JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, May 2011, Vol. 56, No. 3
doi: 10.1111/j.1556-4029.2011.01720.x
Available online at: onlinelibrary.wiley.com

TECHNICAL NOTE

ODONTOLOGY; ANTHROPOLOGY

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Three-dimensional Modeling of the Various Volumes of Canines to Determine Age and Sex: A Preliminary Study

ABSTRACT: Canines are usually used in anthropological and forensic sciences for sex and age determination. The best methods to estimate age are based on secondary dentine apposition, evaluated from periapical X-rays. The aim of this study was to propose a new method of sex and age estimation using 3D models to obtain more precise predictions using tooth volumes. Fifty-eight dental CT scans of patients aged 14–74 with a well-balanced sex ratio composed the sample. One hundred and thirty-three healthy canines were modeled (Mimics 12.0). The sample was divided into a training sample and a validation sample. An age formula was determined using the "pulp volume/tooth volume" ratio. Sex prediction was adjusted with total volumes. Applying the equations to the validation sample, no significant difference was found between the real and predicted ages, and 100% of the sex predictions were correct. This preliminary study gives interesting results, and this method is worth being tested on a larger data sample.

KEYWORDS: forensic science, forensic anthropology, age determination by teeth, sex determination, secondary dentine, three-dimensional models

Teeth are widely used by anthropologists to determine the sex and age of human remains, as they are the best-preserved parts of the human body, regardless of the cause of death or preservation state of the body (1–3). Methods of sex and age estimation also have an important role in forensic sciences.

Currently, many age estimation methods exist based on the different types of tooth changes, such as wear (3,4), evolution of the translucency of the root dentine (5–7), dental color changes (8), increasing tooth cementum annulations with age (9), or even racemization of aspartic acid, according to the changing proportions of the levogyre and dextrogyre forms (10–12). However, most of these techniques are very complex, destructive, and therefore not commonly used (6,10). Another interesting tooth characteristic used in age estimation is the apposition of secondary dentine. Indeed, it is known that specialized cells, the odontoblasts, border the pulp tissue on the dentine surface and deposit secondary dentine regularly during the whole life of a healthy tooth (13). The correlation between age and secondary dentine apposition has been widely demonstrated. Indeed, it is the most frequently used criterion for age estimation in adult subjects, as changes in the size of the pulp canal, resulting from the apposition of secondary dentine, are the best and the most easily available morphometric parameters (14). Secondary dentine apposition can be studied using sections or X-rays (1,2,14–18), but the most precise measurements, which give the best results for age estimation, are periapical X-rays. Periapical X-rays give more detailed information, and thus better results, than orthopantomograms (1,2,15), and complementary data from a second periapical X-ray of the same tooth, taken with a perpendicular incidence ray, allow more accurate estimation of the subject's age (14).

Concerning sex prediction, many previous studies have established that a notable sexual dimorphism exists in the permanent dentition, particularly in the canines (19–22).

The aim of this study was to propose a new method for sex and age estimation based on the pulp and total tooth volumes. These volumes were calculated exactly using IT software that allowed easy creation of a three-dimensional (3D) model of each canine.

Materials and Methods

The sample consisted of 58 dental computerized tomography (CT) scans (from 26 men and 32 women, ranging from 14 to 74 years old) with different slice thickness and interval settings (ranging from 0.3 to 0.6 mm). All scans were obtained from patients of the orthodontics and implantology departments of the School of Dental Medicine, University of Marseille, France, and were collected over the last year.

One hundred and thirty-three completely root-mineralized canines without any pathology were selected. The semi-automated

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Received 9 Nov. 2009; and in revised form 18 April 2010; accepted 2 May 2010.

software MIMICS 12.0® (Materialise NV, Leuven, Belgium) was used to translate the CT data (Fig. 1) into complete 3D models (Fig. 2), using the definite specific gray scale of mineralized dental tissues. Mineral volumes, total volumes (TV), and, by subtraction, pulp volumes (PV) were automatically calculated.

All of the data were collected in a MICROSOFT EXCEL® spreadsheet (Microsoft Corporation, Redmond, WA).

