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Forensic age estimation of living individuals: A retrospective analysis

Valeria Santoro [a,*], Antonio De Donno [a], Maricla Marrone [a], Carlo Pietro Campobasso [b], Francesco Introna [a]

[a] Section of Legal Medicine, University of Bari, P.zza G. Cesare 11, 70124 Bari, Italy
[b] Department of Health Sciences, University of Molise, Via De Sanctis, 86100 Campobasso, Italy

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ABSTRACT

In recent years, skeletal age determination has become increasingly important in criminal investigations for determining the age of living individuals. To increase diagnostic accuracy, a physical examination, an X-ray examination of the left hand, as well as a dental examination including the determination of the dental status and an X-ray of the dentition should always be performed. In this work, the authors analyze a sample of 52 illegal immigrants who came under their observation in the period from May 1989 to September 2007. A statistical analysis of the results of dental and skeletal age estimations was performed as well as an analysis between the reported and assessed ages. The results showed a significant difference between reported age and assessed biological age ($p < 0.001$); however, no statistical difference was shown between skeletal and assessed dental age ($p = 0.431$).

One of the more difficult problems facing forensic medicine is that of estimating the age of living subjects, as in cases where individuals are undergoing criminal proceedings, or are requesting asylum. In cases where authorities are in doubt about the age of a suspected criminal, forensic age estimation is often requested in order to determine if the suspect is of an age in which he may be charged with a crime [1].

In many European countries, the need for accurate age estimation techniques has never been greater than in the last two decades. This is partly due to armed conflicts within the subjects' native countries, resulting in an increased number of immigrants and asylum-seekers. In cases such as these, the refugee's birth might never have been registered, and often, identity documents may never have been issued. Often one of the criteria for having asylum granted is being a minor [2].

In Italy, the age at which a person becomes legally responsible is 14 years. If such a person were charged with a crime, he would be tried in juvenile court, and if convicted, would face the possibility of serving time in a detention center designated for non-adults. At 18 years of age a person is considered to be an adult, and would therefore be tried according to general criminal laws.

Determining the age of a living individual is a rather time consuming task and requires an interdisciplinary approach which involves the services of physicians with forensic experience, knowledge of auxology, radiology, dentistry, and legal medicine [3]. The most commonly used indicators used in age assessment are those related to somatic, sexual, skeletal, and dental maturity [4].

This case study involves the ascertainment of the ages of illegal immigrants from non-EU countries who lacked proper identification documents, and who were either accused of committing a crime and/or requesting asylum. The main objective of this study was to verify the differences and/or similarities between skeletal and dental age assessments. In order to achieve this, a comparison of left hand/wrist radiographs and orthopantomograms (OPGs) was first carried out, followed up by a comparison of reported ages and assessed ages.

1. Materials and methods

The authors have carried out a retrospective review on a sample of 52 immigrants (41 males and 11 females) who arrived in Bari (southern Italy) and who originated from various geographic areas which also happened to be centers of major world conflict—the Balkans (Slovenia, Serbia, Croatia), Albania, and the Middle East (Palestine, Lebanon, Iran, Iraq, Egypt), as well as a few African Countries (Algeria, Morocco, Nigeria).

Forensic age determination was requested by local authorities and the Department of Legal Medicine of the University of Bari was contacted in order to ascertain if the subjects in question were minors, and therefore entitled to diplomatic asylum and not legally responsible for crimes (except in cases when the subjects were 14 years or older), or if they were to be considered adults and therefore subject to legal prosecution.

Data gathered from May 1989 to September 2007 were used in our analysis. The age determination procedure began with a clinical assessment of the individuals, which consisted of a physical examination, which recorded anthropometric data, signs of sexual maturity, and potential age-relevant developmental disorders. Skeletal development, which was evaluated by means of radiologic examination of the left hand/wrist, and the dental examination, which included the inspection of the oral cavity and the assessment of an OPG, were also used in determining the biological age of the individuals. An additional pelvic X-ray was also carried out on 23 individuals.

