Original Article

www.anatomy.org.tr
Received: October 5, 2015; Accepted: February 19, 2016
doi:10.2399/ana.15.020

anatomy
An International Journal of Experimental and Clinical Anatomy

Radiological assessment of age from epiphyseal fusion at the knee joint

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Abstract

Objectives: Age determination is needed in administration of justice, employment, marriage, forensic investigation and identification. This cross-sectional study aimed to investigate the relationship between stages of epiphyseal union at the knee joint and chronological age.

Methods: Anterior posterior and lateral knee radiographs of 100 males and 110 females aged 9–19 years were examined. Epiphyseal union was divided into five specific stages in the femur, tibia and fibula. Fusion was scored as stage 0: non-union, stage 1: beginning union, stage 2: active union, stage 3: recent union, and stage 4: complete union.

Results: Mean age gradually increased with each stage of union and varied between males and females. A statistically significant difference in mean age was recorded between stages for the three epiphyses. Epiphyseal union occurred earlier in females than in males. A statistically significant difference was observed between the mean age of union for males and females for stages 1 and 2 for the femur, and stages 0, 1, 2 and 3 for the tibia and fibula.

Conclusion: The results of this study indicate that radiographic analysis of the knee is a valuable alternative for estimation of chronological age.

Keywords: age estimation; epiphysis; fusion; knee joint; radiograph; skeletal maturation

Anatomy 2016;10(1):1–7

Introduction

Age determination is needed in administration of justice, employment, marriage, forensic investigations and identification. Identification of individuals may be challenging in developing and underdeveloped countries where proper documentation is below standards. Exact age of individuals can only be obtained from certified documents; when absent, there is a need to verify whether an individual should be accepted as a juvenile or adult. Physical and dental examination often used in identification show a wide range of variation.[1]

For providing the most accurate estimate of biological age and chronological age, it is necessary to combine information from physical and dental examination and examination of as many epiphyses as possible. Current research focuses on the multi-factorial methods for accurate age estimation that minimize the error of estimation.[2,3]

As a person grows from fetal life through childhood, puberty to adulthood, bones increase in length and size. These changes can be seen by X-ray. Epiphyses of bones unit at a particular age, and this changes during epiphyseal union provide a skeletal age, which when compared with age-based standards provide an estimation of chronological age.[4,5] Biological anthropologists work on maturation of the human skeleton to develop methods for construction of biological profiles. During skeletal maturation, cartilaginous and membranous bones of the fetus develop to fully ossified bones of the adult.[6] This process is an ideal mechanism for developing of methods to estimate age. Epiphyseal union time can be used to estimate age between 10 and 20 years.[7,8]

The knee is an ideal anatomical location for assessment of epiphyseal union. Clinically, the patient's knee joint is often investigated following trauma. As a result, large data banks of knee radiographs exist. The anterior posterior radiographs of the knee shows three epiphyses - distal femur, proximal tibia and proximal fibula. According to previous studies, differences exist in the timing of epiphyseal union between individuals from different populations.[9,10] Eveleth and Tanner[11] attribute the differences to population variability, climate, nutrition, secular change in growth or to simply lack of standardized methodology. In other parts of the world, the hand-wrist region has received the greatest attention in assessment of skeletal maturation compared to other areas.[12,13]

In Nigeria, not much has been done on radiological assessment of age. This cross-sectional study therefore seeks to investigate stages of epiphyseal union at the knee joint, which provides information for three epiphyses at the same time, and its use in determination of chronological age in a Nigerian population.

Materials and Methods

This retrospective cross-sectional analysis of 210 left side radiographs (100 males, 110 females) was undertaken to establish the relationship between the epiphyseal union at the knee and chronological age using a sample of radiographs from Eku Baptist Hospital, Delta State, Nigeria. All subjects aged 9.1–19 years who presented for an X-ray of the knee following an accident, emergency or outpatient department were retrospectively selected for inclusion. Information available for the date of birth and the date of registration of X-ray was used to calculate chronological age, thus allowing calculation of exact age (year) at the time of X-ray.

