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PAPER

PHYSICAL ANTHROPOLOGY

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Forensic Age Estimation on Digital X-ray Images: Medial Epiphyses of the Clavicle and First Rib Ossification in Relation to Chronological Age*,†

ABSTRACT: In recent years, there has been a renewed interest in forensic sciences about forensic age estimation in living subjects by means of radiological methods. This research was conducted on digital thorax X-rays to test the usefulness of some radiological changes in the clavicle and first rib. The sample consisted in a total of 123 subjects of Spanish origin (61 men and 62 women; age range: 5–75 years). From all subjects, a thorax posterior-anterior radiograph was obtained in digital format. Scoring for fusion of medial epiphyses of the clavicle was carried out by Schmeling's system and ossification of the costal cartilage of the first rib by Michelson's system. Degree of ossification and epiphyseal fusion were analyzed in relation with known age and sex of these subjects. The results give a minimum age of >20 years for full fusion of the medial epiphysis of the clavicle (Stages 4 and 5). Concerning the first rib, all subjects with the final Stage 3 of ossification were above 25 years of age. These results suggest that the first rib ossification might become an additional method to the ones so far recommended for forensic age estimation in subjects around 21. New research would be desirable to confirm this suggestion.

KEYWORDS: forensic science, forensic age estimation, first rib, ossification, clavicle, epiphyses, radiography

In the year 2000, the Arbeitsgemeinschaft für Forensische Altersdiagnostik der Deutschen Gesellschaft für Rechtsmedizin (AGFAD) published its guidelines for the forensic estimation of the chronological age of living individuals subject to criminal proceedings (1–3). These guidelines recommended the performance of the following tests to determine majority or minority of age (18 years) for criminal purposes, in living subjects:

- Physical examination: anthropometrical measurements (weight, height, build); inspection of signs of sexual maturity; identification of diseases which could alter maturity development.
- X-ray examination of the left hand.
- External examination of the condition of teeth and dental X-ray.
- X-ray examination of the clavicle region, to confirm if the chronological age is over or under 21.

When interpreting the results, the guidelines themselves recommend that data from the tests above should be compared with reference studies relevant to the specific individual in question. They finally recommend that, when the final expert assessment has been made, the results of each of the tests performed should be recorded separately and that the age estimated should be identified as the most probable, specifying the degree of probability of each estimated result.

In Spain, there are several studies on our national population according to which the recommended tests can be interpreted with the pertinent adjustments in assumed minors of Spanish origin.

This paper presents a study conducted on a Spanish population sample. The purpose of the study was centered on two different questions:

- Minimum chronological age of complete fusion of the medial clavicle. As this is a parameter recommended by AGFAD for a forensic age estimation (FAE) around 21 years, knowing this minimum age could be a way to define the inferior error limit inherent to this recommended test.
- Relation between chronological age and the process of ossification of the costal cartilage of the first rib. We analyzed this relation to test if it could be a useful indicator for an FAE around 21 years.

Material and Methods

The sample on which the study was conducted consisted of a total of 123 subjects of both sexes (61 men and 62 women). From every subject, a thorax posterior-anterior (PA) radiograph was

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TABLE 1—*Distribution of sexes in relation with age groups in the population sample.*

Age	Males	Females	Total
0–<20	12	12	24
20–<30	20	20	40
30–<40	20	20	40
40–<50	20	20	40
50–<60	20	20	40
60–<70	20	20	40
70–	10	12	22
Total	122	124	246

TABLE 2—*Statistical measures of age distribution in the whole sample of both sexes. Number of cases represents number of hemiradiographs analyzed.*

Age Groups	Average	*N*	Standard Deviation	Minimum	Maximum	Median
Male						
0–<20	17.27	12	3.23	10.61	19.72	18.05
20–<30	24.63	20	2.91	20.09	28.91	24.66
30–<40	35.11	20	3.06	30.67	39.96	34.91
40–<50	44.92	20	2.82	40.40	49.04	44.89
50–<60	55.17	20	2.83	51.44	59.90	55.35
60–<70	64.08	20	2.26	60.66	68.33	64.02
70–	73.03	10	1.99	70.85	75.41	72.82
Total	44.39	122	17.61	10.61	75.41	44.05
Female						
0–<20	14.67	12	5.14	5.35	19.43	16.64
20–<30	25.69	20	2.68	21.07	29.60	25.90
30–<40	35.42	20	2.79	30.84	39.59	35.14
40–<50	45.15	20	2.73	40.63	49.24	45.52
50–<60	55.21	20	2.51	52.07	59.39	54.91
60–<70	64.51	20	2.95	60.21	69.32	64.77
70–	72.41	12	1.72	70.27	75.12	72.58
Total	44.88	124	18.05	5.35	75.12	45.52
Both sexes						
0–<20	15.97	24	4.40	5.35	19.72	17.73
20–<30	25.16	40	2.81	20.09	29.60	25.18
30–<40	35.26	40	2.90	30.67	39.96	35.08
40–<50	45.03	40	2.74	40.40	49.24	45.52
50–<60	55.19	40	2.64	51.44	59.90	54.98
60–<70	64.29	40	2.60	60.21	69.32	64.38
70–80	72.69	22	1.83	70.27	75.41	72.82
Total	44.64	246	17.80	5.35	75.41	45.42

obtained in digital format. Sex, exact birth date, and date at which X-rays were obtained were known from every subject.

Age distribution of these subjects in relation with sex is in Tables 1 and 2. The mean of this sample was 44.63 years. Age ranged between 5.3 and 75.4 years of chronological age at the date of X-ray.

The study conducted on this population sample consisted in the following examinations and additional tests:

- Degree of epiphyseal fusion of medial end of the clavicle on both sides.
- Degree of ossification of the costal cartilage of the first rib on both sides.

