ORIGINAL ARTICLE

Enhanced possibilities to make statements on the ossification status of the medial clavicular epiphysis using an amplified staging scheme in evaluating thin-slice CT scans

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Abstract Thin-slice computed tomography provides the imaging modality of choice in analysing the ossification process of the medial clavicular epiphysis for the purpose of forensic age diagnostics in the living in the course of criminal proceedings. The classification of the ossification stages by Schmeling et al. compass the emergence of an epiphyseal ossification centre (stage 2), the partial fusion of the epiphysis with the metaphysis (stage 3), the complete fusion of these osseous elements including a visible epiphyseal scar (stage 4), and the complete fusion without a visible epiphyseal scar (stage 5). In the present study, each of the ossification stages 2 and 3 was divided into an early, intermediate and late phase. The authors evaluated the thin-slice CT scans of 185 patients aged between 13 and 26 years. In all these cases, a stage 2 or 3 had been determined in a previous study. The late stage 3, which is characterized by a fusion between metaphysis and epiphysis completing more than two thirds of the former epiphyseal gap, first appeared at age 19 in both sexes. If a late stage 3 is found, it is therefore possible to substantiate that an individual has already reached the legally important age threshold of 18 years.

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Introduction

Age diagnostics in living adolescents and young adults undergoing criminal proceedings is a current research sector of medico-legal science [1–6]. When age estimation is requested in the wake of a criminal proceeding, the assigned examiner is supposed to establish whether an individual has already accomplished a certain age or not. The relevant age thresholds concerning criminal liability in many European countries lie between 14 and 21 years [7]. In the vast majority of cases, age diagnostics concerns non-nationals without valid identification documents who either do not know their actual age or who are supposed to give an incorrect age. Under these circumstances, establishing the possible minimum age in an individual is of crucial importance in criminal proceedings with regard to determine whether juvenile penal systems or penal systems in force for adults are to be applied.

Referring to age estimation in living individuals undergoing 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 orthopantomogram. If the hand ossification has been completed, an additional radiological examination of the clavicles by means of conventional radiography and/or computed tomography should be performed [8].

Computed tomography based studies on the ossification status of the medial clavicular epiphysis were conducted by Kreitner et al. in the years [9, 10], Schulz et al. in [11] and Schulze et al. in [11]. The main problem in these studies resulted to be the slice thickness of the scans examined which were basically 7 or 8 mm. It could be demonstrated that evaluating computed tomography (CT) images with a slice thickness greater than 1 mm can lead to determine too

advanced ossification stages [12]. When observing CT images, increased slice thickness results in a visual deception of structures such as a discrete gap between epiphysis and metaphysis or the epiphyseal scar. For this reason, some authors recommended performing a study based on thin-slice CT scans [11–13].

In order to establish reference data for CT based evaluation of the sterno-clavicular joint, [15] conducted a study exclusively using thin-slice CT scans of mainly 1 and 1.25 mm. In this reference study, a reliable determination of the ossification status of the medial clavicular epiphysis was realised in 502 individuals aged between 10 to 35 years.

In the present study, the authors appraised if a subdivision of the ossification stages of the medial clavicular epiphysis is an appropriate method to improve the diagnostic accuracy of CT-based forensic age estimation.

Material and method

The authors re-evaluated the CT scans of a patient population of 185 individuals (81 females, 104 males) aged between 13 and 26 years originally included in a study conducted at the University Hospital of Münster [15]. In that study, a total of 596 thin-slice computed tomography scans of the thorax originally performed during traumatologic and emergency procedures had retrospectively been examined in order to provide reference data for CT-based age diagnostics. The reviewed material comprised all those cases that had been assessed as stage 2 (53) or stage 3 (132) according to the classification of stages by [16]. The image material of the present study included slices of 0.6 (2), 1.0 (106), 1.25 (42) and 1.5 (35) mm. Table 1 shows sample sizes by sex and age group for the cases in which re-evaluation was conducted.

