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Role of Imaging in the Assessment of Age Estimation

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Age assessment by skeletal age estimation of unknown individuals is of paramount importance in forensic science, both for assessing imputability (if the author of a crime is old enough to be tried and judged), both in case of unaccompanied minors, or whether refugees and asylum seekers are adults or juveniles, which implies different legal issues and procedures. The aim of this article is to review the age estimation methods used in forensic practice.
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Introduction

Age assessment by skeletal age estimation of unknown individuals is of paramount importance in forensic science, especially considering the wide immigration phenomena that Europe is facing recently. Age assessment is crucial for immigration authorities to determine whether refugees and asylum seekers are adults or juveniles, which implies different legal issues and procedures. According to the United Nations High Commissioner for Refugees (UNHCR), nearly half of the people forcibly displaced from their homes are children, representing a demographic at particular risk of "abuse, neglect, violence, exploitation, trafficking or forced military recruitment" and in need of international protection.[1,2] The Convention on the Rights of the Child (1990), stipulated that States Parties shall respect and ensure the rights of each child (<18 years of age) within their jurisdiction without discrimination. Frequently difficulty arises when individuals claiming to be children have no legitimate identity documentation to evidence their assertions, and estimating their age is crucial.[1,2] This condition leads to precautionary overestimation of the percentage of younger-that-18 subjects, since the UNHCR Guidelines on Policies and Procedures in Dealing with Unaccompanied Children Seeking Asylum (1997) advise that "if chronological age is uncertain, an unidentified child should be given the benefit of doubt, and that requisite age assessments should accordingly consider whether "an individual demonstrates an 'immaturity' and vulnerability that may require more sensitive treatment."[2] Age determination is important also for legal issue, in order to assess imputability – in other words if the author of a crime is old enough to be tried and judged. Occasionally, this kind of assessment can be requested for adopted children whose age needs to be redefined because of the uncertainties or lack of birth certificates. Exceptionally it can be requested for assessing age on adult individuals, mainly for old age pension or other civil purposes or in cases of adults affected by amnesia.[3,4] Guidelines and scientific societies dealing with age estimation procedures exist, whose aim is to work in favour of homogeneous modalities of intervention and reporting. Three basic operations are required to perform a reliable age estimation: clinical examination, completed by the assessment of maturation degree of sexual characteristics; left hand and wrist X-ray (right hand and wrist if the subject is left-handed) and a panoramic dental X-ray; radiological examination of the sternal end of the clavicle.[5,6]

Hand–wrist

The two main methods frequently consulted to estimate adult/subadult age based on skeletal maturation in the hand–wrist complex are the Gruelich and Pyle – which is based on a mere comparison between investigated subject and published tables[7] – and Tanner et al[8] – which is based on a scoring system, requiring different bone evaluation and giving a general age estimation according to the final sum. Their validity is reduced when considering foreign populations, different from the one

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Figure 1 Example of age estimation at some different ages using Greulich and Pyle method (male stadiation).

upon which they were developed (Caucasian) and when investigating patients older than 13.5 years for males and 15.5 years for females and males, respectively.[7] Like Gruelich and Pyle method (Fig. 1), the Tanner–Whitehouse (TW) method, is mathematical (or scoring) methods, not developed for forensic age estimation, but rather as an aid for pediatricians to evaluate growth disorders.[8] It was originally developed in 1962 (TW1) based on the analysis of anterior–posterior hand–wrist radiographs of British individuals between 1 and 21 years of age, and later adjusted for varying population (Portuguese,[9] Spanish,[10] French,[11] Italian,[12-14] German,[15] Scottish,[16] Dutch,[17] Danish,[18] Central European[19] and Turkish ones.[20-22] In Africa it was applied to Sudanese[23] and Morocco;[24] in Asia to Indian,[25-27] Pakistani,[28-30] Lebanese,[31] Chinese,[32] Iran,[33] Korean,[34,35] USA,[36] and Australian.[37]

In 1994, Cameriere et al[38] developed a system designed specifically for forensic age estimation, which is based on the calculation of a ratio between the total area of the carpal bones and the epiphyses of the ulna, radius, and carpals. This method presented relatively high accuracy, with a Standard Error of the Estimate (SEE) of ± 1.19 years, but it still far beyond the accuracy expected for legal issues, despite providing promising results in living individuals. Radiography of the nondominant hand and wrist is acquired in the antero-posterior view for age estimation and is most commonly assessed by using the method of Tanner Whitehouse or that of Greulich Pyle.[7,8] New automatic evaluation (computed assisted-CAD) of the bone age using the published atlas but also considering different ethnic origins are now available on the market as BoneXpert® (Fig. 2).[39]

