DOI: 10.17986/blm.1641
Adli Tıp Bülteni 2023;28(3):216-223

An Evaluation of Age Determination in Forensic Medicine Using Scoring of the Epiphyses at the Knee Joint on Radiographs

Radyografide Diz Eklemi Epifiz Puanlaması ile Adli Tıpta Yaş Tayini Değerlendirilmesi

Tuba Akkuş Çetinkaya[1], Abdullah Avşar[2], Betül Kızıldağ[3]

[1]Kahramanmaraş Branch Office, Council of Forensic Medicine, Kahramanmaraş, Türkiye
[2]Kahramanmaraş Sütçü İmam University Faculty of Medicine, Department of Forensic Medicine, Kahramanmaraş, Türkiye
[3]Kahramanmaraş Sütçü İmam University Faculty of Medicine, Department of Radiology, Kahramanmaraş, Türkiye

ABSTRACT

Objective: Identification plays an important role in forensic medicine practices. Age estimation is also widely used in identification. The aim of this study is to investigate the applicability of age determination method in Türkiye by examining the radiographs of the knee joint and using the epiphyseal scoring based on the degree of epiphyseal closure.

Methods: Knee graphs of 676 cases (337 women, 339 men) aged between 10 and 26 years were retrospectively analyzed. Distal femur (DF), proximal tibia (PT), and proximal fibula (PF) epiphyseal lines were evaluated separately in each case. The closure of the epiphyses was studied at 3 stages. DF, PT and PF epiphyses were graded 0, 1, 2 for stage 1, 2 and 3 respectively. These three scores obtained in each case were collected and the score of the epiphyses at the knee joint (SKJ) was obtained.

Results: The median age in each of the SKJs increased in both men and women. The difference between the genders was statistically significant according to the median age of 0-5 points ($p<0.001$). As a result of the receptor operating characteristic curve analysis, the highest accuracy value was found to be 6 points in both genders. In males, the sensitivity was 0.989, the specificity was 0.880, and the overall accuracy was 0.943. In females, these values were found to be 1.000 for sensitivity, 0.648 for specificity, and 0.845 for overall accuracy.

Conclusion: The study suggests that knee joint epiphyseal scoring is a simple and practical method with high inter-rater agreement in determining whether a Turkish individual is older than 18 years of age.

Keywords: Forensic medicine, age determination, chronological age, imaging method, knee joint

Address for Correspondence/Yazışma Adresi: Tuba Akkuş Çetinkaya, Kahramanmaraş Branch Office, Council of Forensic Medicine, Kahramanmaraş, Türkiye
E-mail: tubaakkus0289@gmail.com
ORCID ID: orcid.org/0000-0002-4137-0222

Received/Geliş tarihi: 27.11.2022
Accepted/Kabul tarihi: 22.08.2023

ÖZ

Amaç: Adli tıp uygulamalarında kimlik tespiti önemli bir yer almaktadır. Yaş tayini de kimlik tespitinde yaygın olarak kullanılmaktadır. Bu çalışmanın amacı, diz eklemi radyografilerini inceleyerek epifiz kapanma derecesine göre oluşturulan epifiz skorlaması kullanılarak yaş tespiti yönteminin Türkiye'de uygulanabilirliğini araştırmaktır.

Yöntem: Yaşları 10 ile 26 arasında değişen 676 (337 kadın ve 339 erkek) olguya ait diz grafileri retrospektif olarak incelendi. Her olgunun distal femur (DF), proksimal tibia (PT), proksimal fibula (PF) epifiz hatları değerlendirildi. Epifiz hatlarının kapanması 3 evrede incelendi. DF, PT ve PF epifizlerine evre 1, 2 ve 3 için sırasıyla 0, 1 ve 2 puanları verildi. Her bir olguda elde edilen bu üç puan toplanarak diz eklemi epifiz puanı (DEEP) hesaplandı.

Bulgular: DEEP'lerin her birinde ortanca yaş hem erkeklerde hem de kadınlarda artış gösterdi. Sıfır-5 puan ortanca yaş değerlerine göre cinsiyetler arasındaki fark istatistiksel olarak anlamlı bulundu ($p<0,001$). Tanısal alıcı çalışma karakteristiği eğrisi analizi sonucunda her iki cinsiyette de en yüksek doğruluk değeri 6 puan olarak bulundu. Erkeklerde duyarlılık 0,989, özgüllük 0,880 ve genel doğruluk 0,943 bulundu. Kadınlarda bu değerler duyarlılık 1,000, özgüllük 0,648 ve genel doğruluk 0,845 bulundu.

