

Magnetic resonance imaging of the clavicular ossification

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Abstract Assessment of the degree of ossification of the medial clavicular epiphyseal cartilage is of vital importance in forensic age diagnostics of living individuals aged more than 18 years. To date, reference studies on the assessment of clavicular ossification using imaging procedures only relate to conventional radiography and computed tomography (CT). In this study, magnetic resonance (MR) scans of 54 sternoclavicular joints of bodies aged between 6 and 40 years were evaluated prospectively. All of the examined medial clavicular epiphyseal cartilages permitted an assessment of the degree of ossification. Stage 2 was first observed at the age of 15.0 years, the earliest age at which stage 3 was observed was 16.9 years, and stage 4 was first observed at the age of 23.8 years. The observed age intervals of the respective degrees of ossification correspond to the known data from X-ray and CT scan examinations. The achieved results should be examined with a larger number of cases. A modified examination protocol is required for the MR examination of the medial

clavicular epiphyseal cartilage for the purpose of forensic age diagnostics of living individuals.

Keywords Forensic age estimation · Ossification · Clavicle · Magnetic resonance imaging

Introduction

Forensic age diagnostics of living adolescents and young adults is a modern research sector of medico-legal science [1–3, 8, 9, 11, 12, 16–18]. The individuals to whom forensic examination is to be applied are foreigners without valid identification 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. According to recommendations of the Study Group on Forensic Age Diagnostics (Arbeitsgemeinschaft für Forensische Altersdiagnostik, AGFAD; <http://www.charite.de/rechtsmedizin/agfad/index.htm>), age estimations carried out for the purpose of criminal proceedings should consist of a physical examination, an X-ray of the left hand, as well as a dental examination that records the dentition status and evaluates an orthopantomogram. In addition, a radiographic examination or a computed tomographic examination of the medial clavicular epiphyseal cartilage is recommended to establish whether an individual has attained 21 years of age [14]. If there is no legal justification for a radiographic examination, the range of possible methods is limited to a physical and a dental examination [7].

The aim of the present pilot study was to examine whether the degree of ossification of the medial clavicular epiphyses can also be determined using magnetic resonance imaging.

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Materials and methods

Magnetic resonance (MR) scans of 54 sternoclavicular joints of bodies aged between 6 and 40 years, gained in the course of forensic autopsies, were evaluated prospectively. The autopsies had been carried out between January 2004 and December 2005 in the Institute of Legal Medicine Berlin (Charité). Table 1 shows the number of cases by sex and age.

The sternoclavicular joints were kept deep frozen at -20°C for at most 3 months after autopsy. Before MR examinations, each preparation was defrosted at room temperature (20°C) for 24 h.

The examinations were performed with a 1.5-T whole body scanner (Symphony, Siemens, Erlangen, Germany) with a large flex coil. A 3D-T1 gradient echo sequence with isovolumetric voxels (time to repeat 22, time to echo 10, α 40, number of excitations 12, matrix 192, slice thickness 0.6 mm, field of view 110, time of acquisition 1.28 h), permitting the presentation of the epiphyseal cartilage, was applied. In addition, a 3D-proton density-turbo spin-echo sequence was produced to demonstrate the anatomy (time to repeat 500, time to echo 12, α 180, turbo factor 25, number of excitations 1, matrix 192, slice thickness 1.5 mm, field of view 130, time of acquisition 2:57 min).

Table 1 Number of cases by age and sex ($n=54$)

Age (years)	Male	Female
6	1	–
7	–	1
14	2	–
15	–	2
16	2	–
18	2	1
19	2	–
20	4	–
21	1	1
22	–	2
23	2	–
24	2	–
26	3	1
27	1	–
28	1	1
29	1	1
30	1	–
31	–	1
32	2	–
33	2	–
34	3	–
35	1	2
36	3	–
39	2	–
40	2	1
Total	40	14

To assess the degree of ossification of the medial clavicular epiphyses, a classification into four stages was applied [10]:

Stage 1: The ossification center has not ossified.

Stage 2: The ossification center has ossified, the epiphyseal cartilage has not ossified.

Stage 3: The epiphyseal cartilage is partially ossified.

Stage 4: The epiphyseal cartilage is fully ossified.

All stages were determined consensually by two concertedly working experts experienced in radiological evaluation of clavicular ossification.

