

Radiographic staging of ossification of the medial clavicular epiphysis

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Abstract Determination of the stage of ossification of the medial clavicular epiphysis is a crucial part of forensic age estimation when evaluating living subjects over 18 years of age. In the present study, we comparatively assessed conventional radiographs and computed tomography (CT) scans of sternoclavicular joints used to perform forensic age assessments in 57 individuals undergoing criminal proceedings. With CT, it was possible to determine the ossification stage of all clavicles studied. In the case of conventional radiography, reliable assessment of ossification stage was not possible in 15 out of 114 clavicles studied due to the superimposition of other structures. Regarding agreement between the methods, both radiography and CT produced identical staging results in 97 out of 99 clavicular epiphyses. In two cases, however, ossification was classified as stage 2 by CT and as stage 3 by conventional radiography. Regarding stages 4 and 5, both methods produced identical staging results in all cases. In forensic age estimation practice, it is necessary that conventional

radiographic reference studies be used for ossification stage classification by conventional radiography and that CT reference studies be used for ossification stage classification by CT. Further studies in dead bodies of known age are required to issue a recommendation as to whether conventional radiography using obtained in three planes or CT is the method of choice for the assessment of clavicular ossification.

Keywords Forensic age estimation · Ossification · Clavicle · Conventional radiography · Computed tomography

Introduction

Forensic age estimation in living adolescents and young adults undergoing criminal proceedings is a current area of research in the field of forensic science [1–3, 7–9, 13–16]. Such age estimates are performed to determine whether a defendant of questionable age has reached the age of criminal responsibility and whether general criminal law for adults can be applied. In most countries, the age thresholds of legal relevance range between 14 and 21 years of age [4]. According to the recommendations of the Study Group on Forensic Age Diagnostics (Arbeitsgemeinschaft für Forensische Altersdiagnostik, AGFAD, <http://www.charite.de/rechtsmedizin/agfad/index.htm>), all forensic age estimates should be based on combined evidence from a physical examination, an X-ray of the left hand, and a dental examination including a dental status and orthopantomogram. When it is necessary to determine whether the subject has reached the age of 21, additional assessment of the medial clavicular epiphyses by radiography or computed tomography (CT) is recommended [11].

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The Institute of Radiology (CCM) at the Charité Hospital in Berlin, Germany has been performing radiographic staging of medial clavicular epiphyses for forensic age assessment of living persons undergoing criminal proceedings since the year 2000. The assessments were initially performed using conventional radiographic images taken in three planes (one posteroanterior and two anterior oblique projections), but the assessment procedure was modified in 2003. Since then, staging of ossification of the medial clavicular epiphyses has been performed using both CT scans with a slice thickness of 1 mm and conventional posteroanterior radiographs. This modification was based on the assumption that the dual approach provides the highest possible degree of accuracy with the lowest possible radiation exposure.

The aim of the present study was to compare the accuracy of conventional radiography and CT for clavicular ossification staging in the scope of forensic age estimation in living subjects.

Materials and methods

In the present study, we retrospectively analysed conventional posteroanterior radiographs and CT scans of the sternoclavicular joints obtained to determine the ossification stage of the medial clavicular epiphyses of 57 living subjects (53 male, 4 female) examined for forensic age estimation purposes. All of the images were taken at the Institute of Radiology (CCM) of the Charité Hospital in Berlin, Germany in the period from 2003 to 2005. Pursuant to Section 81a of the German Code of Criminal Procedure, a court order authorising the performance of a radiological examination without a medical indication had been issued in each case.

All CT examinations were performed using a Toshiba Asteion (single-slice spiral CT; rotation time=1 s, 120 kV, 130 mA, pitch=1.5, collimation=1 mm, kernel=FC30 [bone kernel], matrix=512×512, scan length=4 cm).

The ossification stages of the medial clavicular epiphyses were defined in accordance with the staging system proposed by Schmeling et al. [12]:

- Stage 1 Non-ossified ossification center.
- Stage 2 Ossified ossification center with non-ossified epiphyseal cartilage.
- Stage 3 Partially ossified epiphyseal cartilage.
- Stage 4 Fully ossified epiphyseal cartilage with a discernable epiphyseal scar.
- Stage 5 Fully ossified epiphyseal cartilage with no discernable epiphyseal scar.

All stage classifications were consensus ratings by two examiners experienced in the radiological staging of

clavicular ossification. In each case, the stage classifications determined by one method were made without prior knowledge of the staging results determined using the other method.

Results

With CT, it was possible to determine the ossification stage of all clavicles studied. Using conventional radiography, however, reliable determination of the ossification stage was not possible in 15 out of the 114 clavicles studied due to the superimposition of other structures. Accordingly, there were 99 clavicles in which clavicular ossification stage classifications by both conventional radiography and CT were available for comparison.

Regarding agreement between the methods, both radiography and CT produced identical results in 97 clavicles. Of these clavicles, 14 were diagnosed as ossification stage 2, 27 as stage 3, 5 as stage 4 and 51 as stage 5.

In the remaining two cases, conventional radiography and CT produced divergent staging results. The two subjects in question were a male and a female from Vietnam. In both cases, left clavicular ossification was classified as stage 3 by both CT and radiography, but right clavicular ossification was classified as stage 2 by CT and as stage 3 by conventional radiography. The right clavicle of the Vietnamese male is shown in Figs. 1 and 2 as visualised by conventional radiography and by CT (representative CT scan), respectively.