Sonuç: Çalışma diz eklemi epifiz puanlamasının, Türk uyruklu bir bireyin 18 yaşından büyük olup olmadığının belirlenmesinde değerlendiriciler arası uyumu yüksek, basit ve pratik bir yöntem olduğunu göstermiştir.

Anahtar Kelimeler: Adli tıp, yaş tayini, kronolojik yaş, görüntüleme yöntemi, diz eklemi

INTRODUCTION

The determination of characteristics identifying a living or dead person or differentiating one from others is known as "identity determination" (1). One of the important elements of identity determination is age determination (2).

Age determination can clarify points which lead to significant legal and social problems for both the individual and society (3). In Türkiye, age determination is requested by the civil and criminal courts. In criminal cases, age determination is generally requested for females who are victims of sexual abuse, and in civil cases it is used for the correction of incorrectly written dates of birth on identity documents (4,5). In European countries, age determination is usually performed because of increasing migration, as many refugees or migrants do not have a birth certificate or do not know their correct age (6-9). Under European laws and international agreements, unaccompanied child refugees or migrants are protected and require special treatment. To prevent abuse of the system, age determination is a priority (10).

The legal age of criminal responsibility varies from country to country. For example, in the UK and Ireland it is 10 years, in China, Japan, Denmark and Spain, it is 14 years, in Belgium, Panama and Peru, 18 years and in Sudan, Pakistan and Jordan, 7 years (11,12). In Türkiye, a child under the age of 12 years at the time of the crime cannot be held criminally responsible. Between the ages of 12 and 15 years, evaluation is made to determine whether or not the child has developed the ability to understand the legal meaning of the action and perceive the consequences, or to manage their behaviour. For those aged between 15 and 18 years, there are reductions in sentencing.

In order to reach the most accurate and reliable result in age determination, it is stated in the studies that a large number of epiphyses should be examined together with physical and dental examinations. The knee joint is an ideal anatomical structure for the evaluation of epiphyseal closure (13). Various studies have been conducted on the skeletal development of the knee joint by examining dry bone, computed tomography, X-ray and magnetic resonance (MR) images (14-17). Cameriere et al. (18) calculated a knee joint epiphysis score using the degree of epiphyseal closure of the distal femur (DF), proximal tibia (PT) and proximal fibula (PF) epiphyses in the knee joint, and investigated the answer to the question of whether or not the person was 18 years old. Galić et al. (19) studied a larger sample with the same method, and unlike the study by Cameriere et al. (18), did not use the presence of epiphyseal wound scar as a criteria (19) in our study; it was aimed to evaluate the relationship between knee joint epiphysis score, which was created according to the degree of closure of the epiphyseal lines, by examining the direct bone radiography images of the knee joint, to discuss in the light of the literature and to investigate its applicability in our country.

MATERIALS AND METHODS

Approval for the current study was granted by the Clinical Research Ethics Committee of Kahramanmaraş Sütçü İmam University Faculty of Medicine (decision no: 11, session no: 2017/04, dated 15.03.2017). A restrospective review was made of 890 anteroposterior radiographs taken for various reasons from patients of both genders aged 10-26 years in the Department of Radiology, Kahramanmaraş Sütçü İmam University, University Medical Faculty Health Practice and Research Hospital. The radiographs were retrieved from the hospital Picture Archiving and Communications System. From the clinical information in the hospital information management system, any patients determined with pathologies which could affect bone age were excluded from the study. Accordingly, a total of 676 cases, comprising 337 females and 339 males were included for evaluation.

Patients were excluded if there were errors in the taking of the radiograph, bone fractures in the knee joint region, surgical fixation material, anomalies, deformity, bone or soft tissue tumour, endocrine disorders affecting bone development (hyperthyroidism, hypothyroidism, vitamin D deficiency etc.), eating disorders, systemic diseases (chronic renal failure, osteopenia, thyroid malignancies etc.), or constitutional retarded development (cerebral palsy, growth development retardation). Foreign nationals were not included. No evaluation was made of socio-economic status or level of sports activity of the cases.

Previous studies have shown that although there is a difference between the right and left sides in the development of the upper extremities, the difference in the lower extremities, especially in the knee region, is insignificant (18). Therefore, although evaluation could be made of both knees in some cases, only radiographs of the left knee were included in the study analyses.

All the direct radiographs were taken on the same digital radiography device (GE Healthcare, Definium 6000, Milwaukee, WI, USA) at the same technical settings (25x30 cm cassette area, 250 mA, 111 msn exposure time, 65 kvP, 0.60 focal spot, fixed/focused grid). The chronological age of each subject was calculated by the device by subtracting the date on which the radiograph was taken from the date of birth. The images were evaluated on a workstation (Ale Inc., Cuertino, California, US, OsiriX V.4.9 imaging software Pixmeo, Switzerland) by a radiologist (B.K.) with 15 years of experience and a forensic medicine resident (T.A.) with 4 years of experience.

