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Technical note

Automatic age estimation in adults by analysis of canine pulp/tooth ratio: Preliminary results

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ABSTRACT

The estimation of age of adult individuals usually employs methods based on age-related changes in the human skeleton. The main aim of this study was to assess dental age through analysis of images from peri-apical x-rays based on a new algorithm for automatic estimation of pulp and tooth area. The algorithm was tested on a sample of 40 canines of males and 30 of females from subjects between the ages of 20 and 70.

1. Introduction

Age estimation is an important aspect of forensic human identification. In the last few years the scientific literature has provided several skeletal and dental methods to assess age, most of which apply many age indicators related to degenerative changes in the skeleton, such as modifications in the pubic symphysis [1,2], in sternal rib ends [3], in auricular surface of the ilium [4], in endo-cranial and ecto-cranial sutures [5,6], while some utilize radiology of the proximal femur and clavicle [7,8].

However, recent and more successful methods reported in the literature to assess age in adults are based on age-related changes of teeth [9–13]. Currently, apposition of secondary dentine is considered a useful tool for age estimation in adults [14–16]. After tooth eruption, the size of the pulp cavity gradually decreases with age due to deposition of secondary dentine in the pulp cavity wall. Irrespective of age, mean dentinal thickness varies significantly across tooth types [17].

These age-related changes can be evaluated by extracting and sectioning a tooth [18,19] or by using two dimensional (2D) dental radiographs [16]. Obviously, the former technique is not ideal for evaluating the age of living adult individuals, and even in the case of deceased subjects, it requires that the forensic staff extract the tooth, a much more onerous process than that of dental radiography, and involves destruction of the tooth material. Instead, the second method offers forensic experts a quick, convenient, user-friendly, and much less expensive method [20].

Some researchers have also tried to relate the pulp/tooth area ratio measured on 2D dental radiographs to chronological age [21,22]. Since 2004, Cameriere et al. [21–29] have published numerous papers on a method of age estimation using the pulp/tooth area ratio to quantify the apposition of secondary dentine in canines, incisors and premolars. These works showed promising results for non-invasive dental age estimation by the use of dental radiographs. However, this method cannot avoid the bias that is inherent in the subjectivity of the observer (see [30] for details).

Recently, owing to the rapid development of image processing techniques, many attempts have been made to obtain fully automatic bone and dental age assessments [31,32]. In particular, recent techniques have made it possible to remove background imagery in order to focus on regions of interest in the tooth, thus reducing the subjectivity inherent in user interaction, and increasing repeatability.

The main aim of this study was to assess dental age (DA) using a new image analysis algorithm that automatically calculates pulp

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Table 1
Age and gender distribution of study sample.

Age	F	M	Tot
20–30	4	7	11
30–40	6	8	14
40–50	7	9	16
50–60	6	8	14
60–70	7	8	15
Total	30	40	70

and tooth area from peri-apical x-ray images of the tooth. The dental age is then obtained by Cameriere's formula [25].

2. Materials

Analyses were conducted on peri-apical x-rays of upper canines from 70 individuals (40 males and 30 females), with known age absolutely certain (see Table 1). The teeth were taken from the osteological collection of Sassari (Sardinia, Italy), that is housed in the Museum of Anthropology, Department of Experimental and Evolutionistic Biology, at the University of Bologna (Italy), see [33].

Teeth with caries, pathological wear, coronal fracture, external resorption or which had undergone conservative, endodontic or prosthetic processes were excluded, as were those with vestibular radio-opaque fillings, crown or pathological processes visible on the radiograph.

3. Methods

3.1. Image production

The images used in this study were peri-apical x-rays taken digitally (FARO Production) at an exposure of 10 ma, 70 kVp with 0.05 s exposure time.

For sake of simplicity, teeth were positioned horizontally, with the crown on the left side of the image, and the root at the right (Fig. 1).

