CLINICAL RESEARCH

Which is the Best Method to Determine the Patellar Height in Children and Adolescents?

**Moon Seok Park MD, Chin Youb Chung MD,
Kyoung Min Lee MD, Sang Hyeong Lee MD,
In Ho Choi MD**

Abstract Patellar height is associated with various clinical syndromes. We asked which of three methods was the most appropriate for measuring patellar height for different age groups in terms of applicability, validity, and reliability. We evaluated 108 children and adolescents with available MR images and lateral knee radiographs using Insall-Salvati (IS), Blackburne-Peel, and Koshino-Sugimoto (KS) methods. Subjects were divided equally into three age groups (A, 5–10.9 years; B, 11–12.9 years; C, 13–18 years). The applicabilities of the three methods were evaluated using bony landmarks identified on lateral radiographs. For validation testing, standardized patellar tendon lengths determined by MRI were used as reference standards, and concurrent validity was analyzed by performing correlation tests. Intraobserver and interobserver reliability were determined using intraclass correlation coefficients. Of the three methods used to measure patellar height in this study, the IS appeared to be the most reliable and valid in patients older than 13 years with nearly complete ossification. Before this stage of ossification had been achieved, the KS was the only applicable and most reliable but less valid method in younger children.
Level of Evidence: Level I, diagnostic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

The patella is a sesamoid bone that increases leverage during knee extension. A high positioned or absent patella reduces the power applied by knee extensor muscles [16, 17, 19] and causes abnormal stress concentrations on the insertion of the patellar tendon [9, 14] and abnormal contact force of the patellofemoral joint [28]. Furthermore, abnormally positioned patellae are associated with various pathologic conditions such as Osgood-Schlatter disease [2, 31], patellar instability [8], disorder of the knee extensor mechanism in immature athletes [13], and cerebral palsy [30]. A previous study of patellar height indicated the clinical importance of its measurements [2]. In addition, some surgical treatments focused on relieving the patella alta such as patellar tendon advancement in cerebral palsy [29].

Various methods have been described to measure patellar position or height on lateral radiographs [5, 11, 15, 18]. However, most of these methods use bony landmarks, and thus, they may not be applicable to young children whose ossification is not completed. Although Blackburne-Peel (BP) and Koshino-Sugimoto (KS) methods reportedly are reliable in children [1, 26], there is a question regarding the validity of these methods given varying stages of ossification of the patella, tibia, and possibly femur [23].

M. S. Park, C. Y. Chung, K. M. Lee (✉), S. H. Lee
Department of Orthopedic Surgery, Seoul National University Bundang Hospital, 300 Gumi-Dong, Bundang-Gu, Sungnam, Kyungki 463-707, Korea
e-mail: oasis100@empal.com

I. H. Choi
Department of Orthopedic Surgery, Seoul National University Children's Hospital, Seoul, Korea

Increased patellar height is believed to be the result of elongation of the patellar tendon [10, 13, 29], and thus, we infer that measurements of patellar height or position reflect mainly patellar tendon length, which eventually affects the patellofemoral joint. These considerations are important when evaluating the validity of methods designed to measure patellar height. MRI has been used to measure patellar height [4, 22, 25], and reportedly provided accurate patellar tendon length [7]. Accordingly, we presumed MRI could be used to provide accurate patella tendon lengths and that these lengths could be used as a reference standard in the validity, although a definite gold standard for measuring patellar height does not exist. In addition, we expected that the position of patellar articular cartilage in relation to the joint line could be observed more accurately on MRI, which might be more closely related to the symptom caused by joint disorders.

We therefore determined which of three methods, IS, BP, and KS, was most appropriate for measuring patellar height in children and adolescents (ages, 5–18 years) by considering the applicability, validity, and reliability. We also endeavored to provide an equation in which the most valid method is expressed by the most applicable method.