The DF, PT, and PF epiphyses of each case were evaluated separately, using the grading system defined by Galić et al. (19). Grade 1: open epiphysis, grade 2: closed epiphysis, epiphyseal scar can be clearly seen, areas adjacent to the epiphysis may not be completely closed, and grade 3: completely ossified epiphysis and the epiphyseal scar can be seen (Figures 1-3).

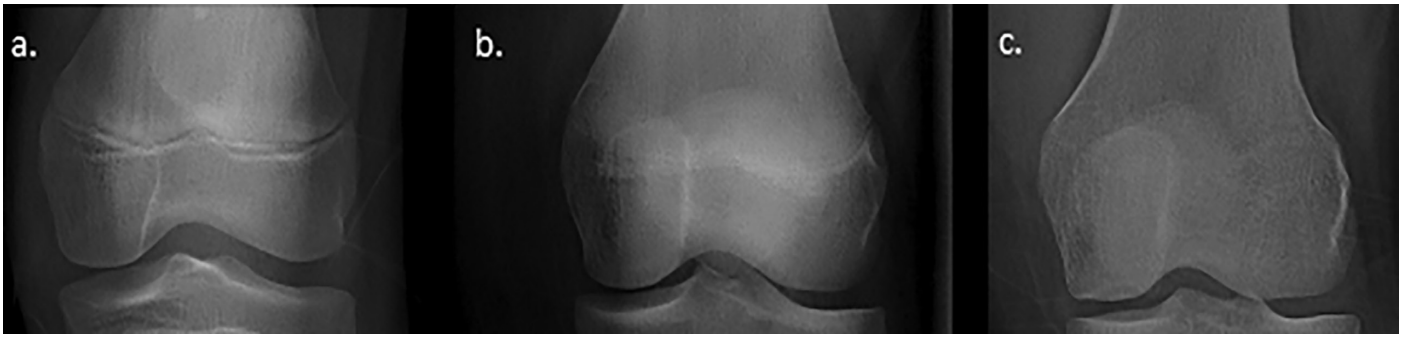

Figure 1. Distal femur epiphysis, **a.** Grade 1, **b.** Grade 2, **c.** Grade 3

Figure 2. Proksimal tibia epiphysis, **a.** Grade 1, **b.** Grade 2, **c.** Grade 3

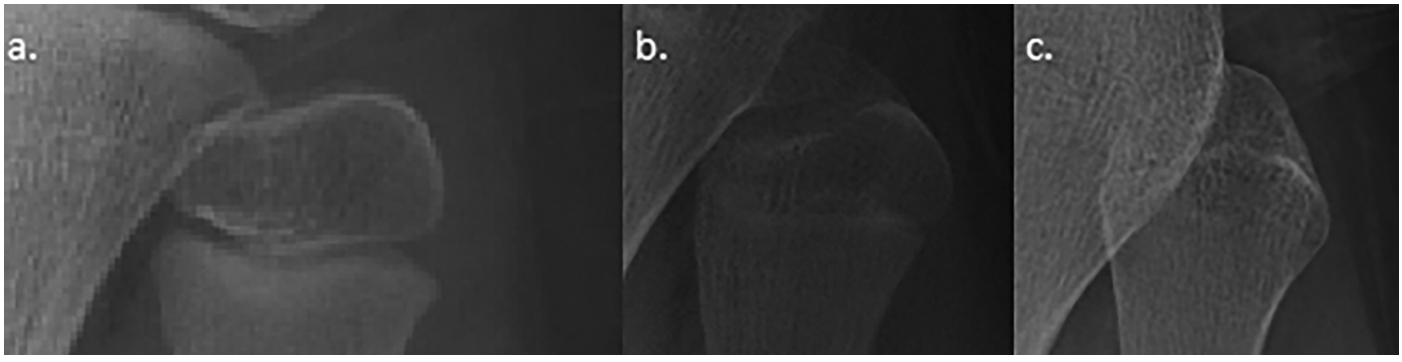

Figure 3. Proksimal fibula epiphysis, **a.** Grade 1, **b.** Grade 2, **c.** Grade 3

Scoring of the epiphyses at the knee joint (SKJ) were calculated for each case. The DF, PT and PF epiphyses were scored separately as 0, 1, or 2 points according to grades 1, 2, and 3, then the 3 scores were totalled to give the SKJ. When the side sections were not ossified despite ossification of the epiphysis, this was evaluated as 1 point. If there was uncertainty during the observation, the lower points were used in accordance with the principle of greater benefit to the person.

