J Forensic Sci, Nov. 2004, Vol. 49, No. 6
Paper ID JFS2004125
Available online at: www.astm.org

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Precision and Reliability of Pulp/Tooth Area Ratio (RA) of Second Molar as Indicator of Adult Age

ABSTRACT: This paper discusses a method for assessing adult age based on the relationship between age and measurement of the pulp/tooth area ratio (RA) of the second molar teeth. The sample consisted of 312 Italian white Caucasian patients (135 men, 177 women) aged between 14 and 24 years. Orthopantomograph samples (OPGs) were analyzed by the same observer and calibrated by κ statistics. Probabilities of an individual being older than 18 years of age (adult age) were derived using measurements of the ratio pulp/tooth area (RA) of the second molar teeth and the dichotomized stages of third molar development (Tm) as explanatory variables. These results were exploited to establish a threshold value to assign an individual to juvenile or adult age. A cut-off value of $RA^* = 0.088$ was applied if $Tm = 0$ and $RA^* = 0.097$ if $Tm = 1$. The sensitivity of this test was 91% and its specificity 94.5%. The proportion of individuals with correct classifications was 92%.

KEYWORDS: forensic science, age determination by teeth, forensic odontology, dental pulp, pulp/tooth area, logistic model

Several papers in the field of forensic odontology deal with estimating chronological age in humans (1–8). Estimation of the age of living individuals is a problem of increasingly great interest in our community, due to the progressively higher numbers of persons without legal documentation of birth, who have immigrated illegally into Italy, and who are suspected of having committing crimes, for whom it is necessary to assess the actual age in order to decide on imputability. Even in proceedings concerning adoption, it sometimes becomes important to assess age when no birth certificate is available.

Therefore, in the last few years, forensic odontology has shown increasing interest in determining biological indicators for age estimation in individuals using dental development. In particular, some studies address the transition range between non-adults and adults. On this issue, the most common method was first published by Demirijan et al. (1,2) and since then odontology has carried out numerous studies to judge the juvenile versus adult status of subjects who lack age documentation. However, we must take into account the fact that, after the age of 14, the third molar is the only remaining tooth that is still developing, and consequently adult status estimation methods must be based on the development of this tooth. Mincer et al. (3), acting for the American Board of Forensic Odontology, evaluated the reliability of the developmental status of the third molar tooth as an element of age determination. In order to define maturation stages (from stage A to H), the growth table of Demirjian et al. (1) was used. The study confirmed the poor sensitivity of attainment of stage H of third molar formation as a test to determine the 18th year of age. However, it also revealed that 90% of male subjects and 92% of female subjects, having third molars in phase H, were of age, i.e., the test showed a high predictive positive value. Other authors have concentrated on the validity of the third molar for age determination, and several studies have been performed to describe better the relationship between maturity score and chronological age (4–9). Alternative approaches based on digitalization of panoramic radiographs and their computerized storage have recently become available. These procedures exploit image analysis to obtain non-destructive metric measurements of some morphological parameters of teeth. Of these techniques, there are some very fine, relatively precise and accurate methods, which are now available to forensic odontologists (10). In addition, computer-assisted image analysis avoids the bias inherent in observer subjectivity, and improves the reliability and consequently the statistical analysis of data. A number of statistical methods have been proposed for age determination, most of which are based on establishing correlations between individual age (dependent variable) and some significant tooth parameters (predictors) obtained from digitized radiographs (11). The most frequently used statistical technique for age estimation in forensic dental medicine is multiple linear regression, although partial least-squares linear regression, polynomial regression, and other robust regression methods are also applied. In (12,13) two methods were presented for assessing chronological age based on the relationship between age and measurement of some morphological parameters of teeth.

The purpose of the present study was to describe a method for assessing adult age based on the relationship between age and measurement of the pulp/tooth area ratio (RA) on second molar teeth. In an attempt to improve the precision and reliability of age estimations, we also took into account gender and the maturation stages of third molar teeth. Various statistical models were compared.