Materials and Methods

We identified 305 pediatric patients who underwent MRI and had lateral radiographs of the knee at our hospital. The inclusion criteria were as follows: all pediatric patients who underwent MRI of the knee at our institute from May 2003 until October 2008, the availability of lateral knee radiographs, age younger than 18 years, and visible patellae on radiographs. We excluded patients with obvious deformity of the knee as a result of trauma, a congenital anomaly, previous knee surgery, an interval greater than 1 month between MRI and radiography, and imaging not performed at our institute. After the exclusions, we selected 108 sets of images that were randomly selected according to one of three age groups: 5 to 10.9 years (Group A), 11 to 12.9 years (Group B), and 13 to 18 years (Group C), 36 patients for each group according to prior sample size analysis. The mean age of the patients was 11.7 years (standard deviation, 3.5; range, 5.0–17.8 years). There were 59 boys and 49 girls (Table 1). This retrospective study was approved by the Institutional Review Board at our hospital.

All measurements were performed using a picture archiving and communication system (Impax; Agfa, Antwerp, Belgium). Angles between long axes of the femur and tibia on lateral radiographs were recorded as degrees of knee flexion. In the current study, the IS [15], BP [5], and KS [18] methods were used to measure patellar height. The

Table 1. Demographic data

Demographics	Group A	Group B	Group C	Total
Number	36	36	36	108
Age range (years)	5–10.9	11–12.9	13–18	
Mean age (standard deviation)	7.5 (1.8)	12.1 (0.6)	15.4 (1.5)	11.7 (3.5)
Male/female	19/17	21/15	19/17	59/49

Fig. 1 In this 15-year-old girl (Group C), the IS (A/B) ratio can be measured as a result of observation of the tibial tuberosity on the lateral radiograph. The BP and KS ratios also can be measured, but there is blurring of the physis owing to closure of the growth plate, which can make the KS difficult or less reliable in such patients.

IS method is the patellar tendon length relative to the length of patellar bone, the BP method is the relative height of the patellar articular surface to the tibial plateau line, and the KS method is the relative length between proximal tibial physis and the center of the patella to the length between distal femoral physis and proximal tibial physis.

We calculated the IS indices from patellar bone length and patellar tendon length, the latter of which was defined as the distance between the proximal point of the tibial tuberosity and the inferior pole of patella (Fig. 1). The BP indices were calculated from patellar articular cartilage length and the distance between the tibial plateau line and the inferior pole of patellar articular cartilage (Fig. 2). The

Fig. 2 On the lateral knee radiograph of a 12-year-old boy (Group B), subchondral sclerosis of the medial tibial condyle and patellar articular surface are more prominent. Using the BP (C/D) method is possible at this stage. The KS method also can be used in these patients. However, the IS method cannot be used owing to incomplete ossification of the tibial tuberosity, which has the appearance of an ossicle on this radiograph.

Fig. 3 The prominent physes of the proximal tibia and distal femur make using the KS (F/E) method possible. However, as this lateral radiograph of a 6-year-old girl (Group A) shows, the patellar articular cartilage and tibial tuberosity cannot be identified, and thus the IS and BP methods are not applicable.

KS indices were calculated from the distance between the midpoint of the patella and the midpoint of the proximal tibial physis and the distance between the midpoint of the proximal tibial physis and the midpoint of the distal femoral physis (Fig. 3).