Digital X-rays were performed in a private Radiology Clinic in Bilbao (Northern Spain). All of the subjects were Spanish and had been attended during the year 2006 in this department because of different pathologies and in most of the cases in the context of preoperatory general medical analysis. During the study, the rater did not find any anatomic indicator of any disease or anomaly that could affect the ossification process and the appropriate interpretation of the results.

FIG. 1—*Degree of ossification of the costal cartilage of the first rib. Stage 0 in the Michelson's stages system, equivalent to no ossification of the cartilage. Outlined contours of first rib, proximal clavicle, and sternum.*

These digital X-ray images were analyzed by one rater (Dr. Garamendi) using a software program specially designed to view and manipulate digital X-ray images: Image-J v. 1.34. This program can be downloaded freely from the web (4).

The data from the X-ray examination of the clavicle were quantified using Schmeling's stages system (5). Stages in this system correspond with:

- Stage 0: there is no ossification of the epiphyseal center of the clavicle.
- Stage 1: the ossification center has not yet ossified (incomplete ossification of the epiphyses).
- Stage 2: the ossification center has ossified, the epiphyseal cartilage has not ossified.
- Stage 3: the epiphyseal cartilage is partially ossified.
- Stage 4: the epiphyseal cartilage is fully ossified.
- Stage 5: the epiphyseal cartilage has fused completely and the epiphyseal scar is no longer visible.

The ossification of the costal cartilage of the first rib was quantified by the system originally described by Ernst (6) and applied for the first time on first rib by Michelson in 1934 (7,8). Examples of this system are shown in Figs 1–4. Stages in this system correspond with:

- Stage 0: no ossification of the costal cartilage of the first rib,
- Stage 1: signs of initial ossification in the cartilage,
- Stage 2: ossification of 50% of the costal cartilage, and
- Stage 3: complete or nearly complete ossification of the costal cartilage of the first rib.

These two X-ray parameters were interpreted by one rater, a forensic physician (Dr. Garamendi). Four weeks after the first test, a sample of 10 X-rays were reinterpreted by the same rater to test the intraobserver correlation for both parameters.

Relation between chronological age and degree of ossification of the first rib was statistically analyzed using Pearson correlation coefficient. Statistical independence between these data was analyzed by chi-square test and univariate general linear model test (stage as a dependent variable and sex and age as fixed factors). Intra-observer correlation was statistically analyzed by Kappa estimator.

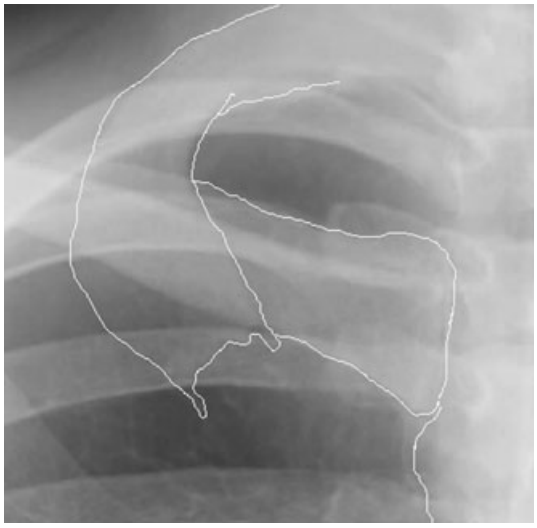

FIG. 2—*Degree of ossification of the costal cartilage of the first rib. Stage 1 in the Michelson's stages system, equivalent to initial ossification of the cartilage. Outlined contours of first rib, proximal clavicle, and sternum.*

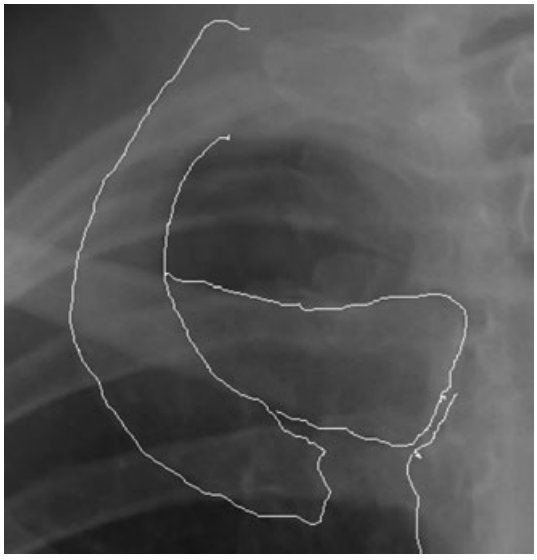

FIG. 3—*Degree of ossification of the costal cartilage of the first rib. Stage 2 in the Michelson's stages system, equivalent to ossification around 50% of the cartilage. Outlined contours of first rib, sternum, and proximal clavicle.*

SPSS 13.0 for Windows (SPSS Inc., Chicago, IL) was the statistical software package used to perform statistical analysis of the results.

Results

Medial Epiphyses of the Clavicle

Results of the study conducted in this sample are in Table 3.

Figure 5 shows the distribution of results of stages of fusion of the medial epiphyses of the clavicle in relation to sex. Figures 6–8 show the relation between chronological age and fusion stages in this sample of both sexes.

Minimum chronological age at which we could observe a Stage 4 of fusion in the Schmeling's stages system was 19.7 years. Maximum age at which we could observe a Stage 1 of fusion was 18.52 and maximum age for Stage 3 was 45.61 years. In our series, we could not assign a Stage 2 of fusion in any subject. Missing cases were coded "9" in cases were the observer was unable to define the precise stage of fusion of the clavicle, because of overlap of bone structures.