Materials and Methods

Subjects and Materials

Orthopantomographs taken from 312 Italian white Caucasian patients (135 men, 177 women) aged between 14 and 24 years were analysed. The selection criteria for inclusion of the OPGs in this study were: Italian Caucasian origin, at least one lower second molar present, and no obvious dental pathology on the panoramic radiology related to these teeth. Orthopantomographs were digitized using a scanner and images were recorded in a computer file.

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Received 20 Mar. 2004; and in revised form 21 May 2004; accepted 5 June 2004; published xxxx.

FIG. 1—*Photograph of a lower second molar with the outlines of pulp and tooth used to estimated RA.*

X-ray images of second molars were processed using a computer-aided drafting program (Adobe Photoshop 7.0, ©Adobe System Inc. 2001). Twenty points from each tooth edge and ten points for the pulp edge were identified and used to evaluate tooth and pulp areas. These measurements of second molar teeth were used to compute the ratio pulp/tooth area (RA). An example of RA measurement is showed in Fig. 1. If both maxillary second molars were present, RA was estimated from an average of the two available ratios.

Following the grade scheme developed by Demirijan et al. (1,2), the observer scored the stage of third molar development, Tm, which was considered as a dichotomous variable: Tm = 1 if the third molar had reached stage H, Tm = 0 otherwise.

Evaluation was carried out on lower third molars, almost always present and the most suitable for evaluation. In the case of disparity in the degree of mineralization of the lower third molars, the tooth with the lesser degree of formation was chosen.

All measurements were carried out by the same observer. To test intra-observer reproducibility, a random sample of 30 orthopantomographs were re-examined after an interval of two weeks.

Statistical Analysis

κ statistics were used to measure the strength of agreement between the two measurements of the observer. Using individual age as a dichotomous response variable (M = 1 if an individual is at least 18 years of age, M = 0 otherwise), and gender, Tm and RA as (independent) predictor variables, a generalized linear model was derived to predict whether an individual was older (M = 1) or younger (M = 0) than 18 years of age by using a logistic model as link function. To summarize model adequacy and to measure the goodness of fit of the chosen model Hosmer-Lemeshow χ^2 statistics (χ^2_{HL}) were applied (14). In order to calculate the value of the statistics, binary observations were arranged in ascending order of their corresponding fitted probabilities according to the model. The order values were then divided into eight groups of the same size. The predictive accuracy of the model was assessed by determining the receiver operating characteristic curve (ROC curve). Statistical analysis was performed with S-PLUS 6 statistical programs (S-PLUS® 6.1 for Windows PROFESSIONAL EDITION Release 1). The significance level was set at 5%.

TABLE 1—*Deviances on fitting the considered linear models to the data.*

	df	Dev. Resid.	df	Deviance	*P*
Null	...	...	311	376.67	...
Sex	1	0.83	310	375.84	0.363
Tm	1	83.73	310	292.94	<0.001
RA	1	241.54	310	135.13	<0.001
RA + Tm	2	4.75	309	130.38	0.029

TABLE 2—*Parameter estimates for logistic model (1).*

Parameter	Value	Std. Error	*t* value
b_0	11.441	1.5638	7.3163
b_1	−118.445	16.134	−7.3415
b_2	1.2065	0.5823	2.0719

Results

For the dichotomized stages of the third molar development we did not observed any disagreement between the two measurements of the observer, i.e., $\kappa = 1$. For the ratio pulp/tooth area, the estimated κ (±standard deviation) was 0.833 (±0.047). κ statistics revealed no significant intra-observer effects ($p < 0.05$), pointing to the substantial homogeneity of operator evaluation. OPG data were obtained to study the extent to which the adult age of an individual was related to the levels of the ratio pulp/tooth area (RA), the stages of third molar development (Tm) and gender (sex = 1, males; 0, females). Using p as the probability that an individual is at least 18 years of age (P(M = 1)), the dependence of this probability on RA, Tm and gender was modeled using a linear logistic model

$$\text{logit}(p) = b_0 + b_1\,\text{RA} + b_2\,\text{Tm} + b_3\ \text{sex}. \qquad (1)$$

