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Effect of radiographic malpositioning on patellar height measurements: implications for diagnosis and surgical planning. A retrospective observational study

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Received: 15 November 2024 / Accepted: 24 February 2025 © The Author(s) 2025

Abstract

Purpose Patella alta stands as a significant predisposing factor for patellofemoral instability. Patellar heights indexes (PHI) require precise lateral knee radiographic projections for accurate computation. However, within clinical contexts, a notable proportion of radiographic images are taken with certain degrees of excessive rotation and/or tilting. The primary aim of this investigation was to assess the impact of suboptimal radiographic positioning on the determination of patellar height, utilizing the Blackburne-Peel (BP), Caton-Deschamps (CD) and Insall-Salvati (IS) indexes. Secondarily, it was evaluated whether any index is more sensible to suboptimal radiographic positioning, and how inter and intra observer reproducibility are affected. **Methods** Thirty-three patients with strictly lateral radiographs and another one demonstrating a noticeable degree of tilt and/ or rotation were included in the study. Four orthopaedic surgeons specialized in knee surgery and four Orthopaedics residents conducted measurements on each radiograph in a randomized sequence at two different time points. A linear mixed-effects model was applied, with the quality of the radiograph (adequate projection vs malrotation, tilt, or both), observer expertise (consultant or resident), and observation time regarded as fixed effects, while consultant and patient were treated as random effects.

Results Statistically significant differences were obtained between strict lateral and tilted radiographs in the BPI, with an overestimation of up to 0.0937; between strict lateral and malrotated radiographs in the ISI, showing an overestimation of up to 0.0696 and between tilted and/or rotated radiographs in the CDI, with overestimation reaching up to 0.0813. No significant differences were observed between resident and consultant observers in any of the indexes. Good inter-observer consistency was achieved.

Conclusion This study showed statistically significant differences in the determination of the three PHIs. Although these differences were small, they may predispose to diagnostic errors and inaccurate surgical planning in cases requiring surgical correction. Future studies quantifying the degrees of malrotation and/or inclination may further clarify these findings.

Keywords Patellar height · Radiography · Positioning · Planning · Diagnostic

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Introduction

Patellofemoral instability (PFI) is a well-known cause of referral to orthopaedic clinics. Predisposing factors, i.e. troclear dysplasia, patellae alta (PA), insufficiency of medial retinacular structures such as the medial patellofemoral ligament (MPFL) or lower limb malalignment, have been extensively studied over the past decades[1]. Patella alta, this meaning an excessively proximal patellar location regarding the knee joint line, is associated with 30–50% of patellar dislocations [2]. Furthermore, a high riding patella is the only factor capable of causing a low-energy dislocation without associated trochlear dysplasia, making it a crucial instability factor and a pivotal consideration in treatment decisions [3]. Additionally, patellar height is also crucial for managing patients following anterior cruciate ligament reconstruction, high tibial osteotomies and total knee replacements, where a reduced patellar height may lead to postoperative complications, as anterior knee pain [4, 5]. Consequently, evaluating patellar height with precision is essential in diagnosing and treating PFI.

Various patellar height indexes (PHI) attempt to establish simple, reliable and reproducible methods for assessing patellar height based on simple radiology. Most PHI are calculated from lateral knee x-rays obtained in a pure or strict projection. Strictly projected lateral radiographs are characterized by the overlap of the femoral condyles, visible space at the patellofemoral joint (in the absence of advanced osteoarthritis), and slight overlap of the fibular head with the tibia [6]. However, in clinical practice, many radiographs are not taken in a proper projection, but with a certain degree of excessive tilting and/or rotation, which hinders their applicability as tools for diagnosis and/or surgical correction planning.

Currently, there is poor evidence on the effects of these technical imperfections on the assessment of PHI and their potential influence on decision-making for patients with patellofemoral pathology [7]. Errors in PHI measurements may result in incorrect surgical indications, such as unnecessary tibial tubercle osteotomy or failure to address patellofemoral instability adequately. Ensuring accurate radiographic acquisition is therefore crucial to optimizing patient outcomes. The main purpose of this study is to evaluate whether the calculation of patellar height in poorly performed radiographs differs significantly from those obtained in correctly performed ones. Secondary objectives include: 1- evaluating whether rotation or tilting have a greater impact on PHI measurements, 2- determining if any specific index is more susceptible to the effects of poor radiographic technique, and 3- assessing inter- and intra-observer reproducibility. The working hypothesis posits that an inadequate radiographic technique significantly influences PHI measurements due to challenges in locating the necessary anatomical landmarks, predisposing to diagnostic errors and inaccurate surgical planning.

