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ORIGINAL ARTICLE

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Studies on the time frame for ossification of the medial clavicular epiphyseal cartilage in conventional radiography

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Abstract Radiological assessment of the degree of ossification of the medial clavicular epiphyseal cartilage plays a vital part in forensic age diagnosis of living adolescents and young adults. A total of 873 plain chest radiographs requested by the staff medical officer for members of staff aged 16–30 at the University Hospital Charité were evaluated retrospectively. Of these X-rays 699 permitted an assessment of ossification of at least 1 side of the clavicle. In addition to the customary stages (1: non-ossified epiphysis, 2: discernible ossification centre, 3: partial fusion, 4: total fusion) a stage 5 was also defined, characterised by the disappearance of the epiphyseal scar following total fusion. The earliest age at which stage 3 was detected in either gender was 16 years. Stage 4 was first observed in women at 20 years and in men at 21 years. In both genders, the earliest observation of stage 5 was at 26 years. It was concluded that plain chest radiographs can essentially be used to assess clavicular ossification. In practice, if overlap in posterior-anterior views impedes evaluation, a lateral view should also be taken to facilitate age estimation. In forensic practice the reference values of the present paper should be applied.

Keywords Forensic age diagnosis · Skeletal age · Ossification · Clavicle

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Introduction

Recent years have brought a worldwide increase in cross-border migration due to a globalised economy and on-going belligerent conflicts. As a result, the percentage of foreigners among the general population has steadily increased not only in Germany, but also in other countries (Angenendt 1999). This trend has triggered a growing demand in forensic medicine to assess the age of adolescents and young adults (Schmeling et al. 2001b). The individuals examined are non-nationals without valid identification documents who do not know their age or are suspected of not giving their age correctly. In Germany the age thresholds of relevance for criminal proceedings are 14, 18 and 21 years (Kaatsch 2001) and in many other countries, the age thresholds which determine criminal liability are similar (Dünkel et al. 1997).

For the purpose of estimating age, the Study Group on Forensic Age Diagnostics recommends combining a physical examination with an X-ray examination of the left hand, a dental examination which records dentition status and evaluates an orthopantogram, and a radiographic or computer tomographic survey of the clavicle (Schmeling et al. 2001a).

In establishing whether an individual has attained the criminal liability threshold of 21 years, the ossification of the sternal clavicular cartilage is of particular interest, as the other systems on which development analysis is based have usually matured fully by this time. Precise methods for adults such as the amino acid racemisation (Ritz et al. 1993; Ohtani 2002; Ohtani et al. 2003) are not applicable to living persons involved in criminal proceedings.

X-rays of the clavicle are also important in helping to ascertain whether a suspect was 18 years old at the time of an offence committed some years prior to clinical examination.

Existing studies on the time frame for ossification of the medial clavicular epiphyseal cartilage raise problems in the forensic application because of small sample size, lack of gender-specific data, uncertainty about precise age or in-

adequate information on the health status of subjects. It is not yet sufficiently clear whether total ossification of the medial clavicular epiphyseal cartilage is an adequate basis, in line with the probability standards of criminal procedure, for certifying that the subject has reached the age of 21. One particularly controversial factor here is whether age ranges for the various stages of ossification determined in studies of anatomical material can also be applied to radiological evaluation.

Material and methods

The 873 plain chest radiographs taken between 1995 and 2002 at the Radiology Unit of the University Hospital Charité in Berlin at the request of the staff medical officer, most of them in conjunction with new staff appointments, were evaluated retrospectively. The subjects were aged between 16 and 30 years. No data could be traced on the ethnic origin of the subjects, but it can be assumed that the sample does not deviate substantially from the average composition of the German population. In 174 X-rays reliable assessment of the degree of ossification of the medial clavicular epiphyseal cartilage proved impossible on both sides due to overlaps or variations in standards. Table 1 shows the age and gender breakdown for the sample of 699 assessable X-rays.

To assess the degree of ossification of the medial clavicular epiphyseal cartilage, the classification into four stages commonly applied in anatomical and radiological studies was applied as follows:

- Stage 1: the ossification centre has not yet ossified
- Stage 2: the ossification centre has ossified, the epiphyseal cartilage has not ossified (Fig. 1)
- Stage 3: the epiphyseal cartilage is partially ossified (Fig. 2)
- Stage 4: the epiphyseal cartilage is fully ossified (Fig. 3).