Statistical Analysis and Data Management

Data obtained in the study were recorded in the Microsoft Excel 2010 Program, and in the statistical analyses, IBM SPSS vn 22 and R 3.3.2 software packages were used. Conformity of the data to normal distribution was assessed with the Kolmogorov-Smirnov test. In the comparisons of two groups of data not showing normal distribution, the Mann-Whitney U test was used. Descriptive statistics of variables were expressed as median and interquartile range values. Correlations between the variables were examined using the Spearman Correlation test. Inter-rater reliability and intra-rater reliability were evaluated using the Intraclass Correlation Coefficient. The Cronbach alpha value was used in the evaluation of the internal consistency of the test.

The cut-off point for whether or not the SKJ and the scores of each epiphysis were for an individual aged >18 years was evaluated with a receiver operating characteristic curve (ROC). The specificity, sensitivity, positive predictive value (PPV) and negative predictive value were calculated for the SKJ positive limit value.

The number of true positive (TP), false positive (FP), true negative (TN) and false negative (FN) cases were determined for the positive limit values. The positive and negative probability ratios were determined. The positive likelihood ratio (LR+) was calculated using the formula of sensitivity/ (1-selectivity) (20). The negativity probability ratio (LR-) was calculated using the formula of (1-sensitivity)/selectivity (21).

To determine the actual probability to be able to determine individuals aged 18 years and over, the accuracy (Acc) value was calculated using the formula (TP+TN)/ (TP+FP+TN+TP) (21).

The diagnostic test probability ratio was calculated using Bayes theorem (Bayes post-test probability) (19).

The values used in the formula represent the probability of p1 sensitivity, p2 specificity, p0 males or females aged 10-26 years being 18 years of age or over. The p0 value was calculated according to information obtained from the Turkish Statistics Institute. Values were determined of 0.537 for females and 0.534 for males.

A value of $p<0.05$ was accepted as statistically significant.

RESULTS

Evaluation was made of a total of 676 AP knee radiographs of 337 females and 339 males aged 10-26 years (Table 1).

For a significance level α:0.05, test power 0.80 and d:0.05 effect size for the calculation of inter-rater and intra-rater reliability, at least 79 subjects were found to be suitable for 2nd evaluation. After the first evaluation by the forensic medicine resident (TA), 103 cases were selected at random for separate evaluation again by the forensic medicine resident (TA) and the radiologist (BK). Very high agreement of inter-rater and intra-rater reliability was found in the grading evaluations. Both the inter-rater and intra-rater agreement was found to be highest for the PF epiphysis (Tables 2, 3).

The median age showed an increase in each SKJ in both females and males. A statistically significant difference was determined

Table 1. Frequency distribution by sex and age cohorts

Age	Female	Male
10	21	14
11	18	14
12	19	23
13	16	16
14	18	18
15	17	26
16	19	12
17	20	19
18	23	32
19	19	27
20	29	24
21	17	21
22	24	22
23	28	33
24	14	20
25	11	10
26	24	8
n	337	339

Table 2. Interrater agreement

	ICC	95% CI	p
DF	0.961	0.943-0.974	**0.000****
PT	0.972	0.959-0.981	**0.000****
PF	0.976	0.964-0.984	**0.000****

DF: Distal femur, PT: Proximal tibia, PF: Proximal fibula, ICC: Intraclass correlation coefficient, CI: Confidence interval

Table 3. Intrarater agreement

	ICC	95% CI	p
DF	0.953	0.931-0.968	**0.000****
PT	0.969	0.954-0.979	**0.000****
PF	0.970	0.956-0.980	**0.000****

DF: Distal femur, PT: Proximal tibia, PF: Proximal fibula, ICC: Intraclass correlation coefficient, CI: Confidence interval

between both genders in respect of the median age for SKJ 0-5 (p<0.001) (Table 4).

The capacity to differentiate and the predictive power of the test to determine individuals aged 18 years and over was evaluated with the ROC curve. The area under the curve (AUC) ± standard error value for the SKJ value was found to be 0.939±0.16 for males and 0.824±0.25 for females (Table 5).

As a result of the ROC analys, the cutoff value for SKJ was found to be 6 for both genders (Table 6).

The SKJ positive limit value for differentiation of age 18 years and over was found to be very good in males and good in females. The general Acc was found to be 0.943 in males and 0.767 in females (Table 7).

Spearman correlation analysis showed a positive relationship between DF, PT and PF epiphysis points and SKJ (p<0.001). The highest correlation coefficient was obtained for SKJ (r: 0.854 in males, r: 0.788 in females) (Table 8).

