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ORIGINAL ARTICLE

The comparison between measurement of open apices of third molars and Demirjian stages to test chronological age of over 18 year olds in living subjects

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Abstract This paper concerns a method for assessing adult age based on the relationship between age and the third molar maturity index (I_{3M}), which is related to the measurement of the open apices of the third molar. Furthermore, this method was compared to those based on Demirjian's stages G and H. The sample consisted of 906 Caucasian individuals aged between 14 and 23 years (53.6% females and 46.4% males). Orthopantomographs were analyzed by two observers and calibrated by means of the concordance correlation coefficient for the reproducibility of the third molar maturity index (I_{3M}) and κ statistics for reproducibility of the Demirjian stages. Probabilities for an individual to be older than 18 years of age (adult age) were derived using the measurements of the third molar maturity index (I_{3M}). These results were exploited to set out a threshold value to assign an individual to juvenile or adult age. A cutoff value of I_{3M}=0.08 was taken. The sensitivity of this test was 70% and specificity was 98%. Furthermore, the proportion of individuals with a correct classification was 83%. The results of the test showed a better specificity when compared to the choice of stage G and a better sensitivity when compared to the choice of stage H for adult age.

Keywords Age determination · Third molar · Linear regression · Illegal immigration

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Introduction

In 1947, J.C. Carothers [1] wrote a paper entitled "Age and wisdom teeth in Africans" because "the east African medical man is often required by the courts to express an opinion as to the age of Africans, as the latter can seldom produce a birth certificate." The problem of subjects without documents is increasing and is currently one of the most important social problems in the European community.

The common use of X-rays has improved methods for age estimation in young people. In 1973, Demirjian at al. [2] published a new classification of stages of tooth mineralization. In 1993, commissioned by the American Board Forensic Odontology, Mincer at al. [3] studied 823 American children, prevalently Caucasians, aged between 14 and 24 years, to evaluate the radiographic reliability of the third molar as an age indicator. Age estimates target between 14.1 and 24.9 years, 80% on X-rays from Caucasian children, 20% Negroid, and 1% other origin; Demirjian's tables were used to determine mineralization stages.

The results confirmed that, although the third molar could not be used as an age indicator, they did highlight the fact that 90% of males and 92% of females with third molars in Demirjian's phase H (end of mineralization) were more than 18 years old. Therefore, subjects with third molars in phase H according to Demirjian were judged to

Table 1 Mean and standard deviations in age of males and females with lower third molars belonging to a given Demirjian stage

Stage/ gender	American (Mincer) [3]	Hispanics from USA (Solari) [4]	German (Olzel) [5]	Japanese (Olze) [6]	Japanese (Arany) [7]	South African (Olze) [5]	Austrian (Meinl) [8]	Turkish (Orhan) [9]	Spanish (Prieto) [10]
E/females	16.9 (1.7)	16.1 (1.4)		18.2 (2.3)	17.25	15.9 (2.3)	17.8 (2.5)	16.1 (2.4)	15.99(1.42)
E/males	17.3 (2.5)	15.8 (1.2)		18.6 (2.9)	16.35	15.2 (2.4)	15.6 (1.8)	15.6 (2.8)	15.22(1.03)
F/females	17.7 (1.8)	17.3 (2.6)	19.0 (2.5)	20.3 (1.9)	18.2			17.0 (2.5	16.83(1.56)
F/males	17.5 (2.1)	16.3 (1.3)	18.2 (2.1)	19.8 (2.2)	17.3	18.7 (2.3)	17.5 (2.6)	16.9 (2.7)	16.43(1.34)
G/females	19.1 (2.1)	18.5 (2.1)	21.6 (2.1)	21.5 (1.8)	19.4	19.8 (2.3)	20.3 (2.1)	17.9 (2.3)	18.41(1.43)
G/males	18.3 (1.9)	17.1 (1.7)	21.2 (1.9)	21.8 (2.1)	18.65	20.8 (2.2)	20.1 (2.1)	17.9 (2.2	17.92(1.50)
H/females	20.9 (2.0)	21.7 (1.8)	22.9 (1.7)	22.1 (1.8)	21.8	22.4 (1.9)	22.9 (1.3)	20.0 (1.9)	19.66(0.97)
H/males	20.5 (1.9)	20.6 (2.3)	22.5 (1.7)	22.5 (1.8)	21.6	22.6 (1.9)	22.4 (1.8)	20.1 (2.0)	19.74(1.08)

be over 18. The high number of subjects over 18 years of age with the third molar still not mature remains an important problem.

