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# Dental age assessment of adolescents and emerging adults in United Kingdom Caucasians using censored data for stage H of third molar roots

Teelana Boonpitaksathit*, Nigel Hunt*, Graham J. Roberts**, Aviva Petrie*** and Victoria S. Lucas**

*Division of Craniofacial Sciences, Department of Orthodontics and ***Unit of Biostatistics, UCL Eastman Dental Institute and **Department of Orthodontics, King's College London Dental Institute, UK

*Correspondence to:* Graham J. Roberts, Paediatric Dentistry, King's College London Dental Institute, Bessemer Road, Camberwell, London SE5 9RS, UK. E-mail: Graham.J.Roberts@kcl.ac.uk

SUMMARY The root of the third permanent molar is the only dental structure that continues development after completion of growth of the second permanent molar. It is claimed that the lack of a clearly defined end point for completion of growth of the third permanent molar means that this tooth cannot be used for dental age assessment. The aim of this study was to estimate the mean age of attainment of the four stages (E, F, G, and H) of root development of the third molar. The way in which the end point of completion of stage H can be identified is described.

A total of 1223 dental panoramic tomographs (DPTs) available in the archives of the Eastman Dental Hospital, London, were used for this study. The ages of the subjects ranged from 12.6 to 24.9 years with 63 per cent of the sample being female. Demirjan's tooth development stages (TDSs), for the first and second molars, were applied to the third molars by a single examiner. For each of stages E, F, and G and for stage H censored data, the mean ages of the males and females were compared, separately within each tooth morphology type using the two sample *t*-test ($P < 0.01$). The same test was used to compare the mean ages of the upper and lower third molars on each side, separately for each gender. The mean age of attainment and the 99 per cent confidence interval (CI) for each TDS were calculated for each third molar. The final stage H data were appropriately censored to exclude data above the age of completion of root growth.

The results showed that, for each gender, the age in years at which individuals attained each of the four TDSs was approximately normally distributed. The mean age for appropriately censored data was always lower than the corresponding mean age of the inappropriately censored data for stage H (male UR8 19.57, UL8 19.53, LL8 19.91, and LR8 20.02 and female UR8 20.08, UL8 20.13, LL8 20.78, and LR8 20.70). This inappropriately censored data overestimated the mean age for stage H. The appropriately censored data for the TDSs of the third molar may be used to estimate the age of adolescents and emerging adults assuming average growth and development and recent attainment of stage H.

## Introduction

The assessment of an individual's age has important roles in social, legal, and forensic settings. Interest in age determination of adolescents and emerging adults has risen in recent years due to an increasing number of mature-looking asylum seekers claiming to be less than 18 years of age. Various methods are available for age assessment (Lewis and Garn, 1960; Anderson *et al.*, 1975; Gulati *et al.*, 1990). One of the important indicators is tooth development (Garn *et al.*, 1962), which is assessed using radiographs (Liversidge *et al.*, 2003). Dental panoramic tomographs (DPTs) provide a useable image of all the tooth morphology types (TMTs) in the permanent dentition, including the third molars (Solari and Abramovitch, 2002).

It has been shown that tooth development is independent of hormonal and nutritional factors (Anderson *et al.*, 1975) and comparative studies have also demonstrated that the age assessed by dental development correlates more closely with chronological age than other developmental measurements, such as skeletal development, height, and weight (Liliequist and Lundberg, 1971; Anderson *et al.*, 1975; Demirjian *et al.*, 1985). It has also been shown that age of attainment of maturity of third molars is closely linked to chronological age (Solari and Abramovitch, 2002). International comparisons indicate sufficient ethnic variation in the age of attainment of tooth development stages (TDSs) to justify the use of ethnicity as a factor in assessing third molar development as an indicator of age (Schmeling *et al.*, 2000; Olze *et al.*, 2004).

