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ORIGINAL RESEARCH

Reliability and Agreement of Four Patellar Height Measurement Methods in Knee Radiographs

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ABSTRACT

This study aimed to evaluate and compare the reliability and agreement of four commonly used methods for patellar height measurement: Insall-Salvati (IS), Modified Insall-Salvati (mIS), Caton-Deschamps (CD), and Blackburne-Peel (BP) indices, using standardized lateral knee radiographs. This prospective study included seventy adult patients with standardized lateral knee radiographs. Radiographs met strict criteria for true-lateral views and appropriate knee flexion angles. Three observers independently measured patellar height using the four methods, each performing two rounds of measurements at a 15-day interval. Intraclass Correlation Coefficients (ICC) were calculated for intra-observer and interobserver reliability. Pairwise agreements between methods were analyzed using Cohen's kappa with 95% confidence intervals (CI). Correlation coefficients (Pearson's r) were computed to assess the relationships between the methods. The BP method exhibited the highest inter-observer reliability (ICC = 0.848, 95% CI: 0.754–0.910) and intra-observer reliability (average ICC = 0.908, 95% CI: 0.829–0.986). This was followed closely by the CD method, while the IS and mIS methods demonstrated moderate reliability. Correlation analysis revealed strong relationships between the BP and CD methods ($r = 0.871$, $p < 0.01$) but weaker correlations between IS and the other methods. Despite high correlation coefficients, agreement in classification was poor, particularly between IS and BP ($\kappa = -0.131$) and IS and mIS ($\kappa = -0.047$).The Blackburne-Peel method is the most reliable and reproducible for patellar height measurement under standardized conditions, making it a robust tool for clinical and research applications. However, the methods were not interchangeable, emphasizing the need for consistent imaging protocols and method selection tailored to clinical objectives.

Keywords: Patellar height. Reliability. Blackburne-Peel index. Caton-Deschamps index. Insall-Salvati ratio. Modified Insall-Salvati ratio.

Diz Radyografilerinde Dört Farklı Patella Yüksekliği Ölçüm Yönteminin Güvenilirliği ve Uyum Analizi

ÖZET

Bu çalışmanın amacı standardize lateral diz radyografileri kullanılarak patellar yükseklik ölçümü için yaygın olarak kullanılan dört yöntemin güvenilirliğini ve uyumunu değerlendirmek ve karşılaştırmaktır: Insall-Salvati (IS), Modifiye Insall-Salvati (mIS), Caton-Deschamps (CD) ve Blackburne-Peel (BP) indeksleri.Bu prospektif çalışmaya standardize lateral diz radyografileri olan yetmiş erişkin hasta dahil edildi. Radyografiler gerçek lateral görünümler ve uygun diz fleksiyon açıları için katı kriterleri karşıladı. Üç gözlemci bağımsız olarak dört yöntemi kullanarak patellar yüksekliği ölçtü ve her biri 15 gün arayla iki tur ölçüm yaptı. Gözlemci içi ve gözlemciler arası güvenilirlik için Sınıf İçi Korelasyon Katsayıları (ICC) hesaplanmıştır. Yöntemler arasındaki ikili anlaşmalar, %95 güven aralıkları (CI) ile Cohen'in kappa'sı kullanılarak analiz edilmiştir. Yöntemler arasındaki ilişkileri değerlendirmek için korelasyon katsayıları (Pearson's r) hesaplanmıştır.BP yöntemi en yüksek gözlemciler arası güvenilirliği (ICC = 0.848, %95 CI: 0.754-0.910) ve gözlemci içi güvenilirliği (ortalama ICC = 0.908, %95 CI: 0.829-0.986) sergilemiştir. CD yöntemi bunu yakından takip ederken, IS ve mIS yöntemleri orta düzeyde güvenilirlik göstermiştir. Korelasyon analizi, BP ve CD yöntemleri arasında güçlü ilişkiler ($r = 0.871$, $p < 0.01$) ancak IS ile diğer yöntemler arasında daha zayıf korelasyonlar ortaya koymuştur. Yüksek korelasyon katsayılarına rağmen, özellikle IS ile BP ($\kappa = -0.131$) ve IS ile mIS ($\kappa = -0.047$) arasında sınıflandırma uyumu zayıftı.Blackburne-Peel yöntemi, standart koşullar altında patellar yükseklik ölçümü için en güvenilir ve tekrarlanabilir yöntemdir, bu da onu klinik ve araştırma uygulamaları için sağlam bir araç haline getirmektedir. Bununla birlikte, yöntemler birbirinin yerine kullanılamaz, bu da tutarlı görüntüleme protokollerine ve klinik hedeflere göre uyarlanmış yöntem seçimine olan ihtiyacı vurgulamaktadır.