* Corresponding author. Tel.: +39 0805478249; fax: +39 0805478301.
E-mail address: vasantoro@virgilio.it (V. Santoro).

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Physical maturity was determined according to body mass index values (BMI), based on height and weight, which is recommended as an additional routine measurement of growth, as it is a valuable index of body composition (adiposity) to determine if the individual is clinically underweight or obese when compared to age/sex specific percentiles from a reference population [5,6,7]. Physical maturity was further assessed using the Tanner Staging System, which is commonly used in determining the status of genital development, breast development and the level of pubic hair growth [8].

Analysis of the hand/wrist X-rays, which are used to evaluate the shape and size of bone elements and the degree of epiphyseal ossification, was carried out using the Greulich and Pyle method, which is an atlas method based on a reference population from the 1930s [9].

As of 2001, along with the Greulich and Pyle method, the FELS method was also used. FELS is a computer-assisted system, which utilizes numerous maturity indicators of the hand/wrist bones in order to determine skeletal age with a standard deviation and a standard error [10].

Dental development and emergence was assessed by clinical inspection of the oral cavity and analysis of the OPG. For younger individuals, age estimation was more accurate due to the presence of many developing teeth, particularly the canines, premolars, as well as first and second molars; the intervals between morphological stages are shorter for individuals younger than 16 years of age and therefore, dental age estimation of these subjects is more accurate. Hence, for younger individuals, the Schour and Massler [11] classification method, the Demirjan et al. method [12] and Portigliatti Barbos–Robetti method [13] were used. For older individuals, whose teeth were all completely mature (with the exception of the third molar), the ABFO (American Board of Forensic Odontology) classification guidelines were used. This classification system is based on the sole evaluation of the radiological development of the third molar, according to Demirijan's schematic definitions of crown and root formation [14].

The Portigliatti Barbos–Robetti method is based on the maturity stages of the roots of three right mandibular teeth (second premolar, second molar and third molar) observed on the OPG, and utilizes a specific formula which establishes a mathematical correlation between the various developmental stages and the ages of the subjects. The results showed different margins of error between the sexes: 312 days for males; and 332 days for females [13].

With regard to third molar development, the ABFO system subdivides the development of wisdom teeth into eight stages (A–H), beginning with Stage A, which concerns mineralization of the non-coalesced cusp tips, ending with Stage H, which shows the complete closure of the apical ends of the roots with uniform width of the periodontal membrane surrounding the root.

This system results in a high correlation between biological age and the development of third molar formation. According to this system, stage H indicates a high probability (90.1% for white males and 92.2% for white females) that an individual is already 18 years of age [14].

Pelvic X-rays were performed in some borderline cases of sub-adult subjects on the assumption that iliac crest usually appears at 16 years in males and 15 years in females, and fuses with the iliac bone at 19 years. Furthermore the ischial tuberosity appears at 17 years in males and 15 years in females and fuses in both sexes at 20 years [15].

The procedures for skeletal and dental examinations were carried out separately by two different specialists: a pathologist and an odontologist. Their results were compared in order to determine the probable age of the individual. This was achieved by a consensus decision taking all evidence into account.

In this case study, the BMI and the presence of developed secondary sex traits were used only as a means to gain supplementary information, as sequence and timing of particular developmental events, which occur during puberty vary considerably. However, physical examination is crucial in singling out any visible signs of age-related illness and in cross-checking if skeletal age and tooth age

Table 1
Assessments performed on each male individual. The reported age (years and months) and assessed dental and skeletal ages as well as the definitive biological ages are provided.