Several studies have tested the *method* of Mincer et al. or used different methods to evaluate the third molar as an age indicator [3–10] (Table 1).

All these papers stressed the problem of using the third molar as an age indicator particularly for the age of 18. In fact, average age at the end of mineralization, i.e., Demirjian's stage H, is usually reported to be more than 20 years and consequently classifying an individual as being over 18 only if the third molars which are in phase according to Demirjian yield a large number of errors (false nonadult).

The aim of this paper was twofold. First, examine the open apices of third molars in discriminating between individuals who are or are not 18 years of age or older and to fix a cutoff for evaluation of the age of 18 for forensic purposes. Second, we compared sensitivity and specificity of this method with stages G and H of Demirjian.

Materials and methods

Subjects and materials

Orthopantomograms (OPGs) of 906 Caucasian individuals aged between 14 and 23 years were evaluated (Table 2).

Table 2 Subdivision according to sex was almost equal (53.6% females, 46.4% males)

Age (years)	Number of girls	Number of boys	Total
15	95	86	181
16	82	92	174
17	61	39	100
18	58	48	106
19	60	45	105
20	57	49	106
21	40	28	68
22	33	33	66
Total	486	420	906

To discriminate between individuals above and below 18 years of age, the apical ends of the roots of the left mandibular third molar of each individual were analyzed and the third molar maturity index I_{3M} has been defined as follows. If the third molar has root development complete, i.e., apical ends of the roots completely closed, then $I_{3M}=0$, else I_{3M} is evaluated as (Fig. 1) the sum of the distances between the inner sides of the two open apices divided by the tooth length. The maturity index I_{3M} is evaluated in a similar way to the ratios A_i to L_i, i=6,7; as reported for the other two teeth with two roots in [11, 12]. Both impacted and not impacted third molars were included in the study provided that their roots were radiographically distinguishable.

Mineralization of the third molar was also evaluated following the eight-stage scheme proposed by Demirjian et al. [2].

Statistical analysis

All measurements were carried out by two observers. In order to evaluate intraobserver and interobserver reliability, the two observers made repeated measures of 30 OPGs at an interval of 2 weeks.

The intraobserver and interobserver reproducibility of the third molar maturity index, $I_{3M,}$ was studied with the

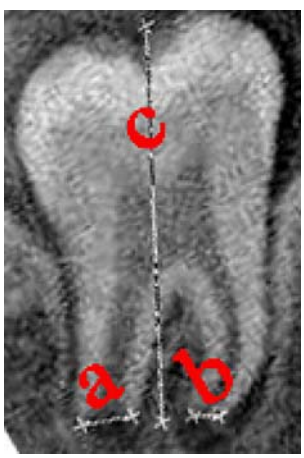

Fig. 1 An example of measurement of a tooth with two roots

Table 3 Mean and standard deviations for mineralization stages in relation to age and gender in study population

	Males	Females
Stage C	15.12 (0.77)	15.18 (1.33)
Stage D	15.82 (1.35)	16.25 (1.7)
Stage E	16.12 (1.44)	16.57 (1.61)
Stage F	17.31 (1.72)	17.76 (1.79)
Stage G	18.62 (1.49)	18.64 (1.67)
Stage H	20.02 (1.46)	20.34 (1.37)

Table 5 Percentage of individuals at least 18 years old or older by stage and gender

	Males	Females
Stage C	0	8
Stage D	11	15
Stage E	10	17
Stage F	35	26
Stage G	55	41
Stage H	96	98

concordance correlation coefficient, and κ statistics were used to measure the intraobserver and interobserver reproducibility of the Demirjian stages. For comparison of age distributions among Demirjian stages and gender, analysis of variance (ANOVA) was performed. With individual age as a dichotomous response variable (E=1 if an individual is at least 18 years of age, E=0 otherwise) and gender and the third molar maturity index I_{3M} as predictor variables, we derived a generalized linear model to predict whether an individual is older (E=1) or younger (E=0) than 18 years of age by using a logistic model as link function. The predictive accuracy of the model was assessed by the determination of the characteristic receiver operating curve (ROC). All significant variables were used to test the medicolegal question as to whether an individual is older or younger than 18 years of age. The test was performed to identify a threshold (cutoff) that could be used to assign an individual to the population of those younger (T=0) or older (T=1) than 18. The sensitivity p_1 of the test (i.e., the proportion of children for or older than 18 years of age, which verifies event T=1) was evaluated and also its specificity, p_2 (i.e., the proportion of individuals younger than 18 who verify the event T=0). Open apices in teeth may help to discriminate between individuals who are or are not aged 18 years or more, by the posttest probability of being 18 years of age or more (i.e., the proportion of individuals aged 18 or over in whom event E=1 is verified). According to Bayes' theorem, posttest probability may be written as:

