Int J Legal Med (2011) 125:227–233
DOI 10.1007/s00414-010-0522-9

ORIGINAL ARTICLE

Accuracy of predicting 18 years of age from mandibular third molar development in an Indian sample using Demirjian's ten-stage criteria

Ashith B. Acharya

Received: 21 July 2010 / Accepted: 1 October 2010 / Published online: 15 October 2010

Abstract Predicting 18 years of age can be crucial in forensic contexts. The third molar is the only tooth developing during this chronological period and has been used to estimate minority/majority status (</≥18 years). Conventionally, Demirjian's grading has been used to assess third molar development although the method was not originally intended for evaluating this tooth. Demirjian incorporated third molar assessment in a recent modification and replaced the alphabetical grading (A to H) with a numerical scale (0 to 9). The new grading system is untested on third molars and this study assessed the tooth's development on orthopantomograms of 221 Indian subjects (68 males, 153 females; age range 15–21 years). The tendency to correctly determine majority/minority status was assessed using three different statistical approaches, viz. traditional regression analysis, logistic regression analysis and Bayesian prediction. The sample was divided in to a reference sample of 180 cases and a test group of 41 subjects. All three statistical methods correctly predicted an individual as being </≥18 years in 73.2% of test subjects. Their ability to correctly identify a minor/juvenile was higher (85.7%) than their capacity to properly identify a major/adult (60%). Using the revised grading system, and irrespective of the statistical method applied, over one quarter of Indian subjects requiring identification as a major/minor were categorised in to the wrong age group. This level of accuracy may be inadequate for courts of law to rule with sufficient levels of certainty about the juvenile/adult status of an individual using third molar development.

Keywords Age estimation · Dental development · Juvenile · Majority status · Logistic regression analysis · Bayesian prediction

Introduction

Eighteen years of age is a chronological landmark with important ramifications in many countries [1–3], including India. It is the threshold at which an individual is legally considered to have attained adulthood and, consequently, the law views a person's actions, and actions against the person, differently. According to the Indian Juvenile Justice (Care and Protection of Children) Act, 2000, an individual who has not attained the age of 18 years is considered as a juvenile [4]. The Juvenile Justice (Care and Protection of Children) Amendment Bill, 2006, states that a 'juvenile in conflict with law', i.e. a juvenile alleged to have committed an offence, cannot be sentenced to death or life imprisonment or committed to prison [4]. Instead, Juvenile Justice Boards exercise powers in relation to such individuals, who may only incur group counselling, community service, payment of fine or be remanded to a special home, usually for 3 years or until the time he/she attains majority status [4]. The amendments have prompted a young high-profile terrorist, apprehended after committing mass murder, to seek refuge in this law by claiming to be a juvenile [5].

Eighteen years is also the legally acceptable age for giving/obtaining consent (Section 87 of the Indian Penal Code or IPC), the legally permissible age for marriage of females (Child Marriage Restraint Act, 1978) as well as the minimum age to enter government service [6]. Kidnapping a minor girl cannot only incur a ten-year imprisonment, but also be viewed as procurement of the girl for prostitution/illicit sexual intercourse (Section 366-A of IPC). Therefore,

A. B. Acharya (✉)
Department of Forensic Odontology,
S.D.M. College of Dental Sciences and Hospital,
Sattur, 580009 Dharwad, India
e-mail: ashith.acharya@sdmcds.edu

predicting whether an individual has (or has not) reached the age of majority can be extremely important in India in a number of forensic circumstances when the age is unknown or under dispute.

There are few reliable predictors of age in the 16–23-year-age group and the dentition is considered to be one of them [1]. In particular, the third molar—whose development commences much later than other teeth—is usually the only tooth that is still undergoing calcification at this age. Hence, although its development may be erratic and the tooth itself has a relatively high incidence of agenesis [7, 8], the third molar has been the subject of immense interest as a predictor of 18 years of age and status of majority [1, 9–11].