N	*H*/*W* (cm/kg)	Reported nationality	Investigations	Reported age	Assessed skel age	Assessed dent age	Estimated biol age
1	160/55	Slovene	Left hand/wrist; Pelvis; OPG	13 years and 7 months	13–14	13–14	13–14
2	162/68	Slovene	Left hand/wrist; Pelvis; OPG	14 years and 1 month	14–16	14–16	14–16
3	170/61	Slovene	Left hand/wrist; Pelvis; OPG	18 years and 7 months	18–19	18–19	18–19
4	169/59	Slovene	Left hand/wrist; Pelvis; OPG	14 years and 10 months	15–17	15–16	15–17
5	156/52	Slovene	Left hand/wrist; OPG	14 years and 4 months	19–21	18–19	18-21
6	176/69	Algerian	Left hand/wrist; Pelvis; OPG	18 years and 4 months	18–20	18	18–20
7	163/56	Albanian	Left hand/wrist; Pelvis; OPG	15 years and 6 months	14–15	13.8 ± 324	14–15
8	164/68	Albanian	Left hand/wrist; Pelvis; OPG	16 years and 8 months	20–21	20–21	20–21
9	160/51	Slovene	Left hand/wrist; Pelvis	16 years and 1 month	15–16	15–17	15–17
10	170/64	Slovene	Left hand/wrist; Pelvis; OPG	11 years and 10 months	13–14	13–14	13–14
11	159/53	Slovene	Left hand/wrist; Pelvis; OPG	15 years and 8 months	18–19	18–19	18–19
12	180/71	Slovene	Left hand/wrist; Pelvis; OPG	18 years and 1 month	18–19	16–18	16–19
13	169/83	Albanian	Left hand/wrist; Pelvis; OPG	14 years and 10 months	16–17	16–17	16–17
14	177/70	Albanian	Left hand/wrist; Pelvis; OPG	17 years and 5 months	18–20	18–20	18–20
15	171/66	Albanian	Left hand/wrist; Pelvis; OPG	17 years and 10 months	17–18	17–18	17–18
16	169/58	Iraqi	OPG and left wrist	16 years and 5 months	20	18–19	18–20
17	169/58	Nigerian	OPG and left wrist	17 years and 5 months	19–20	18–19	18–20
18	145/53	Egyptian	OPG and left wrist	13 years and 2 months	12–13	12–13	12–13
19	179/80	Iranian	OPG and left wrist	15 years and 6 months	17–18	17–18	17–18
20	174/71	Iraqi	OPG and left wrist	17 years and 5 months	17–18	17–18	17–18
21	181/66	Iraqi	OPG and left wrist	16 years and 9 months	18	18–20	18–20
22	167/53	Iraqi	OPG and left wrist	16 years and 8 months	17–18	17–18	17–18
23	167/58	Iraqi	OPG and left wrist	14 years and 4 months	15–16	13–14	13–16
24	167/62	Iraqi	OPG and left wrist	17 years and 5 months	20	18–19	18–20
25	173/63	Algerian	OPG and left wrist	16 years and 8 months	20–25	>20	20–25
26	170/53	Iraqi	OPG and left wrist	16 years and 8 months	17–18	15–17	15–18
27	167/55	Iranian	OPG and left wrist	17 years and 6 months	18–20	18–19	18–20
28	180/78	Egyptian	OPG and left wrist	17 years and 5 months	19–20	18–19	18–20
29	163/56	Iraqi	OPG and left wrist	16 years and 2 months	19–20	18–19	18–20
30	177/73	Egyptian	OPG and left wrist	17 years and 4 months	20–21	20	20–21
31	173/62	Iraqi	OPG and left wrist	17 years and 2 months	20–21	19–20	19–21
32	168/54	Egyptian	OPG and left wrist	16 years and 10 months	18–19	18–19	18–19
33	162/46	Palestinian	OPG and left wrist	17 years and 5 months	18–19	18–19	18–19
34	180/61	Moroccan	OPG and left wrist	18 years and 10 months	18–19	18–19	18–19
35	171/66	Palestinian	OPG and left wrist	16 years and 6 months	17–18	17–18	17–18
36	174/67	Egyptian	OPG and left wrist	16 years and 11 month	18–19	18–19	18–19
37	170/53	Lebanese	OPG and left wrist	17 years and 4 months	16–17	16–17	16–17
38	159/52	Palestinian	OPG and left wrist	16 years and 10 months	18–19	18–19	18–19
39	180/67	Iraqi	OPG and left wrist	17 years and 6 months	17–18	17–18	17–18
40	172/61	Iraqi	OPG and left wrist	16 years and 4 months	19–20	18–20	18–20
41	160/53	Iraqi	OPG and left wrist	15 years and 1 month	18–19	18–19	18–19

