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Age estimation from canine volumes

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Abstract Techniques for estimation of biological age are constantly evolving and are finding daily application in the forensic radiology field in cases concerning the estimation of the chronological age of a corpse in order to reconstruct the biological profile, or of a living subject, for example in cases of immigration of people without identity papers from a civil registry. The deposition of teeth secondary dentine and consequent decrease of pulp chamber in size are well known as aging phenomena, and they have been applied to the forensic context by the development of age estimation procedures, such as Kvaal–Solheim and Cameriere methods. The present study takes into consideration canines pulp chamber volume related to the entire teeth volume, with the aim of proposing new regression formulae for age estimation using 91 cone beam computerized scans and a freeware open-source software, in order to permit affordable reproducibility of volumes calculation.

Keywords Forensic radiology · Age estimation · Dental age · Teeth volume · CBCT · Canines

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Introduction

Methods of estimation of biological age are constantly evolving and find daily application not only in clinical fields such as the differential diagnosis of dysmetabolic disease or orthodontic therapies, but also in forensic radiology field in cases concerning the determination of the chronological age of a corpse or of a living subject.

Age estimation of unidentified bodies is a crucial step in the reconstruction of biological profile. Age estimation on a living person is more frequently approached by forensic pathologists and anthropologists and often concerns migrants from foreign countries without identity papers or information from a civil registry [1]. Teeth and bone development are frequently used for age estimation of subadults and give more precise results if compared to methods commonly used for age estimation of adults.

On the other hand, dental methods have several advantages because teeth are very resistant to chemical and physical factors. Moreover, pathologic and environmental factors have less influence on tooth development if compared to skeletal elements [2]. In addition, teeth may provide information concerning age also in cases of adults, with time dentin and pulp chamber change. In detail, with age, dentine deposition goes on slowly and consequently the pulp chamber decreases in size. Starting from this consideration, various authors developed age estimation methods based on pulp chamber contraction. In 1950, Gustafson [3] published a method that takes into consideration, among other factors, pulp chamber contraction; however, the method cannot be applicable to the living persons, since it requires a thin tooth slice. The improvement of radiographic technology renders less-invasive analysis of pulp chamber and allows operators to develop methods which can be applied also to living subjects. These methods are

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based on the correlation between chronological age and ratio between linear measurements on a tooth radiograph [4–10]. Other methods take into consideration the ratio between the radiographic image of the pulp chamber area and the entire tooth area [11–15]. All these methods are therefore based on mono- or bi-dimensional measurements performed on a radiograph of three-dimensional structures.

The use of computerized tomography (CT) allows the operators to reach a more precise quantitative volume evaluation of all the dental tissues. As a consequence of the technological improvement, in the last years, the 2D and 3D image-based volumetric studies have acquired a growing importance, as also shown by the number of publications concerning the different applications of such technology [16–18].

Literature shows that studies in the field of correlation between teeth volume ratios and chronological age are still at the beginning and are worth being analyzed in depth by further studies. Teeth commonly used by authors are monoradicular ones, often canines; radiographic images come from micro-CT, MDCT and CBCT; volumes are calculated via commercial license software. From the literature review, it also appears how the proposed regression formulae are different among authors, perhaps because of the different geographic origin of the population or the different population age distribution. The present study starts from these considerations, with the aim of proposing new regression formulae using CBCT images, as cone beam tomographs are nowadays quite common in dentistry. Canines were taken into consideration since they usually survive than other teeth regardless of age, are less subjected to wear, and have the biggest pulp chamber among monoradicular teeth. In addition, a freeware, open-source software was used in order to permit affordable reproducibility for calculating volumes.

Materials and methods

CBCT from 91 subjects, 42 males and 49 females aged 17–80 (Table 1) were used to determine pulp chamber volumes and entire dental volume of the upper right canines. All data came from CTs performed because of clinical reasons related neither with the present retrospective cohort study nor with pathologies of upper right canines. The study was performed according to the current rules regarding institutional

review board and informed consent ("Autorizzazione generale al trattamento dei dati personali effettuato per scopi di ricerca scientifica"—Published on "Gazzetta Ufficiale" n. 72 Del 26 marzo 2012). Exclusion criteria were the presence of oral pathologies, facial and oral deformities, and systemic diseases. Only sound, completely developed teeth with closed apices were taken into consideration.

