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ORIGINAL ARTICLE

Forensic age estimation in Barcelona: analysis of expert reports issued between 2011 and 2018

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Abstract

Introduction In recent years, there has been a notable increase of migratory movements into Europe with the arrival of not (reliably) documented young individuals within EU-Member States. Accordingly, the need for forensic age assessments likewise increased in order to administratively differentiate along the legally relevant cut-off age of 18 completed years. The objective of our study was to analyse the expert reports of forensic age estimation issued in Barcelona between 2011 and 2018.

Method In all cases, data on the medical history, physical examination, radiology of the left hand and orthopantomography were collected. In cases without third molars and a complete ossification of the hand, a CT scan of the clavicles was also performed.

Results A total of 2754 expert reports were evaluated; 96.7% were males, the majority were of North African origin, mainly from Morocco (63.6%), and 19.6% were sub-Saharan Africans; 65.4% had a level of bone maturation corresponding to the last three standards of Greulich and Pyle. Most cases had mineralization of the third molar corresponding to the F, G or H stages of Demirjian.

In 85.9%, there was a correspondence between bone and dental age. A total of 28.8% of the subjects were evaluated as being aged over 18 years; 86.2% of North Africans were considered to be younger than 18, and 82% of sub-Saharan Africans were considered to be over 18 years old.

Conclusions In Barcelona, most of the subjects evaluated were male and North African, and 71.2% of the cases were considered to be minors.

Keywords Forensic age estimation · AGFAD recommendations · Bone age · Dental age · Unaccompanied minors

Introduction

Forensic age estimation is common within the field of forensic medicine, both in the living and in cadavers. The way in which this estimation is carried out is explained in the classic reference textbooks [1–3], but the procedure has greatly improved in recent years [4]. Since the early 1990s, the increase in migratory movements in Europe due to socio-economic problems, armed conflicts and other reasons, has led to a dramatic increase in requests for expert reports on forensic age estimation [5]. Allegedly doubtful minors must be evaluated because they lack documents proving their identity and thus their age, with an administrative objective. In most European countries, the relevant age limit for the compulsory protection of minors is 18 years [4, 6].

Due to its geographical location close to the African continent, Spain has experienced a particularly high influx of migrants in recent years. According to Eurostat data [7], from 2011 to 2018, Spain was among the top four countries in the European Community with the highest number of migrants welcomed (with 200 unaccompanied minors and 28,725 first-time applicants of subjects younger than 18 years), being second after Germany in the years 2016 to 2018, with a significant increase in cases in the years 2017 to 2019.

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According to a report of the State Attorney General's Office for the year 2019, around 2000 files for age estimation were initiated per year in Spain from 2013 to 2015, 2971 in 2016, 5600 in 2017 and 12,152 in 2018 [8]. This implies a notable increase in the production of forensic age estimation reports in recent years in Spain, before the SARS-CoV-19 pandemic.

Garamendi and López-Alcaraz recently published an article on the current situation in Spain regarding forensic age estimation reports, in which they described recent advances in the use of international protocols in many Spanish Institutes of Legal Medicine and Forensic Science [9].

Currently, the reference recommendations for forensic age estimation are those approved by the "Study Group on Forensic Age Diagnostics (AGFAD)" of the "German Society of Legal Medicine", which was established in 2000 in Berlin and organizes an annual meeting of the group and a Proficiency Test that consists of correctly solving two practical expert cases [4, 10, 11]. The objective of these tests is to improve the quality of expert reports on forensic age assessment and to harmonize the approach in different countries [10–12]. In Spain, we follow the "Recommendations on methods of forensic age estimation in unaccompanied foreign minors. Consensus Document on Good Practices among the Institutes of Legal Medicine of Spain" (2010) [13], which are different to those of the AGFAD [4, 14].

From the legislative point of view, in Europe, article 25 of Directive 2013/32/EU specifies the path of commissioning medical age assessments by administrative authorities within asylum procedures and remarks that a medical assessment should only be performed in case of a doubtful minority allegation and not as a general evidence gathering in all minors [15]. Besides, in 2014, in Spain, the "Framework Protocol on certain actions in relation to Unaccompanied Foreign Minors" was published in the Official Gazette of the Spanish State, which regulates, among others, the performance of age estimation tests, following the previously mentioned *Consensus Document* [13, 16].