Tooth calcification has been studied with a view to predict biologic age in children and juveniles. Among the various methods developed [12–19], the description of Demirjian et al. [15] is the most widely tested and applied, probably because of its simplicity, the radiographic and schematic illustrations of tooth development and accompanying description which the original work and subsequent modifications provided [15, 20, 21]. However, the method was not initially intended for assessing 18 years of age since it had excluded the third molar. Beginning with Mincer et al. [1], a number of authors [2, 9–11] used Demirjian's grading of tooth development on the third molar with a view to assess age of majority. Demirjian himself included the third molar in order to extend the applicability of his method to a wider age group [21]. In his revision, two stages of dental development were added to incorporate a total of ten stages; also, the alphabetical grading (A to H) was replaced with a numerical scale (stages 0–9).

The third molar development based on these ten stages is, as yet, untested; moreover, no study has so far addressed the issue of age-of-majority determination from third molars in Indians. This study, therefore, ventured to use the tooth and the revised grading on an Indian sample to determine how correctly a subject's majority/minority status could be predicted. While Demirjian's modification [21] recommends the use of regression analysis—in particular polynomial functions—for age estimation, others have explored alternative statistical methods such as logistic regression analysis [22] and Bayesian prediction [23] for differentiating between juvenile status and adulthood. Therefore, the tooth development data was treated with the three statistical approaches to assess if any of these statistical methods was better in predicting the 18-year threshold.

Materials and methods

The sample comprised of 221 orthopantomograms (OPGs) derived from 68 males and 153 females in the age range of 15–21 years (Table 1). The age range was deliberately restricted to this smaller category considering that queries regarding attainment of age of 18 years may be expected to be for subjects in this age range. It is also similar to the age interval examined by a recent study that addressed a similar question [22]; furthermore, one paper recommends that the upper age limit in studies assessing third molars be no greater than 22 years, since the tooth usually completes development by this age [9].

Radiographs were archived in the Department of Orthodontics of this institution and only those of Indian citizens were examined. While many subjects belonged to the south-western part of India, predominantly originating from the states of Karnataka and Maharashtra, individuals were also drawn from diverse regions of India by virtue of them having settled in this region for a couple of generations or being students enrolled in the institution. The sample, therefore, may be considered to represent a microcosm of India as it comprised of not only diverse Indian regions but also all major castes and religious groups of the country. Individuals were healthy, with no history or any apparent sign of developmental anomalies. Radiographs evaluated were pre-treatment in nature and were assessed following the description of Demirjian et al. [15] and its later modifications [20, 21]. All OPGs were evaluated on an illuminated X-ray view box with no prior knowledge of the subject's demographic information.

Following examination, radiographs were decoded and the chronological age of all subjects calculated on the basis of birth date provided in the case records and date of radiography, which was indicated by lead markers on the panoramic film. One hundred and eighty OPGs (124 females, 56 males) were categorised as a reference sample and the remainder 41 (29 female, 12 male) were set aside as a test group. Care was taken to ensure that the age distribution for both males and females in the test group was proportional to that of the reference sample; the mean age for individuals of the reference sample was 17.68 years while that of the test group was 17.54 years.

Table 1 Sample distribution across age groups and the sexes

Age (completed years)	Females	Males	Σ
15	28	10	38
16	24	12	36
17	27	10	37
18	20	13	33
19	25	12	37
20	13	5	18
21	16	6	22
Σ	153	68	221

Table 2 Cross tabulation by age group and developmental stage for the base sample (n=180)

Sex	Age group	Developmental stages										Σ
		0	1	2	3	4	5	6	7	8	9	
Males	<18 years	0	0	0	0	2	5	7	8	5	1	28
	≥18 years	0	0	0	0	0	0	4	6	10	8	28
Females	<18 years	0	0	0	0	1	13	15	20	12	1	62
	≥18 years	0	0	0	0	0	1	5	16	23	17	62

