Forensic Age Estimation of Individuals from Computed Tomography Analysis of Medial Clavicular Epiphysis in Pakistani Population

Mehreen Fatima[1], Binish Rashid[2], Zaheer Amjad[3], Ramlah Naz[1] and Aiman Rahim[4]

[1]*Department of Forensic Medicine, Dow International Medical College, Dow University of Health Sciences, Karachi, Pakistan*
[2]*Department of Radiology, Dow International Medical College, Dow University of Health Sciences, Karachi, Pakistan*
[3]*Department of Anatomy, Dow International Medical College, Dow University of Health Sciences, Karachi, Pakistan*
[4]*Department of Medicine, Dow Medical College, Dow University of Health Sciences, Karachi, Pakistan*

ABSTRACT

Objective: To determine the association of chronological age through ossification of the medial clavicular epiphysis using computed tomography (CT) scan.

Study Design: An Observational study.

Place and Duration of the Study: Dow Institute of Radiology, Dow University Hospital, Karachi, Pakistan, from February 2021 till October 2021.

Methodology: Subjects aged 10-35 years of either gender reported without any clavicular trauma or fracture, no known chronic illness or malignancy, or no congenital bony abnormalities, or any prior surgical intervention to the sterno-clavicular region were included. The fusion of maturity of medial clavicular epiphyses was evaluated on either side by using the five-stage classification system reported by Schmeling.

Results: Of 200 patients, a significant increase in the age of the patients was observed with respect to the increase in the stages ($p < 0.001$). When stratified on the basis of gender, a significant increase in age was also observed with respect to the increase in stages ($p < 0.001$). Stage 4 was observed in majority of the patients, *i.e.*, 81 (40.5%), followed by stages 2 and 3 in 35 (17.5%) each, stage 5 in 32 (16%), while stage 1 was observed in 17 (8.5%) patients. An insignificant difference of age was observed with respect to the gender of the patients ($p = 0.472$, 95% CI -2.91 - 1.35).

Conclusion: The fusion of the medial clavicular epiphysis showed a considerable degree of variability. Fused clavicles at stage 4 could be observed at age 22 years or less in males while at 21 years or less in females.

Key Words: *Age estimation, Schmeling method, Medial clavicular epiphysis, Computed tomography.*

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INTRODUCTION

Age estimation is critical in forensic medicine, as well as in immigration and criminal cases where the laws differ for minors and majors.[1,2] Furthermore, age estimation is especially difficult in developing or underdeveloped countries where birth records are unreliable due to non-hospital births.[3,4] People may also conceal their true age and report false ages in order to deceive law enforcement. These elements increase the importance of forensic age estimation. In countries where the majority of the population is 18 or older, such as Pakistan, forensic age estimation should be well established.[5]

Correspondence to: Dr. Mehreen Fatima, Department of Forensic Medicine, Dow International Medical College, Dow University of Health Sciences, Karachi, Pakistan
E-mail: mehreen.fatima@duhs.edu.pk

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Macroscopic examination of dental development and eruption and radiological examination of the hands and wrist are the two most commonly used methods for estimating age.[6,7] However, due to the completion of dentition and ossification after the age of 18 years, these methods are no longer effective.[8,9] Clavicle is not only the first bone to begin ossification in the embryo, but it is also the last bone to fully ossify in adolescents.[9] The medial end of the clavicle ossifies by endochondral ossification, as opposed to the rest of the clavicle, which ossifies intramembranous.[10] This makes it an extremely useful tool for estimating the age of a living human or a dead body, particularly between the ages of sixteen and thirty, in order to determine whether an individual has reached the age of legal responsibility.[11,12] Because conventional radiography has limitations in analysing the developmental stages of the clavicle due to the superimposition of other thoracic structures,[13-15] the researchers used computed tomography (CT) imaging as an alternative.[16,17] The Schmeling staging system is widely accepted.

Age estimation by CT scan of the medial end of the clavicle has been investigated in various parts of the world, but no such study has been conducted in Pakistan. The sharing of information from other countries is difficult because of variations in genetics, nutritional habits, climate, and environmental factors. As a result, the rationale of this research is to add to the existing body of knowledge and to enable the local validation for the estimation of an individual's age. The objective of this study was to determine the association of chronological age through ossification of the medial clavicular epiphysis using a computed tomography (CT) scan.