DISCUSSION

The age of an individual can be obtained definitively from birth records. As the physical and dental examinations used in age determination show several variations, evaluation is made together with examination of epiphyseal closure. The knee joint is an ideal anatomic structure for the evaluation of epiphyseal closure, as there are 3 epiphyses that can be evaluated on a knee joint radiograph, namely the proximal femur, distal

Table 4. Median age values according to epiphysis scores by both sexes

		Male (n=339)	Female (n=337)	
		Median age (Q1-Q3)	Median age (Q1-Q3)	p
DF score	0	12.04 (11.02-12.70)	10.73 (10.31-10.87)	0.001**
	1	14.90 (13.50-15.55)	12.80 (11.86-13.69)	0.001**
	2	20.98 (18.72-23.53)	20.53 (17.77-23.43)	0.155
PT score	0	12.21 (11.74-13.23)	11.17 (10.52-11.86)	0.001**
	1	15.49 (14.83-15.95)	13.64 (12.71-14.16)	0.001**
	2	21.18 (18.76-23.55)	20.53 (17.85-23.43)	0.107
PF score	0	12.63 (11.93-14.23)	11.34 (10.77-12.68)	0.001**
	1	16.19 (15.64-17.08)	14.18 (13.69-14.56)	0.001**
	2	21.31 (19.12-23.60)	20.83 (18.42-23.59)	0.222

DF: Distal femur, PT: Proximal tibia, PF: Proximal fibula

Table 5. The area under the curve of the ROC curves and the 95% confidence limit values

Sex		AUC	95% CI	Std. D.	p
Male	DF score	0.887	0.845-0.929	0.022	0.001**
	PT score	0.905	0.866-0.944	0.020	0.001**
	PF score	0.938	0.906-0.970	0.016	0.001**
	SKJ	0.939	0.907-0.971	0.016	0.001**
Female	DF score	0.764	0.708-0.819	0.028	0.001**
	PT score	0.770	0.716-0.825	0.028	0.001**
	PF score	0.824	0.775-0.874	0.025	0.001**
	SKJ	0.824	0.775-0.874	0.025	0.001**

DF: Distal femur, PT: Proximal tibia, PF: Proximal fibula, CI: Confidence interval, Std. D.: Standard deviation, AUC: Area under the curve, ROC: Receptor operating characteristic, SKJ: Scoring of the epiphyses at the knee joint

Table 6. The SKJ is 6 to 18 and above the age individuals to determine the performance values

SKJ								
	TP	FP	FN	TN	Sens.	Spec.	PPV	NPV
Male	194	17	2	125	0.989	0.880	0.919	0.984
Female	189	52	0	96	1.000	0.648	0.784	1.000

SKJ: Scoring of the epiphyses at the knee joint, TP: True positive, FP: False positive, TN: True negative, Sens.: Sensitivity, Spec.: Specificity, PPV: Positive predictive value, NPV: Negative predictive value

Table 7. Probability ratios of three epiphysis and SKJ positive limit values by sex

Sex		LR+	LR-	Acc	Bayes PTP
Male	DF score	4.43	0	0.905	0.835
	PT score	5.24	0	0.920	0.857
	PF score	8.24	0.012	0.943	0.904
	SKJ score	8.24	0.012	0.943	0.904
Female	DF score	2.11	0	0.792	0.710
	PT score	2.17	0	0.798	0.716
	PF score	2.84	0	0.845	0.767
	SKJ score	2.84	0	0.845	0.767

DF: Distal femur, PT: Proximal tibia, PF: Proximal fibula, LR: Likelihood ratio, PTP: Post-test probability, Acc: Accuracy, SKJ: Scoring of the epiphyses at the knee joint

Tablo 8. Correlation coefficient between all three epiphysis scores and SKJ

		Age		
		n	r	p
Male	DF score	339	0.816	0.001**
	PT score	339	0.829	0.001**
	PF score	339	0.848	0.001**
	SKJ	339	0.854	0.001**
Female	DF score	337	0.724	0.001**
	PT score	337	0.731	0.001**
	PF score	337	0.785	0.001**
	SKJ	337	0.788	0.001**

DF: Distal femur, PT: Proximal tibia, PF: Proximal fibula, SKJ: Scoring of the epiphyses at the knee joint

tibia and distal fibula. Data accessibility is high as knee joint radiographs are taken after most traumas (22,23). The results of this study showed that evaluation of knee joint radiographs is a method that can be used in the determination of whether or not an individual is aged 18 years and over.

