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PAPER

ODONTOLOGY

Richard B. Bassed,[1] B.D.S.; C. Briggs,[1,2] Ph.D.; and Olaf H. Drummer,[1] Ph.D.

Age Estimation and the Developing Third Molar Tooth: An Analysis of an Australian Population Using Computed Tomography

ABSTRACT: The third molar tooth is one of the few anatomical sites available for age estimation of unknown age individuals in the late adolescent years. Computed tomography (CT) images were assessed in an Australian population aged from 15 to 25 years for development trends, particularly concerning age estimation at the child/adult transition point of 18 years. The CT images were also compared to conventional radiographs to assess the developmental scoring agreement between the two and it was found that agreement of Demirjian scores between the two imaging modalities was excellent. The relatively wide age ranges (mean ± 2SD) indicate that the third molar is not a precise tool for age estimation (age ranges of 3–8 years) but is, however, a useful tool for discriminating the adult/child transition age of 18 years. In the current study 100% of females and 96% of males with completed roots were over 18 years of age.

KEYWORDS: forensic science, forensic odontology, age estimation, third molar tooth, computed tomography, Australian population

The third molar tooth has been the subject of age estimation studies for many years. This marker is of particular relevance when attempting to assess whether an individual is over or under the age of 18 years, an important legal demarcation between child/adult status in many jurisdictions (1–4). There has been increasing interest in the study of the third molar tooth in recent years due to growing pressure from legal systems around the world to provide more accurate age estimations for the increasing numbers of undocumented individuals moving across international borders, and to assist in the definitive identification of victims of mass fatality incidents.

Age estimation for children up until the age of 14–15 years can be reliably determined using dental and skeletal development (5,6). The highest reliability for dental age estimation occurs when the greatest numbers of developing teeth are present (7), and the most common methods in use have been tested by several researchers both theoretically and in practice (8–11). As a person grows beyond these years, developmental variability increases as the effects of environment begin to outweigh the effects of genetics, thus making age estimations far more precise in the early childhood years, and relatively imprecise during adolescence (12). This variability in third molar development has been recognized (13) and its effect on forensic age estimations has been investigated with variable results (14–17). Unfortunately, when trying to ascertain the age of an individual in this age group there are few other age markers available.

[1]Victorian Institute of Forensic Medicine and the Department of Forensic Medicine, Monash University, Melbourne, Vic., Australia.
[2]Department of Anatomy & Cell Biology, University of Melbourne, Melbourne, Vic., Australia.

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A major focus of recent research has been the realization that specific populations require population-specific data in order to arrive at the most reliable age estimate (18,19). To this end, there have been some studies conducted on various populations which have demonstrated this need (20–31). However, to date, there have been no studies conducted for this age group for the Australian population. This population is worthy of study as it is a young multicultural country with over 25% of its citizens born overseas (32).

All previous studies on third molar development have been based on examination of radiographs, usually orthopantomograms (OPG). An alternate imaging modality which is beginning to make inroads into medicolegal death investigation around the world is computed tomography (CT) (33–35). It has been shown that CT scans cause no magnification errors due to geometric distortion, which is a common problem in conventional radiography (36–38), especially regarding the 10% magnification error inherent in OPG images. Furthermore, CT is capable of providing accurate and measurable three-dimensional (3D) images of the third molar which can be rotated in space, thus eliminating the problem of unfavorably angulated teeth, and teeth superimposed on adjacent structures (39).

The morphometric accuracy of 3D CT reconstructions has been validated by several studies (36,40–42) and it is reasonable to conclude that this modality should be just as valid as conventional radiography when assessing development of the root of the third molar tooth. One issue requiring clarification, however, is the comparability between conventional radiography and CT images when assigning developmental scores. The majority of age estimations performed in forensic practice use conventional radiographs, and if this research using CT imaging is to be considered comparable to conventional radiographs, then it needs to be shown that CT images and conventional radiographs of the same tooth will deliver the same developmental score. Recent work has been conducted on younger individuals (43), but further clarification for the older age group is appropriate.

