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Forensic anthropology population data

Age estimation based on pulp chamber volume of first molars from cone-beam computed tomography images

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ABSTRACT

Aim: To establish a method that can be used for human age estimation on the basis of pulp chamber volume of first molars and to identify whether the method is good enough for age estimation in real human cases.

Materials and methods: CBCT images of 373 maxillary first molars and 372 mandibular first molars were collected to establish the mathematical model from 190 female and 213 male patients whose age between 12 and 69 years old. The inclusion criteria of the first molars were: no caries, no excessive tooth wear, no dental restorations, no artifacts due to metal restorative materials present in adjacent teeth, and no pulpal calcification. All the CBCT images were acquired with a CBCT unit NewTom VG (Quantitative Radiology, Verona, Italy) and reconstructed with a voxel-size of 0.15 mm. The images were subsequently exported as DICOM data sets and imported into an open source 3D image semi-automatic segmenting and voxel-counting software ITK-SNAP 2.4 for the calculation of pulp chamber volumes. A logarithmic regression analysis was conducted with age as dependent variable and pulp chamber volume as independent variables to establish a mathematical model for the human age estimation. To identify the precision and accuracy of the model for human age estimation, another 104 maxillary first molars and 103 mandibular first molars from 55 female and 57 male patients whose age between 12 and 67 years old were collected, too. Mean absolute error and root mean square error between the actual age and estimated age were used to determine the precision and accuracy of the mathematical model. The study was approved by the Institutional Review Board of Peking University School and Hospital of Stomatology.

Results: A mathematical model was suggested for: $AGE = 117.691 - 26.442 \times \ln(\text{pulp chamber volume})$. The regression was statistically significant ($p = 0.000 < 0.01$). The coefficient of determination (R^2) was 0.564. There is a mean absolute error of 8.122 and root mean square error of 5.603 between the actual age and estimated age for all the tested teeth.

Conclusion: The pulp chamber volume of first molar is a useful index for the estimation of human age with reasonable precision and accuracy.

1. Introduction

Age estimation of living individuals or corpses is important in forensic sciences. Due to the fact that teeth are highly resistant to mechanical, chemical or physical impacts and time [1,2] as well as that age-related changes of tooth are minimally influenced by the nutrition, environment and living conditions that an individual is submitted to [3,4], many age estimation methods based on teeth have been established. Some of the methods were developed from the time of tooth emergence and tooth calcification in oral cavity [3,5–7]. Analysis on the stage of dentition helps in age determination in children and adolescents but is difficult in adults that the development of permanent dentition completes [3]. The methods based on biochemical characteristics of teeth such as amino acid racemization [8] and carbon-14 isotope [9] was also introduced. However, these methods are time-consuming and require sophisticated laboratory equipment and tooth extraction. Tooth extraction is unethical and impossible in living individuals. Analysis on dental wear is another most commonly used method for age estimation [10,11]. The drawback of the method is that the

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attrition level of tooth is strongly influenced by diet and personal habits [12–14].

Secondary dentine apposition is a significant morphological dental age predictor. It begins after the apical part of root has completely developed, tooth erupted into oral cavity and tooth begins to function. This apposition continues through people's whole life. Decrease in pulp cavity size is an age-associated process, and may be influenced by local factors, such as attrition, carious lesions and changes in osmotic pressure etc. [15–19]. Many two-dimensional images like panoramic [20] or periapical radiograph [21] have been used to quantify the size of pulp cavity and correlate it with age. In recent years, with the wide use of three-dimensional images in practice, three-dimensional image datasets obtained from cone beam CT, CT and Micro CT have been applied to investigating the potential relationship between age and volume ratio of pulp cavity to entire tooth [22–28], and concluded that pulp/tooth volume ratio is a useful indicator for age. In the analysis of these studies, we found that the research samples are relatively small and only included single-rooted teeth. Considering the fact that human teeth contains not only single-rooted but multi-rooted teeth, one study exclusively focusing on multi-root teeth with a relative large sample size is necessary to further disclose the relationship between secondary dentine apposition and age. Thus, the aim of the present study was to establish a method for the age estimation from multi-rooted teeth in the CBCT images and to identify whether the method is good enough for age estimation in real human cases.

