International Journal of Legal Medicine (2019) 133:1517–1528
https://doi.org/10.1007/s00414-019-02065-6

ORIGINAL ARTICLE

Anatomic shape variants of extremitas sternalis claviculae as collected from sternoclavicular thin-slice CT-studies of 2820 male borderline-adults

Ernst Rudolf[1] · Josef Kramer[2] · Sven Schmidt[3] · Volker Vieth[4,5] · Ingemar Winkler[6] · Andreas Schmeling[3]

Received: 27 February 2019 / Accepted: 5 April 2019 / Published online: 18 May 2019

Abstract
Within medical age assessment practice, the indicator "medial clavicular ossification" constitutes crucial evidence capable of excluding age minority "beyond reasonable doubt" concerning age-disputed individuals doubtfully claiming children's rights during legal procedures. Yet, one of its characteristics affects the morphological variability including a fair amount of downright peculiar appearances. As a result, inexperienced examiners are tempted to classify actually not-assessable formations according to the two established developmental typologies of Schmeling et al. and Kellinghaus et al. being at the same time the most frequent systemic error of age-related clavicular taxation. Since a respective overview appears missing, the study extracts not-assessable shape variants of the medial collar bone from a large sample of 2820 male borderline-adults as seen from thin-slice, sternoclavicular computed tomography. The two already highlighted configurations "more than one, medial, secondary ossification centres" and "medial metaphyseal concavity" are found as the most commonly encountered features impeding reliable delineation of staging criteria. In accordance with previous literature, it is emphasized that "qualified" rating of extremitas sternalis claviculae within age assessment practice presupposes "knowledge about the diversity of [its] anatomic shape variants."

Keywords Medical age assessment · Medial clavicular ossification · Not-assessable shape variants · Computed tomography

Introduction

Within the context of applications for international protection, "assessment of facts and circumstances" regarding the not (reliably) documented identity age-assertion 'unaccompanied minority', which equals the claim to far reaching, legal "guarantees" dedicated to "vulnerable" children "below the age of 18 years" [21, 23], belong to the most difficult issues administrative authorities have to deal with [22, 25, 26, 29]. Due to obvious limitations of the basic procedural means of evidence ("personal interview" [21], observation of appearance/demeanor) and to tackle the problem of intentional age-"misrepresentation" [66, 90], EU-Asylum law offers EU-Member States since 20 years the option of assigning age diagnostic expert opinion in case of doubtful minority allegation [67]. The "reliable" standard of such evidence gathering as asked for in Art. 25 para 5 Asylum Procedure Directive 2013 (APD) is summarized within the recommendations of the international and multidisciplinary "Study Group on Forensic Age Diagnostics" (AGFAD) [21, 73, 74]. Following this acknowledged, methodical "state of the art" [1, 4, 9, 84, 92], the age marker "medial clavicular ossification" (MCO) constitutes the decisive factor due to "a uniquely prolonged period of growth-related activity" [10, 83] leading well beyond the respective age limit. According to relevant reference studies comprising different imaging techniques, its sub-final and final developmental phases are solely found after the completed 18th year of life thus allowing for exclusion of age minority "beyond reasonable doubt" in individuals of

✉ Ernst Rudolf

[1] Attnang-Puchheim, Austria

[2] Institute for CT and MRT Diagnostics, Rainerstr. 6-8, 4020 Linz, Austria

[3] Institute of Legal Medicine, University Hospital Münster, Röntgenstraße 23, 48149 Münster, Germany

[4] Department of Clinical Radiology, University Hospital Münster, Albert-Schweitzer-Campus 1, 48149 Münster, Germany

[5] Clinic for Radiology, Klinikum Ibbenbüren, Große Straße 41, 49477 Ibbenbüren, Germany

[6] Rax-Bergen 27, 8380 Jennersdorf, Austria

both sexes [74, 77–79, 94, 99]. To display the anatomic site as accurately as possible, AGFAD-recommendations suggest the use of the imaging modality "sternoclavicular computed tomography" (CT) [73, 74].

Yet, the medial clavicular ossification site is prone to significant shape deformations affecting medial metaphyseal ending as well as the medial, secondary ossification process. Such characteristic not rarely renders categorization in line with the two accepted typologies of Schmeling et al. and Kellinghaus et al. difficult, which term its developmental metamorphosis towards adult state [44, 45, 72]. Accordingly, Wittschieber et al. proved that "an inexperienced examiner, who is unaware of the diversity of variants of the medial clavicular epiphysis, apparently tends to classify more cases than actually possible" coincidently being recognized as the most frequent systemic error of age-related clavicular evaluation [96]. Since a respective overview appears missing, our survey sums up not-assessable shape variants of the medial clavicle from a large sample to support expert's distinction between assessable variations of ideal typical stage norms vs. not-assessable deformations.

Materials and methods

The results of our trial are drawn from the clavicular pairs of 2820 age-disputed, male "unaccompanied minor asylum seekers" allocated consecutively to our interdisciplinary work group for medical age assessment between July 2011 and September 2018 by the "Austrian Federal Office for Immigration and Asylum" and the "Austrian Administrative Court" based on § 2 para 25 Austrian Asylum Act and § 13 para 3 BFA-Procedural Law having completely implemented the provisions of Art. 25 para 5f APD 2013 and of Art. 22 Radiation Protection Directive 2013 [2, 3, 21, 24]. In all cases, the methodological dicta of AGFAD-recommendations were observed as demanded expressis verbis by Austrian Asylum law since 2010 [73]. As the phenomenon "doubtful unaccompanied minority assertion" within asylum procedures shows male predominance by 90% and for the sake of a homogenous sample, we did not enclose females into our study. The inclusion criteria of our test are provided in Table 1.

In line with EU asylum statistics, over 90% of our trial reported six countries of origin [27, 28]. However, individuals from Afghanistan (1889, 66.99%), Nigeria (287, 10.18%), and Somalia (207, 7.34%) accounted for over $^{5}/_{6}$ of the sample (Table 2), which clearly limits the significance of results concerning the other three mentioned source countries due to low numbers of observed clavicles (Pakistan, Gambia, Algeria).

Multidetector computed tomography (MDCT) studies of sternoclavicular regions were obtained using a 16-row MDCT system (SomatomSensation 16, Siemens Medical Solutions) with the technical settings: 130 kV, mAs values by using CareDose, Pitch 1, collimation 0.6, recon increment 1.0, Kernel B60s, SL 1 mm. Images were viewed as axial (ax) sections and coronal (cor) reconstructions depicting extremitas sternalis claviculae (ESC) as two frame-stripes of anterior/posterior and cranial/caudal orientation. Illustrations were gauged on screen of a diagnostic workstation with Siemens software (SyngoSomaris 5VB20B) by two examiners operating on longstanding experience of classifying MCO within the context of medical age assessment [96, 100]. We always drew our observations from all CT-slices of each case [100], since the slightly oblique position of the clavicle relative to ax and cor CT-sections together with the non-geometric character of the medial, clavicular shape [57] as well as secondary, medial calcification result on a regular basis in heterogenic ESC-profiles (Fig. 1). In addition, we made use of 3D-rendering software provided by Siemens as additional CT-data presentation in about 200 cases, because such visualization may facilitate recognition of complex surface morphologies including soft tissue calcifications, both of which are sometimes difficult to understand from ax and cor CT-sections [68].

Table 1 Inclusion criteria of our sample in line with [21, 73]

≻ Within the administrative asylum procedure purported and not (reliably) documented identity trait "unaccompanied minority" appearing "doubtful" from "personal interview", appearance/demeanor or "alias"-identities
≻ Male sex
≻ Anamnesis and physical examination revealing no disorders and medications possibly intermingling with somatic development
≻ No trauma concerning medial clavicles, neither from anamnesis/physical examination nor CT-topograms
≻ Completed epi-/metaphyseal fusion of distal forearm/hand skeleton as seen from a standard hand-x-ray

We differentiated medial clavicular advents according to the two complementary typologies of Schmeling et al. (main stages 1 to 5) and Kellinghaus et al. (sub stages 2a–2c, 3a–3c) [44, 45, 72]. As not-assessable anatomic shape variants, we defined appearances offering obscured representations of the eponymous morphological criteria for stage attribution (Table 3) [100]. Specific features like deep rhomboid fossa usually not touching the medial ossification site [58], polygonal epiphyseal ossification reliefs being frequently encountered (Fig. 2) [95] and partly fused, yet small epiphyses [98] were not considered as such. CT-series infringed by motion artifacts plus rare cases of Allman III fractures and exostotic alterations of the medial clavicle were excluded [14, 39]. We did not see congenital malformations [52, 81], clinical testing never revealed dysfunction of shoulder/arm movements in any of our included cases.