Many scoring systems have been developed which assign a numerical value to the stage of development of a tooth. Some involve arbitrary length measurements, such as 1⁄3 or 2⁄3 of final root length, which are only of value in longitudinal studies where the actual completed root length can subsequently be measured (17,44–46). This is of limited value in forensic situations, where invariably there is only an image of the current level of development, with no possibility of considering the final root length. The most appropriate scoring system for cross-sectional data is that developed by Demirjian et al. (5), which relies upon discrete anatomical stages rather than length measurements, and thus does not require knowledge of final tooth morphology in order to assign a meaningful score. This system has been compared with others in common use and has proved to be the most reliable in terms of both observer agreement and correlation between the stages (47).

The Victorian Institute of Forensic Medicine (VIFM), located in Melbourne, Australia, investigates all deaths reported to the Victorian State Coroner. As part of the routine forensic investigation procedure a full body CT scan is performed on all of these cases. These scans consist of 2 mm slices of the entire body, and 1 mm slices of the head and neck region. Currently the VIFM has performed CT imaging on approximately 15,000 individual forensic cases. This database includes people from all age groups, with approximately 1000 individuals falling into the target age group for this study (15–25 years).

The aim of the current study was to compare the developmental scores obtained from both CT images and conventional OPG radiographs, and to assess the development of the third molar in a sample of the modern Australian population in order to obtain age estimations from these data, particularly the variance seen in those persons at 18 years of age.

Materials and Methods

High resolution multislice CT scans were examined in individuals with known birth date and who were aged from 15 to 25 years. Individuals of unknown age, those with no third molars, or those who had suffered significant head trauma which potentially affected visualization of third molars were excluded from the sample. Chronological age in years for the individuals in the sample was determined by subtracting the date of birth from the date of death and placing them in the appropriate year. No attempt has been made at this stage to categorize individuals according to ancestry or socioeconomic status, although this is the subject of future research.

The imaging system utilized at the VIFM is a Toshiba Aquilion 16® multislice scanner, which captures 1 mm thick slices of the head and neck which are then reconstructed and viewed using the TeraRecon Inc Aquarius-Net® software package.

Third molar images were captured using the 3D maximum intensity projection (MIP) bone algorithm, which provides what is in effect a 3D radiograph which can be rotated in space to optimize the view of the long axis of the tooth and the degree of development of the crown and root. These images were then adjusted for contrast to obtain optimum visualization of the tooth crown and root (Fig. 1).

Upper third molars were eliminated from consideration in this study as they are difficult to visualize and accurately score on standard OPG radiographs, are more variable in their development (22), and so are seldom used for age estimation purposes.

All images were scored using the stages according to Demirjian et al. (5), with a numerical value replacing the standard A–H designations so as to make statistical analysis simpler. Scores were placed into a spreadsheet and analyzed for variation within age and sex groupings. In cases where both lower third molars were available a comparison was made to determine the degree of right⁄left side developmental asymmetry.

Intra-examiner error was tested by the same observer scoring 25 images twice with a 1 month time lapse. Inter-examiner error was tested by two independent observers, both of whom had received training in reading Demirjian scores from CT images, separately scoring 25 case images.

To assess the comparability of scoring between conventional radiographs and CT images, a sample of conventional radiographs for 12 cases was scored according to Demirjian, then 1 month later the CT images of the same cases were scored and the differences were assessed using the kappa measure of agreement.

All statistical analysis was performed using SPSS version 17®. Tests for inter- and intra-examiner reliability, and a comparison of Demirjian scores between conventional radiographs and CT images were assessed using the kappa measure of agreement.

