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MRI and Merchant Radiographs Show Poor Correlation in the Evaluation of the Patellofemoral Joint in Pediatric Patellofemoral Instability

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Background: Patellofemoral instability (PFI) is a common condition in the pediatric population, requiring accurate assessment of patellofemoral joint morphology. While magnetic resonance imaging (MRI) offers detailed visualization of osseous, chondral, and soft tissue structures, Merchant view radiographs (M-XR) are widely used given their accessibility and cost-effectiveness and for detection of small patellar or condylar fragments that are not well-depicted on MRI. Agreement of key patellofemoral parameters between the 2 imaging modalities remains unclear.

Purpose: To assess the agreement between sulcus angle, lateral patellofemoral angle (LPFA), and patellar tilt in pediatric patients with PFI, both before and after medial patellofemoral ligament (MPFL) reconstruction, on MRI and M-XR.

Study Design: Cohort study (diagnosis); Level of evidence, 3.

Methods: A retrospective cohort study was conducted on 84 pediatric patients ≤18 years who underwent MPFL reconstruction. Of these, 74 patients had preoperative MRI and M-XR and 44 had postoperative imaging. Sulcus angle, LPFA, and patellar tilt were measured, agreement between imaging modalities was assessed using single-measure, 2-way random-effects intraclass correlation coefficients (ICC[2,1]). Threshold values were applied to classify normal or abnormal measurements; agreement was assessed using Cohen kappa. Subgroup analyses were performed in patients with and without patella alta. Correlation was analyzed using Spearman coefficients, and paired *t* tests were used to evaluate differences in mean values of paired images.

Results: The cohort had a mean age of 15 ± 2 years and included 51 (60.7%) female patients. Across all parameters, MRI and M-XR demonstrated poor intermodality agreement (ICC < 0.50) and weak positive correlations (Spearman rho, 0.27 to 0.42). Agreement between MRI and M-XR binary classification was poor for pre- and postoperative sulcus angle (kappa, 0.117 and 0.095, respectively), pre- and postoperative patella tilt (kappa, 0.421 and −0.044, respectively) and preoperative LPFA (kappa, 0.132), though postoperative LPFA demonstrated excellent agreement (kappa, 1.00). In 32 patients with preoperative patella alta (CDI ≥ 1.3), agreement in preoperative sulcus angle and LPFA on MRI and M-XR remained poor.

Conclusion: Our study demonstrated that MRI and M-XR yield significantly different measurements of patellofemoral morphology in pediatric patients with PFI, with poor statistical agreement. These modalities should not be used interchangeably for clinical decision making or postoperative follow-up. Establishing novel cutoff values for radiographic-derived measurements applied to MRI is warranted.

Keywords: patellofemoral instability; sulcus angle; patellar tilt; medial patellofemoral ligament reconstruction

Patellofemoral instability (PFI) is a common condition in the pediatric and adolescent populations, with an estimated incidence ranging from 43 to 100 cases per 100,000 children and adolescents per year.[1] Recurrence of ipsilateral dislocation following a primary event occurs in approximately 8% to 13% of cases without risk factors, and in up to 80% when >3 risk factors are present, with the highest risk within the first 5 years after the initial

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dislocation.[17-19] Multiple anatomic risk factors have been implicated in the pathogenesis of PFI, including patella alta, trochlear dysplasia, and patellar malalignment.[5]

In this context, the diagnostic evaluation of PFI typically involves the assessment of several radiographic parameters, including the Caton-Deschamps index (CDI) for patella alta, the sulcus angle for trochlear dysplasia, the lateral patellofemoral angle (LPFA) and patellar tilt for patellar malalignment, and coronal alignment on standing full-length lower limb radiographs to assess varus or valgus deformities that may influence patellar tracking.[7,17] CDI, LPFA, patellar tilt, and sulcus angle have historically been obtained from radiographs. However, with the increasing use of magnetic resonance imaging (MRI), which offers superior visualization of the patellar and trochlear cartilage and of soft tissue structures, including the medial patellofemoral ligament (MPFL), a key structure often injured in PFI, there has been a growing trend to apply these radiographic parameters to MRI. This shift has raised concerns about the reliability and interchangeability of these measurements across imaging modalities.[23]

Patellar tilt, LPFA, and sulcus angle are measured differently on radiography and MRI. On radiographs, LPFA and patellar tilt are typically measured on axial (Merchant) views, and the sulcus angle reflects only the bony contour of the trochlea. These measurements are influenced by patient positioning and degree of knee flexion and only account for osseous landmarks. In contrast, MRI allows for the visualization of both bony and cartilaginous structures, enabling potentially more precise and reproducible assessments.[22] Many advocate measuring the angles along the cartilaginous surfaces, as this provides a more accurate estimation of the patellofemoral dynamics than the bony contours.[22] According to Fabricant et al,[7] patellar tilt and LPFA are considered reliable measurements of patellar position on MRI and radiographs, respectively, while the sulcus angle has demonstrated high interrater reliability on MRI. Nonetheless, in clinical practice, patellar tilt, LPFA, and sulcus angle are often measured interchangeably on radiography and MRI without consistent consideration for modality-specific differences, partly because radiographs are faster, more accessible, and less expensive than MRI in most clinical settings.

