

Evaluation of the ossification of the medial clavicular epiphysis with a digital ultrasonic system to determine the age threshold of 21 years

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Abstract In this study, both medial clavicular epiphyses of 77 men were evaluated by two researchers with a digital ultrasound system. The degree of ossification was classified in four stages according to Schulz et al. (Int J Legal Med 122:55–58, 17). Of the test persons over 21 years of age, stage 4 was found bilaterally in 25 (60%), while for five (12%) stage 4 was found on only one side; 12 (28%) further subjects did not show stage 4 on either side, although nine were exactly 21 years old. For the subjects under 21 years of age, stage 4 was found bilaterally in three cases (8.5%), and in three additional cases stage 4 was found on one side. Particularly, the three cases in which stage 4 was diagnosed bilaterally before completion of the 21st year of age limit the value of the used examinatory technique. For these cases it would be interesting to know if parts of the epiphyseal plate that might have been obstructed from the view of the ultrasound transducer would have been visible with CT.

Keywords Forensic age estimation · Ossification · Clavicle · Digital ultrasonic system

Introduction

It is not certain how many people are living in Germany without residence permits. Many of these entered the Federal Republic via a third country and are not in possession of identification papers proving their nationality or date of birth. Between 1996–2001, 10,000 foreigners brought to Germany illegally by people traffickers were apprehended by the Federal Border Police [1] each year. This development illustrates the growing significance of forensic age assessment of living persons and can now be regarded as one of the classic tasks belonging to legal medicine [3].

Complete ossification of the medial clavicular epiphyseal plate is considered the most important criterion indicating a completion of the 21st year of life. The corpus clavícula develops by direct formation of bone (desmal ossification) and is the first skeletal element to ossify in a human embryo. The medial clavicular epiphysis develops by indirect formation of bone (chondral ossification), and an ossification center within the epiphysis can only be demonstrated after the onset of puberty. The medial clavicular epiphyseal plate is generally the last long bone epiphyseal plate to ossify in the human skeleton [6].

Computed tomography (CT) examinations are considered to be the gold standard in determining the degree of ossification of the medial clavicular epiphysis [5, 7, 11, 16], and a slice thickness of 1 mm is recommended for this purpose [17]. The study group on Forensic Age Diagnostics of the German Society of Legal Medicine (AGFAD) recommends a supplementary CT examination for cases in which ossification of the hand has been completed [9, 10]. This approach is also supported by the papers from Schmidt

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et al. [13, 14] in which the dependency of the age of an individual on the ossification of the epiphyseal plates of hand bones was examined. The study also revealed that complete disappearance of the epiphyseal scar at the lower end of the radius indicated a completion of the 18th year of life in male adolescents. In consequence, examination of the clavicle must be included to determine the age of persons over 18 years of age.

Alternative methods to CT scans are classic sectional radiography (tomography) or, within limits, conventional X-ray examinations [12]. All of these methods are associated with radiation exposure [4, 11] and are only permissible in criminal proceedings with a court order in accordance with §81a of the Federal German Criminal Procedure Code. Recent studies [17] have shown that conventional X-rays of the clavicle should be taken in three planes to allow a sound assessment of the ossification stage. This is, however, accompanied by an increase in radiation exposure, even if the values reached do not compare with those associated with computed tomography [8].

So far, promising pilot studies using magnetic resonance tomography (MRT) [15] and sonography [18] have been conducted in the quest for radiation-free methods that allow an assessment of the degree of ossification of the medial clavicular epiphysis.

Apart from being radiation-free, sonography has additional advantages of being economical and fast. A drawback to its application in forensic age diagnostics is that, to date, insufficient case numbers have been investigated. Also, sonography has a lower resolution than methods using X-rays or MRT. Since sonography is a dynamic examination procedure, a further problem that arises is the difficulty of adequately documenting findings in still images.

A newest generation ultrasound system was available for this study. The manufacturer of this digital ultrasound system assured far higher resolution and easier digital image documentation of findings than was possible with conventional analogue ultrasound systems. The primary purpose of this study was to assess whether the system could be used to evaluate the degree of ossification of the medial clavicular epiphyseal plate. A further goal of the study was to establish at what age full ossification could be demonstrated with this ultrasound system, and also to see if this criterion, as proof that 21 years of age had been reached, could be demonstrated with the necessary degree of reliability required by criminal law. Based on current radiodiagnostic data, results documenting a full ossification before completion of the 21st year of age could lead to an erroneous assessment of age with possible negative consequences for the subject involved.

Materials and methods

In this study, 77 male volunteers of Caucasian origin, aged between 18–24 years (mean age 21.4 years; median age 21.2 years) were assessed. Of these, 42 had completed the 21st year of life, and 35 were younger than 21 years old (Fig. 1). Personal data were anonymized. The examinations were conducted in an orthopedic practice. The orthopedist selected the test persons from the patient pool and made sure that they neither had any disease that might affect skeletal maturation nor any injuries, fresh or healed, to the shoulder girdle. The chosen test persons, who were anonymous to the examiners, were sent to these by the orthopedist without any direct contact between the orthopedist and the examiners. These examiners prepared for the experiment by completing the DEGUM (German Society for Ultrasound in Medicine) introductory course to the locomotor system. After the course, they familiarized themselves with the ultrasound system and then absolved a training phase in which they examined at least ten patients of known age.