Results

There were 1006 deceased persons aged between 15 and 25 years that had CT images stored in the database. Using the declared exclusion criteria, the number of cases left to study was

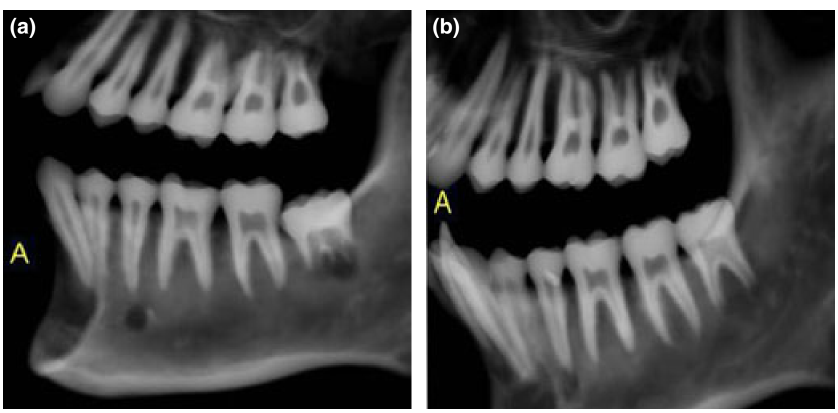

FIG. 1—*CT images showing differential development of third molar in the same 18-year-old individual. Note: Left third molar is at stage E and the right is at stage G according to Demerjian classification (5).*

TABLE 1—*Age distribution of the sample population.*

Age (years)	15	16	17	18	19	20	21	22	23	24	25	Total
Male	19	24	34	43	42	51	53	39	47	54	45	451
Female	9	23	17	29	19	18	11	17	21	25	27	216
Total cases used	28	47	51	72	61	69	64	56	68	79	72	667
Exclusions	4	4	18	25	33	29	36	40	41	52	57	339

TABLE 2—*Intra- and inter-observer agreement.*

	Intra-Examiner	Inter-Examiner
No. of cases	25	25
Mean of difference	0.04	0.12
SD of difference	0.2	0.33
Score agreement (%)	96%	88%
Kappa (*k*)	0.949	0.842

TABLE 3—*CT comparison with conventional radiography (CR) scoring using Demirjian et al. (5) stages.*

		CT Scores		CR Scores	
Age (years)	Sex	L	R	L	R
15	F	D	D	D	D
16	M	G	G	F	F
17	M	G	G	G	G
18	F	H	H	H	H
18	M	F	F	E	E
18	M	H	H	H	H
18	M	D	D	D	D
19	F	H	H	H	H
19	F	H	G	H	G
19	M	H	H	H	H
18	M	F	E	F	E
21	F	G	G	G	G

Note: Disagreement in two individuals out of 12, both of which are explainable (see discussion), demonstrating excellent agreement when comparing CT images to conventional radiographs.

667 (216 females and 451 males). Of the 667 individuals in the sample, 570 possessed both lower third molars, with the remainder having just one. The total number of teeth examined was 1237. Younger age groups, especially females were under-represented compared to males. The age distribution of the cohort is shown in Table 1.

There was only one intra-examiner disagreement of one stage resulting in a 96% agreement rate and a kappa score of 0.95 (SEM = 0.05). There were three different readings of one stage for inter-examiner comparisons resulting in an 88% agreement rate and a kappa score of 0.84 (SEM = 0.08) (Table 2).

There were two disagreements of one stage when Demirjian scores for conventional radiographs and CT images were compared. This resulted in a kappa measure of agreement of 0.780 (SEM = 0.13) (Table 3 and Fig. 2).

In terms of left/right asymmetry 72 individuals (12.6%) differed in development by one stage, and six individuals (1%) by two stages out of the 570 individuals who had both lower third molars present. Kappa statistics for the entire sample reveal a measure of agreement of 0.76 (SEM = 0.02). Figure 1 shows CT images from left and right side from the same individual (female age 18 years) with a two-stage developmental discrepancy.

Degree of third molar root development in relation to age is expressed in graphical form in Figs 3 and 4 for males and females, respectively. Both left and right third molars are treated separately and the standard deviation for each age group is represented by error bars above each column. Mean age and standard deviation for each stage was calculated, although the results are somewhat skewed since there were not equal numbers in each age group, especially in the younger female age categories, and there were no individuals in this sample below the age of 15 years. Whilst this imperfect population distribution is not ideal (48), it is still useful for assessment of the overall developmental trend (Tables 4 and 5).