The machine used was an i-Cat Next Generation (Imaging Sciences International, Hatfield, Pa) with the following setting: voxel size 0.4 mm, scan time 8.9 s, mA 5, mAs 19, kV 120, scan width 23.2 cm, and scan height 17 cm. DICOM files were then elaborated via the freeware and open-source software OsiriX [19]. Pulp chamber and entire dental volumes were calculated highlighting on axial slices the entire tooth and the pulp chamber perimeters by the tool ROI (Region of Interest). OsiriX can automatically generate ROIs on slices between two manually created ROIs, so, via the tool, "pencil" ROIs were generated every 3–4 slices, from the tooth apex to the most occlusal point of the crown.

Missing ROIs were then automatically generated by the software by the function "generate missing ROIs" and were verified analyzing each axial slice to correct them if necessary. Volumes ROIs were calculated by the OsiriX function "ROI Volume—Compute Volume". Teeth volumes (DV), pulp chamber volumes (PV), and their ratios (PV/DV) were then calculated.

In order to verify the correlation between volumetric PV/PD ratios and age, a linear regression analysis was conducted, in which the PV/PD ratio and age were considered, respectively, as dependent variable and independent variable. The possible difference between a male and female subpopulation was verified by means the application of Student's t test. The regression line by means of ordinary least-squares method for whole population and for male and female subpopulations was calculated. The estimation of uncertainty degree of the regression was measured using the parameters r (correlation coefficient or Pearson product moment correlation coefficient) e R^2 (coefficient of determination). Statistical analysis was performed by Microsoft Excel©.

Results

Dental volumes have a continuous distribution with a maximum modal from 0.4 to 0.5 cm^3 in the female group and

Table 1 Age distribution within the chosen population

Age (ranges)	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–75	75–80	80–85	85–90	Total
All	10	7	8	6	8	6	6	8	5	10	7	8	1	1	0	91
Males	5	2	2	4	5	3	3	4	1	4	5	3	1	0	0	42
Females	5	5	6	2	3	3	3	4	4	6	2	5	0	1	0	49