Methods

This study was designed as a retrospective observational study. Knee radiographs were selected from the already existing in the Radiology Department database; no additional captures were taken for the purpose of this study. All retrieved images were anonymized before analysis; approval from the local Ethics Committee was obtained (CEI/CEIM 2023–446-1).

Participants

A custom-made database was obtained from the Complejo Hospitalario Universitario Insular y Materno Infantil (CHUIMI) Radiology Department database: patients with at least two x-rays from the same knee performed in 2022. 409 patients were reviewed to reach the target sample size. The list was screened to select patients with the following criteria:

• Inclusion criteria:

• Patients with at least one strictly lateral radiograph and another exhibiting significant malrotation or tilting, on the same knee. Strict lateral projections were defined as those showing overlap of the femoral condyles, femoropatelar joint space, and slight overlap of the fibular head with the tibia, as defined by Murphy (Figure 1) [6]. Image selection was performed by JGC and SBR; the degree of tilting and/or rotation could not be calculated due to the retrospective nature of the study and the lack of angular calibration of the pre-existing images.

• Exclusion criteria:



Fig. 1 Image A shows a strict lateral projection, as described by Murphy (10): clear femoropatelar joint space (FPJS); overlap of the femoral condyles (FCO) and slight overlap of the fibular head with the proximal tibia (FHTO). Image B shows a tilted lateral projection, with a distortion in the horizontal plane. Image C shows a rotated lateral view, with the distortion occurring in the sagittal plane

• Knee flexion above 70° or below 30°.

- Patellar fracture.
- Previous knee surgery.
- Skeletal immaturity (open tibial/femoral/fibular physis).
- Gross distal femoral and/or proximal tibial deformities.

Sample size estimation

A sample size of 33 elements provided a 95% confidence interval and a margin of error of 0.17. Consequently, 33 sets of 2 lateral knee x-rays were obtained.

Procedures

The 66 radiographs were independently assessed in a randomized sequence by eight observers; 4 senior orthopaedic surgeons specialized in knee surgery and 4 Orthopaedics residents. Measurements were conducted independently on two separate occasions, spaced at least one week apart, in a different image sequence order. All observers were blinded to the patients' information, the results of their colleagues and their own previous calculations. Measurements were obtained using *Horos* (*free and open source code software* (*FOSS*) sponsored by Nimble Co LLC d/b/a Purview in Annapolis, MD USA) [8].

Three PHI were calculated, according to the indications in their original publications: Blackburne-Peel ratio (BP), Insall-Salvati index (IS) and Caton-Deschamps ratio (CD). Figure 2 shows a diagram of the indexes and calculation instructions employed by all observers.

Statistical analysis

A linear mixed-effects model was applied to account for variability among patients and observers [9, 10]. Fixed effects included radiographic quality, observer category, and observation time, while random effects accounted for inter-observer and intra-observer variability. Coefficients (SE), 95% confidence intervals (95% CI), p values were summarized. Statistical significance was set at p < 0.05. Data were analysed using R software (*R Core Team (2021). R: A language and environment for statistical computing, Vienna, Austria*) [11].

Results

No statistically significant differences were observed among observations in relation to the level of experience (consultants vs trainees). A summary of the main findings is presented in Table 1. The results obtained for each index are presented below:



Fig. 2 From left to right: BP (Blackbourne-Peel), measured by projecting an anterior intercondylar line and determining the perpendicular distance from this line to the underside of the patellar cartilage (a), which is then divided by the surface area of the patellar cartilage (b). IS (Insall-Salvati), calculated by dividing the length of the patellar tendon (a) by the length of the patella (b). CD (Caton-Deschamps),

dividing the distance from the inferior border of the patella to the superior tibial border (a) by the length of the patellar cartilage (b). All three indexes are the result of a/b. BP should be measured with the knee at 30 degrees of flexion or more, IS between 20 and 70 degrees and CD between 10 and 90(1)

Table 1 Summary table with mean values, standard deviations, and significant differences

