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Estimation of Forensic Age from Bony Fusion of Distal Femoral and Proximal Tibial Epiphyses by MRI of the Knee

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Abstract. To test the relevance of bony fusion of distal femoral and proximal tibial epiphysis by means of Magnetic Resonance Imaging (MRI), a cross-sectional study was performed to determine the reliability of 16th and 18th years of life. Methodology: We scanned 140 Indian (Bengali) subjects in the age bracket of 3 and 35 using 1.5 T MR-scanner utilising T1 turbo spin-echo sequence representing true bone anatomy, in the Indian Bengali population. Minimum, maximum, mean and standard deviation were defined. Bony fusion took place before the 18th year of life. Intra- and interobserver agreements were determined by calculating the kappa coefficients. Bony fusion of distal femoral and proximal tibial epiphyses in 1.5 Tesla MRI is useful only to a certain extent in determining age 16 to 17 years of life in both sexes, but completion of 18th year of life cannot be solely determined by MRI from bony fusion of knee.

Keywords: Forensic; Age estimation; MRI; Knee.

1. Introduction

Applied forensic age diagnostics can be used for the process of forensic identification. Age interval is of importance as it contains several relevant age thresholds in medico-legal cases including the 16th, 18th and 21st years of life^{1,2}. For example, to deal with child sexual abuse cases (that regards any sexual activity with a child below 18 years a crime), in some countries like India there is a special law, The Protection of Children from Sexual Offences (POCSO) Act, 2012^{3,4}.

Victims who seek justice for child sexual abuse cases face a lot of difficulties if they don't have a proper birth certificate or other authentic documents to prove their age.

Proof of age of a person is needed for legal purposes. Several studies have been published on this topic by using traditional method of anthropology and by studying bones of the dead⁵⁻⁸. However, advanced methods involving X-Ray and CT scan is seen to produce better results because of their high-quality images. In this context, study of age-related progression of epiphyseal-metaphyseal bony fusion and epiphyseal ossification proved to be useful in populations across the globe^{9,10}. Growth rate of body is diverse for different ethnic groups and for this reason in this study we have attempted to determine age by studying the MRI images of the bony fusion of the distal femoral epiphysis and the proximal tibial epiphysis in the Indian Bengali population. The aim of the present study is to determine how strongly the chronological age relates to ossification of the knee when a 5-stage grading system was used. Objective of this study was to determine age of study subjects, aged between 3 and 35 years, by studying the MRI images of the bony fusion of the distal femoral epiphysis and the proximal tibial epiphysis

2. Methodology

2.1. Study participants

Study was conducted on the 140 selected Indian Bengali patients (by simple random sampling)¹¹, aged between 3 and 35 years, brought for MRI examination of knee for various reasons at Calcutta National Medical College digital MRI centre, using 1.5 T MRI. 6 months was the study period. The ages of study subjects were verified from unique identification card issued by Govt. of India (Aadhar Card) and cards issued by State Govt for free cashless treatment in hospitals (Swasthya Sathi Card). Those subjects whose ages could not be verified were excluded from this study. Proper informed consent was taken from patient/next of kin. Ethical Clearance (CM/CNMC/1993) for this study was taken from Ethics Committee of Calcutta National Medical College.

2.2. MRI analysis

All our scans were performed with same scanner in same sequence. All MRI images were transferred to a commercially available workstation. On the workstation, the images were studied using RadiAnt DICOM Viewer software and ossification stages were noted under the supervision of the Radiologist of that centre. In order to define

the different ossification stages, the established classification of Schmeling et al.¹² was used.