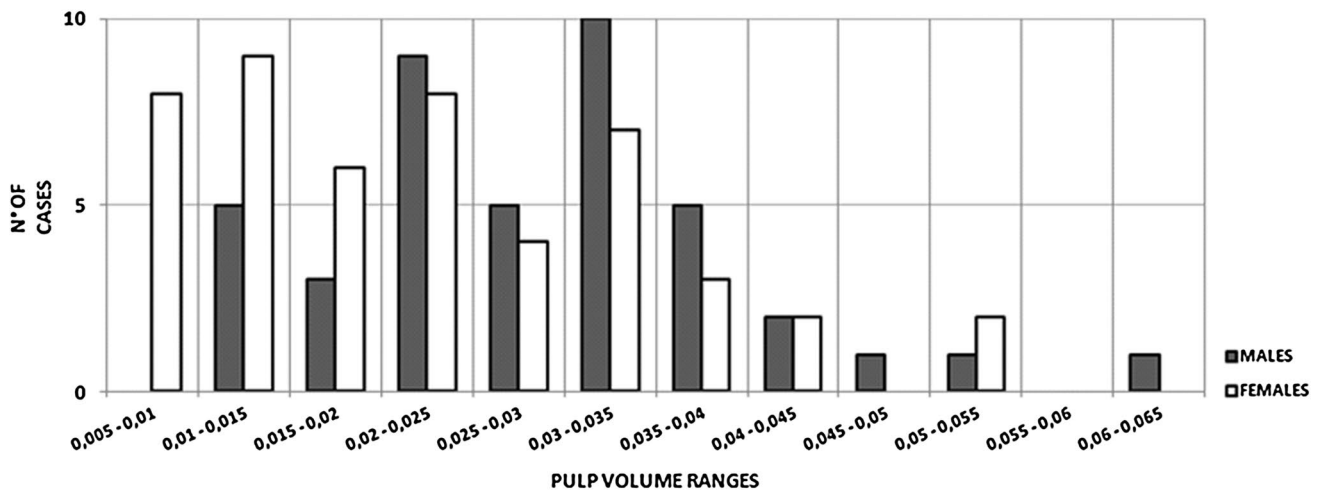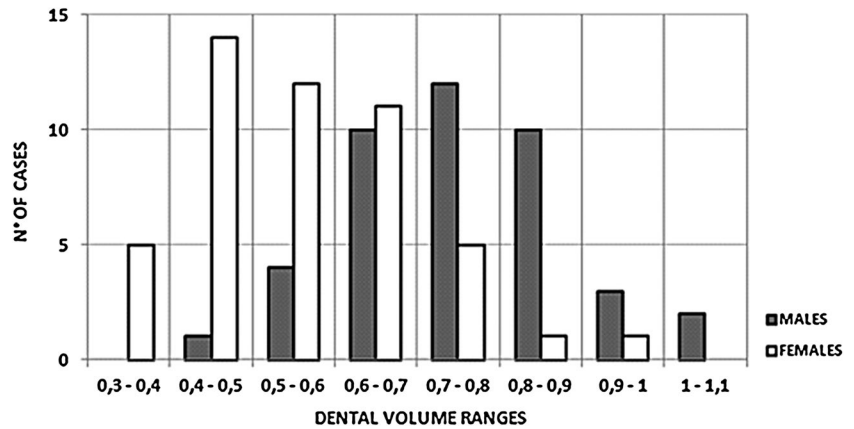**Fig. 1** Dental volumes distribution in both sex

Fig. 2 Pulp distribution in both sex

from 0.7 to 0.8 cm^3 in the male group (Fig. 1) Pulp chamber distribution is homogeneous in both sexes with the exception of the lower interval from 0.005 to e 0.01 cm^3 (Fig. 2). The PV/PD ratios distribution is homogeneous, with the exception of the upper interval from 0.07 to 0.08 cm^3.

As data distribution did not show any abnormal or significantly eccentric element, all 91 teeth were included for the regression analysis. Regression formulae obtained are shown in Table 2 with respective r and R^2 parameters.

PV/DV ratio turned out to be moderately correlated to chronological age with linear function for the female group and less correlated, but statistically significantly, for the male and the whole population. However, the comparison between two regression lines for males and females by Student's t test did not detect a significant difference (two-tailed p value for slope is 0.93 and 0.92 for intercept), and therefore it is possible to adopt a common regression line to all samples.

The better correlation in the female group is probably due to the more steady distribution in the higher PV/DV

Table 2 Regression formulas and respective r and R^2 for whole population and for male and female subpopulations

	Regression formula	r	R^2
Male group	$Y = -795.3X + 75.5$	-0.513	0.263
Female group	$Y = -774.8X + 74.4$	-0.696	0.485
Global sample	$Y = -780.9X + 74.4$	-0.624	0.389

values (>0.5), while in the male group, there is a higher density in intermediate values (0.03–0.04).

Prediction intervals, predicted by desired confidence intervals and defined as observed data variance function, were calculated to describe prevision accuracy (Table 3; Fig. 3).

Age estimation using linear regression formulae from the studied sample seems not to be very precise: prediction interval is around ±30 years with 95 % confidence for males and females. Different intervals with a lower excursion (higher precision) are therefore listed, but they

Table 3 Prediction interval with different confidence intervals

Estimated age by linear regression	Confidence estimation (%)	Prediction interval (years)
All ($Y = -780.9X + 74.7$)	95	±29
	90	±24
	80	±19
	70	±15
	60	±12
Males ($Y = -795.3X + 75.5$)	95	±32
	90	±27
	80	±21
	70	±17
	60	±14
Females ($Y = -774.8X + 74.4$)	95	±28
	90	±23
	80	±18
	70	±15
	60	±12

are obviously associated with a higher uncertainty (lower accuracy); at 60 % confidence interval, there is a prevision interval of ±12 years in the female group and ±14 years for males.