The aim of the present study is to assess both the correlation and the agreement between MRI and Merchant view radiographs (M-XR) in measuring sulcus angle, LPFA, and patellar tilt in pediatric patients with PFI, both before and after surgical intervention. A secondary aim is to evaluate the agreement between MRI and M-XR in identifying PFI patients based on established cutoff values and to assess whether this agreement differs in patients with patella alta.

Based on the known differences in measurement techniques and anatomical landmarks between MRI and radiographs, we hypothesized that MRI and Merchant view radiographs would demonstrate poor agreement in the evaluation of sulcus angle, LPFA, and patellar tilt in pediatric patients with PFI, both pre- and postoperatively.

METHODS

Study Cohort

Following institutional review board approval, a retrospective study was conducted on pediatric patients aged $\leq$18 years with a history of $\geq$2 episodes of patellar dislocation or symptomatic patellofemoral instability who had failed conservative treatment and subsequently undergone MPFL reconstruction from January 1, 2016, to August 15, 2025. Informed consent was not required by the institutional review board, as this study was retrospective. To be included, patients were required to have both MRI and M-XR preoperatively, both MRI and M-XR postoperatively, or both. Patients were therefore excluded if they did not have a corresponding paired study for direct comparison at either the pre- or postoperative time point, had a history of prior ipsilateral knee surgery, were syndromic, or were obligatory or fixed dislocators.

Measurements

All MRI measurements were conducted using a proton-density sequence, which maximized the spatial resolution. Sulcus angle, LPFA, and patellar tilt were measured on all 4 images (pre- and postoperative MRI and radiography). Interrater reliability was conducted for 15 MRIs and 15 radiographs across 2 raters, both senior orthopaedic surgery residents (G.B. and M.C.), trained by a senior musculoskeletal radiologist with expertise in patellofemoral imaging (D.J.), with intraclass correlation coefficients (ICCs) using single-measure, 2-way random-effects models with absolute agreement, after which patients were divided equally between the 2 raters; ICC values $<$0.50 indicated poor agreement, between 0.50 and 0.75 indicated moderate agreement, between 0.76 and 0.90 indicated good agreement, and $>$0.90 indicated excellent agreement.[14] All values demonstrated good interrater reliability (ICC $>$ 0.80; $P < .001$). The remaining images were then assessed

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Ethical approval for this study was obtained from Hospital for Special Surgery institutional review board (No. 2022-1725).