Results

All of the examined clavicles ($n=108$) permitted an assessment of the degree of ossification. Figures 1, 2, 3, and 4 show the ossification stages 1–4, respectively, in correspondence with the MR findings.

Table 2 shows the minimum and maximum age of the respective ossification stages. Stage 2 was first observed at the age of 15.0 years. The earliest age at which stage 3 was observed was 16.9 years. Stage 4 was first observed at the age of 23.8 years.

The degrees of ossification of the right and the left clavicle varied in only one case. The subject was a 16-year-old male adolescent, whose left clavicle had the ossification stage 2; the right clavicle had the ossification stage 3. In Table 2, the subject was categorized in stage 2.

Discussion

Assessment of the clavicular ossification is of vital importance in forensic age diagnostics of living individuals more than 18 years of age because, at this age, sexual

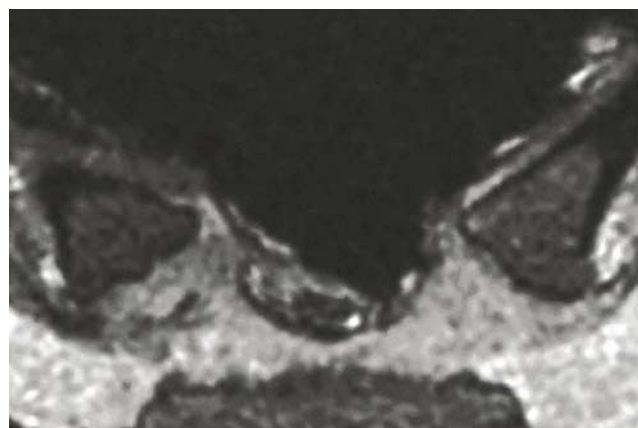


Fig. 1 MR scan of ossification stage 1 of the medial clavicular epiphysis: ossification center not ossified (female, 7.7 years)

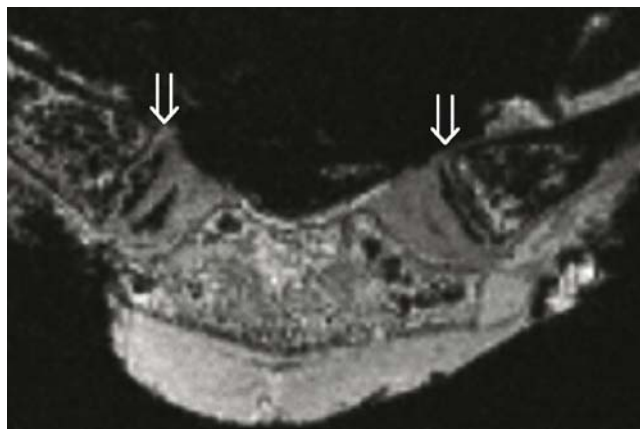


Fig. 2 MR scan of ossification stage 2 of the medial clavicular epiphysis: ossification center ossified, epiphyseal cartilage not ossified (female, 14.9 years). The arrow shows the open epiphyseal cartilage

maturation, hand ossification, and third molar mineralization should be completed.

Up-to-date reference studies on the assessment of the degree of ossification of the medial clavicular epiphyseal cartilages relate to computed tomography [5, 6, 18, 19] as well as to conventional radiography [15].

Due to the German regulations for X-ray treatment, X-ray examinations without medical indication are allowed only in statutory cases. The only legal basis for X-ray examinations carried out for forensic age diagnostics is the Code of Criminal Procedure. That is why X-ray examinations carried out for age estimations are not justified in civil and asylum proceedings. As a result in these cases, the examinations are limited to a physical examination and dental examination of the oral cavity [7], which leads to a considerable decrease in diagnostic reliability of the age diagnosis. For age estimations carried out for the purpose of criminal proceedings, a non-ionized procedure for the presentation of the medial clavicular epiphyseal cartilage would be desirable as well, as the radiation exposure from

