The role of cone-beam computed tomography in age estimation

ABSTRACT

Objective. To assess the use of cone-beam computed tomography in age estimation. Methods. Randomly selected 100 sets of cone-beam computed tomographic images were inspected and a mandibular left lateral incisor was chosen for the measurement of the dental pulp in each case using the SimPlant Pro Crystal. The axial section of the image was selected and magnified. The portion of the tooth selected for analysis was the most coronal slice without enamel and the next 10 slices going up to the crown or down to the root. The volumes of pulp and pulp plus dentin were calculated. Individual pulp-to-tooth volume ratios were also calculated and analyzed. Results. There was a strong inverse relationship between age and pulp volume and turned out to be statistically significant (P<0.001). However, there was no relationship between age and dentin volume, and no significant correlation between pulp volume and dentin volume. Conclusion. The use of cone-beam computed tomography was very useful for age analysis. It accurately revealed the inverse relationship between age and pulp volume. However, due to the large variation of pulp size within a given age-group, in this study pulp size was not an accurate indicator of age. Further comparisons using pulp versus dentin volume ratios should be carried out.

Key words: Age factors; Cone-beam computed tomography; Forensic dentistry

Introduction

Age determination is one of the most important issues in the field of forensic science. In cases where human remains cannot be clearly identified due to incineration, mutilation or decomposition (as a result of chemical immersion), dentition becomes the only means of deriving information about the individual’s identity. Moreover, if the individual’s age can be accurately estimated, the field of possible identities can be narrowed and time spent on subsequent investigations can be considerably shortened.

Forensic dentists analyze the unique features of teeth to aid age estimation. For example, the assessment of tooth counts, the stage and status of tooth eruption \(^{1-6}\); the Demirjian’s system \(^{7,8}\); the Gustafson’s method \(^{9,11}\); the aspartic acid racemization \(^{12}\); the Carbon-14 method \(^{13}\); the measurement of enamel cross-striation \(^{14,15}\); and pulp/dentin volume \(^{16-18}\) all have a role.

Based on the fact that there is a slow age-progressive deposition of secondary
dentin that ultimately occludes the dental pulp chamber, a relationship between the pulp volume, dentin volume, and age can be derived. The radiographic measurement of pulp volume and dimensions can be readily undertaken with the assistance of computer programs. These methods are non-invasive, relatively inexpensive, and do not require tooth extraction. Hence, they can also be performed in living individuals.

The cone-beam computed tomography (CBCT) machine can produce incredibly precise and profound images, data, and information. These three-dimensional (3-D) imaging techniques make image visualization much clearer and accurate, and allow the observer to view the specimen in coronal, sagittal, and axial planes. The reconstructed data in 3-D gray-scale and color formats make visualization of the anatomical structures much clearer and precise. Image manipulation allows tooth measurement in 3-D planes that enables accurate measurement compared to 2-dimensional images (like the orthopantomogram and periapical radiographs). The latter may suffer from inherent magnification and distortion, depending on which technique has been used to obtain the image.

The application of CBCT machinery and the relevant computer software can greatly improve the confidence with which one can measure small areas like the pulp and dentin. The dimensional accuracy of CBCT has been shown to be comparable to conventional CT 19. Moreover, Star et al. 20 quantified the accuracy of the volume calculations performed with SimPlant Pro software (Materialise Dental NV, Leuven, Belgium) by measuring the real pulp and tooth volumes of three extracted monoradicular teeth with reamed pulp canals. Last but not least, the radiation dose of CBCT is lower than that of conventional CT 21. The present study was conducted to assess the use of CBCT in age estimation.

Methods

A random selection of 100 sets of patient images undertaken with the iCAT Classic (Imaging Sciences, Hatfield [PA], USA) CBCT device at the Prince Philip Dental Hospital, Hong Kong were investigated from March to September 2011. All images were inspected and a mandibular left lateral incisor was chosen for the measurement of the dental pulp in each case.

The ethnic origins of the samples were Chinese. All the patients had been scanned with the same iCAT machine under the same specifications (the slice thickness and the slice interval). The default slice thickness of the captured CBCT data in this iCAT was 0.4 mm. In other words, the total thickness of 4 mm was reviewed in each sample. The chronological ages at the moment of radiological exposure were recorded. The medical and dental histories of the subjects associated with the selected samples were revealed to ensure that there were no systemic or genetic conditions that could affect tooth and pulp volume (e.g. acromegaly, dwarfism, vitamin D deficiency, dentinal dysplasia, and cleidocranial dysostosis).

The teeth selected had not been transplanted, were deemed to be intact, fully developed, free of caries, had not been subject to dental restoration, nor did they display evidence of a root filling or severe incisal wear. Moreover, the teeth examined were free of metal and other artifacts which might affect the assessment of the pulp chamber. If any patient presented with these features, they were excluded from the study.

