

Ultrasound studies on the time course of clavicular ossification

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Abstract When preparing forensic age estimates for living subjects over 18 years of age, it is crucial to evaluate the stage of ossification of the medial clavicular epiphysis. The establishment of radiation-free imaging techniques for assessment of clavicular ossification would be desirable in order to reduce the radiation exposure associated with forensic age estimations. In the present study, 84 right clavicles of test subjects 12–30 years of age were prospectively evaluated by means of ultrasound. Ossification stage classification was possible in 80 of the 84 medial clavicular epiphyses studied. In the remaining cases, stage classification was not possible due to the presence of developmental anomalies. The earliest ages at which the respective ossification stages were observed were 17.1 years for stage 2, 16.7 years for stage 3, and 22.5 years for stage 4. The age intervals observed for the ossification stages are

consistent with the known data from radiological and computed tomography assessments. The present study results should be confirmed in a larger number of cases and with analysis of observer variability. Evaluation of medial clavicular epiphyseal ossification by ultrasound could ultimately be a rapid and economic non-ionizing diagnostic imaging procedure for forensic age estimation.

Keywords Forensic age estimation · Ossification · Clavicle · Sonography

Introduction

Forensic age estimation in living adolescents and young adults is a current area of research in the field of forensic science [2–4, 16, 18, 20, 24–27]. The persons to whom forensic examination is to be applied are non-nationals without valid identity documents who are suspected of making false statements about their age and whose genuine age needs to be ascertained for legal purposes. In many countries, the age thresholds relevant for criminal, civil, and asylum proceedings lie between 14 and 22 years of age. Concerning estimation of the age of living subjects for criminal investigation purposes, the German Study Group on Forensic Age Diagnostics (Arbeitsgemeinschaft für Forensische Altersdiagnostik, AGFAD) (<http://www.charite.de/rechtsmedizin/agfad/index.htm>), recommends that all forensic age estimates should be based on the findings of a physical examination, an X-ray of the left hand, and a dental examination including dentition status and orthopantomogram evaluation [22]. Evaluation of the ossification stage of the medial clavicular epiphyses is of decisive importance when performing forensic age

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Table 1 Number of cases by age and sex ($n=84$)

Age (years)	Male	Female
11	–	1
12	1	1
13	2	3
14	6	4
15	5	1
16	3	3
17	5	5
18	6	2
19	1	1
20	1	5
21	2	1
22	1	2
23	1	2
24	3	1
25	2	4
26	2	–
27	3	2
28	1	–
29	–	–
30	–	1
Total	45	39

diagnostics in living subjects above the age of 18 years because sexual maturation, ossification of the hand, and mineralization of the third molars can be completed by this age. Only conventional radiology [23], computed tomography [10, 11, 28, 29] and magnetic resonance imaging studies [26] have been performed for assessment of ossification staging of the medial clavicular epiphysis for forensic age estimation purposes so far.

A few articles on ultrasonic determination of skeletal age are currently available. Some of the research groups investigated whether it is possible to detect ossification centers or epiphyseal cartilage in various bones of the hand or iliac crest by ultrasound [1, 8, 13, 17, 30]. Mentzel et al. [14, 15] determined the correlation between the speed of sound waves passing through the distal radial and ulnar epiphyses and skeletal age according to the Greulich and Pyle atlas [9]. Castriota-Scanderbeg et al. [5–7] pursued the question whether ultrasonically obtained femoral head and femoral condyle cartilage thickness measurements were suitable measures of skeletal age.

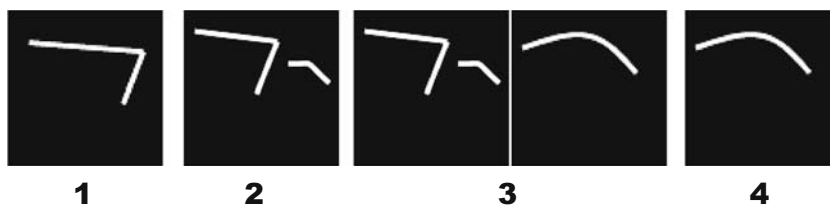
The present pilot study was conducted to determine whether the ossification stage of the medial clavicular epiphyses can also be determined by ultrasonography.