A randomized sample of 30 canines (feasibility sample) was selected to the test intra- and inter-observer reproducibilities.

The whole sample was then divided into a training sample, composed of 101 canines from 50 CT scans of which one to three canines were useful, and a validation sample, with 32 canines issued from eight CT scans.

Statistical calculations were carried out with the software SYSTAT 8.0® (Systat Software; SPSS, Inc., Chicago, IL) and SAS 9.1® (SAS Institute, Inc., Cary, NC). The statistical threshold chosen was 0.05.

Total Sample

Descriptive analysis was conducted using frequencies for the qualitative data (sex and canine grouping) and the mean, median, confidence interval, and standard deviation for the quantitative data (age, TV, PV, and PV/TV ratio). The grouping of canines by sex (chi-square test), TV by sex (analysis of variance [ANOVA]), TV by sex for maxillary or mandibular canines (ANOVA), and TV by side (*t*-test) was also evaluated. The potential link between the PV/TV ratio and age was also tested (Pearson).

Feasibility Sample

Intra- and inter-observer reproducibility were evaluated (paired-samples *t*-test) by comparing the first trial and the second trial of the first observer, with the two trials separated by an interval of 3 months, and the first trial of the first observer and the first trial of the second observer, respectively.

Training Sample

Age Estimation—Three simple linear regressions were calculated to model the age of (i) all individuals, (ii) men, and (iii) women.

Sex Estimation—A logistic regression was established to predict sex based on calculated thresholds (cut-off values of the "sensibility" and "specificity" graphs illustrating, respectively, the probabilities of a tooth belonging to a man or a woman); the regression covered only the mandibular canines of this same sample.

Validation Sample

Age Estimation—The equations obtained were applied to test the accuracy of age predictions. It was then possible to compare predicted and actual ages (Wilcoxon test).

Sex Estimation—The formula was applied to propose a sex for each mandibular canine according to the cut-off values. Then, the sex of each individual was deduced from the several predictions for that individual's mandibular canines. The frequency of correct predictions was calculated.

Results

Total Sample

The sample was composed of 26 men (45.11%) and 32 women (54.89%). The 133 canines used consisted of 35 right upper (26.32%), 37 left upper (27.82%), 31 right lower (23.31%), and 30 left lower (22.56%) canines. The chi-square test did not reveal any statistically significant difference either in sex or in grouping of canines for this sample.

Medians, means, confidence intervals, and standard deviations were calculated for the quantitative parameters: age, TV, PV, and PV/TV ratio. The descriptive statistics are illustrated in Table 1. The bivariate analysis of the grouping of canines by sex did not show a statistically significant difference (chi-square; $p = 0.845$).

The TV was more important for men (TV of all men canines = 713.73 mm^3 and TV of all female canines = 559.74 mm^3; ANOVA; $p \leq 0.0001$) and for maxillary canines for both men (with mean of TV of upper canines = 759.36 mm^3 and lower canines = 654.05 mm^3; ANOVA; $p \leq 0.001$) and women (with mean of TV of upper canines = 587.55 mm^3 and lower canines = 527.46 mm^3; ANOVA; $p \leq 0.001$). No difference existed between the right and left sides for the upper or lower canines (paired-samples *t*-test; respectively, $p = 0.676$ and $p = 0.989$). A negative correlation was observed between the PV/TV ratio and age (Pearson; $p < 0.001$ and $r = -0.591$).

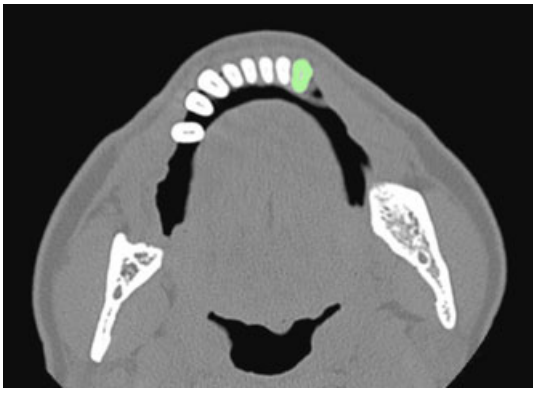

FIG. 1—*Configuration of the CT dentascanner data with the modeling software MIMICS 12.0®.*

