



Research Article

Radiographic Assessment of Wrist Epiphyseal Fusion for Forensic Age Estimation in the Gadag Population of Karnataka

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ABSTRACT

Background: Age estimation plays a significant role in forensic medicine, civil identification, criminal investigations, and clinical practice. Radiological assessment of epiphyseal fusion is considered a reliable method for determining skeletal maturity. However, the timing of epiphyseal fusion varies according to geographic, genetic, nutritional, and environmental factors, necessitating population-specific standards.

Aim: To evaluate the age of epiphyseal fusion around the wrist joint in the Gadag population using radiographic assessment.

Materials and Methods: A prospective cross-sectional study was conducted among 95 healthy individuals comprising 57 males and 38 females aged between 12 and 20 years. Standard anteroposterior radiographs of both wrist joints were obtained after informed consent. The fusion status of the distal radius, distal ulna, base of the first metacarpal, and appearance of the pisiform bone were evaluated. Statistical analysis was performed using descriptive statistics.

Results: Complete fusion of the distal radial epiphysis was observed at 19–20 years in males and 18–19 years in females. Fusion of the distal ulnar epiphysis occurred at 19–20 years in males and 16–17 years in females. Complete fusion of the base of the first metacarpal was noted at 18–19 years in males and 17–18 years in females. The pisiform bone was visualized in all males by 14–15 years of age, whereas in females it was observed as early as 12–13 years of age.

Conclusion: The present study demonstrates earlier skeletal maturation in females compared to males and highlights regional variation in epiphyseal fusion patterns. These findings may be useful for forensic age estimation in the Gadag population.

Keywords: Age estimation, epiphyseal fusion, wrist joint, radiology, forensic medicine, skeletal maturity.

INTRODUCTION

Bone age is a vital measure used to determine an individual's biological and structural maturity. (1-4). The global rise in juvenile crimes, increased reports of child abuse, and growing numbers of immigrant cases have underscored the medico-legal importance of accurately estimating children's ages. Moreover, precise age determination in the pediatric population is essential in fields such as forensic medicine, endocrinology, and planning orthodontic treatments. (5-6)

Human skeletal growth follows a sequential pattern, with epiphyseal fusion serving as a key marker of biological age. Radiographic assessments allow forensic experts to estimate chronological age in both living individuals and skeletal remains. However, past research highlights significant variability in fusion timelines due to regional, genetic, and environmental factors.

The most advanced method for age estimation currently available is the radiological examination of epiphyseal union in long bones. Research conducted on both international and Indian populations indicates that a single standard for epiphyseal fusion, including joints like the wrist and ankle, cannot be universally applied. This variability is attributed to factors such as genetics, diet, climate, geographic location, and environmental conditions, all of which may evolve over time. (7-9)

MATERIALS AND METHODS

Study Design

A prospective cross-sectional study was conducted in the Department of Radiodiagnosis in collaboration with the Department of Forensic Medicine.

Study Population

The study included 95 healthy individuals comprising 57 males and 38 females in the age group of 12–20 years.

Inclusion Criteria

- Healthy individuals aged between 12 and 20 years
- Individuals born and brought up in Gadag for at least 5 years
- Individuals willing to participate in the study

Exclusion Criteria

- Individuals with congenital skeletal abnormalities
- History of previous fractures involving the wrist joint
- Metabolic or endocrine disorders affecting bone growth
- Nutritional deficiencies or chronic systemic illness
- Poor quality radiographs

Ethical Considerations

Institutional Ethical Committee approval was obtained prior to commencement of the study. Written informed consent was obtained from all participants and from parents or guardians in the case of minors.

METHODOLOGY

The date of birth of all participants was confirmed using Aadhaar card records or other valid government-issued documents.

Standard anteroposterior radiographs of both wrist joints were obtained. The following bones were studied:

- Distal radius
- Distal ulna
- Base of first metacarpal
- Pisiform bone

The degree of epiphyseal fusion was categorized as:

1. No fusion
2. Partial fusion
3. Complete fusion

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using descriptive statistical methods. Results were expressed as percentages and age ranges. Categorical variables were analyzed using the Chi-square test. A p-value <0.05 was considered statistically significant.

