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Original Article

Forensic Section

The Chronology of Medial Clavicle Epiphysis Ossification using Computed Tomography

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ABSTRACT

Introduction: Age estimation has a paramount importance in forensic practice. Maturation of medial epiphysis of the clavicle plays an important role in age estimation when evaluating individuals between the ages of 13 and 22 years. To get the maximum accuracy in age estimation for criminal proceedings, it is recommended to use maturation stages of the clavicle along with other methods in living as well as deceased.

Aim: To assess the relationship between development of the medial clavicular epiphysis and age in an Indian population and to analyse the chronology of maturity of the clavicle using CT.

Materials and Methods: In the present retrospective study authors evaluated thin slice multidetector Computed Tomography (CT) images of 462 individuals aged between 10 and 30 years retrieved from the SDM College of Medical Sciences and Hospital, Dharwad. The ossification status of the medial epiphysis of the clavicle was determined using the five stage classification mentioned by Schmeling followed by the statistical analysis using SPSS 17.0.

Results: Maturation Stage 2 was first presented at 13 years of age for both sexes, Stage 3 at 16 years in both sexes, Stage 4 at 24 years in females and 22 years in males and the maturation Stage 5 was first presented at 27 years in females and 25 years in males.

Conclusion: Present study reveals that the clavicular maturation Stage 2 represent age >13 years, Stage 3 represent age >16 years, Stage 4 represent age >22 years and Stage 5 represent age >25 years for an Indian.

Keywords: Age estimation, Clavicle, Ossification, Skeletal age

INTRODUCTION

Age estimation has long been used to help identify victims of mass disaster and for medico legal proceedings like identification, narrowing the search possibilities of unknown victims, estimating the age at death, differentiation of cluster victims, determining eligibility for social benefits and aiding immigration services in the processing of undocumented immigrants [1]. In majority of countries, age limits relevant in criminal law for the existence of criminal responsibilities lie between 14th and 21st year of life [2]. Forensic practitioners are constantly improving the accuracy of age determination to improve legal certainty. Maturation of sexual characteristics, teeth and skeleton has been used to determine age [3].

For the purpose of estimating age, the study group on forensic age diagnostics recommends combining a physical examination with an X-ray examination of the left hand and wrist, a dental examination which records dentition status and evaluates an orthopantogram and a radiographic or CT survey of the clavicle [2]. In establishing whether an individual has attained the criminal liability threshold of 18 years, the ossification of sternal clavicular cartilage is of particular interest, as the other systems on which development analysis is based have usually matured by this time. Precise methods for adults such as the amino acid racemisation are not applicable to living persons involved in criminal proceedings [4-6]. X-rays or CT-scan of the clavicle will also play a vital role in ascertaining the suspects age at the time of assault some time prior to the clinical examination.

Since long, correlations between individual age and clavicle maturation have been studied in dry bones and autopsy specimens [7-9]. Recently, the utility of imaging tools such as radiography, ultrasonography, CT, and Magnetic Resonance Imaging (MRI) are used in various studies in evaluating clavicular maturation. Of all the imaging tools, CT has particular advantages including high image resolution, accuracy in detecting ossification centers and lack of super imposed soft tissue and can be used in either living or dead individuals as post mortem imaging [10-13].

The use of CT in evaluation of the medial epiphysis of clavicle was first introduced by Kreitner KF et al., [14]. Later,

Schmeling A et al., [2] developed the commonly used staging system dividing clavicle maturation into 5 stages: beginning with non ossified ossification center and ending with complete ossification and union with metaphysis. There are a number of negative effects due to ionizing radiation produced by CT. The new techniques may evolve in future which reduce the ionizing effect. Of course this can be neglected when it is applied to a deceased person.

Currently, majority of the studies using CT to evaluate clavicle maturation were conducted in Europe [10-12,14-16]. The aim of present study was to assess the relationship between development of the medial clavicular epiphysis and age in an Indian population.

