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ORIGINAL ARTICLE

Forensic age estimation in living subjects based on the ossification status of the medial clavicular epiphysis as revealed by thin-slice multidetector computed tomography

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Abstract Determination of the stage of ossification of the medial clavicular epiphysis is a crucial part of age estimation in criminal proceedings when evaluating individuals with completed hand ossification. In order to ensure a maximum of accuracy in forensic age estimation practise, it is recommended to perform thin-slice CT scans; but to date there exist no reference data on the bone development of the region in question based on thin-slice computed tomography. In this retrospective study, the authors evaluated thin-slice multidetector CT images of 592 individuals aged between 10 and 35 years produced in the University Hospital of Münster. The ossification status of the medial epiphysis of the clavicle could be reliably determined in 502 cases using the classification of stages by Schmeling et al. In male individuals, stage 2 was first noted at age 14, in female individuals at age 13. Stage 3 was first achieved by male individuals at age 17, by female individuals at age 16. The occurrence of stage 4 was first found in both sexes at the age of 21. In either sex, the earliest observation of stage 5 was at age 26. The findings are basically in line with those from the only CT-based study on the subject in question using the same classification of five stages, except from the fact that in the present study, stage 5 first occurs at age 26, which is 4 or 5 years later than what was found in the CT study using 7 mm slices in the majority of cases. This vast difference may be explained through the partial volume effect occurring with thick-slice CT images by a visual deception of the epiphyseal scar occurring with stage 4.

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

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Introduction

Forensic age diagnostics in living adolescents and young adults is an established research sector in the field of forensic science [1–11].

For the purpose of assessing age in individuals in criminal proceedings, the Study Group on Forensic Age Diagnostics recommends the combination of a physical examination with an X-ray examination of the left hand, a dental examination including the determination of the dentition status and the evaluation of an orthopantogram. If the bone development of the hand has been completed, an additional radiological examination of the clavicles by means of conventional radiography and/or computed tomography should be realised [6].

In 1997 and 1998, Kreitner et al. [12, 13] published the first CT-based studies in which the medial epiphyseal ossification of the clavicle was evaluated applying a four stage scheme. Since these studies did not discriminate results by sexes, their forensic value is limited. In a CT study conducted by Schulz et al. [14] in 2005, presenting more cases and results discriminated by sexes, the five

stage classification by Schmeling et al. [15] was used. Evaluating the results of this study, it was assumed that the main problem of the existing CT studies was the thickness of the slices examined, which were 7 or 8 mm in the majority of cases. Subsequently, it could be shown that examining CT images with a slice thickness greater than 1 mm can lead to misinterpretation referring to the ossification status due to the partial volume effect [16].

The aim of this study was to determine the stage of clavicle ossification by means of thin-slice computed tomography.

Materials and methods

The CT scans of a patient population of 592 individuals with proven age originally obtained during trauma and emergency diagnostics at the University Hospital of Münster in the period between 2005 and 2008 were examined retrospectively. The subjects ranged in age from 10 to 35 years. Since the CT scans emerged during trauma and emergency diagnostics, it may be assumed that the vast majority of the individuals examined never displayed any disease affecting their skeletal development. The image material available included slices of 0.6 (3), 1.0 (301), 1.25 (122) and 1.5 (77) mm. In 90 cases (15.1%), a reliable assessment of the ossification status was not possible owing to fractures of the clavicle, beam-hardening artefacts from contrast medium, movement artefacts or variants of normality (in particular, funnel-shaped clavicular epiphyses). The population that permitted reliable examination included 214 female (42.6%) and 288 male (57.4%) individuals. Table 1 shows sample sizes by sex and age group for the 502 cases in which reliable assessment of the ossification status was possible.

Multidetector computed tomography (MDCT) studies were obtained using a 16-row MDCT system (Somatom Sensation 16, Siemens Medical Solutions) for the period 2005 to November 2007. From November 2007 to 2008, a 40-row MDCT system was used (Somatom Sensation 40, Siemens Medical Solutions). Technical settings, 120 kV, reference mAs 120 using CareDose, Pitch 1.3, collimation 0.6, recon increment 1.0, Kernel B50f. Due to the fact that all the scans analysed were based on high resolution thin-slice MDCT imaging, it can be assumed that the scans provided a comparable and sufficient image quality with regard to the evaluation of osseous structures.

The CT images were evaluated on screen using a workstation with Siemens software (Syngo Somaris 5-VB20B). The material was viewed in axial images and in multiplanar reconstruction (MPR technique).