Third molar development data from the reference sample was subjected to regression analysis using the SPSS 10.0 statistical package (SPSS Inc, Chicago, IL, USA). While performing the analysis, the numerical developmental stage (0–9) of the third molar was entered as independent variable and the known chronological age (in completed years) as dependent variable. Although Demirjian's revised method [21] has provided biologically weighted scores for the third molar, these maturity scores are intended for use in conjunction with the remaining seven teeth of the left mandible as part of the updated 8-teeth method [21]; moreover, the authors converted the alphabetical stages to numbers specifically to enable the construction of mathematical models [21]. Therefore, in the present study, the numerical developmental stages have been directly regressed to known chronological age. The regression formulae derived (linear, quadratic and cubic functions) were tested on the test group (n=41). The age estimation on the test group did not assess the *accuracy* of the age estimates per se; rather, they looked at whether the regression formulae could correctly identify the subjects as <18 years old (minors) or ≥18 years old (majors). In effect, it was assessed if the mean age estimate produced by the regression equations could correctly categorise an individual as being a minor/juvenile or a major/adult.

The reference sample was also subjected to logistic regression analysis (LRA) using the same software programme and logistic regression equations derived, which were once again applied on the test group. While undertaking LRA, the reference sample was divided in to two groups—a <18 years old group (15–17-year-olds) and a ≥18 years old group (18–21-year-olds). This ensured that the binary dependent variables were the two age groups, thus producing a logistic regression equation that could provide a log odd or logit to differentiate the groups. A predicted probability (P), which falls between 0 and 1, can be derived from the logit using the function $P=1/(1+e^{-L})$, where L is the logit of the logistic regression equation (i.e. $L=\beta_0+\beta_1 X_1$). The default cutoff in logistic regression is 0.50 (50%), so an individual with a probability >0.50 would be categorised as ≥18 years old while $P<0.50$ would be considered <18 years old [24]. The closer the value is to 1, the greater the probability that the subject is a major; on the other hand, a value closer to 0 indicates a greater probability of the individual being a minor.

Lastly, a cross tabulation of the data from the reference sample was undertaken on the basis of age group (whether < or ≥18 years old) and third molar development stage (0–9) for calculating the probabilities using Bayes' theorem (Table 2), as described by Lucy et al. [25]; the posterior probabilities of each individual in the test group was calculated based on the reference samples' cross tabulation. Briefly, the posterior probability is the conditional probability of a hypothesis being correct given the value of the observed information [25]. It is the probability that an individual belongs to a particular age group after considering prior information about incidence of a particular developmental stage of the tooth in the reference sample as well as observed evidence of the third molar developmental stage in the subject of interest (i.e. subject from the test group). In both male and female reference samples, the number of individuals in the two age categories (< or ≥18 years old) was kept equal to ensure each age group was given the same (prior) probability [23]. A 50% probability, which appeared to be a reasonable threshold, was taken as a minimum for categorising an individual as belonging to either age group.

Considering various reports of sexual dimorphism in dental development, including that of third molars [1, 3, 8], all analyses were undertaken separately for males and females. However, the results are pooled to gauge the usefulness of third molars and to compare the effectiveness of the three statistical methods in majority/minority prediction across the sexes and on a larger sample.

Table 3 Coefficient of determination of the traditional regression analyses for males and females

Sex	n	r^2		
		Linear	Quadratic	Cubic
Male	56	0.379	0.391	0.393
Female	124	0.303	0.323	0.323

Table 4 Results of the test of the traditional regression analyses, logistic regression analysis, and Bayesian prediction on the control sample (n=41)