Discussion

The estimation of chronological age in cases of unknown decedents is a crucial step in the biological profile reconstruction and provides relevant information for personal identification; age estimation is important as well when applied to the livings for civil, criminal, or social issues.

Methods developed for subadult subjects are indeed more precise than those used when bones and teeth are completely developed; therefore, the need for improving methods of age estimation applicable to adults is mandatory. The deposition of secondary dentine, and consequent decrease in pulp chamber, is well known by the forensic community and widely used for age estimation through different methods. In the last few years, different authors have studied the correlation between chronological age and the ratio between the volume of the pulp chamber of a tooth and its entire volume adopting images from micro-CT, MDCT e CBCT processed by commercial software. Vandevoort et al. [20] were the first to use a micro-CT on 43 monoradicular teeth to assess the correlation between chronological age and the ratio between the pulp chamber volume and the entire tooth volume by specifically developed software. Though it turned out to be a time-consuming method and the correlation coefficient was moderate ($r = -0.57$; $R^2 = 0.31$), the authors gave a great impulse to the following research.

Aboshi et al. [21] used 100 lower premolars to develop an age estimation method based on the ratio between the pulp chamber volume and the entire tooth volume determined via a micro-CT and 3D reconstruction via TRI/3D-BON software. Someda et al. [22] performed micro-CTs on 155 sound central inferior incisors with closed apices. With the aid of commercial software (TRI/3D-BON, Ratoc System Engineering, Japan), they obtained regression formulae which consider the ratio between the pulp chamber volume and the entire tooth volume except the enamel.

Yang et al. [23] found a moderate correlation coefficient from a linear regression ($r = -0.54$; $R^2 = 0.29$) using the ratio between volumes of pulp chambers and of the entire tooth of 28 monoradicular teeth. They used a cone beam computed tomography (CBCT) and specifically developed software.

Tardivo et al. [24] evaluated volumes of 133 canines via CBCT. Volumes were calculated using CBCT and the commercial software MIMICS (Materialise NV, Leuven, Belgium). Authors published three regression formulae with a correlation coefficient of -0.62 and a coefficient of determination of 0.38 including male and females together,
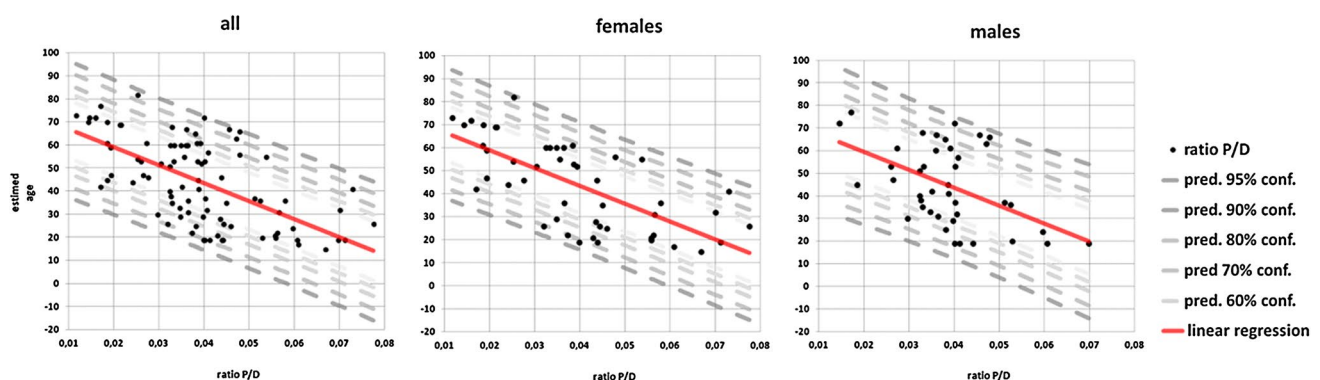
Fig. 3 Confidence and prediction interval graphs

$r = -0.68$ and $R^2 = 0.47$ for males and $r = -0.57$ e $R^2 = 0.32$ for females.