The staging scheme applied on the material represents a sub-classification of the known stages 2 and 3. According to [16], a stage 2 is defined as showing an ossified epiphyseal ossification centre without epiphyseal-metaphyseal fusion and a stage 3 is characterized by an incomplete ossification of the epiphyseal cartilage. For the purposes of the present study, the sub-classification stages were defined as follows:

Stage 2a: The lengthwise epiphyseal measurement is one third or less compared to the widthwise measurement of the metaphyseal ending
Stage 2b: The lengthwise epiphyseal measurement is over one third until two thirds compared to the widthwise measurement of the metaphyseal ending
Stage 2c: The lengthwise epiphyseal measurement is over two thirds compared to the widthwise measurement of the metaphyseal ending

Table 1 Number of cases by age and sex

Age (years)	Female	Male
13	2	0
14	2	2
15	5	0
16	5	4
17	9	14
18	14	14
19	6	9
20	8	16
21	12	10
22	8	8
23	5	12
24	3	9
25	1	4
26	1	2
Total	81	104

Stage 3a: The epiphyseal-metaphyseal fusion completes one third or less of the former gap between epiphysis and metaphysis
Stage 3b: The epiphyseal-metaphyseal fusion completes over one third until two thirds of the former gap between epiphysis and metaphysis
Stage 3c: The epiphyseal-metaphyseal fusion completes over two thirds of the former gap between epiphysis and metaphysis

Figure 1 shows schematic drawings and pictures of the individual stages.

If there was any problem to decide on the correct stage due to the fact that relation of measurements was in some cases hard to determine by mere inspection, a measuring tool included in the viewing software (Syngo Somaris 5-VB20B) was applied.

If developmental differences between the left and right side were observed, which was the case in 32 cases (17.3%), we chose the more advanced side to determine the ossification status.

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 analyzed using Mann-Whitney U test for two independent groups. 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 2a-3c separately for each sex.
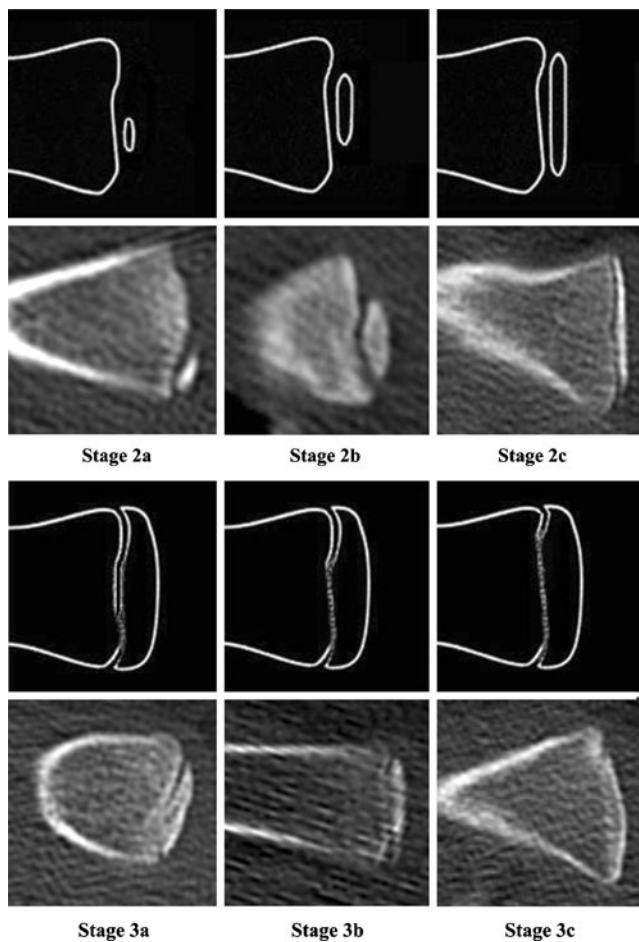
Fig. 1 Schematic drawings and pictures of the stages 2a-3c of clavicular ossification

A comparison between male and female data did not reveal statistically significant differences concerning the appearance of the stages. Stage 2a first appeared at age 14.4 in males and at age 13.1 in females. The earliest appearance for stage 2b was with 16.4 years of age for males and 15.4 years of age for females. Stage 2c was first seen at age 17.1 in males and age 15.6 in females.

The earliest appearance for stage 3a was at 17.5 years of age in males and 16.8 years of age in females. Stage 3b was first noted at age 18.3 in males and at age 17.8 in females.

It was found that the earliest appearance of stage 3c was with 19.7 years of age in male individuals and 19.5 years of age in female individuals.

Discussion

The radiological examination of the medial clavicular epiphysis is of particular interest to age estimation in living subjects due to the fact that the sterno-clavicular joint displays a relatively late maturation process compared to

other regions of interest for age diagnostics. In individuals older than 18 years of age, diagnostic possibilities to assess age are limited because sexual maturation, hand ossification, and wisdom teeth mineralization can be completed by this time [17–19]. The radiological approach to assess maturation processes of the sterno-clavicular joint encompasses conventional radiography, computed tomography, as well as radiation free methods as magnet resonance tomography and ultrasoundsonography.