Fig. 1 Conventional posteroanterior radiograph of the medial epiphyseal cartilage of the right clavicle (detail) of the Vietnamese male; ossification stage 3

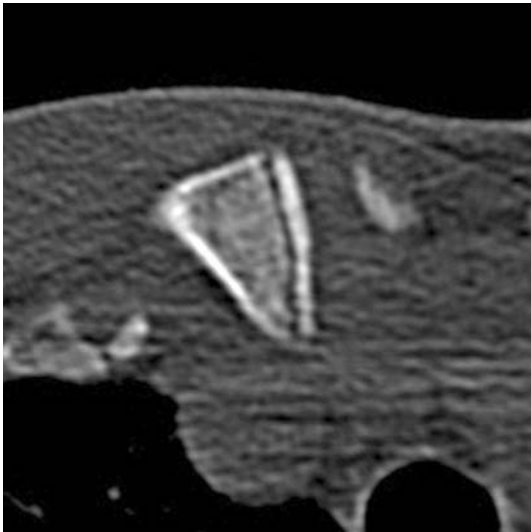


Fig. 2 CT scan of the medial epiphyseal cartilage of the right clavicle (detail) of the Vietnamese male; ossification stage 2

Discussion

When performing forensic age diagnostics in living subjects above the age of 18 years, assessment of ossification of the medial clavicular epiphyseal cartilage is crucial because sexual maturation, ossification of the hand and mineralisation of the third molars may be completed by this age.

Current reference studies on assessment of the degree of ossification of the medial clavicular epiphyseal cartilage by CT [5, 6, 17, 18] and conventional radiography [12] are available.

All of the available CT reference studies are based on images obtained using a slice thickness of 7 or 8 mm in the majority of cases. However, Mühler et al. [7] showed that the ossification stage could be misdiagnosed when slice thicknesses larger than 1 mm are used because fine anatomical structures may then be partially or completely masked due to partial volume effects. The authors therefore concluded that slice thicknesses of 1 mm should be used to produce forensic age assessments with the greatest possible degree of accuracy. Forensic age estimation can be problematic in practice, especially with regard to the diagnosis of ossification stage 5 by CT. In the only CT study with data on stage 5 diagnosis [17], this stage was found to occur 5 years earlier than in the corresponding radiological study [12]. In the CT study, a slice thickness of 7 mm was used in 546 out of 629 cases. Therefore, in cases where an “early” stage 5 was diagnosed, it cannot be excluded that the epiphyseal scar may have been still present but masked due to the large slice thickness and that the true ossification stage may have actually been stage 4. Regarding the question of whether the ossification stage-related age intervals determined in the conventional radiography study by Schmeling et al. [12] can be

extended to CT-based ossification stage classifications, this appears doubtful due to the differences in the two image generation techniques.

One advantage of conventional radiography over CT is its higher spatial resolution [10]. A disadvantage, however, is the potential superimposition of other skeletal structures on the clavicular epiphyseal cartilage, which can partly or completely prevent the assessment of ossification stage.

In consideration of these issues, the present study was performed to provide a comparative analysis of the ability of conventional radiography and CT to assess the stage of clavicular ossification. Because of the superimposition of other structures, it was not possible to reliably determine the ossification stage of the clavicle by conventional radiography in 15 out of 114 clavicles assessed; however, no anterior oblique projections were available. Both conventional radiography and CT produced identical development stage classification results in 97 out of 99 clavicular epiphyses. However, the two methods did not produce identical stage classifications in two cases. In both cases, ossification was classified as stage 2 by CT and as stage 3 by conventional radiography. The actual chronological ages of the investigated subjects are unknown. However, due to the fact that ossification on the right side was diagnosed as stage 3 by both methods and in both subjects, it can be concluded that ossification on the left side must have been a late stage 2. When assessed by conventional radiography, it would appear that late stage 2 might be misinterpreted as stage 3 due to summation effects. It must be assumed that these cases were also classified as stage 3 in the conventional radiographic reference studies. In forensic age estimation practice, it is therefore necessary to require that radiographic reference studies be used for ossification stage classification by conventional radiography and that CT reference studies be used for ossification stage classification by CT.

In the present study, all discernable epiphyseal scars on conventional radiographs were also visible on the corresponding CT scans. However, it must be pointed out that this was the case in only five of the subjects investigated in the present study. It is therefore recommended that a CT reference study be conducted using a slice thickness of 1 mm.

Conclusions

1. In the present study, it was not possible to reliably determine the ossification stage of the medial clavicular epiphyseal cartilage based on conventional posteroanterior radiographic images in 13% of cases due to the superimposition of other structures. Future studies should be carried out to evaluate whether the use of

conventional radiographic images obtained in three planes (one posteroanterior and two anterior oblique projections) will make it possible to obtain a valid radiographic assessment of the medial clavicular epiphyses in every case.

2. In two cases, the conventional radiography and CT staging results for a clavicle were not in agreement. In forensic age estimation practice, it is therefore necessary that conventional radiographic reference studies be used for ossification stage classification by conventional radiography and that CT reference studies be used for ossification stage classification by CT.
3. Because of the small number of cases with ossification stage 4, it was not possible to definitively answer the question whether reliable visualisation of the epiphyseal scar is possible in every case using CT scans made with a slice thickness of 1 mm in the present study. We therefore recommend that a CT reference study be conducted using a slice thickness of 1 mm.
4. To make a recommendation concerning the method of choice for the assessment of clavicular ossification, staging studies comparing three-plane conventional radiography with CT in individuals of known age will be required. For ethical reasons, this type of study can only be performed as a cadaver study.

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