Index	Strict Lateral	Tilting	Malrotation	Combined malpositioning
BPI	0.8434 ± 0.0526	$0.9121 \pm 0.025 \ (p < 0.001)$	0.8571 ± 0.0305 (NS)	$0.8954 \pm 0.178 \ (p < 0.001)$
ISI	1.2359 ± 0.1152	1.2502 ± 0.0221 (NS)	$1.1872 \pm 0.027 \ (p < 0.001)$	1.2462 ± 0.0156 (NS)
CDI	0.9478 ± 0.0557	$1.004 \pm 0.0248 \ (p < 0.001)$	$0.9901 \pm 0.0305 \ (p = 0.007)$	$0.9967 \pm 0.0178 \ (p < 0.001)$



Fig. 3 Graphic representation of the linear mixed-effect model results for the analysed PHIs

Table 2 Linear mixed-effects model for the BPI

Effect	Coefficient (SE)	CI 95%	Р
σ_P	0.1286	(0.1006; 0.1658)	
σ_d	0.0274	(0.0142; 0.0481)	
σ	0.1091	(0.1043; 0.1138)	
μ	0.8435 (0.0271)	(0.7909; 0.8961)	<.001
$\alpha_I(R)$	0.0136 (0.0156)	(-0.0169; 0.0442)	0.383
$\alpha_I(I)$	0.0686 (0.0128)	(0.0436; 0.0937)	<.001
$\alpha_I(IR)$	0.0519 (0.0090)	(0.0341; 0.0696)	<.001
$\beta_C(R)$	0.0024 (0.0205)	(-0.0398; 0.0446)	0.911
γ_2	0.0125 (0.0067)	(-0.0006; 0.0257)	0.062

Blackburne-Peel index

Statistically significant differences were observed between strictly lateral radiographs and all those with some degree of tilting (Fig. 3). Tilting overestimates the BPI up to 0.0937. Combined tilting and rotation resulted in an index overestimation up to 0.0696. Isolated malrotation did not significantly affect the BPI. Good interobserver and intra-observer reproducibility were observed for BPI calculations (Table 2).

Insall-Salvati index

Excessive rotation resulted in statistically significant differences, up to -0.0757 (Table 3). There were no statistically significant differences found between control radiographs and those with some degree of tilting (Fig. 3). Good inter-observer and intra-observer reproducibility was consistently observed (Table 3). **Table 3** Linear mixed-effects model for the ISI. In the model's parameterization, the random effect of patient observation is assumed to be a normally distributed random variable with a mean of 0 and standard deviation σ_p , where σ_p represents de the variability among patients. μ denotes the expected value of the evaluated index. $\alpha_I(I)$ represents the difference attributed to a radiograph with only inclination, $\alpha_I(R)$ indicates the difference attributed to a radiograph with only rotation and $\alpha_I(IR)$ represents the difference attributed to a radiograph with both inclination and rotation simultaneously. $\beta_C(R)$ stands for the effect (fixed) of a trainee compared to a senior consultant. γ_2 signifies the fixed effect of the observation time, indicating the difference activity of the effect.

Effect	Coefficient (se)	CI 95%	Р
σ_P	0.1677	(0.1326; 0.2172)	
σ_d	0.1031	(0.0595; 0.1661)	
σ	0.0961	(0.0919; 0.1002)	
μ	1.2359 (0.0595)	(1.1207; 1.3512)	<.001
$\alpha_I(R)$	-0.0487 (0.0138)	(-0.0757; -0.0216)	<.001
$\alpha_I(I)$	0.0143 (0.0113)	(-0.0078; 0.0364)	0.206
$\alpha_I(IR)$	0.0103 (0.0080)	(-0.0053; 0.0260)	0.196
$\beta_C(R)$	-0.0067 (0.0731)	(-0.1518; 0.1384)	0.930
γ_2	0.0007 (0.0059)	(-0.0109; 0.0123)	0.902

Caton-deschamps index

Statistically significant differences were noted between defective radiographs and strict lateral ones; tilting overestimates the CDI up to 0.0813; rotation up to 0.0728 and both combined effects affected it up to 0.0665 (Fig. 3). Good inter-observer reproducibility was observed; however, intra-observer reproducibility was not satisfactory (Table 4). As a result of the latter, a consistency subanalysis was performed independently for optimal and suboptimal radiographs (Table 5); good inter-observer reproducibility was achieved regardless of the quality of the radiographic projection, while steady intra-observer