Anahtar Kelimeler: Patellar yükseklik. Güvenilirlik. Blackburne-Peel indeksi. Caton-Deschamps indeksi. Insall-Salvati oranı. Modifiye Insall-Salvati oranı.

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Patellar height measurement is critical in evaluating disorders affecting the patellofemoral joint, including instability and anterior knee pain. Abnormalities such as patella alta and patella baja have been identified as risk factors for patellofemoral (PF) disorders, including instability, maltracking, and degenerative PF osteoarthritis[1,2]. Such conditions have the potential to alter knee biomechanics, thereby increasing the risk of cartilage damage and accelerating joint degeneration. Consequently, an accurate assessment of patellar height is crucial for both the diagnosis and the guidance of surgical treatment in PF disorders, as it provides surgeons with essential insights into biomechanical abnormalities that may require correction.

While advanced imaging modalities like computerized tomography (CT) and magnetic resonance imaging (MRI) offer detailed assessments of patellar height, they are often expensive, less accessible, and involve higher radiation doses or time requirements. Lateral knee radiographs, in contrast, remain the first-line imaging modality due to their affordability, availability, and relatively low radiation exposure. However, the accuracy of radiographic measurements depends heavily on the method used and the standardization of radiographic techniques, such as achieving a true-lateral view and consistent knee flexion angles.

Over the years, several methods for assessing patellar height have been developed, with the Insall-Salvati (IS) ratio, the modified Insall-Salvati (mIS) ratio, the Caton-Deschamps (CD) index, and the Blackburne-Peel (BP) method being the most widely used. Despite their widespread application, each method has limitations, particularly in their sensitivity to radiographic angles, anatomical variations, and observer reliability. For example, the IS and mIS ratios are highly influenced by variations in the length and attachment of the patellar tendon, whereas the CD and BP methods may offer greater anatomical precision. Although the reliability of these methods has been evaluated in previous studies, significant gaps remain in understanding their relative performance under standardized radiographic conditions. Most studies have focused on single methods or have not rigorously compared intraobserver and interobserver reliability across multiple methods[3]. Furthermore, there is limited data on the correlation between these methods and their practical applicability in clinical decision-making. This study addresses these gaps by comprehensively comparing the reliability and consistency of these four patellar height measurement methods.

Given the critical role of patellar height assessment in managing PF disorders, this study aims to identify the most reliable and consistent method under standardized conditions. The findings are expected to guide clinicians in selecting the most robust method for routine practice, thereby improving diagnostic accuracy and treatment planning. This study hypothesized that the Blackburne-Peel (BP) and Caton-Deschamps (CD) methods would demonstrate superior reliability compared to the Insall-Salvati (IS) and modified Insall-Salvati (mIS) ratios, particularly in terms of interobserver and intra-observer consistency. This study aimed to evaluate and compare the reliability and agreement of four commonly used methods for patellar height measurement.

Material and Method

Patients and study design

The institutional review board approved the study protocol (date/protocol: 24.10.2024, 338-16/11). The study was conducted following the principles of the Declaration of Helsinki. The ethics committee waived the need for patient consent because the study only involved radiographic data. The study was designed as a prospective observational study. Radiographs were obtained by searching the digital image database using the Picture Archiving and Communication System (PACS). Patients were eligible if they were 18 or older and had reached skeletal maturity. Exclusion criteria included any history of acute or healed fractures, previous knee surgery, the presence of implants, a diagnosis of severe knee osteoarthritis (Kellgren-Lawrence Classification, Grade III & IV), and radiographs that did not conform to the specific radiographic acquisition techniques described below.