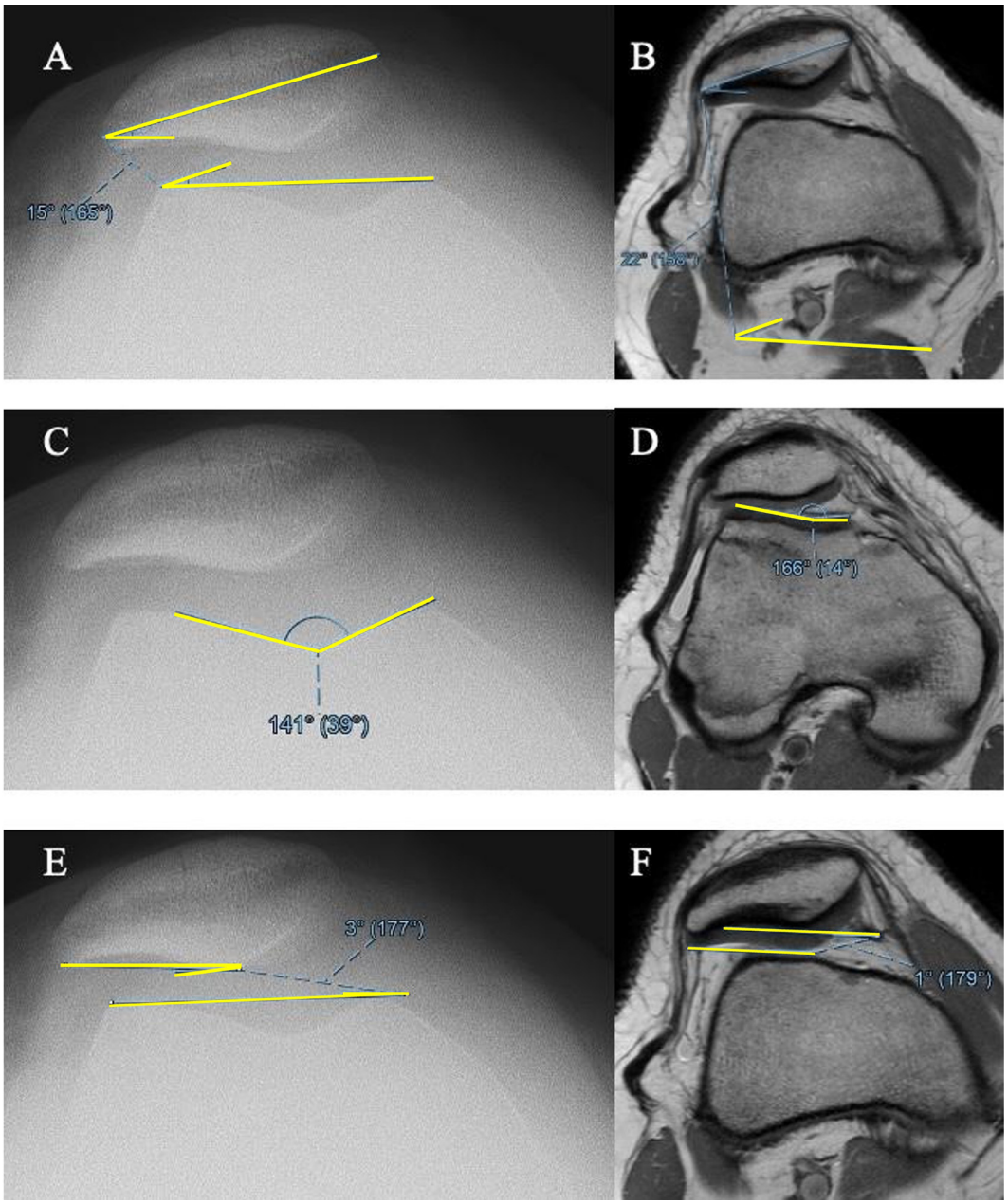


Figure 1. (A) Patellar tilt on Merchant view radiograph: angle between the maximal patellar length and a tangent to the posterior femoral condyles. (B) Patellar tilt on axial magnetic resonance imaging (MRI) T-1 proton density (PD) sequence: angle between the maximal patellar width (top blue line; image of greatest dimension) and a tangent to the cartilaginous posterior femoral condyles (bottom yellow line) (see sulcus angle image). (C) Sulcus angle on Merchant view radiograph: angle between lines from the deepest point of the trochlear groove to the peaks of the medial and lateral condyles. (D) Sulcus angle on axial MRI T-1 PD sequence: measured on the first axial image showing trochlear cartilage, defined between the deepest cartilaginous point and the medial/lateral cartilage peaks. (E) Lateral patellofemoral angle (LPFA) on Merchant view radiograph: angle between the lateral patellar facet and a tangent to the anterior femoral condyles. (F) LPFA on axial MRI T-1 PD sequence: angle between the cartilaginous lateral patellar facet (image of maximal width) and a tangent to the cartilaginous anterior femoral condyles (sulcus angle image).

independently, and values from the senior radiologist were used for the cases originally included in the ICC assessment. The measurements were assessed as described in Haj-Mirzaian et al[11] and below:

- Sulcus angle (Figure 1, A and B)
  - M-XR: angle between lines drawn from the deepest point of the trochlear groove to the

