

Radiographic Analysis of Shoulder Ossification Compared to Hand/Wrist X-Rays for Age Estimation in Late Adolescents and Young Adults: A Medico - Legal Perspective in Services Hospital, Hyderabad

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ABSTRACT

OBJECTIVE: To assess and compare inter-and intra-observer reproducibility and accuracy of shoulder bone ossification with conventional hand and wrist X-rays for age estimation in late adolescents and young adults, and to correlate the ossification of the clavicle with wrist bones in medico-legal assessment of age at Services Hospital, Hyderabad.

METHODOLOGY: This cross-sectional radiographic study, approved by the institutional ethical review board, was conducted over a period of six months. One hundred (n=100) participants, both male and female participants, in the age group of 12–25 years were included using purposive sampling. Any patient having underlying endocrinological disorders, prior fractures in the surgical area, a history of surgery in areas relevant to femoral diversion, a congenital or developmental abnormality, or pregnancy was excluded. Ossification characteristics and developmental stages were evaluated on unilateral (left-sided) shoulder and bilateral hand/wrist radiographs.

RESULTS: Most of them were in the age group of 16. The occurrence of wrist ossification Stage V from age 17 onwards suggested that wrist maturation may be earlier than shoulder maturation. In some participants, ossification of wrists reached Stage V with shoulders as low as Stages 3 or 4, indicating shoulder delays. Classes 4 and 5 were mainly observed in subjects aged 19–25 years, consistent with prolonged shoulder ossification.

CONCLUSION: The use of hand/wrist and shoulder X-rays together improves age estimation for medico-legal analysis, as these bones mature at different times. In forensic settings in Pakistan, reliable birth records are often lacking. This overarching strategy is particularly valuable.

KEYWORDS: Radiographic age estimation; Shoulder ossification; Hand/wrist X-rays; Medico-legal age estimation; skeletal maturation; Forensic radiology

INTRODUCTION

Radiological determination of skeletal maturation has always been a cornerstone of forensic age estimation, especially in situations where no documents prove the birth date. It's popular because of its scientific basis, non-invasive process, and availability for forensic investigations globally¹. This is important in several legal situations, such as identifying unknown individuals, assessing age of criminal liability, resolving disputes about age and immigration processes². The correct determination of an age is essential, for example, in cases involving unknown persons, determining the ability to commit a crime or the capacity for criminal responsibility (the ability to distinguish right from wrong), age conflicts in judicial proceedings and processing immigration cases. In the context of asylum seekers, juvenile justice, and disaster victim identification, GCR is particularly well-suited because it offers an optimal trade-off among accuracy, reproducibility, and ethical acceptability. Age in Pakistan also has extra complications because

people are often not registered at birth, and particularly in the case of births which take place outside health facilities (which tends to be common practice for many births in rural/under-served areas)^{3,4}. It is, therefore, crucial that age determination can be accurate to guarantee legal protection, an entitlement to education and social services, eligibility for treatment and appropriate treatment in the justice system⁵. It is equally important for differentiating minors from adults in criminal proceedings and for ensuring the protection of unaccompanied minors in refugee matters. One aspect of radiographic age estimation we can capitalize on is that rates of skeletal maturation proceed relatively predictably during growth.

The Greulich and Pyle atlas, based on hand and wrist radiographs, has been traditionally considered the gold standard for age estimation in children and adolescents⁶. Nevertheless, in late adolescence and adulthood, the hand and wrist are usually fully developed, limiting their utility as predictors in older ages. Consequently, other skeletal locations have been targeted for meticulous timing of recovery due to their extended ossification timelines, including the medial clavicle, pelvis, knee, leg, foot, and shoulder

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joints, where protracted healing also occurs. However, a few studies have tried to combine different assessment methods (dental evaluation and hand/wrist radiographs) for better age estimation. The medial clavicular epiphysis and proximal humerus, which are inherent to the shoulder complex, have lengthy ossification windows that should prove helpful radiographic predictors in late adolescence into early adulthood⁷. The X-ray of these regions might be more informative, or serve as an adjunct, than conventional hand/wrist X-rays, but mostly when skeletal maturity in the hand and wrist has finished. While different countries have developed international standards, forensic age estimation has long been underdeveloped in Pakistan due to underdeveloped standardized protocols, a lack of trained bone specialists, and ethical issues surrounding the X-ray examination of still-living individuals. Given the large population near the legal threshold of 18 years, establishing reliable, locally validated age-estimation methods is crucial. Currently, no research from Hyderabad, Pakistan, has directly compared shoulder and hand/wrist radiographs for age estimation in young adults. Considering that skeletal development is influenced by genetic, nutritional, and environmental factors, international findings may not be fully applicable to the local population. This study, therefore, aims to assess and compare the reliability of shoulder and hand/wrist radiographs for estimating chronological age, thereby strengthening forensic age-assessment practices in Pakistan.