Table 2 Numbers (n) of included individuals (Ind) and resulting single ESC (sc), of individuals with anomalies (Ind + anom) separated into bilateral (Ind + bianom) and unilateral anomalies (Ind + unianom) plus respective ratios per main reported countries of origin (CoO)

	Afghanistan	Nigeria	Somalia	Pakistan	Gambia	Algeria	Others	Σ/%
n	1889	287	207	69	62	53	253	2820
% sample	66.99	10.18	7.34	2.45	2.20	1.88	8.97	100.00
Ind + anom	371	72	26	17	14	12	54	566
% CoO	19.64	25.09	12.56	24.64	22.58	22.64	21.34	20.07
Ind + bianom	152	33	13	5	6	9	22	240
% Ind + anom	40.97	45.83	50.00	29.41	42.86	75.00	40.74	42.40
Ind + unianom	219	39	13	12	8	3	32	326
% Ind + anom	59.03	54.17	50.00	70.59	57.14	25.00	59.26	57.60
n sc	3778	574	414	138	124	106	506	5640
n sc anom	523	105	39	22	20	21	76	806
% n sc	13.84	18.29	9.42	15.94	16.13	19.81	15.02	14.29

In the past, two general ESC-appearances were labeled as not-assessable shape variants, a metaphyseal trait and an epiphyseal one [96, 100]:

- Medial metaphyseal concavities (<MMC>) equalling a substantial loss of subchondral bone structure inside the medial cortical tube of various form, extent and depth (metaphors from 2D-imaging: "fish-mouth", "wrench", "bowl", "funnel", etc.
- More than one, medial, endochondral, secondary ossification centers unconnected to each other in all of the multiple CT-sections of ax and cor picture planes (syn. "multiple epiphyseal ossification centres", <MEOC>).

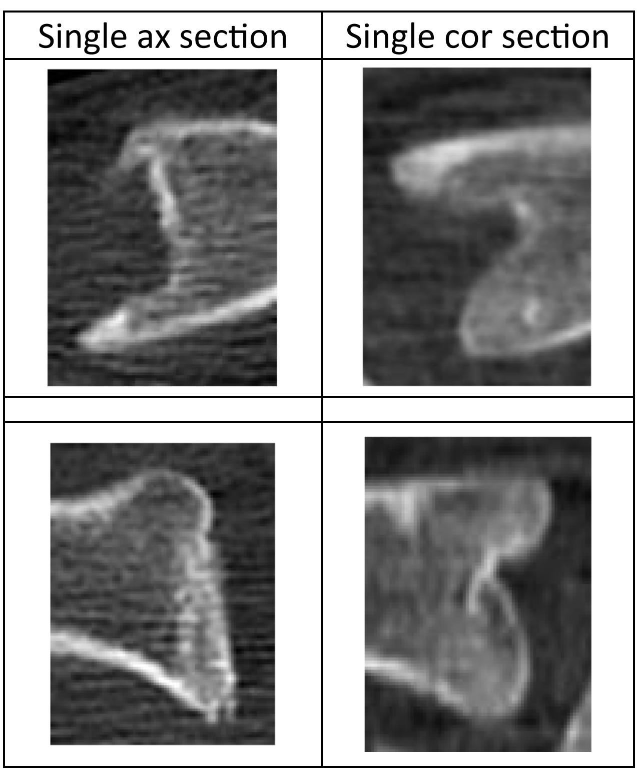

Fig. 1 Two examples of <MMC> with differing aspects in axial and coronal sections due to the non-geometric character of ESC

Proceeding from that, we built a typological template with standardized descriptions of these two generic features and its varieties ranking those as "type A" (<MMC>) and "type B" (<MEOC>) (Table 4). In a subsequent step, we integrated all 2820 cases into an IT-database, whose registry contained case-information (identification-number, reported country of origin, date of investigation, body side of anomaly), furthermore linking the entries straight to the individual CT-presentations for repeated evaluation and fast comparison. Finally, we crosschecked atypical ESC-appearances of our trial with the records of the initial

Table 3 Morphological structures of medial clavicular ossification relevant for stage attribution in line with [44, 45, 73, 100]

- Medial, metaphyseal ending unimpeded by substantial deficiency of subchondral bone structure inside the cortical tube
- A more or less contrasted, single, medial, endochondral, secondary ossification center with or without medial "cortical density," an epiphyseal characteristic highlighted by Kreitner et al. [47, 102]
- A not contrasted (cartilaginous) space between medial, clavicular metaphysis and a single, medial, endochondral, secondary ossification center (growth gap)
- One or more, smaller or wider, osseous epi-/metaphyseal bridging crossing the physis
- A thin line of higher density representing the border area in case of completed epi-/metaphyseal fusion [38], a formation being labeled as "scar" by Wolff [101]

Fig. 2 Example of an ESC-face with single, partly fused, map-like, medial, secondary ossification structure next illustrations of more than one epiphyseal kernel in cases without metaphyseal concavities as seen from 3D-renderings (type B)

template to qualify and quantify respective formations. As a result, we added a "type C" comprising further anomalies.

Results

Our sample consisted of 2820 male borderline adults (Table 2), out of which 240 individuals (8.51%) presented bilateral anomalies and 326 (11.56%) unilateral ones (Σ_{tot} = 566, 20.07%). One hundred fifty-six persons (65% of 240) with bilateral anomalies showed the same typus both sided (Fig. 3) and 84 (35%) divergent ones. One hundred seventy (52.15% of 326) unilateral deformations were found on the right side and 156 (47.85%) on the left one vis-à-vis to all nine regular types of MCO-classification from stage 1 down to stage 5. Altogether, from 5640 (= 2 × 2820) observed single ESC 806 (= 2 × 240 + 326, 14.29%) anatomic shape variants were extracted, distributed as almost equal numbers between the ESC-antimeres (Table 4). Hence, we saw no lateral preference regarding formation of anomalies [69, 70].

Table 4 Typological template of not-assessable shape variants of the medial clavicle (n number, R right, L left, ax axial plane, cor coronal plane)

Type	Standardized description	Questionable stage impression	nR	nL	Σ	%
A	ESC-concavity					
A.1	Large ESC-concavity comprising > $^1/_3$ of the metaphyseal diameter in at least one of ax ± cor sections					
A.1.1	Without detectable epiphyseal-like structure	1 vs 5	21	32	53	6.58
A.1.2	With single epiphyseal-like structure					
A.1.2.1	With single thin epiphyseal-like structure					
A.1.2.1.1	Unfused (missing fusion zones)	2	5	6	11	1.36
A.1.2.1.2	partly fused (fig. 3)	3	82	78	160	19.85
A.1.2.1.3	Fused (detectable "scar"-like structure)	4	2	4	6	0.74
A.1.2.2	With single embedded epiphyseal-like structure					
A.1.2.2.1	Unfused (missing fusion zones)	2	5	6	11	1.36
A.1.2.2.2	partly fused (Fig. 7)	3	19	14	33	4.09
A.1.2.2.3	Fused (detectable "scar"-like structure)	4	1	2	3	0.37
A.1.3	With >1 epiphyseal-like structures	2.3	17	15	32	3.97
$\Sigma_{A.1}$			152	157	309	38.34
A.2	Small ESC-concavity never exceeding ≤ $^1/_3$ of the metaphyseal diameter in all ax/cor sections					
A.2.1	Without detectable epiphyseal-like structure (Fig. 8)	1 vs 5	8	6	14	1.74
A.2.2	With single epiphyseal-like structure					
A.2.2.1	unfused (missing fusion zones)	2	2	0	2	0.25
A.2.2.2	partly fused	3	13	22	35	4.34
A.2.2.3	Fused (detectable "scar"-like structure)	4	0	2	2	0.25
A.2.3	With > 1 epiphyseal-like structures	2.3	11	6	17	2.11
$\Sigma_{A.2}$			34	36	70	8.68
B	More than one epiphyseal kernels detectable without ESC-concavity					
B.1	2 epiphyseal kernels (Fig. 2)	2.3	172	157	329	40.82
B.2	3 epiphyseal kernels [68]	2.3	24	15	39	4.84
B.3	> 3 epiphyseal kernels (Figs. 2 and 6)	2.3	2	5	7	0.87
Σ_B			198	177	375	46.53
C	Other irregularities (Figs. 5 and 6)		26	26	52	6.45
Σ_{tot}			410	396	806	100.00