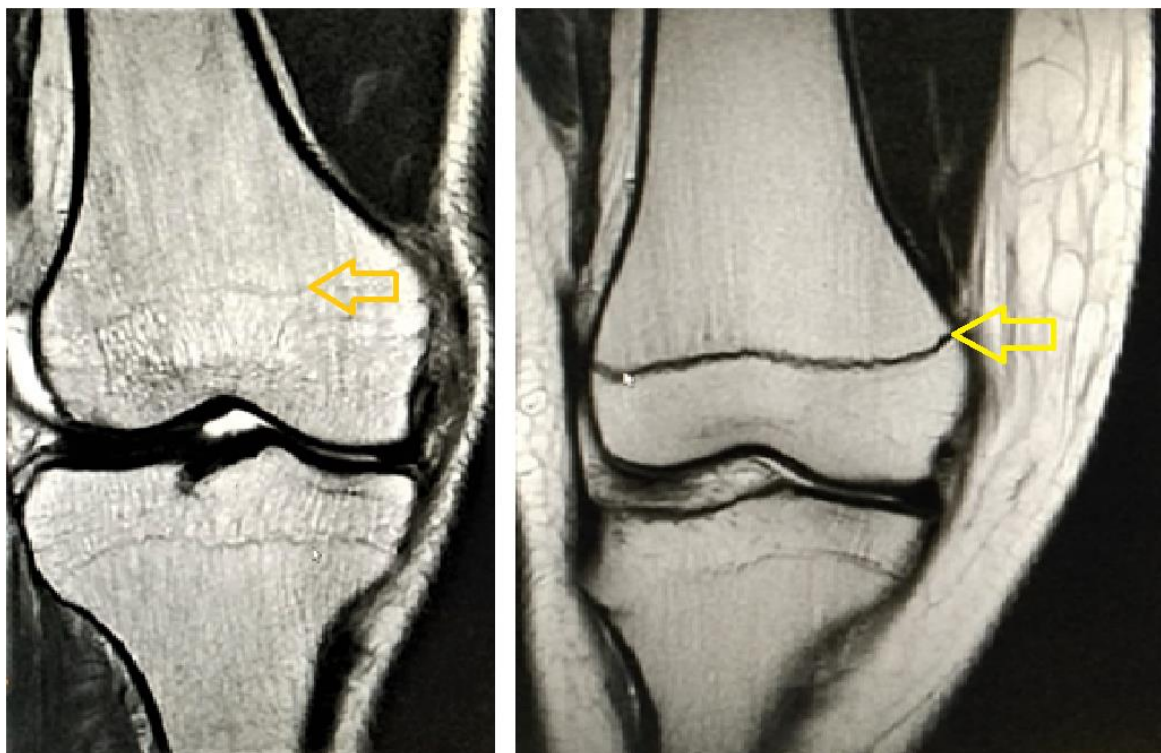


Figure 1. MRI of knee showing ossification of epiphysis (Arrow pointed).

2.3. Parameter used in the study are:

(Classification of ossification stages according to Schmeling et al.¹²)

Grade 1, Ossification centre has not yet ossified.

Grade 2, Ossification centre has ossified. Epiphyseal cartilage has not ossified.

Grade 3, Epiphyseal cartilage has partially ossified.

Grade 4, Epiphyseal cartilage has completely ossified. Epiphyseal scar is visible.

Grade 5, Epiphyseal cartilage has completely ossified. Epiphyseal scar is not visible anymore.

2.4. Inclusion Criteria for the study are:

1. Subject's age between 3 and 35 years at the time the MRI was considered
2. Good quality MRI scans were taken
3. All subjects with stable hemodynamic status and normal MRI scan of knee were considered

2.5. Exclusion criteria for the study are:

1. Subjects with congenital, endocrine or other serious diseases were excluded
2. Overlapping or unclear MRI scans were excluded
3. Subjects whose ages could not be verified

The images were first evaluated by an examiner with experience in MRI diagnostics with a re-evaluation of 55 randomly chosen cases after a lapse of 1 month. A second qualified examiner with profound expertise in musculoskeletal radiology also evaluated the same group of 55 cases without knowledge of the previously determined stages. The evaluations were also performed without knowledge of the sex and age of the examined volunteers. Intra- and interobserver agreements were determined by calculating the kappa coefficients.

2.6. Statistical analysis

All data was collected, compiled and subjected to suitable statistical analysis using appropriate methods in SPSS software (v. 20). Minimum, maximum, mean and standard deviation were defined.

3. Results

Of the 140 patients, 110 were males and 30 were females. The males were in the range of 5 to 34 years (mean age 22.44 years) and the females were in the range of 3 to 34 years (mean age 20.43 years) as shown in table 1. Of the 110 males, 14 were of grade 2, 7 were of grade 3, 70 were of grade 4 and 19 were of grade 5. Among the 30 females, 5 were of grade 2, 2 was of grade 3, 15 were of grade 4 and 8 were of grade 5. On comparing stages of ossification with age (as shown in Table 2), we found that in case of males; grade 2 was achieved in between 5 to 19 years with the mean age for achieving this grade being 13.93 years. In case of females, grade 2 was achieved in between 3 to 15 years with the mean age of achieving this grade being 10.40 years. In case of males; grade 3 was achieved in between 16 to 19 years with the mean age for achieving this grade being 17.86 years. In case of females, grade 3 was achieved between 17 to 18 years with the mean age of achieving this grade being 17.50 years. In case of males; grade 4 was achieved in between 17 to 34 years with the mean age for achieving this grade being 23.54 years. In case of females, grade 4 was achieved in between 16 to 27 years with the mean age of achieving this grade being 21.07 years. In case of males; grade 5 was achieved in between 16 to 30 years with the mean age