The age range for each stage (mean ± 2SD) was calculated, and the percentage of individuals at each chronological age who were within the age range for their Demirjian score was determined (Table 6). It was seen that of the entire sample the chronological ages of 10 males and nine females fell outside the age range for their developmental stage.

The first root completion (stage H) was not seen in males and females until the age of 17 years, where one tooth out of 32 for females had reached completion (3.1%) and eight teeth out of 64 (12.5%) for males demonstrated complete root formation. At the age of 21 years 89% of third molars were fully developed for males, whilst only 50% of third molars in females had reached their final form. Females did not reach a comparable percentage completion to males at 21 years until the age of 23 years. At age 25 years, 2% of individuals still displayed incomplete root development, although all of these were at stage G.

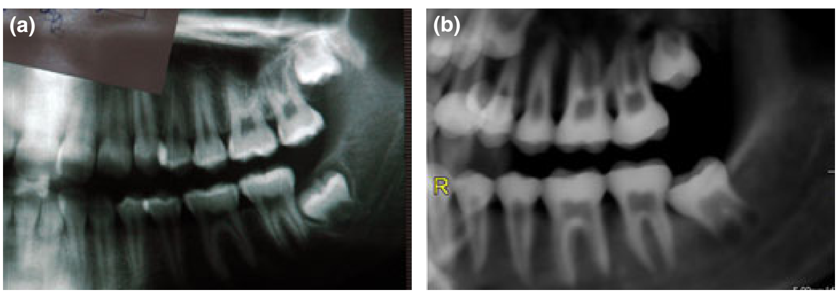

FIG. 2—*Comparison of CT image with conventional radiograph of same individual showing different degree of development. Note: Conventional radiograph scored as stage E and CT image scored as stage F. Difference is due to conventional radiograph being taken 12 months prior to the CT image. See discussion for detailed explanation.*

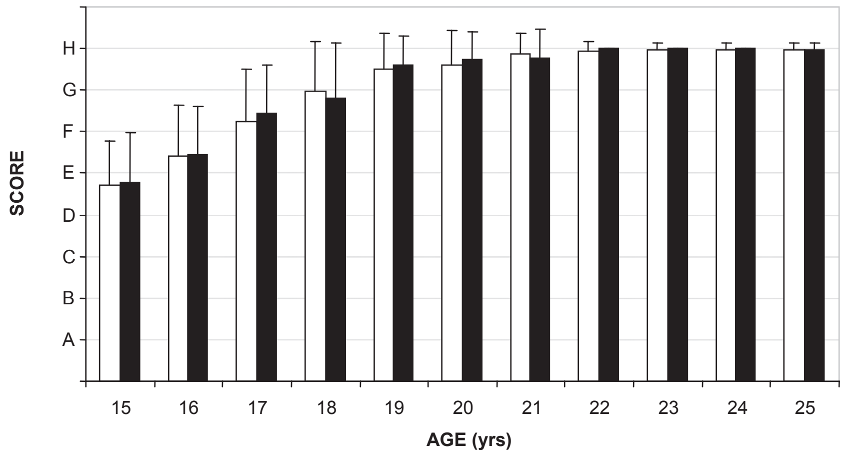

FIG. 3—*Mean development score for each age group (males) for left third molar (clear bars) and right third molar (solid bars). Note: Standard deviations for each age are represented by error bars.*