Two generic topics dominated our overview by far (93.55%) adding up to 375 (46.53%) single clavicles with <MEOC> and 330 (40.94%) <MMC> (Table 4). In addition, we saw 49 (6.08%) combinations of these two leading features and also associations of large and small concavities within one and the same ESC, the latter being listed under A.1 (Fig. 4). Two entries of our template accounted for 60% (type B.1, 40.82%, Fig. 2; type A.1.2.1.2, 19.85%, Fig. 3). Fifty-two (6.45%) shape variants refused fitting into the two main categories A and B and were listed as "type C," which also contains unusual examples of suspected calcified articular capsules (Figs. 5 and 6) [5, 96, 100].

Regarding the incidence of single, medial, clavicular deformations, the main reported source countries of our clientele offered different rates. Individuals from Algeria and Nigeria showed the relatively highest counts of aberrations from the norm (18–19%) and Somalia the lowest (9.42%) with Gambia, Pakistan, and Afghanistan ranging in between (Table 5). Furthermore, we saw differing tendencies as to which anomalies were found predominantly per reported source country. For example, individuals from Somalia and Algeria presented comparatively small numbers concerning the most prominent type B.1 of our template. On the other hand, persons from Nigeria showed counts of the second most type A.1.2.1.2 below average and those from Algeria above it. Our additional type C was found mainly in people from

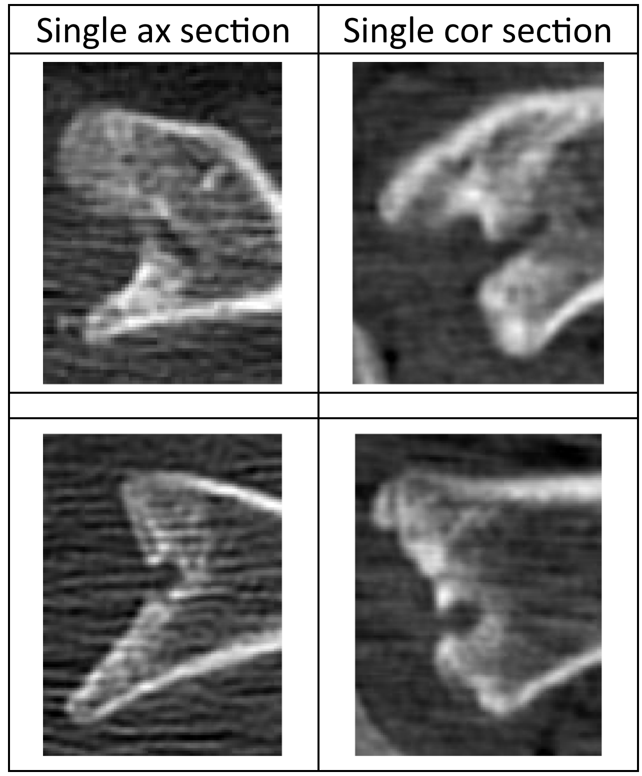

Fig. 4 Two examples comprising combinations of large and small concavities

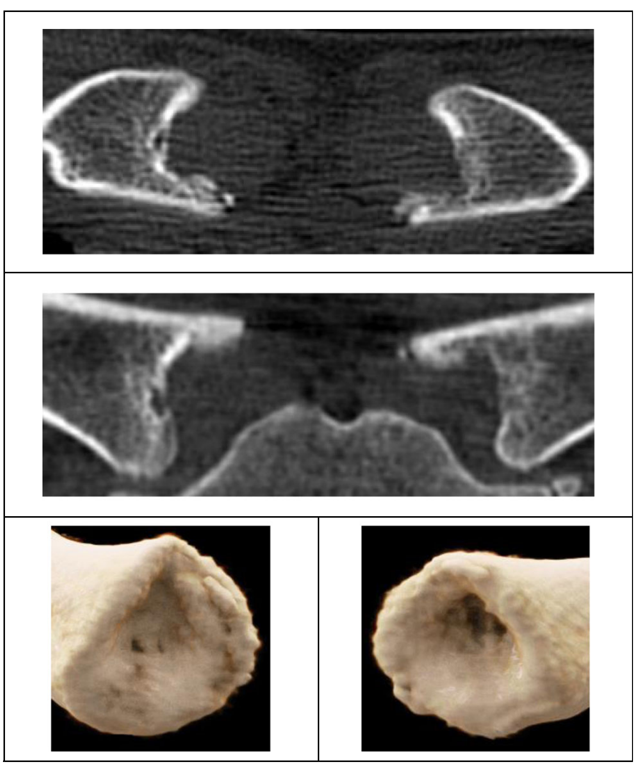

Fig. 3 Bilaterally deformed, medial collar bones with metaphyseal excavations and thin, epiphyseal-like structures (type 1.2.1.2)

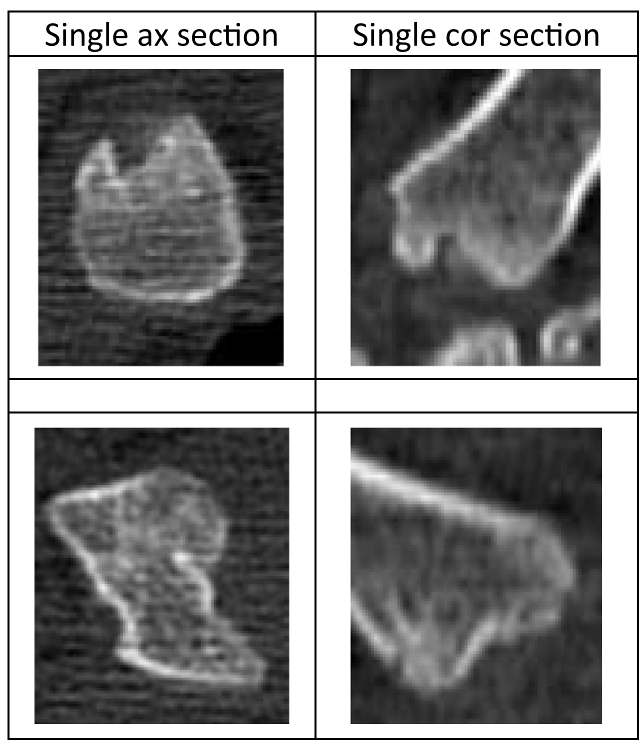

Fig. 5 Two ESC-appearances not allowing for outlining staging criteria according to [44, 45, 73, 100] (type C)