The most frequently used method of dental age assessment (DAA) is that of Demirjian *et al.* (1973) and Demirjian and Goldstein (1976). The disadvantage is that it is limited to

the use of data from the development of the first seven permanent mandibular teeth (Jaffe *et al.*, 1990; Davis and Hägg, 1994; Liversidge *et al.*, 1999; Kostara *et al.*, 2000). As this excludes the third molars, it is unsuited to assessing a subject's dental age at the 18 year threshold. Thus, there are only a few publications on the third permanent molars that can be used in DAA from population samples in the USA (Mincer *et al.*, 1993; Solari and Abramovitch, 2002), Belgium (Willems *et al.*, 2002), Germany (Olze *et al.*, 2004), and South Africa (Nortje, 1983). None of these deals appropriately with the final stage (H) of third molar root development and these studies do not relate to Caucasians. The third molars provide a measurement of development beyond the age of 15.75 years when the second permanent molar completes development (Demirjian *et al.*, 1973).

The use of the final stage H of third molar development is problematic as it is not possible to identify the attainment of the end point of root development from a single radiograph. A prevailing belief is that a tooth with completed growth (stage H) for any TMT should not be used for DAA. This is based on the premise that it is impossible, when viewing different TMTs, to identify precisely when all subjects in a reference sample have achieved stage H (Kullman *et al.*, 1992). However, most investigators use stage H but in various ways. Usually, the age is capped at some defined value (i.e. any subject whose age is above this cap is excluded from the data set), although these values for capping vary from one study to another. For example, Nortje (1983) capped at 21 years, Kullman *et al.* (1992) at 25 years, Mincer *et al.* (1993) at 24.9 years, and Olze *et al.* (2004) at 26 years. Using this approach, the mean ages for attainment of stage H, for example, are 20.9 years (Mincer *et al.*, 1993) and 22.5 years (Olze *et al.*, 2004), a range of nearly 2 years. This is clearly unsuitable and is a consequence of those investigators failing to indicate how they identified the appropriate age at which to cap the data. For future reference, the use of a data set that has been capped in this way is referred to as 'inappropriately censored' data set.

The aim of this study was to explore the possibility of excluding data above the age at which apical closure is complete in all subjects in a population sample. It gives an indication of how reference data relating to third molar root development, including the final stage of apical closure, can be used to estimate the dental age of emerging adults.

## Materials and methods

### *Ethical approval and radiographs*

The protocol for the study received ethical approval from the University College Hospitals NHS Trust—reference 03/E023. The data for this study were obtained by reuse of DPTs provided for routine dental assessments. Patients with medical conditions that might have affected growth and development were excluded. The sample comprised female and male Caucasian adolescents and emerging adults who were resident in the London area of the UK. Radiographs obtained for clinical purposes from consecutive patients, with known dates of birth, attending the Eastman Dental Hospital between March 2005 and July 2006, were examined and, if of good diagnostic quality, the parents and/or patients were approached and asked if the radiograph could be included in the reference database for research purposes. In addition, radiographs from the Eastman Dental Hospital archives were included, giving a total of 1223 radiographs, which met the inclusion criteria. The information on third molars obtained from radiographs comprised the data used in this study. Ethnicity was obtained from the clinical records, demographic data sheets, or by direct examination and questioning of parents and/or patients.

### *Tooth development stages*

The assessment of TDSs was carried out using the method described and defined by Demirjian and Goldstein (1976) (Figure 1). One investigator (TB) examined all the radiographs. The reference database comprised the ages of attainment of the TDSs for all 16 TMTs, by convention on the left side, present in the human dentition. Because of the relatively frequent developmental absence of third molars, data were also obtained for the lower and upper right third molars (LR8 and UR8). These reference data are designed to be used to estimate the age of emerging adults with no birth records (Olze *et al.*, 2004).

### *Statistical analysis*

A set of 30 randomly chosen DPTs from the database, each with four third molars, was used to assess intra- and inter-rater agreement of the TDSs present in the third molars. Two raters (TB and GJR) assessed all DPTs twice; the order of the TDSs was randomized and the time interval between the two 'blind' assessments was 1 week. In addition, the first assessment of all the DPTs by each of the two raters was used to determine inter-rater agreement. The degree of agreement in each instance was calculated using the Kappa statistic (Cohen, 1960) and assessed according to the categories suggested by Landis and Koch (1977).

For each of stages E, F, and G, for every third molar tooth, the patient's chronological age together with other demographic information was entered onto a proforma, transferred into a Microsoft Access database, and exported to a Microsoft Excel spreadsheet. The frequency distributions of age were graphed using Stata (Stata Corporation, College Station, Texas, USA). As they each exhibited an approximately normal (Gaussian) distribution, the mean ages for these stages, with the data partitioned by gender and ethnicity, were calculated.

