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Development of a biometric method to estimate age on hand radiographs

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ABSTRACT

Age estimation of living individuals aged less than 13, 18 or 21 years, which are some relevant legal ages in most European countries, is currently problematic in the forensic context. Thus, numerous methods are available for legal authorities, although their efficiency can be discussed. For those reasons, we aimed to propose a new method, based on the biometric analysis of hand bones. 451 hand radiographs of French individuals under the age of 21 were retrospectively analyzed. This total sample was divided into three subgroups bounded by the relevant legal ages previously mentioned: 0–13, 13–18 and 18–21 years. On these radiographs, we numerically applied the osteometric board method used in anthropology, by including each metacarpal and proximal phalange of the five hand rays in the smallest rectangle possible. In that we can access their length and width information thanks to a measurement protocol developed precisely for our treatment with the ORS Visual® software. Then, a statistical analysis was performed from these biometric data: a Linear Discriminant Analysis (LDA) evaluated the probability for an individual to belong to one of the age group (0–13, 13–18 or 18–21); and several multivariate regression models were tested for the establishment of age estimation formulas for each of these age groups. The mean Correlation Coefficient between chronological age and both lengths and widths of hand bones is equal to 0.90 for the total sample. Repeatability and reproducibility were assessed. The LDA could more easily predict the belonging to the 0–13 age group. Age can be estimated with a mean standard error which never exceeds 1 year for the 95% confidence interval. Finally, compared to the literature, we can conclude that estimating an age from the biometric information of metacarpals and proximal phalanges is promising.

1. Introduction

With European integration, transnational migratory activity is on the rise [1]. Thus, many young individuals do not have the necessary documents for assessing their identity. Yet, individuals aged less than 18, even 21, in most European countries have particular rights and can access particular protection [2]. In criminal proceedings, the legal authority often requests expert analysis to determine whether an individual has reached the age he claims, so he can rightly benefit from a particular legal treatment according to his actual age [3]. Regarding age estimation in living individuals, the International Interdisciplinary Study Group of Forensic Age Diagnostics [4,5] recommends the estimation of skeletal age, in addition to a physical inspection [6] and a dental examination [7].

Experts have numerous methods to estimate the age of a person [5]. Because hand ossification is considered representative of skeletal maturation as a whole, skeletal age can be estimated by methods based on hand study [8]. The most widely known method utilizes the Greulich & Pyle Atlas (GPA) [9]. It is a qualitative

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method, only based on user observation, implying variable results among and between observers [10]. This atlas is based on the study of hand radiographs of North Americans, collected between 1931 and 1942. Yet, it has been demonstrated that this method can incorrectly estimate age in foreign populations [11], such as French individuals [12]. Another currently used method for skeletal age estimation is the one developed by Tanner & Whitehouse (TW) [13–15]. However, the results for age estimation are not better than those obtained via the GPA method [16].

Because the relevance of the GPA method is actually discussed, current research in the age estimation field has as principal purpose the development of methods based on a quantitative approach for the establishment of new age estimation formulas. Our study was oriented toward this issue: we developed a method based on the morphometric information of hand bones, determined with biometric techniques on radiological images. Then, after leading a Linear Discriminant Analysis (LDA), we proceeded to several multivariate regression models in order to select the most efficient age estimation formulas, specific to some relevant thresholds for minor as defined in French law: 13, 18 and 21 years.

2. Materials and method

2.1. Materials

We retrospectively collected frontal hand radiographs of individuals, males and females, aged less than 21 years. Our sample included both left and right hand radiographs because no influence of laterality on skeletal age estimation has been demonstrated elsewhere [17,18]. This study was based on a sample composed of individuals younger than 13, 18 and 21 years old which are the main age threshold for minors in most European countries. Subjects were excluded from the sample if they demonstrated any trauma or pathology of the hand.

At last, ten radiographs per gender were gathered for each age class. An age class n was defined as a class including individuals whose age lies in the range $n \leq \text{age} < n+1$.

The exams were performed at Nancy University Hospital (France), between January 2004 and March 2015 for traumatic diagnostics. This research utilized the Picture Archiving and Communication System® (PACS®) used by the hospital. Images were stored on the local research storage platform ArchiMed [19].