M3 stage	Actual Age (in completed years)	Sex	Predicted Age (in years) for traditional regression analyses			Logistic regression probability	Bayesian posterior probability
			Linear	Quadratic	Cubic		
<18 years[b]							
6	15	M	16.62	16.51	16.52	0.30	63.64%
6	15	F	16.67	16.56	16.60	0.27	75.00%
6	15	F	16.67	16.56	16.60	0.27	75.00%
5	15	F	15.79	16.18	16.18	0.14	92.86%
6	15	F	16.67	16.56	16.60	0.27	75.00%
5	15	F	15.79	16.18	16.18	0.14	92.86%
5	15	F	15.79	16.18	16.18	0.14	92.86%
5	16	F	15.79	16.18	16.18	0.14	92.86%
6	16	F	16.67	16.56	16.60	0.27	75.00%
6	16	F	16.67	16.56	16.60	0.27	75.00%
7	16	F	17.54	17.28	17.29	0.47	55.56%
5	16	F	15.79	16.18	16.18	0.14	92.86%
6	16	M	16.62	16.51	16.52	0.30	63.64%
7	16	M	17.46	17.28	17.27	0.48	57.14%
7	17	M	17.46	17.28	17.27	0.48	57.14%
9	17	F	19.28[a]	19.70[a]	19.75[a]	0.83[a]	5.56%[a]
7	17	F	17.54	17.28	17.29	0.47	55.56%
8	17	F	18.41[a]	18.32[a]	18.32[a]	0.67[a]	34.29%[a]
8	17	F	18.41[a]	18.32[a]	18.32[a]	0.67[a]	34.29%[a]
6	17	F	16.67	16.56	16.60	0.27	75.00%
6	17	F	16.67	16.56	16.60	0.27	75.00%
≥18 years[b]							
8	18	M	18.31	18.25	18.24	0.66	66.67%
6	18	M	16.62[a]	16.51[a]	16.52[a]	0.30[a]	36.36%[a]
7	18	M	17.46[a]	17.28[a]	17.27[a]	0.48[a]	42.86%[a]
6	18	F	16.67[a]	16.56[a]	16.60[a]	0.27[a]	25.00%[a]
6	18	F	16.67[a]	16.56[a]	16.60[a]	0.27[a]	25.00%[a]
7	18	F	17.54[a]	17.28[a]	17.29[a]	0.47[a]	44.44%[a]
7	18	F	17.54[a]	17.28[a]	17.29[a]	0.47[a]	44.44%[a]
8	19	F	18.41	18.32	18.32	0.67	65.71%
6	19	F	16.67[a]	16.56[a]	16.60[a]	0.27[a]	25.00%[a]
8	19	F	18.41	18.32	18.32	0.67	65.71%
7	19	F	17.54[a]	17.28[a]	17.29[a]	0.47[a]	44.44%[a]
9	19	M	19.15	19.41	19.47	0.81	88.89%
9	19	M	19.15	19.41	19.47	0.81	88.89%
9	20	M	19.15	19.41	19.47	0.81	88.89%
8	20	M	18.31	18.25	18.24	0.66	66.67%
9	21	M	19.15	19.41	19.47	0.81	88.89%
8	20	F	18.41	18.32	18.32	0.67	65.71%
9	20	F	19.28	19.70	19.75	0.83	94.44%
8	21	F	18.41	18.32	18.32	0.67	65.71%
9	21	F	19.28	19.70	19.75	0.83	94.44%

[a] Subjects whose predicted age/probability did not correspond to their actual age group

[b] Age group

Results

Regression analyses revealed a moderate correlation of third molar tooth development to chronological age, with curvilinear models (quadratic and cubic functions) showing slightly stronger correlation than the linear model (Table 3). Application of the regression equations to the respective male and female test samples resulted in a correct prediction of a subject's majority/minority status in 30/41 (73.2%) cases for all regression models (Table 4). While <18 years old subjects were correctly predicted as such in 18/21 (85.7%) cases, accurate prediction was possible in 12/20 (60%) individuals who were ≥18 years old.

The logistic regression equations for males and females and the goodness of fit of the LRA models (denoted by the −2 log likelihood or −2LL), is listed in Table 5. Lower the −2LL statistic, better the fit of the model to the data [26]. The expected allocation accuracy for the LRA was 78.9% for minors and 64.4% for majors, with an overall allocation accuracy of 71.7%. Indeed, it was found that LRA correctly categorised 30/41 (73.2%) test subjects to their respective age groups. Of these 18/21 (85.7%) were minors and 12/20 (60%) had reached majority status (Table 4). The average probability of the correctly identified minors was 71.7%, while the corresponding figure for majors was 74.2%.

Bayesian analysis also revealed that 30/41 (73.2%) test subjects were categorised to their respective age group with a posterior probability of >50% and were thus eligible to be classified as belonging to the 'correct' age group, as defined in this study (see the "Materials and methods" section). Among the correctly identified subjects, 18/21 (85.7%) were minors while 12/20 (60%) individuals were majors (Table 4). The average posterior probability of the correctly classified minors was 74.6%, while the corresponding figure for the majors was 78.4%.

