	2.41	15.02, 24.67
Japanese	Ri				16.06	1.84	12.78, 20.11
	Rcl				16.52	1.86	13.19, 20.49
	R¼				17.16	1.97	13.72, 21.43
	R½				18.01	1.99	14.43, 22.20
	R¾				18.85	2.15	15.09, 23.39
	Rc				19.46	2.28	15.34, 24.18
	A½				20.15	2.33	16.01, 25.04
Malaysian	Ri	14.10	1.33	11.74, 16.92	14.51	1.60	11.62, 17.88
	Rcl	14.92	1.43	12.37, 17.90	15.52	1.73	12.46, 19.16
	R¼	15.88	1.50	13.10, 19.10	16.66	1.86	13.19, 20.64
	R½	16.89	1.64	13.91, 20.34	17.79	1.99	14.39, 22.12
	R¾	17.85	1.68	14.82, 21.52	18.70	2.07	14.95, 23.10
	Rc	18.62	1.74	15.46, 22.27	19.29	2.10	15.44, 23.75
	A½	19.76	1.88	16.36, 23.65	20.68	2.39	16.41, 25.73
White UK	Ri	14.66	1.44	12.04, 17.64	15.07	1.88	11.65, 19.15
	Rcl	15.12	1.47	12.37, 18.33	15.64	1.86	12.26, 19.52
	R¼	15.86	1.60	12.93, 19.04	16.66	2.04	12.99, 21.00
	R½	16.65	1.66	13.67, 19.93	17.63	2.15	13.77, 22.17
	R¾	17.45	1.73	14.29, 20.95	18.63	2.34	14.35, 23.66
	Rc	18.32	1.84	15.04, 22.29	19.82	2.40	15.57, 24.95

	A½	19.10	1.90	15.62, 23.08	20.79	2.54	16.24, 26.12
Bangladeshi UK	Ri	14.16	1.68	11.12, 17.70	14.84	1.58	11.96, 18.21
	Rcl	14.72	1.74	11.54, 18.39	15.42	1.66	12.43, 18.87
	R¼	15.86	1.90	12.53, 19.94	16.24	1.67	13.13, 19.71
	R½	17.00	1.98	13.57, 21.25	17.14	1.81	13.96, 20.91
	R¾	17.90	2.15	14.04, 22.43	17.89	1.82	14.68, 21.63
	Rc	18.67	2.20	14.67, 23.46	18.75	1.97	15.17, 22.80
	A½	19.42	2.26	15.45, 24.20	19.68	1.99	15.99, 23.77

Table 3: The estimated and actual observed (in parenthesis) percent of individuals 18 or older for M3 stages R¼ to A½. (R¼ = root quarter, R½ = root half, R¾ = root three quarters, Rc = root complete, A½ = apex half closed)

M3 stage	**Males**				**Females**				
	Sub-Saharan Africa	**Malaysia**	**White UK**	**Bangladeshi UK**	**Sub-Saharan Africa**	**Malaysia**	**Japan**	**White UK**	**Bangladeshi UK**
R¼	8.44 (10.87)	8.68 (2.94)	8.88 (0.00)	13.44 (8.82)	7.84 (0.00)	22.08 (8.47)	31.56 (23.81)	24.00 (25.00)	14.60 (40.91)
R½	21.68 (10.20)	24.56 (3.45)	20.48 (33.33)	28.84 (31.58)	20.60 (5.88)	42.36 (26.09)	49.68 (41.18)	40.80 (48.65)	30.44 (22.22)
R¾	36.00 (34.29)	44.16 (23.53)	36.32 (21.14)	45.68 (14.29)	37.44 (21.62)	61.40 (29.41)	62.68 (30.77)	59.00 (57.89)	45.44 (56.25)
Rc	55.72 (58.62)	62.08 (50.00)	56.16 (55.56)	60.40 (46.67)	54.52 (60.00)	72.12 (50.00)	72.40 (60.00)	77.56 (78.26)	62.12 (72.00)
A½	68.04 (62.50)	82.96 (80.00)	71.16 (82.76)	72.80 (80.00)	71.36 (62.86)	88.12 (72.09)	82.60 (88.89)	87.12 (89.36)	80.04 (88.89)

Although there is some disparity depending on which test is used, this suggests that there are significant differences between ethnic groups in the timing of M3 in both males and females.