for achieving this grade being 26.37 years. In case of females, grade 5 was achieved in between 21 to 34 years with the mean age of achieving this grade being 26.25 years. The correlation between age and stage of ossification was found to be significant by Chi-Square Test ($p < 0.05$). The inter-observer variability for the assessing the stages of ossification was in the range of 0.88 to 0.99, which indicates a very high reliability.

Table 1. Descriptive statistics.

Sex	Number of persons	Minimum Age	Maximum Age	Mean Age	Std. Deviation
Male	110	5.00	34.00	22.4455	5.46338
Female	30	3.00	34.00	20.4333	6.88572

Table 2. Comparing stages of ossification with age.

Stage	Sex	Number of Persons	Minimum Age	Maximum Age	Mean Age	Std. Deviation
Grade 2	Male	14	5	19	13.9286	3.40733
	Female	5	3	15	10.4000	4.87852
Grade 3	Male	7	16	19	17.8571	1.21499
	Female	2	17	18	17.5000	0.70711
Grade 4	Male	70	17	34	23.5429	4.38603
	Female	15	16	27	21.0667	3.03472
Grade 5	Male	19	16	30	26.3684	4.36158
	Female	8	21	34	26.2500	5.65054

Table 3. Distribution of Stages of Ossification in Age Group.

Sex	Age Gr.	Grade (Stage of Ossification)				Total	
		Grade 2	Grade 3	Grade 4	Grade 5		
Male	Age Gr.	3-5 years	1	0	0	0	1
		9-11 years	1	0	0	0	1
		12-14 years	5	0	0	0	5
		15-17 years	6	3	3	1	13
		18-20 years	1	4	18	1	24
		21-23 years	0	0	17	2	19
		24-26 years	0	0	15	4	19
		27-29 years	0	0	8	3	11
		30-32 years	0	0	7	8	15
		33-34 years	0	0	2	0	2
Total		14	7	70	19	110	

Female	Age	3-5 years	1	0	0	0	1	
		Gr.	6-8 years	1	0	0	0	1
			12-14 years	2	0	0	0	2
			15-17 years	1	1	2	0	4
			18-20 years	0	1	5	0	6
			21-23 years	0	0	4	4	8
			24-26 years	0	0	3	0	3
			27-29 years	0	0	1	1	2
			30-32 years	0	0	0	1	1
			33-34 years	0	0	0	2	2
	Total		5	2	15	8	30	
Total	Age	3-5 years	2	0	0	0	2	
		Gr.	6-8 years	1	0	0	0	1
			9-11 years	1	0	0	0	1
			12-14 years	7	0	0	0	7
			15-17 years	7	4	5	1	17
			18-20 years	1	5	23	1	30
			21-23 years	0	0	21	6	27
			24-26 years	0	0	18	4	22
			27-29 years	0	0	9	4	13
			30-32 years	0	0	7	9	16
			33-34 years	0	0	2	2	4
	Total		19	9	85	27	140	

4. Discussion

There are many bones and epiphyses in the hand and wrist that progress in a well-defined manner over time and can be evaluated through a single radiograph. Due to the presence of three epiphyses in a small area and the ability to radiograph the region with minimal radiation exposure, the knee is another site that can yield information about three epiphyses, distal femur, proximal tibia and proximal fibula. Very few studies have evaluated MRI of the distal femoral and proximal tibial epiphyses as a method of age assessment. The skeletal maturation of the knee has already been studied anthropologically in dry bones and radiologically in living subjects. The most detailed anthropological study¹³ was done by McKern and Stewart on American soldiers who died during the Korean War. The most exhaustive radiological study on knee was performed by Pyle and Houerr¹⁴ in North American children born between 1931 and 1942. The results were published in Atlas in 1955 consisting of X-rays of male and

female subjects including antero-posterior and lateral incidences of the knee. In this there is definite fusion of the central epiphyseal plate at 14.5 years in girls and 17 years in boys. And growth plates were replaced by lines of fusion at 15.5 years in girls and 18 years in boys. Previous radiological studies state that the distal femoral epiphyses occur between 14-18 years in females and 16-19 years in males¹⁵⁻¹⁷. Recent study indicated that the earliest appearance of complete fusion of distal femoral epiphyses in MRI was in 14 years in females and 16 years in males.

