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CT evaluation of medial clavicular epiphysis as a method of bone age determination in adolescents and young adults

Furkan Ufuk
Kadir Agladioglu
Nevzat Karabulut

PURPOSE
We aimed to investigate the use of computed tomography (CT) staging of the medial clavicular epiphysis ossification in forensic bone age determination, and find a CT criterion to determine whether an individual is adult or not.

METHODS
Chest CT and pulmonary CT angiography exams of 354 patients between 10 and 30 years of age (mean, 21.4 years) were retrospectively evaluated for epiphyseal ossification phase of the bilateral medial clavicles (708 clavicles) and compared with the sex and chronologic age of the individuals. The ossification phase of the medial clavicular epiphyses was classified from stage I to stage V using a modified staging system.

RESULTS
Epiphyseal ossification center appeared from 11 to 21 years of age. Partial fusion occurred between 16 and 23 years of age. Complete fusion was first achieved at the ages of 18 and 19 years for male and female individuals, respectively. The probability of an individual being ≥18 years old was 70.8% in stage III A and 100% in stages III B, IV, and V in females and males.

CONCLUSION
CT evaluation of the medial clavicular epiphysis is helpful in forensic age determination and stage III B can be used as a criterion to make the prediction that an individual is older than 18 years.

Forensic bone age identification of teenagers and young adults has been a topic of interest in criminal procedures. Age assessment is also used by immigration authorities to determine whether refugees and asylum seekers are adults or juveniles (1). It is also important as 18 years of age is accepted as a threshold for legal liability in many countries. There is no criminal responsibility for children who committed a crime before completing the age of 10–12 years, in many European countries. Between the ages of 12 and 18 years, the punishment is reduced according to the age. However, the punishment that is stipulated by the laws will be fully applied in individuals older than 18 years in many European countries (2). The age assessment methods for adolescents and young adults often include hand bone ossification, third molar tooth mineralization, and union of the medial clavicular epiphysis. The evaluation of the ossification status of medial epiphyses of the clavicles by thin-section CT is a method recommended by Forensic Age Diagnostics of the German Association of Forensic Medicine (AGFAD) in adolescents and young adults since sexual maturation, hand bone ossification, and third molar tooth growth can be completed by this period (3). Previous studies have shown that the recommended method can be an instrumental tool in the age estimation of young individuals (4–7).

In this study, we aimed to assess the medial clavicular epiphysis ossification stage in Turkish population and find a computed tomography (CT) criterion to establish whether an individual is adult or not.

Methods

Study population

This retrospective study was approved by the local ethics committee. We reviewed the chest CT and pulmonary CT angiography examinations of patients between 10 and 30 years of age, acquired from September 2012 to June 2013. Overall, images of 354 subjects (209

From the Department of Diagnostic Radiology (F.U. ✉ *furkan.ufuk@hotmail.com*), University of Pamukkale, Denizli, Turkey.

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male, 145 female) with 708 clavicles were evaluated for medial clavicular epiphyseal ossification. Fifty-four subjects (15.2%) were excluded from the study, due to history of malignancy (n=40, 11.2%), rickets (n=2, 0.5%), growth hormone deficiency (n=1, 0.3%), thyroid hormone deficiency (n=3, 0.8%), and insufficient documentation of the sternoclavicular joints because of artifacts or significant anatomic variations (n=8, 2.3%). After excluding subjects with insufficient documentation of the sternoclavicular joints and those with medical conditions that may potentially influence bone development, the final study population comprised 300 patients (181 males, 119 females) with a mean age of 21.4±5.22 years (range, 10–30 years) (Table 1). The CT images of the subjects were fetched from hospital picture archiving and communication system for the evaluation of epiphyseal ossification phase of the medial clavicle. The most common requisitions for the CT study were thoracic trauma in 109 subjects (36.3%), acute infectious disease in 84 cases (28%), and suspected pulmonary nodule or hilar lymphadenopathy in 67 cases (22.3%). In the remaining 40 cases (13.3%), the CT indications varied as interstitial lung disease (n=11), primary spontaneous pneumothorax (n=10), pulmonary embolism (n=9), corrosive substance ingestion (n=7), and idiopathic scoliosis (n=3).