Effect	Coefficient	CI 95%	Р
σ_P	0.1405	(0.1100; 0.1808)	
σ_d	0.0266	(0.0137; 0.0470)	
σ	0.1087	(0.1040; 0.1134)	
μ	0.9478 (0.0286)	(0.8921; 1.0035)	<.001
$\alpha_I(R)$	0.0423 (0.0156)	(0.0118; 0.0728)	0.007
$\alpha_I(I)$	0.0562 (0.0127)	(0.0314; 0.0813)	<.001
$\alpha_I(IR)$	0.0489 (0.0090)	(0.0311; 0.0665)	<.001
$\beta_C(R)$	0.0099 (0.0200)	(-0.0313; 0.0510)	0.639
γ_2	0.0166 (0.0067)	(0.0035; 0.0297)	0.013

 Table 4
 Linear mixed-effects model for the CDI

reproducibility was achieved with strictly lateral projections, but not with defective ones.

Discussion

The main finding of this study is that inadequate radiographic projections favour inexact PHI calculations, which may predispose to diagnostic errors and/or inaccurate surgical planning. The main clinical implication would be the assumption that a significant proportion of these decisions factually rely on measurements derived from suboptimal radiographic images; it has been assumed that variations nearing 0.1 in any of the three PHI are deemed clinically relevant, as described by Huddleston et al. [7].

The BPI has been appointed as one of the most recommendable PHIs, as it provides a direct estimation of patellar position in relation to the joint line [12]. For this index, values are significantly affected by tilting, whereas excessive rotation seems not to cause a relevant impact. This can be easily understood in a three-dimensional model: rotation alters horizontal distances and tilting modifies vertical distances (Fig. 4). A similar effect was found by Bixby et al. for tibial slope calculation [13]. Moreover, when radiographs are not acquired with a perfectly lateral view, the tibial plateaus do not appear parallel in the image, complicating line placement [14] (Fig. 2, left image).

Fig. 4 Three-dimensional representation of the effect of rotation and tilting in patellar height variation. Image A represents a strict lateral projection, image B a rotated projection, and Image C a tilted projection. Note how tilting affects patella-joint line distance more than rotation

In relation to the Insall-Salvatti index, values showed differences that could be clinically relevant between malrotated and control radiographs, underestimating the patellar height up to 0.0757. These differences could be explained by the increased hassle in locating the anterior tibial tuberosity when the projection is rotated, altering the apparent position of the patellar tendon. No clinically relevant differences were observed between the radiographs with a certain degree of tilting and the controls.

The impact of suboptimal radiographic projection in CDI has been evaluated by Huddleston et al. [7]. They conducted a study involving five cadaveric knees and obtained pure lateral radiographs at 5° , 10° , and 15° of flexion in both clockwise and counter clockwise directions, in the axial and coronal planes. PHI measurements were assessed by three orthopaedic surgeons; statistically and clinically significant results were obtained particularly in cases of counter clockwise malrotation, whereas our study found smaller discrepancies. This discrepancy may be to the differences in methodology, including the degree of malrotation evaluated. Additionally, Huddleston et al. found that greater degrees of malrotation in this plane led to increased errors. Additionally, they proposed that all degrees of malrotation or tilting in both directions have the potential to produce clinically significant changes based on the maximum differences observed in each malrotation state. In the present study, it

Table 5Linear mixed effectsmodel for CDI. X-rays wereclustered according to thequality of the radiographicprojection

	Correct projections			Suboptimal projections		
effect	coefficient (se)	CI 95%	Р	coefficient (se)	CI 95%	Р
σ_P	0.1450	(0.1135; 0.1871)		0.1496	(0.1169; 0.1929)	
σ_d	0.0304	(0.0151; 0.0539)		0.0219	(0.0078; 0.0414)	
σ	0.0971	(0.0913; 0.1035)		0.1036	(0.0974; 0.1104)	
μ	0.9477 (0.0304)	(0.8887; 1.0067)	<.001	0.9976 (0.0293)	(0.9403; 1.0549)	<.001
$\beta_C(R)$	0.0117 (0.0231)	(-0.0358; 0.0591)	0.631	0.0080 (0.0179)	(-0.0291; 0.0452)	0.669
γ_2	0.0150 (0.0085)	(-0.0016; 0.0316)	0.076	0.0181 (0.0090)	(0.0004; 0.0358)	0.045

was observed how CDI is also influenced by both rotation and tilting, resulting in the most sensitive PHI to inadequate radiographic knee positioning. However, the shown discrepancies were smaller compared to those observed by Huddleston et al., which could be attributed to differences in quantification of malrotation and/or tilting degrees, sample size, or number of observers and their level of experience.