FIG. 2—*3D model of a canine elaborated with the software MIMICS 12.0® from a dental CT scan.*

TABLE 1—*Descriptive analysis of quantitative items.*

	Age	TV	PV	PV/TV Ratio
N of cases	133	133	133	133
Minimum	14.212	388.280	1.440	0.219
Maximum	74.283	1000.790	49.110	10.887
Median	48.244	615.540	13.830	2.462
Mean	43.275	628.665	15.888	2.537
95% CI Upper	46.433	650.818	17.638	2.823
95% CI Lower	40.116	606.511	14.137	2.251
Standard Dev	18.414	129.161	10.207	1.668

Age is given in years and PV and TV in cubic millimeter. N, number of canines; CI, confidence interval; Standard Dev, standard deviation.

TABLE 2—*Mean differences and standard deviations of TV and PV.*

	TV			PV		
	MD	SD		MD	SD	
Obs 1/Obs 1	0.12	3.53	N.S.	−0.07	0.65	N.S.
Obs 1/Obs 2	−0.15	2.37	N.S.	−0.06	0.64	N.S.

The tests were made between the serie 1 of the observer 1 versus the serie 2 of the observer 1 and the serie 1 of the observer 1 versus the serie 1 of the observer 2. The results of means differences are given in mm^3.

MD, means difference; SD, standard deviation; N.S., not significant.

Feasibility Sample

Intra-observer and inter-observer reproducibility of modeling the TV and PV did not reveal any statistically significant difference (paired-samples *t*-test; Table 2).

Training Sample

Age Estimation—The equations given by the simple linear regressions to model age were as follows:

- for all individuals: age = 9.22 × PV/TV ratio ($p < 0.001$; $R^2 = 0.38$),
- for men: age = 11.98 × PV/TV ratio ($p < 0.001$; $R^2 = 0.47$),
- for women: age = 7.57 × PV/TV ratio ($p < 0.001$; $R^2 = 0.32$).

Sex Estimation—The logistic regression developed from mandibular canines gave the following equation to determine sex: −6.855 + 0.011 TV, with the corresponding sensibility and specificity graphs illustrated in Fig. 3. The cut-off value was 0.395 ($c = 0.733$).

Validation Sample

Age Estimation—Applying the three linear regression models, it was possible to compare the real and predicted ages with a Wilcoxon test, which showed no statistically significant difference between the real and predicted ages, as illustrated in Table 3.

Sex Estimation—All of the predictions obtained with the logistic regression concerning the mandibular canines were correct (100%).

Discussion

The need to estimate the age of skeletons of adults is important in both anthropological and forensic sciences. Unfortunately, the poor condition of human remains often prevents their use for age estimation. For this reason and because of their high resistance to all environmental conditions, teeth are the most widely used elements for age estimation (1–3).

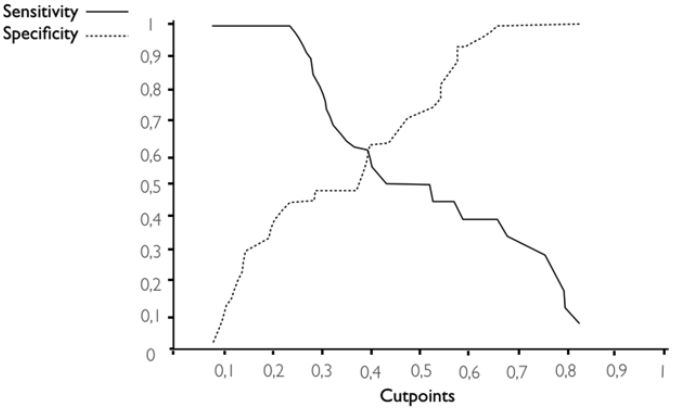

FIG. 3—*Graphic determination of the cut-off value in the logistic regression from mandibular canines.*

TABLE 3— *Comparison of means difference between chronological and predicted ages.*

	Global Equation	Male	Female
Means difference	−1.45	2.02	−4.90
p	0.39	0.67	0.09

The results are given in years.