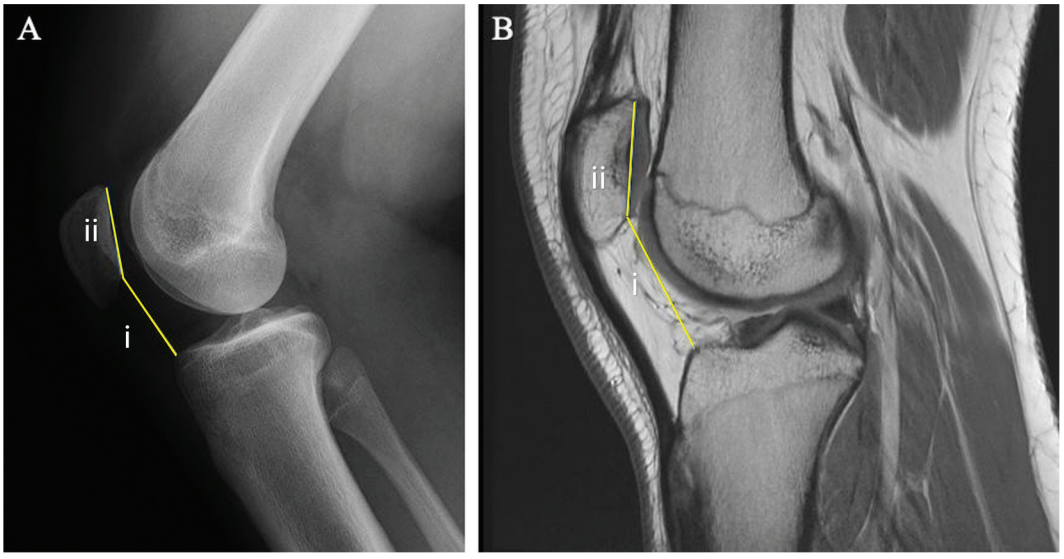


Figure 2. Caton-Deschamps index: (A) On lateral radiograph: ratio between the distance from the inferior margin of the patellar articular surface to the anterior border of the tibial plateau (*i*) and the length of the patellar articular surface (*ii*) (shown in yellow). (B) On sagittal magnetic resonance imaging (MRI) T-1 proton density sequence: ratio between the distance from the inferior margin of the patellar articular cartilage to the anterior border of the tibial plateau cartilage (*i*) and the length of the patellar articular cartilage (*ii*) (shown in yellow).

highest point of the medial and lateral femoral condyles
  - MRI (axial proton density [PD] sequence): angle between the deepest cartilaginous point of the trochlear groove and the peaks of the lateral and medial trochlear cartilage; the most cephalad axial image with visible trochlear cartilage, showing sulcus formation and the beginning of the medial facet was chosen, corresponding to the proximal trochlea as described by Dejour et al[5] for MRI assessment of trochlear morphology, and subsequently applied by Green et al[9]; the cartilaginous sulcus was considered the preferred landmark because it more closely reflected the true engagement of the patella within the trochlea

- LPFA (Figure 1, C and D)
  - M-XR: angle between the line drawn along the lateral facet of the patella and a second line tangential to the anterior aspects of the femoral condyles
  - MRI (axial PD sequence): angle between a line along the cartilaginous lateral facet of the patella (on the image showing the maximal patellar width) and a line tangential to the cartilaginous anterior aspects of the femoral condyles (on the image used for measuring the sulcus angle)
- Patellar tilt (Figure 1, E and F)
  - M-XR: angle between the maximal width of the patella and a line tangent to the posterior femoral condyle
  - MRI (axial PD sequence): angle between a line through the maximal patellar width (on the axial image showing the maximal patellar width) and a line tangential to the cartilaginous posterior aspects of the femoral condyles (on the image used for the sulcus angle)
- CDI (Figure 2, A and B)
  - Lateral radiograph: ratio between the distance from the inferior margin of the patellar articular surface to the anterior border of the tibial plateau and the length of the patellar articular surface
  - MRI (sagittal PD sequence): ratio between the distance from the inferior margin of the patellar articular cartilage to the anterior border of the tibial plateau cartilage and the length of the patellar articular surface (measured on the image with the greatest patellar cartilage length)

Statistical Analysis

Agreement between imaging modalities was assessed using single-measures ICCs using a 2-way random-effects

TABLE 1
ICC and Spearman Rho Values Between MR and Radiographic Measurements[a]

Comparison	ICC	Agreement	Spearman Correlation
Preoperative MRI vs radiographic sulcus angle	0.326 (95% CI, 0.107-0.515); $P = .002$	Poor	0.266 (95% CI, 0.033-0.471); $P = .02$
Preoperative MRI vs radiographic patellar tilt	0.376 (95% CI, 0.166-0.553); $P < .001$	Poor	0.368 (95% CI, 0.148-0.552); $P = .001$
Preoperative MRI vs radiographic LPFA	0.373 (95% CI, 0.159-0.553); $P < .001$	Poor	0.314 (95% CI, 0.086-0.512); $P = .006$
Postoperative MRI vs radiographic sulcus angle	0.403 (95% CI, 0.124-0.623); $P = .003$	Poor	0.394 (95% CI, 0.101-0.624); $P = .008$
Postoperative MRI vs radiographic patellar tilt	0.311 (95% CI, 0.019-0.554); $P = .02$	Poor	0.400 (95% CI, 0.108-0.628); $P = .007$
Postoperative MRI vs radiographic LPFA	0.399 (95% CI, 0.112-0.625); $P = .004$	Poor	0.420 (95% CI, 0.124-0.647); $P = .006$