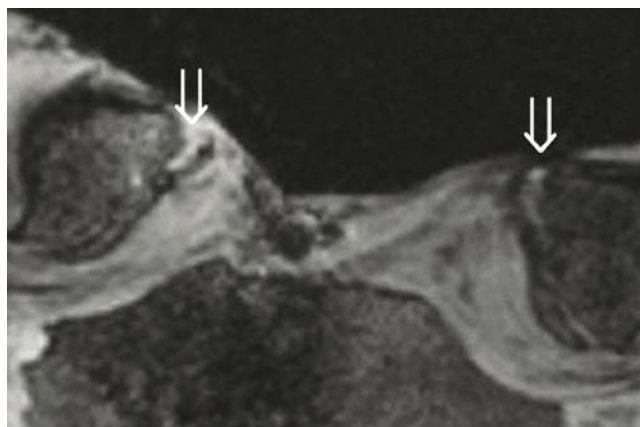


Fig. 3 MR scan of ossification stage 3 of the medial clavicular epiphysis: epiphyseal cartilage partially ossified (female, 22.3 years). The arrow shows the partial fusion with the clavicular metaphysis

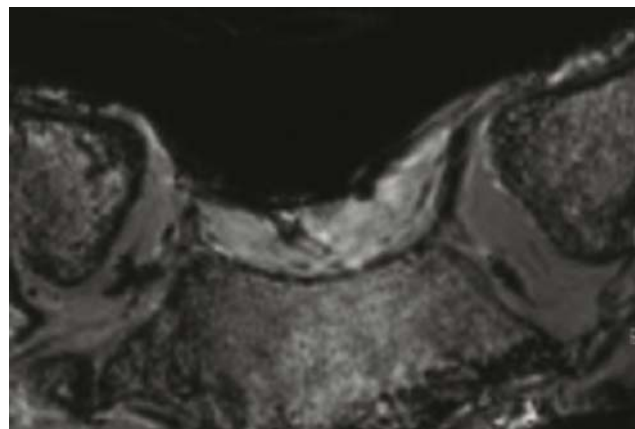


Fig. 4 MR scan of ossification stage 4 of the medial clavicular epiphysis: epiphyseal cartilage fully ossified (male, 36.3 years)

the necessary imaging examination could be decreased considerably [13].

Against this background, it was the aim of the present paper to study whether the degree of ossification of the medial clavicular epiphyseal cartilage can be assessed using magnetic resonance imaging. To our knowledge, this is the first MR study on clavicular ossification.

Because there are data on the reduction in the MR signal with decreasing temperature in frozen tissues [4], we performed imaging on completely thawed material in our investigation. Moreover, it was demonstrated that repeatedly freezing and defrosting may not alter the quality of magnetic resonance images of biological tissues [20].

All of the examined clavicles ($n=108$) permitted an assessment of the degree of ossification. Stage 2 was first observed at the age of 15.0 years, the earliest age at which stage 3 was observed was at 16.9 years, and stage 4 was first observed at the age of 23.8 years.

In the present reference studies on the assessment of the degree of ossification of the medial clavicular epiphyseal cartilage in radiography and computed tomography (CT) scans, the minimum age for stage 2 was between 11 and 16 years, the minimum age for stage 3 was at 16 years, and the minimum age for stage 4 was between 19 and 22 years [5, 6, 15, 18, 19]. The minimum ages determined in our study are in correspondence with these results.

Table 2 Minimum and maximum ages by sex for ossification stages 1–4 ($n=54$)

Stage	Case number	Minimum–maximum (years)
1	3	6.5–14.5
2	6	15.0–35.9
3	18	16.9–34.8
4	27	23.8–40.4

Conclusions

We were able to assess in all cases the degree of ossification of the medial clavicular epiphyseal cartilages using magnetic resonance imaging.

The determined age intervals of the respective degrees of ossification correspond to the known data from X-ray and CT examinations. However, the achieved results should be examined with a larger number of cases separately for each sex.

The MR examination of the medial clavicular epiphyseal cartilage for the purpose of forensic age estimation of living individuals without justification of X-ray examinations would lead to a considerable improvement of the diagnostic reliability of age diagnosis. In forensic age estimations with justification of X-ray examinations, the MR examination of the medial clavicular epiphyseal cartilage can considerably decrease the radiation exposure by the necessary imaging procedures. A modified examination protocol is required for the MR examination of the medial clavicular epiphyseal cartilage for the purpose of forensic age diagnostics of living individuals. The main task consists in reducing measuring time to produce the decisive A3D-T1 gradient echo sequence for that purpose.

