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ORIGINAL ARTICLE

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Studies on the time frame for ossification of the medial epiphysis of the clavicle as revealed by CT scans

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Abstract The authors retrospectively analyzed 629 CT images of patients aged between 15 and 30 years produced during multiple trauma diagnostics at the Unfallkrankenhaus Berlin. For the purposes of this study, the authors reliably determined the ossification status of the medial epiphysis of the clavicle in 556 cases, using the classification of stages by Schmeling et al. In both sexes, stage 2 was first noted at age 15. In male patients, the earliest occurrence of stage 3 was noted at age 17, in female patients at age 16. Stage 4 was first achieved by both sexes at age 21. Stage 5 was first noted in female patients at age 21 and in male patients at age 22, which is 4 or 5 years earlier than was observed by a comparable study using conventional radiographs. The partial-volume effect in computed tomography using the thick slice scanning mode was discussed as a possible explanation for this early visualization. The question of how slice thickness affects the age intervals between ossification stages identified by CT examinations should be examined in additional studies.

Keywords Forensic age diagnosis · Skeletal age · Ossification · Clavicle · Computed tomography

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Introduction

Today, forensic age diagnostics is an established research sector of legal medicine in its own right (Ohtani et al 2003; Olze et al 2004, 2005; Paewinsky et al 2005; Ritz-Timme et al 2003; Schmeling et al 2004; Takasaki et al 2003). In recent years it has become increasingly important to determine, in particular, the ages of living persons (Schmeling et al 2001b). From a legal perspective, such age estimates are carried out to determine whether a suspect without valid identification documents has reached the age of criminal responsibility and whether general criminal law in force for adults is to be applied. In Germany the age thresholds of relevance for criminal proceedings are 14, 18 and 21 years (Kaatsch 2001) and are similar to those in many other countries (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 fully matured by this time. X-rays of the clavicle are also important in helping to ascertain whether a suspect was 18 at the time of an offence committed some years prior to clinical examination. A basic prerequisite for estimating a person's age by radiological means is a physical examination, performed in order to establish whether the person has a disease that may affect skeletal development.

To date, the only reference study which lends itself to forensic use relates to conventional X-ray examination of clavicle ossification (Schmeling et al 2004). Since the computed tomography-based studies published by Kreitner et al (1997, 1998) do not discriminate results by sex, their forensic value is limited.

Materials and methods

We retrospectively analyzed 629 CT scans of patients aged between 15 and 30 years that had been performed during diagnosis of multiple trauma at the Unfallkrankenhaus Berlin in the period between 1997 and 2003. It may be assumed that the patients never displayed any disease affecting their skeletal development. 40 CT scans were not included because the exact ages of the patients could not be verified. Owing to beam-hardening artefacts from contrast medium, norm variants (in particular funnel-shaped clavicular epiphyses) and fractures, the ossification status of the medial epiphysis of the clavicle could not be determined reliably in 33 cases (5.6%). These cases were also excluded from our analysis of the results. Table 1 shows sample sizes grouped by sex and age for the remaining 556 CT images.

The CT scans were performed with a Siemens Sensation (four-row multidetector CT, Siemens AG Erlangen, Germany) (standard settings: matrix 512; 120 kV; 140 mAs; rotation time 0.5 s; collimation 4×2.5 mm; pitch 0.75).

The slice thicknesses of the scans suitable for evaluation in this study were as follows: 7 mm in 546 cases, 5 mm in 2 cases, 3 mm in 4 cases, 2 mm in 1 case and 1 mm in 3 cases.

Classification of stages according to Schmeling et al (2004) was used to evaluate the ossification status of the medial clavicular epiphyseal cartilage as follows:

- Stage 1: Ossification centre not ossified.
- Stage 2: Ossification centre ossified, epiphyseal cartilage not ossified.
- Stage 3: Epiphyseal cartilage partly ossified.
- Stage 4: Epiphyseal cartilage fully ossified, epiphyseal scar visible.
- Stage 5: Epiphyseal cartilage fully ossified, epiphyseal scar no longer visible.

Figures 1, 2, 3 and 4 show the CT findings that correspond to stages 2–5, respectively.