Standards of the Radiographs

Two primary criteria were applied when selecting radiographs for inclusion in this study. First, the radiographs had to present true-lateral views, ensuring a complete overlap of the posterior condyles (Figure. 1a and 1b). Second, the knee flexion angle had to be between 20° and 30°, measured as the angle between the anatomical axes of the femur and tibia (Figure. 1c). To account for variability and obtain sufficient suitable images, radiographs with knee flexion angles within a 3° tolerance (i.e., 17° to 33°) were also included. A radiologist with over ten years of experience in musculoskeletal radiology evaluated the images for true-lateral view suitability and measured the knee flexion angles. The radiologist carefully selected appropriate patients based on the radiographic standards and the inclusion and exclusion criteria. The radiologist measured the knee flexion angles twice, with a minimum interval of 15 days between the measurements. The intra-observer reliability, assessed using the intraclass correlation coefficient (ICC), was calculated to be excellent, with a value of 0.885 (95%

CI: 0.821–0.927). Following two measurements, the mean knee flexion angle was 28.8 ± 3.8° (18.9–32.9°).

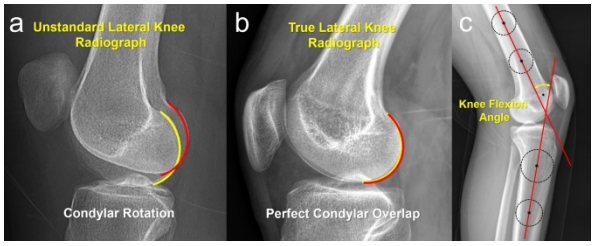

Figure 1.

(a) Example of an unstandardized lateral knee radiograph with visible condylar rotation, demonstrating the lack of complete overlap between the posterior condyles (highlighted with yellow and red arcs). (b) An example of a true lateral knee radiograph showing perfect condylar overlap (highlighted with a single red arc) meets the first inclusion criterion for radiograph selection. ***(c)*** *The knee flexion angle is measured as the angle between the anatomical axes of the femur and tibia, indicating the acceptable range of 20°–30° for inclusion. The yellow arrow highlights the angle, and the red lines illustrate the anatomical axes of the femur and tibia.*

Sample Size Calculation

The sample size was calculated based on the expected inter-rater reliability (Intraclass Correlation Coefficient, ICC) for measuring distances on radiographs by three raters[4] . The expected ICC was set at 0.900, with an acceptable minimum ICC of 0.700, considering a two-way random-effects model for consistency. To achieve 80% power at a significance level of 0.05, a minimum of 68 subjects were required. The calculation was performed using Bonett's method for estimating sample size in reliability studies, considering the number of raters and the difference between the expected and acceptable ICC values. To ensure adequate power, we included 70 randomly selected participants in the study. The study group consisted of 20 females and 50 males with a mean age of 34.6±14.4 years (range 18–76). The mean Body Mass Index (BMI) was 25.5±3.4 (range 19.2–34.5). 27 right knees and 43 left knees were evaluated. Demographic characteristics of patients are presented in Table I.

Measurement methods and normal values

This study used four most frequently used methods to assess patellar height: the Insall-Salvati ratio, the modified Insall-Salvati ratio, the Caton-Deschamps index, and the Blackburne-Peel method (Figure 2). Insall-Salvati Ratio: This method involves measuring the length of the patellar tendon and the greatest diagonal length of the patella. The ratio is calculated by dividing the tendon length by the patellar length[5]. Modified Insall-Salvati Ratio: Similar to the Insall-Salvati ratio, but this method accounts for the patellar tendon attachment by measuring from the lower pole of the patella to the tibial tubercle[6]. Caton-Deschamps Index: This method measures the distance from the inferior edge of the patella to the tibial plateau, divided by the length of the patellar articular surface[7]. Blackburne-Peel Method: The Blackburne-Peel method uses the ratio of the perpendicular height from the tibial plateau to the lower edge of the patellar articular surface divided by the length of the patella's articular surface[8]. Table II summarizes the threshold values for the discrimination of patellar height. Using these thresholds, we have categorized each patient as patella alta, patella norma and patella baja.

Table I. Demographic characteristics of the study population.