Materials and methods

In this study, 84 right sternoclavicular joints of healthy volunteers 12 to 30 years of age were prospectively evaluated by means of ultrasound. This research was carried out with the consent of the volunteers and/or of their parents in the case of minors. Prior approval was obtained from the responsible ethics committee. Table 1 shows the age and sex structure of the study population with the respective number of cases. The examinations were carried out by a physician qualified and certified in the area of arthrosonography. The examiner did not know the chronological age of the subjects.

The studies were performed using a Pro Focus 2202 ultrasound system (B-K Medical, Herlev, Denmark) equipped with an 8 MHz linear transducer and a standoff pad. The transducer works as a transmitter and a receiver of sound waves. When a soundwave vertically hits the interface of a medium with high density (e.g. bones), it is reflected. As a result, the ossified metaphysis and the ossified epiphysis appear white. When a soundwave hits the interface of a medium with low density (e.g. cartilage), it spreads out in the medium. Hence the cartilaginous part of the epiphyseal plate appears black. The medial clavicular epiphyses were imaged in transverse scans, i.e., using planes perpendicular to the epiphyseal cartilage. For the sonographic assessment of the clavicle ossification, the traditional classification into four stages by Owings Webb and Myers Suchey [19] was applied as follows:

- Stage 1 (ossification center not ossified): the medial end of the clavicle is configured acute-angled. A bony center of ossification is not representable.
- Stage 2 (ossification center ossified, epiphyseal plate not ossified): the medial end of the clavicle is separated from the bony center of ossification by a sound gap.
- Stage 3 (epiphyseal plate partly ossified): both an ultrasound gap with a bony center of ossification and

Fig. 1 Schematic representation of the ossification stages 1–4

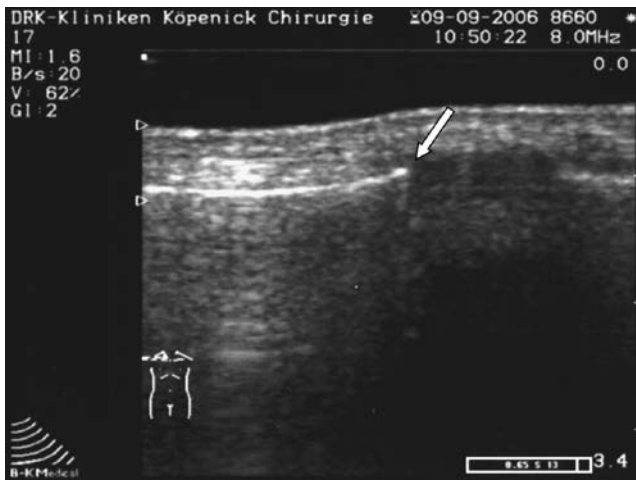


Fig. 2 Sonographic finding of a non-ossified epiphyseal center in a 14.6-year-old girl. The *arrow* indicates the acute-angled end of the clavicle



Fig. 4 Sonographic finding of a fully ossified epiphyseal plate in a 25.9-year-old woman. The *arrow* indicates the convex curved end of the clavicle

a fully ossified epiphyseal plate with a convex curved end of the clavicle are representable.

Stage 4 (epiphyseal plate fully ossified): the medial end of the clavicle is convex curved. A bony center of ossification is not representable.

In Fig. 1, these four stages are represented schematically. Figures 2, 3 and 4 show sonographic findings of a non-ossified epiphyseal center, an ossified epiphyseal center with non-ossified epiphyseal plate, as well as a fully ossified epiphyseal plate.



Fig. 3 Sonographic finding of an ossified epiphyseal center with a non-ossified epiphyseal plate in a 20.9-year-old woman. *Arrow 1* indicates the ossified metaphysis, *arrow 2* indicates the cartilaginous epiphyseal plate presenting itself as a soundgap and *arrow 3* indicates the ossified epiphyseal center

Results

Ossification stage classification was possible in 80 out of 84 clavicles studied. In the remaining cases, stage classification was not possible due to the presence of developmental anomalies. Table 2 shows the minimum, maximum, and mean ages (\pm SD) of occurrence of the respective ossification stages according to sex. The earliest age of occurrence of stage 2 was 18.7 years in boys and 17.1 years in girls. The minimum age for stage 3 was 16.7 years in boys and 17.6 years in girls. The earliest age of occurrence of stage 4 was 22.9 years in males and 22.5 years in females.

