ACCURACY OF RADIOGRAPHIC EVALUATION OF CLAVICULAR OSSIFICATION FOR AGE ESTIMATION IN MARDAN, PAKISTAN

Shahid Iqbal[1], Mian Hasnain Ali[2], Qudsia Hassan[3], Falak Nigar[2], Naveed Ali Qadri[4], Sadia Abdul Qayyum[5]

ABSTRACT

Background: In forensic medicolegal examination, the individuality of a person, whether living or deceased, is essential for establishing their absolute identity in both civil and criminal cases. Medical professionals play a primary role in verifying and confirming personal identities. An individual's identity is determined by factors such as age, sex, race, and stature, with age being a key factor in absolute identification. We conducted a study on the population of Mardan, Khyber Pakhtunkhwa (KPK), Pakistan, to estimate the age of individuals between 17 and 30 years. The study included both males and females who were referred to the department of Forensic Medicine & Toxicology, Bacha Khan Medical College, Mardan, specifically for age Determination.

Methods: This cross-sectional study was conducted in the Department of Forensic Medicine and Toxicology at Bacha Khan Medical College, Mardan, KPK, after obtaining ethical approval from the chairman of the Ethics Committee. Meeting the inclusion Criteria, cases were enrolled in the study.

Results: This study concluded that the majority of cases showed complete union of the clavicle epiphysis in males between 21 and 22 years of age and in females between 19 and 20 years of age.

Conclusion: The current study determined that the slight variation in the age of complete fusion of the medical end of the clavicle is 21-22 years in males and 19-20 years in females, respectively.

Keywords: Age Assessment, Age of Fusion, Clavicular Ossification Center, Forensic, Medial Clavicular Epiphysis, Radiological Assessments.

INTRODUCTION

The establishment of an individual's identity is fundamental in civil and criminal medico-legal investigations. Medical professionals assist law enforcement agencies and courts in determining identity parameters such as age, sex, race, and stature.[1] Among these parameters, age estimation has particular forensic importance. [2]

Age determination is commonly required for the issuance of computerized national identity cards and B-forms in Pakistan. It is especially relevant in illiterate individuals lacking documented birth records.

Age assessment is also crucial in criminal proceedings to determine legal responsibility and eligibility for trial under juvenile justice laws. [3]

Radiological evaluation of the clavicle, particularly the medial epiphysis, has gained prominence in forensic age estimation due to its predictable ossification timeline and the ease with which it can be visualized using imaging modalities such as chest X-ray, CT scans, or MRI. The Schmeling technique, a widely used and standardized protocol in forensic science, assesses the fusion stages of the medial clavicular epiphysis. This method divides ossification into five stages, each corresponding to specific age ranges, enabling forensic experts to estimate an individual's age with reliable accuracy.[4]

Age estimation strategies in forensic practice are classified into clinical, dental, and skeletal methods. Among skeletal indicators, bone fusion stages, specifically of the long bones and the clavicle, provide important information. Before the age of 20 years, several long bones, including the radius, ulna, femur, and tibia, exhibit active ossification centers, which are assessed for their fusion status. However, most long bone fusion methods have traditionally been applied during teenage years, making them less useful for age estimation in individuals over 18 years.[5-6]

[1] Bacha Khan Medical College, Mardan
[2] Combined Military Hospital (CMH), Mardan
[3] Ziauddin University Karachi
[4] Isra University, Hyderabad, Sindh
[5] Liaquat National Hospital and Medical College, Karachi

Address for Correspondence
Dr. Shahid Iqbal
Assistant Professor, Forensic Medicine and Toxicology, Bacha Khan Medical College, Mardan, KPK, Pakistan
Zain696.si@gmail.com
+92-3432738696

One of the key benefits of using the clavicle for age estimation is that it can be assessed using commonly available radiological tools, such as chest X-ray (posteroanterior views). In resource-limited settings, including Mardan District in Pakistan, advanced imaging modalities such as CT or MRI may not always be accessible due to high costs or lack of infrastructure. In contrast, chest radiography (posteroanterior radiographs of the chest were examined to determine the age at the sternal end of the clavicle) is inexpensive and widely available, even in small healthcare facilities, and can effectively visualize the fusion status of the medial end of the clavicle without requiring specialized equipment.[7]