Variables	Data
Age (years±SD)	34.6±14.4 (range, 18-76)
Sex (n, %)	
Male	20 (28.6%)
Female	50 (71.4%)
Side (n, %)	
Right	27 (38.6%)
Left	43 (61.4%)
Height (cm±SD)	171.1±7.3 (range, 150-183)
Weight (kg±SD)	74.7±11.0 (range, 55-112)
BMI (kg/m²±SD)	25.5±3.3 (range, 19.2-34.5)

Abbreviations, BMI: Body mass index, SD: Standard deviation

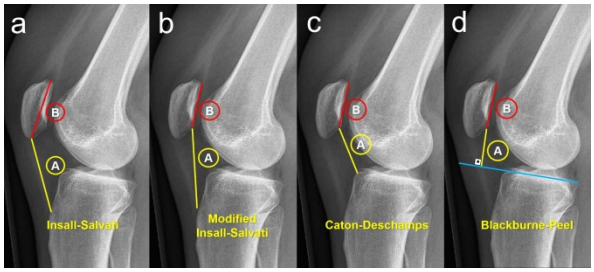

Figure 2.

Illustration of the four methods used to evaluate patellar height. All measurements were calculated as A/B ratios and documented as proportional values. (a) Insall-Salvati ratio, (b) Modified Insall-Salvati ratio. (c) Caton-Deschamps index. (d) Blackburne-Peel method.

Table II. Normal range for patellar height measurements

Method	Patella Alta	Patella Norma	Patella Baja
Insall-Salvati Index	>1.2	0.8-1.2	<0.8
Modified Insall-Salvati Index	>2	≤2	NA
Caton-Deshamphs Index	>1.3	0.6-1.3	<0.6
Blackburne-Peel Index	>1.0	0.5-1.0	<0.5

NA: Not applicable

Reliability Study

Three orthopedic specialists performed the measurements, each conducting two rounds of measurements on the radiographs with at least a 15-day interval between them. All observers were blinded to both their initial measurements and those of the other observers. Any identifying information on the radiographs, such as patient names, ages, and dates, was removed to ensure blinding. Before commencing the study, a meeting was held with all observers to review the measurement methods in detail. A visual aid demonstrating the measurement technique was provided, and the observers were allowed to refer to this image during the measurement process. All measurements were conducted on digital radiographs stored in DICOM format using the RadiAnt DICOM Viewer software (Medixant, Poland).

Statistical Analysis

Descriptive statistics were calculated for demographic and clinical variables, with results presented as means ± standard deviations (SD) or medians with ranges, as appropriate. Intraobserver and interobserver reliability were evaluated using Intraclass Correlation Coefficients (ICC) with 95% confidence intervals (CIs). A two-way random-effects model was used for interobserver reliability, which assessed both absolute agreement and consistency. ICC values were interpreted as poor (< 0.50), moderate (0.50–0.75), good (0.75–0.90), or excellent (> 0.90)[9]. Pairwise agreements between the four methods (IS, mIS, CD, BP) were analyzed using Cohen's Kappa statistic with 95% Cis. Kappa values were interpreted as poor (< 0.00), slight (0.00–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), or almost perfect (0.81–1.00)[10]. Pearson correlation analysis was conducted to evaluate the relationships between the patellar height measurement methods, with correlation coefficients (r) interpreted as very weak (< 0.20), weak (0.20–0.39), moderate (0.40–0.59), strong (0.60–0.79), or very strong (≥ 0.80). The significance level of $p<0.05$ was considered statistically significant[11] .

Results

The study included 70 patients (20 females and 50 males) with a mean age of 34.6 ± 14.4 years (range, 18–76) and a mean BMI of 25.5 ± 3.4 kg/m^2) (range, 19.2–34.5). Of the 70 knees, 27 (38.6%) were right, and 43 (61.4%) were left.

The interobserver reliability analysis demonstrated good levels of agreement (ICC between 0.750-0.900) among the four patellar height measurement methods, with the results summarized in Table III. The Blackburne-Peel (BP) method exhibited the highest interobserver reliability. The intra-observer reliability analysis revealed the highest agreement for the BP method, with an average ICC of 0.908 (95% CI: 0.829–0.986). The other three methods showed good levels of agreement (Table IV) (Figure 3).

Table III. Results of interobserver reliability analysis.