In a study by Cameriere et al. (18), the relationship between an age of 18 years and over and the radiological analysis of knee joint epiphyses was examined. A total of 215 AP knee radiographs of 99 males and 116 females, aged 14-24 years, were examined. The AUC of the ROC curve was found to be 0.961±0.018 in males and 0.915±0.023 in females. With a score of 3 in males, a high Acc value was obtained with high sensitivity (93.33%) and specificity (89.29%) and PPV of 94.42%. The highest Acc values in females were obtained with 3 and 4 points. When 4 points was accepted as the cutoff value, it was found to be closer to 0.1, showing the ideal point on the ROC curve (18).

In the current study, the highest AUC, sensitivity and specificity values were obtained at 6 points in males and females. The AUC was found to be higher in males than females. The reasons for the higher positive limit value in this study can be considered to be the difference in the grading system and the higher number of cases. When the ROC curve and AUC values of each epiphysis and SKJ were compared, the power of age differentiation was found to be lower when the 3 epiphyses were used separately compared to the SKJ in males. This showed that the effect of separate evaluation of the epiphysis points in males was low. In females, the PF and SKJ AUC, sensitivity and specificity values were found to be equal. This demonstrated that in females, SKJ and PF points could be used in the differentiation of subjects aged 18 years and over.

In a study by Cameriere et al. (18), age distribution increased gradually at each point for both genders. A difference was seen between the genders in the mean age (± standard error), but the difference was not statistically significant ($p>0.11$). Galić et al. (19) also found no statistically significant difference between the genders in respect of the 3 epiphyses closure grades ($p>0.05$). In the current study, a difference was seen in median age at 0 and 1 point for all 3 epiphyses and at SKJ 0-5, and the difference was determined to be statistically significant ($p<0.001$).

In the Galić et al. (19) study, the highest age difference was found at SKJ 4 (males: 18.32±1.02 years, females:17.67±1.42 years). In the current study, the greatest age difference was determined at SKJ 5 [males:17.12 (range, 16.95-17.80), females: 14.56 (range, 14.25-15.48)].

Galić et al. (19) reported the highest inter-rater reliability value for DF epiphysis, and the highest intra-rater reliability for PF epiphysis. In the current study, the highest inter-rater and intra-rater reliability values were determined for the PF epiphysis.

In the study by Galić et al. (19), the correlation values between age and DF, PT and PF epiphyses were found to be 0.835, 0.872, 0.878 in males and 0.789, 0.799, 0.826 in females and the correlation coefficient between SKJ and age was 0.899 in males and 0.881 in females ($p<0.01$). The highest correlation in both genders was found between SKJ and age (19). Similar values were determined in the current study.

In the study by Galić et al. (19), the ROC curves of the SKJ from all 3 epiphyses were found to have greater differentiation power in both genders. The AUC values were found to be 0.991 in males and 0.968 in females for SKJ. These values for the DF, PT and PF points were determined as 0.944, 0.962, 0.974 for males and 0.891, 0.910, 0.918 for females. All the points were determined to have excellent diagnostic value in both genders (19). In the current study, in males, diagnostic value was at an excellent level for SKJ, and at a good level for DF points. In females, the diagnostic value was found to be at a moderate level for DF and PT points and at a moderate level for PF and SKJ. This difference was considered to be due to be due to the earlier epiphyseal closure in females.

Galić et al. (19) found the positive limit value for age of 18 years and over to be 4 in males and 5 in females. For SKJ 4 in males, senstivity was 0.94, specificity was 0.96, and for SKJ 5 in females, sensitivity was 0.89 and specificity was 0.92. In the current study, the positive limit value was determined as 6 in both genders. Sensitivity was 0.98 in males and 1.00 in females and specificity was 0.88 in males and 0.64 in females. According to SKJ 6, the possibility of being 18 years and over was 77% in females and 90% in males. Although the SKJ limit value was determined to be more reliable in the determination of individuals aged 18 years and over in males, it was seen that it could be used as an assistive method.

Previous studies of knee epiphysis closure made with anthropological and radiological examinations have shown that the PT matures earlier than the DF (13). In the current study, it was determined that DF and PT closure occured at the same age in females, whereas in males, DF closure was earlier than PT.

In previous studies, the Greulich-Pyle method has been reported to be simple and repeatable, and can be evaluated with high reliability by physicians who are not radiologists (24). As the epiphyses in the hand complete ossification by the age of 16 years, they cannot be used for an age limit of 18 years. Therefore, it became necessary to develop highly reliable methods for other anatomic regions for the age limit of 18 years (25).

There are studies that have contributed to the literature using MR imaging of knee joint epiphyseal closures (14,16,26). Studies have shown that completed knee maturation radiographic image and MR image may correspond to different stages. This is because MR images provides better contrast and definition than plain X-rays. For example, in the fusion period, it is observed as complete in X-rays due to edema in the growth plate, but in MR images it is observed as incomplete (13). It was not found appropriate to compare the results of our study based on the age test performed with the MR image and the results of our study based on direct radiography cases.