Here, we present the results of a review of the expert age estimation reports, issued in the city of Barcelona, from 2011 to 2018.

Material and methods

The forensic age estimation reports issued by the expert forensic doctors of the Institute of Legal Medicine and Forensic Sciences of Catalonia (IMLCFC) in the city of Barcelona, in the period between Jan 01, 2011 and Dec 31, 2018, were reviewed, most of them having been requested by the Juvenile Prosecutor's Office in the province of Barcelona. In Spain, the Juvenile Prosecutor is also responsible for age assessments of unaccompanied minors who are not accused of any crime. They only requested us these reports when there was a doubt about the age of the subject.

These reports were based on the standardized forensic age estimation protocol of the IMLCFC. We recorded sex, birth country, ethnic background, the reported age, nutritional information related to childhood, current or pre-existing diseases (especially those related to growth), medication and family diseases. The clinical examination included weight, height, constitutional type, calculated Body Mass Index, signs of sexual maturation (with specific consent) and dental examination to evaluate dental eruption, especially of the third molars. In all cases, an X-ray of the left hand and orthopantomography were performed. Before taking the radiographs, the subjects signed a written informed consent for these examinations, after being advised of the very improbable health risks. Those reports without a CT scan of the clavicles were signed by a specialized forensic physician. When a CT scan had to be evaluated, two experts signed the report. Cases of missing third molars in which a CT scan of the medial epiphysis of both clavicles had not been performed, incomplete reports and cases with severe dental pathology were discarded. Among a total of 2910 cases, 156 were excluded, leaving a final sample of 2754 cases.

From these, we obtained data referring to the medical history, physical examination, results of the X-ray examination of the left hand according to the Greulich and Pyle standard (G-P) [17], the third molar mineralization according to the typology of Demirjian et al. [18] and in some cases the medial clavicular ossification on CT according to the Schmeling stages and Kellinghaus substages [19, 20].

All CT studies were performed on two Siemens Somatom Sensation 64 scanners and one Siemens Somatom go-Top 128 scanner. Subjects were placed in the supine position on the scanner table with their arms alongside their body. The FOV (field of view) used was 20 cm including both medial clavicular epiphyses. The thickness of the applied slice was 1 mm. A standard bone kernel was used for image reconstruction. Reconstructions of both medial clavicular epiphyses were performed in the axial, sagittal, and coronal planes, and the coronal epiphyses were reconstructed following the axis of the sternum. The images were reviewed in a bone window.

For data processing, the Statistical Package for the Social Sciences (SPSS) 17.0 was applied. Descriptive statistics of all the variables were calculated, and an analysis of variance was performed to compare bone age (G-P) with dental maturation (Demirjian stage).

Following the recommendations of the *Spanish Consensus Document* [13], we considered that a subject was at least 18 years old when the physical examination was compatible, the radiograph of the hand showed a standard of 18 or 19 years according to G-P and the orthopantomogram

showed a third molar in Demirjian stage H, in the absence of developmental disorders. In doubtful cases or those without third molars with a complete ossification of the hand skeleton, a CT scan of the medial epiphysis of both clavicles was performed in axial and coronal projection. Accordingly, we do not totally follow AGFAD recommendations. The subject was considered older than 18 years when they had stage 3c, 4 or 5 of clavicular ossification according to the Schmeling stages and Kellinghaus substages [5, 19–21].

Results

Of the 2754 cases studied, 2672 were requested by the Juvenile Prosecutor's Office, 80 by an investigating court, one by a criminal court and one by a prison supervision court.