2. Materials and methods

2.1. Method establishment

2.1.1. Subjects

CBCT images of 373 maxillary first molars and 372 mandibular first molars were retrospectively collected from 190 female and 213 male patients whose age between 12 and 69 years old from the database in Peking University School and Hospital of Stomatology. The birth date of all subjects was confirmed in the hospital's patient information system. The age and sex distributions of the subjects are shown in Table 1.

The inclusion criteria of the first molars were: no caries, no excessive tooth wear, no dental restorations, no artifacts due to metal restorative materials present in adjacent teeth, and no pulpal calcification. To specify the extent of "excessive tooth wear", we borrowed the Smith and Knight's tooth wear index (TWI, Table 2) [29] and the results from the tooth wear epidemiological investigation in Chinese population [30]. The tooth with TWI $\leq$ 2 before 50 years and TWI $\leq$ 3 after 50 years was included. Only one maxillary first molar and one mandibular first molar in each person were included for analysis.

2.1.2. Image acquisition and segmentation

All the CBCT images were acquired with a CBCT unit NewTom VG (Quantitative Radiology, Verona, Italy). Exposure parameters for CBCT image were 110 kVp, 4.19–107.39 mAs in accordance with patient size and filed of view. Selection of field of view (FOV) was based on clinical need. The FOVs included 6 cm × 6 cm, 8 cm × 8 cm, 12 cm × 8 cm or 15 cm × 15 cm.

Acquired images were subsequently reconstructed with a voxel-size of 0.15 mm and exported as DICOM data sets. These data were then imported into a 3D image semi-automatic segmenting and voxel-counting software ITK-SNAP 2.4 (open source software, www.itksnap.org) for the calculation of pulp chamber volumes [31].

To avoid the influence of the complex root system of first molars and also to simplify the segmentation procedure, we set the pulp chamber floor as the "cut plane" to cut off the roots and calculate the volume of tooth pulp chamber. The final segmented image of tooth pulp chamber is shown in Fig. 1.

2.1.3. Mathematical model establishment

Logarithmic regression analysis was conducted with age as dependent variable and pulp chamber volume as independent variable to establish a mathematical model for the estimation of human age. To establish age estimation mathematical models suitable for unknown sex, logarithmic regression analysis was also conducted with age as dependent variable and pulp chamber volume as independent variable for maxillary first molars and mandibular first molars separately.

2.1.4. Segmentation accuracy

To validate the measurement accuracy of image segmentation and volume calculation, images of ten extracted molars were acquired with the CBCT unit NewTom VG and a high-resolution Micro CT unit (Inveon, Siemens, Germany). Projecting parameter of the Micro CT was 80 kV, 500 mA, and 8.82 μm-effective pixel size. The images were then imported into the software ITK-SNAP 2.4 to calculate the pulp chamber volume. With the volume calculated from Micro CT images as the reference standard, the volume calculated from the CBCT images was quantified for the accuracy of the volume calculation.

2.1.5. Inter-and intra-observer variability

All measurements were carried out by the same examiner. To test intra-examiner reproducibility, slice data of a random sample of 20 maxillary first molars and 20 mandibular first molars were re-examined after an interval of 3 weeks. At the same time, the same slice data of 20 maxillary first molars and 20 mandibular first

Table 1
Age and sex distribution of group samples used for method establishment.

Age (year)	Male	Female	Maxillary first molars	Mandibular first molars
12–20	43	43	86	86
21–30	47	44	91	91
31–40	51	48	91	90
41–50	36	28	56	58
51–60	23	19	33	30
61–69	13	8	14	17
Total	213	190	373	372

Table 2
Smith and Knight tooth wear index.

Score	Tooth surface	Criteria
0	B/L/O/I	No loss of enamel surface characteristics
	C	No loss of contour
1	B/L/O/I	Loss of enamel surface characteristics
	C	Minimal loss of contour
2	B/L/O	Loss of enamel exposing dentine for less than one third of surface
	I	Loss of enamel just exposing dentine
	C	Defect less than 1 mm deep
3	B/L/O	Loss of enamel exposing dentine for more than one third of surface
	I	Loss of enamel and substantial loss of dentine
	C	Defect less than 1–2 mm deep
4	B/L/O	Complete enamel loss-pulp exposure-secondary dentine exposure
	I	Pulp exposure or exposure of secondary dentine
	C	Defect more than 2 mm deep-pulp exposure-secondary dentine exposure

B = buccal; L = lingual; O = occlusal; I = incisal; C = cervical.