METHODOLOGY

This observational study was carried out at Dow University of Health Sciences (DUHS) following approval from the Institutional Review Board (IRB No. 1907/DUHS/Approval/2021, dated: 3rd February 2021). CT scans of chest conducted from February till October 2021 whether with contrast or as high-resolution CT scan chest (HRCT) images of patients who presented to the Radiology Department of Dow University of Health Sciences with an already prescribed clinical indication were evaluated retrospectively. By using the Hospital management and information system (HMIS) and by using the option of archive in desk board, researchers searched the CT scan and narrowed down the search with the option of utilising age and time brackets.

CT images of 200 patients (103 males and 97 females) were reviewed. Patients with clavicular trauma or fracture, known chronic illness or malignancy, immunosuppressive drugs (as they may potentially affect bone development), congenital bony abnormalities, or any prior surgical intervention to the sterno-clavicular region were excluded from the study. CT scan chest was performed on 128 slice GE Optima (R).

The volumetric CT data was sent to the workstation and the HMIS. A radiologist with approximately 8 years of post-fellowship experience evaluated all CT images primarily in bone window settings (width/level 1500/450) but was free to change window and reformat images in any plane or window setting as needed for optimal visualisation of medial clavicular epiphyses. The ages of the patient were initially blinded for the observing radiologist. The stages of fusion of maturity of medial clavicular epiphyses were evaluated on either side by using the classification system reported by Schmeling[11] (Figure I). To keep the left and right clavicular measurements in sync, the greatest ossification stage was assigned to individuals whose results differed.

The Statistical Package for the Social Sciences (SPSS) (version 17) software was used to conduct the statistical analysis. The mean, median, standard deviation, and lowest and maximum values were used to represent the study data. Categorical variables were expressed as percentages. The association between age and ossification stage was assessed using a one-way ANOVA test. A two-sample independent t-test was used to compare the two genders. Statistical significance was considered at a p-value of 0.05.

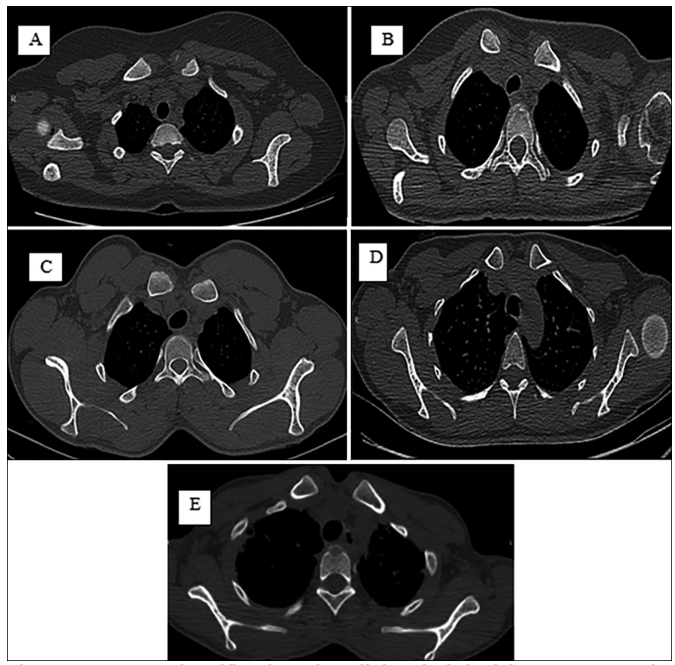

Figure 1: Stages of ossification of medial end of clavicle A,B, C, D, and E corresponding to stages 1, 2 3, 4, and 5 of Schmeling classification, respectively. Stage 1: Non-visible ossification centre. Stage 2: Ossification centre visible, the epiphyseal cartilage is not ossified. Stage 3: Partly visible epiphyseal cartilage. Stage 4: The epiphyseal cartilage has fully ossified, and the epiphyseal scar is evident. Stage 5: Epiphyseal scar and fully ossified epiphyseal cartilage are no longer evident.