In the course of the present study it was observed that stage 4 lent itself to further morphological differentiation and a new criterion was added for consideration at stage 4: the visibility of the epiphyseal scar.

A fifth stage was then defined:

- Stage 5: the epiphyseal cartilage has fused completely and the epiphyseal scar is no longer visible (Fig. 4).

Results are expressed as minimum, maximum, mean±standard deviation and median with lower and upper quartiles. Statistical analyses were performed using SPSS for Windows (Release 11.0.1,

Table 1 Number of cases by age and gender

Age	Male	Female
16	2	14
17	4	32
18	1	26
19	8	33
20	15	33
21	9	30
22	15	33
23	16	36
24	26	30
25	22	29
26	26	31
27	29	28
28	27	35
29	20	29
30	23	37
Total	243	456

Fig. 1 Stage 2, male, 17.9 years old, detail of right clavicle from plain chest radiograph, the arrow shows the non-ossified epiphyseal cartilage

Fig. 2 Stage 3, female, 20.3 years old, detail of right clavicle from plain chest radiograph, the arrow shows the partially ossified epiphyseal cartilage

Fig. 3 Stage 4, male, 30.0 years old, detail of right clavicle from plain chest radiograph, the arrow shows the epiphyseal scar

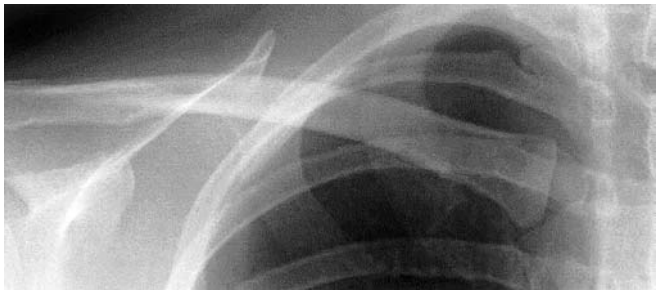

Fig. 4 Stage 5, female, 30.3 years old, detail of right clavicle from plain chest radiograph, the epiphyseal scar has disappeared

Table 2 Statistical parameters by gender for ossification stages 3–5

Stage	Gender	Min–Max	Mean±SD	Median, LQ, UQ
3	Male	16.7–24.0	20.8±1.7	20.9, 19.9, 22.3
	Female	16.0–26.8	20.0±2.1	19.9, 18.2, 21.5
4	Male	21.3–30.9	26.7±2.3	26.7, 24.8, 28.5
	Female	20.0 30.9	26.7±2.6	26.7, 24.8, 28.9
5	Male	26.0–30.4	28.5±1.5	28.3, 27.1, 29.9
	Female	26.7–30.9	29.0±1.4	29.1, 27.7, 30.5

Min Minimum
Max Maximum
SD Standard deviation
LQ Lower quartile
UQ Upper quartile

Copyright SPSS Inc. 1989–2001). Because of the categorical scaling of the data, differences between interesting groups of individuals were analysed using non-parametric statistical tests (Mann-Whitney-U test for two independent groups or Wilcoxon test for paired observations). Exact versions of the tests were applied to handle major differences in sample sizes (StatXact 5, Cytel Software Corp. Cambridge, MA 02139 USA, 2001). Significance was assessed at $p< 0.05$, exact, two-sided.

Results

Table 2 shows the minimum, maximum, mean±standard deviation (SD) and median with lower and upper quartiles for stages 3–5 by gender. Given the age spectrum of the sample investigated, stage 1 did not occur. No statistical parameters were calculated for stage 2 because the subsample was too small. The results have not been broken down according to side due to the statistical insignificance of the difference between left and right (0.6% of cases).

Gender comparison produced significant differences at stage 3 (p=0.006), with the female subjects reaching this stage 1 year earlier than their male counterparts. In both genders stage 3 first occurred at the age of 16, the maximum age for men being 24 and the maximum age for women 27.

There were no statistically significant gender differences at stages 4 and 5. Stage 4 was first observed in male subjects at 21 years and in female subjects at 20 years. In each gender the lowest age for stage 5 was 26.