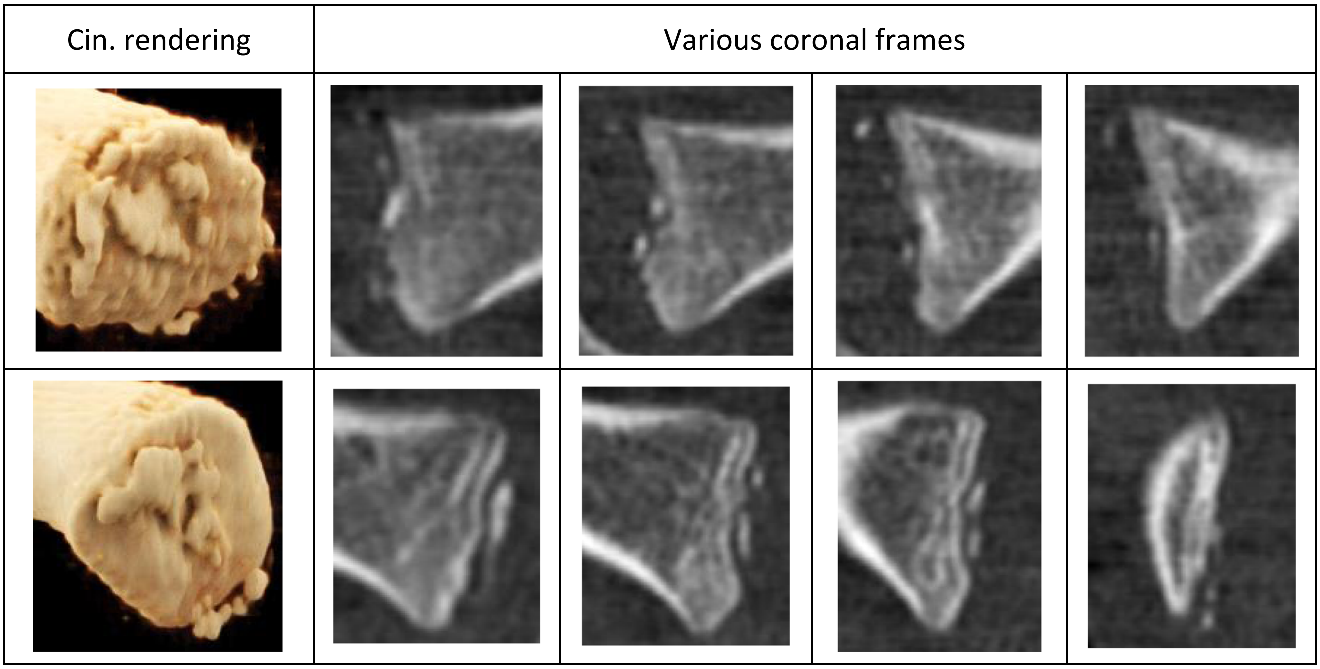

Fig. 6 Suspected calcinations of the articular capsule following in part the metaphyseal contour next <MEOC> as seen from coronal sections and "cinematic rendering"

Nigeria and Algeria and not at all in those from Pakistan and Gambia (Table 5).

Discussion

Peculiar morphologies of ESC have "always been known to anatomists and radiologists" [63]. In particular, the extraordinary looks of medial, clavicular concavities attracted regular attention and are described in literature as geode [15], subchondral sclerosis [5] or erosion [51, 87], wrench- [56], bowl- [96], dish- [30, 79] or chalice-like [46], fossa-like [77] or fish mouth depression [63], bifid- [15, 16], funnel- [78], trumpet- [41] or V-shaped [57], caved-in sternal end [61], cupped medial clavicular end [49], or fork deformity [82]. Early referrals are found. e.g.. in Stevenson, Todd/D'Errico, Flecker, Ravelli, Fischer, McKern/Stewart, Teplick et al., Jit/Kulkarni, Owings Webb/Myers Suchey, Kumar et al., Schmidt/Freyschmidt, and Keats/Anderson 1996 [30, 31, 42, 43, 49, 53, 57, 63, 75, 83, 87, 88]. Also, <MEOC> in the region of ESC have been mentioned since long [30, 50, 65, 75, 91, 95].

In recent literature concerning forensic age assessment, ESC-appearances deviating from the norm are addressed repeatedly and examples are displayed occasionally. Initially, Kreitner et al. mentioned in their CT-pilot study "the persistence of the medial epiphyseal ossification center [as] the only possible diagnostic pitfall "in evaluating MCO for age assessment purposes [30, 48]. As early as 2004, Schmeling et al. and Schulz et al. saw in "norm variants (in particular funnel-shaped clavicular epiphyses) "one of the major reasons challenging reliable ESC-classification [72, 78]. On the contrary, Schulze et al. did not refer to shape variants of the medial clavicle [80]. Butting 2008 mentioned the possibility of <MEOC> [12]. Depictions of an ossified epiphyseal kernel embedded into a medial, metaphyseal concavity as seen from different imaging modalities are shown in Vieth et al. 2010 [93]. In 2011, Garamendi et al. illustrated a "fish mouth

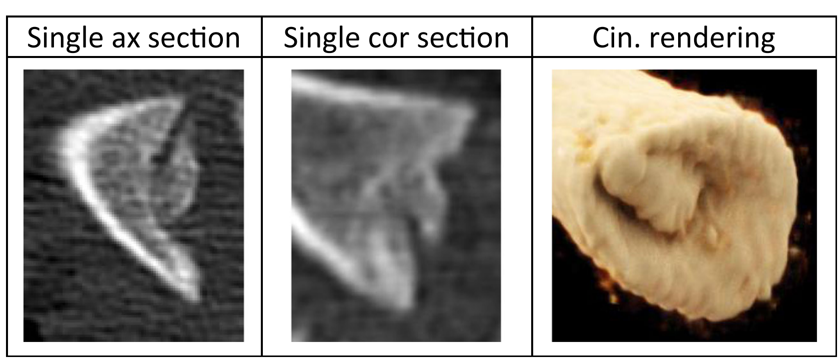

Fig. 7 Partly fused, single epiphysis embedded in metaphyseal cavity forming sometimes more or less a "trident" resemblance in certain slices (type 1.2.2.2)

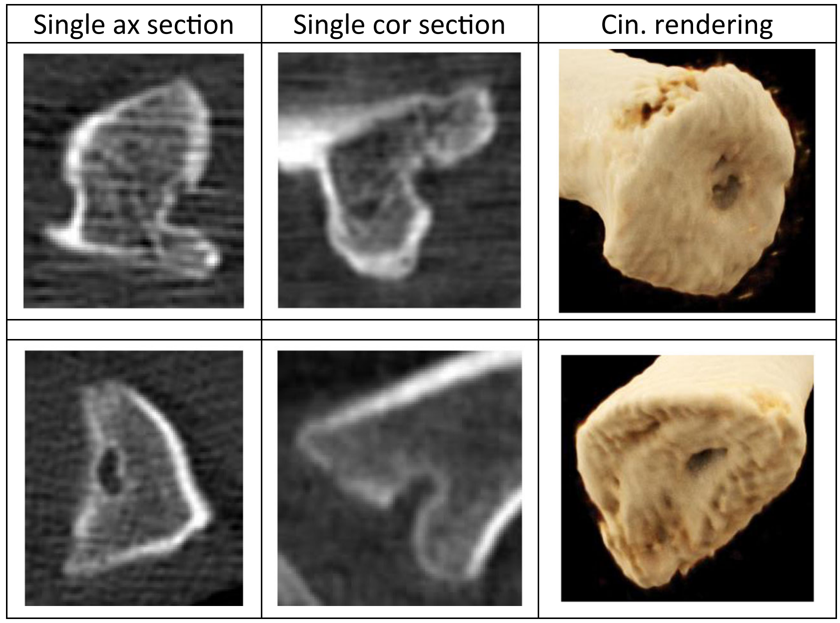

Fig. 8 Two examples of small ESC-concavities without detectable epiphyseal-like structure sometimes pretending a cyst in certain frames (type 2.1)

anomaly" interestingly understood as a risk of "underestimation of the stage of development of the medial epiphyses of the clavicle, if investigators are not aware of the possible existence of this abnormality" [33]. Examples of fish mouth, bowl, and trident buildings are presented by Brinkmeier and Küppers; "concaaf" and "bifid" appearances of medial clavicles are provided by De Meulenaere [11, 16, 50]. Milenković displayed peculiar ESC as preserved specimens, and Ottow et al. MRI-based pictures of fish mouth, bowl-like, and wrench-like buildings [54, 56]. Gonsior pointed out that "alone on the grounds of barely possible identification of norm variants, the suitability of sonographic determination of ossification state of the medial clavicle has to be critically considered" [34].