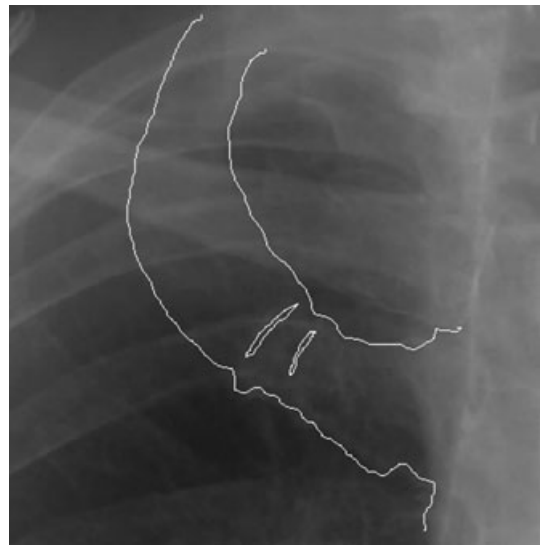

FIG. 4—*Degree of ossification of the costal cartilage of the first rib. Stage 3 in the Michelson's stages system, equivalent to complete or nearly complete ossification of the cartilage. Outlined contours of first rib and sternum.*

TABLE 3—*Distribution of results of Schmeling's stages in relation with the age. Both sexes sample.*

Clavicular Epiphyses	Average	*N*	Standard Deviation	Minimum	Maximum	Median
0	10.04	7	3.61	5.35	15.46	10.61
1	17.68	8	1.00	15.46	18.52	17.64
3	22.90	12	7.45	17.82	45.61	20.09
4	26.64	7	5.13	19.72	32.99	26.88
5	49.34	204	15.28	20.60	75.41	50.34
Missing	30.25	8	12.39	17.82	48.67	26.20
Total	44.64	246	17.80	5.35	75.41	45.42

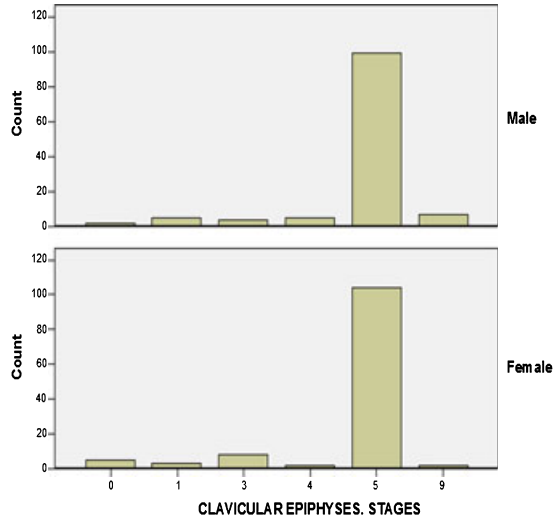

FIG. 5—*Bar chart of distribution of cases in relation with sex and degree of fusion of medial epiphyses of the clavicle.*

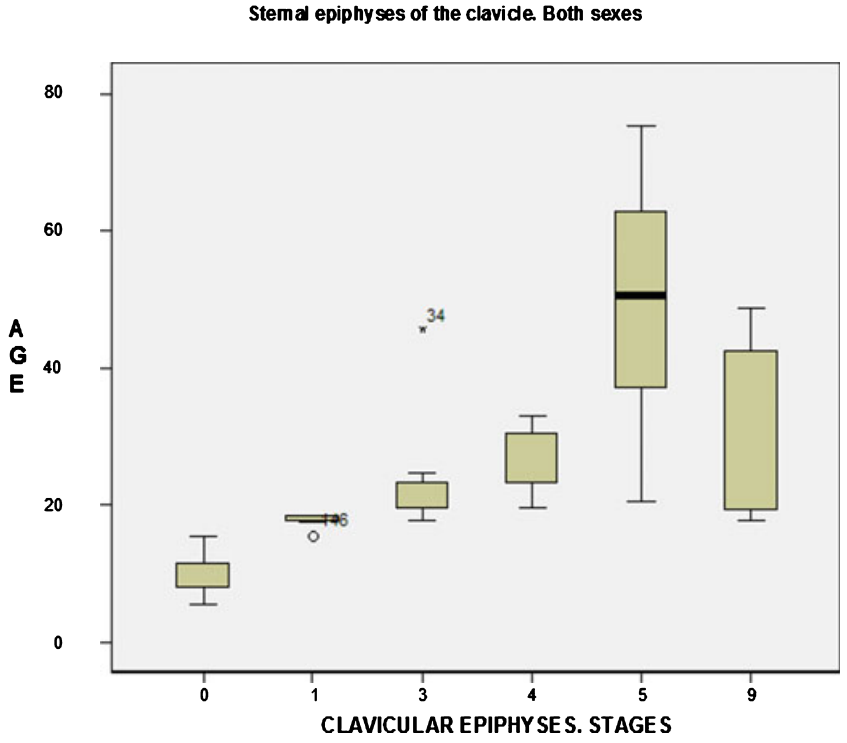

FIG. 6—*Age distribution in relation with the fusion stages in the Schmeling's system. Sternal epiphyses data number 0 to 5 represent the results in relation with the Schmeling's stages system; 9 represents missing cases. Both sexes sample.*