The data for stage H were treated differently. Initially, the age data for each third molar tooth attaining stages G

| Tooth Development Stages of Molar Roots. | Description of the individual stages |
|---|---|
| E  | **Stage E:**<br>a. Initial formation of the radicular bifurcation as seen in the form of either a calcified point or semilunar shape.<br>b. Root length is less than crown height. |
| F  | **Stage F:**<br>a. The calcified region of the bifurcation has developed further down from its semilunar stage to give the roots a more definite and distinct outline, with funnel shaped endings.<br>b. The root length is equal to or greater than crown height. |
| G  | **Stage G:**<br>a. The walls of the root canals are now parallel (distal root of the molars).<br>b. The apical end of the root canal is still partially open (distal root of molars). |
| H  | **Stage H:**<br>a. The apical end of the root canal is completely closed (distal root of molars).<br>b. The periodontal membrane has a uniform width around the root and apex |

**Figure 1** The four tooth development stages of the molar redrawn according to the description of Demirjian *et al.* (1973).

and H were arranged in ascending order with an indication of the associated TDS, either G or H. This enabled the identification of the youngest age beyond which there were only cases of stage H (i.e. no more cases of stage G) for the single third molar. All cases older than this age were excluded from the data set. The remaining data are referenced to the appropriately censored data as opposed to the inappropriately censored data which has an 'arbitrary' cut-off point. The appropriately censored data had a cut-off of 23.92 years.

To obtain inappropriately censored age, colleagues were informally asked the question 'what is the age of the oldest patient who still has an immature root (stage G) of the third molar?' The oldest age provided was 23.5 years. To ensure that all developing third molars were included in the sample, the age was arbitrarily capped at 24.99 years.

The appropriately censored age data were approximately normally distributed so the estimated mean age of stage H of each third molar in the appropriately censored sample was determined, together with the 99 per cent confidence interval (CI) for the mean (Altman, 1991). Previous investigators (Mincer *et al.*, 1993; Willershausen *et al.*, 2001; Solari and Abramovitch, 2002; Willems *et al.*, 2002; Olze *et al.*, 2004) have calculated the mean age of the inappropriately censored data, so, in order to assess the effect

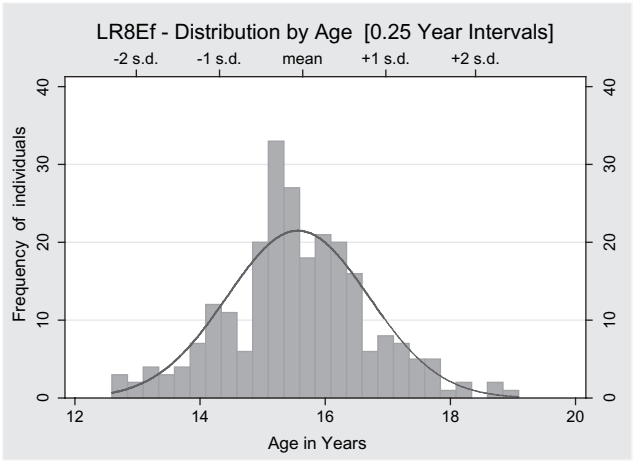


**Figure 2** Lower right third permanent molar stage F, female (LR8Ef).

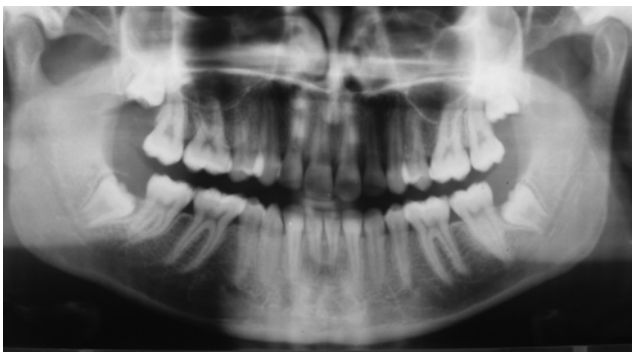

**Figure 3** Example of a subject with an unknown date of birth with the lower third molars at stage F.

of censoring, the mean age (99 per cent CI) of the inappropriately censored data from the sample was also calculated and visually compared with the mean age of the appropriately censored data. It was not appropriate to perform a formal statistical hypothesis test to compare the mean values because the appropriately censored data were a subset of the inappropriately censored data.