Patellar tendon lengths were measured using sagittal MR images and these were taken to be true patellar tendon lengths, in which it was presumed that MR images could be used to provide accurate patella tendon lengths [7]. In addition, to standardize patellar tendon lengths with respect to body size, patellar tendon lengths were divided by whole patellar lengths, including the cartilaginous portion (Fig. 4). MR images were obtained using a 1.5-Tesla scanner (Intera; Philips, Best, The Netherlands), and patellar heights were measured on proton density-weighted sagittal images (repetition time [ms]/echo time [ms] = 2200 to 3900/12–20; 3-mm section thickness; 512 × 512 matrix) containing a median cut of the patellar tendon. Lateral knee radiographs were taken using a UT 2000 unit (Philips, Eindhoven, The Netherlands) in semiflexion at a source-to-image distance of approximately 100 cm and 70 kVp and 7 mAs, which were considered acceptable if the superimposition of the shape of the dorsal femoral condyles was less than 3 mm [3].
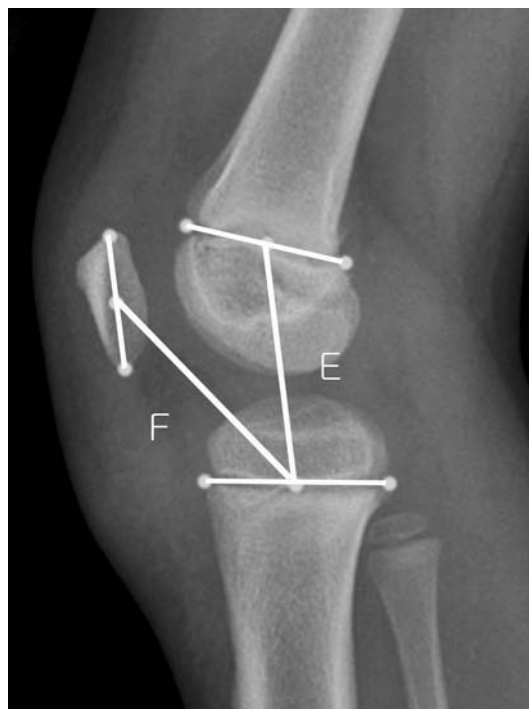
Applicability was defined as the possibility of identifying the bony landmarks to which each measurement refers. To determine the applicability of the three measurements, bony landmarks were recorded, which were the tibial tuberosity, the patellar inferior pole (for the IS method), the tibial plateau line and the articular surface of the patella (for the BP method), and the tibial and femoral physes (for the KS method). For children with incomplete ossification of the tibial tuberosity, the IS indices could not be measured. The BP indices were not applicable when the articular surface of the patella or the tibial plateau line could not be identified. Thus, individual methods were deemed applicable or inapplicable in all patients based on the identification of bony landmarks.

Validity was defined as proximity to the reference standard. For validity testing, one author (KM) (unaware of clinical information) measured patellar height indices on lateral radiographs and standardized patellar tendon lengths on MR images. Lateral knee radiographs and MR images were presented in random order. Correlation between standardized patellar tendon lengths and the three patellar height indices was analyzed to determine concurrent validity.

Reliability was defined as the consistency of the measurement. For reliability testing, consensus building of
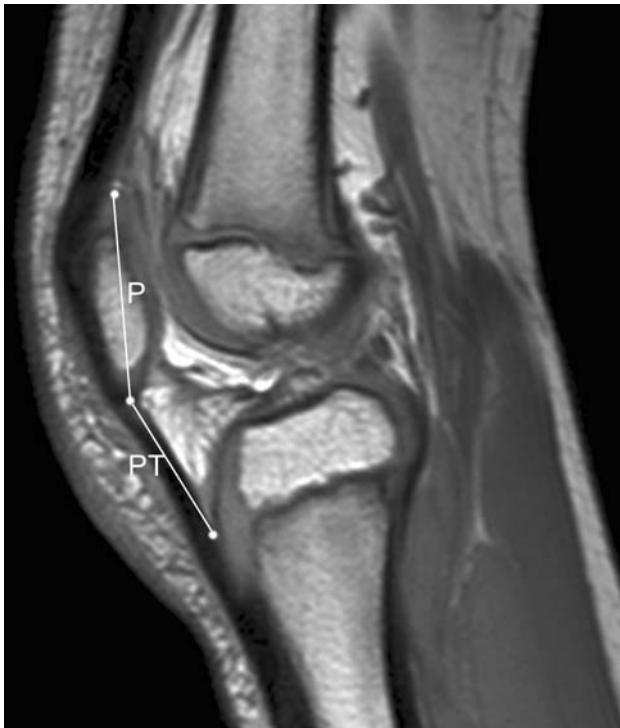
Fig. 4 A T1 sagittal MR image of the knee of a 6-year-old girl shows the patella and tibial tuberosity contain considerable cartilaginous material. The MR-based IS (PT/P) index was used as a reference standard calculated from true patellar tendon length (PT) and whole patellar length (P, which included ossified bone and cartilage).

participating observers was performed before reliability sessions. Interobserver and intraobserver reliability were determined using three observers (MS, SH, KM) with 8, 7, and 4 years of orthopaedic experience, respectively. These three observers separately measured patella heights using the IS, BP, and KS methods while unaware of patient data and the findings of other observers. Reliability sessions were conducted twice with an interval of 1 month. Orders of measurement were assigned randomly, and all data were collected by a research assistant who otherwise did not participate in the reliability sessions. To determine intraobserver and interobserver reliability, we calculated intraclass correlation coefficients (ICCs) with 95% confidence intervals [20].