The choice to use canines was made for several reasons (2,15,20,21,23–31):

- their high level of survival in the dentition, regardless of age,
- they undergo less wear than posterior teeth because of the diet, and they undergo less wear than anterior teeth because of their specific particular function,
- they are the single-root teeth with the largest PV, which allows modifications to be observed more easily than for other teeth with smaller PV or for pluriradicular teeth,
- they are normally the oldest teeth and, thus, are found even in historical populations,
- mandibular canines present the most important sexual dimorphism.

To be included in the sample, the canines had to be healthy and have completed root edification, which corresponds to individuals older than 13 years old. The teeth could not have caries, apical pathology, or particular abrasions, which could modify the normal continual apposition of secondary dentine (3,5,18,23–25).

The total procedure proposed, including image reconstruction and all calculations, took about 20 min per tooth, which is much faster than the time required for other protocols previously reported in the literature (26).

In this study, 30 canines were randomly selected to test and confirm the intra- and inter-observer reproducibility of the method. Previous studies also dealing with the correlation between age and the apposition of secondary dentine either did not show any reproducibility (2,14,27) or only showed intra-observer reproducibility (1,7,16,18,28).

The choice to include dental CT scans including one to three useful canines in the training sample and to include only scans with four useful canines in the validation sample was made to develop a technique that would be reliable even when all of an individual's canines are not available.

Concerning age estimation, the use of secondary dentine apposition allows age estimation of individuals of any age because it will work for any teeth for which root edification is finished, contrary to many other techniques that are only efficient for the young (29) or for adults over 50 (7).

The interest in using the PV/TV ratio for age estimation has been highlighted in many previous studies using the "pulp area/tooth area" ratio (1,2,14–18,30,31). The negative correlation between the PV/TV ratio and biological age was confirmed in this work. The PV/TV ratio parameter is advantageous because it is more scientifically controllable and much less dependent on technical ability compared with the parameters proposed in many other studies, such as attrition (4,29,32,33), periodontosis height (7,29), root dentine translucency (5–7,24,34,35), dental color (8), or cementum apposition (36). All of the inconsistencies in these parameters have already been discussed (37–41).

The use of dental CT scans has several advantages: it is possible to work with objective and precise criteria, such as the PV/TV ratio; it is a simple technique to implement and is applicable to a wide range of subjects or specimens, including living persons and corpses from both present and past populations (1,2,15); and it does not require tooth extraction for sections or periapical X-rays with perpendicular incidence rays (14). Because of the increasing use of virtopsy, this method could even be easily used in current forensic practice.

With the new proposed equations to estimate age, no significant difference was found between the predicted and real mean ages. The initial results obtained in this preliminary work, with R^2 values between 0.32 and 0.47, are better than those of the only previously reported pilot study, which used 28 single-root teeth and proposed a dental age estimation method without tooth extraction using cone-beam CT scanners and 3D models, with $R^2 = 0.29$ (27). The difference could be explained by the larger sample used in the present study, which allowed better adjustment of the equations and covered a wider age range. The statistical analysis of this preliminary study by comparison of averages allowed confirmation of the adequacy of the model and authorizes the implementation of this protocol adapted to a forensic context and thus estimation of an individual's age. A larger data sample with a homogeneous age distribution is now required to optimize the method.

Finally, concerning sex evaluation, the use of the TV of the mandibular canines gave excellent results (100% correct predictions). This confirms the results of many previous studies that have shown that the greatest sexual dimorphism among all teeth exists in the mandibular canines (19,22,28,42). Our results are comparable to those of these studies, which also used the lower canines but used the ratio of the maximum crown width to the inter-canine width, giving the mandibular canine index (MCI). The MCI was able to determine sex with an accuracy of 83.3–84.3% in men and 81–87.5% in women (43–45). These results are slightly better than the best results obtained up to that point in a reported study, with 64–94% correct sex predictions (46). This result could be explained by the fact that 3D models allow 3D measurements, which are more precise than the simple distances used previously with other radiographic techniques.

This study is a promising preliminary work, which must be expanded with a larger data sample with a more homogeneous age distribution to refine this new proposed method.

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