1. Sociodemographic data:
   Figure 1 shows the number of cases per year and the considerable increase from 2016, with cases increasing to a maximum in 2018. In terms of sex, 96.7% were male. Over the years we studied, the percentage of women ranged from 1.2% (2011) to 5.8% (2014).
   Regarding the birth countries, it stands out that more than half came from Morocco (Table 1). By geographical area, 72% were from North Africa, 19.6% were sub-Saharan African, 6.5% Asian, 1.5% European and 0.4% "other" (8 from Chile, 1 from Cuba and 1 from Haiti). Figure 2 shows the distribution by geographical area over the years, highlighting that 2011 was the only year in which sub-Saharan Africans predominated (Fig. 2).
2. Physical examinations: We did not identify any cases with developmental disorders. 62% of the subjects consented to evaluate the assessment of sexual maturity signs.
3. Findings of radiology:
   The results of the radiographs of the left hand are detailed in Table 2, which highlights that 65.4% corresponded to the last three standards of G-P [17]. Review of these data for the two main geographical areas revealed that the 18- and 19-year-old standards predominated among sub-Saharans, whereas the 16- and 17-year-old standards predominated among the North Africans (Fig. 3).
   The Demirjian stage of the third molar is presented in Table 3; most of the cases were in stages F, G and H [18]. Considering only the two main geographical areas, we observed the predominance of stages G and H among sub-Saharans and stages D, E, F and G in North Africans (Fig. 4).
   Fifteen CT studies of the medial epiphysis of both clavicles were performed (Table 4), most of them due to the absence of third molars, except for two that were ordered directly by the judicial authority.
   Figure 5 shows the relationship between the result of the X-ray examination of the hand and the mineralization stage of the third molar in our series. A high cor-

Table 1 Distribution of cases by country of origin

Country of origin	Number	Per cent
Morocco	1753	63.65
Algeria	210	7.63
Ghana	147	5.34
Guinea Conakry	104	3.78
Pakistan	77	2.80
Gambia	67	2.43
Mali	44	1.60
Senegal	41	1.49
Afghanistan	30	1.09
Nigeria	30	1.09
Ivory Coast	27	0.98
Viet Nam	23	0.84
Cameroon	20	0.73
Other countries	181	6.57
Total	2754	100

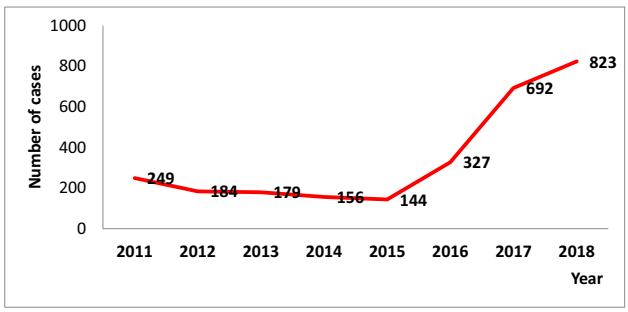

Fig. 1 Number of forensic age estimation reports issued each year

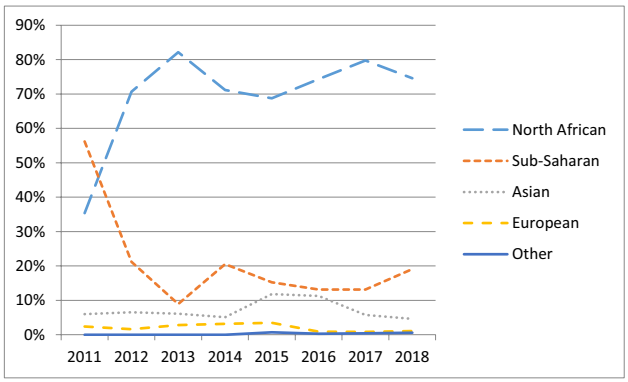

Fig. 2 Distribution of cases by geographical area over the studied period

Table 2 X-ray examination of left hand (G-P*)

G-P (years)	Number	Per cent
10	1	0.04
11	5	0.18
11.5	1	0.04
12	2	0.07
12.5	12	0.44
13	37	1.34
13.5	28	1.02
14	193	7.01
15	228	8.28
15.5	86	3.12
16	352	12.78
16.5	8	0.29
17	685	24.87
18	450	16.34
19	666	24.18
Total	**2754**	**100**

*Greulich and Pyle

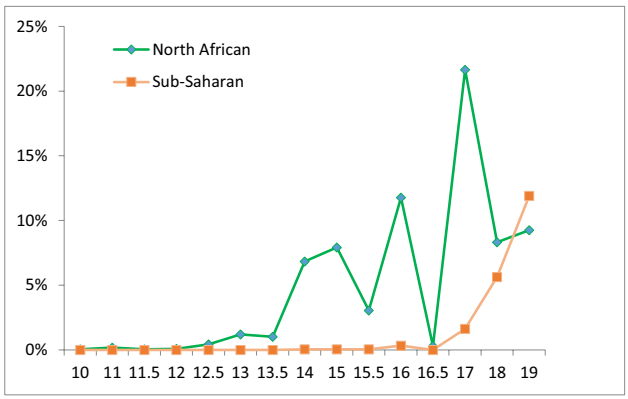

Fig. 3 Bone maturation in the two predominant populations (G-P standards)