RESULTS

Demographic Distribution

A total of 95 healthy individuals aged 12–20 years were included in the study, comprising 57 males (60%) and 38 females (40%). The maximum number of participants belonged to the 12–13 year age group (n=19), followed by the 14–15 year age group (n=17). No statistically significant difference was observed in gender distribution across age groups ($p = 0.877$).

Table 1. Age and gender distribution of study participants

Age group (years)	Males	Females	Total
12–13	9	10	19
13–14	8	4	12
14–15	9	8	17
15–16	4	2	6
16–17	9	3	12
17–18	9	6	15
18–19	6	3	9
19–20	3	2	5
Total	57	38	95

Fusion of Distal Radius

Complete fusion of the distal radial epiphysis was observed between 19–20 years in males and between 18–19 years in females. Partial fusion was first noted in the 16–17 year age group among males and in the 14–15 year age group among females. Females demonstrated earlier epiphyseal fusion compared to males.

Fusion of Distal Ulna

Fusion of the distal ulnar epiphysis was completed between 19–20 years in males and between 16–17 years in females. Partial fusion of the ulna appeared earlier in females than in males, indicating relatively earlier skeletal maturation in females.

Fusion of Base of First Metacarpal

Complete fusion of the base of the first metacarpal occurred between 18–19 years in males and 17–18 years in females. Partial fusion was noted from 13–14 years onwards in both sexes, with females showing earlier progression toward complete fusion.

Appearance of Pisiform Bone

The pisiform bone was visualized in all males by the age group of 14–15 years. In females, the pisiform bone was observed as early as 12–13 years of age.

Table 2. Age of complete epiphyseal fusion in the present study

Structure	Males (years)	Females (years)
Distal radius	19–20	18–19
Distal ulna	19–20	16–17
Base of 1st metacarpal	18–19	17–18
Pisiform appearance	14–15	12–13

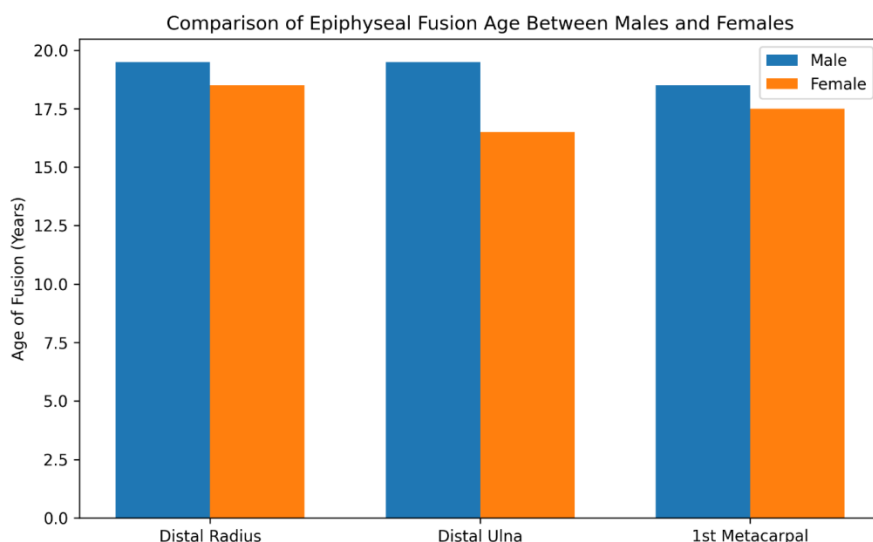


Figure 1.

Bar graph showing comparison of age of complete epiphyseal fusion of the distal radius, distal ulna, and base of the first metacarpal between males and females. Earlier fusion was observed in females compared to males across all studied bones.