For each of stages E, F, and G and for stage H censored data, the mean ages of males and females were compared, separately within each TMT using the two sample *t*-test. The same test was used to compare the mean ages of the upper and lower third molars on each side, separately for each gender. To avoid spurious results as a consequence of multiple testing, a significance level of 0.01 was used.

## Results

All subjects were physically healthy, their chronological ages ranged from 12.6 to 24.9 years with females comprising 63 per cent of the sample. The intra-rater agreement using Cohen's kappa was 'almost perfect': 0.94 for examiner 1 and 0.85 for examiner 2. The inter-rater agreement between the two investigators was 0.69, which is 'substantial'.

**Table 1** Summary measurements for age of attainment in years of stages E, F, G, and H of third molar root formation in males and females.

| Tooth | Mean and 99% CI | Stage E | | Stage F | | Stage G | | Stage H inappropriately censored data | |
|---|---|---|---|---|---|---|---|---|---|
| | | Male | Female | Male | Female | Male | Female | Male | Female |
| UR8 | *n* | 123 | 181 | 81 | 191 | 92 | 127 | 74 | 101 |
| | Mean | 15.09 | 14.98 | 15.33 | 16.21 | 17.24 | 17.53 | 19.57 | 20.08 |
| | 99% CI | 14.84–15.34 | 14.77–15.91 | 15.15–15.51 | 16.00–16.42 | 16.99–17.50 | 17.26–17.79 | 19.07–20.01 | 19.70–20.45 |
| UL8 | *n* | 124 | 200 | 131 | 197 | 87 | 122 | 70 | 101 |
| | Mean | 15.14 | 14.98 | 16.01 | 16.16 | 17.20 | 17.63 | 19.53 | 20.13 |
| | 99% CI | 14.88–15.39 | 14.70–15.20 | 15.78–16.23 | 15.94–16.38 | 16.94–17.47 | 17.37–17.88 | 18.67–19.66 | 19.74–20.49 |
| LL8 | *n* | 137 | 188 | 131 | 165 | 71 | 99 | 50 | 59 |
| | Mean | 15.34 | 15.45 | 16.53 | 16.68 | 17.56 | 18.25 | 19.91 | 20.78 |
| | 99% CI | 15.09–15.58 | 15.21–15.69 | 16.29–16.78 | 16.41–16.95 | 17.21–17.91 | 17.85–18.65 | 19.25–20.57 | 20.32–21.24 |
| LR8 | *n* | 149 | 178 | 129 | 162 | 69 | 112 | 49 | 60 |
| | Mean | 15.40 | 15.59 | 16.42 | 16.46 | 17.71 | 18.18 | 20.02 | 20.70 |
| | 99% CI | 15.13–15.67 | 15.33–15.85 | 16.18–16.67 | 16.20–16.72 | 17.34–18.08 | 17.83–18.51 | 19.35–20.68 | 20.27–21.17 |

The age of attainment of tooth development stages (TDSs) was achieved earlier in males when compared with females by approximately 11 months. The order was reversed for UR8, UL8, and UL8. Of the 16 comparisons, only eight were statistically significant. The age of attainment of all TDSs of the upper teeth was always ahead of the lower teeth. This was statistically significant at $P < 0.01$ for 10 of the 16 comparisons, and between $P < 0.05$ and $P < 0.01$ for four comparisons. The remaining two differences were not statistically significant.

**Table 2** Comparison between summary data of stage H using the inappropriately censored data set and the appropriately censored data set for males and females.