To examine the effect of including one of the three factors in the model, or excluding it, the difference in deviance between two nested models was examined (Table 1). The change in deviance on adding the variable sex to a model that includes a constant term alone (null model) was 376.67 − 375.84 = 0.83 on 1 degree of freedom (df), which was not significant. Instead, when Tm or RA was added to the null model, the deviance was reduced by highly significant amounts. On including Tm in the model that already had RA, the deviance fell from 135.13 to 130.38, a significant amount when judged against a chi-squared variant on 1 df ($p < 0.05$).

In summary, the probability that an individual is of age (M = 1) depends both on the ratio pulp/tooth area of the second molar, RA, and on the degree of maturation of the third molar, Tm, but it does not significantly depend on gender. Hence equation (1) can be rewritten:

$$p = \frac{1}{1 + e^{-(b_0 + b_1\text{RA} + b_2\text{Tm})}}. \qquad (2)$$

The maximum likelihood estimates of the model parameters (Table 2) evaluated the probability that an individual was older than 18 years of age, p, given the values of the factors (variables) Tm and RA through the logistic model (2). The logistic model with optimum parameters is shown in figure 1, which plots the probability that an individual is an adult as a function of RA for Tm = 0 (Fig. 2a) and Tm = 1 (Fig. 2b), with the observed binary responses. In order to measure the goodness of fit of the model, Hosmer-Lemeshow χ^2 statistics were applied. The value of χ^2_{HL} was found to be 5.547 on 6 df. Because this was not significant ($P = 0.476$), we concluded that the fitted model is satisfactory. The predictive accuracy of equation (2) and its discrimination capacity was also assessed by determining the ROC curve) by classification matrices