Five stages of epiphyseal union were identified as described by O'Connor et al.[14] Anterior, posterior and lateral radiographs were used together when assessing the stage of epiphyseal union. If there was a difference in the stage of union between radiographic views, the radiograph of the growth plate demonstrating the least mature view was selected. For example, in the case of the distal femur, fusion may appear to have commenced in the anterior posterior view. However, a radioluscent gap between epiphysis and diaphysis may be observed in the lateral view, indicating that union in fact has not commenced.[14] The five stages of epiphyseal union as described by O'Connor et al.[14] are:

Stage 0 – Non-union: The diaphyseal and epiphyseal bones are adjacent to each other but not yet in intimate relationship. The epiphysis is separate from the diaphysis due to the presence of the cartilaginous growth plate (**Figure 1**). This should be apparent in at least one view on the radiograph, as a continuous radiolucent gap between the epiphysis and diaphysis.[14,15]

Stage 1 – Beginning union: The epiphyseal and diaphyseal surfaces closely move towards each other. There is a narrow radiolucent strip between adjacent surfaces of the epiphysis and diaphysis when compared to the state of non-union. There is a radiolucent gap which is not continuous from anterior to posterior or medial to lateral, indicating that union has begun centrally, but has not yet commenced on the remainder of the growth plate. In radiographic views, the later stage should be selected.[14]

Stage 2 – Active union: The epiphysis and diaphysis cap each other, the epiphysis overlapping the metaphysis.[11] The terminal plate of the epiphysis can no longer be distinguished. A fusion line or zone of greater density than the adjacent bone replaces the epiphyseal cartilage (**Figure 2**). There is a radiodense region indicating that fusion is actively occurring.[14]

Figure 1. Plain anteroposterior (**a**) and lateral (**b**) radiographs of a child (<9 years) showing non-union.

Figure 2. Plain anteroposterior (**a**) and lateral (**b**) radiographs of a 16-year-old male showing active union.

Stage 3 – Recent union: The epiphysis and diaphysis now form a single unit of bone; there is complete capping. The position of the former epiphysis and diaphysis can still be observed. There may be a fine line of fusion of greater density between the epiphysis and diaphysis, and a discontinuity of trabeculae between these. A slight notch at the margin of the growth plate (less than 2 mm) can be observed that is not yet completely calcified (**Figure 3**). These indicate that the bone has recently united.[14]

Stage 4 – Complete union: The epiphysis and diaphysis are united as a single unit of bone. There is continuity of trabeculae from shaft to former epiphysis. This is presented as a uniformity of internal bone pattern throughout the length of the long bone up to the articular surface. All traces of epiphyseal differentiation have been lost. The growth plate has now completely ossified and the bone is fused in its entirety; there are no radiolucent notches evident at the peripheral margin of the bone (**Figure 4**).[14]

All data (mean±standard deviation) were analyzed with SPSS Statistical Package for Social Sciences (SPSS) software (version 16; SPSS Inc, Chicago, IL, USA). A p value less than 0.05 was considered as statistically significant. The research and ethics committee of the Eku Baptist hospital approved the study.

Results

Table 1 reveals the number of male subjects at each stage of the union with respect to age. Nine males, three in each group, were between ages 9.1–10, 10.1–11 and 11.1–12. At this age there was non-union at femur, tibia or fibula. In age group 12.1–13, there were three males with non-union at femur, four with non-union at tibia and seven with non-union at fibula, and also five males at the beginning of union for femur, four at the beginning of union for tibia and one at the beginning of union for fibula. Earliest age of complete union was at 18.1–19 for femur, 17.1–18 for tibia and 16.1–17 for fibula (**Table 1**).

Table 2 provides the number of females at each stage of union with respect to age. There was one female between ages 9.1–10; at this age, there was no union at femur, tibia or fibula. For both femur and tibia, there were twelve females between ages 10.1–11, ten of these presented non-union at femur and two beginning of union. Twelve subjects were at the non-union stage for the fibula. The earliest age of complete union for femur and tibia was 16.1, and 15.1–16 for fibula in females (**Table 2**).