Table 3 Third molar Demirjian stage

Demirjian stage	Number	Per cent
A	1	0.04
B	2	0.07
C	12	0.44
D	347	12.60
E	378	13.73
F	534	19.39
G	627	22.77
H	842	30.57
Absence of third molars	11	0.40
Total	**2754**	**100**

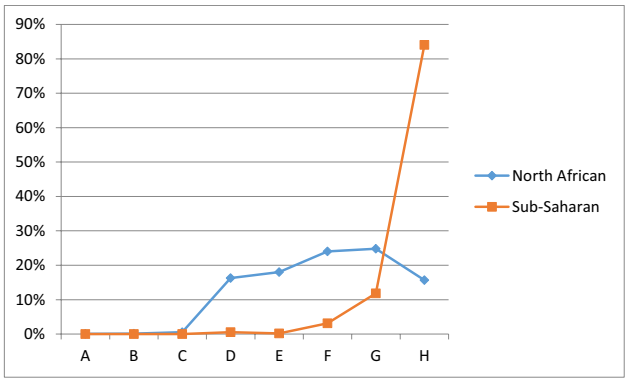

Fig. 4 Demirjian stages of the third molar in the two predominant populations

relation between bone and dental maturation ($p < 0.001$) was observed.

Bone age (classified as ≥ 18 years if we had obtained a G-P standard in the hand radiograph of 18 or 19 years, or < 18 years if we had evaluated another standard) was related to dental age (classified as ≥ 18 years if we had recorded a Demirjian H stage in the third molar, or < 18 years if we had recorded an A-G stage). Concordance was found between the results of the two tests in 85.9% of cases. In cases of discrepancy, there was more often complete bone maturation and incomplete dental mineralization (Fig. 6).

4. Conclusions of the expert reports:

A total of 71.2% of the individuals were assessed as being under 18 years old (28.8% were older than 18 years). By geographical area, 86.2% of North Africans, 18% of sub-Saharans, 80.9% of Caucasians, 61.2% of Asians and 100% of others were considered younger than 18 years old.

Discussion

We reviewed 2754 forensic age estimation reports issued in Barcelona over 8 years (2011–2018). This is similar in number to the Hamburg series, which included 2578 cases in the period from 2009 to 2015 [12]. Most of the subjects were male (96.7%), and the percentage remained fairly stable throughout the period studied. Other series were also dominated by men: in Berlin (91%) [22] and Münster (91.8%) [23], and in Danish (93.1%) [24] and French series (97.7%) [25]. In our series, 91.6% came from the African continent. Of the total, Moroccans (63.6%) and sub-Saharans (19.6%) predominated; the majority were sub-Saharan (56.2% of a total of 249) only in 2011. In Spain, there has

Table 4 Findings of the cases in which clavicle CT was performed ($n = 15$)

Country	Geographical areas	Hand x-ray (G-P) (years)	Orthopantomogram (third molar's Demirjian stage)	Clavicle CT (Schmeling stage and Kellinghaus substage)	Medicolegal assessment (> 18 years or < 18 years)
Guinea Conakry	Sub-Saharan	19	38H	5	> 18 years
Afganisthan	Asian	19	Third molars missing	3c	> 18 years
Morocco	North African	19	Third molars missing	3a	< 18 years
Morocco	North African	15.5	Third molars missing	1	< 18 years
Morocco	North African	19	38H	3c	> 18 years
Algeria	North African	19	Third molars missing	3c	> 18 years
Algeria	North African	19	Third molars missing	3c	> 18 years
Morocco	North African	18	Third molars missing	3c	> 18 years
Morocco	North African	19	Third molars missing	3c	> 18 years
Morocco	North African	19	Third molars missing	2a	< 18 years
Algeria	North African	19	Third molars missing	2b	< 18 years
Guinea Conakry	Sub-Saharan	19	Third molars missing	2b	< 18 years
Morocco	North African	19	38 missing. 48H	3c	> 18 years
Albanian	European	18	38 and 48 missing	2c	< 18 years
Morocco	North African	19	Third molars missing	3b	< 18 years