In 2012, Cameriere et al. stated that "deficient knowledge of normal morphological variants becomes crucial while differentiating between normal and abnormal shape" [13]. Wittschieber et al. proved that an inexperienced examiner is tempted to classify actually not-assessable ESC-appearances being described as "bowl- or funnel-like shape variants" [96]. Such study result is corroborated by Tangmose et al. [85, 86], El Morsi et al. [19], De Meulenaere [16], and Richel [64], all

Table 5 Numbers (n) and percentages of single ESC-anomalies according to the typological template per main reported countries of origin

Type	Afghanistan (n/%)	Nigeria (n/%)	Somalia (n/%)	Pakistan (n/%)	Gambia (n/%)	Algeria (n/%)	All (n/%)
	523	105	39	22	20	21	806
A.1.1	5.74	5.71	10.26	0.00	10.00	19.05	6.58
A.1.2.1.1	1.15	1.90	2.56	0.00	0.00	0.00	1.36
A.1.2.1.2	21.22	12.38	23.08	18.18	5.00	28.57	19.85
A.1.2.1.3	0.96	0.00	0.00	0.00	0.00	0.00	0.74
A.1.2.2.1	1.53	0.00	0.00	4.55	0.00	0.00	1.36
A.1.2.2.2	5.16	0.00	2.56	4.55	5.00	0.00	4.09
A.1.2.2.3	0.38	0.95	0.00	0.00	0.00	0.00	0.37
A.1.3	4.02	5.71	7.69	0.00	0.00	0.00	3.97
A.2.1	0.57	4.76	5.13	0.00	5.00	0.00	1.74
A.2.2.1	0.19	0.00	0.00	0.00	0.00	0.00	0.25
A.2.2.2	4.21	4.76	7.69	9.09	5.00	4.76	4.34
A.2.2.3	0.38	0.00	0.00	0.00	0.00	0.00	0.25
A.2.3	2.87	0.95	0.00	0.00	0.00	4.76	2.11
B.1	42.26	42.86	30.77	50.00	60.00	23.81	40.82
B.2	3.63	8.57	5.13	13.64	5.00	4.76	4.84
B.3	0.76	0.95	0.00	0.00	5.00	0.00	0.87
C	4.97	10.48	5.13	0.00	0.00	14.29	6.45
Σ (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 6 Thin-slice CT studies addressing medial clavicular development

Authors	Staging systems	No. of cases with not-assessable appearances per sample-size (♀ and ♂)	Comments
Patil et al. [59]	Main	?/462 cases (final sample)	Ossification patterns unclassifiable hence were excluded
Ramadan et al. [62]	Main/sub	107(?)/859 cases (12.45%)	Developmental abnormalities (?, 37) and anatomic shape variants (107)
Gunawardena et al. [35]	Main/sub	13 (final sample)	Shape variants not mentioned
Gurses et al. [37]	Sub	61(?)/? cases	Patients with developmental abnormalities (?, 9 cases). A total of 74 patients with anatomical shape variants (61 cases,?)
Gurses et al. [36]	Main/sub	131(?)/1041 cases (12.58%)	Developmental abnormalities (?, 20) and anatomic shape variants (131)
Houpert et al. [40]	Main/sub	?/319 cases (final sample)	Variants of physeal configuration were excluded
Ufuk et al. [89]	Divergent	8/354 cases (2.26%)	We did not specifically assess the anatomic shape variants and encountered some challenges during the evaluation … anatomic variations ($n = 8$, 2.3%)
Franklin/Flavel [32]	Main	55(?)/388–333 (initial/final sample)	Exclusions were most commonly made on the basis of anatomical shape variants associated with the medial end (e.g. “bowl-like” or “fish-mouth-like” variants)
Pattamapaspong et al. [60]	Main/sub	8/417 (1.9%)	Eight of the 417 patients (1.9%) had ossification patterns that were unclassifiable and have been excluded from the study
El Morsi et al. [19]	Main	142 (final sample)	Shape variants not mentioned
Zhang et al. [103]	Main	?/752 (final sample)	Cases were excluded due to cases of normal variation (e.g., funnel-shaped clavicular epiphyses)
Wei et al. [95]	VRI	?/795 (final sample)	Epiphyses with norm variants (bowl, fish mouth, multiple ossification centers) were excluded from 795 CT examinations(?)
Wittschieber et al. [97], Scharte et al. [71]	Main/sub	180/539 × 2 = 1078 single clavicles (16.69%)	79 (of 572) cases had to be excluded for the following reasons: first, the bilateral presence of anatomic shape variants and second, missing or doubtful information about sex or age (Scharte et al.: 33). Only one clavicular side was assessable in 73 of the assessable male cases, and in 15 of the assessable female cases, because of a not-assessable anatomic shape variant on the other side (= 88)
Ekizoglu et al. [17]	Sub	11/573 (1.9%)	Bilateral presence of anatomical shape variation (11 cases)
Ekizoglu et al. [18]	Sub	503 (final sample)	Referral to Wittschieber et al. 2014, otherwise shape variants not mentioned
El-Gerby et al. [20]	Main	130 (final sample)	Shape variants not mentioned
Zhao et al. [104]	Main	565 (final sample)	Shape variants not mentioned
Tangmose et al. [85]	Main	1/47 (2.1%)	By CT, one subject was assessed as “unable to score” due to bilateral developmental variants
Bassed et al. [8]	Main	604 (final sample)	Shape variants not mentioned
Bassed et al. [6]	Main	605 (final sample)	Shape variants not mentioned
Bassed et al. [7]	Main	674 or 670 (final sample)	Shape variants not mentioned
Kellinghaus et al. [45]	Main	90(?)/592 (Initial sample)	In 90 cases (15.2%), a reliable assessment of the ossification status was not possible owing to fractures of the clavicle, beam-hardening artifacts from contrast medium, movement artifacts or variants of normality (in particular, funnel-shaped clavicular epiphyses)

Three studies mention “developmental abnormalities” next to “anatomic shape variants”, both of which may fall under the category “not-assessable shape variants” of which illustrate and stage obvious cases of <MMC>. Accordingly, Wittschieber et al. concluded that reliable ESC-scoring directly depends on “high degree of specific qualification, particularly the knowledge about the diversity of anatomic shape variants,” [96] a statement that was repeated and referred to by Franklin/Flavel and Gurses et al. [32, 36].

Concerning the incidence of atypical MCO-formations, we experienced difficulties comparing our results with most thin-slice CT-studies, since those often do not deliver the number of anomalies per observed single ESC (Table 6). Furthermore, studies like Ufuk et al., Tangmose et al., and Pattamapaspong et al. report astonishingly low counts [60, 85, 89]; others like Patil et al. and Houpert et al. avoid designating figures of “unclassifiable ossification patterns” altogether [40, 59]. Still others, like El Morsi et al., El-Gerby et al., and Bassed et al. do not even mention this important ESC-characteristic seemingly oblivious of the impediment (Milenkovic et al.: “possible inadmissible stage evaluation of anatomic shape variants“) [6–8, 19, 20, 55].

However, we found our outcome consistent with reliable results so far transmitted. Kellinghaus et al. reported that within their trial, an assessment of the “ossification status was not possible” in 90 (15.2%) out of 592 cases “owing to [amongst other] variants of normality (in particular, funnel-shaped clavicular epiphyses)” [45]. Wittschieber et al. and Scharte et al. both elaborating on the same sample counted 180 anomalies out of 1078 single clavicles (16.69%) [71, 97]. Vieth et al. excluded 20% of MRI-based ESC-imaging from stage classification because of “norm variants [appearing as] fish mouth form, bowl form, trident form and multiple ossification centres” (61/304 single clavicles) [94]. Schmidt et al. and Schmidt et al. had to ignore 8.1% and 14.8%, respectively, of their MRI-samples, because of (among other) “unclassifiable anatomical variants (e.g., bowl-like shape) “of ESC [76, 77].

Regarding our typology of not-assessable shape variants, we did not intend to describe the morphological variability of MCO in general. Instead, we aimed at questionable stage impressions arising from deviations of the norm, which are referred to in an additional column of the template (Table 4). To that end, we concentrated on the two primary topographies <MEOC> and <MMC> already mentioned before, which dominated our summary by over 90% appearing therefore most important for MCO-distinction as “assessable” vs. “not-assessable.” Upon encountering such features, a further morphological description of the site is not required within age assessment practice. For example, concerning <MEOC>, it is not necessary to count the number of epiphyses and to consider the metaphyseal shape. The judgment suffices that medial clavicular cartilage contains more than one to refrain from proceeding towards MCO-classification. Accordingly, we did not observe epi-/metaphyseal relationships at the sight of more than one epiphysis, apart from difficulties to distinguish small, partly, or completely fused kernels from a ragged metaphyseal ending. Likewise, in case of substantial <MMC> valuation of medial, secondary ossification seems dispensable. Beyond <MEOC> and <MMC>, Wittschieber et al. highlighted the importance of specific staging criteria to categorize a certain MCO-appearance [100].