References

1. Braga J, Heuze Y, Chabadel O, Sonan NK, Gueramy A (2005) Non-adult dental age assessment: correspondence analysis and linear regression versus Bayesian predictions. *Int J Leg Med* 119:260–274
2. Cameriere R, Ferrante L, Cingolani M (2006a) Age estimation in children by measurement of open apices in teeth. *Int J Leg Med* 120:49–52
3. Cameriere R, Ferrante L, Mirtella D, Cingolani M (2006b) Carpals and epiphyses of radius and ulna as age indicators. *Int J Leg Med* 120:143–146
4. Daniel BL, Butts K, Block WF (1999) Magnetic resonance imaging of frozen tissues: temperature-dependent MR signal characteristics and relevance for MR monitoring of cryosurgery. *Magn Reson Med* 41:627–630
5. Kreitner K-F, Schweden F, Schild HH, Riepert T, Nafe B (1997) Die computertomographisch bestimmte Ausreifung der medialen Klavikulaepiphyse-eine additive Methode zur Altersbestimmung im Adoleszentenalter und in der dritten Lebensdekade? *Fortschr Röntgenstr* 166:481–486
6. Kreitner K-F, Schweden FJ, Riepert T, Nafe B, Thelen M (1998) Bone age determination based on the study of the medial extremity of the clavicle. *Eur Radiol* 8:1116–1122
7. Lockemann U, Fuhrmann A, Püschel K, Schmeling A, Geserick G (2004) Empfehlungen für die Altersdiagnostik bei Jugendlichen und jungen Erwachsenen außerhalb des Strafverfahrens. *Rechtsmedizin* 14:123–125
8. Mühler M, Schulz R, Schmidt S, Schmeling A, Reisinger W (2006) The influence of slice thickness on assessment of clavicle ossification in forensic age diagnostics. *Int J Leg Med* 120:15–17
9. Olze A, Bilang D, Schmidt S, Wernecke K-D, Geserick G, Schmeling A (2005) Validation of common classification systems for assessing the mineralization of third molars. *Int J Leg Med* 119:22–26
10. Owings Webb PA, Myers Suchey J (1985) Epiphyseal union of the anterior iliac crest and medial clavicle in a modern multiracial sample of American males and females. *Am J Phys Anthropol* 68:457–466
11. Paewinsky E, Pfeiffer H, Brinkmann B (2005) Quantification of secondary dentine formation from orthopantomograms—a contribution to forensic age estimation methods in adults. *Int J Leg Med* 119:27–30
12. Prieto JL, Barberia E, Ortega R, Magana C (2005) Evaluation of chronological age based on third molar development in the Spanish population. *Int J Leg Med* 119:349–354
13. Schmeling A, Reisinger W, Wormanns D, Geserick G (2000) Strahlenexposition bei Röntgenuntersuchungen zur forensischen Altersschätzung Lebender. *Rechtsmedizin* 10:135–137
14. Schmeling A, Kaatsch H-J, Marré B, Reisinger W, Riepert T, Ritz-Timme S, Rösing FW, Röttscher K, Geserick G (2001) Empfehlungen für die Altersdiagnostik bei Lebenden im Strafverfahren. *Rechtsmedizin* 11:1–3
15. Schmeling A, Schulz R, Reisinger W, Mühler M, Wernecke K-D, Geserick G (2004) Studies on the time frame for ossification of medial clavicular epiphyseal cartilage in conventional radiography. *Int J Leg Med* 118:5–8
16. Schmeling A, Baumann U, Schmidt S, Wernecke KD, Reisinger W (2006) Reference data for the Thiemann–Nitz method of assessing skeletal age for the purpose of forensic age estimation. *Int J Leg Med* 120:1–4
17. Schmeling A, Schulz R, Danner B, Rösing FW (2006) The impact of economic progress and modernization in medicine on the ossification of hand and wrist. *Int J Leg Med* 120:121–126
18. Schulz R, Mühler M, Mutze S, Schmidt S, Reisinger W, Schmeling A (2005) Studies on the time frame for ossification of the medial epiphysis of the clavicle revealed by CT scans. *Int J Leg Med* 119:142–145
19. Schulze D, Rother U, Fuhrmann A, Richel S, Faulmann G, Heiland M (2006) Correlation of age and ossification of the medial clavicular epiphysis using computed tomography. *Forensic Sci Int* 158:184–189
20. Widmer WR, Buckwalter KA, Hill MA, Fessler JF, Ivancevich S (1999) A technique for magnetic resonance imaging of equine cadaver specimens. *Vet Radiol Ultrasound* 40:10–14