Method	Time 1, ICC 95% CI	Time 2, ICC 95% CI	Average, ICC 95% CI
IS	0.739 (0.612-0.830)	0.835 (0.755-0.892)	0.786 (0.612-0.892)
mIS	0.738 (0.610-0.829)	0.736 (0.608-0.828)	0.737 (0.608-0.829)
CD	0.825 (0.740-0.886)	0.845 (0.769-0.898)	0.835 (0.740-0.898)
BP	0.835 (0.754-0.892)	0.862 (0.795-0.910)	0.848 (0.754-0.910)

Abbreviations, ICC: Interclass correlation coefficient, CI: Confidence interval, IS: Insall-Salvati, mIS: Modified Insall-Salvati, CD: Caton-Deschamps, BP: Blackburne-Peel.

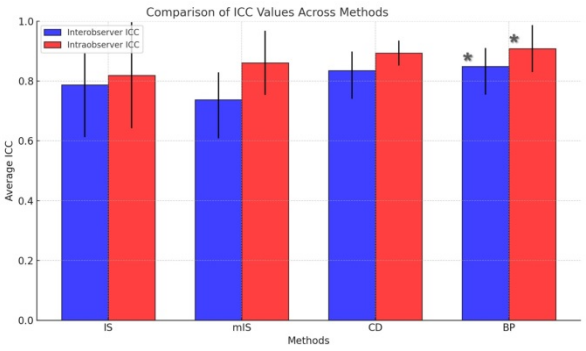

Figure 3.
Comparison of ICC values for interobserver (blue bars) and intraobserver (red bars) reliability across four patellar height measurement methods: Insall-Salvati (IS), modified Insall-Salvati (mIS), Caton-Deschamps (CD), and Blackburne-Peel (BP). Error bars indicate standard deviations. Asterisks (*) denote the methods with significantly higher ICC values compared to others ($p < 0.05$).

Table IV. Results of intra-observer reliability analysis.

Methods	Observer A	Observer B	Observer C	Average
	ICC 95% CI	ICC 95% CI	ICC 95% CI	ICC 95% CI
IS	0.913 (0.863-0.945)	0.638 (0.475-0.758)	0.907 (0.854-0.941)	0.819 (0.641-0.997)
mIS	0.817 (0.721-0.882)	0.795 (0.689-0.867)	0.969 (0.950-0.980)	0.860 (0.753-0.967)
CD	0.904 (0.849-0.939)	0.852 (0.771-0.905)	0.924 (0.880-0.952)	0.893 (0.851-0.935)
BP	0.939 (0.904-0.962)	0.829 (0.738-0.890)	0.957 (0.932-0.973)	0.908 (0.829-0.986)

Abbreviations, ICC: Interclass correlation coefficient, CI: Confidence interval, IS: Insall-Salvati, mIS: Modified Insall-Salvati, CD: Caton-Deschamps, BP: Blackburne-Peel.

Correlation analysis revealed a strong relationship between the CD and BP methods (r = 0.871, p < 0.01) and moderate-to-strong correlations between other methods, such as mIS and BP (r = 0.716, p < 0.01) and IS and CD (r = 0.488, p < 0.01). The IS method showed weaker correlations with mIS (r = 0.348, p < 0.01) and BP (r = 0.344, p < 0.01) (**Figure 4**).

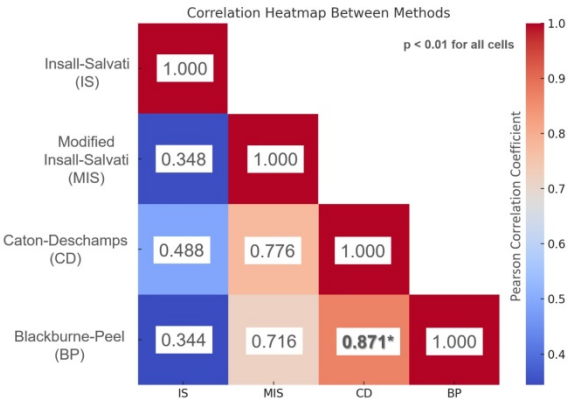

Figure 4.