Panoramic Dental X-ray

Teeth are one of the most reliable biological indicators for age estimation in subadult subjects (Fig. 3), but they are useful even in adult cases or when reconstructing a biological profile of an unknown corpse is needed. All these methods result

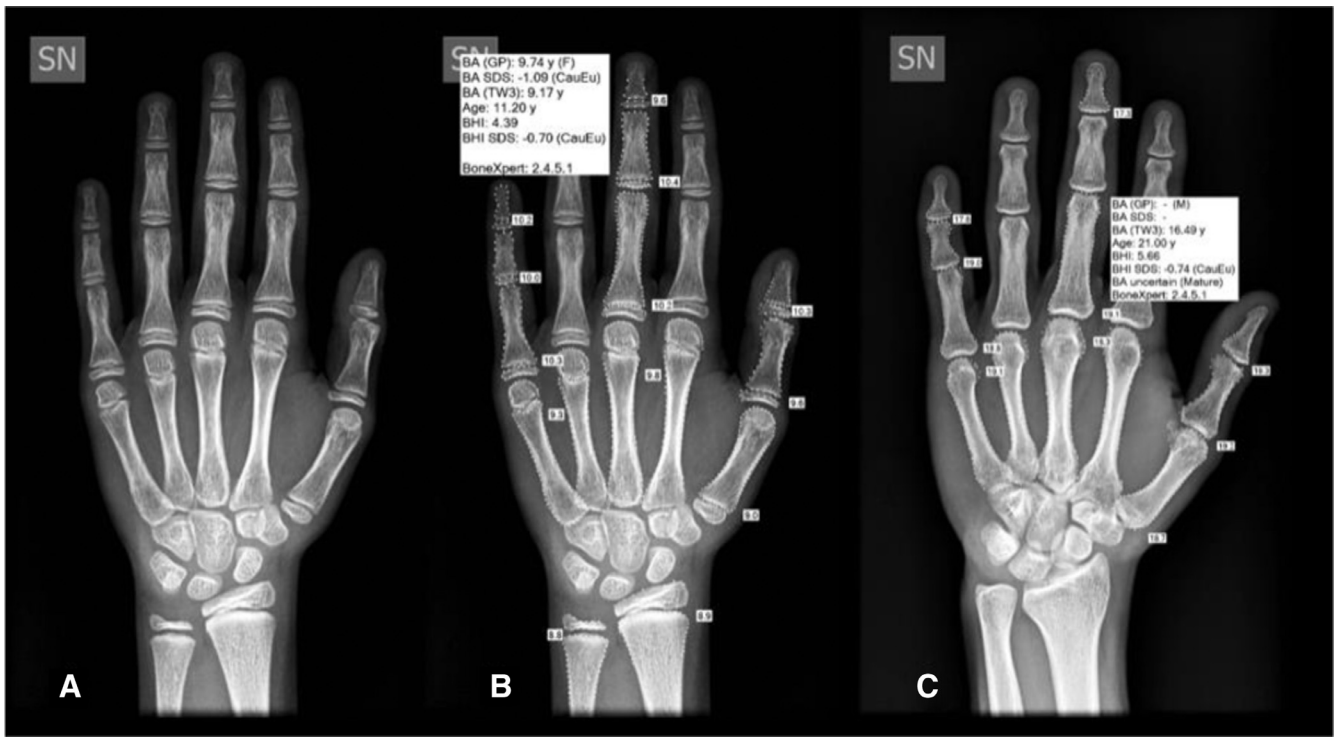

Figure 2 (A and B) Left wrist and hand X-ray image of a 11 year old male evaluated with BonExpert® tool; (C) Left wrist and hand X-ray image of a 21-year-old male evaluated with BonExpert® tool.

Figure 3 Example of dental development in a young female.

from comparison between investigated subjects and atlas or published tables. For example, Ubelaker[40] and AlQahtani[41] schemes for foetal dental development in subject whose teeth are not completely developed, or Moorees classification[42] (1963) or the Demirijian method,[43] to evaluate development of primary and permanent teeth, and further utilized in other different papers (ie, Mincer 1993, Kasper 2009, Solari 2002, Blankenship 2007, Olze 2003)[44-48] to study wisdom tooth development chronology.