In contrast, orthopantomography (OPG), which is frequently used for dental age estimation, may not be available in many tertiary care hospitals, even those with a dental department [1]. While dental age estimation is generally reliable, its applicability becomes limited beyond the age of 17 years. Consequently, skeletal age estimation, particularly of the clavicle, becomes critical for individuals aged 17-30 years, a period during which other traditional age indicators lose their reliability.[8]

International studies have supported the use of these methods, highlighting the reproducibility and reliability of the CT-based clavicular age estimation in adolescent and younger adults, even when employing a low-dose radiation protocol [9,10]

In the Pakistani context, a growing body of local studies supports the reliability and validity of clavicular epiphyseal ossification as a tool for age estimation. Radiographic evaluation of the clavicle in Pakistani populations has demonstrated findings consistent with global ossification timelines [1,8]. Similarly, CT-based studies conducted in Peshawar and Karachi have reinforced the consistency of medial clavicular ossification patterns across diverse ethnic and regional populations. [7,11]

In addition to its application in civil and criminal cases, clavicular ossification assessment is also used in migration and asylum assessments. In several European and North American countries, verification of age in unaccompanied minors is essential. It is required for determining access to social services. The Schmeling technique is routinely employed in these settings as part of forensic clinical assessments. [8] This highlights its global relevance and supports its adoption in Pakistani forensic practices.

This study aims to assess the accuracy and applicability of radiographic evaluation of clavicular ossification for age estimation in individuals aged 17–30 years. By focusing on real-world cases referred to the forensic department for age determination, the study seeks to provide evidence for the practicality and reliability of using readily available imaging, particularly chest X-rays (posteroanterior radiographs of the chest were examined to determine the age at the sternal end of the clavicle), as a forensic tool. In doing so, it aims to bridge the gap between high-cost advanced imaging modalities and resource-limited settings, promoting a more inclusive forensic protocol adaptable to the constraints of Pakistan's healthcare system.

MATERIAL AND METHODS

Study design: Cross-sectional study

Settings: This research is conducted in the Department of Forensic Medicine and Toxicology, Bacha Khan Medical College, Mardan, KPK, Pakistan. After the ethical approval from the Chairman of the Ethical Committee, Reference No 799/BKMC dated 16/05/2025 was granted to Assistant Professor Dr Shahid Iqbal. Meeting the inclusion criteria, cases were enrolled in the study.

Duration of the Study: Within six months after the approval of the study by the institutional Ethical Review Committee of the institution.

Sample size:

A total of 311 cases of age estimation were referred from DHQ hospital Mardan to the forensic department in the month of June 2025. In this study, 100 subjects were selected for the study as per the population sample of the study of Mardan, KPK, Pakistan. Matching the inclusion criteria. Both 50 males and 50 females were included.

Sampling Techniques: Consecutive Sampling Technique

Sample Selection:

Inclusion Criteria: All the medicolegal cases referred to the forensic department for age estimation between 17-30 years, both genders included.

Exclusion Criteria:

All the medicolegal cases presenting to the forensic department, court cases for age determination, Previous fracture of the clavicle,

Down and Turner syndromes, and Congenital birth defects of the clavicle, Chronic illness, malignancy, pathological, nutritional, endocrine disorders, and the use of immunocompromised drugs that affect bone growth & development

Data Collection Procedure: Data were collected by interviewing the referred case to determine the indication for age estimation. To improve accuracy, a dual radiographic approach was used, employing more than one skeletal indicator for cross-verification. For young adults, an orthopantomogram (OPG), a panoramic dental X-ray, and a chest X-ray including both Sholders ere advised for age determination. All the X-rays were carefully analyzed by a radiologist to assess the appearance and fusion of the medial clavicular ossification center.