Discussion

Due to restrictions imposed by the German X-ray Ordinance, radiological examinations without a medical indication are not permissible except in cases provided for by law. The sole

Table 2 Statistical parameters, in years and by sex, for ossification stages 1–4 ($n=80$)

Stage	Sex	Number of cases	Min–max	Mean \pm SD
1	Male	21	12.4–18.1	15.4 \pm 1.5
	Female	14	11.7–18.2	14.7 \pm 1.9
2	Male	4	18.7–21.4	19.7 \pm 1.2
	Female	5	17.1–20.8	18.7 \pm 1.8
3	Male	5	17.6–21.5	19.3 \pm 2.1
	Female	8	16.7–23.9	20.7 \pm 2.1
4	Male	13	22.9–28.3	25.8 \pm 1.6
	Female	10	22.5–30.4	25.9 \pm 2.2

Min Minimum, *max* maximum, *SD* standard deviation

legal basis for radiological examination for the exclusive purpose of forensic age estimation is the Code of Criminal Procedure. Therefore, radiological examinations for forensic age assessment are not legitimized by law in the case of civilian and asylum proceedings. The range of permissible examinations in these cases is therefore limited to physical examination and to dental inspection of the oral cavity [12]. This considerably reduces the reliability of forensic age estimates. Non-ionizing techniques for assessment of skeletal development for forensic age estimation purposes would therefore be desirable, not only in these cases, but also in criminal proceedings since this would permit a significant reduction of radiation exposure for the test subjects during the required examinations [21].

To our knowledge, the present study is the first to investigate the question of whether it is possible to determine the ossification stage of the medial clavicular epiphyses by ultrasound. Ossification stage classification was possible in 80 out of 84 clavicles studied. In the remaining four cases, ultrasonic stage classification was not possible due to the presence of developmental anomalies (cup-shaped epiphyses). Reliable ultrasonographic ossification stage classification was therefore possible in all of the normally developed clavicular epiphyses studied. For forensic age estimations, the minimum age of the respective stage of ossification is of particular importance. In the present study, the earliest age of occurrence of stage 2 was 18.7 years in boys and 17.1 years in girls. The minimum age for stage 3 was 16.7 years in boys and 17.6 years in girls. The earliest age of occurrence of stage 4 was 22.9 years in males and 22.5 years in females. In the available reference studies on assessment of the degree of ossification of the medial clavicular epiphyseal cartilage by means of radiography and computed tomography, the minimum age for Stage 2 was between 11 and 16 years, the minimum age for stage 3 was 16 years and the minimum age for stage 4 was between 19 and 22 years [10, 11, 23, 28, 29]. As opposed to visualization of the epiphyseal cartilage by conventional radiography and computed tomography, only a portion of the bone surface can be visualized by ultrasonography. In spite of these methodological differences, the ultrasonographic minimum ages determined in our study were consistent with the known minimum ages determined by X-ray and CT. This means that in the present study the minimum ages for all stages of ossification are above the values known from the radiological and CT-studies. These differences can be explained by the relatively low number of cases of our sample.

Evaluation of medial clavicular epiphyseal ossification by ultrasound could prove to be a rapid and economic non-ionizing diagnostic imaging procedure for forensic age estimation. However, the results of the present study should

first be confirmed in a larger number of cases and with analysis of observer variability.

Conclusions

Reliable ultrasonographic ossification stage classification was possible for all the normally developed clavicular epiphyses evaluated in the present study. The age intervals observed for the ossification stages were consistent with the known data from radiological and computed tomography assessments. However, the results of the present study should be confirmed in a larger number of cases with analysis of observer variability. Evaluation of medial clavicular epiphyseal ossification by ultrasound could prove to be a rapid and economic non-ionizing diagnostic imaging procedure for forensic age estimation.

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