Table 1 Number of cases, grouped by age and sex

Age (years)	Male	Female
15	14	8
16	19	11
17	24	9
18	54	15
19	52	19
20	44	7
21	33	10
22	23	8
23	24	5
24	23	7
25	14	5
26	20	6
27	17	8
28	16	9
29	19	8
30	21	4
Total	417	139

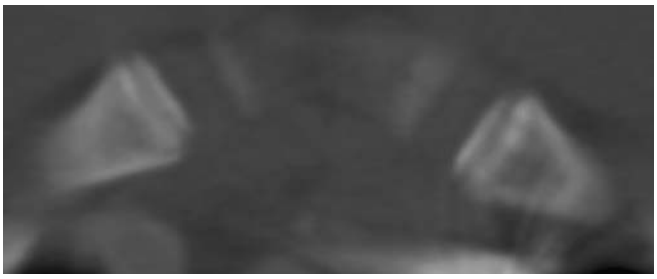

Fig. 1 Reduced detail of a CT scan of ossification stage 2 of the medial clavicular epiphysis: ossification centre ossified, epiphyseal cartilage not ossified (male 17.3 years)

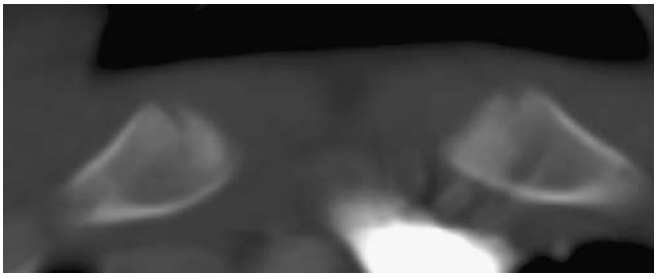

Fig. 2 Reduced detail of a CT scan of ossification stage 3 of the medial clavicular epiphysis: epiphyseal cartilage partly ossified (male 20.1 years)

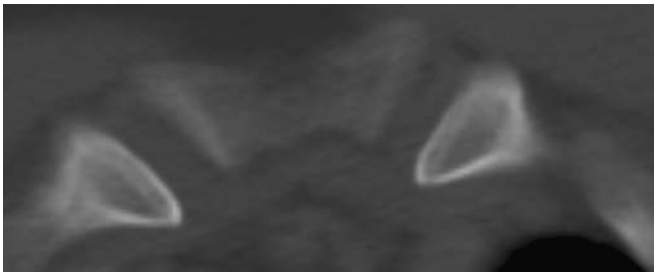

Fig. 3 Reduced detail of a CT scan of ossification stage 4 of the medial clavicular epiphysis: epiphyseal cartilage fully ossified, epiphyseal scar visible (male 30.4 years)

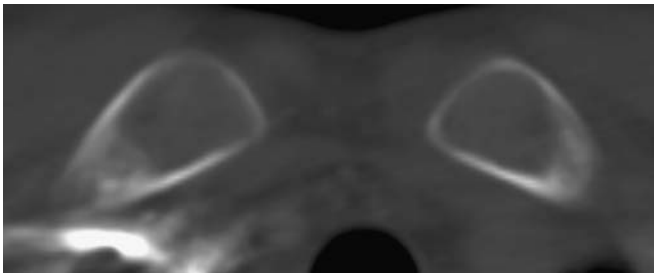

Fig. 4 Reduced detail of a CT scan of ossification stage 4 of the medial clavicular epiphysis: epiphyseal cartilage fully ossified, epiphyseal scar no longer visible (male 30.1 years)

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, SPSS Inc. 1989–2001). To cope with outliers and/or skew distributions, differences between interesting groups of individuals were analyzed using non-parametric statistical tests (Kruskal–Wallis test for several

groups, 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 Cambridge, MA). Significance was assessed at $p<0.05$, exact, two-sided.

Results

Table 2 presents the minimum, maximum, mean±standard deviation and median with lower and upper quartiles for stages 2–5 separately for each sex. Because of the insufficient sample size no statistical measurement data were calculated for stage 1.

Developmental differences between the left and right sides were observed in 10.5% of all cases, which is not statistically significant ($p=0.588$). Therefore, the results are not presented separately for each side.

A comparison between male and female data revealed statistically significant differences for stage 2 ($p=0.021$), with the female patients achieving that stage on average eight months earlier than the male patients. In both sexes, stage 2 was first noted at age 15. For stages 3, 4 and 5 no statistically significant differences between the sexes were observed. In male patients, the earliest occurrence of stage 3 was noted at age 17, in female patients at age 16. The earliest occurrence of stage 4 in both male and female patients was observed at age 21. The minimum age for stage 5 was 22 years in male patients and 21 years in female patients.