Conclusions

The medial, clavicular ossification site shows considerable morphological diversity in borderline adults reaching sometimes extreme deformations. Depending on the source countries of observed male individuals, in about 10–20% of evaluated, single, medial clavicles not-assessable shape variants have to be expected within medical age assessment practice.

We could confirm that variations of the already denoted anomalies “more than one, medial, secondary ossification centres” and “ESC-concavities” are by far the most common ones. These two generic features plus further erratic ones carry in common the impossibility to reliably outline the leading criteria for comprehensible MCO-classification.

An inexperienced examiner is tempted to draw questionable stage impressions from anatomic shape variants constituting the major systemic error of MCO-scoring. Accordingly, reliability of ESC-evaluation within medical age assessment practice directly depends on “high degree of specific qualification”, part of which is “knowledge about the diversity of anatomic shape variants” [96], a requirement accentuated by Art. 25 para 5 APD demanding that age-related “medical examinations shall be carried out by qualified medical professionals” [21].

Acknowledgments The authors would like to thank Herr A. Böhm from “Siemens Healthineers Austria” for suggesting 3D-“cinematic rendering” by means of syngo.via® software, which allows for viewing photorealistic, plastic renditions of ESC-appearances, and Mrs. Liu Ping for translating [104].

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Administrative High Court Bremen 04.06.2018, 1 B 82/18
2. Austrian Asylum Act: https://www.ris.bka.gv.at/GeltendeFassung/Bundesnormen/20004240/AsylG%202005%2c%20Fassung%20vom%2015.08.2017.pdf. Access date: 15.02.2019
3. Austrian BFA-Procedural Law: https://www.ris.bka.gv.at/GeltendeFassung/Bundesnormen/20007944/BFA-VG%2c%20Fassung%20vom%2001.01.2014.pdf?FassungVom=2014-01-01. Access date: 15.02.2019

4. Austrian Supreme Court 08.11.2017, 21 Bs 309/17w
5. Baker ME, Martinez S, Kier R, Wain S (1988) High resolution computed tomography of the cadaveric sternoclavicular joint: findings in degenerative joint disease. J Comput Tomogr 12(1): 13ff. https://doi.org/10.1016/0149-936X(88)90022-7
6. Bassed RB, Briggs C, Drummer OH (2011) Age estimation using CT imaging of the third molar tooth, the medial clavicular epiphysis, and the spheno-occipital synchondrosis: a multifactorial approach. Forensic Sci Int 212(1-3):273.e1ff. https://doi.org/10.1016/j.forsciint.2011.06.007
7. Bassed RB, Briggs C, Drummer OH, Valenzuela A (2011) Age estimation and the medial clavicular epiphysis: analysis of the age of majority in an Australian population using computed tomography. Forensic Sci Med Pathol 7(2):148ff. https://doi.org/10.1007/s12024-010-9200-y
8. Bassed RB, Briggs C, Drummer OH (2012) The incidence of asymmetrical left/right skeletal and dental development in an Australian population and the effect of this on forensic age estimations. Int J Legal Med 126(2):251ff. https://doi.org/10.1007/s00414-011-0621-2
9. Bavarian Administrative High Court, 23.09.2014, 12 C 14.1865
10. Black S, Scheuer L (1996) Age changes in the clavicle: from the early neonatal period to skeletal maturity. Int J Osteoarchaeol 6(5): 425ff. https://doi.org/10.1002/(SICI)1099-1212(199612)6:5
11. Brinkmeier PAW (2013) Altersdiagnostik bei U20-Fußballspielern durch prospektive Untersuchung der Ossifikation der medialen Claviculaepiphyse im 3 T – MRT. Thesis University Münster
12. Butting H (2008) Die Computertomographisch ermittelte Ausreifung der medialen Claviculaepiphyse als Untersuchungsmethode der Lebensaltersbestimmung. Thesis University Hamburg
13. Cameriere R, De Luca S, De Angelis D (2012) Reliability of Schmeling's stages of ossification of medial clavicular epiphyses and its validity to assess 18 years of age in living subjects. Int J Legal Med 126(6):23ff. https://doi.org/10.1007/s00414-012-0769-4
14. Carrol MB (2011) Sternoclavicular hyperostosis: a review. Ther Adv Musculoskelet Dis 3(2):101ff. https://doi.org/10.1177/1759720X11398333
15. De Maeseneer M, Lenchik L, Buls N et al (2016) High-resolution CT of the sternoclavicular joint and first costochondral synchondrosis in asymptomatic individuals. Skelet Radiol 45(9): 1257ff. https://doi.org/10.1007/s00256-016-2414-7
16. De Meulenaere A (2012) Radiological evaluation of the clavicula for determination of skeletal age: deepening morphology and classification. Thesis University Gent
17. Ekizoglu O, Hoçaoglu E, Inci E et al (2015) Estimation of forensic age using substages of ossification of the medial clavicle in living individuals. Int J Legal Med 129(6):1259ff. https://doi.org/10.1007/s00414-015-1234-y
18. Ekizoglu O, Hoçaoglu E, Inci E et al (2015) Forensic age estimation by the Schmeling method: computed tomography analysis of the medial clavicular epiphysis. Int J Legal Med 129(1):203ff. https://doi.org/10.1007/s00414-014-1121-y
19. El Morsi DA, El-Atta HMA, El-Maadawy M et al (2015) Age estimation from ossification of the medial clavicular epiphysis by computed tomography. Int J Morphol 33(4):1419ff. https://doi.org/10.4067/S0717-95022015000400038
20. El-Gerby KM, Mohammad AS, Gomaa MS (2013) Using thin-slice multidetector computed tomography in forensic age estimation based on the ossification status of the medial clavicular epiphysis among Egyptian subjects. Med J Cairo Univ 81(2):221ff
21. EU-"Asylum Procedure" Directive 2013/32/EU (26.06.2013)
22. EU-"Family Reunification" Directive 2003/86/EC (22.09.2003)
23. EU-"Qualification" Directive 2011/95/EU (13.12.2011)
24. EU-"Radiation Protection" Directive 2013/59/EURATOM (05.12.2013)
25. EU-"Returning" Directive 2008/115/EC (16.12.2008)
26. EU-„Dublin III" Regulation 604/2013 (26.06.2013)
27. European Asylum Support Office – EASO (2012–2018) Newsletters: https://www.easo.europa.eu/news-events/newsletters-archive. Access date: 15.02.2019
28. European Border and Coast Guard Agency – Frontex (2011–2018) Risk analysis network quarterly reports: http://frontex.europa.eu/publications/. Access date: 15.02.2019
29. European Migration Network (2018) Approaches to Unaccompanied Minors Following Status Determination in the EU plus Norway: https://www.emn.at/wp-content/uploads/2018/07/emn-synthesis-report-2018_-unaccompanied-minors-following-status-determination.pdf. Access date: 15.02.2019
30. Fischer E (1957) Persistierende Klavikulaapophyse. Fortschr Röntgenstr 86(4):532f. https://doi.org/10.1055/s-0029-1213187
31. Flecker H (1932) Roentgenographic observations of the times of appearance of epiphyses and their fusion with the diaphyses. J Anat 67(1):118ff
32. Franklin D, Flavel A (2015) CT evaluation of timing for ossification of the medial clavicular epiphysis in a contemporary Western Australian population. Int J Legal Med 129(3):583ff. https://doi.org/10.1007/s00414-014-1116-8
33. Garamendi PM, Landa MI, Botella MC, Alemán I (2011) Forensic age estimation on digital X-ray images: medial epiphyses of the clavicle and first rib ossification in relation to chronological age. J Forensic Sci 56(Suppl 1):S3ff. https://doi.org/10.1111/j.1556-4029.2010.01626.x
34. Gonsior M (2017) Die Ossifikation der medialen Klavikulaepiphyse in der forensischen Altersdiagnostik zur Feststellung der Vollendung des 21. Lebensjahres – Sonografische Beurteilung und morphologische Ursachen für Differenzen zur Computertomografie und Makroskopie. Thesis University Gießen
35. Gunawardena SA, Liyanage UA, Weeratna JB et al (2017) Forensic age estimation in anti-piracy trials in Seychelles: experiences and challenges faced. Forensic Sci Int:270, 278.e1ff. https://doi.org/10.1016/j.forsciint.2016.11.010
36. Gurses MS, Inanir NT, Gokalp E et al (2016) Evaluation of age estimation in forensic medicine by examination of medial clavicular ossification from thin-slice computed tomography images. Int J Legal Med 130(5):1343ff. https://doi.org/10.1007/s00414-016-1408-2
37. Gurses MS, Inanir NT, Soylu E et al (2017) Evaluation of the ossification of the medial clavicle according to the Kellinghaus substage system in identifying the 18-year-old age limit in the estimation of forensic age - is it necessary. Int J Legal Med 131(2):585ff. https://doi.org/10.1007/s00414-016-1515-0
38. Heiß H (1922) Untersuchung über die Epiphysennarbe des menschlichen Skeletts. Archiv Entwicklungsmechanik der Organismen 50(3-4):375ff
39. Holder J, Kolla S, Lehto S (2017) Clavicle fractures: Allman and Neer classification. J Adv Radiol Med Image 2(1):1ff. https://doi.org/10.15744/2456-5504.2.102
40. Houpert T, Rérolle C, Savall F et al (2016) Is a CT-scan of the medial clavicle epiphysis a good exam to attest to the 18-year threshold in forensic age estimation. Forensic Sci Int 260: 103.e1ff. https://doi.org/10.1016/j.forsciint.2015.12.007
41. Inthasan C, Mahakkanukrauh P (2017) Age estimation from clavicle by histomorphometry method: a review. Med Health 12(1): 4ff. https://doi.org/10.17576/MH.2017.1201.02
42. Jit I, Kulkarni M (1976) Times of appearances and fusion of epiphysis at the medial end of the clavicle. Indian J Med Res 64(5):773ff