The digital ultrasound system Sarano (Shimadzu, Kyoto, Japan), equipped with a linear 8–15 MHz multifrequency transducer, was used for this investigation. The apparatus settings (brightness, contrast, and zoom) were kept constant for the entire experiment. Both medial clavicular epiphyseal plates of each subject were independently assessed by the two examiners.

During the examination, the probe was moved around the medial clavicular epiphysis in different positions to obtain a maximum angle of view. For each side, three images were taken for two extreme positions of the probe and for a middle position. The acquired images were digitally saved.

The degree of ossification of the medial epiphyseal plate was classified according to the 4 stages defined by Schulz et al. [18] (Table 1).

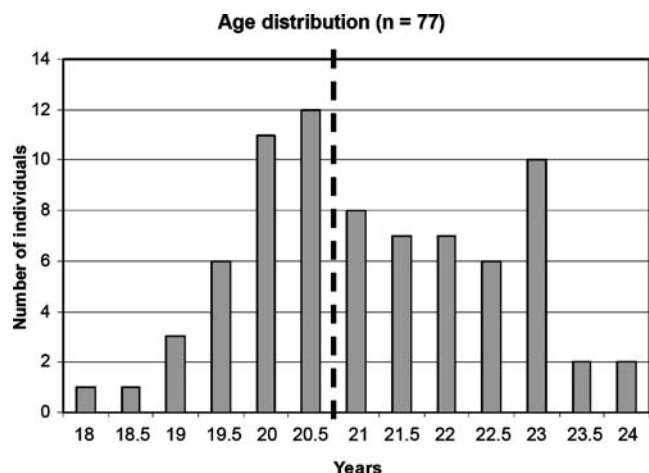


Fig. 1 Age distribution of the male subjects examined in this study

Table 1 Stages of ossification of the medial clavicular epiphysis according to Schulz et al. [17] in sonograms

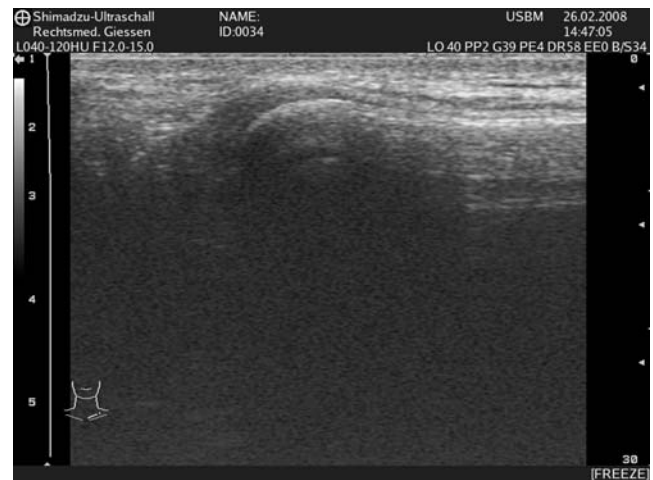
Stage	Criteria
1	Ossification center not visibly ossified
2	Ossification center visible in non-ossified epiphyseal plate
3	Epiphyseal plate partly ossified
4	Epiphyseal plate fully ossified

Results

The clavicle could be imaged in high resolution allowing a high-resolution assessment of the epiphyseal plate (Figs. 2 and 3). Small residues of the epiphyseal plate were easy to discern (Fig. 2). The option of being able to save the digital images directly onto the USB stick was a fast, comfortable way of recording data.

A clear-cut classification of the stages was possible. No morphologically apparent developmental anomalies in the medial clavicular epiphyses were observed.

There were no differences between the assessments of the two examiners. There were no cases in which the ossification stages for both sides of an individual subject differed by more than one stage. The age distribution of the subjects could, therefore, be plotted against the mean values of the stages (Fig. 4). This graph revealed that cases occurred in which subjects older than 21 years still showed stage 1 on both sides. On the other hand, stage 4 could also be observed for subjects under the age of 21 years. When the subjects who were 21 years old and older were viewed as a group, 25 (60%) showed stage 4 on both sides, and five (12%) showed stage 4 on only one side. There were 12

**Fig. 2** Still discernible epiphyseal plate (arrow) in stage 3 for one of the transducer positions**Fig. 3** Full ossification of the epiphyseal plate in stage 4

(28%) subjects who did not show stage 4 on either side and of these nine were exactly 21 years old.