CT examination

All pulmonary CT angiography and chest CT examinations were performed in supine position using a 16-slice CT scanner (Brilliance 16, Philips Medical Systems). The scanning parameters on chest CT were 120 kV; 50 mAs; collimation, 16×1.5 mm; pitch, 0.938; and rotation time, 0.4 s. CT pulmonary angiography was performed using 120 kV, 100 mAs; collimation, 16×0.75 mm; pitch, 1.063; and rotation time, 0.5 seconds. Nonionic iodine-based contrast material (350 mg I/mL) was injected in all CT pulmonary angiography exams, and in CT scans of patients with tumor, trauma and heart or great vessel diseases. The data acquired from CT scans were reconstructed in axial 1–3 mm slice thickness.

Main points

- Forensic bone age identification of teenagers and young adults has been a topic of interest in criminal procedures.
- Computed tomography assessment of medial clavicular epiphyseal stage correlate well with the chronologic age in adolescents and young adults.
- There were no significant differences between left/right clavicular epiphyseal stages in our study.
- Regardless of the sex, the chronologic age of an individual can be estimated to be ≥18 years when complete (stage IV, V) or >2/3 but not complete (stage III B) ossification of epiphyseal cartilage is observed.

Image interpretation

We transferred the volumetric CT data electronically to a workstation (MxView*exp*; release 4.01, Philips Medical Systems). A radiologist with six years of experience and a fourth year radiology resident evaluated all CT images in consensus. The observers used bone window setting (width/level, 1500/450 Hounsfield units) for optimal visualization of the medial clavicular epiphysis, but they were free to change the settings and perform multiplanar reformats. The age of the individuals was blinded to the observers. The stages of fusion and maturity of the medial clavicular epiphysis on each side were evaluated by modifying the classification reported by Schmeling et al. (7). We divided the stage III into two subgroups: stage III A and III B. The cross section with the most advanced ossification stage was considered in determination of the stage (Table 2 and Fig.)

Statistical analysis

Statistical analyses were performed using SPSS version 18.0 (SPSS for Windows, release 18.0; SPSS Inc.). Quantitative variables were expressed as minimum, maximum, mean±standard deviation (SD), and median. Intergroup comparisons were performed using independent t-test for continuous variables and the chi-square test for categorical variables. Kruskal Wallis test was used to analyze the differences in ossification stage according to the age. Post-hoc Mann Whitney U test with Bonferroni correction was used when the Kruskal Wallis test determined a significant difference. Spearman's correlation coefficients were used to detect the relationship between ossification stage of the medial clavicular epiphysis and the chronologic age. A *P* value less than 0.05 was considered to indicate significant difference.

Results

The medial clavicular epiphyseal stages were significantly different at different ages ($P < 0.001$). We found a strong correlation

Table 1. Age distribution of study subjects

Age	Male, n (%)	Female, n (%)
10	4 (1.3)	5 (1.7)
11	2 (0.7)	4 (1.3)
12	5 (1.7)	2 (0.7)
13	7 (2.3)	3 (1.0)
14	7 (2.3)	4 (1.3)
15	5 (1.7)	3 (1.0)
16	7 (2.3)	3 (1.0)
17	6 (2.0)	2 (0.7)
18	8 (2.7)	5 (1.7)
19	8 (2.7)	9 (3.0)
20	8 (2.7)	6 (2.0)
21	13 (4.3)	6 (2.0)
22	11 (3.7)	12 (4.0)
23	10 (3.3)	11 (3.7)
24	15 (5.0)	4 (1.3)
25	14 (4.7)	10 (3.3)
26	19 (6.3)	8 (2.7)
27	13 (4.3)	11 (3.7)
28	8 (2.7)	5 (1.7)
29	10 (3.3)	4 (1.3)
30	2 (0.7)	1 (0.3)
Total	182 (60.7)	118 (39.3)