Previously, our study was the subject of a CNIL (Commission Nationale de l'Informatique et des Libertés [20]) declaration to ensure the protection of patients and their personal data. Thus, the ethical framework was respected. We guaranteed no distortion or damage to the files, as well as the confidentiality of the data. We performed to a de-identification of the radiographs so that none of them could be traced back to the original patient's identity. Moreover, the only personal data available for our study were age and sex.

Our total study sample consists of 473 frontal and healthy hand radiographs of males and females hospitalized at Nancy University Hospital (France) and aged between 4.60 days and 20.88 years. For the purpose of our study, this population was divided into three subgroups bounded by some relevant legal age for most European countries, these three categories being 0–13, 13–18 and 18–21. Respectively, these samples include two hundred and eighty one individuals aged up to 12.94 years, one hundred and nine aged between 13.02 and 17.86, and sixty one aged from 18.06 to 20.88 years.

Their distribution by gender and age class is presented in Fig. 1. In Table 1 the position parameters of our study population are summarized as the number of subjects, and the mean and the median age for our three previously defined samples.

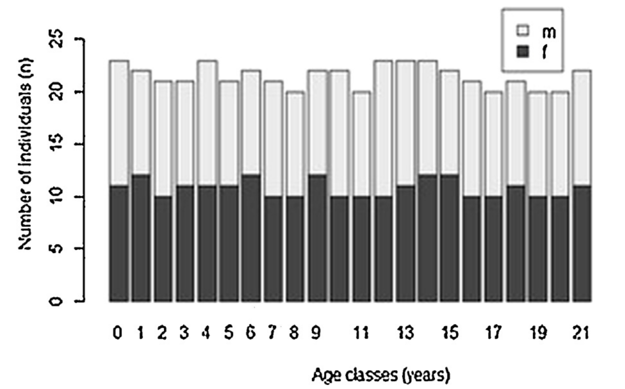

Fig. 1. The study sample: number of individuals per age class and per sex of the total study sample (1 column fitting image).

2.2. Measurements protocol

For each radiograph, the osteometric board concept used in anthropology was virtually applied [21]. According to this concept and following Lalys work [22,23], each metacarpal and each proximal phalange were included in the smallest rectangle possible to obtain measurements. Thus, the maximal lengths and widths of the bone are those of a virtual rectangle in which one measured bone has been included.

We used ORS® (Object Research System) Visual®, a software specialized in medical image processing. We added a new plug-in named "HandBones" developed in our lab for this purpose. Thus, other functions were available by rotating the image and drawing the rectangles. Measures were obtained automatically from the plots, in millimeters calculated from the pixel spacing specific to each image.

For each metacarpal and proximal phalange (named, respectively, MCn and PHn where n referred to the corresponding ray number) of the five rays of the hand, two rectangles were drawn: one to obtain the length (LG) and the proximal width (LGP) of the bone, and a second to obtain its distal width (LGD). Thus, we collected thirty measurements for each hand radiograph, by drawing twenty rectangles (Fig. 2).

It should be noted that, for the youngest individuals of the study sample, rectangles were drawn so that they included the total diaphysis and, as soon as they appear (i.e. at approximately the age of 1 year) [24], the epiphyses ossification centers, even if they were distant from the diaphysis extremities.

To facilitate and optimize readings for all these measurements, only the grayscale and the zoom could be different for each radiograph. It would be especially useful in cases of superimposition of bones. Four steps were applied:

Table 1
The study sample: number of subjects, mean and median age for each sample and each sex.

Sample	Number of subjects (n)	Mean age (years)	Median age (years)
0–13	281	6.47	6.46
Males	141	6.54	6.81
Females	140	6.39	6.18
13–18	109	15.37	15.27
Males	54	15.37	15.29
Females	55	15.36	15.27
18–21	61	19.32	19.24
Males	30	19.36	19.31
Females	31	19.28	19.18
0–21	451	10.35	10.24
Males	225	10.34	10.18
Females	226	10.37	10.38