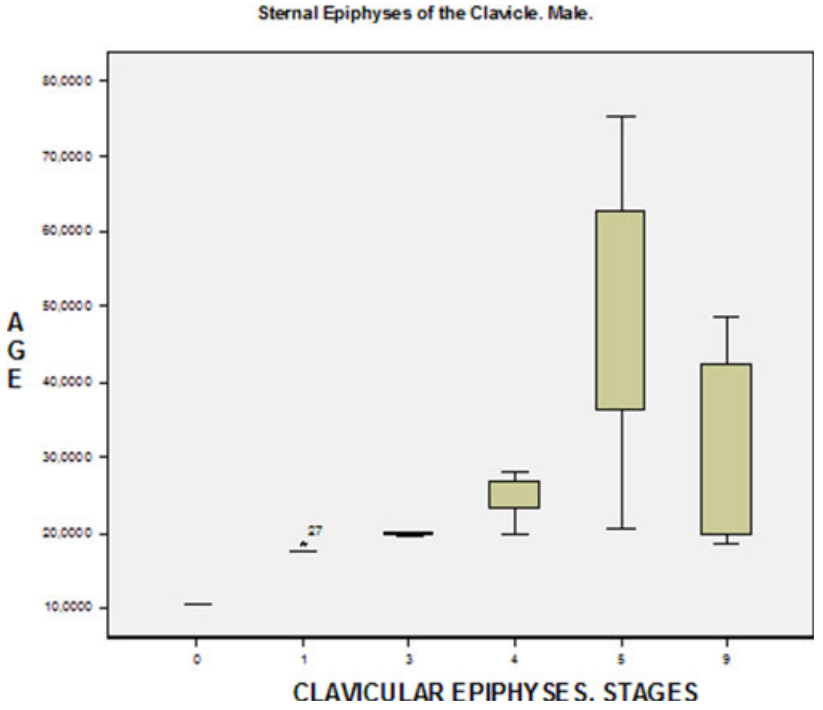

FIG. 7—*Degree of fusion of sternal epiphyses of the clavicle in relation with sex and age (Schmeling's system). Male subsample. Box and whiskers plot.*

Chi-square test was unuseful to confirm or reject the independence of sex (male vs. female) in relation with chronological age and degree of fusion, because 66.7% of the cells counted <5. Univariate general linear model test (stage as a dependent variable and sex and age as fixed factors) indicated a high *p*-value for *F*-test of sex controlling for age, indicating that sex does not significantly affect the relation between age and stage. It was found also a very low *p*-value for *F*-test of age confirming the strong relation between age and stage (Table 4).

Ossification of the First Rib

Figure 9 shows the distribution of results of stages of ossification of the first rib in relation with sex.

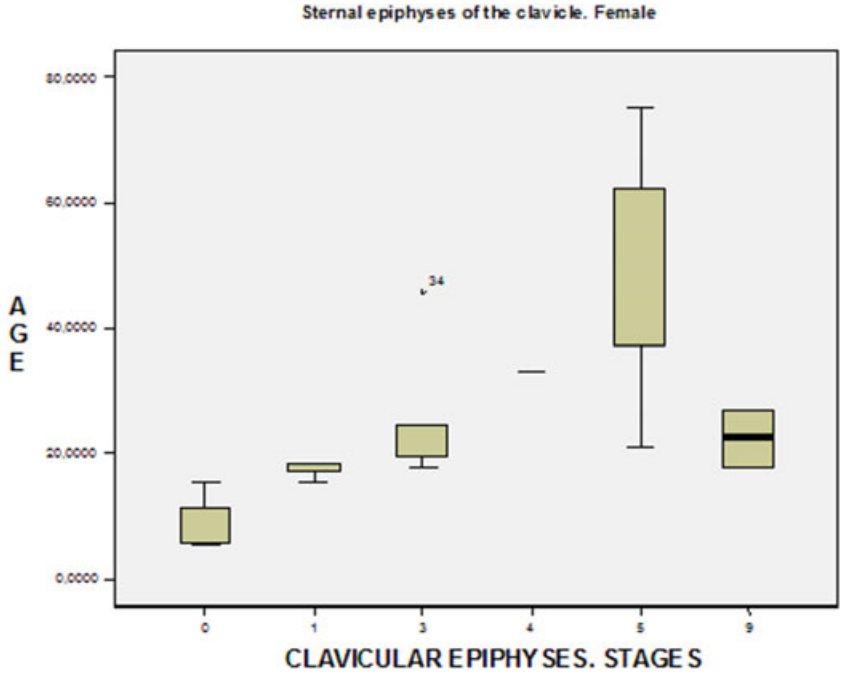

FIG. 8—*Degree of fusion of sternal epiphyses of the clavicle in relation with sex and age (Schmeling's system). Female subsample. Box and whiskers plot.*

TABLE 4—*Univariate general linear model for clavicular epiphyses. Stages of fusion of medial clavicle are dependent variable and sex and age fixed factors.*

Source	Type III Sum of Squares	d.f.	Mean Square	*F*	Sig.
Corrected model	378.293*	124	3.051	4.102	0.000
Intercept	5419.442	1	5419.442	7286.139	0.000
Sex	0.000	1	0.000	0.000	1.000
AGE	375.226	123	3.051	4.101	0.000
Sex × age	0.000	0			
Error	90.000	121	0.744		
Total	5976.000	246			
Corrected total	468.293	245			

Tests of between-subjects effects.
Dependent variable: clavicle.
*R-squared = 0.808 (adjusted R-squared = 0.611).

Pearson correlation coefficient between chronological age and degree of ossification (Michelson's system) was 0.749 for both sexes, 0.774 for men, and 0.730 for women.

Chi-square test confirms the independence of laterality (right vs. left sides) in relation with chronological age and degree of ossification (χ^2 = 1.827, 3 d.f.).

Chi-square test rejects the independence in relation with the sex of the subjects (χ^2 = 16.090, 3 d.f.).

Cross table (Table 5) shows that men are more prone to achieve stages of complete ossification (Stage 3) whereas women are more likely to achieve only incomplete ossification (Stage 2).