After correlation testing and linear regression analysis, the IS indices were estimated as an equation that included the other indices and correlated factors such as knee flexion angle.

Prior precision analysis was conducted to determine minimal sample sizes. The study was designed such that ICCs could be used to examine reliability [21]. Using an ICC target value of 0.8, Bonett's approximation was used in the setting of 0.2 as a 95% confidence interval for three observers [6]. ICCs were calculated in the assumption of a two-way mixed model for absolute agreement in single

measurement [27]. The minimum sample size was calculated to be 36 subjects per group. To determine the participating children in each group, stratified random allocation by age was used.

Binomial logistic regression was used to determine the applicability of each method in the form of the probability. For validity testing, we assumed that 36 subjects provided representative patellar height measurements of the age-stratified population. Pearson's correlation coefficients were used to determine concurrent validity between the three patellar height measurements and standardized patellar tendon lengths on MR images. Multiple regression was used to estimate the IS as an equation using the other indices and correlated factors such as age and degrees of knee flexion. All data were tested for normality using the Kolmogorov-Smirnov test and analyzed using SPSS 11.0 (SPSS, Chicago, IL).

Results

On lateral knee radiographs, ossifying patellae, the proximal tibial physis, and the distal femoral physis were identified in all study subjects. In Group A (between 5 and 10.9 years old), the KS method was the only method applicable for all patients (Fig. 3). In Group B (between 11 and 12.9 years old), the KS was applicable for all patients (100%) and the BP for 34 of 36 patients (94%) (Fig. 2), but the IS could be used only in 21 of the 36 patients (58%). In Group C (between 13 and 18 years old), all three methods were applicable in all patients (Fig. 1). Applicability curves according to age were drawn using binomial logistic regression scatterplots (Fig. 5). The BP was applicable in 80% of patients at the age of 11.2 years, and the IS acquired 80% of applicability at the age of 11.9 years.
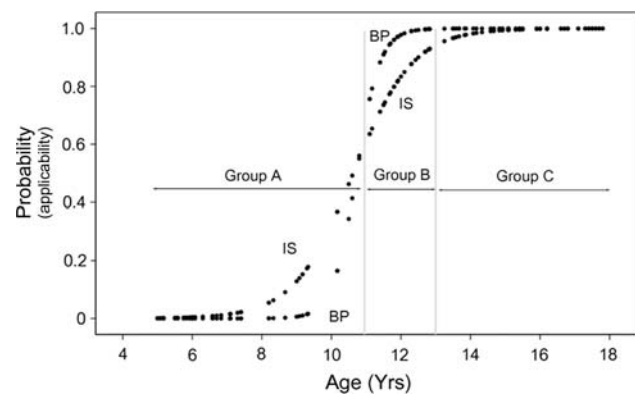

Fig. 5 Patellar height is expressed as probability in this logistic regression curve. In Group A, the IS and BP showed low probability, which means the KS is the only applicable method to use. The BP begins to acquire appropriate applicability in Group B, and the IS and BP were applicable in Group C.

Of the three methods, the IS had highest concurrent validity, whereas the BP had the lowest. The concurrent validity of the IS tended to increase with age. In Group A, the KS did not appear to be valid, although it was the only applicable method (r = 0.251, p = 0.140) (Table 2).

Intraobserver reliability was highest for the IS and lowest for the BP. Intraobserver reliability of the IS tended to increase with age and that of the KS was lowest in the oldest group (Group C) (Table 3). Interobserver reliability was lower than intraobserver reliability and was highest for the KS and lowest for the BP. Interobserver reliability for the IS was higher in Group C than in Group B and that of the KS was lowest in Group C (Table 4).