Correlation heatmap between the patellar height measurement methods. The heatmap displays the Pearson correlation coefficients (r) between the Insall-Salvati (IS), Modified Insall-Salvati (MIS), Caton-Deschamps (CD), and Blackburne-Peel (BP) methods. All correlation coefficients are significant at p<0.01. The strength of the correlations is indicated by the color intensity, ranging from low (blue) to high (red). The highest correlation (r=0.871) is observed between the Caton-Deschamps (CD) and Blackburne-Peel (BP) methods, denoted with an asterisk (*). Diagonal values represent self-correlation (r=1.000).

Despite the high correlation observed between the measured ratios, a notable lack of consistency was evident in the classification results (Table V). The agreement between the Insall-Salvati (IS) and Modified Insall-Salvati (mIS) methods was poor, with a kappa value of -0.047 (95% CI: -0.104 to 0.010). The agreement between IS and Blackburne-Peel (BP) was also poor, with a kappa value of -0.131 (95% CI: -0.200 to -0.062). A moderate agreement was observed between mIS and BP, with a kappa value of 0.419 (95% CI: 0.019 to 0.819). The agreement involving the Caton-Deschamps (CD) method could not be calculated because all classifications under this method were constant, precluding meaningful comparisons. The agreement between the patellar height measurement methods is summarized in Table V. Patient-wise classifications of patellar height based on four methods are presented in Figure 5.

Table V. Pairwise agreement between the methods. Cohen's Kappa and 95% Confidence Interval.

	IS	mIS	CD	BP
IS	1			
mIS	-0.047 (-0.104-0.010)	1		
CD	NA	NA	1	
BP	-0.131 (-0.200-0.062)	0.419 (0.019-0.819	NA	1

Abbreviations, ICC: Interclass correlation coefficient, CI: Confidence interval, IS: Insall-Salvati, mIS: Modified Insall-Salvati, CD: Caton-Deschamps, BP: Blackburne-Peel.NA: Not Applicable. Since all classifications in CD were normal, agreement between methods cannot be calculated.

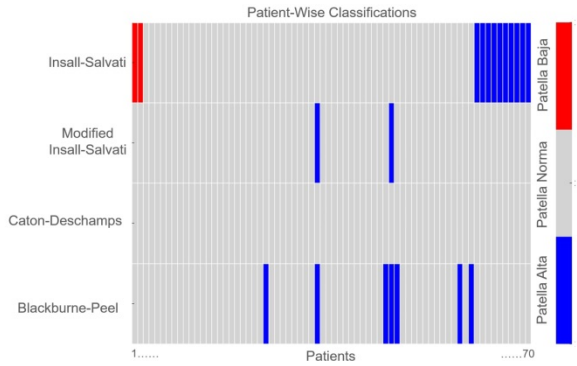

Figure 5.

Patient-wise classifications of patellar height based on four methods: Insall-Salvati, Modified Insall-Salvati, Caton-Deschamps, and Blackburne-Peel. Each row represents one method, and each column corresponds to an individual patient. Colors indicate patellar height categories: red (patella alta), gray (normal), and blue (patella baja). The figure demonstrates variability in classifications across methods, highlighting discrepancies in categorization for some patients.

Discussion and Conclusion

This study sought to evaluate the reliability and agreement of four commonly used patellar height measurement methods, namely Insall-Salvati, Modified Insall-Salvati, Caton-Deschamps, and Blackburne-Peel, using standardized lateral knee radiographs. The findings revealed that the Blackburne-Peel and Caton-Deschamps methods demonstrated superior intra- and inter-observer reliability compared to the Insall-Salvati and Modified Insall-Salvati methods. The BP method demonstrated the highest reliability, with an average ICC exceeding 0.90 for both intra- and inter-observer evaluations, closely followed by the CD method. The results of the correlation analysis demonstrated a strong relationship between the BP and CD methods, while the IS and

mIS methods exhibited weaker correlations with the other methods. Despite the high correlation between the measured ratios, there was poor agreement in the classifications, particularly between the IS and mIS (κ = −0.047, κ = −0.047) and the IS and BP (κ = −0.131, κ = −0.131). These findings underscore the superior reliability and consistency of the BP and CD methods, suggesting their potential as robust tools for clinical and research applications in patellar height assessment. Based on these findings, we recommend choosing the BP method for patellar height measurements. Furthermore, these methods cannot be used interchangeably.