In the present study, with multiple observers with diverse experience level, factors of poor radiographic projection and knee flexion have been controlled. Good inter-observer reproducibility was achieved across all indices, regardless of the observers' expertise. Intra-observer reproducibility is good in ISI and BPI, but not in CDI (Tables 1–3), concurring in part with previous reports [15]. Taking into account that in CDI there was good inter-observer reproducibility, poor intra-observer reproducibility can be explained by already described difficulty in defining the anterior tibial spine, since it often presents a non-acute border [16] and by the additional difficulty due to the effects of malrotation and/ or tilting. This is supported by the findings of the CDI subanalysis in two groups of optimal vs suboptimal radiographs (Table 5).

As seen here, the most frequently utilized in practice PHIs are susceptible to clinically significant alterations due to suboptimal radiographic projection. Currently, advancements in artificial intelligence (AI) are being made to enhance measurement precision. Adleberg et al. developed an AI model that measured the Insall-Salvati index on lateral knee radiographs in a highly consistent manner, with minimal mean distance error [17]. However, it has been previously disclosed that an ideal patellar hight measurement should rely on three-dimensional imaging, rather than on plain x-rays subjected to patient malpositioning [18]. In this regard, several MRI and CT techniques have been described for patellar height calculation, often under quadriceps contraction or even active knee movement [19]. The results of the present study support the convenience of these imaging modalities for a precise assessment of patellar height, a fact that should be taken into account not only for diagnostic purposes but also for surgical planning.

Another critical finding of this study was that most screened images exhibited suboptimal radiographic projections (Fig. 1): it was noted that many excluded patients had between three and ten radiographs lacking strictly lateral views. The analysed database comprise a clinical collection of radiographic studies obtained in a third level European institution; if this situation is extrapolated globally, it could be assumed that a high proportion of clinically used images lack adequate quality. Brunner et al. stated that a combination of altered rotation and flexion in lower limb image acquisition can easily reach clinically relevant alterations of alignment measures [20]. The implications of inadequate radiologic projections have been extensively discussed [21, 22] and healthcare facilities should implement quality protocols to avoid fawlty radiologic examinations [23].

As any other, this study has limitations. A potentially relevant one is the lack of standardized calibration across radiographs, which may introduce variability in measurements. Future studies should aim to quantify malrotation and tilting in degrees for a more precise assessment. Another constraint may be sample size. To achieve a 95% confidence level with a margin of error of 0.05, a total of 384 images would have been necessary; this requirement would have complicated patient selection and collaboration among researchers. However, the achieved confidence level of 95%, with a 0.17 error may be considered excellent for a research of this nature. Among the strengths of this study was the employment of actual clinical practice radiographs, the inclusion of a variety of commonly used PHI, and a large party of researchers performing multiple observations.

Conclusions

Calculation of patellar heigh indexes is not reliable when inadequate radiological projections are performed. Tilting primarily impacts the BPI, ISI is affected by rotation and the CDI is affected by both rotation and tilting. Deviations in obtained values may be minimal, but do have the potential of resulting in diagnostic or surgical planning errors. Standardized patient positioning and radiography acquisition techniques should be implemented in all health care facilities, ensuring strict lateral projections, minimising measurement variability and thus improving clinical decision-making.

Acknowledgements The authors would like to acknowledge the essential participation of Samuel Hernández, Cristina Valencia, Jorge Mata, Antonio Ortega, Fernando Bañolas, Jose María Monasterio, Bárbara González and Daniel de Santos, and thank their implication and support towards the present study.

Author Contribution All authors contributed to the study conception and design. Conceptualization and bibliographic review was carried out by SB. Material preparation and data collection were performed by JG. Statistical analysis was performed by CNH. The first draft of the manuscript was written by JG, and was revised by SB. All authors read and approved the final manuscript.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. This research did not receive external funding.

Data availability Research data is available upon reasonable request.

Declarations

Conflict of interests The authors declare no competing interests.

Ethical approval This study was approved by the Ethics and Clinical Research Committee of the Hospital Universitario de Gran Canaria Dr. Negrín. Patient anonymity was guaranteed throughout the study.

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