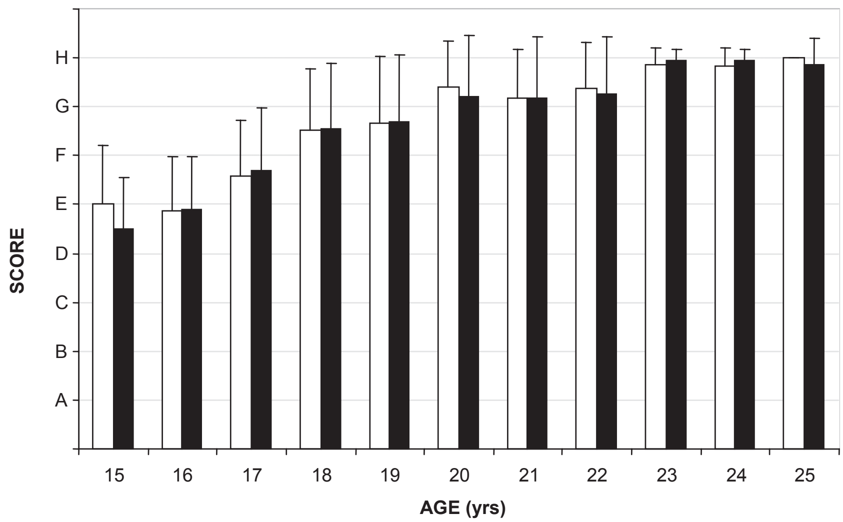

FIG. 4—*Mean development score for each age group (females) for left third molar (clear bars) and right third molar (solid bars). Note: Standard deviations for each age are represented by error bars.*

TABLE 4—*Mean age in each stage—female.*

Stage	Mean Age (years)	SD
C	15.00	N/D
D	16.65	1.46
E	18.03	2.00
F	18.52	2.31
G	19.50	2.65
H	22.08	2.28

Stage refers to Demirjian et al. (5).

TABLE 5—*Mean age in each stage—male.*

Stage	Mean Age (years)	SD
C	15.25	0.50
D	16.40	1.53
E	16.92	1.41
F	17.68	1.75
G	18.65	2.10
H	22.00	2.15

Stage refers to Demirjian et al. (5).

Interpreting the data in a slightly different way, by scoring each individual person rather than separately scoring individual teeth, and assigning the lowest stage seen as the score for that individual, there were no individual females below the age of 18 years who displayed a score of H, and only 4% of males below the age of 18 years had completed root formation, all of these at 17 years. The percentage of each age displaying completed root formation can be seen in Table 7. For individuals 18 years and older, the scores show that 43.8% of females and 18.4% of males had not reached root completion.

Discussion

The kappa scores for both intra- and inter-examiner reliability represent excellent agreement (49) and this indicates substantial homogeneity of evaluation between observers, thus validating the precision of this scoring system when applied to CT images of the developing third molar.

The results of this research demonstrate that CT images depicting dental development are directly comparable to conventional radiographs, both in terms of overall morphology and in achieving

TABLE 6—*Percentage of individuals at each age falling within the age range (mean ± 2SD) for their developmental stage.*

Age (years)	Male: Number Within Age Range (%)	Female: Number Within Age Range (%)
15	100	100
16	96	100
17	93.7	100
18	100	100
19	100	89.5
20	96.1	100
21	96.2	90.1
22	100	76.5
23	97.9	100
24	98.1	100
25	97.7	93.3

Note: Of the entire sample, the chronological ages of 10 males and nine females were outside the age range for their respective developmental stage.

TABLE 7—*Percentage of individuals at each age with completed third molars.*

	Percentage Individuals at Stage H	
Age (years)	Female	Male
15	0	0
16	0	0
17	0	9.4
18	27.6	34.9
19	36.8	64.3
20	41.1	80.4
21	45.4	84.9
22	58.8	92.3
23	83.3	97.9
24	84.2	98.1
25	93.2	98.0

Note: Percentage of total number of individuals below age of 18 years at stage H is 0% for females and 4% for males.

comparable development scores, and as such, the population data used in this study should be applicable to those cases where only conventional radiographs are available. It can also be seen that independent examiners can achieve parity in scoring these CT images with a minimum of training, as CT images are similar to conventional radiographs, and little extra training is required to convert from one image modality to the other. The two different readings which were noted were due to the OPG radiograph being taken some time prior to the CT scan of the deceased individual, therefore allowing some root growth to occur, which accounts for the different readings seen (Fig. 2). It was not always possible to obtain conventional radiographs at the same time as the CT images, as this depended upon the time of last attendance at a dentist prior to death, hence the resultant developmental differences in two of the cases.