RESULTS

During June 2025, a total of 311 cases were referred to the forensic department of the Bacha Khan Medical College, Mardan, KPK, for age assessments. After applying the inclusion criteria, 100 cases (comprising 50 males and 50 females) were selected for detailed analysis. The age of these individuals ranged from 17 to 30 years. Assessment was performed using chest X-rays by a consultant radiologist, focusing on the stage of epiphyseal appearance and fusion.

The findings revealed a clear trend in the development and fusion of the medial clavicular epiphysis with increasing age. In the 17-18 age groups, 5 males showed no sign of ossification, while some males and females showed the presence of the ossification center without any union. Partial fusion began to appear in both sexes, more frequently in females. Interestingly, complete union was already seen in 4 females in this earliest age group, suggesting that clavicular fusion tends to occur earlier in females.

In the 19-20 age group, the number of individuals with complete union increased notably; 16 females and a few males achieved complete fusion. This highlights a significant gender difference in bone maturation, with females showing earlier epiphyseal fusion than males. The 21-22 age group showed the highest number of males with complete union, 14 cases, indicating that the majority of males complete clavicular fusion during this period.

Beyond 22 years of age, most individuals of both sexes had completed fusion. Only a few cases showed partial union in the 23-24 and 25-26 age groups, and none showed an unfused or absent ossification center after age 22.

The overall study demonstrates that the medial clavicular epiphysis typically completes fusion between 19 and 20 years in females and between 21 and 22 years in males. These findings are consistent with established forensic literature and highlight the value of clavicular radiography in estimating age in young adults, particularly in the 17-25 age range, where legal and medicolegal distinctions of adulthood are most critical.

Table I: Stages of Epiphysis Union [4]

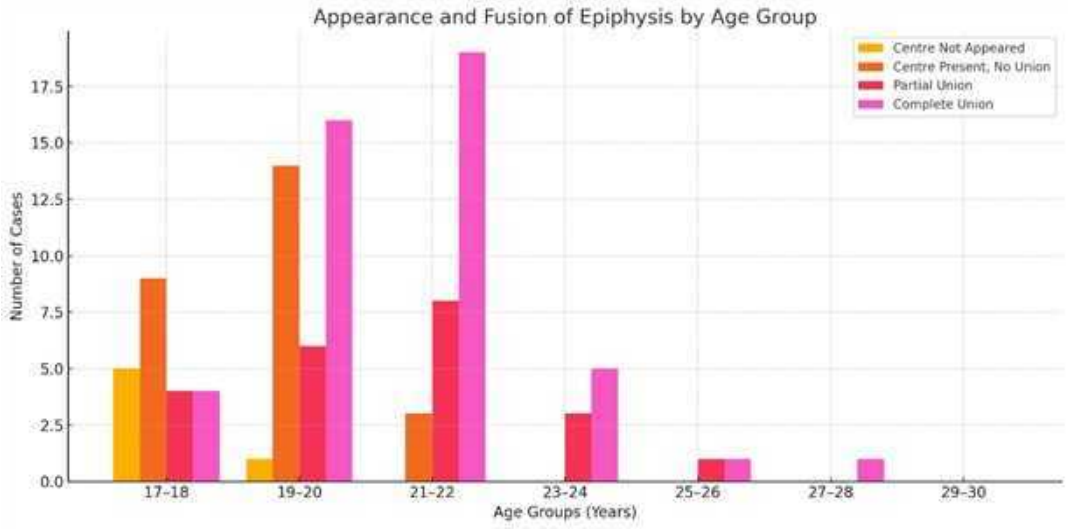
Stage	Appearance and fusion of epiphysis	Garding
1	The center of ossification did not appear.	A
2	Center present but non-union	B
3	Union partially seen	C
4	Union completed	D

Table II: extent of fusion of the medial end of the clavicle in different age and sex wise groups

Appearance and fusion of epiphysis	Age groups 17-18		Age groups 19-20		Age groups 21-22		Age groups 23-24		Age groups 25-26		Age groups 27-28		Age groups 29-30		Total
The center of ossification did not appear.	M	F	M	F	M	F	M	F	M	F	M	F	M	F	
	5	0	1	0	0	0	0	0	0	0	0	0	0	0	6
Center present but non-union	4	5	8	6	2	1	0	0	0	0	0	0	0	0	26