METHODOLOGY

The study used a descriptive cross-sectional design and was conducted over 6 months July 2025 to December 2025 following ethics committee approval. A pool of 100 participants, both male and female, aged 12-25 years, was selected purposively from cases referred for routine evaluation at a service hospital in Hyderabad. The reason for selecting this method was the controlled hospital-based setting and the accessibility of eligible participants. Purposive sampling might limit generalizability, but it did allow inclusion of a representative range of skeletal developmental stages within a target age group. The chosen pool of participants was deemed sufficient to represent a variety of skeletal growth stages within the selected age range. For each individual, X-rays of both shoulders and both hands/wrists were obtained to assess bone growth and developmental changes. For maintaining uniformity and accuracy, standard positioning procedures were applied at the time of image collection. Each image was then examined to determine the extent of ossification and the level of bone maturity. Findings from shoulder and wrist images were compared to understand patterns of

bone formation and their link to chronological age. Participants were included if they were of good health and within the desired age range. Individuals who had a hormonal disorder, prior bone fractures, surgical interventions in the examined areas, developmental irregularities or pregnancy were not considered. These restrictions helped ensure that the data reflected normal bone growth and that basic demographic details, such as age and gender, were recorded to correlate with the ossification findings. Retrieval of radiographic data was recorded and analyzed with Statistical Package for Social Sciences (SPSS) version 22. Descriptive statistics (mean, standard deviation, and frequency distributions) were used to summarize age and ossification stages. The ossification stages were scored on a 5-point scale, with Stage 1 = initial ossification and Stage V = complete epiphyseal fusion.

RESULTS

The study noted that the majority of cases occurred in the 16-20-year age group, based on a sample ranging from 12-25 years. (Table I)

Table I: Distribution of Wrist and Shoulder Ossification Stages by Age (n=100)

Age Group (years)	Mean Wrist Stage (±SD)	Mean Shoulder Stage(±SD)	Number of Cases (n)	Most Frequent Stage (Wrist/ Shoulder)
12 - 13	3.0 ± 0.0	2.5 ± 0.5	6	III / II-III
14 - 16	4.3 ± 0.4	3.0 ± 0.5	25	IV / III
17 - 18	4.9 ± 0.2	4.3 ± 0.4	30	V / IV
19 - 20	5.0 ± 0.0	4.8 ± 0.3	30	V / IV-V
21 - 25	5.0 ± 0.0	5.0 ± 0.0	9	V / V
Total	-	-	100	-

Wrist compared with shoulder maturation. In some cases, they have Stage V wrist ossification and Stage 3 or 4 in the shoulder bone, indicating a delay of shoulder ossification relative to wrist ossification. Shoulder (4 and 5) advanced most often between 19-25 years, suggesting that at least some of shoulder maturation occurs after wrist. However, the wrist and shoulder ossification stages showed a modest positive correlation, indicating that these regions ossify in general synchrony, though with occasional lapses. Ossification of the shoulder continued into early adulthood, but that of the wrist had reached a plateau far earlier. Such correlation here is strong evidence for the adjunctive role of shoulder X-ray in age estimation. Wrist X-rays' potential to provide more precise age ranges during mid-adolescence, and the specific role of shoulder ossification as a marker for differentiating ages in late adolescence/early adulthood, where wrist maturation had significantly plateaued. (Figure 1)