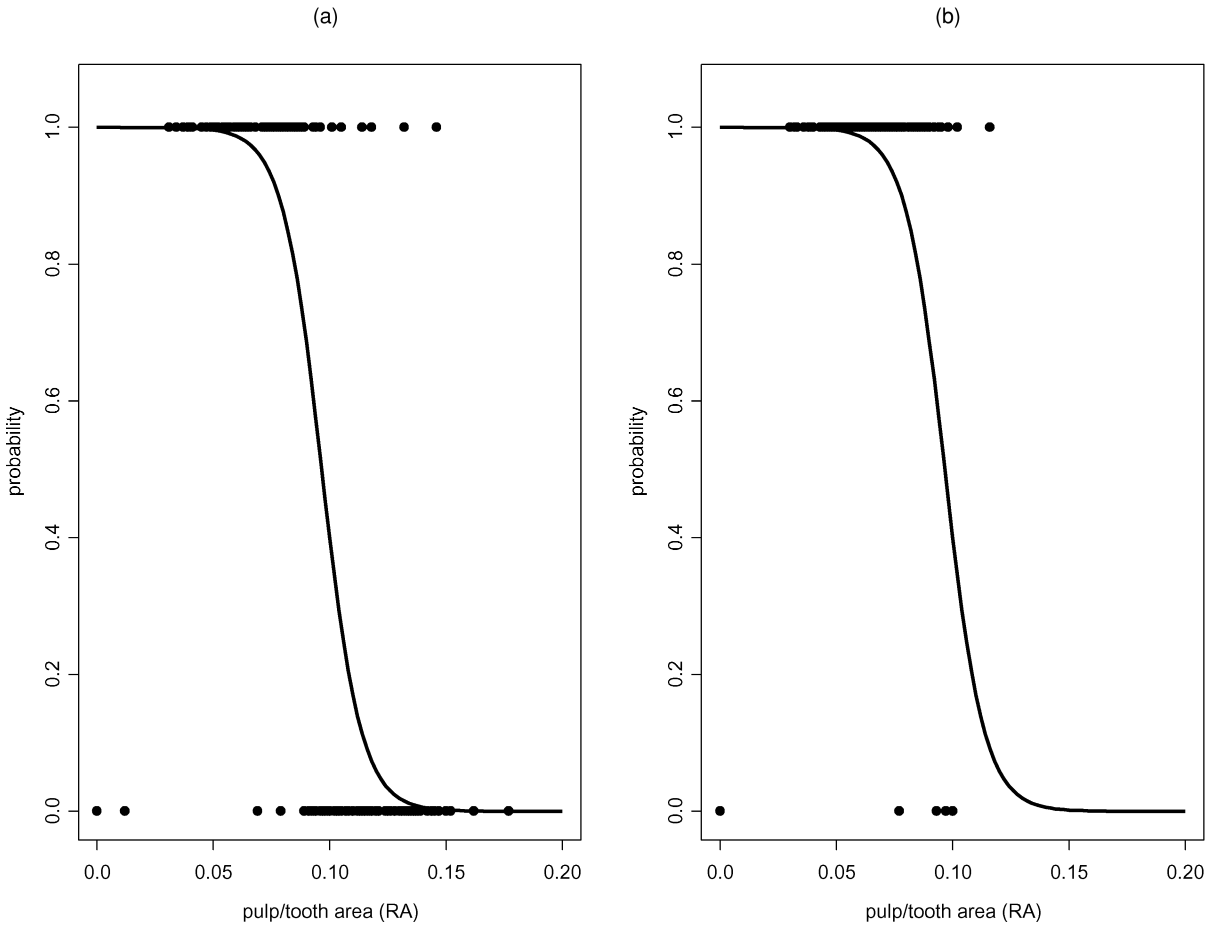

FIG. 2—*Relationship between the probability that the an individual is at least 18 years of age and the values of the ratio pulp/tooth area (RA) for Tm = 0 (a) and Tm = 1 (b).*

TABLE 3—*Classification table of 76 per cent predicted probability to be older than 18 years (predictions are derived from the logistic equation (2)).*

	Age		
	<18	≥18	Total
RA > RA*	86	20	106
RA ≤ RA*	5	201	206
Total	91	221	312

se = 0,850679 Sensitivity.
sp = 0,945055 Specificity.
VVP = 0,974093 Positive predictive value.
VVN = 0,722689 Negative predictive value.
E = 0,878205 Total correct classification.

for different levels of predicted probability that an individual is of age. The resulting ROC curve is shown in Fig. 2.

To test the legal question of whether an individual is older or younger than 18 years of age and consequently to assign an individual to the juvenile or adult population, a threshold (cut-off) value, RA*, had to be identified, where RA* is such that the individual is assigned to the juvenile population if RA > RA* and to the adult population if RA ≤ RA*. For forensic purposes, it is important that the test shows a low proportion of individuals younger than 18 years of age whose RA values were lower than or equal to RA*, and so it seemed appropriate to pay more attention to the chance of a false positive than to that of a false negative (Table 3).

TABLE 4—*Classification table which describes the discrimination performance of the third molar.*

	Age		
	<18	≥18	Total
Tm = 0	86	95	181
Tm = 1	5	126	131
Total	91	221	312

se = 0,570136 Sensitivity.
sp = 0,945055 Specificity.
VVP = 0,961832 Positive predictive value.
VVN = 0,475138 Negative predictive value.
E = 0,679487 Total correct classification.

On these grounds, we established a cut-off value of $RA^* = 0.088$ if $Tm = 0$ and $RA^* = 0.097$ if $Tm = 1$.

The sensitivity of this test (the proportion of individuals being of age whose RA ≤ RA*) was 0.91, and its specificity (the proportion of individuals younger than 18 years of age whose RA > RA*) was 0.945. The proportion of individuals with correct classifications was 92% (Table 4).

Discussion

The need for effective and reliable scientific methods to determine age, particularly adult age, within a specific population has become increasingly important in resolving court cases.