MATERIALS AND METHODS

The present retrospective study was conducted on Indian population. CT-scans of the neck or chest of patients aged between 10 and 30 years taken between January 2010 and 2016 in the Department of Radiology at Shri Dharmasthala Manjunatheswar (SDM) College of Medical Sciences and Hospital, Karnataka, India, were evaluated. Ethical approval was obtained by Institutional Ethical Committee prior to evaluation. All patients were Indian nationals by birth. Medical records were reviewed for year of birth, date of performing CT to calculate the completed age in years, and medical conditions. Patients with diseases that may affect bone development including previous fractures of the clavicle, chronic illness, hormonal imbalance, congenital anomalies, and patients who were treated by steroids, chemotherapy or immunosuppressive drugs were excluded from this study. Data on nutrition or socioeconomic status was inaccessible.

High resolution thin slice imaging was obtained using 128 row multidetector scanner (single source CT system, Somatom definition AS, Siemens, Erlangen, Germany). All axial and coronal images of 1 mm slice thickness were used in evaluation. The CT images were evaluated on a standard picture archiving and communication system (PACS) (Medsynapse version 5.0.1.3, Pune). Standard viewing tools such as zoom tools, window leveling, and measurement were used. The thin slice axial images (1 mm) allow subsequent reconstruction to the high quality images on coronal, sagittal and oblique plane also called multiplanar reformatted images. When stages remain in doubt on axial and coronal views, the multiplanar images in the long axis of clavicle were used.

The clavicular maturation stages were scored by two radiologists experienced for eight years at two different time intervals to see any intraobserver and interobserver variability. Both examiners routinely determined skeletal maturation using clavicles on CT as a part of evaluation for chest wall. The staging followed the five stages of maturation described by Schmeling A et al., [2] [Table/Fig-1]. The stages were as follows:

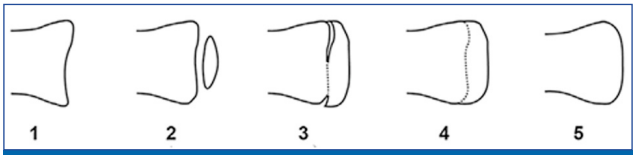
Stage 1: Non-ossified epiphysis.

Stage 2: Ossified epiphysis, growth plate not ossified.

Stage 3: Growth plate is partially fused.

Stage 4: Complete union of the epiphysis and metaphysis; physeal scar is visible.

Stage 5: Complete union of the epiphysis and metaphysis; physeal scar is no longer visible.



[Table/Fig-1]: Stage of maturation of the medial epiphysis of clavicle described by Schmeling et al (2004).

Right and left clavicles were staged separately. The images were scored by method described by Schmeling A et al., [2]. Both observers were blinded for patient's chronological age. In certain cases where a different ossification status observed between right and left clavicles, the more advanced (Stage) side was used for analysis.

STATISTICAL ANALYSIS

Statistical analyses were performed using statistical software SPSS version 17.0. Results are expressed as minimum, maximum, mean and standard deviation. The differences of each maturation stage between both sexes were analysed by using two sample 't'-test. Statistical significance was set at $p< 0.05$. The box and whiskers plot will express the degree of maturation of medical clavicular epiphysis with chronological age and sex.

RESULTS

A total of 462 CT scans met criteria after analysing all the scans performed over six years in retrospective manner. Selection was done as per pre specified inclusion and exclusion criteria. Certain scans with poor image quality and ossification patterns were unclassifiable hence were excluded. The assessment of ossification of medial clavicle was performed in 462 patients (180 females and 282 males). The intraobserver variability was negligible with Kappa value of 0.97, interobserver variability was very less with Kappa value of 0.85, showing that there was very good strength of agreement between two observers.