G-P Greulich and Pyle

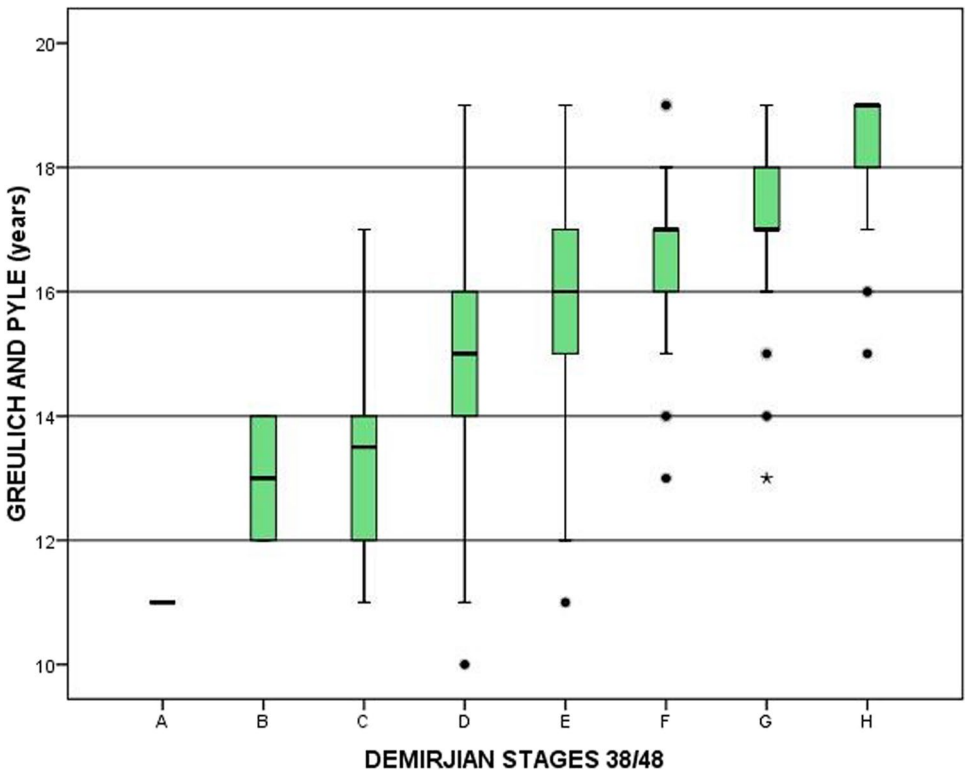

Fig. 5 Correlation between bone maturation and third molar mineralization

been a progressive increase in cases from 2016, with a maximum in 2018, reflecting the massive increase in immigration [26], a pattern analogous to that observed in our series. In the Finnish series [27], an increase in cases was observed in 2015 (149 cases) compared to previous years. In the Münster series [23], there was an increase in the number of reports in 2015, a subsequent decrease and a further increase in 2018, although the number of immigrants recorded this year was clearly lower than in 2016. These differences could be explained by the origin of the migratory flow. In Barcelona,

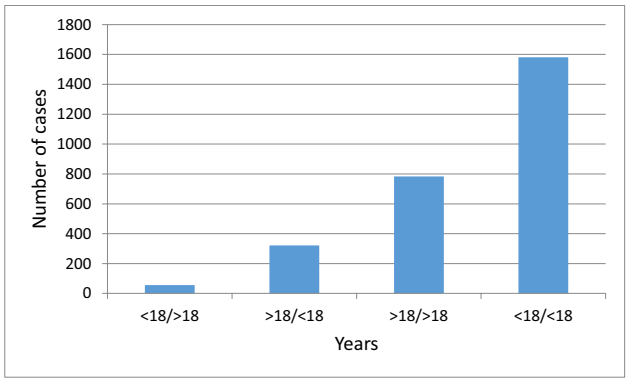

Fig. 6 Relationship between bone and dental age results ($N = 2754$)