Discussion

Several studies have examined the time frame for ossification of the medial epiphyseal cartilage in the age group of legal concern. These studies adopted either an anatomical approach, evaluating ossification status through post-mortem examinations, or, in the case of skeletons, direct 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), or a radiological approach (conventional X-ray or CT) (Flecker 1933; Galstaun 1937; Jit and Kullkarni 1976; Kreitner et al 1997, 1998; Schmeling et al 2004). However, it is debatable whether the age intervals for the various stages of ossification identified by anatomical studies can also be applied to X-ray images (Jit and Kullkarni 1976; Kreitner et al 1997; Schmeling et al 2004). Therefore radiological reference studies are needed to aid forensic age estimation in living individuals.

Schmeling et al (2004) examined 873 general X-rays of the thoraxes of patients aged between 16 and 30 years. In 174 cases the ossification status of the medial clavicular epiphysis could not be determined reliably owing to overlapping effects or norm variants. In both sexes, stage 3 was first noted at age 16. In female patients, the earliest occurrence of stage 4 was noted at age 20, in male patients at age 21 and stage 5 was first noted in both sexes at 26 years of age.

Computed tomography is valuable when assessing ossification status, because it allows imaging of the medial epiphysis of the clavicle without any overlapping. Kreitner et al published their studies based on computed tomography examinations in 1997 and 1998, the latter study incorporating a greater number of cases. They examined 380 CT scans of patients aged 0 to 30 years. Slice thickness was 8 mm in 202 cases, 5 mm in 88 cases, 4 mm in 54 cases and 1, 2 or 3 mm in 36 cases. Developmental differences between the left and the right side were observed in six instances (1.6%). Stage 2 was first noted at age 11, stage 3 at age 16 and stage 4 at age 22. The forensic usefulness of these studies is restricted by the fact that the data were not analyzed separately for males and females (Schmeling et al 2001a).

The present study first noted stage 2 in both sexes at age 15 years. In male patients, the earliest occurrence of stage 3 was noted at age 17, in female patients at age 16 and stage 4 was first achieved by both sexes at age 21 years. These figures are within the range of data published by Kreitner et al (1997, 1998) and Schmeling et al. (2004), with the minimum age for stage 2 in the present study being determined by the lower threshold of the age group examined.

Stage 5 was first noted in female patients at age 21 and in male patients at age 22, which is four or five years earlier than was observed in a comparable study by Schmeling et al (2004) using conventional radiographs. The radiological imaging technique should be discussed as a possible explanation for the early occurrence of stage 5. Increasing slice thickness in computed tomography may mask fine anatomical structures because of the partial-volume effect, whereas conventional radiographs allow better visualization due to higher spatial resolution. As a result of the partial-volume effect, the epiphyseal scar, a very fragile anatomical structure, ceases to be visible on CT scans earlier than on conventional radiographs.

Statistically significant differences between the sexes were observed by the present study only with regard to stage 2, with the female patients achieving that stage on average eight months earlier than the male patients.

Table 2 Statistical parameters, in years and by sex, for ossification stages 2–5

Stage	Sex	Min–max	Mean±SD	Median, LQ, UQ
2	Male	15.2–23.9	18.9±1.7	18.9, 16.9, 20.0
	Female	15.0–21.6	18.2±1.6	18.5, 16.9, 19.4
3	Male	17.5–27.2	20.9±1.9	20.7, 19.4, 21.9
	Female	16.6–28.6	20.5±2.7	20.0, 18.4, 22.0
4	Male	21.2–30.4	25.2±2.7	24.7, 23.1, 27.4
	Female	21.5–29.9	25.1±2.8	24.3, 22.8, 27.8
5	Male	22.4–30.9	27.6±2.3	27.8, 26.0, 29.7
	Female	21.9–30.9	27.4±2.3	27.9, 25.7, 29.5

Min minimum, *max* maximum, *SD* standard deviation, *LQ* lower quartile, *UQ* upper quartile

The present study observed developmental differences between the left and right clavicle in 10.5% of cases. This difference between sides was not relevant in statistical terms.

Since the ethnic origin does not apparently exert any notable influence on the rate of ossification within the relevant age group, the reference data presented can be used to estimate the ages of members of all ethnic groups (Schmeling et al 2000, 2004).

Conclusions

The five stages defined by Schmeling et al. (2004) to describe ossification of the medial epiphysis of the clavicle on the basis of conventional radiographs can also be observed on CT scans.

The statistical measurement data presented for ossification stage 5 cannot be applied for forensic purposes, owing to inappropriately high slice thickness of the CT scans. The question of how slice thickness affects the age intervals between ossification stages should be examined in further studies.

In order to achieve the best possible results and ensure maximum accuracy in age estimation practice, the authors recommend performing CT scans with 1 mm slice thickness.

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