Age by sex distribution of patients has been summarised in [Table/Fig-2]. Descriptive statistics are divided into maturation stages in [Table/Fig-3]. Sex based comparisons revealed statistically significant differences in mean age at maturation Stage 1, 3 and 5. The maturation at Stage 1 occurred 16 months earlier in female (mean age 12.08 vs. 13.39 years), at Stage 3, 14 months earlier in female (mean age 20.67 vs. 21.94 years) whereas, Stage 5, 12 months earlier in males

Age (Y)	Sex		Total
	Female	Male	
10	6	2	8
11	4	4	8
12	6	6	12
13	4	12	16
14	4	3	7
15	8	14	22
16	4	14	18
17	14	13	27
18	21	12	33
19	16	12	28
20	13	13	26
21	12	18	30
22	9	18	27
23	5	3	8
24	4	24	28
25	15	35	50
26	7	23	30
27	6	16	22
28	8	26	34
29	2	4	6
30	12	10	22
Total	180	282	462

[Table/Fig-2]: Age by sex distribution of patient.

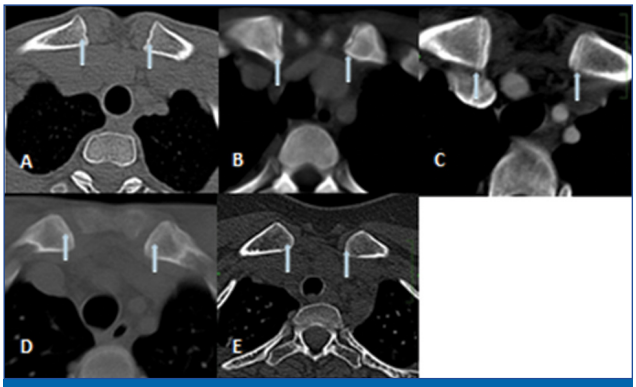
(mean age 27.84 vs. 28.85 years) compared to females [Table/Fig-4]. No statistically significant differences were noted in other maturation stages (2 and 4) [Table/Fig-4]. The box and whiskers plots of all stage values reveal the degree of maturation of medical clavicular epiphysis with chronological age and sex [Table/Fig-5].

Maturation Stage 2 was first presented at 13 years of age for both sexes with mean age at 17.79 and 17.85 for females and males respectively. Maturation Stage 3 was first presented at age 16 years in both sexes with mean age of 20.67 and 21.94 in females and males respectively. Maturation Stage 4 was first presented at 24 years in females and 22 years in males with a mean age of 25.30 and 25.55 respectively. Maturation Stage 5 was first presented at 27 years in females and 25 years in males [Table/Fig-3].

The study sample was used to calculate age of individuals by using the results of present study and tabulated separately. Then this sets of calculated age was correlated with chronological age of individuals, which gives Pearson's correlation coefficient (r) of 0.9153, which indicate that age calculated by results of present study provide higher correlation for the referred population [Table/Fig-6].

Stage	Sex	N	Range	Mean	Std. Deviation	Std. Error of Mean	p-value
1	F	24	10-15	12.08	1.792	0.366	0.009*
	M	36	10-16	13.39	1.886	0.314	
	Total	60	10-16	12.87	1.944	0.251	
2	F	52	13-23	17.79	2.071	0.287	0.882
	M	60	13-21	17.85	2.193	0.283	
	Total	112	13-23	17.82	2.128	0.201	
3	F	58	16-26	20.67	2.544	0.334	0.011*
	M	64	16-26	21.94	2.883	0.360	
	Total	122	16-26	21.34	2.789	0.253	
4	F	20	24-27	25.30	0.801	0.179	0.557
	M	84	22-29	25.55	1.852	0.202	
	Total	104	22-29	25.50	1.701	0.167	
5	F	26	27-30	28.85	1.190	0.233	0.01*
	M	38	25-30	27.84	1.653	0.268	
	Total	64	25-30	28.25	1.553	0.194	
Total	F	180	10-30	20.39	5.318	0.396	
	M	282	10-30	21.85	5.121	0.305	
	Total	462	10-30	21.28	5.241	0.244	

[Table/Fig-3]: Descriptive statistics for age by sex and ossification stage expressed in year.
*Significant was set at p-value < 0.05