The correlation coefficients of knee flexion with the IS, BP, and KS were −0.291 (p = 0.030), −0.076 (p = 0.529), and −0.584 (p < 0.001), respectively. The IS correlated (r = 0.421, p = 0.001) with the KS and with (r = −0.257, p = 0.056) degree of knee flexion. A

Table 2. Concurrent validity as correlation with patellar tendon length in MRI

Group	IS		BP		KS	
	r	p	r	p	r	p
A					0.251	0.140
B	0.743	< 0.001	0.191	0.280	0.537	0.001
C	0.824	< 0.001	0.043	0.804	0.493	0.002
Total	0.782	< 0.001	0.092	0.452	0.405	< 0.001

IS = Insall-Salvati index; BP = Blackburne-Peel index; KS = Koshino-Sugimoto index; r = coefficient of correlation.

Table 3. Intraobserver reliability by ICC (between first and second sessions)

Group	Observers	IS		BP		KS	
		ICC	95% CI	ICC	95% CI	ICC	95% CI
A	First					0.684	0.460–0.826
	Second					0.930	0.867–0.964
	Third					0.845	0.719–0.918
	Overall					0.820	
B	First	0.753	0.568–0.866	0.665	0.427–0.816	0.734	0.537–0.855
	Second	0.859	0.743–0.926	0.789	0.626–0.887	0.908	0.828–0.952
	Third	0.936	0.873–0.968	0.699	0.473–0.838	0.832	0.680–0.913
	Overall	0.849		0.718		0.825	
C	First	0.745	0.557–0.861	0.382	0.079–0.624	0.761	0.580–0.871
	Second	0.910	0.474–0.971	0.600	0.342–0.774	0.920	0.849–0.958
	Third	0.930	0.868–0.964	0.427	0.002–0.699	0.745	0.174–0.903
	Overall	0.862		0.470		0.809	

IS = Insall-Salvati index; BP = Blackburne-Peel index; KS = Koshino-Sugimoto index; ICC = intraclass correlation coefficient; CI = confidence interval.

Table 4. Interobserver reliability evaluated by ICC with 95% CI (for three observers)

Group	Session	IS		BP		KS	
		ICC	95% CI	ICC	95% CI	ICC	95% CI
A	First					0.701	0.548–0.821
	Second					0.845	0.764–0.917
	Overall					0.786	
B	First	0.658	0.445–0.809	0.486	0.188–0.706	0.747	0.582–0.858
	Second	0.614	0.399–0.777	0.445	0.212–0.652	0.839	0.714–0.913
	Overall	0.635		0.517		0.788	
C	First	0.636	0.434–0.786	0.226	0.010–0.464	0.760	0.627–0.859
	Second	0.802	0.438–0.918	0.313	0.115–0.523	0.682	0.365–0.843
	Overall	0.731		0.312		0.740	

IS = Insall-Salvati index; BP = Blackburne-Peel index; KS = Koshino-Sugimoto index; ICC = intraclass correlation coefficient; CI = confidence interval.

mathematical equation was derived to estimate the IS based on the KS and knee flexions by multiple regression, namely:

$$IS = 0.673 \times KS - 0.001 \times \text{knee flexion} \; (°) \\ + 0.309 \; (R^2 = 0.181)$$

For example, if the KS index is 0.80 and the knee flexion on the lateral radiograph is 30°, the IS index is assumed to be approximately 0.82. By this equation, the IS index can be calculated even in Group A or Group B in which the IS is not applicable.

Discussion

Studies have been done to test the reliability of methods of measuring patellar height in children and adolescents [1, 26]. However, these methods are not always applicable owing to incomplete ossification of bony landmarks in children or adolescents. Furthermore, this could affect the validity and reliability of methods. In this study, we aimed to determine the most appropriate method at particular ages for measuring patellar height in children and adolescents in terms of applicability, concurrent validity, and reliability.