H, height; *W*, weight; skel, skeletal; dent, dental; biol, biological; OPG, orthopantomogram.

Table 2
Assessments performed on each female individual. The reported age (years and months) and assessed dental and skeletal ages as well as the definitive biological ages are provided.

N	*H*/*W* (cm/kg)	Referred nationality	Rx	Reported age	Assessed skel age	Assessed dent age	Estimated biol age
1	–	Slovene	OPG	14 years and 11 months	–	17–18	17–18
2	163/67	Slovene	Left hand/wrist; pelvis Rx; OPG	16 years and 11 months	18–19	18–19	18–19
3	163/67	Slovene	Left hand/wrist; pelvis Rx; OPG	17 years	18–19	18–19	18–19
4	162/48	Slovene	Abdominal ultrasound[a]; left hand/wrist, pelvis Rx; OPG	14 years and 2 months	15–17	16–17	15–17
5	164/62	Slovene	Abdominal ultrasound[a]; left hand/wrist, pelvis Rx; OPG	16 years and 8 months	18–19	19–20	18–20
6	159/65	Slovene	Left hand/wrist; pelvis; OPG	14 years and 2 months	13–15	14–15	13–15
7	153/45	Croatian	Left hand/wrist; pelvis; OPG	12 years and 4 months	13–15	14–15	13–15
8	158/53	Croatian	Left hand/wrist; pelvis; OPG	14 years and 2 months	17– 18	17– 18	17–18
9	153/55	Serbian	Left hand/wrist; pelvis; OPG	17 years and 4 months	17–18	17–18	17–18
10	152/45	Slovene	OPG and left hand/wrist	12 years and 8 months	13–15	12–14	12–15
11	160/50	Slovene	Left hand/wrist; pelvis; OPG	14 years and 4 months	17–18	17– 18	17–18

H, height; *W*, weight; skel, skeletal; dent, dental; biol, biological; OPG, orthopantomogram.
[a] Preliminary examination to exclude pregnancy (in case of pregnancy X-ray exposure was avoided).

correspond to overall physical development [16]. In cases where it was unclear if subjects were 14 or 18 years old, they were given the benefit of the doubt and assigned the younger age.

Statistical analyses were performed in order to verify differences or similarities between skeletal and dental ages and those of reported and assessed ages. To determine if the age was distributed along a normal curve (p-values less than 0.01 were considered significant), the Kolmogorov–Smirnov test was used. Following this, a comparison of the two groups (reported age and biological age) was performed by means of the *t*-test.

p-Values less than 0.05 were considered significant. Analysis was performed with the SPSS 13.0 statistical software package.

Table 3
Results of investigations (m, male; f, female).

Reported age (52 subjects)	Assessment confirmed biological age	Assessment confirmed discrepancy
<14 years (5)	17 Subjects (11 m and 6 f)	26 subjects (23 m and 3 f)
<18 years (43)	4 Subjects (m)	0
>18 years (4)	5 Subjects (3 m and 2 f)	0

2. Results

This study has revealed that 26 of the 52 individuals had reported ages lower than the assessed ages. In 43 of all cases (34 males and nine females), the reported age was ≤18 years, but only 17 (11 males and six females) were confirmed by radiographic examinations (OPGs and hand/wrist X-rays); whereas, in 26 cases (23 males and three females) age estimation revealed that the individuals were older than had been reported.