Up to date, reference data could be made available only for conventional radiography and computed tomography [15, 16]. MRI and ultrasoundsonography were applied in first pilot studies [14, 20, 21] and future studies have to show whether these imaging methods can be applied as reliable methods in age estimation practise.

It cannot be assumed that the evaluation of the ossification status of the medial clavicular epiphysis determined by means of different radiological imaging methods (conventional radiography, CT, MRI, and ultrasound sonography) results in identical findings as the techniques and imaging possibilities differ from each other. Furthermore, it is doubtful if it is possible to compare data derived from radiological imaging with data given in anatomical studies. This issue has to be investigated in a comparative study in which the ossification status is determined both anatomically and radiologically in autopsy material. 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 [13]. Encouraged by this finding, it was stated that in age estimation practice, it is necessary to use conventional radiographic reference studies for the ossification stage classification by

Table 2 Statistical parameters in years by sex for ossification stages 2a-3c

Stage	Sex	Min-max	Mean ± SD	Median, LQ, UQ
2a	Male	14.4–20.0	17.4±1.4	17.8, 16.8, 18.2
	Female	13.1–18.2	15.8±1.8	15.8, 14.2, 17.5
2b	Male	16.4–20.1	18.2±1.1	18.1, 17.6, 18.8
	Female	15.4–19.3	17.4±1.4	17.8, 16.0, 18.2
2c	Male	17.1–20.2	18.6±1.4	18.5, 17.3, 19.9
	Female	15.6–18.2	17.3±0.9	17.8, 16.7, 18.0
3a	Male	17.5–20.7	19.0±1.1	18.6, 18.4, 20.4
	Female	16.8–22.1	19.6±1.6	19.6, 18.5, 21.0
3b	Male	18.3–25.4	21.1±2.0	21.1, 19.8, 22.1
	Female	17.8–24.4	21.0±1.9	21.1, 19.6, 22.4
3c	Male	19.7–26.2	22.9±1.8	23.3, 21.4, 24.1
	Female	19.5–26.2	22.5±1.8	22.1, 21.3, 23.7

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

conventional radiography, and CT reference studies for the ossification stage classification by CT.

In analysing the medial clavicular epiphysis in computed tomography, two staging schemes were applied. The four stages-scheme of the ossification process is based on the appearance of the epiphyseal ossification centre (stage 2) and its partial (stage 3) or complete fusion with the metaphysis (stage 4) [9, 10, 22]. The five stages scheme by [16] additionally takes into account the visibility and disappearance of the epiphyseal scar. According to this scheme a stage 4 is given if the epiphyseal cartilage is fully ossified and the epiphyseal scar is visible. In stage 5, the epiphyseal scar has fully disappeared and is no longer observable.

By applying the classification of stages by [16] in analysing thin-slice computed tomography scans, a minimum age of 21 can be determined when a stage 4 is given and a minimum age of 26 can be stated in case a stage 5 is observed [15].

The data presented in this study allow determining an age over 18 even if fusion between the medial metaphyseal ending and the epiphysis (stage 4 or 5) has not been completed. In the present study, the mean value concerning stage 3c in male individuals was 22.9 years of age and 22.5 years of age in females. The minimum age at with stage 3c could be observed was 19.7 years in males and 19.5 years in females. Up to the present, comparable data derived from CT images or other material is non-existent because a sub-classification of the ossification stages of the sterno-clavicular joint has not been undertaken before.

Due to the fact that in the vast majority of cases age is estimated in non-nationals, it is a matter of importance if the reference data available can be applied to age estimation in individuals who originate from foreign countries or stem from different ethnic origins. Regarding this issue, it was stated that the ethnic origin does not have a notable influence on the pace of skeletal development [16, 23]. However, it could be ascertained that the socio-economic status does have an impact on the pace of ossification with relatively low socio-economic status delaying development. Referring to estimating age in individuals with delayed development as a consequence of undernourishment or other factors related to a low socio-economic status, the age of the individuals is most likely to be underestimated. From a legal perspective, this would not result in a disadvantageous situation for individuals undergoing criminal proceedings.

Conclusions

By applying the sub-classification scheme of the stages 2 and 3 in CT-based age diagnostics, it is possible to narrow the interval of the estimated age. In order to determine whether an individual has already reached the age of criminal liability or not, the CT-based reference data known prior to the present study only allowed to establish a minimum age of 21 years in case of a stage 4 and a minimum age of 26 in the case of a stage 5. It should be of interest to age estimation practise that a late stage 3 (stage 3c) does not appear prior to the age of 19 years in both sexes. Based on this finding, it can reliably be stated that an individual has already accomplished 18 years of age even if epiphyseal-metaphyseal fusion is not fully completed.

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