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Original Research Article

Radiological Age Estimation from Epiphyseal Fusion of Distal Femur and Proximal Tibia

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Key words
Age estimation,
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Abstract

Introduction: Forensic anthropology utilizes age estimation techniques based on the examination of the distal femur and proximal tibia to determine the age of an individual. This method involves analyzing the fusion of epiphyseal plates, which are located at the ends of these long bones and play a key role in bone growth during childhood and adolescence. To estimate age, radiographic imaging techniques such as X-rays are used to visualize the skeletal structure of the distal femur and proximal tibia. **Materials and Methods:** This study involved patients who underwent digital X-ray examinations in Department of Radiology, Sri Ramachandra Institute of Higher Education and Research, Chennai during the year 2023. Total of 200 cases (108 males and 92 females) were randomly selected between the age group of 10 – 20 years. The stages of ossification at the epiphyseal fusion of the distal femur and proximal tibia were analyzed in Department of Forensic Medicine after obtaining the digital X-rays of the knee joint in antero-posterior view. **Results:** The results are significant in concluding that if the union of distal femur and proximal tibia are in stage 0 and 1, the age of the individual is less than 13 years, if in stage 2 and 3, the age is between 14-17 years and if in stage 3 and 4, the age is more than 18 years.

1. Introduction

Forensic anthropology utilizes age estimation techniques based on the examination of the distal femur and proximal tibia to determine the age of an individual. The bones of human skeletons develop from separate ossification centers. From these centers, ossification progresses till the bone is completely formed. These changes can be studied by means of X-rays.

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It is therefore possible to determine the approximate age of an individual by radiological examination of bones till ossification is complete.[1,2] This method involves analyzing the fusion of epiphyseal plates, which are located at the ends of these long bones and play a key role in bone growth during childhood and adolescence. To estimate age, radiographic imaging techniques such as X-rays are used to visualize the skeletal structure of the distal femur and proximal tibia. By examining the fusion patterns of the epiphyseal plates in these regions, forensic anthropologists can make inferences about the individual's age. [3, 4, 5]

X- rays of the long bones can be examined to determine the degree of fusion, which can then be compared to established age standards to estimate the individual's age. This method is particularly useful when other methods of age estimation are inconclusive or unavailable, and can provide important information in cases where the individual's identity is unknown or disputed.[6] Forensic age assessment in living subjects has become increasingly important over the last few years in both civil and criminal cases, especially in the age group between 14 and 21 years.[7] This information can also help to identify the deceased human remains, particularly in cases of mass disasters, unidentified bodies and age assessment in legal contexts.[8] Age determination by radiography of the relevant bones and joint is a well-accepted fact in the field of forensic medicine and among the various parameters available, skeletal age determination is considered the best. Sometimes, it serves an important piece of evidence of age determination in sensitive criminal cases to fix the punishment for the accused especially in cases of juvenile or young perpetrator. Estimating the age from ossification of bones radiographically is very crucial in cases of child sexual abuse & sexual assaults, trafficking, violent deaths and also in civil cases of inheritance, child labor and marriage.[9] It is imperative in medico-legal proceedings to accurately estimate the age of an individual as many laws and criminal codes are dependent on the age of the victim or the accused.[10, 11, 12]

2. Materials and Methods

This study involved patients who underwent digital X-ray examinations in Department of Radiology, Tertiary care hospital during the year 2023 for various medical reasons. A total of 200 cases (108 males and 92 females) were randomly selected between the age group of 10 – 20 years based on specific inclusion and exclusion criteria. The study design for this research was a cross-sectional study and individuals willing to participate in the study were included after obtaining informed consent. The stages of ossification at the epiphyseal fusion of the distal femur and proximal tibia were analyzed in Department of Forensic Medicine after obtaining the digital X-rays of the knee joint in antero-posterior view. Chi-square and ANOVA tests were performed using SPSS software (Statistical Package for the Social Sciences) to demonstrate the significance of the estimated ages and to compare different age groups.