Overall, the results show that among the test subjects who were <18 years old, only those who were 17 years of age had a tendency to be wrongly categorised as a major (Table 4); on the other hand, in the ≥18 years old group, subjects who were 18 or 19 years old had a tendency to be falsely categorised as minors (Table 4). The results also reveal that a subject ≥18 years old and with a development grade of 8 or 9 is correctly categorised as a major whereas subjects <18 years old and with a grade ≤7 are correctly identified as minors (Table 4).

Table 5 The goodness of fit of the LRA models and the regression equations for males and females

Sex	*n*	−2LL	LRA constant	LRA coefficient
Male	56	61.86	−5.436	0.765
Female	124	135.06	−6.070	0.848

Discussion

The third molars' development has traditionally been associated with a youth's transformation to adulthood. The term 'wisdom tooth', used commonly in the English literature to denote the tooth's development coinciding with a person attaining temporal maturity, is also reflected in other regions and cultures—it is referred to as the 'mind teeth' in Romania, 'love teeth' in Korea and '20-year teeth' in Turkey [27]. Third molars have been studied for their development, emergence, incidence and agenesis for over seven decades [7, 8, 28, 29] and its calcification correlated to chronological age [30]. However, it was only in the last two decades that its use specifically in predicting the age of 18 years, which is the age of majority in diverse jurisdictions, was assessed [1–3, 9, 10]. Mincer et al. [1] adopted Demirjian's dental development grading for the third molar and calculated the empirical likelihood of an individual being at least 18 years of age based on mean age and standard deviation at each grade. They found that if third molar development was complete, there was ~90–92% probability of the subject being at least 18 years old. Others followed this approach in different populations and ethnic groups [9, 10] and found that probabilities for predicting age of 18 years based on third molar root completion varied between 97–99% [2], 85–92% [9] and 98–99% [10].

However, Knell et al. [22; p. 468] have questioned the validity of this approach owing to inherent statistical limitations. They believe that in order to arrive at a correct conclusion for mean age groups, the statistics for all age groups should be taken into consideration, which may result in misinterpreting the mean values. As an alternative, they suggested the use of LRA since it does not depend on the age group selected [22]. On the other hand, Thevissen et al. [23] recently compared traditional regression analyses and Bayesian prediction and found that the latter allowed 'a more appropriate discrimination of subjects being older than 18 years'. Lucy et al. [25] have described a number of disadvantages that traditional regression analysis has. Most important of these, probably, is that regression analysis assumes the independent variable as being on a continuous scale and is therefore unsuitable for ordinal variables, such as Demirjian's grading of tooth development (regressing ordinal variables can lead to a loss of information which obscures the real probability distribution of the predicted age). On the other hand, both the Bayesian method and LRA are suitable for assessing ordinal variables; moreover, they produce *probabilities* that can be used to predict group membership (in this case < or ≥18 years, i.e. majority or minority status, juvenile or adult). While the application of regression analysis to ordinal data may not be appropriate and has been criticised [25], its continued use and recommendation

[21] were among the reasons for considering it in the present study.

The results of the present study show that all three statistical approaches (traditional regression analyses, LRA and Bayesian method) were equally able to correctly/ incorrectly predicting the age of 18 years (Table 4). No study has so far compared Bayesian analysis with LRA in-so-far as age estimation is concerned and the results herein suggests no advantage of one over the other. With respect to Bayesian prediction vs. traditional regression analysis, the results of the present study are in contrast to previous reports, wherein the former was *better* [23, 25, 31, 32]. However, Thevissen et al. [23] observed that, in general, the Bayesian model did not 'strongly outperform' regression analysis as they did not find a major reduction in differences between the observed and predicted age nor an increase in precision for the Bayesian approach. Indeed, Lucy et al. [25] have stated that although ordinal data may not fit in to the various assumptions of regression analysis, it does not imply that the regression formulae would result in inaccurate or imprecise age estimates; however, they stress that there is no 'rationally justifiable reason' for using regression analysis on ordinal data [25; p. 190], such as those obtained from Demirjian's tooth grading.