Table 3. Comparison of age of epiphyseal fusion with previous studies

Study	No. of subjects	Radius (Male)	Radius (Female)	Ulna (Male)	Ulna (Female)
Banerjee et al.	180	19–20	18–19	19–20	18–19
Nemade et al.	80	20–21	19–20	19–20	19–20
Hassan et al.	160	18–19	17–18	18–19	17–18
Krishnamoorthy et al.	296	18–19	17–18	16–17	15–16
Ebeye et al.	384	18–19	18–19	18–19	18–19
Present study	95	19–20	18–19	19–20	16–17

Figure 2



Anteroposterior radiograph of the left wrist and hand of a male subject aged approximately 11–12 years showing non-appearance of the pisiform bone with non-fusion of the distal radial and distal ulnar epiphyses, as well as non-fusion of the base of the first metacarpal.

Figure 3



Radiograph of the wrist shows complete fusion of the epiphysis at the base of the first metacarpal with partial fusion of the distal radial and ulnar epiphyses. Pisiform ossification is present. These findings correspond to a skeletal age of approximately 15–16 years in females.

Figure 4



Anteroposterior radiograph of the left wrist and hand of a male subject showing complete fusion of the distal radial and distal ulnar epiphyses along with complete fusion of the base of the first metacarpal, indicating attainment of skeletal maturity.

DISCUSSION

Age estimation is an important component of forensic medicine and is frequently required in civil and criminal cases, identification procedures, juvenile justice matters, and medico-legal investigations. Radiological assessment of epiphyseal fusion is considered a reliable and widely accepted method for skeletal age estimation. However, the timing of epiphyseal fusion varies among populations due to genetic, nutritional, environmental, climatic, and socioeconomic factors. Therefore, population-specific studies are essential for improving the accuracy of forensic age estimation.

In the present study, complete fusion of the distal radial epiphysis was observed at 19–20 years in males and 18–19 years in females. These findings are comparable to those reported by Banerjee et al., who also observed fusion at 19–20 years in males and 18–19 years in females.⁽¹⁰⁾ Similar findings have been reported in several Indian studies, suggesting relatively consistent fusion patterns of the distal radius across different populations.^(15–18) However, Hassan et al. and Krishnamoorthy et al. reported slightly earlier fusion, occurring at 18–19 years in males and 17–18 years in females.^(12,13) In contrast, Nemade et al. documented comparatively delayed fusion, with complete union occurring at 20–21 years in males and 19–20 years in females.⁽¹¹⁾

In the current study, complete fusion of the distal ulnar epiphysis was observed at 19–20 years in males and 16–17 years in females. Similar ages of fusion in males were reported by Banerjee et al. and Nemade et al.^(10,11) Hassan et al. and Ebeye et al. observed fusion of the distal ulna at 18–19 years in both sexes.^(12,14) Krishnamoorthy et al. reported earlier fusion, particularly in females, with complete union occurring at 15–16 years.⁽¹³⁾ The earlier fusion observed in females in the present study supports the established concept that skeletal maturation occurs earlier in females than in males.

The present study also evaluated fusion of the base of the first metacarpal. Complete fusion was observed at 18–19 years in males and 17–18 years in females. Females demonstrated earlier progression toward complete fusion compared to males. Similar observations have been reported by Singh et al., who noted complete fusion of the secondary ossification center of the base of the first metacarpal in the majority of subjects by 17 years of age.⁽¹⁹⁾

Assessment of the pisiform bone revealed that it was visualized in all males by 14–15 years of age, whereas in females it was observed as early as 12–13 years. Earlier ossification in females further supports the pattern of accelerated skeletal maturation in females compared to males. The findings of the present study are consistent with the general observation that ossification centers appear and fuse earlier in females.

The findings of the present study emphasize the importance of regional standards in forensic age estimation. Variations in skeletal maturation among different populations highlight the limited applicability of universal standards for age estimation. The present study therefore provides useful reference data for forensic experts, radiologists, and clinicians dealing with age estimation in the Gadag population of Karnataka.

CONCLUSION

The present study demonstrates that epiphyseal fusion around the wrist joint occurs earlier in females compared to males. Complete fusion of the distal radius and ulna occurred between 18 and 20 years of age, while fusion of the base of the first metacarpal occurred slightly earlier.

These findings provide useful regional reference data for forensic age estimation in the Gadag population and highlight the importance of population-specific standards in skeletal age assessment.

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