The distal femur has an epiphyseal growth plate called the distal femoral epiphysis and the proximal tibia has an epiphyseal growth plate called the proximal tibial epiphysis located near the knee joint. The appearance and fusion status of this growth plate were examined. The degree of closure or ossification of the distal femoral and proximal tibial growth plates were evaluated and compared to established age standards. Based on the appearance and fusion status of the distal femoral and proximal tibial growth plates the individual's age was estimated.

The epiphyseal union of distal femur and proximal tibia of five stages with estimation of age described by O'Connor et al [2] is given in **table no. 1**.

Table no. 1: Five stages of the epiphyseal union of distal femur and proximal tibia.

Stage 0	Non-union	Age between 10 – 12 years
Stage 1	Beginning union	Age between 12 – 14 years
Stage 2	Active union	Age between 14 – 16 years
Stage 3	Recent union	Age between 16 – 18 years
Stage 4	Complete union	Age above 18 years

Using X-ray film, age is estimated according to the above grading and the individual's age is identified.

3. Results:

Findings of femur bone (distal end of femur) are tabulated in **table no. 2**.

Table 2: Number of male & female subjects according to stages.

Male		Female	
Stages	**Subjects(n=54)**	**Stages**	**Subjects(n=46)**
Stage 0	15	Stage 0	8
Stage 1	10	Stage 1	6
Stage 2	9	Stage 2	10
Stage 3	11	Stage 3	12
Stage 4	9	Stage 4	10

Age groups for both males and females were

categorized into three ranges: 10-13, 14-17, and 18-20. A grade system was employed to predict age using data from the distal femur (**table 3**). Validation of the estimated ages was conducted through separate chi-square tests for males and females, utilizing distal femur data. In both genders, the estimated age derived from the distal femur yielded a p-value of 0.000, which was statistically significant.

Table 3: Age prediction from distal end of femur

Gender	Group (estimated age in yrs)	Stages					sig. (p <0.05)
		Stage 0	Stage 1	Stage 2	Stage 3	Stage 4	
Male	1 (10 – 13)	8	5	2	0	0	
	2 (14 – 17)	0	1	8	10	0	
	3 (18 – 20)	0	0	0	2	10	
	Total	8	6	10	12	10	0.000
Female	1 (10 – 13)	15	10	1	0	0	
	2 (14 – 17)	0	0	8	8	0	
	3 (18 – 20)	0	0	0	3	9	
	Total	15	10	9	11	9	
Total	(0 to 4)	23	16	19	23	19	

Table 4: Comparison of femur distal ages with between groups and within groups.

Between groups	Within groups	Sig. (p < 0.05)
1 (10 – 13)	2 (14 – 17) 3 (18 – 20)	0.000
2 (14 – 17)	1 (10 – 13) 3 (18 – 20)	0.000
3 (18 – 20)	1 (10 – 13) 2 (14 – 17)	0.000

In order to assess statistical significance, an ANOVA test was used to compare femur distal ages with between groups and within groups. It was statistically significant for both groups with a p-value of 0.000 (**table 4**).

Findings of tibia bone (proximal end of tibia) are tabulated in **table no. 5**.

Table 5: Number of female & Male subjects according to stages.

Female		Male	
Stages	Subjects (n=46)	Stages	Subjects (n=54)
Stage 0	8	Stage 0	15
Stage 1	6	Stage 1	10
Stage 2	9	Stage 2	9
Stage 3	13	Stage 3	8
Stage 4	10	Stage 4	12

Table 6: Age prediction from proximal end of tibia.

