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Short report

Age estimation by pulp/tooth ratio in lateral and central incisors by peri-apical X-ray

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ABSTRACT

Since 2004, several papers on the analysis of the apposition of secondary dentine have been published. The aim of this paper was to study a sample of peri-apical X-ray images of upper and lower incisors, both lateral and medial, to examine the application of pulp/tooth area ratio as an indicator of age. A sample of 116 individuals, 62 men and 54 women, aged between 18 and 74 years, was studied. Data were fitted with age as a linear function of the pulp/tooth ratio of incisors. The total variance explained by the regression equation ranged from 51.3% of age, when lower lateral incisors were used as explanatory variable, to 81.6% when upper lateral incisors were used. The accuracy of the corresponding regression model yielded ME = 8.44 and 5.34 years, respectively. These results show that, although incisors are less reliable than canines or lower premolars, they can be used to estimate age-at-death when the latter are absent.

1. Introduction

The forensic literature has provided several methods for estimating age in adults, both dead and living.[1,2] Many of these methods are macroscopic,[3–5] only some are based on the study of teeth[6–10] and a few on radiographic evaluation of both skeletal and dental districts.[11–14]

According to a recent study on current practices used by forensic anthropologists in adult skeletal age estimation, the Suchey–Brooks pubic symphysis method remains the preferred technique, cranial sutures and dental attrition or abrasion being the least frequently chosen, regardless of experience.[15] Moreover, there is no standardized way of combining information from multiple age estimation methods into a final age range to present to the authorities requesting them.[15] As several authors have noted, although historically age estimation has been regarded as "ultimately an art, not a precise science" (Maples, 1989), in the face of the Daubert challenge[16–18] and our current era of validation and scientific rigor, these problems need to be addressed.[15]

Thanks to recent and substantial advances in physical anthropology, old methods have been improved and new techniques have been proposed.[2] Of these, analysis of the apposition of secondary dentine is of particular interest.[19] After tooth eruption, it is well-known that the size of the pulp cavity decreases gradually with age, because of the deposition of secondary dentine in the pulp cavity wall.[20] This process is caused by the continual secretion of dentinal matrix by odontoblasts (physiological secondary dentinogenesis). Dentine is a living tissue containing odontoblasts which form the tooth. During a person's lifetime, for both physiological and pathological reasons (attrition, abrasion, erosion, caries), the

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odontoblasts deposit layers of secondary dentine, which gradually obliterates the pulp chamber. The mean rates of increasing dentinal thickness have been found to be 6.5 μm/year for the crown and 10 μm/year for the root. The effect is a progressive increase in dentinal thickness of 0.45 mm (17.1%) and 0.60 mm (24.3%) in the crown and root areas, respectively.[20] However, as Murray et al.[20] noted, age-related differences are observed between different tooth types: the increase in dentinal thickness in the crown aspect of canine teeth may be as low as + 3.4%, whereas that of the crown of incisors and premolars may be 15.5% and 34.1% respectively, in older patients. Irrespective of age, mean dentinal thickness is observed to vary significantly across tooth types.

Since 1925, when Bodecker[21] ascertained that the apposition of secondary dentine was correlated with chronological age, new detailed studies of the pattern and rate of secondary dentine apposition in upper and lower anterior teeth have been performed. Secondary dentine deposition was included in the method pioneered by Gustafson,[22] in which dentine transparency and secondary dentine values showed the highest correlation with age. Philippas[23] was one of the first to use the radiographic method to verify the influence of age on the formation of dentine. In 1995, Kvaal et al.[24] developed a new method for estimating age in adults, based on the relationship between age and pulp size on peri-apical dental radiographs. Paewinsky et al.[25] also tested the method of Kvaal et al.[24] on digital panoramic radiographs, but specific regression formulas were developed by these authors for their sample. Currently, thanks to some conventional techniques, such as standard radiographs, or newly developed ones, such as micro-focus X-ray computed tomography, apposition of secondary dentine is a useful tool for age estimation in adults.[2] Among these techniques, dental radiography is a convenient, simple, and much less expensive method which a legal medical expert can apply practically in several types of situations. A destructive approach, while more accurate, may not be acceptable in many forensic cases, due to the loss of evidence, or in living subjects in whom the tooth must be sacrificed.[2]