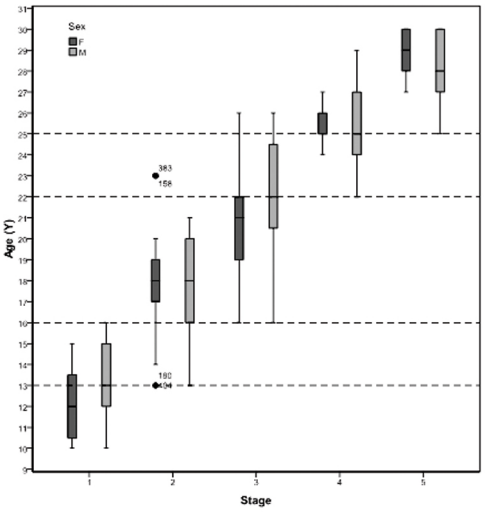


[Table/Fig-4]: Stages of union of medial clavicular epiphyses. a) Stage 1: Non-ossified epiphysis; b) Stage 2: Ossified epiphysis, growth plate is not ossified; c) Stage 3: Growth plate is partially fused; d) Stage 4: Complete union of the epiphysis and metaphysis; epiphyseal scar is visible; e) Stage 5: Complete union of the epiphysis and metaphysis; epiphyseal scar is no longer visible.

A linear regression was calculated for age as independent variable and Stage as dependent variable. The regression equation for the age and Stage for females is age = -1.472 + 0.212 (Stage) and for males is age = -1.69 + 0.219 (Stage).

DISCUSSION

Schmeling A et al., described five stages of clavicular maturation, as given in [Table/Fig-1]. Hence, the use of these stages in age estimation is easy to implement. As per the literature, these stages are used to assess maturation of



[Table/Fig-5]: Box plots of the correlation between chronological age and stages for maturation of the medial epiphysis of clavicle with reference line at 13, 16, 22 and 25 years and outlier marked ( ) (statistically).

	Pearson's correlation coefficient (r)	p-value	R squared
Present study results	0.9153	<0.001	0.83

[Table/Fig-6]: Correlation of present study results with chronological age.

	Kellinghaus M et al., [16]	Wittschieber D et al., [10]	Present study
Study characteristics			
n	502	493	462
Age	10-35	10-40	10-30
Slice thickness (mm)	0.6–1.5	0.6	1
Minimum–maximum age by maturation stages (years)			
1	10-15	10-15	10-16
2	13-20	14-20	13-23
3	16-26	15-36	16-27
4	21-35	21-40	22-29
5	26-35	26-40	25-30

[Table/Fig-7]: Comparison of study results conducted on different population using maturation of medial clavicular epiphysis.

medial epiphysis of the clavicle in adolescents and young adults in varied populations [10,16,17].

Present study provides evidence of correlations between maturation of medial epiphyseal center of clavicle and chronological age in Indian young adults [Table/Fig-6]. The summary of these results [Table/Fig-3,4], can be used to create reference data along with similar studies conducted on a large population data for age estimation.

In Indians, the active phase of maturation (Stage 2) began at <14 years which is consistent with European and Thai populations [16,17], whereas, Wittschieber D et al., observed it at 14 years in his study on German population [10] [Table/Fig-7].

Although, the first presence of epiphysis in this study was 13 years before, a year earlier than that found in German population, an outlier or the completed age in years used during the data collection has likely caused this difference. This earlier Stage 2 maturation in females was also noted in another study of Caucasian origin [16].

Many countries use age 18 and 21 as a cut off point for whether juvenile or adult penal systems are to be applied. In India 16 and 18 years are the landmarks to decide whether a male or a female is a juvenile or an adult respectively. For age estimation, maturation Stage 3 represents 16 years or older in many European countries [16]. This criterion was derived appropriately from European studies where maturation Stage 3 did not occur before 16 years. But few studies conducted on the same population revealed that Stage 3 could represent 15 years or older [10]. However, present study reveals that Stage 3 was first present at age of 16 years which is an important land mark in the Indian judiciary to decide whether an Indian male is a juvenile or an adult in cases of heinous crimes.