There is currently no consensus in the literature regarding the most appropriate method for measuring patellar height. Different authors have advocated for the superiority of various methods while highlighting the disadvantages of others. This lack of agreement may stem from several factors. One key reason is the variability in imaging modalities used for measurement. For instance, the anatomical landmarks differ between children and adults due to incomplete ossification in pediatric populations. Additionally, the presence of osteoarthritis can alter these landmarks due to osteophyte formation. Beyond modality differences, the standardization of imaging techniques is another critical factor influencing measurement accuracy. Obtaining a true lateral knee radiograph with 30 degrees of knee flexion is essential for standardization and reliable measurements, as studies have shown that rotational misalignment significantly affects results. Similarly, changes in knee flexion angle alter patellar height measurements; reduced flexion leads to patellar tendon relaxation and lower patellar tendon length, while increased flexion results in elongation of the patellar tendon and increase the tendon length. This underscores the importance of maintaining consistent flexion angles during imaging. In MRI, where the knee is often positioned near full extension, the normal and pathological thresholds for patellar height classification differ from those established for radiographs, necessitating the development of adjusted classification ranges. Furthermore, the Insall-Salvati (IS) ratio was modified by Grelsamer to create the Modified Insall-Salvati (mIS) ratio, which focuses on the patella-trochlear engagement, emphasizing the importance of the articulating surface of the patella. However, the Blackburne-Peel (BP) method has been reported to vary with changes in tibial slope, highlighting the influence of anatomical and imaging factors on measurement reliability.

Huddleston et al. and Becher et al. both highlighted critical factors influencing the accuracy of patellar height measurements, emphasizing the need for precise imaging conditions[12,13]. Huddleston et al. demonstrated that aberrant radiographic rotation, particularly in the axial and counterclockwise directions, significantly alters Caton-Deschamps Index (CDI) measurements, with all degrees of rotational error in axial and coronal planes potentially causing clinically significant differences (≥0.1)[12]. This underscores the importance of obtaining true-lateral radiographs to ensure accurate patellar height assessment. Similarly, Becher et al. showed that increasing knee flexion angles significantly affected patellar height indices, including CDI and Patellotrochlear Index (PTI), which decreased progressively with increased flexion, with the most notable reductions observed at 45° flexion[13]. These findings highlight the dynamic nature of patellar positioning with knee flexion and rotation, reinforcing the necessity of controlling both knee angle and radiographic alignment during clinical and imaging evaluations.

The present study builds on the findings of the Berg and Seil studies by reaffirming the reliability of the Blackburne-Peel (BP) method as the most reproducible for patellar height measurement, demonstrating superior inter- and intraobserver reliability across methods[14,15]. Similar to Berg et al., we emphasize the importance of strict radiographic standards and consistent knee flexion angles, with our findings further showing strong correlations between BP and the Caton-Deschamps (CD) index ($r = 0.871$, $p < 0.01$)[14]. Both our study and Seil et al. noted variability among methods, including poor concordance between IS and BP (κ values below zero in our study; 57% in Seil et al.)[15]. While Seil et al. assessed additional methods, such as Labelle-Laurin, both studies strongly advocate for methods that rely on patellar articular surface relationships, like BP and CD[15]. By providing comprehensive correlation data and highlighting poor agreement between IS, Modified Insall-Salvati (MIS), and BP, our study extends these earlier findings and underscores the necessity of standardized imaging conditions to improve reliability.

The present study stands in contrast to the findings of Moon Seok Park et al., Duijvenbode et al., and Verhulst et al., as it advocates for the Blackburne-Peel (BP) method as the most reliable and clinically applicable measure of patellar height, particularly in adults[3,16,17]. While Moon et al. highlighted the limitations of BP in pediatric populations due to indistinct bony landmarks, our results demonstrate its superior reproducibility in adults, where ossification is complete[16]. In contrast to Duijvenbode et al., who recommended the Insall-Salvati (IS) and Modified Insall-Salvati (MIS) methods for their reliability and validity, our findings emphasize BP's resilience in identifying patella alta and baja, especially under standardized radiographic conditions[3]. Similarly, Verhulst et al. favored IS for its inter-method

reliability across imaging modalities. However, we observed that BP outperforms IS in consistency and clinical utility when clear imaging protocols are applied[17]. Our study also addresses some of the criticisms of BP noted in these works, including variability related to landmark identification. We minimised these issues by employing strict radiographic acquisition protocols, further reinforcing BP's practicality and reliability. These differences underscore the importance of considering patient population and imaging conditions, as we argue that BP provides the most accurate and reproducible results in clinical practice, particularly in adults with standardized imaging.