Table 1 Number of cases by age and sex

Age (years)	Female	Male
10	10	7
11	3	4
12	10	6
13	10	6
14	11	14
15	8	7
16	5	3
17	9	14
18	14	14
19	6	9
20	8	16
21	15	11
22	10	10
23	11	17
24	6	16
25	7	13
26	12	9
27	7	7
28	3	10
29	7	15
30	6	15
31	7	7
32	6	12
33	9	9
34	7	16
35	7	21
Total	214	288

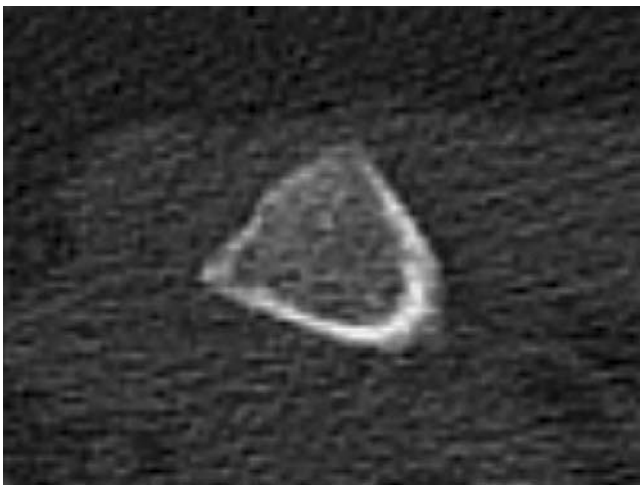

Fig. 1 Reduced detail of a CT scan of ossification stage 1 of the medial clavicular epiphysis: ossification centre not ossified (male, 11 years, slice thickness 1.25 mm, 512×512 pixel)

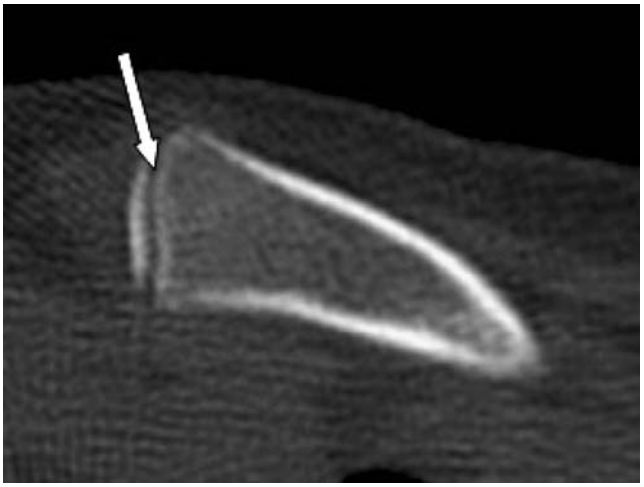

Fig. 2 Reduced detail of a CT scan of ossification stage 2 of the medial clavicular epiphysis: ossification centre ossified, epiphyseal cartilage not ossified, the *arrow* shows the open epiphyseal cartilage (female, 16 years, slice thickness 1.5 mm, 512×512 pixel)

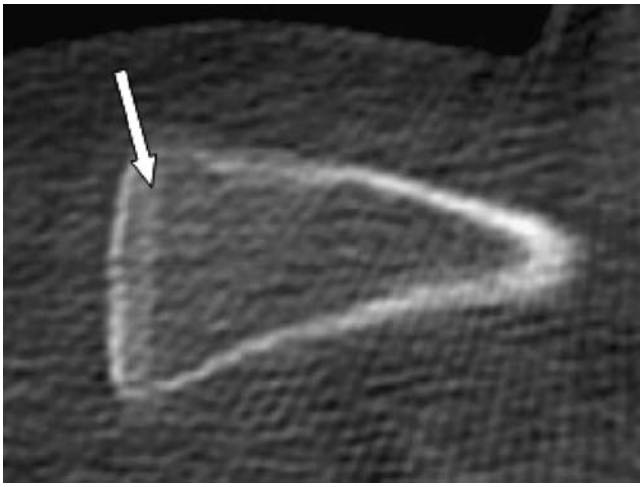

Fig. 4 Reduced detail of a CT scan of ossification stage 4 of the medial clavicular epiphysis: epiphyseal cartilage fully ossified, epiphyseal scar visible, the *arrow* shows the epiphyseal scar (female, 21 years, slice thickness 1.5 mm, 512×512 pixel)

The developmental status of the medial clavicular epiphyseal cartilage was evaluated using the classification of stages by Schmeling et al. [15] 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, 4 and 5 show the findings that correspond to each of the stages 1–5. All cross sections were evaluated for the respective epiphysis. The cross section with the most advanced ossification stage was decisive for the stage diagnosis. All evaluations were made by one examiner. Prior to and during analysis of the MDCT images, the age of the individuals was not known to the examiner.