The Demirijian development stages have been also used by various authors. Radiographic subadult dental age estimation procedures also comprise methods based on some measurements of biological variables as the degree of tooth apex closure.[49]

Medial Clavicle

Because sexual maturation, hand bone ossification, and third molar tooth growth can be completed in adolescents and young adults, a widely used method for skeletal age estimation is the evaluation of the clavicles medial epiphyses ossification by thin-section CT, recommended by Forensic Age Diagnostics of the German Association of Forensic Medicine (AGFAD). This promising method, initially pioneering by Todd and D'Errico and McKern and Stewart,[50-52] was developed using anatomical specimens to establish links between epiphyseal fusion in the medial clavicle and the age of a decedent.

Further studies (Schmeling et al[53]) (Figs. 4 and 5), focusing on the median clavicle ossification, were developed using plan radiographic data and computed tomography (CT) scans, using grading ossification in order to assign each stage with a corresponding age range, further validated for different populations.

This method is based to the following classification:

- Stage 1: Ossification center not ossified.
- Stage 2: Ossification center ossified but epiphyseal cartilage not ossified.
- Stage 3: Epiphyseal cartilage partially ossified: younger than 20.
- Stage 4: Epiphyseal cartilage completely ossified but scar visible: 21.3 years and 20.0 years in males and females, respectively.
- Stage 5: Epiphyseal cartilage completely fused with scar no longer visible: >21 years.

It is important to mention moreover that many socio-economic factors, such as diet and nutrition, directly affect bone growth, leading to misleading results: bones of individuals with poor nutrition condition and socio-economic states tend to fuse later. This must be taken into account when dealing with young adults which come from developing countries.[52-56]

This method presented many critical points, but in literature has proven to be reliable and accurate for subject >21 years old[52-56]:

- Superimposition effects in the posterior–anterior radiographic imaging of the medial clavicle impede the assessment of fusion stage – the level of error introduced indicates that projection radiography of this structure is inappropriate and that CT is the exclusive imaging modality of choice. So the correct execution of this examination is crucial.
- Optimal multiple detector CT slice thickness (scan resolution) for forensic age estimation purposes is <1 mm – thick slice CT scans result in lower intra- and interobserver accordance;
- Radiation exposure and high cost are the disadvantages of CT.

As aforementioned, radiological exams must be corroborated by physical examination, performed by forensic practitioners

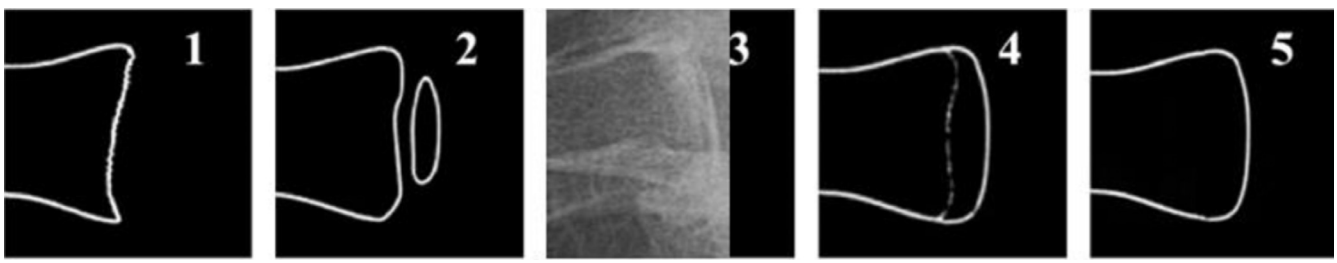

Figure 4 Fusion stages of the sternal end of clavicle (Schmeling et al, 2004).[53]

Figure 5 Age estimation using CT clavicle evaluation compared to wrist and hand X-ray respectively in a 17 years old Nigerian male (A-B) and in a 19 years old Nigerian male (C-D).

and which is based on anamnestic data, psychological development, sexual maturation and physical features. Age estimation represents in conclusion a complex procedure because of its specific characteristics and different fields of application. In fact, it requires an estimation through the quantification and classification of specific variables. Therefore, the final result should be a number, with an adequate error range and the age interval should always be discussed.

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