The results comparing three model alternatives for M3 are shown in Table 5 for male female comparisons for each ethnic group. Small differences are apparent between the BIC and AIC approaches, indicating that there are small but significant differences between males and females for all groups, with the exception of Malaysians. These differences between the timing of M3 formation in males and females are smaller than those between ethnic groups.

Table 4: Comparison of three model alternatives testing M3 formation in ethnic groups: (1) a separate model for each ethnic group, (2) a joint model for all ethnic groups, same α and β (3) a joint model for all ethnic groups, same α but different β. (Log L = log likelihood, n = number of parameters, BIC = Bayesian information criteria, AIC = Akaikes information criteria, Log L R = log likelihood ratio, 2 v 1 = model 2 versus 1, 3 v 1 = model 3 versus 1)

Group	Log L	n	BIC	AIC	Log L R	
Males						
1	-2808.80	56	6036.75	5673.59		
2	-2895.04	14	5894.87	5818.08	2 v 1	T=172.49
3	-2880.65	17	5888.86	5795.29	3 v 1	T=143.70
Females						
1	-4143.91	70	8834.25	8427.81		
2	-4366.26	14	8841.80	8760.51	2 v 1	T=444.70
3	-4250.12	18	8640.75	8536.24	3 v 1	T=212.43

Table 5: Comparison of three model alternatives testing differences between M2 formation in males and females: (1) a separate model for males and females, (2) a joint model for males and females, same α and β (3) a joint model for males and females, same α but different β. (Log L = log likelihood, n = number of parameters, BIC = Bayesian information criteria, AIC = Akaikes information criteria, Log L R = log likelihood ratio, 2 v 1 = model 2 versus 1, 3 v 1 = model 3 versus 1)

Group	Log L	n	BIC	AIC	Log L R	
Sub-Saharan Africa						
1	-2251.96	28	4706.09	4559.92		
2	-2268.68	14	4638.45	4565.37	2 v 1	T=33.45
3	-2265.69	15	4639.68	4561.37	3 v 1	T=27.46
Malaysia						
1	-1698.83	28	3589.81	3453.65		
2	-1714.02	14	3524.11	3456.04	2 v 1	T=30.38
3	-1708.10	15	3519.14	3446.20	3 v 1	T=18.54
White UK						
1	-1583.32	28	3359.83	3222.64		
2	-1611.78	14	3320.12	6251.56	2 v 1	T=56.92
3	-1601.83	15	3307.15	3233.65	3 v 1	T=37.02
Bangladeshi UK						
1	-905.17	28	1990.14	1866.34		
2	-917.63	14	1925.15	1863.25	2 v 1	T=24.91
3	-916.57	15	1929.46	1863.14	3 v 1	T=22.80

DISCUSSION

The mandibular third molar root development was studied on a convenience collection of dental radiographs from several world regions including Sub-Saharan Africa, Japanese, Malaysian, White/European UK and Bangladesh UK. The material included radiographs from children and adolescence aged 10-25 years and in this study seven stages of M3 root development (Ri to A½) were considered. We excluded stage apex closed, because once the root is mature, age cannot be estimated from development.

Our results show the existence of small differences between M3 root stages between ethnic groups in both males and females. However, because of the large age variation in all M3 tooth formation stages, these small differences have little impact on the 95% confidence interval of estimated age. Similarly, our results show the existence of small differences between M3 root stages between males and females in each ethnic group, with the exception of Malaysians. These difference in the timing of M3 root stages are smaller between males and females than between ethnic groups.

Strengths of this study include the world regions that are represented in the sample and the statistical approach using appropriate methods of analyses. Reference data that use descriptive statistics of mean age within a tooth stage (condition on tooth stage) are no longer considered appropriate to estimate age.[19,20,23,29] Recent developments in Bayesian methods (condition on age) and the use of a uniform age distribution avoid the problem of age mimicry and are gaining acceptance as the correct approach to estimate an age distribution, given a specific tooth stage. The 95% confidence interval for root stage of M3 can be as much as 9 years and many methods estimate age with bias.[24,27]

We aimed for a wide age range and a fairly uniform sample, but this was not always possible. The limitations of this study include insufficient number of Japanese males for analysis and no knowledge of socio-economic status or other factors. Another limitation is the subjective estimation of root fractions as well as the effect inter-observer reliability may have had on the results.

The estimated mean age in Table 2 indicate that the Sub-Saharan African males and females are slightly earlier in their M3 development than other groups. This is in agreement with previous studies that use descriptive statistics to show individuals of African origin are slightly earlier in tooth development.[5,6,8,10,11] Our study confirms these previous findings with more robust statistics. The magnitude of these differences, means that the significant difference in timing of M3 formation between ethnic groups in males has little impact on the confidence interval of estimated age.[21,22] Our findings suggest that population specific reference data for the timing of M3 in males are probably unnecessary, particularly in light of the wide 95% confidence intervals.