Results are expressed as minimum, maximum, mean ± standard deviation and median with lower and upper quartiles. Statistical analyses were performed using SPSS VERSION 16.0.1 for Windows (Release 07.12.2007, SPSS Inc. 1989–2007). To cope with outliers and/or skew distributions, sexual differences were analysed using Mann–Whitney *U* test for two independent groups. Significance was assessed at $p<0.05$, exact, two-sided.

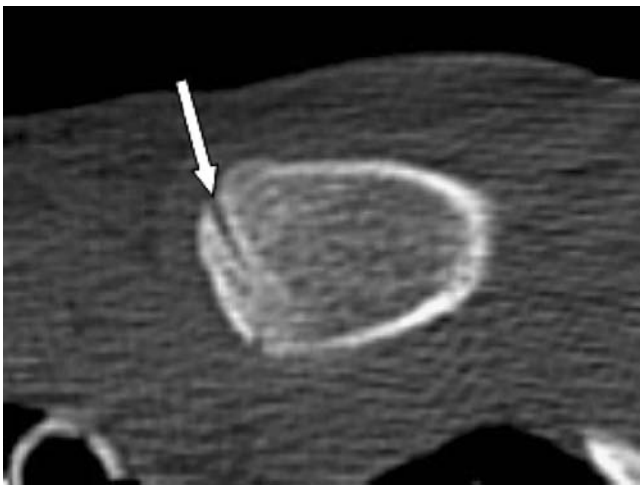

Fig. 3 Reduced detail of a CT scan of ossification stage 3 of the medial clavicular epiphysis: epiphyseal cartilage partly ossified, the *arrow* shows the partially ossified epiphyseal cartilage (male, 18 years, slice thickness 1.5 mm, 512×512 pixel)

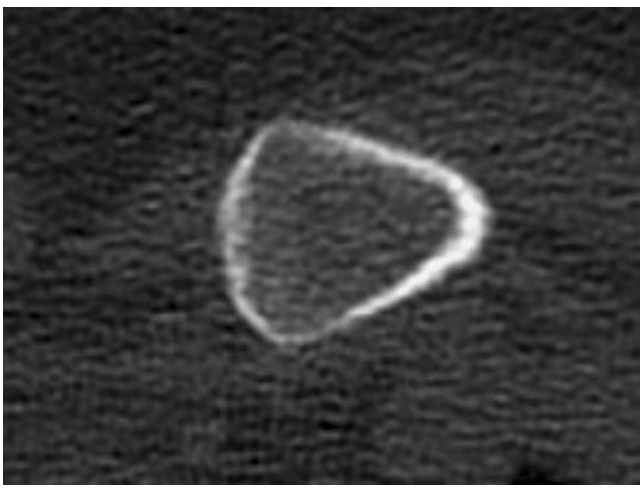

Fig. 5 Reduced detail of a CT scan of ossification stage 5 of the medial clavicular epiphysis: epiphyseal cartilage fully ossified, epiphyseal scar no longer visible (female, 31 years, slice thickness 1.5 mm, 512×512 pixel)

Table 2 Statistical parameters in years by sex for ossification stages 1–5

Stage	Sex	Min–Max	Mean ± SD	Median; LQ; UQ
1	Male	10.03–15.98	13.28±1.74	13.54; 11.67; 14.70
	Female	10.06–15.87	12.70±1.69	12.86; 11.21; 14.27
2	Male	14.43–20.26	17.81±1.37	17.93; 17.15; 18.53
	Female	13.11–19.29	16.28±1.59	17.12; 15.62; 18.04
3	Male	17.53–26.15	21.73±0.26	21.39; 20.13; 23.88
	Female	16.75–26.15	21.14±2.14	21.25; 19.60; 22.49
4	Male	21.63–35.84	29.63±4.16	29.76; 25.78; 33.35
	Female	21.31–35.19	28.21±4.21	27.94; 24.89; 32.47
5	Male	26.39–35.76	31.77±2.74	31.78; 29.25; 34.53
	Female	26.10–35.74	30.88±3.20	31.18; 27.24; 33.44

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

Results

Table 2 presents the minimum, maximum, mean ± standard deviation and median with lower and upper quartiles for stages 1–5 separately for each sex.

Developmental differences between the left and right side were observed in 31 cases (6.2%). In these cases, the side showing the more advanced development was chosen for evaluation.

A comparison between male and female data revealed statistically significant differences for stage 2 (p=0.048), with the female patients achieving that stage on average 18 months earlier than the male patients. In male individuals, stage 2 was first noted at age 14, in female individuals at age 13. For stages 3, 4 and 5, no statistically significant differences between the sexes were observed. Stage 3 was first achieved by male individuals at age 17, by female individuals at age 16. The occurrence of stage 4 was first found in both sexes at the age of 21. In either sex, the earliest observation of stage 5 was at age 26.