The degree of asymmetry between left and right sides was assessed and this demonstrated that there is good statistical agreement between contralateral sides. Notwithstanding this, it must also be noted that in 1% of cases there was a two-stage discrepancy (see Fig. 1) which would have resulted in a significantly different age estimate if only one side was used. This is not so much of a problem if both third molars are present and the usual practice of scoring the least developed side is taken, but it would create a significant issue if one of these teeth had been lost due to trauma, decomposition, or postmortem predation. This raises the question of the validity of applying population-based data to individual forensic cases, when the case being examined may not necessarily fall within the established norms for that population, thus potentially arriving at an erroneous age estimation.

It has been shown that timing of third molar development varies with sex (50,51) so males and females have been treated separately in this study. Results show that males mature earlier than females, which is in accord with previous research. This preliminary research did not discriminate between ancestry and socio-economic status, which is believed to have a bearing upon development, and as such may be an important factor which will be taken into account in future research.

This research has demonstrated that CT imaging is a valid technology for use in dental age estimation in a forensic setting. The results may also be applied to data gathered using conventional radiography as it has been demonstrated that there is no significant difference between the developmental scores obtained using either modality.

The width of the age ranges seen in this study (mean age ± 2SD), which can be calculated from the data in Tables 4 and 5, indicate that development of the third molar will not provide particularly precise age estimations in this population. Age estimations with ranges of 3–8 years are unsatisfactory from a legal standpoint and of limited use in forensic investigations where accurate age determination is an important factor. When assessing whether or not an individual is over or under the age of 18 years, however, more positive conclusions may be drawn.

For individuals in this population with fully developed lower third molars at stage H, if male they are at least 17 years of age, and if female at least 18 years (Table 6). Meinl et al. (29) also found that there were very few individuals displaying root completion of mandibular third molars below the age of 18 years. In their study of an Austrian population, only one male and one female from a population subsample of 179 individuals reached completion prior to 18 years. Mincer et al. (14) also ascribed a high probability for an individual being 18 years or older if lower third molars had achieved stage H with figures of 90.1% for males, and 92.2% for females.

In considering the occurrence of the earlier developmental stages it was noted that if an individual possesses third molars at stage D, when crown formation is complete, then for females they will be no older than 19 years, and for males they will be a maximum age of 18 years. Stage C was seen in only four individuals in the 15 year age group and only one individual at age 16 years. It is interesting to compare these data with those of Knell et al. for a European population (52) who showed the presence of stage C at 19 years, and 91% completed roots by 22 years. They described the latest appearance for stage D at age 18 years for males (7% of individuals), and age 19 years for females (10% of individuals), which compares favorably with this research.

Third molar root development is completed for some individuals by the age of 17 years, but is still incomplete for others at 25 years, which highlights the difficulty of using this developmental marker in isolation as an age estimation tool. Nevertheless, it appears that the development of the third molar may be a useful indicator for discriminating ages under or over 18 years. It is possible that a multifactorial approach may result in more precise age ranges being achieved. For individuals in this age group, however, the choice of age markers is limited. Several studies have analyzed the medial clavicular epiphysis using CT imaging (53–56), and the ability of this imaging method to enable accurate observation of the various stages of clavicular fusion is encouraging.

In summary, it is seen in this population that for individuals at Demirjian stage D, females will be a maximum age of 19 years, and males no older than 18 years. At stage F, the maximum age for females is 22 years, and males 21 years. For those individuals with completed root formation this work has shown that females will be at least 18 years, and males will have a 96% certainty of being 18 years of age or older.

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Additional information and reprint requests:
Richard B. Bassed, B.D.S.
Victorian Institute of Forensic Medicine
and the Department of Forensic Medicine, Monash University
Southbank
Melbourne
Victoria 3006
Australia
E-mail: richardb@vifm.org