Table 3 shows the age (years) for each stage of union at epiphyses of the distal femur, proximal tibia and fibula in male and females. The earliest age for beginning union was 12.1 for males and 10.1 for females. The mean age (mean age=a+b/2) was calculated as 16.55 for males and 14.55 for females. The results of previous studies from Britain, America, Australia, India and our study in Nigeria are shown in **Table 4**.[10,14,16–28]

Discussion

Biological anthropologists as well as clinical and forensic investigators call for methods that can provide estimates of chronological age. In law, crime and punishment are

Figure 3. Plain anteroposterior (**a**) and lateral (**b**) radiographs showing recent-union.

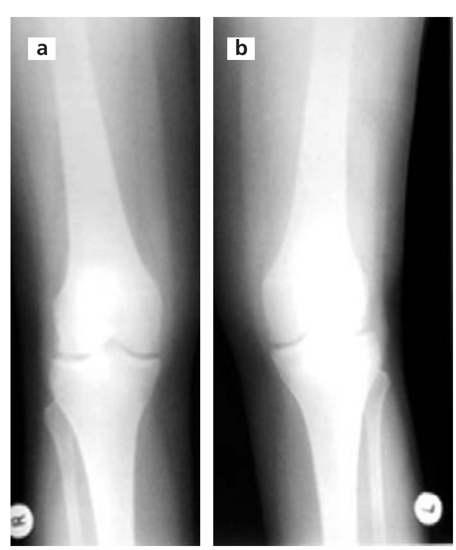

Figure 4. Plain anteroposterior (**a**) and lateral (**b**) radiographs showing complete union.

Table 1

Number of male subjects (n) at each stage of union for the distal femur, proximal tibia and fibula in each age group (years).

	Number of subjects	Femur stage of union					Tibia stage of union					Fibula stage of union				
Age (years)	n	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
9.1–10	3	3	-	-	-	-	3	-	-	-	-	3	-	-	-	-
10.1–11	3	3	-	-	-	-	3	-	-	-	-	3	-	-	-	-
11.1–12	4	4	-	-	-	-	4	-	-	-	-	4	-	-	-	-
12.1–13	8	3	5	-	-	-	4	4	-	-		7	1	-	-	-
13.1–14	10	1	7	2	-	-	2	6	2	-	-	6	3	1	-	-
14.1–15	14	-	9	4	1	-	2	7	4	1	-	5	7	2	-	-
15.1–16	14	-	7	7	-	-	-	5	7	2	-	3	5	6	-	-
16.1–17	20	-	1	14	5	-	-	1	12	7	-	1	5	8	4	2
17.1–18	18	-	-	5	13	-	-	-	2	14	2	-	-	5	11	2
18.1–19	6	-	-	1	4	1	-	-	-	6	-	-	-	1	3	2

based on criminal responsibility and this in turn depends on the age of a person.[5] Reports have shown that the study of epiphyseal union of bones is considered as a reasonable scientific and acceptable method for age determination by the law courts all over the world.[9,29]

The fundamental basis of age estimation techniques in young people is based on the fact that the skeleton is constantly changing in small increments until the adult state is reached.[30] Previous authors described mainly two stages of union: non-union or completed union. There is inconsistency between authors in proving a range for the age of complete union. Johnston,[25] in American Indians, described fusion as the age category at which 50% or more of the group showed complete union. Saksena and Vyas[27] described the age of complete union at the youngest age group when 85% of the cases were united in an Indian population, whereas Das Gupta et al.[20] classified the age of complete union when 100% of cases were united, he carried out his study in boys and girls of Uttar Pradesh in India. As a result it makes comparison between the age ranges provided quite difficult. A comparison could not be made with other Nigerian studies as this study appears to be the very first.

The studies of McKern and Stewart,[24] Schaefer and Black[10] and O'Connor et al.[14] are the most similar in methodology to our study, and our results were com-

Table 2

Number of female subjects (n) at each stage of union for the distal femur, proximal tibia and fibula in each age group (years).