Thevissen et al. [23] found that the incidence of categorising juveniles as adults was less using the Bayesian approach when compared to regression analysis, which has an inherent tendency to overestimate age in younger individuals while underestimating age in older subjects. No such trend, however, was seen in the present study (Table 4). In fact, all statistical approaches were able to correctly identify minors ~86% of the time, keeping the number of 'ethically unacceptable errors' (i.e. identifying a minor as a major) [11; p. 10] relatively low. This is important since categorising a juvenile as being ≥18 years old leads to a situation wherein the individual is awarded a harsher penalty, causing a violation of human rights [11]. On the other hand, the ability of all statistical approaches to correctly categorise a major as being ≥18 years old was 60%, implying that at least one in three subjects who has reached majority status may be falsely identified as a minor. This is termed as 'technically unacceptable errors' and leads to more generous criminal treatment of these subjects, normally reserved for minors [11; p. 10].

It was observed that individuals around the threshold of 18 years (i.e. subjects between 17 and 19 years) were the ones most likely to be falsely categorised to a different age group (Table 4), i.e. 17-year-old subjects may be categorised as majors/adults, while 18–19-year-old individuals could be categorised as minors/juveniles. Therefore, both ethically and technically unacceptable results may be a harsh reality while using third molar development for predicting majority/minority status.

Overall, using Demirjian's ten-stage criteria [21] on the mandibular (left) third molar, the various statistical approaches could correctly predict the age of majority/ minority to equal levels. However, considering the inappropriateness of traditional regression analysis for ordinal data, it is prudent to apply the more suitable methods such as LRA and Bayesian prediction. Irrespective of the statistical approach utilised, however, correct prediction of an individual as < or ≥18 years of age was possible in approximately three quarters of the Indian test cases, i.e. about one in four subjects requiring identification as a major/minor was categorised in to the wrong age group. This level of accuracy may not be sufficient for the courts of law to rule on the juvenile/adult status of an individual in question with adequate levels of certainty.

Acknowledgments The author wishes to thank Prof. C. Bhasker Rao, Director, and Prof. Srinath L. Thakur, Principal, S.D.M. College of Dental Sciences and Hospital, for their continued support to the Department of Forensic Odontology and research in the subject. The author also expresses his gratitude to Prof. Sanjay V. Ganeshkar, Head of Orthodontics, for providing access to the radiographs archived in his department. Many thanks also go to Dr. Harshavardhan Kidiyoor and the postgraduate students of the same department for assistance during case/radiograph selection. Special thanks are also owed to Prof. Mahadevayya V. Muddapur, retired Professor of Statistics, for verifying the correctness of the statistical methods used in this paper.

References

1. Mincer HH, Harris EF, Berryman HE (1993) The ABFO study of third molar development and its use as an estimator of chronological age. J Forensic Sci 38(2):379–390
2. De Salvia A, Calzetta C, Orrico M, De Leo D (2004) Third mandibular molar radiological development as an indicator of chronological age in a European population. Forensic Sci Int 146 S:S9–S12
3. Martin-de las Heras S, García-Fortea P, Ortega A, Zodocovich S, Valenzuela A (2008) Third molar development according to chronological age in populations from Spanish and Magrebian origin. Forensic Sci Int 174(1):47–53
4. Reddy KSN (2009) The essential of forensic medicine and toxicology, 3rd edn. K Suguna Devi, Hyderabad, pp 73–74
5. Tripathi K (2009) Kasab juvenile or not? Court orders inquiry. In: Times of India, Mumbai. http://timesofindia.indiatimes.com//City/Mumbai/Kasab-juvenile-or-not-Court-orders-inquiry/articleshow/4446878.cms. Accessed 21 July 2010
6. Pillay VV (2004) Textbook of forensic medicine and toxicology, 14th edn. Paras Medical Publisher, Hyderabad, p 70
7. Garn SM, Lewis AB (1962) The relationship between third molar agenesis and reduction in tooth number. Angle Orthod 32(1):14–18
8. Levesque GY, Demirijian A, Tanguay R (1981) Sexual dimorphism in the development, emergence, and agenesis of the mandibular third molar. J Dent Res 60(10):1735–1741
9. Solari AC, Abramovitch K (2002) The accuracy and precision of third molar development as indicator of chronological age in Hispanics. J Forensic Sci 47(3):531–535
10. Arany S, Iino M, Yoshioka N (2004) Radiographic survey of third molar development in relation to chronological age among Japanese juveniles. J Forensic Sci 49:534–538