RESULTS

A total of 200 patients were included. The mean age of the patients was 24.68 ±7.63 years (range 11-35). There were 103 (51.5%) males and 97 (48.5%) females. A significant increase in the age of the patients was observed with respect to the increase in the stages ($p < 0.001$). When stratified on the basis of gender, a significant increase in age was also observed with respect to the increase in the stages ($p < 0.001$, Table I).

Table I: Mean distribution of age with respect to stages.

	n	Mean age (years)	SD	Age range (min-max)	p-value
Total (n=200)					
Stage 1	17	12.4	1.82	11-17	<0.001
Stage 2	35	15.80	2.52	11-23	
Stage 3	35	22.23	3.94	16-31	
Stage 4	81	28.64	4.01	21-35	
Stage 5	32	33.66	1.47	30-35	
Males (n= 103)					
Stage 1	9	12.78	2.33	11-17	<0.001
Stage 2	20	15.75	2.04	11-19	
Stage 3	14	21.43	3.69	17-27	
Stage 4	38	29.08	3.88	22-35	
Stage 5	22	33.91	1.38	30-35	
Females (n=97)					
Stage 1	8	11.63	0.74	11-13	<0.001
Stage 2	15	15.87	3.11	11-23	
Stage 3	21	22.76	4.09	16-31	
Stage 4	43	28.26	4.12	21-35	
Stage 5	10	33.10	1.59	31-35	

One-Way ANOVA test applied, p-value <0.05 considered as significant.

Frequency of stages showed that stage 4 was observed in majority of the patients, *i.e.*, 81 (40.5%), followed by stages 2 and 3 in 35 (17.5%) each, stage 5 in 32 (16%), while stage 1 was observed in 17 (8.5%) patients (Table II). The age distribution

of participants by the stage of maturation of the medial clavicular epiphysis showed that among patients with 11-15 years of age, stage 1 was observed in majority 15 (51.7%) of the patients. Among patients with 16-20 years of age, stage 2 was observed in majority 20 (57.1%) of the patients. Among patients with 21-25 and with 26-30 years of age, stage 4 was most commonly observed *i.e.*, in 22 (59.5%) and 32 (80.0%) patients, respectively (Table II).

An insignificant difference in age was observed with respect to the gender of the patients. The mean age of male patients was 24.28±7.26 years compared to 25.06±7.99 years (p= 0.472, 95% CI -2.91 - 1.35).

Table II: Percentage of participants in each stage.

Age (years)	Stage 1 n (%)	Stage 2 n (%)	Stage 3 n (%)	Stage 4 n (%)	Stage 5 n (%)	Total
11-15	15 (51.7)	14 (48.3)	-	-	-	29
16-20	2 (5.7)	20 (57.1)	13 (37.1)	-	-	35
21-25	-	1 (2.7)	14 (37.8)	22 (59.5)	-	37
26-30	-	-	7 (17.5)	32 (80.0)	1 (2.5)	40
31-35	-	-	1 (1.7)	27 (45.8)	31 (52.5)	59
Total	17(8.5)	35(17.5)	35(17.5)	81(40.5)	32(16)	200

DISCUSSION

In the current study, there was a significant increase in the age of the patients as the stages increased. When stratified by gender, a significant increase in age was observed in relation to the increase in stages. Stage 1 ossification was first observed in both genders at the age of eleven. Stage 1 was first observed in Kellinghaus *et al*. and Wittschieber *et al*. at age of ten years,[18,19] but not in the current study until the age of eleven. Kellinghaus *et al*. and Wittschieber *et al*. both reported a maximum age of fifteen years at stage 1.[18,19] However, this study reported the oldest age for stage 1 as seventeen years which is also reported as the oldest age for stage 1 by Ekizoglu *et al*.[3] Stage 2 was first observed in both males and females at the age of 11 years and did not appear until the age of 23 years. Bassed *et al*. reported similar findings, with the maximum age for stage 2 being 23 years.[15] According to Pattamapaspong *et al*.,[9] stage 2 appears at ages 14-21 years in males and 12-19 years in females. These ages were 14-20 years in males and 13-19 years in females, according to Kellinghaus *et al*.[18] According to Wittschieber *et al*.,[19] males are 15-20 years old and females are 14-18 years old at stage 2. These findings contradict what was discovered in this research.