Table 2. The stages of maturity and status of the medial clavicular epiphysis

Stage	Medial clavicular epiphyseal status
I	Ossification center is not visible (nonossified)
II	Ossification center is visible (ossified) but epiphyseal cartilage is not ossified
III A	Ossification of ≤2/3 of epiphyseal cartilage
III B	Ossification of >2/3 of epiphyseal cartilage
IV	Complete ossification of epiphyseal cartilage with visible epiphyseal line
V	Complete ossification of epiphyseal cartilage without visible epiphyseal line

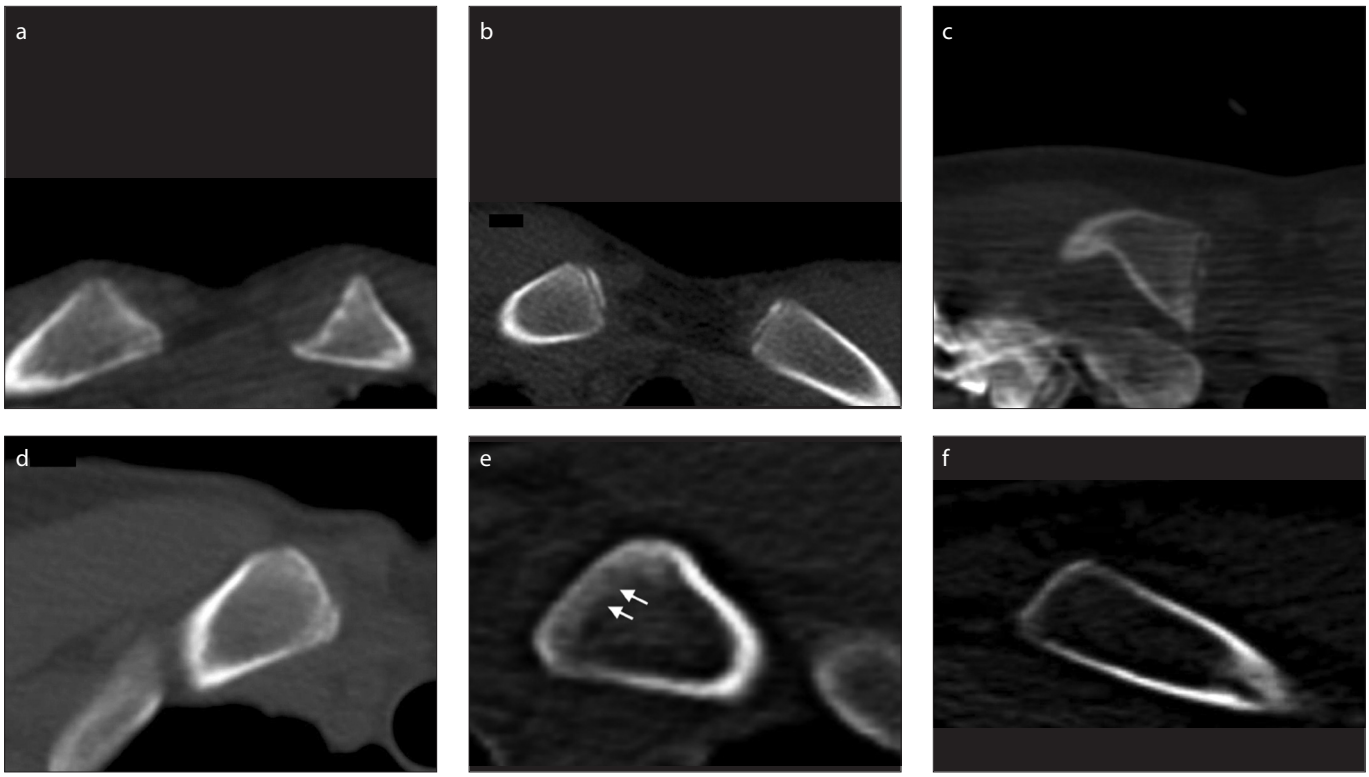

Figure. a–f. Axial CT images of the medial clavicle(s). A 10-year-old male **(a)** shows no ossification center in the medial clavicles (stage I). A 14-year-old female **(b)** shows ossified center with visible nonossified epiphyseal line in the medial clavicle (stage II). A 17-year-old female **(c)** shows ossification of ≤2/3 of epiphyseal cartilage (stage III A). A 20-year-old female **(d)** shows incomplete ossification of >2/3 of epiphyseal cartilage (stage III B). A 24-year-old male **(e)** shows complete ossification of epiphyseal cartilage with visible epiphyseal scar (*arrows*) (stage IV). A 26-year-old male **(f)** shows complete ossification of epiphyseal cartilage without visible epiphyseal scar (stage V).

between age and medial clavicular epiphyseal ossification stage (r=0.897, $P < 0.001$).