Our study has some limitations that should be addressed. First, we could not control degree of knee flexion because of the retrospective nature of this study. Furthermore, degrees of knee flexion on lateral knee radiographs differed from those on MR images, and this could have affected our concurrent validity findings. Variation in knee flexion on lateral knee radiographs and MRI might have acted as a

confounding factor as well in each measurement. Second, although MRI can reflect actual patellar heights well, different knee rotations on MR images and lateral knee radiographs could have caused differences. In addition, 3-mm sections of MRI in children could not have guaranteed the inclusion of a real midcut of the patellar tendon. Third, we assumed the pathology of increased patellar height is the result of an elongation of the patellar tendon and that measurements of patellar height or position should reflect patellar tendon length [10, 29]. However, one could argue that the pathology involves inadequate articulation of the patellofemoral joint as the lever arm of the knee extension mechanism. We consider that elongation of the patellar tendon and inadequate articulation are two different aspects of the same phenomenon. Fourth, our study subjects were confined to children and adolescents. Differences between our results and those of other studies are believed to be caused by subject age differences and the statistical method used (Table 5).

We examined the three most commonly used methods for determining patellar height, namely the IS [15], BP [5], and KS [18] methods. However, only the KS index can be used before the patellar articular surface and tibial tuberosity are identifiable on radiograms. After age 11 years when the patellar articular surface and tibial plateau line can be identified, the BP also can be used, and when the tibial tuberosity is observed at age 13, the IS can be used. This staged ossification of bony landmarks determines the applicability of methods at particular ages. We used standardized patellar tendon lengths based on applying the IS to MR images as a reference standard, because patellar tendon lengths as determined by MRI are known to well

Table 5. Published rates of interobserver reliability of the measurements of patellar height

Study	Number of patients	Mean age* (range)	Observers (trials)	Method	Statistics				Reliability
					ANOVA (p)	Standard error	Correlation (r)	ICC	
Shin et al. [26]	20	11 (2–17)	3 (3)	IS	0.011				Decline all three methods
				BP	0.001				
				KS	0.001				
Aparicio et al. [1]	36	*(10–15)	3 (1)	BP	0.001		0.63–0.79		Advocate KS
				KS	0.953		0.70–0.77		
Berg et al. [3]	15	*(25–61)	3 (3)	IS		0.059			Advocate BP
				BP		0.03			
Seil et al. [24]	22	*(17–76)	2 (1)	IS		0.044	0.86		Advocate BP
				BP		0.046	0.86		
Current study	108	11.7 (5–18)	3 (2)	IS				0.683	Advocate IS and KS (depending on age groups)
				BP				0.426	
				KS				0.771	

* Data were not provided in the original paper; ANOVA = analysis of variance; ICC = intraclass correlation coefficient; KS = Koshino-Sugimoto index; IS = Insall-Salvati index; BP = Blackburne-Peel index.

represent actual lengths determined using ex vivo specimens [7]. Furthermore, MRI visualizes cartilaginous tissues well, which we believed would be useful for measuring patellar height in children and adolescents.

The IS had the highest concurrent validity, which was expected, because our reference standard used essentially the same method. However, although the BP had the lowest concurrent validity, this does not mean the BP method has no merit clinically. In fact, it might reflect pathologic symptoms of the patellofemoral joint better than the other methods because it places emphasis on the position of articular cartilage.