72% of the subjects came from North Africa, 19.6% were sub-Saharan, and 6.5% were Asian (includes individuals from Middle Eastern countries). Morocco was the prevailing country of origin in our study, which reflects its proximity to Spain as a country providing access to Europe. In contrast, in Finland, most came from Afghanistan, Iraq and Somalia [27]; in Berlin, from 1992 to 2000, the main countries of origin were Vietnam, Romania, Lebanon, Bangladesh and Turkey [22]; and in Münster, Asian subjects predominated between 2009 and 2016, whereas sub-Saharans predominated in 2017 and 2018 [23]. In contrast, in Montpellier, 80.4% of the cases evaluated were sub-Saharan [25].

Of the total number of cases included, 40.5% had a G-P standard of 18 or 19, unlike in the Danish series, in which almost all cases (91.4%) had a G-P standard of 18 or 19 [24]. In the majority of our series (85.9%) and in all the populations studied, there was a strong correlation between the results of bone age and dental age, as it was explained previously. When there was a discrepancy between the results, it was more frequent to find complete bone maturation and incomplete dental mineralization. The correlation between these two parameters was also evaluated in the Danish series, with a correlation in 94% of cases; in most of the cases where there was no correlation, dental age was greater than bone age, unlike in our series [24].

The difference between our protocol [13] and the AGFAD protocol [4, 5] is that in the AGFAD, a CT scan of the clavicles is performed in all cases in which the ossification of the hand is complete [28], as carried out by the working groups of Rudolf et al. [29], Hagen et al. [23] and Lossois et al. [25]. We performed 15 CT scans of the clavicles, and in all cases, the scan allowed us to estimate the forensic age beyond reasonable doubt [5]. Obviously, in our fourth CT case (Table 4), the CT was wrongly indicated because the X-ray hand was not completely ossified. It was a mistake by an inexpert forensic physician on duty at the beginning of the period using the CT in our institute. Identifying that error has allowed us to prevent it from happening again.

The objective test that an individual has reached the age of 18, without doubt, is the presence of stage 3c, 4 or 5 ossification on the CT scan of the clavicles [5, 20, 21, 23, 30]. However, only 12 of 30 European countries use radiology of the clavicles in forensic age studies [23, 31]. In Spain, the *Consensus Document* [13] mentions the possibility of performing a CT scan of the clavicles as an option in doubtful cases, or in a population that has not been well studied, if the X-ray of the hand indicates a bone age ≥ 18 years; the importance of keeping in mind the radiation dose of the examinations, of medically assessing its indication and not repeating tests, is also emphasized.

Following Schmeling, the radiation required to perform an X-ray of the hand is 0.0001 mSv, and for an orthopantomography, it is 0.026 mSv [4], which are considered almost completely harmless doses [32]. The irradiation required for a CT of the proximal end of the clavicles would be about 0.6–0.8 mSv [32], but this amount would be much lower than the annual natural radiation dose in Germany, with averages 2.1 mSv and in some regions up to 2.6 mSv per year [4, 33, 34]. That is, the radiation doses necessary to perform radiological tests for forensic age estimation are below the radiation exposures of daily life [33, 34]. Therefore, in cases where a clavicular CT scan is indicated, if it is performed by expert radiologists and in subjects around the age of 18 years or older, it can be performed with virtually no risk [32].

In 2003, Schmeling et al. reviewed 247 age assessments, performed in Berlin, which were based on history, physical examination, hand X-ray, orthopantomography and in some cases on clavicle X-ray. They obtained an error of ± 12 months in the 45 subjects whose ages were verified [22].

In other series, such as the Finnish and Danish series, the clavicle was not evaluated. In the Finnish work, forensic age assessment from 2005 to 2015 was based on hand radiography and orthopantomography [27], and in the 2012 Danish series, it was based on physical examination (without clinical dental assessment), hand radiography and dental radiographs (orthopantomography and third molar intraoral radiographs) [24]. As in our work, the 2017 Hamburg study limited CT scan of the clavicles to doubtful cases. However, it differed in that orthopantomography was performed first, and this test carries a lot of weight; if it was not conclusive, an X-ray of the hand was performed, which helped to calculate the minimum age if the subject was less than 18 years old. They only performed a CT scan of the clavicles when the third molars were missing or the two radiographic tests give quite different results [12]. Therefore, in these three publications, they do not follow the AGFAD recommendations.