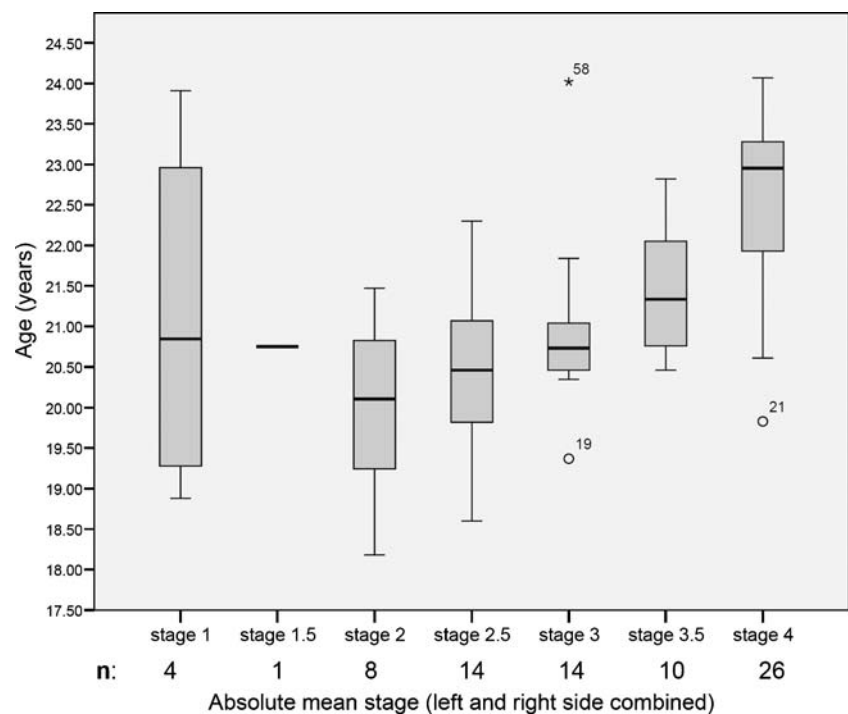
In the group of subjects younger than 21 years of age there were three cases (8.5%) in which stage 4 could be found on both sides and three further cases in which stage 4 could be found on one side only. Of the six subjects younger than 21 years of age 4 were in the second half of their 21st year of life. One of the subjects was in the first half of the 21st year of life and a second subject was in the second half of the 20th year of life.

Discussion

The digital ultrasound system and multifrequency transducer at our disposal produced high image quality, unrivalled by the conventional systems we were so far familiar with. Our experience was that the ossification stages according to Schulz et al. [18] could be assessed very well. We found it notable that in our examinations there were no differences in the assessment of the stages by the two examiners. Further validation through an interobserver study with a minimum of four examiners and further samples is, nevertheless, necessary and is in preparation.

Our study only examined males. As experience has shown these are more frequently involved as suspects in criminal cases than females. In 2007, for example, only 24.2% of the 2,294,883 suspects in the Federal Republic of Germany were female [2]. However, these preliminary results should be validated on females in further studies. This study has examined the largest number so far of subjects between 18–24 years of age ($n=77$), an age range that is critical to criminal law proceedings. Of the examined subjects, 23 had

Fig. 4 Age distribution for the average stage of an individual (stage on right side plus stage on left side divided by 2)



not yet completed the 21st year of life (Fig. 1). For the first time, the sternoclavicular joints on both body sides of each subject were independently assessed by two examiners. Through the lack of contact between the examiners and the orthopedist, who functioned as the experiment supervisor, the experimental design created a situation essentially equal to a blinded experiment.

Limitations in answering the critical and forensically relevant question of whether the subject had completed the 21st year of life were found. The fact that incompletely ossified epiphyseal plates (no stage 4) and even the lack of visible ossification centers (stage 1) could be found for subjects older than 21 years of age, which would lead to a false negative assessment of the subject's age, would not be detrimental to a suspect in respect to the age threshold of criminal responsibility. However, the false positive classification of subjects younger than 21 years of age into the group of over 21 year olds poses a far greater problem: stage 4 was diagnosed on least one side for six of the 35 subjects who had not yet reached the age of 21. This leads to the conclusion that finding full ossification of the medial clavicular epiphysis with ultrasound, as a way of determining the completion of the 21st year of life, is, for the time being, a method insufficient for criminal law proceedings.

An important issue is whether there was still a residue of the epiphyseal plate left in the 6 false positive cases that might have been visible in X-ray or CT examination. It is safe to assume that the ultrasound system we used represents the upper limit of what is currently technically possible with regard to resolution. However, in sonographic examinations of bones the angle of view is basically restricted, so that it is possible that epiphyseal residues were hidden in the shadow of the ultrasound wave. An evaluation of the sonography results with the aid of CT data would be useful, but is not an option that can be applied to test persons due to the associated radiation exposure. A viable course could be to additionally examine patients who undergo a medically indicated CT examination with ultrasound. Another alternative open to discussion is the examination of corpses.

Further studies are necessary to clarify whether ultrasound examinations can be used in future as a method for forensic age assessment. They should primarily be conducted to acquire an additional method, free of ionizing radiation, for age assessments also in civil and asylum law cases. Apart from being a radiation-free method, sonography has the further advantages of being rapid and easy to use, and the digital sonograph used in this study can be applied as a mobile unit.

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