| Tooth | Statistic | Stage H—males | | Stage H—females | |
|---|---|---|---|---|---|
| | | Inappropriately censored | Appropriately censored | Inappropriately censored | Appropriately censored |
| UR8 | *n* | 74 | 72 | 101 | 93 |
| | Mean | 19.57 | 19.42 | 20.08 | 19.81 |
| | 99% CI | 19.07–20.1 | 18.96–19.88 | 19.70–20.45 | 19.47–20.15 |
| UL8 | *n* | 70 | 68 | 101 | 91 |
| | Mean | 19.53 | 19.38 | 20.13 | 19.77 |
| | 99% CI | 18.67–19.66 | 18.91–19.45 | 19.74–20.49 | 19.43–20.09 |
| LL8 | *n* | 50 | 45 | 59 | 51 |
| | Mean | 19.91 | 19.46 | 20.78 | 20.34 |
| | 99% CI | 19.25–20.57 | 18.87–20.05 | 20.32–21.24 | 19.94–20.74 |
| LR8 | *n* | 49 | 47 | 60 | 58 |
| | Mean | 20.02 | 19.81 | 20.70 | 19.71 |
| | 99% CI | 19.35–20.68 | 19.18–20.45 | 20.27–21.17 | 20.24–21.16 |

Statistical analysis was not carried out as the appropriately censored data set was a subset of the inappropriately censored data.

The frequency distributions of age for stages E, F, and G of third molars for both females and males all approximated a normal distribution (Figure 2 shows one example; Figure 3 illustrates an example of a case with third molars present at stage F). The mean age (99 per cent CI) for the data for stages E, F, and G and for the appropriately censored data for stage H for both females and males are shown in Table 1.

Upper third molar stages E, F, and G for both females and males showed a tendency for completion of growth earlier than the comparable lower third molar (Table 1). The differences in mean age between the upper and lower third molars varied from approximately 3 to 9 months, with almost all differences statistically significantly different ($P < 0.01$). There was no consistent pattern in the gender comparison and few of the differences in mean age between males and females were statistically significantly (Table 1).

The mean age for attainment of stage H for each third molar in the appropriately and inappropriately censored data sets were compared and the estimated mean ages for theses data sets are presented in Table 2. As expected, comparison showed that, for each gender, the mean age of the appropriately censored data was consistently lower than the corresponding mean age from the inappropriately censored data. The differences in the mean ages ranged from 0.20 to 0.67 years.

## Discussion

The sample data in this study indicate that, on average, males achieved most of the TDSs for third molar teeth significantly later than females (Tables 1 and 2). This is consistent with other studies of third molar maturation (Haavikko, 1974; Levesque *et al.*, 1981; Mincer *et al.*, 1993).

This investigation, which is the first to apply appropriate censoring to the stage H data set, appears to raise the issue of the impact of inappropriately censored data. It is clear that for both males and females in stage H, each mean age derived from the appropriately censored data set is lower by approximately 2 to 4 months than the corresponding 'pseudo' mean age derived from the inappropriately censored data set (Table 2). This is not surprising as the act of appropriately censoring the data excludes the highest ages and the values previously included which are beyond the true end point of stage H.

Age assessment for subjects up to the age of 15.75 years with multiple developing teeth, including third molars, using TDSs (Demirjian and Goldstein, 1976) and the mathematical techniques of meta-analysis, has recently been published (Roberts *et al.*, 2008). In older subjects who have only stage H of their third molars, the appropriately censored data can be used to estimate the dental age of the emerging adult. It is important to recognize that when estimating age, an overall assessment of the subject is required. This should take account physical appearance, demeanour, and further radiographic information such as a postero-anterior chest view, which visualizes the stage of development of the sterno-clavicular joint (Kreitner *et al.*, 1998). Further research is required to extend these procedures for stage H to examine the relationship between third molar development and ethnicity.

## Conclusions

The results showed that, for each gender, the age in years at which individuals attained each of the four TDSs was approximately normally distributed. The mean age for appropriately censored data was always lower than the corresponding mean age of the inappropriately censored data for stage H. This inappropriately censored data overestimates the mean age for stage H. The appropriately censored data for the TDSs of the third molar may be used to estimate the age of adolescents and emerging adults: this assumes average growth and development and recent attainment of stage H. In the absence of any developing TDSs, a subject's age may be estimated using the mean age of attainment of stage H of the third molars from an appropriately censored data set.