	Number of subjects	Femur stage of union					Tibia stage of union					Fibula stage of union				
Age (years)	n	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
9.1–10	1	1	-	-	-	-	1	-	-	-	-	1	-	-	-	-
10.1–11	12	10	2	-	-	-	10	2	-	-	-	12	-	-	-	-
11.1–12	10	2	6	2	-	-	2	6	2	-	-	8	2	-	-	-
12.1–13	8	-	8	-	-	-	-	8	-	-	-	4	4	-	-	-
13.1–14	10	-	3	7	-	-	-	3	7	-	-	-	9	1	-	-
14.1–15	12	-	3	7	2	-	-	3	3	6	-	2	2	7	1	-
15.1–16	11	-	-	2	9	-	-	-	-	11	-	-	-	4	5	2
16.1–17	12	-	-	2	9	1	-	-	-	11	1	-	-	2	10	-
17.1–18	20	-	-	6	13	1	-	-	4	15	1	-	-	2	16	2
18.1–19	14	-	-	1	12	1	-	-	1	12	1	-	-	-	8	6

Table 3
Mean, standard deviation (SD) and range in age (years) for each stage of union at epiphyses of the distal femur, proximal tibia and fibula in males and females.

	Males (n)	Stage of union	Range	Mean age ±SD	Females (n)	Stage of union	Range	Mean age ± SD
Femur	14	0	9.1–13.55	11.28±1.51	13	0	9.1–11.55	10.23±1.13
	29	1	12.1–16.55	14.33±1.49	22	1	10.1–14.55	12.33±1.49
	33	2	13.1–18.55	15.83±1.65	27	2	11.1–18.55	14.83±1.93
	23	3	14.1–18.55	16.33±1.49	45	3	14.1–18.55	16.33±1.49
	1	4	18.1–18.55	18.33±0.47	3	4	16.1–18.55	17.33±1.11
Tibia	18	0	9.1–14.55	11.78±1.67	13	0	9–11.55	10.23±1.13
	23	1	12.1–16.55	14.33±1.49	22	1	10.1–14.55	12.33±1.49
	27	2	13.1–17.55	15.33±1.49	17	2	11.1–18.55	14.83±1.93
	30	3	14.1–18.55	16.33±1.49	55	3	14.1–18.55	16.33±1.49
	2	4	17.1–17.55	17.33±0.47	3	4	16.1–18.55	17.33±1.11
Fibula	32	0	9.1–16.55	12.78±1.94	27	0	9–14.55	11.78±1.67
	21	1	12.1–16.55	14.33±1.49	17	1	11.1–14.55	12.83±1.31
	23	2	13.1–18.55	15.83±1.65	16	2	13.1–17.55	15.33±1.49
	18	3	16.1–18.55	17.33±1.11	40	3	14.1–18.55	16.33±1.49
	6	4	16.1–18.55	17.33±1.11	10	4	15.1–18.55	16.83±1.31

pared with theirs. These studies were conducted in United States, Bosnia and Ireland respectively. Complete union was the only stage of union that was comparable to all previous radiographic studies (**Table 4**). In this study, the youngest males demonstrating complete union of the femur, tibia and fibula were aged 18.1, 17.1 and 16.1 years, respectively. The youngest females having reached complete fusion of the femur, tibia and fibula epiphyses were aged 16.1, 16.1 and 15.1 years, respectively. The age of subjects that reached complete union in this study is similar to previous studies. However, the age of complete union for the fibula does not appear consistent among authors; as also reflected by this study, the fibula is outside this range in some cases

Table 4
Summary of previous studies providing age ranges for completion of epiphyseal union at the knee for males (M) and females (F).