Lateral incisors were also chosen in this study because in the Chinese population they are less liable to caries than premolars and molars 22. Moreover, since the mandibular incisor is further away from the dental restorations of the posterior teeth, possible effects from artifacts can be minimised.

The samples investigated were subjects aged from 12 to 81 years, and were divided according to age as follows: 10 to 19 years, 20 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years, 60 to 69 years, and 70 years or above. All of the patients had undergone a CBCT examination for another clinical reason, and so none were subjected to ionizing radiation as part of this project. Since the project depended on retrospective imaging data, ethical approval was deemed unnecessary, which was in agreement with The University of Hong Kong for this project.

All the data were treated with the agreement of The University of Hong Kong and patient details were deemed unnecessary. The subject data collected included age, medical history, dental history, as well as family and social history. The analysis, measurement, and calculations
relevant to each sample took approximately an hour. Due to the limitation of time, 100 patients were randomly selected. Among these 100 selected scans, three entailed motion artifact that degraded the images making them unsuitable for analysis. Two of the scans suffered a beam-hardening artifact from the metallic restorations on adjacent or opposing teeth. Two others showed restorations on the coronal part of the examined tooth, while one of patients had a root-filled mandibular lateral incisor. Besides, the fields of view of another 44 CBCT scans did not cover the radicular portion of the mandibular incisors. Therefore, only 48 were suitable for this research project.

All DICOM images selected were saved onto a compact disk, with the patients’ personal information (name, gender, and contact details) anonymized. The images were then imported into another computer (CEC Commtech Intel Core 2 computer model: CT-P4C2D; display: Dell 2408WFP [digital] on ASUS X1950 series) installed with Microsoft Windows XP (Oregon [WA], USA) and the Materialise software SimPlant Pro Crystal version 13.0. On this second computer, the analyses, measurements, and calculations of pulp and dentin volumes were performed.

Using the SimPlant Pro Crystal, the axial section of the image was selected and magnified. The portion of the tooth selected for analysis was the most coronal slice without enamel and the next 10 slices going up to the crown or down to the root (Fig 1). Highlighting of the pulp and pulp plus dentin were performed separately by setting a threshold value referring to the gray-scale of the different tooth substances as displayed in the profile line drawn across the tooth (Fig 2). The highlighted area was adjusted and corrected manually if necessary. The methodology is displayed and explained in Figures 1 to 3.

**Figure 2** A profile line (in red) was drawn across the tooth. The threshold value could be estimated accordingly from the curve showing the gray-scale of different tooth substances.

**Figure 1** The axial section of the sample in the SimPlant Pro Crystal program was chosen for the measurement and analysis. For clearer vision and easier measurement, the image was magnified (3x). The portion of the tooth selected for analysis was the most coronal slice with no enamel and the next 10 slices.

**Figure 3** (a) The function ‘draw/erase mask’ was used, and the pulp of the tooth in each slice was highlighted with a pre-determined color (in yellow). After highlighting the pulp of the tooth in the next 10 slices, the function of ‘region growing’ was applied. Here the computer program automatically assigned another color to the highlighted pulp, and the volume (in mm³) of the highlighted pulp could then be calculated. (b) By using the same ‘draw/erase mask’ function, the total volume of pulp and dentin highlighted (in purple) could then be calculated by selecting the appropriate threshold value for each of the chosen tissues/structures.
Results

The volume of dentin (as opposed to that of pulp plus dentin) was calculated for each sample. Since the data were not normally distributed, the Spearman correlation coefficient \( r \) was adopted to investigate the relationship between different variables. A significant negative correlation was shown between age and pulp volume \( (r=-0.717; P<0.001) \), whereas pulp volume and dentin volume was positively correlated, though not statistically significant \( (r=0.139; P=0.481) \). These relationships are shown in Figure 4. However, there was no association between age and dentin volume.

The Spearman correlation coefficient for age versus dentin volume showed a positive value of 0.06, which means the dentin volume increased with age. However, this relationship was statistically insignificant.

Discussion

In this study, 100 iCAT CBCT datasets were randomly selected, and the dropout rate was 52%. In contrast to other studies \(^{16,23} \), only one tooth in each sample was adopted for this project. Star \( et \ al. \) \(^{20} \) found the strongest Pearson’s coefficient between pulp-to-tooth ratio and incisor age. Kvaal \( et \ al. \) \(^{24} \) also provided the highest correlation outcomes between the variable ratios related to secondary dentin formation and age. This may be explained by the lowest morphological diversity of incisors (especially the mandibular incisors) among human teeth.