Study Limitations

A primary limitation of this study was that ethnic identity was not known and therefore, the effect was not considered. The levels of physical activity of the cases were not evaluated. Any cases with chronic pain in the anamnesis taken from the hospital information management system were not included in the study.

Another limitation of the current study were the lack of socio-economic data, retrospective design and that normal age distribution was not shown.

CONCLUSION

The results of this study showed a higher correlation of age with the combined knee joint epiphyseal points than with the separate evaluations of the 3 epiphyses. This was found to be a method that can be used for the differentiation of age 18 years and over in both genders, with higher Acc and reliability in males than females. There is a need for further studies of the knee joint in other regions of Türkiye and therefore this study can be considered of guidance as a preliminary step.

ETHICS

Ethics Committee Approval: Approval for the current study was granted by the Clinical Research Ethics Committee of Kahramanmaraş Sütçü İmam University Faculty of Medicine (decision no: 11, session no: 2017/04, dated 15.03.2017).

Peer-review: Externally and internally peer-reviewed.

Authorship Contributions

Concept: T.A.Ç., Design: T.A.Ç., Data Collection or Processing: T.A.Ç., B.K., Analysis or Interpretation: T.A.Ç., A.A., B.K., Literature Search: T.A.Ç., A.A., Writing: T.A.Ç., A.A.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

REFERENCES

1. Isır Baransel A. Adli Hekimlikte Yaş Tayini. Klin Gelişim Dergisi (Adli Tıp Özel Sayısı). 2009;22:114-121. https://klinikgelisim.org.tr/eskisayi/klinik_2009_22/18.pdf