The present study aligns with previous works, including those by Picken et al., Hunter et al., and Kwak et al., in emphasizing the challenges and variability of patellar height measurement methods[2,18,19]. The study also advocates for the Blackburne-Peel (BP) method as the most reliable under standardized conditions. Like Picken et al., we acknowledge the superior reliability of the Insall-Salvati (IS) ratio across observers and modalities but observed higher reliability for BP in our dataset due to stringent radiographic standardization. While Picken et al. highlighted the need for modality-specific normative values, particularly for MRI, our focus on consistent imaging conditions reinforces the importance of clear anatomical landmarks for accurate measurement[18]. Similarly, our findings parallel Hunter et al.'s observations on the variability and poor interchangeability of common indices, but we differ by identifying BP as the most reproducible method when standardization is ensured, contrasting with their findings favoring IS for inter-rater reliability[2]. Kwak et al. further highlighted the importance of age- and modality-specific approaches, demonstrating the Koshino–Sugimoto method's superiority in pediatric populations[19]. In contrast, our study, limited to adult patients, identified BP as the most consistent and clinically applicable method. Collectively, these findings emphasize the critical role of imaging standardization and tailored approaches to improve the accuracy and reliability of patellar height measurements across diverse patient populations.

One important consideration in patellar height measurement is the potential influence of racial and regional differences. While most commonly used methods, such as Insall-Salvati, Modified Insall-Salvati, Caton-Deschamps, and Blackburne-Peel, were originally developed and validated in Western populations, recent studies have shown that these methods may yield different results in non-Western populations. For example, a study conducted in Indonesia reported lower normal values for the Insall-Salvati method (0.78–1.26) compared to the standard Western values (0.8–1.2), suggesting that ethnic differences may influence patellar height measurements[20]. In contrast, a study conducted in Turkey found that patellar height values measured with the same methods were consistent with Western norms, indicating that these standardized methods can be reliably applied to the Turkish population[21]. These findings emphasize the importance of validating measurement techniques across different populations to ensure accurate and reliable clinical assessments.

This study has several limitations. First, the sample consisted solely of adult patients, limiting the generalizability of the findings to pediatric populations or those with incomplete ossification. Additionally, the use of standardized lateral knee radiographs excludes variability seen in routine clinical imaging, which may affect real-world applicability. The study also did not evaluate imaging modalities other than radiographs, such as MRI or CT, which are increasingly utilized in patellar height assessment. Furthermore, the exclusion of patients with severe osteoarthritis or prior surgeries may underestimate the challenges of landmark identification in more complex clinical cases. Despite these limitations, the study has several notable strengths. Its prospective design and rigorous radiographic standardization ensured the collection of high-quality data. Including multiple observers and repeated measurements allowed for a robust assessment of inter- and intra-observer reliability. Additionally, the comparative analysis of four commonly used measurement methods under consistent conditions provided valuable insights into their reliability and applicability, particularly emphasizing the Blackburne-Peel method as a reliable option for both clinical and research settings.

This study highlights the Blackburne-Peel (BP) method as the most reliable and consistent technique for patellar height measurement under standardized conditions, outperforming the Insall-Salvati (IS), Modified Insall-Salvati (mIS), and Caton-Deschamps (CD) methods in terms of both inter- and intra-observer reliability. While the BP method demonstrated superior reproducibility, the variability in classifications across methods underscores the importance of selecting appropriate measurement techniques tailored to specific clinical or research needs. These findings emphasize the necessity of achieving true-lateral radiographs with consistent knee flexion angles to enhance measurement accuracy. Future studies should explore the applicability of the BP method across different imaging modalities, pediatric populations, and in the presence of osteoarthritis to establish a more comprehensive understanding and foster a consensus on patellar height assessment.

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