Main results for both sexes in relation with chronological age and ossification stages are in Tables 6–8. Table 9 indicates the number of cases in relation to age group, and Figs 10–12 show relation between age and degree of ossification in both sexes.

Nevertheless, Univariate general linear model test (stage as a dependent variable and sex and age as fixed factors) indicated a high p-value for F-test of sex controlling for age, indicating that sex does not significantly affect the relation between age and stage. This suggests an artifact of sampling that could have produced a rejection of the null in the analysis of cross tables. It was found also a very low p-value for F-test of age confirming the strong relation between age and stage (Table 10).

The intra-observer correlation for both parameters, clavicle and rib, analyzed by Cohen's kappa estimator was very high (Kappa = 1.00).

Discussion

In the medico-legal and anthropological literature, there have been an important number of previous studies that have analyzed the relation between chronological age and the process of fusion of the medial epiphyses of the clavicle. Table 11 includes the different results of main studies on this subject and minimum age at which these researchers observed a complete fusion of this epiphyses (Stage 4 or over in Schmeling's stages system or similar stages in other systems). The table also includes the source of the sample used in these different studies: osteological, radiographic, or computerized tomography (5,9–27).

In our series, minimum age at which we could observe complete fusion (Stage 4) was a chronological age of 19.7 years old. These results are similar to those obtained by other researchers, such as Richel (26), Veschi and Facchini (21), Schulze et al. (24), or Galstaun (11) who reported minimum ages around 19 years of age, but different from those by Schmeling et al. (5) or Kreitner et al. (23) who reported minimum ages for a complete fusion around 21 years of age.

As a conclusion, we suggest that when applying AGFAD recommendations of using clavicle epiphyses as an FAE indicator in subjects around 21 years of age, in Stages 4 or 5 in the Schmeling's system, it could also be indicated that the minimum chronological age in the literature and maximum known limit of the error of the test would be 19 years old. From an ethical point of view, expert reports about FAE should indicate not only the most probable age

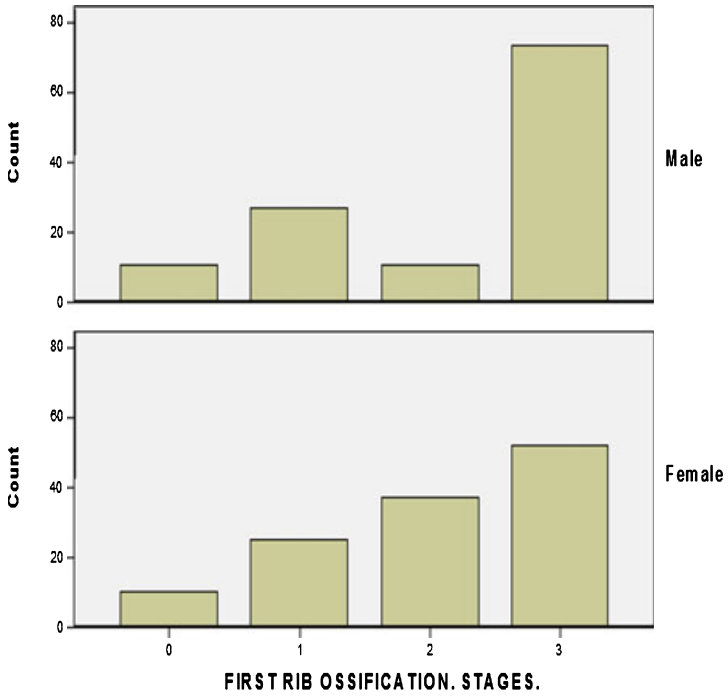

FIG. 9—*Bar chart of distribution of cases in relation with sex and degree of ossification of the first rib.*

TABLE 5—*Cross table. Sex versus first rib ossification stages (Michelson's system). Cases expected in an independent distribution and real cases in the sample analyzed are shown.*

			First RIB Ossification				
			0	1	2	3	Total
Sex	Female	Real	10	25	37	52	
		Expected cases	10	26	24	62	124
	Male	Real	11	27	12	72	
		Expected cases	10	25	24	61	122
Total		Real	21	52	49	12	
		Expected cases	21	52	49	124	246

TABLE 6—*Age distribution in relation with first rib ossification (Michelson's system). Both sexes sample.*

First Rib Ossification	Average	*N*	Standard Deviation	Minimum	Maximum	Median
0	18.03	21	9.36	5.35	46.83	17.64
1	28.09	52	9.23	17.61	67.72	26.88
2	45.74	48	11.57	24.87	65.59	46.45
3	55.56	125	13.06	25.49	75.41	57.28
Total	44.64	246	17.80	5.35	75.41	45.42

TABLE 7—*Age distribution in relation with first rib ossification (Michelson's system). Male sample.*

First Rib Ossification	Average	*N*	Standard Deviation	Minimum	Maximum	Median
0	21.66	11	10.87	10.61	46.83	18.46
1	26.55	27	7.37	17.61	51.44	25.78
2	39.82	12	8.31	30.67	52.07	38.76
3	55.32	72	12.48	25.48	75.41	56.90
Total	44.39	122	17.61	10.61	75.41	44.05

TABLE 8—*Age distribution in relation with first rib ossification (Michelson's system). Female sample.*

First Rib Ossification	Average	*N*	Standard Deviation	Minimum	Maximum	Median
0	14.044	10	5.44	5.35	19.43	15.46
1	29.75	25	10.81	17.82	67.72	27.071
2	47.68	37	11.76	24.87	65.59	48.345
3	56.08	52	13.99	28.12	75.12	58.90
Total	44.88	124	18.05	5.35	75.12	45.52

TABLE 9—*Cross table. Relation between age groups and first rib ossification quantified by Michelson's stages system.*

		First Rib				
		0	1	2	3	Total
Age groups	0–<20	17	7	0	0	24
	20–<30	2	30	4	4	40
	30–<40	1	12	11	16	40
	40–<50	1	0	15	24	40
	50–<60	0	2	11	27	40
	60–<70	0	1	7	32	40
	70–	0	0	0	22	22
Total		21	52	48	125	246

estimation but, when known, maximum error limits so that judges and prosecutors can understand more clearly the extent of the error inherent to these FAE tests (29).