2. Hosmani A, Pathak H, Khartade H, Jadav D, Shedge R, Pawar M, et al. Age Estimation in Sportspersons From the Epiphyseal Fusion Around Wrist, Elbow, and Pelvic Joints. Cureus. 2023;15(1):e33282. http://doi.org/10.7759/cureus.33282
3. Ritz-Timme S, Cattaneo C, Collins MJ, Waite ER, Schütz HW, Kaatsch HJ, et al. Age estimation: The state of the art in relation to the specific demands of forensic practise. Int J Legal Med. 2000;113(3):129-136. https://doi.org/10.1007/s004140050283
4. Karabakır B. Adli olgularda canlıda yaş tayini açısından incelenmesi (Doktora Tezi). İstanbul Üniversitesi Adli Tıp Enstitüsü Sos Bilim Anabilim Dalı; 2015. https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=mqmyDr3gNq7iu_2sht4vYw&no=azOZQ250vzuv1uNSkYZhtw
5. Demirkıran DS, Çelikel A, Zeren C, Arslan MM. Methods for age estimation. Dicle Med J. 2014;41(1):238-243. http://doi.org/10.5798/diclemedj.0921.2014.01.0410
6. Chitavishvili N, Papageorgiou I, Malich A, Hahnemann ML, Mall G, Mentzel HJ, et al. The distal femoral epiphysis in forensic age diagnostics: studies on the evaluation of the ossification process by means of T1- and PD/T2-weighted magnetic resonance imaging. Int J Legal Med. 2023;137(2):427-435. https://doi.org/10.1007/s00414-022-02927-6
7. Hillewig E, De Tobel J, Cuche O, Vandemaele P, Piette M, Verstraete K. Magnetic resonance imaging of the medial extremity of the clavicle in forensic bone age determination: a new four-minute approach. Eur Radiol. 2011;21(4):757-767. http://doi.org/10.1007/s00330-010-1978-1
8. Schmeling A, Schulz R, Reisinger W, Mühler M, Wernecke KD, Geserick G. Studies on the time frame for ossification of the medial clavicular epiphyseal cartilage in conventional radiography. Int J Legal Med. 2004;118(1):5-8. http://doi.org/10.1007/s00414-003-0404-5
9. Schulz R, Zwiesigk P, Schiborr M, Schmidt S, Schmeling A. Ultrasound studies on the time course of clavicular ossification. Int J Legal Med. 2008;122(2):163-167. http://doi.org/10.1007/s00414-007-0220-4
10. Cameriere R, De Luca S, De Angelis D, Merelli V, Giuliodori A, Cingolani M. Reliability of Schmeling's stages of ossification of medial clavicular epiphyses and its validity to assess 18 years of age in living subjects. Int J Legal Med. 2012;126(6):923-932. http://doi.org/10.1007/s00414-012-0769-4
11. İnan Aynur. Pelvis radyografis yöntemi ile 18-22 yaş erkek ve kadınlarda yaş tayini (Uzmanlık Tezi). Ankara Üniversitesi Adli Tıp Anabilim Dalı; 2016. https://dspace.ankara.edu.tr/xmlui/handle/20.500.12575/83542
12. Focardi M, Pinchi V, De Luca F, Norelli GA. Reply to the letter to the editor. Int J Legal Med. 2015;129(6):1275-1276. http://link.springer.com/10.1007/s00414-014-1044-7
13. Dedouit F, Auriol J, Rousseau H, Rougé D, Crubézy E, Telmon N. Age assessment by magnetic resonance imaging of the knee: a preliminary study. Forensic Sci Int. 2012;217(1-3):232. http://doi.org/10.1016/j.forsciint.2011.11.013
14. Ekizoglu O, Er A, Bozdag M, Basa CD, Kacmaz IE, Moghaddam N, et al. Forensic age estimation via magnetic resonance imaging of knee in the Turkish population: use of T1-TSE sequence. Int J Legal Med. 2021;135(2):631-637. http://doi.org/10.1007/s00414-020-02402-0
15. Demircioğlu A, Quinsten AS, Forsting M, Umutlu L, Nassenstein K. Pediatric age estimation from radiographs of the knee using deep learning. Eur Radiol. 2022;32(7):4813-4822. http://doi.org/10.1007/s00330-022-08582-0
16. Auf der Mauer M, Säring D, Stanczus B, Herrmann J, Groth M, Jopp-van Well E. A 2-year follow-up MRI study for the evaluation of an age estimation method based on knee bone development. Int J Legal Med. 2019;133(1):205-215. http://doi.org/10.1007/s00414-018-1826-4
17. Kerley ER. The microscopic determination of age in human bone. Am J Phys Anthropol. 1965;23(2):149-163. http://doi.org/10.1002/ajpa.1330230215
18. Cameriere R, Cingolani M, Giuliodori A, De Luca S, Ferrante L. Radiographic analysis of epiphyseal fusion at knee joint to assess likelihood of having attained 18 years of age. Int J Legal Med. 2012;126(6):889-899. http://doi.org/10.1007/s00414-012-0754-y
19. Galić I, Mihanović F, Giuliodori A, Conforti F, Cingolani M, Cameriere R. Accuracy of scoring of the epiphyses at the knee joint (SKJ) for assessing legal adult age of 18 years. Int J Legal Med. 2016;130(4):1129-1142. http://doi.org/10.1007/s00414-016-1348-x
20. Aktürk Z, Acemoğlu H. Sağlık çalışanları için araştırma ve pratik istatistik. Örnek problemler ve SPSS çözümleri. İstanbul: Anadolu Matbaası; 2011. http://www.aile.net/img/dosya/akturkzsaglikcalisanlariicinpratikistatistik.pdf
21. Ertosun AD, Bağ B, Uzar G, Turanoğlu MA, ROC (receiver operating characteristic) eğrisi yöntemi ile tanı testlerinin performanslarının değerlendirilmesi. http://tip.baskent.edu.tr/kw/upload/600/dosyalar/cg/sempozyum/ogrsmpzsnm12/10.2.pdf. Erişim tarihi: 27.03.2018
22. Ebeye OA, Eboh DE, Onyia NS. Radiological assessment of age from epiphyseal fusion at the knee joint. Anatomy. 2016;10(1):1-7. http://doi.org/10.2399/ana.15.020
23. O'Connor JE, Bogue C, Spence LD, Last J. A method to establish the relationship between chronological age and stage of union from radiographic assessment of epiphyseal fusion at the knee: an Irish population study. J Anat. 2008;212(2):198-209. http://doi.org/10.1111/j.1469-7580.2007.00847.x
24. Saint-Martin P, Rérolle C, Dedouit F, Rousseau H, Rougé D, Telmon N. Evaluation of an automatic method for forensic age estimation by magnetic resonance imaging of the distal tibial epiphysis--a preliminary study focusing on the 18-year threshold. Int J Legal Med. 2014;128(4):675-683. http://doi.org/10.1007/s00414-014-0987-z
25. Faisant M, Rerolle C, Faber C, Dedouit F, Telmon N, Saint-Martin P. Is the persistence of an epiphyseal scar of the knee a reliable marker of biological age? Int J Legal Med. 2015;129(3):603-608. http://doi.org/10.1007/s00414-014-1130-x
26. Hao HX, Wang YH, Zhou ZL, Liu TA, Chen J, He YH, et al. Research Progress of Age Estimation in the Living by Knee Joint MRI. Fa Yi Xue Za Zhi. 2023;39(1):66-71. http://doi.org/10.12116/j.issn.1004-5619.2022.220503