43. Keats TE, Anderson WA (1996) Atlas of normal Roentgen variants that may simulate disease. Mosby-Year Book, Inc., St. Louis
44. Kellinghaus M, Schulz R, Vieth V et al (2010) 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. Int J Legal Med 124(4):321ff. https://doi.org/10.1007/s00414-010-0448-2
45. Kellinghaus M, Schulz R, Vieth V et al (2010) Forensic age estimation in living subjects based on the ossification status of the medial clavicular epiphysis as revealed by thin-slice multidetector computed tomography. Int J Legal Med 124(2):149ff. https://doi.org/10.1007/s00414-009-0398-8
46. Konermann Ph (2014) Lateralität der sternalen Clavikularentwicklung am nativen Knochen - Implikationen für die forensische Altersdiagnostik. Thesis University Vienna
47. Kreitner KF, Schweden F, Schild HH (1997) The epiphyseal union of the medial clavicle determined by CT - an axillary method in age identification during adolescence und 3rd decade of life. Fortschr Röntgenstr 166(6):481ff. https://doi.org/10.1055/s-2007-1015463
48. Kreitner KF, Schweden FJ, Riepert T et al (1998) Bone age determination based on the study of the medial extremity of the clavicle. Eur Radiol 8(7):1116ff. https://doi.org/10.1007/s003300050518
49. Kumar R, Madewell JE, Swischuk LE (1989) The clavicle: normal and abnormal. Radiographics 9(4):677ff. https://doi.org/10.1148/radiographics.9.4.2756192
50. Küppers MA (2013) Die computertomographische Analyse der medialen Klavikulaepiphyse zur Lebensaltersbestimmung und der Einfluss von Schichtdicke und Erfahrung des Untersuchers auf die Stadieneinteilung. Thesis University Essen
51. Lucet L, Le Loët X, Ménard JF et al (1996) Computed tomography of the normal sternoclavicular joint. Skelet Radiol 25(3):237ff
52. Magu NK, Singla R, Devgan A, Gogna P (2014) Congenital pseudoarthrosis of the clavicle with bifurcation. Indian J Orthop 48(4):435ff. https://doi.org/10.4103/0019-5413.136314
53. McKern TW, Stewart TD (1957) Skeletal age changes in young American males. Quartermaster Research and Development Center, Environmental Protection Research Division. Technical Report EP-45. https://apps.dtic.mil/dtic/tr/fulltext/u2/147240.pdf. Access date: 15.02.2019
54. Milenkovic P, Djukic K, Djonic D et al (2013) Skeletal age estimation based on medial clavicle—a test of the method reliability. Int J Legal Med 127(3):667ff. https://doi.org/10.1007/s00414-012-0791-6
55. Milenkovic P, Djuric M, Milovanovic P et al (2014) The role of CT analyses of the sternal end of the clavicle and the first costal cartilage in age estimation. Int J Legal Med 128(5):825ff. https://doi.org/10.1007/s00414-014-1026-9
56. Ottow C, Krämer JA, Olze A et al (2015) Magnetic resonance tomography studies on age estimation of unaccompanied minor refugees. Rechtsmedizin 25(1):12ff. https://doi.org/10.1007/s00194-014-0991-0
57. 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(4):457ff. https://doi.org/10.1002/ajpa.1330680402
58. Paraskevas GK (2016) What morphological pattern of "impressio ligament costoclavicularis" is the most predominant. Surg Radiol Anat 38(1):161ff. https://doi.org/10.1007/s00276-015-1528-2
59. Patil PM, Kiran R, Maled V, Dakhankar S (2018) The chronology of medial clavicle epiphysis ossification using computed tomography. IJARS 7(1):23ff. https://doi.org/10.7860/IJARS/2018/32595:2357
60. Pattamapaspong N, Madla C, Mekjaidee K, Namwongprom S (2015) Age estimation of a Thai population based on maturation of the medial clavicular epiphysis using computed tomography. Forensic Sci Int 246:123.e1ff. https://doi.org/10.1016/j.forsciint.2014.10.044
61. Price MD (2017) Age estimation using the sternal end of the clavicle: a test of the Falys and Prangle (2014) archaeological method for forensic application. Thesis University Boston
62. Ramadan SU, Gurses MS, Inanir NT et al (2017) Evaluation of the medial clavicular epiphysis according to the Schmeling and Kellinghaus method in living individuals: a retrospective CT study. Legal Med 25:16ff. https://doi.org/10.1016/j.legalmed.2016.12.012
63. Ravelli A (1955) Über eine eigenartige Form des sternalen Schlüsselbeins ("Fischmaulform"). Fortschr Röntgenstr 82:827f
64. Richel S (2005) Der Stellenwert verschiedener röntgenologischer Kriterien in der Panoramaschichtaufnahme sowie der medialen Claviculaepiphyse im Rahmen von Altersbestimmungen. Thesis University Hamburg
65. Roche AF, Sunderland S (1959) Multiple ossification centres in the epiphyses of the long bones of the human hand and foot. J Bone Joint Surg (Br) 41-B(2):375ff. https://doi.org/10.1302/0301-620X.41B2.375
66. Roscam Abbing HDC (2011) Age determination of unaccompanied asylum seeking minors in the European Union: a health law perspective. Eur J Health Law 18(1):11ff. https://doi.org/10.1163/157180911X546101
67. Rudolf E (2016) Medical age assessment in the case of a "doubtful" claim to being an unaccompanied minor as set forth in article 25 Para 5 sentences one to three of the recast asylum procedures directive 2013. The establishment of identity in the migration process. EMN-conference Vienna: https://www.emn.at/wp-content/uploads/2017/01/EMN-Tagungsbericht_web.pdf. Access date: 15.02.2019
68. Rudolf E, Kramer J, Winkler I, Schmeling A (2018) Technical note: utilization of 3D-rendering for CT-evaluation of extremitas sternalis claviculae within medical age assessment practice. Int J Legal Med. 133(3):931ff. https://doi.org/10.1007/s00414-019-02025-0
69. Rudolf E, Kramer J, Schmidt S et al (2018) On the influence of hand-preference on the phenomenon of intraindividual differing appearances of the paired age marker 'medial clavicular ossification' in borderline-adults as seen from the sternoclavicular regions of 2,546 male persons by means of thin-slice CT-imaging. Arch Kriminol 241(5-6):183ff
70. Rudolf E, Kramer J, Schmidt S et al (2018) Intraindividual incongruences of medially ossifying clavicles in borderline adults as seen from thin-slice CT-studies of 2,595 male persons. Int J Legal Med 132(2):629ff. https://doi.org/10.1007/s00414-017-1694-3
71. Scharte P, Vieth V, Schulz R et al (2017) Comparison of imaging planes during CT-based evaluation of clavicular ossification: a multi-center study. Int J Legal Med 131(5):1391ff. https://doi.org/10.1007/s00414-017-1615-5
72. Schmeling A, Schulz R, Reisinger W et al (2004) Studies on the time frame for ossification of the medial clavicular epiphyseal cartilage in conventional radiography. Int J Legal Med 118(1):5ff. https://doi.org/10.1007/s00414-003-0404-5
73. Schmeling A, Grundmann C, Fuhrmann A et al (2008) Criteria for age estimation in living individuals. Int J Legal Med 122(6):457ff. https://doi.org/10.1007/s00414-008-0254-2
74. Schmeling A, Dettmeyer R, Rudolf E et al (2016) Forensic age estimation: methods, certainty, and the law. Dtsch Arztebl Int 113(4):44ff. https://doi.org/10.3238/arztebl.2016.0044
75. Schmidt H, Freyschmidt J (1993) Köhler/Zimmer's borderlands of normal and early pathological findings in skeletal radiography. Georg Thieme Verlag Stuttgart, New York