$$p = \frac{p_1 p_0}{p_1 p_0 + (1 - p_2)(1 - p_0)} \quad (1)$$

where p is posttest probability and p_0 is the probability that an individual is 18 or older given that he or she is aged between 14 and 23 years which represents our target population. This probability p_0 was evaluated with the data obtained from the statistical office of Italy (Istituto Nazionale di Statistica, http://demo.istat.it/pop2004/index.html). Statistical analysis of data and related graphs was carried out with the S-PLUS 6 statistical program (S-PLUS® 6.1 for Windows. PROFESSIONAL EDITION, release 1) and the Microsoft Excel® program. The significance level was set at 5%.

Results

Reproducibility of Demirjian stages was done by observing any disagreement between two measurements made by the same observer, i.e., κ=1.

The interobserver reproducibility of Demirjian stages was good with Cohen's κ statistic (±standard deviation) at κ=0.93±0.07, indicating substantial homogeneity of evaluation between operators.

With regards to the reproducibility of the third molar maturity index, I_{3M}, the estimated concordance correlation coefficient (±standard deviation) was ρ_c=0.950±0.010 for observer 1. ρ_c=0.970±0.001 for observer 2, and ρ_c=0.949±0.011 when the measures of both observers were compared.

The interobserver reproducibility of I_{3M} did not reveal any significant intraobserver or interobserver effects, indicating substantial homogeneity of evaluation between operators.

Following the method of Mincer et al. [3], we characterized the individual age in the sample using the Demirjian stages of third molars and gender (Table 3).

With regard to differences in age distributions among Demirjian stages and gender, the ANOVA (Table 4)

Table 4 Summary table of ANOVA

	df	SSQ	MSSQ	*F*	Pr(*F*)
Gender	1	4	3.6	1.5	0.216
Stage	5	2,779	555.9	237.9	<0.001
Gender·stage	5	5	1.0	0.4	0.815
Residuals	894	2,089	2.3		

Table 6 Deviance on fitting linear models to data

	df	Dev.	Resid. *df*	Deviance	*P*
Null	–	–	905	1,253	–
I_{3M}	1	437	904	816	<0.001
Gender	1	2.3	903	814	0.129

Table 7 Parameter estimates for logistic model (3)

Parameter	Value	Std. Error	*t* value
b0	1.415	0.1155	12.26
b1	−5.113	0.3527	−14.50

revealed that gender had no significant effect on the mean value of the age distributions (p=0.815).

The frequency distribution by gender and stages of individuals older than or at least 18 years old, shown in Table 5, revealed that only stage H can be used to test adult age. In fact, we found that 96% of males and 98% of females in stage H were adults. However, the choice of stage H to characterize adult age yields a high percentage of false negatives. For instance, in our sample, only 58% of adults were in stage H.

When we used the third molar maturity index, I_{3M}, we found a cutoff value of I_{3M} for adult age which maximized the posttest probability and, at the same time, minimized the frequency of false negatives (i.e., the proportion of individuals of 18 years of age or older who were erroneously assigned to the subadult population).

Setting $p=P(E=1)$ as the probability that an individual was at least 18 years old, we modeled the dependence of this probability on I_{3M} and gender with a linear logistic model

$$\text{logit}(p)=b_0+b_1\ I_{3M}+b_2\ \text{gender}. \quad (2)$$

To examine the effect of including one of the two factors in or excluding it from the model, we considered the difference in deviance among different models with or without gender and I_{3M} (Table 6).

The change in deviance on adding the variable gender to a model that includes a constant term alone (null model) was not significant. Instead, when I_{3M} was added to the null model, the deviance was reduced by a highly significant amount ($p<0.001$).

In sum, the probability that an individual is 18 years or older depends on the degree of maturity of the third molar I_{3M}, but it does not significantly depend on gender. Hence, Eq. 2 may be rewritten, removing the covariate gender and including only the covariate I_{3M}:

$$\text{logit}(p)=b_0+b_1\ I_{3M}. \quad (3)$$

The maximum likelihood estimates of parameters of the logistic model (3) used to evaluate the probability that an individual was 18 years of age or older, p, given the values of the factor I_{3M}, are listed in Table 7.