In our series, we also found some difficulties collecting a sample of at least 100 X-rays in which we could clearly view medial clavicle and manage to define precisely the stage of fusion of its epiphyses. As other authors, such as Schmeling et al. or Galstaun, previously have pointed out, this is probably because PA projection is not the ideal radiographic projection to view medial epiphyses of the clavicle (5,11).

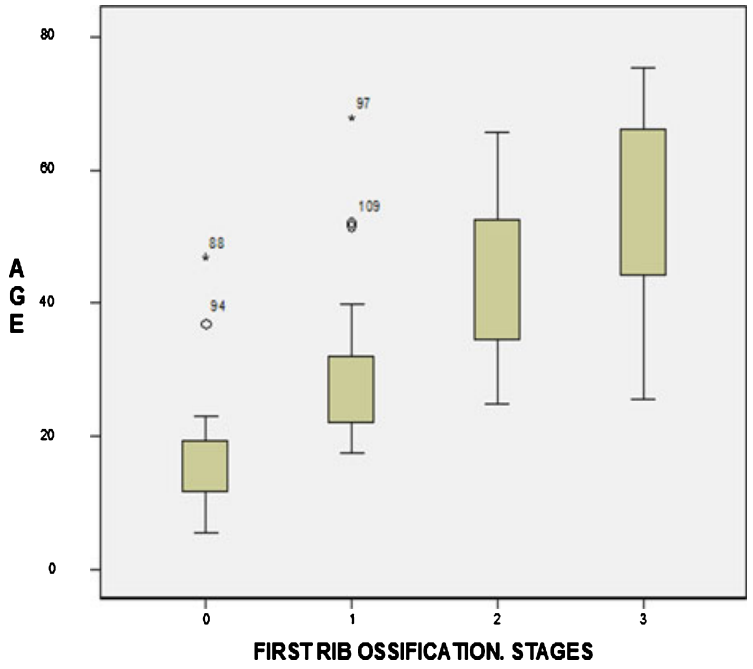

FIG. 10—*Degree of ossification of the first rib in relation with ages; both sexes sample (Michelson's stages system).*

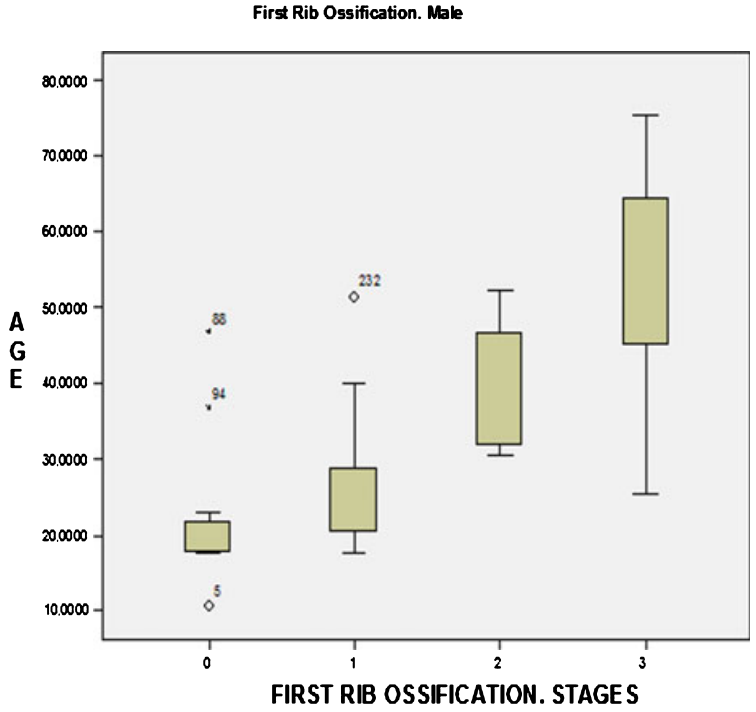

FIG. 11—*Degree of ossification of the first rib in relation with sex and age (Michelson's system). Male subsample. Box and whiskers plot.*

We have also found a few cases in which we could see a developmental abnormality of the medial clavicle that Freyschmidt et al. (30) called "fish mouth" abnormality (Fig. 13). It was identified in four subjects, in all cases older than 30 years and in one case bilaterally. If investigators are not aware of the possible existence of this abnormality, it can lead to an underestimation of the stage of development of the medial epiphyses of the clavicle.

Our first rib ossification results were compared with those obtained by previous authors. After a bibliographic review, we could find some studies in which the relation of chronological age and degree of ossification was described, but in only one case, these results were expressed in a way that could be useful for an FAE (7,8,31–36). This paper was published by Dr. Nicholas Michelson in 1934 (7). In his research, Michelson (7) analyzed 5098 thorax X-rays in which he quantified the degree of ossification of the costal cartilage of the first rib. His sample consisted in a population from the U.S.A. of both sexes and of Negroid and Caucasian races. The main results of his series are in Tables 12 and 13.