Stage 3 appeared in females at the age of 16 and in males at the age of 17, while stage 4 appeared in females at the age of 21 and in males at the age of 22. Kellinghaus *et al*.[18] and Schulz *et al*.[14] reported that stage 4 ossification initially appeared in both genders at the age of 21. Kreitner *et al*.[10] identified stage 4 at 22 years, and Wittschieber *et al*.[19] at 21 years. According to Gakhar *et al*., and Houpert *et al*., stage 4 was detected in females at 20 years of age and in males at 21 years of age.[20,21]

Stage 5 ossification was first observed in males at 30 years of age and females at 31 years. Kellinghaus *et al*., Wittschieber *et al*., and Schmeling *et al*. reported that stage 5 appears at the age of 26.[18,19,22] Furthermore, Ekizoglu *et al*., and Bassed *et al*., reported these ages as 25 and 24 years old, respectively.[3,15]

This study found that the difference in epiphyseal development between males and females is not statistically significant. This was consistent with the findings of several other studies. Pattamapaspong *et al*. reported an insignificant difference in epiphyseal development with respect to gender (except in stage 2).[9]

When compared to other studies conducted in different parts of the world, one notable finding of this study is the delayed appearance of stage 5 in both males and females. It is believed that the disparity in the socioeconomic status of the states in which the studies were conducted is responsible for these variances. Many studies have found that socioeconomic status influences the rate of ossification, with low socioeconomic status slowing development.[3,18,23,24]

There was no definitive data about the socioeconomic status of the countries where the studies were conducted in the literature search, but the authors used human development index reports prepared by the United Nations, which are known to provide significant data about the socioeconomic status of several countries.[3,25] Pakistan ranked 154th on this index, which takes into account a variety of factors. Other countries where such studies are being conducted include Germany; which is ranked sixth on the list; Australia, which is ranked eighth; and France, which is ranked 26th on the list.

The findings of this study revealed a fairly broad age range (4-8 years) for each developmental stage. In addition, extreme diversity was observed in the epiphyseal fusion of the medial end of the clavicle. There was a lot of overlap between stages. Although two distinct males were observed to have reached stage 4 by the age of 22 years, another male was still at stage 3 at the age of 27 years. In terms of statistics, when assessing general developmental trends, these individuals may be regarded as exceptions, and these observations may be overlooked. However, when estimating age in a forensic setting, it is impossible to confirm where the subject falls on the variability scale. This makes determining an individual's exact age difficult. The most significant conclusion that can be derived from this data is that if a person in this demographic has fused clavicles at stage 4, they must be at least 22 years old for males and 21 years old for females. Thus, a multifactorial approach is proposed for determining the age of maturity from a judicial standpoint, as well as in cases of disaster victim identification, utilising the ossification stages of the medial clavicle, which is further authenticated by additional investigations, such as physical examination, X-ray, and dental examination.

To the best of the authors' knowledge, no other computed tomography study on age estimation from medial clavicular epiphyseal fusion has been conducted in Pakistani cohort. This study, however, had several limitations. The results of this study cannot be generalised to the entire population due to the non-probability sampling technique, small sample size, and

single centre used. Additional research with a larger sample size is required.

CONCLUSION

Fusion of the medial clavicular epiphysis was found to be a highly variable in the Pakistani cohort. As a result, determining an individual's age can be difficult. The most important conclusion is that if someone in this community has fused clavicles at stage 4, they must be at least 22 years old male and 21 years old female. Future research will contribute to expanding the database on this topic and improving the measurement procedure.

ETHICAL APPROVAL:

Institutional Review Committee of Dow University of Health Sciences approved this study (Ref: IRB-1907/DUHS/Approval/2021, dated 3rd February 2021). Ethical approvals were obtained prior to initiation of the research work.

PATIENTS' CONSENT:

As data were evaluated retrospectively patients' consent is not applicable.

COMPETING INTEREST:

The authors declared no competing interest.

AUTHORS' CONTRIBUTION:

MF: Literature search, study design and concept, questionnaire design, data interpretation, and manuscript writing.
BR: Study design and concept, questionnaire design, data collection, and data analysis.
ZA: Literature search, questionnaire design, and manuscript writing.
RN: Data interpretation, data analysis, and critical review of the manuscript.
AR: Study design, data interpretation, and data analysis.
All the authors have approved the final version of the manuscript to be published.

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