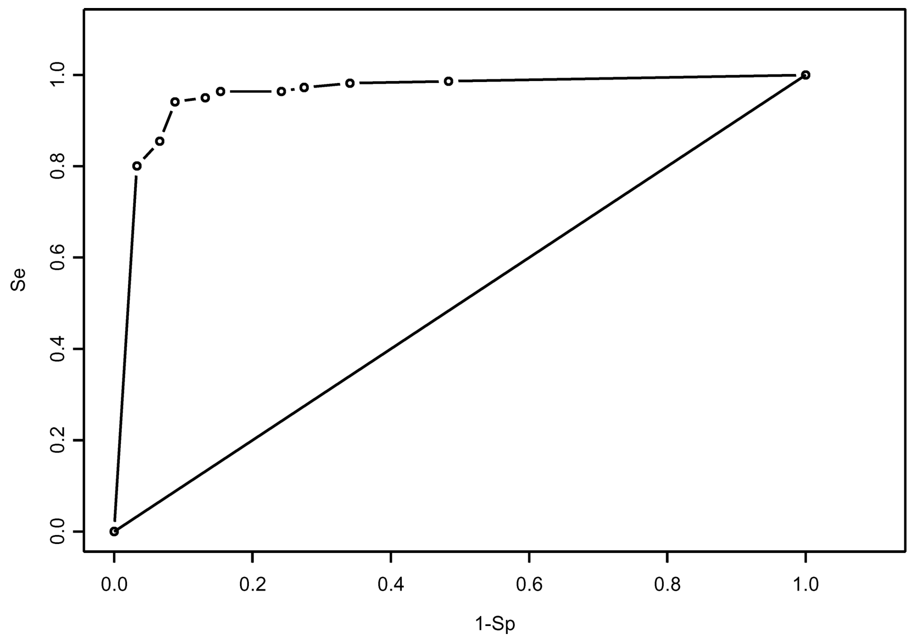

FIG. 3—*Receiver operating characteristic curve (AUC = 0.97) for of age (adult) status.*

The possibility of involving the third molar tooth as a decisive element for dental age estimation was first applied by Mincer et al. in 1993 (3), and thereafter reconsidered in many further publications (6,7,8,15). It is now the method most frequently applied method to estimate ages in the living. However, the stage of third molar formation is probably not the ideal marker to identify adult individuals.

Our data confirmed 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 0.96. However, the proportion of individuals of age whose third molars are at terminal grade H was only 57%, and the match between "at or over 18 years, or under 18 years" and "belonging to phase H or not," was 68% (Table 4).

In sum, some limitations in the use of this chronological age predictor follow from the observation that, even after adult age, many third molars have not reached complete maturation (grade H). To improve the ability to assess adult age based on molar teeth, we derive a logistic model (2) to describe the relationship between the probability that an individual is of age and two predictors: the dichotomized stage of third molar formation, Tm, and the ratio pulp/tooth area, RA. This model proved particularly appropriate for analyzing our data, which were collected retrospectively. Furthermore, logistic transformation has a direct interpretation in terms of the logarithm of the odds of the event "an individual is older than or equal to 18 years of age." The results highlight the importance and practicality of the measurement of the ratio pulp/tooth area of the second molar tooth in estimating chronological age. Allowing for RA significantly increased the sensitivity of the test (from 57.0% to 85.1%) as regards the level of third molar formation (grade H or not) to provide the "probability of having reached the 18th year of age."

To be of use in forensic odontology, logistic model (2) must produce a valid assessment of the probability of being of age. That our model achieves this aim is well demonstrated by the ROC curve (Fig. 3) and the use of Hosmer-Lemeshow χ^2 statistics to compare the actual proportions of adult subjects versus estimated probabilities.

This study also confirms our finding (13) that gender is not a significant explanatory variable of the probability that an individual is of age, when second and third molars are taken into account.

Lastly, the results of this study confirm the validity of dental methods, together with other methods for accessing biological age, in helping judges to reach proper conclusions.

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