Conversely, agreement between reported and assessed ages were obtained for only nine individuals: four males reported ages older than 18 years and five individuals (three males and two females) reported ages lower than 14 years (Tables 1–3).

The greatest discrepancy in reported age was 5 years and 10 months [case no. 25: reported age 16 years and 8 months, estimated biological age (mean) 22 years and 6 months].

The Kolmogorov–Smirnov test revealed that samples were distributed along a normal curve ($p = 0.072$). The student's *t*-test for independent samples was then used to determine if there were statistical differences between reported age/assessed age and skeletal/dental age.

The results showed a statistically significant difference between reported age and assessed biological age ($t = 4.085$; $p < 0.001$); conversely, no statistically significant difference was observed between skeletal age and assessed dental age ($t = 0.791$; $p = 0.431$).

3. Discussion

Analysis of the data revealed a significant correlation between the results obtained from the left hand/wrist X-rays and the OPGs in almost every individual, indicating similar growth patterns of skeletal and dental structures. This was particularly evident in the younger subjects (younger than 16 years of age), where age assessment is more reliable than in older subjects due to the presence of numerous growth indicators including teeth in their developmental stages [17].

Upon completion of skeletal growth and development, very few age dependent characteristics remain for purposes of age estimation using morphological and morphometrical methods. As a result, the older a subject becomes, the less accurate the methods are at reliably establishing age [18].

Taken together, markers for bones, teeth, and sexual development are considered to be the only reliable indices for assessing a living individual's age in forensic settings. Furthermore, comprehensive approaches to age estimation, which considers multiple maturity indicators are superior to those, which use non-comprehensive methods [3,19,20].

Sexual development markers and the BMI should only be used as supplementary information due to their variability. For example, some diseases, which are the result of malnutrition or congenital disorders, give rise to disproportionate growth. In the clinical setting, growth measurement is crucial for detecting and treating illnesses and developmental disorders, but is not appropriate for age estimation. Therefore, physical examination may provide only empirical probability of an individual's age. On the other hand, it can be quite useful when the subjects are younger than 14 years of age, but not in young adults between 14 and 18 years who have already gone through puberty [21].

Of all the various methods and procedures available for age estimation, X-rays represent the most objective method for assessing dental and bone maturity. It is also important to stress, however, that a methodological approach to age assessment of a living individual establishes his physiological age and that sexual, dental and skeletal development is representative of the individual's overall physical maturity and not his chronological age [22].

This study has highlighted a very clear trend in which immigrants, in an attempt to avoid criminal prosecution, tend to report their ages as younger than they actually are. This particular phenomenon is on the rise in Italy as well as in other EU countries as requests for political asylum increase [23].

4. Conclusions

The study demonstrates that standardization of methods used in the age estimation of living individuals is imperative. It is important to emphasize that all of the techniques employed to determine the age of a living individual can only provide estimates of biological age but no certainties with regard to chronological age. However, it is generally agreed that age assessment is more accurate when derived from multiple indicators. In addition, the developmental differences associated with various ethnic groups must also be considered.

Although several studies have shown [20,24,25] that differences in the rate of ossification in various age-groups seem to be primarily the result of socioeconomic factors, further research is required to determine the influence of ethnicity on skeletal, dental and sexual maturity. The study by Olze et al. [26], for example, observed some differences in third molar development between the ethnic groups. It surveyed and concluded that population-specific standards would enhance the accuracy of forensic age estimates based on wisdom tooth mineralization in living subjects.

A careful approach to age determination is necessary since few physicians are skilled in forensic age determination. Entrusting expert pathologists and odontologists with the task of performing age assessments is advised. Furthermore, a search for improved methods of age estimation, in particular, objective methods based on morphometrical and statistical analyses is essential [20,22, 27,28,29]. Moreover, some of the methods currently used need updating (e.g., the development of secondary sexual characteristics) and expansion to include people from different regions.

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