Stage I last appeared in females at 14 years of age and in males at 16 years of age. Stage II was first seen in females at 11 years and in males at 14 years. Stage II was last noted in males at 21 years of age. The occurrence of stage III A was first observed in both sexes at the age of 16 years. The earliest appearance of stage III B was at 18 years of age in either sex. Stage IV was initially recorded in males at 18 years, and in females at 19 years, whereas stage V was first observed in males at 21 years and females at 22 years. Complete union of the medial clavicular epiphysis was achieved in all individuals at the age of 28 years. A minimum age of 18 years was determined when stage IV ossification was seen, and a minimum age of 21 years was estimated in subjects with stage V ossification. A comparison between female and male individuals revealed no statistically significant differences in any of the stages ($P > 0.05$). Sex did not significantly affect the relation between age and stage ($P = 0.344$) (Table 3).

There was no significant difference between left/right clavicular epiphyseal stages ($P = 0.438$). Only 18 cases (6%) showed left/right epiphyseal ossification stage differences. Left and right differences were only one stage apart (e.g., epiphyseal stage II on the right versus epiphyseal stage I or III A on the left side) in all cases. The majority (38.8%) of the left/right differences were seen in stages III B and IV (Table 4).

Table 3. Age distribution and comparison of ossification status of the medial clavicular epiphysis in females and males

Stage	Gender	Subject (n)	Age (years)	*P*
I	Male	27	12.78±1.74	0.062
	Female	15	11.67±1.59	
II	Male	18	16.56±1.79	0.099
	Female	10	15.20±2.39	
III A	Male	13	18.77±1.59	0.563
	Female	10	18.60±1.84	
III B	Male	17	20.23±1.98	0.985
	Female	15	20.40±2.23	
IV	Male	51	23.59±2.11	0.891
	Female	40	23.55±2.15	
V	Male	55	26.60±1.96	0.574
	Female	29	26.17±2.19	

Ossification of ≤2/3 of epiphyseal cartilage (stage III A) showed 70.8% probability of an individual being ≥18 years old, whereas ossification of >2/3 of epiphyseal cartilage (stage III B) indicated 100% probability of an individual being ≥18 years old. Complete ossification of medial clavicular epiphyseal car-

tilage with or without visible epiphyseal line (stages IV and V) indicated that all subjects were ≥18 years old (Table 5).

Discussion

Our study showed a strong correlation between age and medial clavicular epiphyseal ossification stage. Sex had no significant effect on the stage of medial clavicular epiphyseal ossification, and there was no significant difference between male and female groups in any of the epiphyseal ossification stages.

In the present study, the ossification stages of medial clavicular epiphysis were defined using a modified version of the Schmeling classification (7), which is a widely accepted system (8–17). Previous studies showed that an individual can be estimated to be ≥18 years when complete ossification of epiphyseal cartilage (stage IV, V) is observed (8–17). Since stage III is a borderline to determine whether an individual is adult or not, we modified this classification to evaluate stage III epiphysis in more detail and divided stage III into two subgroups (stage III A, ≤2/3, ossification of epiphyseal cartilage; stage III B, >2/3 but not complete ossification of epiphyseal cartilage). Due to the relatively small population we did not divide stage II into subgroups.

Forensic bone age determination is important to discriminate juveniles from adults. Patients sometimes declare the wrong age to escape from criminal responsibility. Radiologists are commonly asked to determine the age of an individual for legal or medical purposes. The most common method used for age determination in our center is the evaluation of hand wrist x-rays by Greulich and Pyle method (18). The recent increase of asylums and illegal immigration further emphasized the importance of forensic determination of the age.