Star et al. [25] adopted the software SimPlant Pro in order to calculate volumes from 111 teeth CBCT; they found a higher correlation between volume ratios and chronological age in females than in males ($R^2 = 0.37$ females; $R^2 = 0.30$ males) and a higher correlation using incisors ($r = -0.27$) if compared to canines. The lower correlation found using canines could be due to the small number of teeth (32).

Jagannathan et al. [26] performed CBCT of 188 canines and calculated pulp chamber and tooth volume via a software by GE Systems, USA; they elaborated a regression formula with a lower error ($r = -0.63$) than Yang's one (2006). Authors suggest then that correlations may vary in different populations and specific formulae should be applied for the age estimation.

Sakuma et al. [27] used a multi-detector computed tomography (MDCT) and the commercial software Synapse (Fujifilm Medical Co., Ltd., Tokyo, Japan) in order to determine the volumes of 136 inferior premolars. Correlation coefficients between volume ratios and chronological age are $r = -0.43$ and $R^2 = 0.186$ for females and $r = -0.772$ and $R^2 = 0.596$ for males.

Finally, Tardivo et al. [28] studied 210 CT scans from individuals with four canines aged from 15 to 85 using the commercial software Mimics 10.01. They developed seven mathematical models which appear more efficient than those of their previous studies; they also found that the most powerful model was the one that took into consideration maxillary canines.

In this study, CBCT of sound upper canines from living subjects were used to evaluate the correlation between patients' age and the volume ratio between pulp chamber and entire tooth with the aid of a freeware, open-source software. CBCTs were used because nowadays, and they are quite common among dental practitioner; canines were chosen because they are already analyzed in previous studies and frequently found to be more sound than other teeth in situ; lastly a freeware, open-source software was used in order to render more affordable reproduction of the proposed method and formulae.

Linear models published by Star et al. [25] and by Tardivo [28] (who studied the correlation between canines volumes and age) have correlation indices (r) ranging between a minimum of 0.27 and a maximum of 0.68. Correlation coefficients from the present study are similar to Tardivo's results published in 2011, but lower than Tardivo's data published in 2014. Comparing the results from the present study to Star's, a higher correlation can be noticed in the present study, probably because of the lower number of canines used by Star (32) in comparison with the present study (91).

Determination index R^2 for females is 0.485; 0.263 for males, and 0.389 when considering both sex. The higher correlation among the female group is probably due to a steadier distribution even in higher values of PV/DV (>0.05), while in the male group, a higher density was observed in intermediate values.

Age estimation adopting the proposed regression formulae has a prediction interval of ±12 years with 60 % confidence interval; however, with 95 % confidence, the prediction interval is ±30 years. The error range is higher than those reported by methods of age estimation usually applied to subadults, but is comparable with data reported by methods commonly applied to the adults, both in cases of unknown decedents [2] and living people [2, 8, 13, 14]. In addition, the large diffusion of CT scan technology will enable the operators to provide a more detailed analysis of pulp chamber size and therefore will improve the development of methods based on the deposition of secondary dentine, which will gain in the next future more and more importance, not only in the forensic context, but also in the clinical practice; in fact one has also to consider that, for example, migrants without identity information need to be adequately assessed from a clinical point of view, although different biological parameters have to be evaluated by comparing their degree of development with the real age in order to provide an early diagnosis. From this point of view, reliable age estimation has a clinical impact, with consequent improvement of the patient's health conditions.

In conclusion, the exposed data suggest that the study of pulp chamber contraction for age estimation is promising and is worth being analyzed in depth by further studies focused on larger samples, characterized by a steady age distribution. The next studies will also take into consideration other dental elements in order to improve the performances of regression formulae.

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