3.2. Image analysis

In order to simplify or alter a digitalized image to make it more readable or easier to analyse, it is segmented or partitioned into multiple segments (sets of pixels, also known as superpixels) in a process called segmentation. The x-ray image of a tooth (which will be called “I” in our mathematical formulas) can be viewed as a matrix having r rows and c columns. The grey levels of I range from 0 (black) to 1 (white). In x-ray images, the background usually has darker pixels than the portrayed objects. In image segmentation, each pixel of the image must be classified into one of the two classes: one corresponding to the object of interest, and another for all the other objects.

In age evaluation, we need to solve two segmentation problems: the detection of the tooth pixels, and the detection of the pulp pixels. Moreover, the second problem must be solved after the first one; in fact pulp pixels must be retrieved from the tooth pixels. These two segmentation problems are very different, so appropriate methods must be used to solve each one of them efficiently. In particular, the main difference is that the intensity of the pixels is greater in the tooth than in the background, and so we can solve this problem through the usual thresholding techniques [34,35]. However, these techniques are usually inadequate for the second problem, the detection of the pulp pixels, because the grey levels of the pulp pixels are not very different from those of the tooth pixels, even if local and adaptive strategies [34] are used. In this study, we propose solving this problem with an algorithm for shape analysis [36]. In the following text, the methods for segmenting tooth pixels and that for segmenting pulp pixels are presented.

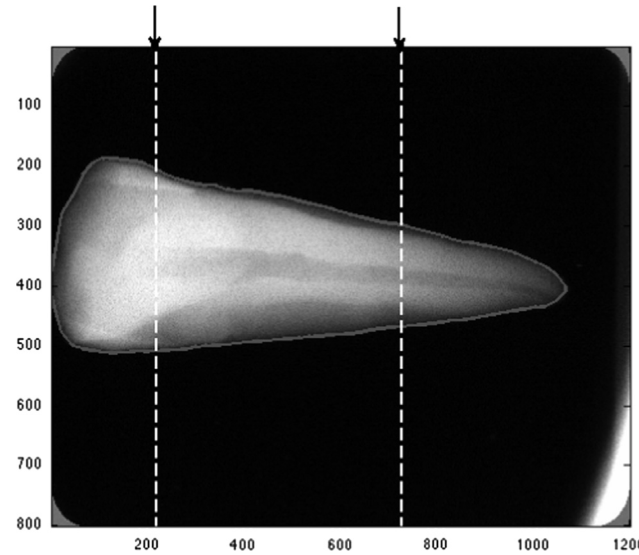

Fig. 1. Segmentation of the tooth.

3.3. The segmentation of the tooth

The intensity of the pixels is greater in the tooth than in the background. This property can be easily exploited for the detection of the tooth, using the following terms and computations. Let T be the tooth area, and let τ_T be a suitable threshold; the pixels $(i,j) \in T$ can be detected by a simple test: $I(i,j) > \tau_T$. Actually, this test selects all the pixels of the area T when τ_T has an appropriate value, but in this way other different pixels may be selected as consequence of image noise. To compensate, set T is computed as the maximal connected component [37] of the set described by the above-mentioned grey level test.

From the knowledge of set T, a piecewise linear approximation of its boundary is computed. This is an important item of information in the segmentation of the pulp. In fact, the boundary of the tooth encloses the region where the pixels of the pulp area can be found. Fig. 1 shows this approximation of the boundary of T in an example.

3.4. The segmentation of the pulp

The segmentation of the pulp is based on a local analysis of the shape performed using the grey levels of the pixels in the tooth area. In particular, this shape analysis is applied to all the transversal (i.e. vertical) sections of the tooth. The results obtained for the different sections are compared and a final global result is achieved for the segmentation problem under study.

The shape analysis of the transversal sections is based on the characteristic M-shape of the corresponding grey level function; see Fig. 2(a) for the description of a typical example. In principle, the section of the pulp area is bounded by the two maxima in this grey level function, so very simple techniques of signal analysis seem to be effective in the solution of this problem. However, the image noise and the presence of degenerate cases make this problem quite difficult; see Fig. 3(a) for an example of a degenerate transverse section of tooth.