CONCLUSION

This study showed small differences in the timing of root development in M3 between world groups, however, because of the large standard deviations in age for each M3 root stage and therefore large 95% confidence interval, this has little impact on estimating age using M3 root formation. This suggests that a reference data set (with a wide age range and uniform age distribution) and appropriate statistical approach are probably more important than a population specific convenience sample to estimate age of an individual using M3.

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SUPPLEMENTAL METHODS

The age given stage distributions were derived in a two-step procedure. In the first step we fitted a probit model for categorical data. We let the molar stages depend upon ln(age), where ln is the natural logarithm. From this probit model analysis we obtained the mean transition ages between stages and the (common) standard age deviation for transitions. A model for the molar stages, as dependent upon age, was fitted in step two, giving the age distribution for each stage. The first step was carried out using the statistical software R and the second step was carried out using WinBUGS.

Step 1: Categorical data analysis

The purpose of the first step was to obtain the mean age for transition between stages and the (common) standard age deviation for transitions. For each molar for each ethnic group and gender we considered a data matrix containing two columns; the first contained the individual's actual age and the second the recorded molar stage (stages j=1, ..., J).

A probit model is a regression model where the dependent variable can only take a known set of discrete values, such as molar stages (in a bivariate probit model there are only two discrete outcomes, in a multivariate model there are several outcomes). The probit model can be written as

$$probit\left(stage_j\right) \sim f\left(\ln\left(age_i\right)\right) = \propto_j + \beta \ln\left(age_i\right),$$

$$j = stage\ 1, \ldots, J-1, i = individual\ 1, \ldots, I.$$

This gave J-1 intercept estimates (α_j) and one slope parameter (β). The estimated mean age of transition between the stages j and (j+1) (on the natural logarithmic scale) are given by $\hat{\mu}_j = \hat{\alpha}_j / -\hat{\beta}$, j=1,..., J-1. The estimated common standard deviation for transitions (on the natural logarithmic scale) are given by $\hat{\sigma} = 1/-\hat{\beta}$. Hence, the estimated mean age for transition between stage one and two, on the natural logarithmic scale, is given by $\hat{\alpha}_1 / -\hat{\beta}$.

Step 2: Conditional age distribution

The purpose of this step was to obtain the age distribution for each stage. We assumed the stages to be multinomial distributed given age. p_{ij} denoted the probability for the tooth to be in stage j given age_i. The p_{ij}'s are given by

$$p_{i1} = 1 - \Phi\left(\frac{\ln\left(age_i\right) - \hat{\mu}_1}{\hat{\sigma}}\right), for\ stage\ j = 1$$

$$p_{ij} = \Phi\left(\frac{\ln\left(age_i\right) - \hat{\mu}_{j-1}}{\hat{\sigma}}\right) - \Phi\left(\frac{\ln\left(age_i\right) - \hat{\mu}_j}{\hat{\sigma}}\right), for\ j = 2, \ldots, J-1$$

$$p_{iJ} = \Phi\left(\frac{\ln\left(age_i\right) - \hat{\mu}_{J-1}}{\hat{\sigma}}\right), for\ stage\ J.$$

The estimated parameters $\hat{\mu}_1, \ldots, \hat{\mu}_{J-1}$ and $\hat{\sigma}$ were obtained in the first step, so the only unknown in these equations were the ages. The age for a given stage was uncertain, and we chose to express this uncertainty a priori by letting age_i be uniformly distributed between 0 and 110.

We fitted our model using WinBUGS by performing initial 250 000 simulations (so-called burn-ins and hence disregarded) and then another 250 000 iterations, where we retained every 100th iteration.

Fitting this model in WinBUGS gave the posterior distribution for age given stage. In this procedure the age estimates for the lowest and highest stage was bounded (the lowest by 0 and the highest by 110). What should a priori be set as boundaries for age is debatable, and a general idea is that 0 and 110 is "sufficiently large". From the model it is clear that the estimate of the lowest and highest stage will be influenced by the lower and upper bound in the prior distribution, how much of course depends upon the observed data. As a consequence, the estimated age distributions for the lowest and highest stages should be disregarded as they are clearly affected by these boundary choices (in this case stages up to crown complete and then apex closed for M3).