Gender	Group (estimated age in yrs)	Stages					Sig. (p <0.05)
		Stage 0	Stage 1	Stage 2	Stage 3	Stage 4	
Male	1 (10 – 13)	8	5	2	0	0	
	2 (14 – 17)	0	1	7	8	0	
	3 (18 – 20)	0	0	0	5	10	
	Total	8	6	9	13	10	0.000
Female	1 (10 – 13)	15	10	2	0	0	
	2 (14 – 17)	0	0	7	4	0	
	3 (18 – 20)	0	0	0	4	12	
	Total	15	10	9	8	12	
Total	0 to 4	23	16	18	21	22	

The age groups for both males and females were divided into three distinct ranges: 10-13, 14-17, and 18- 20 years (**table 6**). Employing a grade system, age prediction was based on information extracted from the proximal tibia. To validate the accuracy of the estimated ages, chi-square tests were performed for males and females, utilizing data from the proximal tibia. Remarkably, in both genders, the estimated age obtained from the proximal tibia yielded a p-value of 0.000, which was statistically significant.

Table 7: Comparison of tibia proximal ages between groups and within groups.

Between groups	Within groups	Sig. (p < 0.05)
1 (10 – 13)	2 (14 – 17) 3 (18 – 20)	0.000
2 (14 – 17)	1 (10 – 13) 3 (18 – 20)	0.000
3 (18 – 20)	1 (10 – 13) 2 (14 – 17)	0.000

The ANOVA test demonstrated statistical significance in comparing proximal tibia ages both betweengroups and within groups, with a remarkably

low p-value of 0.000 (**Table 7**).

4. Discussion

Age estimation using X-rays of the distal femur (the lower part of the thigh bone) and proximal tibia (the upper part of the shinbone) is a commonly employed method in forensic anthropology and skeletal age assessment. The development and fusion of specific ossification centers in these bones can provide valuable information about a person's age. Ossification centers are areas of bone formation that appear as radiolucent regions on X-rays.[13] The X-ray images of these bones can provide valuable information about the skeletal development and fusion of specific growth centers, which can be used to estimate a person's age.[14] Age estimation using X-rays of the distal femur and proximal tibia is typically performed by comparing the findings with established reference standards or age estimation charts.[15]

Aly SM et al. reviewed retrospectively a total of 479 anteroposterior and lateral radiographs of the knee in subjects aged between 10 and 20 years old; 255 males and 224 females. Epiphyseal union was scored as stage 0 (non-union), stage 1 (beginning union), stage 2 (active union), stage 3 (recent union) or stage 4 (complete union). It has been noted that union occurs at an earlier age in the Chinese population. As expected, epiphyseal union in females occurred earlier than males.[16]

In the current study, Age estimation can be made by assessing the fusion stages of the epiphysis at the distal end of the femurusing a 5-stage scale. The analysis of the samples showed that among females, there were 8 cases in stage 0, 6 cases in stage 1, 10 cases in stage 2, 12 cases in stage 3, and 10 cases in stage 4 and among males, there were 15 cases in stage 0, 10 cases in stage 1, 9 cases in stage 2, 11 cases in stage 3, and 9 cases in stage 4.

Age estimation can be made by assessing the fusion stages of the epiphysis at the proximal tibia using 5-stages. The analysis of the samples showed that among females, there were 8 cases in stage 0, 6 cases in stage 1, 9 cases in stage 2, 13 cases in stage 3, and 10 cases in stage 4 and among males, there were 15 cases in stage 0, 10 cases in stage 1, 9 cases in stage 2, 8 cases in stage 3, and 12 cases in stage 4.

Anil Aggrawal et al. has stated that the lower end of femur and upper end of tibia unites with the shaft at 18 years.[17] Other textbook authors have also stated the same but various stages of union of long bones have not been completely studied further in Indian population.