Our results support the previous studies where CT assessment of medial clavicular epiphyseal stage was shown to correlate well with the chronologic age in adolescents and young adults (Table 6) (8–17). Kreitner et al. (7), Kellinghaus et al. (9), Franklin et al. (14), and Zhang et al. (16) reported complete union of the medial clavicular epiphysis in 100% of the study subjects at the age of 27 years, which is similar to the findings in the present study. However, our results were different from Schulze et al. (9), Wittschieber et al. (13), and Ekizoglu et al. (17). The difference can be attributed to the smaller series (100 subjects) and thicker slices (1–10 mm) used in the study of Schulze et al. (9). The slice thickness is important for accurate delineation of epiphyseal ossification. In the present study, we used a slice thickness of 1–3 mm. The delay in complete epiphyseal fusion reported by Wittschieber et al. (13) and Ekizoglu et al. (17) might also be due to the characteristics of study populations, since they included all patients presenting with trauma, and did not exclude patients with infection, malignancy, or those using medications that might have an adverse effect on bone development.

We observed stage III epiphysis earliest at 16 years of age similar to previous studies (8–13, 16, 17). Our results in stages I, II, and III are very similar to the findings of Pattamapaspong et al. (15) and Ekizoglu et al. (17).

The significant relationship between age and medial clavicular epiphyseal ossification stages observed in our study is very similar to the results of another study conducted in the Turkish population (17). Socioeconomic status and ethnicity are important factors for the ossification of medial clavicular epiphysis, and delayed ossification can be seen in subjects with low socioeconomic status (3). Nevertheless, there is no study investigating the association between socioeconomic status and ossification of medial clavicular epiphysis in the literature; future studies should also take this into account when assessing ossification of medial clavicular epiphysis.

We showed that a minimum age of 18 years can be determined when a stage III B or stage IV is seen, and a minimum age of 21 years can be determined in subjects with a stage V ossification. These results

Table 4. Discrepant medial clavicular epiphyseal stages between left and right sides in 18 subjects

Right clavicle stage	Left clavicle stage	Number of cases
I	II	1
II	I	2
II	III A	1
III A	III B	2
III B	III A	3
III B	IV	5
IV	III B	2
V	IV	2

Table 5. The probability of an individual being ≥18 years old according to the medial clavicular epiphyseal ossification stage

	Medial clavicular epiphyseal stage						
Age	I	II	III A	III B	IV	V	Total
< 18 years	85 (100)	43 (79.7)	14 (29.2)	0 (0)	0 (0)	0 (0)	144 (24)
≥ 18 years	0 (0)	11 (20.3)	34 (70.8)	60 (100)	187 (100)	166 (100)	456 (76)

Data represent the number of clavicles and the percentage of patients.

Table 6. Review of CT studies regarding the development of the medial clavicular epiphysis

Study	n	Slice thickness (mm)	Origin of the study	Age (years)			
				Stage 2	Stage 3	Stage 4	Stage 5
Kreitner et al. (8)	380	1–8	Germany	11–22	16–26	22–29	–
Kellinghaus et al. (9)	592	0.6–1.5	Germany	13–20	16–26	21–35	26–35
Schulze et al. (10)	100	1–10	Germany	16–24	16–25	19–25	–
Schulz et al. (11)	629	1–7	Germany	15–23	16–28	21–30	21–30
Kreitner et al. (12)	279	1–8	Germany	13–22	16–26	22–29	–
Wittschieber et al. (13)	572	0.6	Germany	14–20	16–36	21–40	27–40
Franklin et al. (14)	388	0.6–2	Australia	14–23	17–26	20–34	24–35
Pattamapaspong et al. (15)	409	0.6–1	Thailand	12–21	15–27	18–29	20–29
Zhang et al. (16)	752	1	China	15–21	16–26	19–26	–
Ekizoglu et al. (17)	503	1	Turkey	13–25	16–29	20–35	25–35
Present study	300	1–3	Turkey	11–21	16–26	18–28	21–30