The ossification stages 1 did not occur in our study in neither of the sexes. The minimal age for stage 5 was 16 years in male and 21 years in females. The mean however for achieving this stage was 26.37 years in case of males and 26.25 years in case of females. These observations were similar or in agreement with those of Kramer et al.¹⁰ who found the age limit for this stage in both sexes being above 24 years of age. The earliest age for appearance of grade 3 was 17 years in females and 16 years in males with mean age of 17.5 in females and 17.85 years in males. In case of grade 4, the minimum age for achievement of this stage was 17 years in males and 16 years in females with the mean age of 23.54 years in males and 21.07 years in females. The female subjects in our study displayed an earlier onset of ossification stages of distal femoral epiphyses and of the proximal tibial epiphyses over that of the male subjects. In our study, the earliest documented stage 4 of distal femoral epiphyses was below 18 years in several cases. The history of these cases was taken for skeletal related diseases but none were found. Therefore, these cases mark the earliest onset of stage 4. Female individuals displayed an earlier onset of distal femoral epiphyses and proximal tibial epiphyses compared to male individuals. These are similar to the earlier results of Dedouit et al.¹⁸, Kramer et al.¹⁹, Ekizoglu et al.²⁰ and Fan et al.²¹ who also found similar trends in epiphyseal ossification. For ossification stage 5, the minimum age was about 21 years in males and females with mean age of 26.36 in males and 26.25 in females. Future studies concerning minima and maxima need to choose adjusted age brackets. The knee joint offers opportunity to examine three epiphyses in relatively small region of interest as was stated by Fan et al.²¹ However similar to the previous studies, we would recommend not evaluating proximal fibular epiphyses as it is only visible in a few MRI slices. The advantage of the knee joint is that it is readily accessible and not prone to movement artefacts unlike the medial epiphyses of the clavicle. The strong points in favour of this study design lie in its prospective selection of patients and the ability for us to exclude the patients having pathology

which affect the concerned epiphyseal ossification. The reliability of the results of retrospective studies conducted by Dedouit et al.¹⁸, Kramer et al.¹⁹, Ekizoglu et al.²⁰, Fan et al.²¹ and Saint-Martin et al.²² was limited by potential presence of negative influential factors while having the benefit of readily available images.

All our scans were performed with same scanner in same sequence. The noted studies previously done utilized at least one uniform sequence among others for all individuals. Some used different scanner and different field strength in the same population. Higher field strength yielded better signal to noise ratio and therefore may alter the acquired data by giving more detail which would mean a more precise depiction of osseous structures and bony epiphyseal-metaphyseal fusion line. The T1 sequence was chosen to provide closest to bone depiction of the trabecular bone structure of epiphyses. Due to varying approaches of differently weighted MRI sequences, a comparison of results using method similar to that of Dedouit et al.¹⁸ and Kramer et al.¹⁹ with our method was difficult. The classification of Schmeling et al.¹² is well recognised and used by specially trained examiners. Other pre-existing MRI staging systems for long bone epiphyses like that of Devorak et al.²³ were not chosen for our study as they include absolute measurements within the acquired images. The classification provided by Jopp et al.²⁴ and consequently the results are partially comparable.

5. Conclusion

We can conclude that bony fusion of distal femoral and proximal tibial epiphyses in 1.5 Tesla MRI can be used in determination of Forensic Age in conjunction with other methods. However, forensic age estimation in living individuals by MRI of knee is feasible and this modality provides data about the individual skeletal age without the use of ionizing radiation. The used classification is for practical use for trained professionals with high intra and inter observer agreement. It is also a fact that has been shown from the unreliability of determination of grade 5 in females compared to males that only 1.5 Tesla MRI is not suitable as a sole indicator of maturity in majority in either sex in compliance with criteria for forensic age estimation. It can be useful only to a certain extent in determining age 16 to 17 years of life in both sexes.

Conflict of interest

All authors declared that there is no conflict of interest.

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