Our intraobserver and interobserver reliability tests showed similar patterns according to age. In terms of reliability, the IS and KS were suitable methods for measuring patellar height. The IS method could be used after bony landmarks became prominent at 13 years of age and was more reliable in Group C than in Group B. However, the KS method was usable in all children with an ossified patella, but its reliability tended to be poorer in Group C. We believe closing or thinning of the growth plate caused blurring of the physis on lateral knee radiographs and this affected the results of reliability tests. The BP method had the lowest reliability, and this was contradictory to the results of other studies performed for adults, which advocated the BP method [3, 24]. We believe low reliability of the BP method in our study is the result of more indefinite bony landmarks in children than in adults. The inferior pole of the patellar articular cartilage is somewhat difficult to identify as was reported in a previous study [12], and this may be more accurate in children. Furthermore, the anterior end of the tibial articular surface, in which the tibial plateau line refers to, was occasionally indistinct in our experience. Intraobserver and interobserver reliability of the BP indices were higher in Group B than in Group C, which was an unexpected result, because bony landmarks become more prominent with age. We attributed this result to a greater proportional increase in the numerator than the denominator with age. This relative discordant increase is believed to have caused the greater variability observed in Group C than in Group B and affected the reliability of the BP method. In terms of the IS method, intraobserver and interobserver reliability in Group B were higher than we had expected. The proximal point of tibial tuberosity that we refer to as the insertion of patellar tendon was somewhat prominent in Group B despite incomplete ossification (Fig. 6A). Furthermore, this point was less prominent in some patients in Group C (Fig. 6B). These degrees of prominence are believed to have affected the reliability of the IS method.

Correlation testing also showed the KS method can be affected by degree of knee flexion. The correlation coefficient between the KS indices and knee flexion was −0.584 (p < 0.001), which concurs with the original article on the topic [18]. This finding means degree of knee flexion on lateral knee radiographs is important, especially when the KS method is used, and this should be borne in mind when degree of knee flexion is difficult to control, eg, subjects who are noncompliant.

We do not know which method of measuring patellar height is best in terms of correlations with symptoms and prognosis. Therefore, when examining the merits of these three methods, we focused on communicability, which is reflected by reliability. The IS method appeared to be the better method in patients older than 13 years in terms of its applicability, validity, and reliability. However, the KS

Fig. 6A–B (**A**) The concave or notch-like portion (white arrow) is well seen on this lateral radiograph of a 12.8-year-old girl (Group B) despite incomplete ossification of the tibial tuberosity, which makes it easier to use the IS method. (**B**) Despite nearly complete ossification of the tibial tuberosity as seen on this lateral radiograph of a 14.7-year-old girl (Group C), the distal landmark of the patellar tendon (white arrowhead) is less prominent in some patients. The soft tissue shadow of the patellar tendon (asterisk) helps identify its distal insertion as required by the IS method.
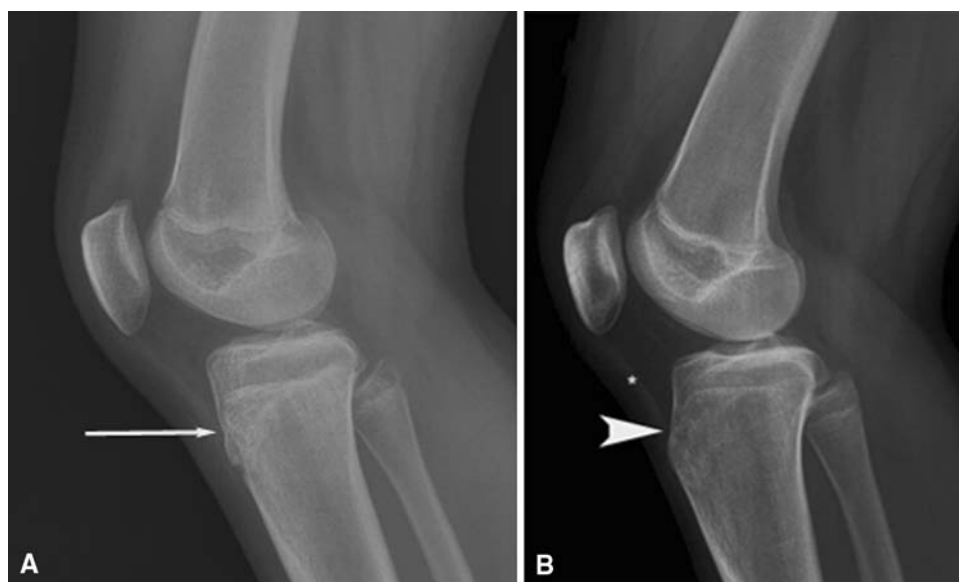
method appeared to be the better method in patients younger than 13 years, with reservations concerning the importance of degree of knee flexion.

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