are consistent with those of Kellinghaus et al. (9) who reported a minimum age of 21 years and Ekizoglu et al. (17) who reported a minimum age of 20 years when stage IV ossification is observed. We found that a minimum age of 21 years can be determined in a subject with stage V ossification, in accordance with Schulz et al. (11). Using thinner slices, the minimum age in a subject with stage V ossification was reported to be 26 years by Kellinghaus et al. (9), 27 years by Wittschieber et al. (13), and 25 years by Ekizoglu et al. (17). Incorrect interpretation of the ossification phase may result from partial volume effects due to thicker slices and anatomic shape variants. Mühler et al. (1) reported that a CT slice thickness less than 5 mm reduces the risk of misdiagnosis in the ossification phase. Wittschieber et al. (19) reported that the most common mistake was the incorrect interpretation of the variations of the anatomical picture, followed by the overlooking of a scar in the ossified epiphysis leading to mislabeling of stage IV as stage V. We think that the slice thickness mostly influences the differentiation of stage I and stage, II since thicker slices may obscure the thin epiphyseal line at stage II and lead to misinterpratation of it as stage I.

Our results showed no significant differences between left/right clavicular epiphyseal stages. We found left/right epiphyseal ossification stage differences in 18 subjects (6%). This figure was reported in the range of 0.4%–20.1% in previous studies (7, 8, 11, 20, 21). The rate of left/right difference in our study was comparable to 8.6% reported by Hillewig et al. (21) and 8% reported by Franklin et al. (14). To our knowledge, no previous study has analyzed the epiphyseal stages showing left/right difference. In our study, the majority (38.8%) of the left/right differences were seen in stages III B and IV. This may be due to the relatively large number of subjects in these stages.

In line with previous studies, we did not observe significant differences between male and female subjects in the ossification stages of clavicular epiphysis (8, 10–12). In contrast, Ekizoglu et al. (17) reported that there was a significant difference between male and female patients in stages I and IV. Although we observed earlier ossification in female subjects in stages I and IV similar to Ekizoglu et al. (17), this difference was not statistically significant. This may be attributable to the smaller number of subjects in the current study.

Since individuals vary in developmental stage, no age determination method can produce the exact chronologic age. Thus, it is better to provide age intervals instead of point estimates. In the present study, we found that 100% of subjects with stage IV and V ossification were ≥18 years similar to Pattamapaspong et al. (15) and Zhang et al. (16). Our study showed that subjects of both sexes with stage III B have 0% probability to be <18 years, and those with stage II have a probability of 79.3% to be <18 years. If an individual has >2/3 fusion of epiphyseal cartilage of clavicles (stage III B), then the age of at least 18 years can be estimated for males and females, respectively. The minimum age for stage III B was 18 years in both sexes. Similar to Kreitner et al. (8), the earliest age at which the process of partial union of the medial clavicular epiphysis (stage III A) occurs was found to be 16 years of age in our study. In this study, we also reviewed the relevant literature to investigate the possible effects of race and ethnicity. As summarized in Table 6, the inter-racial differences are relatively slight, and the method can be used universally.

Our study has some limitations. First, our study population was relatively small; the change of ossification phases can be proven more clearly in larger series. Second, we did not consider the socioeconomic status of the subjects, which might have influenced bone maturation. Third, in our study CT slice thickness was relatively thick; using thinner slices can reduce the misdiagnosis. Fourth, we did not specifically assess the anatomic shape variants and encountered some challenges during the evaluation. Fifth, we relied on hospital documentation system for chronologic age of the subjects. However, it is not uncommon that officially recorded age may be different from the real chronologic age in underdeveloped or developing countries. Finally, since we performed a consensus reading, we did not assess interobserver variation in the evaluation of epiphyseal ossification stage.

In conclusion, CT assessment of medial clavicular epiphyseal ossification is instrumental in forensic age determination. Radiation exposure and high cost are the disadvantages of CT. Regardless of the sex, the chronologic age of an individual can be estimated to be ≥18 years when complete (stages IV or V) or >2/3 but not complete ossification (stage III B) of epiphyseal cartilage is observed. We propose that stage III B can be used as a criterion to make the prediction that an individual is ≥18 years, which is particularly important in the assessment of legal liability.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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