Author	Year	Sample size	Population	Stage	Males Femur	Males Tibia	Males Fibula	Females Femur	Females Tibia	Females Fibula
Stevenson[16]	1924	90 (M); 20 (F)	US	4	19	19	19	19	19	19
Davies and Parsons[17]	1927	N/S	UK	2	19	19–20	20–22	19	19–20	20–22
Paterson[18]	1929	<100	UK	2	18	18–19	18	16–17	16	16–17
Flecker[19]	1932	70 (M); 38 (F)	Australia	2	16–19	16–19	16–19	14–19	14–19	14–18
Pillai[20]	1936	100	Indian	N/S	14–17	14–17	14–17	14–17	14–17	14–17
Galstaun[21]	1937	N/S	Indian	2	>18	16–17	16	>17	14–15	16
Flecker[22]	1942	76 (M); 41 (F)	Australia	2	16–19	16–19	16–19	14–19	14–19	14–18
Aggarwal and Pathak[23]	1957	95 (F)	Indian	N/S	-	-	-	14.5–16.5	14.5–16.5	15–16.5
McKern and Stewart[24]	1957	450 (M)	US	5	22	23	22	-	-	-
Johnston[25]	1961	35 (M); 27 (F)	American Indian	3	18.5	18	18	17–18	17–18	17–19
Hansman[26]	1962	102 (M); 105 (F)	US	2	14–19	14.4–19.5	15–20	12–17	12–17	12–17
Saksena and Vyas[27]	1969	50 (M); 25 (F)	Indian	2	18–19	18–19	18–19	16–17	16–17	16–17
Das Gupta et al.[28]	1974	44 (M); 31 (F)	Indian	2	18–19	18–19	20–21	17–18	17–18	20–21
Schaefer and Black[10]	2005	114 (M)	Bosnian	5	17–20	17–20	17–20	-	-	-
O'Connor et al.[14]	2008	148 (M); 86 (F)	Irish	5	18.5	17.2	16.6	16.4	16.4	15.3
This study	2014	100 (M); 110 (F)	Nigerian	5	18.1	17.1	16.1	16.1	16.1	15.1

(**Table 4**). This may be based on how the authors classified their range of union; i.e., whether they classified it as 100% of subjects demonstrating complete union, in this case some subjects might have fallen outside this range.

Table 3 presents the chronological age (years) range, mean age and standard deviation values for the youngest and oldest subjects recorded at each stage of union for each of the three epiphyses at the knee for males and females. In males, the youngest subject recorded as having a beginning union of the distal femoral epiphysis was aged 12.1 years, and the oldest was 16.5 years. The mean age of male subjects showing beginning union was 14.3 years. The number of subjects at stage 4 was not many, yet they have been included for completeness of the data. The mean age provides an indication of the typical age at which each stage of union occurs, showing a gradual increase with each stage of union and also varying between males and females. Femur, tibia and fibula were found to start union at the same stage. Six male and ten female subjects were recorded at the state of complete union of the fibula by comparison with one and three subjects for the femur, and two and three subjects for the tibia, respectively (**Table 3**).

The youngest male in the study of O'Connor et al.[10] was recorded as having recent union at age 14.7 years for the femur and tibia and 16.1 years for fibula. This is similar to the current study which records ages for recent union as 14.1 years for the femur and tibia and 16.1 years for the fibula. However, McKern and Stewart[24] and Schaefer and Black[10] reported older ages by comparison. The upper value of the age range for recent union in this study which is 18.5 years, does, however fall within the limit reported by the other three authors.[10,24]

The current study found that females develop at a younger age than their male counterparts. This is in agreement with the results of previous studies, which found that females typically develop approximately two years in advance of males.[26,31,32] The results of our study showed that there is generally a mean difference of 1.5 years between males and females.

Conclusion

Although the wrist joint received greater attention as compared to the knee, the knee is also a very reliable joint for age estimation. In cases where only the knee is available in accident scenes or following mass disasters, age can be accurately estimated from the knee joint. When epiphyseal changes of the knee joint are also combined with that of the wrist, a more accurate age estimation of an individual is possible.

Acknowledgements

The authors wish to thank the staff of the Department of Radiology at Eku Baptist Hospital, Delta State, Nigeria for their assistance with this project, especially consultant radiologist Dr. Gabriel Oboreh.

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Online available at:
www.anatomy.org.tr
doi:10.2399/ana.15.020
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Conflict of interest statement: No conflicts declared.