The predictive accuracy of Eq. 3 and its discrimination capacity were also assessed by determining the ROC from classification matrices for different levels of predicted probability that an individual is of age. The resulting ROC is shown in Fig. 2.

To test the legal question of whether an individual is older or younger than 18, a procedure had to be identified, so that an individual was assigned to the population of those younger than 18 if the test resulted negative (T=0) and to the older population if the test resulted positive (T=1).

For forensic purposes, it is important that the test shows a low proportion of individuals younger than 18 whose test is positive (T=1), and so it seemed appropriate to pay more attention to the chance of a false positive than to that of a false negative.

On these grounds, we established that an individual is considered to be 18 years of age or older (the test is positive, T=1) if I_{3M} is lower than the cutoff value of 0.08;

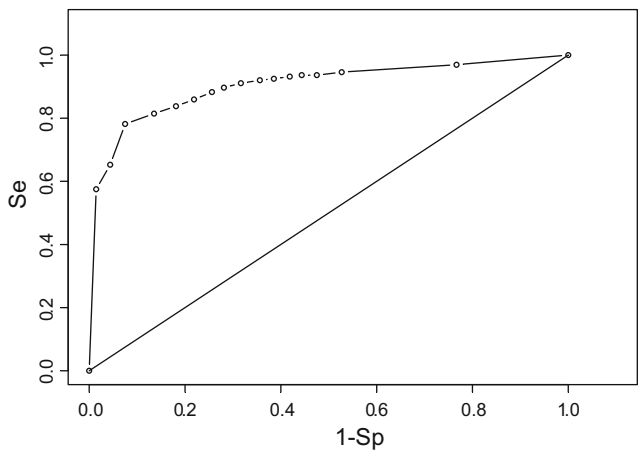

Fig. 2 Receiver operating characteristic curve for "18 years of age or older" status

Table 8 Classification table describing discrimination performance of the test

	Age		Total
	<18	≥18	
T=0	454	130	584
T=1	26	296	322
Total	480	426	906

Table 9 Percentages of sensitivity, specificity, correct classification, and posttest probability (95% confidence interval) of test of adult age when stages G and H and I_{3M} index<0.08 are used to discriminate between individuals who are or are not aged 18 years or more

	Phase G	Phase H	I_{3M}<0.08
Sensitivity	75	58	70
Specificity	90	98	98
Correct classification	83	79	83
Posttest probability	94 (92–96)	98 (97–99)	98 (97–99)

otherwise, an individual is considered to be under 18 (the test is negative, $T=0$).

The sensitivity of this test (the proportion of individuals being 18 years of age or older whose test is positive) was 70%, and its specificity (the proportion of individuals younger than 18 whose test is negative) was 95%. The proportion of correctly classified individuals was 83% (Table 8). Estimated posttest probability, p, was 98%, with a 95% confidence interval=(97%, 99%). Hence, the probability that a subject positive on the test ($T=1$) was 18 years of age or older was 98%.

Discussion

Age estimation methods involving examination of the development of the third molar have been used for many years, initially by assessing the eruption of this tooth [1] and later by studying its mineralization [3, 5, 13–17].

Although the method initially proposed by Mincer et al. [3] is the most frequently applied to estimate ages in the living, it is probably not an ideal marker in identifying adult individuals.

As shown in Table 9, our results showed that, if the root apices of the third molar are closed (i.e., the third molar is at terminal grade H), then there is a high probability that the subject is indeed at least 18 years of age: the estimated probability that a subject with the third molar at terminal grade H has reached 18 years of age is 0.98.

However, individuals of adult age whose third molars are at terminal grade H total only 58%, and the match between "at or over 18 years or under 18 years" and "belonging to phase H or not" was 79%.

In an attempt to improve the sensitivity of the method, phase G may be chosen as a marker of adult age. This choice increases the sensitivity of the method but at the same time significantly decreases the specificity and the probability that a subject with the third molar in at least grade G has reached 18 years of age.

Thus, choosing phase G as a marker of adult age, on the one hand, improves test sensitivity with respect to phase H but, on the other, it significantly increases the number of subjects judged to be of age (false positives), which represents a larger margin of error from a juridical viewpoint.

Instead, choosing a cutoff of 0.08 for the I_{3M} index not only significantly increases test sensitivity with respect to phase H but does not increase the number of false positives.

In conclusion, choice of the third molar maturity index, $I_{3M}<0.08$, is the most suitable method of determining adult age (18 years) for forensic purposes.

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