The combination of physical examination, hand radiography and orthopantomography was recommended in the Moroccan population by Garamendi et al. in 2005 [35] to avoid false positives of people over 18 years old (underage

subjects considered as older, which would be an ethically unacceptable error), despite increasing the number of false negatives (older subjects evaluated as minors). Using the two tests, we ensured a very high probability that the subject was over 18 years old, as corroborated in the Hamburg study [12]. However, in the sub-Saharan population, we know that the minimum age of a subject with a lower third molar in stage H is 17.3 years [36], and therefore, in these cases, when the ossification of the hand is complete, a clavicular CT scan should be performed [4, 5]. In any case, we believe that the percentage of error in these cases is very low, since a recent meta-analysis of the mineralization of the third molar in 19,690 subjects of all ethnic groups confirmed that the percentage of false positives was very low, at 3.1% [37]. Likewise, in the recent work by Lossois et al., in which 80.4% of the subjects evaluated were sub-Saharan, 89% of the orthopantomographies performed found a Demirjian H stage in the third molars and, given that they followed the AGFAD recommendations for forensic age estimation (a clavicular CT scan was performed in all cases with complete ossification of the hand), they concluded that 95.85% of the cases studied were most likely at least 18 years old [25].

The difference between the high number of CT studies performed in Münster and Austria [23, 29], compared to the few or lack of CT studies performed in Hamburg, Denmark, Finland, Sweden and Barcelona [12, 24, 27, 38], can be attributed to the high radiation exposure and cost, and lack of therapeutic purposes.

On the other hand, in Sweden [38], forensic age estimation is based on MRI of the knee and radiographic study of the third molar in the mandible, in which subjects who have completed maturation in one or the two tests are assessed as adults (Schmeling et al. stage 4 or 5 in the knee or Demirjian stage H in the lower third molar); however, the authors considered that around 33% of juvenile males were erroneously classified as adults. These results exemplify the importance of reducing the ethically unacceptable error highlighted by Garamendi et al. in 2005 [35], in the sense of minimizing to the maximum the number of minors misclassified as adults.

In our sample, 28.8% of individuals were assessed as older than 18 years, whereas in the Münster series, Hagen et al. reported that 74.5% of the subjects had most probably reached the age of majority [23]. These results also differ from the Finnish study conducted in 2015, which concluded that 28% of their series were minors, although in 11% of cases, the results were inconclusive [27]. In the Danish series, 80% were assessed as being older than 18 years, bearing in mind that the authors accepted a risk of age overestimation, although it was low, by not using a clavicle scan [24]. In the Austrian series, 61% were considered older [29] and in the French series [25], 95.85% were considered older than 18 years.

One of the limitations of our work is that it was a retrospective study, although it should be noted that the assessment and reporting protocol of the IMLCFC and the Spanish *Consensus Document* [13] was followed in all the cases we included. Probably the number of subjects classified as minors is too high because we try to avoid ethically unacceptable errors (minor subjects classified as adults), and that is the reason that some adults have probably been considered as minors [35].

Another limitation is the assessment method, which did not include a CT scan of the clavicles in subjects where skeletal development of the hand was completed, that is, we do not totally follow the AGFAD recommendations.

In conclusion, in our large sample of forensic age estimation reports issued in Barcelona, the vast majority were male and of North African origin (especially from Morocco), and 71.2% of cases were estimated to be minors. The majority (86.2%) of North African subjects were minors whereas the majority of sub-Saharans (82%) were considered to be over 18 years old. We really suggest modifying our current protocol and adapting it to AGFAD recommendations [4, 5, 10] as well as applying the minimum age concept in all cases [4, 5, 14].

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Declarations

This retrospective study conducted with human participants was conducted in accordance with the 1964 Declaration of Helsinki and its latest amendments or comparable ethical standards. The study was approved by the "Research Ethics Committee of the Hospital Universitari de Bellvitge", L'Hospitalet de Llobregat (Barcelona) (PR286/22). All the procedures carried out were part of the daily expert practice requested by the Prosecutor's Office or judicial authorities.

Conflict of interest The authors declare no conflict of interest.

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