Since 2004, Cameriere et al.[26,27] have published several papers on a method of age estimation using the pulp/tooth area ratio to quantify the apposition of secondary dentine. The canine was the first tooth studied by Cameriere et al.[26] and Cameriere and Ferrante.[26] Canines were chosen for a number of reasons: they are often present in old age, they are less likely than other anterior teeth to suffer attrition or abrasion as a result of particular work, and they are the single-root teeth with the largest pulp area and thus the easiest to analyse.[26] Although this tooth type proved to be very reliable in earlier publications,[28] lower premolars were later considered.[29] These single-rooted teeth have a pulp size which is more evident than in other teeth, and they are comparable to canines. They are less easily damaged by direct heat or traumatic force than incisors or canines, as they are covered by the soft tissue of the cheek, and are not as easily lost in dry skull material as single-rooted anterior teeth.[29] They show good correlations between the decrease in dental pulp and increasing age.[29]

After analysis of canines and premolars, this study focused on the remaining group of single-rooted teeth, i.e., the upper and lower central and lateral incisors. As a rule, anterior teeth tend to be extracted before canines, but for aesthetic reasons patients wish to keep their front teeth as long as possible. The anterior teeth are much smaller and have less pulp than canines, particularly the lower incisors. In addition, variations in the root canal system of the lower incisors are quite high: over 40% of these teeth have two canals.[30,31] The smaller pulp and the presence of a second canal, which cannot be observed in frontal peri-apical X-ray, reduce the probability of correct measurements and, consequently, accuracy in age estimation. This reduced pulp and the great variation in the presence or absence of a second and/or later canal had already been noted in previous studies,[30–35] thus directing research toward study of canines and premolars.

The aim of this paper is to study a sample of peri-apical X-ray images of upper and lower incisors, both lateral and central, to examine the application of the pulp/tooth area ratio as an indicator of age. This information would be very helpful as a reference for clinical root canal therapy and for age identification of skeletal remains in forensic human identification.[1,2]

2. Materials and methods

2.1. Samples

Samples come from two of the Coimbra Identified Osteological Collections in the Department of Life Sciences at the University of Coimbra (Portugal): the Medical School Skull Collection and the International Exchange skull collections.

The skulls in the Medical School collection were acquired from the Schools of Medicine in Lisbon and Porto and from the Anatomical Theater of the University of Coimbra (Portugal). It is composed of 585 complete skulls, collected between 1895 and 1903 by Bernardino Machado, and was the first identified osteological collection to be amassed in Coimbra.[36]

The skulls from the International Exchange collection were recovered from the *Cemitério Municipal da Conchada* in Coimbra (Portugal). This collection was probably initiated in 1915 by E. Tamagnini, who actively participated in accessions until 1942.[36]

In Portuguese cemeteries, it is common practice to perform exhumations after a period of five years, and bones are transferred for deposition in an ossuary. However, if relatives do not claim the remains after exhumation or if they cease payment of ossuary fees, the remains are either placed in a communal grave or cremated. In these cases, the University of Coimbra may intervene and request the remains for research purposes.[36]

The individuals in the above-mentioned collections died between the years 1895–1903 and 1904–1938, respectively. As they were fully identified, detailed information about each of them – date and place of birth, sex, age at death, year and place of death, illness or cause of death, and occupation, and any other pertinent details – were compiled in record books. These records clearly indicate the low socio-economic status of most of the individuals: the women were almost all housewives, and the men were mainly employed as farm workers and artisans. The provenance of their bodies may also be considered a sign of their low socio-economic status, because in most cases their families could not afford adequate burial.[36] From these collections, random samples of 116 individuals were made, 62 men and 54 women, aged between 18 and 74 years. In total, peri-apical X-ray of 427 lateral and central incisors were taken: 19% are central upper, 26% lateral upper, 28% central lower and 27% lateral lower. Of all incisors, 43.3% belonged to women and 56.7% to men. The inclusion criteria were: peri-apical X-ray selected from subjects aged between 18 and 75 years; the selected tooth on the radiograph, the maxillary incisor, was fully erupted into the oral cavity; the root of the incisor was fully formed. The exclusion criteria were: teeth showing signs of root canal treatment, impacted teeth, and teeth with vestibular radio-opaque fillings, crowns or pathological processes visible on the peri-apical radiograph. Radiographs showing badly rotated teeth or teeth with large areas of enamel overlap between neighboring teeth were also excluded. The study samples also show minimal attrition. The distributions of tooth type according to subjects' sex and age at death are listed in Table 1.

The selected nomenclature to classify the teeth is that proposed by the *Fédération Dentaire Internationale* (FDI). Protocols to collect radiographs for human subjects were approved by the Ethics