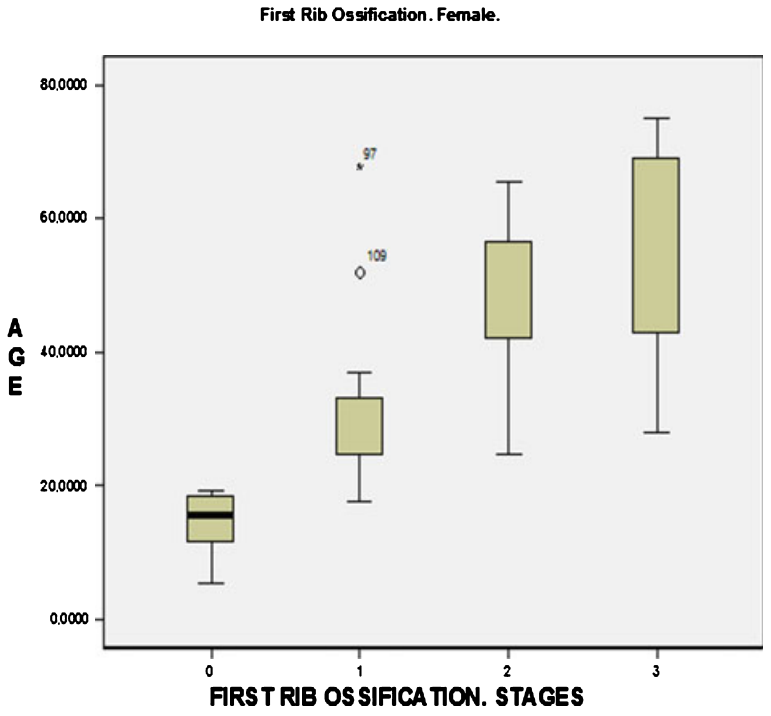

FIG. 12—*Degree of ossification of the first rib in relation with sex and age (Michelson's system). Female subsample. Box and whiskers plot.*

TABLE 10—*Univariate general linear model for ossification of first costal cartilage. Stages of fusion of medial clavicle are dependent variable and sex and age fixed factors.*

Source	Type III Sum of Squares	d.f.	Mean Square	*F*	Sig.
Corrected model	237.341*	124	1.914	12.189	0.000
Intercept	1073.506	1	1073.506	6836.539	0.000
SEX	0.000	1	0.000	0.000	1.000
AGE	236.269	123	1.921	12.233	0.000
Sex × age	0.000	0			
Error	19.000	121	0.157		
Total	1364.000	246			
Corrected total	256.341	245			

Tests of between-subjects effects.
Dependent variable: first costal cartilage.
*R-squared = 0.926 (adjusted R-squared = 0.850).

From the results of our series and the previous one by Michelson, it could be pointed out that there is no published study in which a subject being younger than 21 years of chronological age has a first rib ossification in a Stage 3 of Michelson's stages system. On the other hand, in most of the cases, when a subject has a first rib in a Stage 0 of ossification, his chronological age is younger than 25 years in Michelson's series and even younger than 20 years in our series. More studies in actual populations could be necessary in the future to confirm, reject or extend these provisional conclusions.

Other previous authors, such as King (37), Semine and Damon (31) or Barchilon et al. (8), have analyzed the ossification process of the first rib from radiological, osteological, biochemical, and histopathological points of view. These authors indicate that calcification of the costal cartilage of the first rib is a real ossification process, not just a form of heterotopic calcification. In this process, respiratory stress seems to be the main cause of ossification of the first rib, whereas in lower ribs chest expansion seems to be the main cause of ossification. This may be the reason why the ossification of the first rib is usually more advanced in men than in women, as they are more usually exposed to recreational and labor respiratory stress. Some authors have also pointed out that some jobs could cause a more advanced evolution of this ossification process. As an example, combat pilots in Barchilon et al.'s series had an advanced ossification of this costal cartilage of the first rib probably because of the exposure to fast acceleration during air flights and respiratory stress (8). In the same way, in 1994 during the Paleopathology meeting in Göttingen, Friedrich Rösing presented the results of a study conducted on a sample of late medieval and early modern skeletons from the Franciscan friary in Ülm (Germany). In this unpublished series, the author observed a high number of first ribs completely ossified without no clear relation with the subjects age. Rösing interpreted this result as a consequence of mechanical stress because of physical work load. A substantial part of these subjects lived in a very poor environment and must have worked extremely hard.

Some pathologies, such as SAPHO syndrome (synovitis, acne, pustulosis, hyperostosis, osteitis) (38) or condensing osteitis (39), cause an unusual ossification of the first rib, but in these cases pathological signs are rare in juveniles and this unusual ossification usually appear in the first rib accompanied with other abnormalities, such as hyperostosis or osteitis in sternum and/or clavicle and/or dermatological signs (40).

Freyschmidt et al. have pointed out that a global increase in bone density of one or several ribs suggests some congenital conditions, such as osteopetrosis, endosteal hyperostosis, or osteodysplastia, and some acquired disorders, such as fluorosis or osteomyelosclerosis syndrome (30). These nosological entities rarely express only in the first rib. The forensic investigator should be aware that other radiological signs suggest pathological changes in the ribs that have to be excluded in case of FAE (30,41):

- Eleven pairs of ribs.
- Exceptionally broad and thick ribs (acromegaly, fluorosis, Paget disease, and storage diseases, such as Gaucher disease).