Discussion

Since the second decade of the last century, several researchers have dedicated themselves to study the time frame for the ossification of the medial clavicular epiphysis. One group of researchers approached the subject assessing ossification by means of autopsy or direct skeletal inspection [17–23], while the other group took a radiological approach applying conventional radiography [15, 24–26], computed tomography [12–14, 27], magnetic resonance tomography [28] and ultrasound [4, 10].

So far, it is a question to be answered whether the assessment of the ossification status from direct anatomical inspection and radiological imaging generally brings forth identical findings if applied to one and the same material. This would require a comparative study of autopsy material in which the ossification status is determined both anatomically and radiologically for each individual. A similar situation is given concerning different radiological imaging methods (conventional radiography, CT, MRT and ultrasound). In the only comparative study referring to staging results based on conventional radiography and computed tomography, it was reported that in two out of 99 cases the examination outcome was not in agreement [9]. Due to these findings, it was concluded that in age estimation practise, it is necessary to use conventional radiographic reference studies for the ossification stage classification by conventional radiography and CT reference studies for the ossification stage classification by CT.

Table 3 CT studies dealing with the ossification of the medial clavicular epiphysis

Study	Case number	Sex separation	Age (in years)	Slice thickness (in mm)	Stage 2 (age in years)	Stage 3 (age in years)	Stage 4 (age in years)	Stage 5 (age in years)
Kreitner et al. [12]	279	No	0–29	1–8	13–22	16–26	22–29	–
Kreitner et al. [13]	380	No	0–29	1–8	11–22	16–26	22–29	–
Schulz et al. [14]	629	Yes	15–30	1–7	15–23	16–28	21–30	21–30
Schulze et al. [27]	100	No	16–25	1–10	16–24	16–25	19–25	–
Present study	592	Yes	10–35	0.6–1.5	13–20	16–26	21–35	26–35

Preliminary CT-based studies have a limited validity due to results un-separated by sexes [12, 13, 27] or evaluation of thick-slice images of 7 or 8 mm in the majority of cases [12–14, 27]. Mühler et al. [16] could show that slice thickness of CT scans has a decisive influence on the evaluation of the clavicle ossification status. They reported that the assessment of ossification stages differed for slice thicknesses of 1 and 3 mm, 3 and 5 mm as well as 5 and 7 mm. Such differences affected stages 2 and 3, stages 3 and 5 and stages 4 and 5. In all cases in which slice thickness made a difference, increased slice thickness resulted in determining higher ossification stages. Based on these findings, it can be concluded that with thick-slice CT imaging, higher ossification stages tend to appear at earlier ages. The partial volume effect occurring with thick-slice CT images is held responsible for the partial or complete visual masking of fine structures such as the epiphyseal plate as well as the epiphyseal scar.

In the present study, we observed a stage 4 in 139 cases (88 males, 51 females) occurring first at the age of 21 in either sex, which is exactly concordant with the data established by Schulz et al. [14] and conformable with the findings by Kreitner et al. [12, 13] in which the minimum age for stage 4 was found to be 22 years. Deviant to these concurrent outcomes, Schulze et al. [27] reported a minimum age of 19 years for stage 4, which may possibly be interpreted as a consequence of the partial volume effect. Table 3 provides an overview of the mentioned CT studies on the ossification of the medial clavicular epiphysis.

We saw a stage 5 in 94 cases (55 males, 39 females) with an appearance not earlier than at age 26 in both sexes, which is precisely in line with the findings of the conventional X-ray study by Schmeling et al. [15]. In the only previous CT study in which a discrimination of stage 4 and 5 was taken into account, stage 5 was first observed at age 22 in males and at age 21 in females [14]. It was assumed that the apparent discrepancy concerning stage 5 classification by means of conventional radiography and computed tomography could be explained by the described masking effect that comes along with thick-slice CT imaging. In a comparative study, all observable epiphyseal scars on conventional radiographs could also be seen on the corresponding CT images; but owing to a small sample size of these cases, it could not be concluded that reliable visualisation of the epiphyseal scar is possible in every case using CT images with a slice thickness of 1 mm [9]. Due to the present findings, we may reason that an existing epiphyseal scar can be identified using thin-slice computed tomography.

Since the ethnic origin does not apparently exert any notable influence on the rate of ossification within the relevant age group, the presented reference data can be used in age determination practise for members of all ethnic groups [15, 29]. By contrast, it was reported that the socio-economic status does have an impact on the pace of ossification with relatively low socio-economic status delaying development. If reference values drawn from studies with socio-economic advanced populations were applied in age estimation concerning individuals stemming from a relatively low socio-economic background, their age would be underestimated. In criminal proceedings, this would not result in a derogatory situation for the individual concerned [30].

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