Present study reveals that maturation Stage 4 represents 22 and 24 years for males and females respectively, whereas, studies conducted on European population represented 21 years [10,16]. Maturation Stage 5 represents 25 years or older in the present study, whereas studies conducted on European population revealed 26 years or older respectively [10,16] [Table/Fig-7]. These findings reflect that maturation of the medial epiphysis of the clavicle occur at different ages in different population and ethnic groups.

Hence, for age estimation in Indian population, Stage 2, 3, 4 and 5 of maturation should represent ages >13,>16,>22 and >25 years respectively. This modification is especially critical since age thresholds for Indian criminal laws are 16 and 21 years.

A CT-scan image in multiple planes enhances accuracy of classification. When staging is doubtful on the axial plane, we found that multiplanar reformatted images perpendicular to the growth plate helped to solve this problem.

Potential difficulties in staging include the presence of variants of epiphysis, overlooking epiphyseal scars and misinterpretation between Stage 1 and 4. The different forms of epiphyseal configuration, can lead to inappropriate grading of maturation [18]. The different forms include fish mouth, bowl-like, and trident [18,19]. Since, the effect of configuration on maturation speed remains unknown Wittschieber D et al., recommended avoiding staging when these variants are present [19]. Overlooking epiphyseal scar can lead to misinterpretation of Stage 4 as Stage 5. This difficulty can be avoided by utilizing

thin slice scans (< 1 mm), appropriate window selection for bone, and viewing images in all slices [19,20]. Stage 1 and 4 may be misinterpreted since both stages do not present separated epiphyseal centers. This difficulty can be avoided by adding hand radiographs or dental radiographs to aid in interpretation. Stage 4 of maturation should be present in ages over 18 years when skeletal maturation of the hand or dentition of third molar is complete [21,22].

Ultrasonography, and MRI are non-radioactive methods used in living persons [23-25]. Ultrasonography is more accessible than MRI but accuracy is limited by the restricted angle of view resulting in only partial visibility of the bone surface. Moreover, growth plate residues in the center are hidden in the shadows of ultrasound waves [23,26]. Radiography is a safe and widely accessible method, but evaluation of the medial clavicular epiphysis is difficult owing to overlapping ribs, vertebrae, and mediastinal structures [27]. Radiation exposure from CT is approximately 0.6-0.8 mSv for imaging clavicle, which is higher than the conventional radiograph (0.2 mSv) but lower than other diagnostic CT examinations such as 2-11mSv for head, chest, abdomen, and pelvis scans [28,29].

LIMITATION

This study has few limitations that need to be considered while interpreting our results. Images used in present study were retrieved from clinical cases. Occasionally, intravenous contrast and endotracheal intubation created linear streak artifacts over the medial clavicle resembling growth plates. Extensive experience with artifact appearance has helped experts to differentiate these radiolucency streaks from the unfused growth plate. Linear streak artifacts are usually darker than the growth plate and often extend beyond the clavicle. Different CT techniques such as patient's position, arm position and radiation dose may affect the sharpness of images of medial clavicular epiphysis. From our observation this effect did not profoundly degrade the interpretation if thin slice images were used. Present study sample is hospital based with no defined population base, male and female study groups are unbalanced in their sample size as well as very low number of patients in some age ranges. Hence, the sample may not be is representative to create a reference data for Indian population.

Further, subjects completed age in years is considered for statistical analysis which may give an estimated age in wider range and potential of rounding down to almost near to one year. This rounding up of completed age in years may create difference in comparing the present study with the previous studies. If the same is considered in months or weeks it may give a narrow range of estimated age which is much more precise and vital in age estimation for judicial proceedings.

CONCLUSION

Present study results suggest that the clavicular maturation Stage 2 represent age >13 years, Stage 3 represent age >16 years, Stage 4 represent age >22 years and Stage 5 represent age >25 years. CT is a very useful visualisation tool for estimating chronological age throughout adolescence and young adulthood. Similar studies can be conducted over a large population dataset in different parts of India to create a reference data to estimate age of an Indian.

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