76. Schmidt S, Henke CA, Wittschieber D et al (2016) Optimising magnetic resonance imaging-based evaluation of the ossification of the medial clavicular epiphysis: a multi-centre study. Int J Legal Med 130(6):1615ff. https://doi.org/10.1007/s00414-016-1442-0
77. Schmidt S, Ottow C, Pfeiffer H et al (2017) Magnetic resonance imaging-based evaluation of ossification of the medial clavicular epiphysis in forensic age assessment. Int J Legal Med 131(6): 1665ff. https://doi.org/10.1007/s00414-017-1676-5
78. Schulz R, Mühler M, Mutze S et al (2004) Studies on the time frame for ossification of the medial epiphysis of the clavicle as revealed by CT scans. Int J Legal Med 119(3):142ff. https://doi.org/10.1007/s00414-005-0529-9
79. Schulz R, Schiborr M, Pfeiffer H et al (2013) Sonographic assessment of the ossification of the medial clavicular epiphysis in 616 individuals. Forensic Sci Med Pathol 9(3):351ff. https://doi.org/10.1007/s12024-013-9440-8
80. Schulze D, Rother U, Fuhrmann A et al (2006) Correlation of age and ossification of the medial clavicular epiphysis using computed tomography. Forensic Sci Int 158(2-3):184ff. https://doi.org/10.1016/j.forsciint.2005.05.033
81. Shaikh T, Ansari S, Mandhane N et al (2015) Bilateral total duplication of clavicle: 1st reported case. Int J Res Med Sci 3(7):1780f. https://doi.org/10.18203/2320-6012.ijrms20150269
82. Skalski M (2013) From the case: forked clavicle: https://radiopaedia.org/images/2953544. Access date: 15.02.2019
83. Stevenson PH (1924) Age order of epiphyseal union in man. Am J Phys Anthropol 7(1):53ff. https://doi.org/10.1002/ajpa.1330070115
84. Swiss Supreme Administrative Court 10.01.2017, D-6422/2016; 07.04.2016, D-859/2016
85. Tangmose S, Jensen KE, Lynnerup N (2013) Comparative study on developmental stages of the clavicle by postmortem MRI and CT imaging. JOFRI 1(3):102ff. https://doi.org/10.1016/j.jofri.2013.05.008
86. Tangmose S, Jensen KE, Villa C, Lynnerup N (2014) Forensic age estimation from the clavicle using 1.0 T MRI—preliminary results. Forensic Sci Int 234:7ff. https://doi.org/10.1016/j.forsciint.2013.10.027
87. Teplick JG, Eftekhari F, Haskin ME (1974) Erosion of the sternal ends of the clavicles. Radiology 113(2):323ff. https://doi.org/10.1148/113.2.323
88. Todd TW, D'Errico J (1928) The clavicular epiphyses. Am J Phys Anthropol 41(1):25ff. https://doi.org/10.1002/aja.1000410103
89. Ufuk F, Agladioglu K, Karabulut N (2016) CT evaluation of medial clavicular epiphysis as a method of bone age determination in adolescents and young adults. Diagn Interv Radiol 22(3):241ff. https://doi.org/10.5152/dir.2016.15355
90. UNHCR (1997) Guidelines on policies and procedures in dealing with unaccompanied children seeking asylum, 5.11: http://www.refworld.org/docid/3ae6b3360.html. Access date: 15.02.2019
91. Viehweger G (1968) Schlüsselbein und Schultereckgelenk. In: Diethelm L et al (eds) Handbuch der Medizinischen Radiologie. Springer, Berlin Heidelberg
92. Viennese High Court 08.11.2017, 21 Bs 309/17w
93. Vieth V, Kellinghaus M, Schulz R et al (2010) Ossification stage of the medial clavicular epiphysis. Comparison of projectional radiography, computed tomography and magnetic resonance imaging. Rechtsmedizin 20(6):483ff. https://doi.org/10.1007/s00194-010-0709-x
94. Vieth V, Schulz R, Brinkmeier P et al (2014) Age estimation in U-20 football players using 3.0 tesla MRI of the clavicle. Forensic Sci Int 241:118ff. https://doi.org/10.1016/j.forsciint.2014.05.008
95. Wei H, Zhu GY, Lei W et al (2015) Correlation between age and the parameters of medial epiphysis and metaphysis of the clavicle using CT volume rendering images. Forensic Sci Int 244:316.e1ff. https://doi.org/10.1016/j.forsciint.2014.09.006
96. Wittschieber D, Schulz R, Vieth V et al (2014) Influence of the examiner's qualification and sources of error during stage determination of the medial clavicular epiphysis by means of computed tomography. Int J Legal Med 128(1):183ff. https://doi.org/10.1007/s00414-013-0932-6
97. Wittschieber D, Schulz R, Vieth V et al (2014) The value of substages and thin slices for the assessment of the medial clavicular epiphysis: a prospective multi-center CT study. Forensic Sci Med Pathol 10(2):163ff. https://doi.org/10.1007/s12024-013-9511-x
98. Wittschieber D, Schmidt S, Vieth V et al (2014) Subclassification of clavicular substage 3a is useful for diagnosing the age of 17 years. Rechtsmedizin 24(6):485ff. https://doi.org/10.1007/s00194-014-0990-1
99. Wittschieber D, Ottow C, Schulz R et al (2016) Forensic age diagnostics using projection radiography of the clavicle: a prospective multi-center validation study. Int J Legal Med 130(1): 213ff. https://doi.org/10.1007/s00414-015-1285-0
100. Wittschieber D, Schulz R, Pfeiffer H et al (2017) Systematic procedure for identifying the five main ossification stages of the medial clavicular epiphysis using computed tomography: a practical proposal for forensic age diagnostics. Int J Legal Med 131(1): 217ff. https://doi.org/10.1007/s00414-016-1444-y
101. Wolff J (1870) Ueber die innere Architectur der Knochen und ihre Bedeutung für die Frage vom Knochenwachsthum. Virchows Arch Pathol Anat Physiol 50:389ff
102. Yoon SH, Yoo HY, Yoo RE et al (2016) Ossification of the medial clavicular epiphysis on chest radiographs: utility and diagnostic accuracy in identifying Korean adolescents and young adults under the age of majority. J Korean Med Sci 31(10):1538ff. https://doi.org/10.3346/jkms.2016.31.10.1538
103. Zhang K, Chen XG, Zhao H et al (2015) Forensic age estimation using thin-slice multidetector CT of the clavicular epiphyses among adolescent Western Chinese. J Forensic Sci 60(3):675ff. https://doi.org/10.1111/1556-4029.12739
104. Zhao H, Dong XA, Zheng T et al (2011) Skeletal age estimation of sternal end of clavicle in Sichuan Han nationality youth using thin-section computed tomography. Fa Yi Xue Za Zhi 27(6):417ff. https://doi.org/10.3969/j.issn.1004-5619.2011.06.005