The results using X-rays is a valid method of estimating age and is consistent with the following studies. The Suchey-Brooks Atlas named after the researchers, George R. Suchey and Stanley Rhine Brooks involves the examination of several features on X-ray images, including the appearance of the medial clavicle, the proximal tibial epiphysis, and the distal femoral epiphysis. Each feature is scored based on its developmental stage, and the scores from different features are combined to estimate the individual's age.[18]

The Ubelaker Method, developed by Douglas H. Ubelaker, for age estimation using X-ray images of the distal femur and proximal tibia compared the data to estimate the age from sub adults and young adults. This method utilizes the X-ray data from the distal femur, the proximal tibia, and the medial clavicle. It is based on a regression formula that combines the age-related changes observed in these bones to estimate age.[19]

O'Connor et al. described the epiphyseal union method to estimate age using X-ray based on the observation of the fusion or closure of epiphyseal growth plates in the distal femur and proximal tibia. The study included 200 subjects 108 were males and 22 were females aged between 10 to 20 years, the findings revealed that a significant majority of cases exhibit complete fusion of the lower end of the femur at approximately 19- 20 years for males and 17-18 years for females. Notably, females tend to achieve fusion earlier than males.[4]

MK Meena et al. carried out a study to determine age by epiphyses fusion at knee joint by X-Ray in age group of 14 to 21 years. 100 subjects (64 males, 36 females) were selected randomly from various schools and neighborhood. The age was verified by checking the date of birth from school admission records. Anteroposterior & lateral views of knee joint was taken for fusion of ossification centre. Maximum number of cases belongs to 17-18 years of age group in both genders. Complete fusion of epiphysis and diaphysis in lower end of femur was observed at 18-19 years of age in male and 17-18 years of age in females.[20]

The current study findings indicate that a significant majority of cases exhibit complete fusion of the lower end of the femur and proximal tibia at around 19-20 years for males and at 17-18 years for females. Nermeen N. Welson et al (2019) conducted a study and estimated maturation of the knee joint

starts from the age of 10 and ends at 20 years. The epiphyseal unions were higher in females than males from the distal femur and proximal tibia and their score was statistically significant.[21]

Galic I et al. analyzed a sample of anteroposterior x-rays of the knee joints from 446 living individuals from Umbria, Italy (234 males and 212 females), aged between 12 and 26 years and evaluated the ossification of the distal femoral (DF), proximal tibial (PT), and proximal fibular (PF) epiphyses. They took into account possible persistence of the epiphyseal scars in the ossified epiphyses by the adopted stages of those previously introduced by Cameriere et al. (2012) and also used measurements from all three epiphyses to calculate the total score of maturation for the knee joint (SKJ). These results indicate that the SKJ method may give valuable supporting information in forensic procedures for discriminating individuals of legal adult age of 18 years. [22, 23]

The results of the current study also demonstrate that skeletal maturation fusion happens earlier in females than in males, with a significant mean difference of 19 years for males and 17 years for females and is a potential site for age estimation in late adolescence.

5. Limitations

For age estimation from the proximal tibia and distal femur using X-ray technique, several limitations have to be considered when interpreting the results like Population Variation, Individual Variation, Age Range Limitations, Sex Differences, Postmortem changes and also a much larger sample size.

6. Conclusion

The X-ray technique is utilized for age estimation in subadults and adolescents, as well as in unidentified decayed and missing individuals, to narrow down potential matches. Age indicators such as dental development or long bone lengths are commonly employed in such cases. This study presents alternative techniques for age estimation of fragmentary remains, demonstrating that the size of the metaphyses and epiphyses at the knee exhibits a remarkably strong correlation with chronological age.

A grading score system can be used with a higher degree of accuracy and reliability in estimating age based on these measurements. The study findings indicate that a significant majority of cases exhibit complete fusion of the lower end of the femur and proximal tibia at around 19-20 years for males and at 17-18 years for females, with females generally completing fusion earlier than males. Also, the results are significant in concluding that if the union of distal femur and proximal tibia are in stage 0 and 1, the age of the individual is less than 13 years, if in stage 2 and 3, the age is between 14-17 years and if in stage 3 and 4, the age is more than 18 years. So, observing the various stages of union from long bones from x-rays will be useful to estimate the age in different ranges with precision.

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