11. Garamendi PM, Landa MI, Ballesteros J, Solano MA (2005) Reliability of the methods applied to assess age minority in living subjects around 18 years old: a survey on a Moroccan origin population. Forensic Sci Int 154:3–12
12. Schour I, Massler M (1940) Studies in tooth development: the growth pattern of human teeth. J Am Dent Assoc 27:1918–1931
13. Nolla CM (1963) The development of the permanent teeth. J Dent Child 27:254–266
14. Moorrees CFA, Fanning EA, Hunt EE Jr (1963) Age variation of formation stages for ten permanent teeth. J Dent Res 42(6):1490–1502
15. Demirjian A, Godstein LH, Tanner JH (1973) A new system of dental age assessment. Hum Biol 42:211–227
16. Gustafson G, Koch G (1974) Age estimation up to 16 years of age based on dental development. Odontol Revy 25:297–306
17. Kullman L (1995) Accuracy of two dental and one skeletal age estimation method in Swedish adolescents. Forensic Sci Int 75:225–236
18. Foti B, Lalys L, Adalian P, Giustiniani J, Maczel M, Signoli M, Dutour O, Leonetti G (2003) New forensic approach to age determination in children based on tooth eruption. Forensic Sci Int 132:49–56
19. Cameriere R, Ferrante L, Cingolani M (2006) Age estimation in children by measurement of open apices in teeth. Int J Leg Med 120:49–52
20. Levesque GY, Demirjian A (1980) The inter-examiner variation in rating dental formation from radiographs. J Dent Res 59(7):1123–1126
21. Chaillet N, Demirjian A (2004) Dental maturity in south France: a comparison between Demirjian's method and polynomial functions. J Forensic Sci 49(5):1059–1066
22. Knell B, Ruhstaller P, Prieels F, Schmeling A (2009) Dental age diagnostics by means of radiographical evaluation of the growth stages of lower wisdom teeth. Int J Leg Med 123(6):465–469
23. Thevissen PW, Fieuws S, Willems G (2010) Human dental age estimation using third molar developmental stages: does a Bayesian approach outperform regression models to discriminate between juveniles and adults? Int J Leg Med 124:35–42
24. Spicer J (2004) Making sense of multivariate data analysis: an intuitive approach. Sage, Thousand Oaks
25. Lucy D, Aykroyd RG, Pollard AM, Solheim T (1996) A Bayesian approach to adult human age estimation from dental observations by Johanson's age changes. J Forensic Sci 41(2):189–194
26. Albanese J (2003) A metric method for sex determination using the hip bone and the femur. J Forensic Sci 48(2):263–273
27. Silver M (2008) Chewing on wisdom teeth. Natl Geogr Mag 213 (3):32
28. Banks HV (1934) Incidence of third molar development. Angle Orthod 4(3):223–233
29. Garn SM, Lewis AB, Bonné B (1962) Third molar formation and its development course. Angle Orthod 32(4):270–279
30. Engström C, Engström H, Sagne S (1983) Lower third molar development in relation to skeletal maturity and chronological age. Angle Orthod 53(2):97–106
31. Braga J, Heuze Y, Chabadel O, Sonan NK, Gueramy A (2005) Non-adult dental age assessment: correspondence analysis and linear regression versus Bayesian predictions. Int J Leg Med 119:260–274
32. Prince DA, Konigsberg LW (2008) New formulae for estimating age-at-death in the Balkans utilizing Lamendin's dental technique and Bayesian analysis. J Forensic Sci 53:578–587