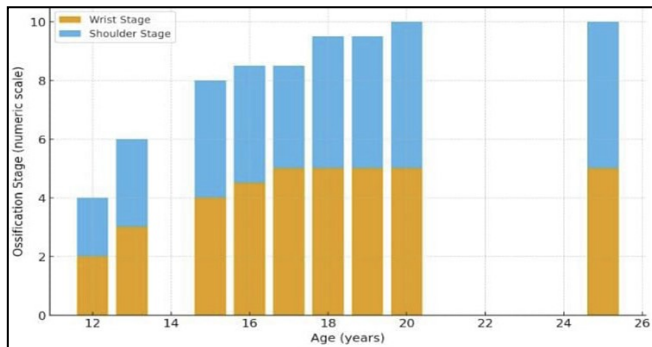


Figure 1: Distribution of Wrist and Shoulder Ossification by Age

DISCUSSION

The wrist ossified relatively early, generally maturing around 17 years of age, limiting its effectiveness for age estimation in late adolescence. While shoulder ossification is a more reliable marker for age estimation in late adolescence and early adulthood. Notably, some participants showed fully matured wrist ossification, while shoulder ossification remained immature. Demonstrating that shoulder maturity is the more credible measure for accuracy in borderline cases. These findings align with international literature identifying the clavicle and shoulder regions as among the last skeletal sites to mature. Therefore, dual-site radiographs of the wrist and shoulder enhance medico-legal age estimation. However, the study has limitations, including a hospital-based cross-sectional design and potential observer variability. Overall, the results support the inclusion of combined wrist and shoulder imaging in forensic practice.

This work demonstrates that assessment of ossification of the shoulder bone, specifically the medial clavicular epiphysis, augments 2-dimensional hand and wrist radiographs for medico-legal age estimation in late adolescence/early adulthood. Radiographs of the hand and wrist, which are the most commonly used method for skeletal age assessment, remain informative in certain cases; however, epiphyseal fusion of wrist bones is typically completed around late adolescence, limiting their use beyond 18 years⁸. In contrast, clavicular ossification and calcification persist well into the first third (up to two thirds) of the second decade of life, thereby providing additional discriminating information with respect to individuals around the legally relevant age boundaries (i.e., 18-21 years)⁹. Similar results have been seen in previous forensic studies, which show that combinations of the clavicular epiphysis are more certain than just wrist and hand X-rays for assessment of age for older adolescents and early adult individuals. The present study also reported acceptable inter- and intra-observer reproducibility, indicating that shoulder radiographs could be reproducible and practical in a medico-legal context. In addition to indicating a positive association among the ossification stages of the clavicle and bone

maturation in the wrist, this study also demonstrated that combining analyses across different anatomical locations can enhance the overall effectiveness of forensic age determination. In earlier work, we have shown that this multifactorial skeletal evaluation is more precise medico-legally than the assessment of a single radiographic site, especially in cohorts with genetic and ethnic diversity^{10,11}. Few studies conducted in South Asian populations have reported small regional differences in the timing of fusion of clavicles, highlighting the importance of using local normal reference standards for Pakistani individuals. The potential to replicate these findings may reduce inter-observer variation and enhance the applicability of proof of radiological age assessment in legal practice. Thus, the combined evaluation of bilateral shoulder and wrist left ossification is a simple, cheap and convenient method to estimate age in forensic cases arriving in tertiary care centres¹².

Limitations

Several limitations should be considered. This purposive sampling method may cause selection bias and limit the generalizability of the results. These ossification changes could not be evaluated over time due of their cross-sectional design. Second, the sample was a specific 12-25 age group, without reference to older age groups that may play a role in other forensic contexts. Future studies should be more longitudinal in nature, use larger samples and predictive models and utilize a more diverse set of demographic variables to enhance reliability and the generalizability of findings.

CONCLUSION

Results confirm that hand and wrist x-rays remain the most accurate basis for age estimation in late adolescence, but are less useful when the degree of ossification from the scapula to the measurement site is close to peak. Conversely, when there is redundancy in the evolution of changes in the wrist bones for age-based evaluation of late adolescents and young adults, the shoulder bones provide very good supplementary evidence. The age-determination process through medico-legal analysis has been shown to be more precise when using both wrist and shoulder radiography.

Ethical permission: Liaquat University of Medical and Health Sciences (LUMHS), Jamshoro, , Pakistan, ERC approval letter No. LUMHS/REC/-868.

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AUTHOR CONTRIBUTION

Bibi I: Conceptualization and study design

Umar M: Data Collection

Siddique M: Data analysis and Interpretation

Khatri P: Manuscript drafting

Kumari P: Manuscript drafting

Saleem S: Critical revision

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