Discussion

A number of studies have already been conducted on the time frame for the ossification of the medial clavicular epiphyseal cartilage in the age group concerned for criminal liability procedures. One group of studies adopted an anatomical perspective, assessing ossification by means of autopsy or direct skeletal inspection (Todd and D'Errico 1928; McKern and Stewart 1957; Owings Webb and Myers Suchey 1985; MacLaughlin 1990; Ji et al. 1994; Black and Scheuer 1996), while the other group took a radiological approach (conventional or CT) (Flecker 1933; Galstaun 1937; Jit and Kullkarni 1976; Kreitner et al. 1997, 1998).

The crucial question facing the forensic practice is the minimum age at which ossification can be completed. The existing studies define the final stage as total ossification of the epiphyseal cartilage, but without taking note of scar visibility. Radiological studies concur in establishing 22 as the minimum age for total fusion of the epiphysis (Flecker 1933; Jit and Kullkarni 1976; Kreitner et al. 1997, 1998). Anatomical studies, however, have observed younger ages. Total fusion of the epiphysis has been reported at 21 in men and at 20 in women (Owings Webb and Myers Suchey 1985; Ji et al. 1994). No definitive conclusions have been drawn to date as to whether the age ranges for stages of ossification established in anatomical studies can be applied to assessments based on radiological material. Jit and Kullkarni (1976), for example, argued that the stage of total epiphyseal cartilage fusion is diagnosed earlier in anatomical examinations because a naked eye assessment of bone directly can discern growth cartilage over a longer period than an X-ray. Kreitner et al. (1997) on the other hand, expressed the hypothesis that radiology is more likely to detect incipient ossification than an autopsy.

In our study the earliest age at which stage 4 ossification was observed in male subjects was 21 years, and in female subjects 20 years. These age thresholds precisely reflect the values provided in the anatomical studies by Owings Webb & Myers Suchey (1985) and Ji et al. (1994). The present study does not, however, provide an adequate foundation for concluding whether or not the assessment of ossification from anatomical and X-ray material will generally result in identical findings. This would require a comparative study of autopsy material in which the degree of ossification is established both anatomically and radiologically for each individual.

During this study an additional stage of ossification was defined. This stage 5 is characterised by total fusion of the epiphyseal cartilage and the disappearance of the epiphyseal scar. In both genders, the lowest age at which stage 5 was observed was 26 years. Forensic age diagnosis of living subjects in the context of criminal investigations can assume that when this stage of ossification is observed the subject must have attained the age of 21 at least 5 years prior to the examination and the age of 18 at least 8 years prior to the examination. Statistically significant gender differences were only encountered in this study at stage 3. This observation tallies well with studies on dental mineralisation which indicate that the female developmental lead over males is eradicated or reversed around the time when the last tooth, the third molar, is mineralised (Kahl and Schwarze 1988; Olze et al. 2003).

Our study revealed a maturity gap between the left and right clavicle in 0.6% of cases but the gap was not statistically significant. It seems justifiable, therefore, to apply reference values regardless of which side is used in forensic practice. When age estimates are to be used in criminal prosecution, the less developed side should provide the basis for the age diagnosis.

One important question of practical relevance is whether the results of our study can be applied to subjects of different ethnic origin. The existing studies were predominantly

performed with Caucasian samples. Todd and D'Errico (1928) also examined black Americans in the United States; Owings Webb & Myers Suchey (1985) included both white and black US populations and also Latin Americans; Ji et. al (1994) worked with an Asian sample. These authors did not report any major interethnic differences. In an extensive survey of the literature on the time frame for ossification of the hand, which is regarded as representative of the overall skeletal system, Schmeling et al. (2000) concluded that ethnic origin does not apparently exert any notable influence on the rate of ossification within a particular age group. By contrast, the socio-economic status of the sample does have a decisive impact on the pace of ossification, with relatively low socio-economic status delaying development. In other words, if reference values drawn from studies with socio-economically advanced populations were to be applied to subjects from populations whose bone development is slower, their age would be underestimated. In criminal proceedings, this would not be detrimental to the individual concerned. It seems justified, therefore, to apply the reference values established in the present study to members of all ethnic groups when estimating age.

In summary, we can conclude that plain chest radiographs can essentially provide a basis for assessing clavicular ossification. If overlap in posterior-anterior views impedes evaluation, a lateral view should also be taken to facilitate age estimation. At ossification stage 4 it cannot reliably be ruled out that a female subject is under 21 years old. At ossification stage 5 a minimum age of 26 can be assumed for both genders. In the forensic practice the reference values of the present paper should be applied.

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