There was no statistical evidence of an association between age and dentin volume, as well as pulp volume and dentin volume. The Spearman correlation coefficient for pulp volume versus dentin volume showed a positive value of 0.139, though insignificant, means that pulp volume increased with the dentin volume. This relationship appears contradictory, as it is believed that increased formation of dentin causes a decrease in the pulp volume so warrants further investigation and analysis using a larger sample. These can possibly be explained by the difficulty in measuring the dentin volume accurately. The computerized distinction between the dentin and jaw bone based on the established threshold values becomes less reliable at the level of the cementoenamel junction. The need for manual correction and adjustment in highlighting the dentin had a negative influence on the precision of the measurement.

As reported in the study by Star \( et \ al. \) \(^{20} \), the ratio of the variables indicating secondary dentin formation observed on the 3-D radiological images was inferior in relation to age than the ratios, indicating the secondary dentin formation reported by Kvaal \( et \ al. \) \(^{24} \) using 2-dimensional radiological images.

By comparing with the study by Star \( et \ al. \) \(^{20} \), which measured the pulp and tooth volume of the whole tooth, the present study concentrated on the most coronal slice without enamel and the next 10 slices going up to the crown or down to the root. This was because of the manual intervention into the automatic separation and segmentation process, which was most extensive at the apical quarter of the tooth root. Moreover, Green \(^{25} \) reported that the amount of secondary dentin was larger in the roof of the pulp chamber than that in the floor of the pulp chamber. Thus, the 10 slices captured for measurement in this study also covered and concentrated more on the roof of the pulp chamber.

The strong inverse relationship between age and pulp volume can be explained by the increased formation of secondary and tertiary dentin as people get older. The increased formation of secondary and tertiary dentin ‘squeezes’ the pulp of the tooth. In other words, the pulp

---

**Figure 4** Scattergram of age versus pulp volume
volume decreases with age. This can be seen from routine radiographs as well. Younger patients usually present with a larger pulp chamber and clearer root canal system, while older ones usually have smaller pulp chamber (sometimes even obliterated) and less well-defined root canals. Therefore, the size of the pulp can definitely be used as an indicator in age estimation. Although not statistically significant, the trend of an increased dentin volume with aging may also be attributed to increase formation of secondary and tertiary dentin.

Since there was a strong inverse relationship between age and pulp volume, the mean pulp volume in each age-group was calculated (Table). If more samples can be measured, probably the age range of an unknown person could be derived from the calculation of his or her pulp volume. This is because the success of correlation analysis depends on variables having a wide and representative distribution. Thus, the larger the amount of data collected and the wider the age range sampled, the better results one will get. The present study was only a preliminary pilot study using samples from the local population. Regrettably, due to limitations of time and resources, the sample size was very small, and there was an obvious missing age-group (aged between 20 and 49 years) due to the limited number of CBCT images in the computer database. Therefore, as of now, this method is not appropriate for accurately calculating a subject’s age.

Moreover, there was a large variation in pulp chamber size within each age-group. This was due to the anatomical variants related to congenital, developmental, and nutritional factors. Therefore, further investigations and comparison should be made between age and the pulp versus dentin volume ratio.

**Conclusion**

An important aspect in dental age estimation is that the investigator should apply a number of different techniques available and perform repetitive measurements and calculations in order to improve reproducibility and reliability of the age estimation. The present method of age estimation by CBCT scans that depends on fully developed mono-radicular teeth from living individuals is not complicated. It can be applied for radiological age estimation on living individuals without tooth extraction. Since the errors from image magnification and distortion are minimized, the measurements are relatively more accurate and reliable.

The use of CBCT was found very useful in age analysis. It accurately describes the inverse relationship between age and pulp volume. If more samples are recruited and measured, a formula could be derived, which might show the actual relationship between age, pulp volume, and dentin volume in a better way. However, due to the large variation of pulp size within any age-group, in this study pulp size did not seem to be an accurate indicator of age. Further comparisons using the pulp versus dentin volume ratios should be explored.

**Acknowledgments**

I wish to acknowledge and express my sincerest appreciation to Dr Thomas Ka-Lun Li and Ms Anson Cheuk-Man Chau for their contribution toward the preparation of this study.

**References**

4. Hägg U, Taranger J. Dental development, dental age and tooth

CONTINUING EDUCATION PRIZES 2011

The Hong Kong Dental Journal Editorial Board would like to express their heartiest congratulations to the winner of the Continuing Education Prizes 2011, Dr Cynthia Kar-Yung Yiu et al, for their paper “Employer perceptions of the competence of dental graduates from The University of Hong Kong’s integrated problem-based learning dental curriculum” (Hong Kong Dent J 2011;8:72-7).

The runner-up prize is awarded to Dr Timothy G. Wigal et al for their paper “Condyle/glenoid fossa changes of Class II patients treated with the edgewise crowned Herbst appliance in the early mixed dentition period” (Hong Kong Dent J 2011;8:9-17).