TABLE 11—*Main series that have analyzed the fusion of medial epiphyses of the clavicle with the age. Minimum ages at which had been observed complete fusion with or without epiphyseal scar.*

Series	Source of the Sample	Stage (Complete Ossification)	Minimum Age
Henle (1871) (9)	Unknown	Complete fusion	18
Dwight (1911) (9)	Unknown	Complete fusion	18
Testut (1921) (9)	Unknown	Complete fusion	22–25
Terry (1925) (9)	Unknown	Complete fusion	25
Stevenson (1924) (9)	Osteological, USA	Stage 4 (Stevenson)	24–28
Todd and D'Errico (1928) (10)	Osteological, USA	Stage 4 (Stevenson)	22
Galstaun (1930) (11)	Radiographic, India	Complete fusion	19
McKern and Stewart (1957) (12)	Osteological, USA	Stage 4 (McKern–Stewart)	23
Jit and Kulkarni (1976) (20)	Radiographic, India	Stage 3 (Jit–Kulkarni)	22
Szilvassy (1977) (13)	Osteological, Germany	Stage 3 (Szilvassy)	26–30
Owings Webb and Suchey (1985) (15)	Osteological, USA	Stage 4 (McKern–Stewart)	20
Bass (1986) (16)	Osteological, Unknown	Complete fusion	23
Mac Laughlin (1990) (17)	Osteological, Portugal	Stage 5 (Mac Laughlin)	27
Yoldi et al. (1991) (18)	Osteological, Spain (Granada)	Stage 4 (McKern–Stewart)	21
Ji (1994) (14)	Osteological, Japan	Stage 4 (McKern–Stewart)	20
Black and Scheuer (1996) (19)	Osteological, Europe	Stage 5 (Mac Laughlin)	20
Kreitner et al. (1997, 1998) (22,23)	CT, Germany	Stage 4 (McKern–Stewart)	22
Veschi and Facchini (2002) (21)	Osteological, Italy	Complete fusion	19
Schmeling et al. (2004) (5)	Radiographic, Germany	Stage 4 (Schmeling)	20
Schulz (2005) (25)	CT, Germany	Stage 4 (Schmeling)	21.2
Schulze (2006) (24)	CT, Germany	Stage 4 (Schmeling)	19.14
Richel (2005) (26)	CT, Germany	Stage 4 (Schmeling)	19.14
Schaeffer and Black (2005, 2007) (27,28)	Osteological, Bosnia	Stage 4 (McKern–Stewart)	21

TABLE 12—*Michelson's series results in white males (Michelson, 1934).*

Age (Years)	Stage 0 or 0%	Stage 1 or 30%	Stage 2 or 60%	Stage 3 or 90%	Total	Average Ossification (%)
6–10	54 (100%)	0			54	0
11–15	43 (82.7%)	9 (17.3%)	0		52	5.2%
16–20	83 (41.7%)	114 (57.3%)	2 (1.0%)	0	199	17.8%
21–25	22 (8.9%)	159 (64.1%)	66 (26.6%)	1 (0.4%)	248	35.6%
26–30	0	112 (46.5%)	126 (52.3%)	3 (1.2%)	241	46.4%
31–35	0	32 (16.6%)	126 (65.3%)	35 (18.1%)	193	60.5%
36–40	1 (0.4%)	16 (6.6%)	143 (59.3%)	81 (33.6%)	241	67.8%
41–45	–	7 (3.4%)	104 (51.0%)	93 (45.6%)	204	72.6%
46–50	–	1 (0.6%)	66 (42.0%)	90 (57.3%)	157	77.0%
51–55	–	–	27 (30.0%)	63 (70.0%)	90	81.0%
56–60	–	–	12 (25.0%)	36 (75.0%)	48	82.5%
61–65	–	–	1 (7.1 %)	13 (92.9%)	14	87.9%
66–70	–	–	–	13 (100 %)	13	90%
71–	–	–	–	4 (100 %)	4	90%
Total					1758	

TABLE 13—*Michelson's series results in white females (Michelson, 1934).*

Age (Years)	Stage 0 or 0%	Stage 1 or 30%	Stage 2 or 60%	Stage 3 or 90%	Total	Average Ossification
6–10	44 (100%)	0	–	–	44	0
11–15	40 (76.9%)	12 (23.1%)	0	–	52	6.9 %
16–20	149 (54.0%)	124 (44.9%)	3 (1.1%)	0	276	41.1 %
21–25	33 (16.6%)	146 (73.4%)	20 (10.0%)	0	199	28.0 %
26–30	2 (1.2%)	113 (65.3%)	58 (33.5%)	0	173	39.7 %
31–35	1 (0.6%)	68 (41.7%)	87 (53.4%)	7 (4.3 %)	163	48.4 %
36–40	1 (0.7%)	43 (29.7%)	96 (66.2%)	5 (3.4 %)	145	51.7 %
41–45	–	21 (21.4%)	65 (66.3%)	12 (12.3%)	98	57.2 %
46–50	–	6 (7.4 %)	61 (75.3%)	14 (17.3%)	81	63.0 %
51–55	–	4 (11.4%)	22 (62.9%)	9 (25.7%)	35	64.3 %
56–60	–	–	10 (76.0%)	3 (23.1%)	13	66.9 %
61–65	–	–	4 (57.1 %)	3 (42.9%)	7	72.9 %
66–70	–	–	–	3 (100%)	3	90 %
71–	–	–	–	1 (100%)	1	90 %
Total					1290	

FIG. 13—"*Fish mouth*" *anomaly (30).*

- Short and asymmetrical ribs.
- Associated abnormalities in clavicle and sternum.

So, for medico-legal purposes in case of FAE, it could be suggested that around 21 years of age, first rib ossification radiographic examination could be a complementary test to the ones recommended by the AGFAD. In addition, to analyze this parameter, no new X-rays would be needed if the clavicle was to be analyzed, as both parameters could be properly viewed in one X-ray. This would not need an additional exposure to ionizing radiation, potentially harmful for patients, a very important fact when practicing medical tests in the medico-legal context (42).

In cases when there are bone abnormalities or pathologies, or when the subject works in places where he must be exposed to unusual respiratory stress, these previous results about FAE should be interpreted with special precaution.

New research on other populations about age estimation based on the degree of ossification of the costal cartilage of the first rib should be advisable before of using this test in medico-legal practice.

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