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## References

Altman D G 1991 Practical statistics for medical research. Chapman & Hall, London

Anderson D L, Thompson G W, Popovich F 1975 Interrelationships of dental maturity, skeletal maturity, height and weight from 4 to 14 years. Growth 39: 453–462

Cohen J 1960 A coefficient of agreement for nominal scales. Educational and Psychological Measurement 20: 37–46

Davis J, Hägg U 1994 The accuracy and precision of the 'Demirjian system' when used for age determination in Chinese children. Swedish Dental Journal 18: 113–116

Demirjian A, Goldstein H 1976 New systems for dental maturity based on seven and four teeth. Annals of Human Biology 3: 411–412

Demirjian A, Goldstein H, Tanner J M 1973 A new system of dental age assessment. Human Biology 45: 221–227

Demirjian A, Buschang P H, Tanguay R, Patterson D K 1985 Interrelationships among measures of somatic, skeletal, dental, and sexual maturity. American Journal of Orthodontics 88: 433–437

Garn S M, Lewis B, Bonne B 1962 Third molar formation and its development course. Angle Orthodontist 32: 270–279

Gulati A, Taneja J R, Chopra S L, Madan S, Amritsar P 1990 Inter-relationship between dental, skeletal and chronological ages in well-nourished and mal-nourished children. Journal of the Indian Society of Pedodontics and Preventive Dentistry 8: 19–23

Haavikko K 1974 Skeletal age estimated on a few selected ossification centres of hand and wrist. A simple method for clinical use. Proceedings of the Finnish Dental Society 70: 7–14

Jaffe E C, Roberts G J, Chantler C, Carter J E 1990 Dental maturity in children with chronic renal failure assessed from dental panoramic tomographs. Journal of Dentistry for Children 20: 54–58

Kostara A, Gelbier M, Roberts G J 2000 Dental maturity in children with dystrophic epidermolysis bullosa. Pediatric Dentistry 22: 385–388

Kreitner K F, Schweden F J, Reipert T, Nafe B, Thelen M 1998 Bone age determination based on the study of the medial extremity of the clavicle. European Radiology 8: 1116–1122

Kullman L, Johanson G, Akesson L 1992 Root development of the lower third molar and its relation to chronological age. Swedish Dental Journal 16: 161–167

Landis J R, Koch G G 1977 The measurement of observer agreement for categorical data. Biometrics 33: 159–174

Levesque G Y, Demirjian A, Tanguay R 1981 Sexual dimorphism in the development, emergence and agenesis of the mandibular third molar. Journal of Dental Research 60: 1735–1741

Lewis A B, Garn S M 1960 The relationship between tooth formation and other maturational factors. Angle Orthodontist 30: 70–77

Liliequist B, Lundberg M 1971 Skeletal and tooth development. A methodological investigation. Acta Radiologica 11: 97–112

Liversidge H M, Speechly T, Hector M P 1999 Dental maturation in British children: are Demirjian's standards applicable? International Journal of Paediatric Dentistry 9: 263–269

Liversidge H M, Lyons F, Hector M P 2003 The accuracy of three methods of age estimation using radiographic measurements of developing teeth. Forensic Science International 13: 22–29

Mincer H H, Harris E F, Berryman H E 1993 The ABFO study of third molar development and its use as an estimator of chronological age. Journal of Forensic Science 38: 379–390

Nortje C J 1983 The permanent third molar. Its value in age determination. Journal of Forensic Odonto Stomatology 1: 27–31

Olze A, Schmeling A, Taniguchi M, Van Niekerk P, Wernecke K D, Geserick G 2004 Forensic age estimation in living subjects: the ethnic factor in wisdom tooth mineralization. International Journal of Legal Medicine 118: 170–173

Roberts G J, Petrie A, Parekh S, Lucas V S 2008 Dental age assessment: a simplified approach. British Dental Journal 204: E7

Schmeling A, Reisinger W, Loreck D, Vendura K, Markus W, Geserick G 2000 Effects of ethnicity on skeletal maturation: consequences for forensic age estimations. International Journal of Legal Medicine 13: 135–137

Solari A C, Abramovitch K 2002 The accuracy and precision of third molar development as an indicator of chronological age in Hispanics. Journal of Forensic Science 47: 531–535

Willems G, Moulin-Romsee C, Solheim T 2002 Non-destructive dental-age calculation methods in adults: intra- and inter-observer effects. Forensic Science International 126: 221–226

Willershausen B, Loffler N, Schulze R 2001 Analysis of 1202 orthopantograms to evaluate the potential of forensic age determination based on third molar developmental stages. European Journal of Medical Research 6: 377–384