Union partially seen	0	4	1	5	7	1	2	1	0	1	0	0	0	0	22
Union completed	0	4	0	16	14	5	4	1	1	0	1	0	0	0	46
Total	9	13	10	27	23	7	6	2	1	1	1	0	0	0	100

*M= male, F=female



DISCUSSION

This study assessed the degree of fusion of the medial clavicular epiphysis. Complete fusion (Degree D) of the medial clavicle is typically observed in males between 21 and 22 years and in females between 19 and 20 years. This pattern reflects the well-documented sexual dimorphism in skeletal maturation, with females generally reaching skeletal maturity earlier than males. (**14,15).**

Comparable findings had been mentioned in neighboring South Asian populations. For example, in Pakistan. Mentioned that level D fusion is normally carried out among 21-23 years in adult males and 19-21 years in females, with the main effects of the ethnic and dietary habits running parallel. **(5,16).** While CT imaging gives us advanced resolution, as our population can't afford it, our findings advocate that chest radiographs continue to be a legitimate and reachable device for age estimation.

International comparisons show similar findings. In Turkey, level D ossification was observed at approximately 22 years in males and 20 years in females using CT imaging, likely influenced by population genetics and the detection capabilities of CT scans **(16,18).** Similarly, studies from Nepal and Sri Lanka reported comparable age ranges for complete clavicular fusion. **(19,20).**

The information presented in Table 2 highlights clear sex-specific differences in fusion timelines. At 19-20 years, 16 females exhibited complete union, compared to 14 males at 21-22 years. These findings confirmed the sexual dimorphism observed in clavicular ossification. This pattern aligns with Schmeling's methods, which emphasize gender-specific interpretation in forensic protocols for clavicular age estimation **(18,21-22,23,25).**

Stage A (absence of an ossification center) was observed only in the youngest age group (11-18 years), occurring in 5 males and 1 female. This agrees with previous studies reporting that the ossification center first appears during late adolescence (19-20 years). Stage B (presence of the ossification center without fusion) was most common in males aged 19-20 years, indicating active fusion. Stage C (partial fusion) was seen over a wider age range (17-24 years), with one case over 24 years showing incomplete fusion. These results support earlier research showing that complete fusion (stage D) is usually achieved by 26 years in almost all individuals **(18,23).**

Although CT and MRI provide higher precision in assessing clavicular ossification, their routine

use is often limited by cost, availability, and ethical considerations, particularly in resource-constrained regions **(24,25).** Conventional radiography, while less detailed, has been widely applied for systemic evaluation of clavicular development. Our study supports this approach, demonstrating reliable results using a practical and accessible imaging technique. Previous research has highlighted the diagnostic advantages of CT in detecting subtle ossification changes **(26,27).** Nonetheless, due to concerns about radiation exposure and limited access to advanced imaging, radiographs remain a practical and appropriate option in many forensic settings.

CONCLUSION

This study demonstrates that sex and age significantly influence the appearance and fusion of the medial clavicular epiphysis. In males aged 17-18 years, the ossification center was largely absent, while partial union was most frequent between 19-22 years. Complete epiphyseal union generally occurred at 21-22 years in males and 19-20 years in females in the Mardan population. These findings provide valuable reference data for medico-legal age estimation and support the practical use of accessible imaging techniques, such as radiography, in forensic evaluation within the local population.

Author's Contribution:

1. **Dr. Shahid Iqbal**
   Idea, background, ethical approval, result compiling, and correspondence to the journal.
2. **Dr. Mian Hasnain Ali**
   Database search, referencing, and citation, Introduction
3. **Professor Dr Qudsia Hassan**
   Proofreading
4. **Dr Falak Nigar**
   X-rays result interpretation, filing, Materials and Methods
5. **Dr. Naveed Ali Qadri**
   Assistance in the discussion and conclusion
6. **Dr Sadia Abdul Qayyum**
   Provide overall excellence and support throughout the research and manuscript preparation process.

Conflict of interests: None

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