[a]ICC values <0.50 indicate poor agreement, between 0.50 and 0.75 indicate moderate agreement, between 0.76 and 0.90 indicate good agreement, and >0.90 indicate excellent agreement.[14] ICC, intraclass correlation coefficient; LPFA, lateral patellofemoral angle; MRI, magnetic resonance imaging.

model. Correlation was analyzed using Spearman coefficients, and paired *t* tests were used to evaluate differences in mean values of paired images. Threshold values based on current literature were applied to classify each measurement as normal or abnormal. Abnormal thresholds for MRI were a sulcus angle >145°,[16] LPFA >0°,[11] and tilt >11°.[6] Sulcus angle threshold of 151 was additionally applied based on the novel thresholds proposed by Green et al.[9] Abnormal thresholds for M-XR were sulcus angle >145°[4] and 151°,[9] LPFA >0°,[11] and tilt >5°.[10] Patella alta was defined as CDI >1.3,[12] measured on both preoperative or postoperative MRI and radiographs. Subgroup analyses comparing patients with and without patella alta were performed based on this definition at both time points. Agreement between MRI and M-XR based binary classifications (normal/abnormal) was assessed using Cohen kappa with subgroup analyses performed in patients with and without patella alta, with perfect agreement being 1 and no agreement being 0. All statistical analyses were performed using SPSS Version 29 (IBM Corp) and with a 2-tailed significance threshold of $P \leq .05$.

RESULTS

A total of 80 patients (84 knees) who underwent MPFL reconstruction were included in the current study. Mean age at surgery was 15 ± 2 years with 51 (60.7%) female patients. Of these patients, 74 had preoperative and MRI and M-XR that were analyzed (148 images), while 44 had postoperative MRI and M-XR (88 images). Therefore, a total of 236 images were included. Across all parameters, MRI and M-XR demonstrated poor agreement (ICC < 0.50) and weak positive correlations (Spearman rho ranging from 0.27 to 0.42) (Table 1). MRI and M-XR demonstrated significant differences in measurements in both preoperative and postoperative groups.

TABLE 2
Paired *t* Tests Comparing MR and Radiographic Measurements[a]

	Preoperative MRI (n = 74)	Preoperative Radiograph (n = 74)	*P*
Sulcus angle	161.90 ± 7.67	146.77 ± 7.88	<.001
Patellar tilt	21.33 ± 7.48	18.23 ± 7.45	.002
LPFA	–3.00 ± 7.81	3.16 ± 7.39	<.001
	Postoperative MRI (n = 44)	**Postoperative Radiograph (n = 44)**	***P***
Sulcus angle	161.56 ± 7.69	147.14 ± 7.80	<.001
Patellar tilt	18.31 ± 9.54	15.49 ± 5.75	.05
LPFA	0.68 ± 7.63	5.87 ± 4.38	<.001

[a]Data are presented as mean ± SD. LPFA, lateral patellofemoral angle; MRI, magnetic resonance imaging.

Measurements

Preoperative sulcus angle was 161.9° ± 7.67° and 146.77° ± 7.88° ($P < .001$) on MRI and M-XR, respectively, whereas postoperative sulcus angle was 161.56° ± 7.69° and 147.14° ± 7.80° ($P < .001$) on MRI and M-XR, respectively. Preoperative patellar tilt was 21.33° ± 7.48° and 18.23° ± 7.45° ($P = .002$) on MRI and M-XR, respectively whereas postoperative patellar tilt was 18.31° ± 9.54° and 15.49° ± 5.75° ($P = .05$) on MRI and M-XR, respectively. Preoperative LPFA was −3.00° ± 7.81° and 3.16° ± 7.39° ($P < .001$) on MRI and M-XR, respectively, whereas postoperative LPFA was 0.68° ± 7.63° and 5.87° ± 4.38° ($P < .001$) on MRI and M-XR, respectively (Table 2). Values obtained from M-XR were consistently lower than those measured on MRI for sulcus angle and

patellar tilt; however, values obtained from M-XR were on average greater for LPFA.

Binary Classification Agreement

Agreement between MRI and M-XR binary classification was poor for preoperative sulcus angle (kappa, 0.044) using a threshold of 145° on MRI and M-XR. Agreement could not be calculated for postoperative sulcus angle as all patients had an angle >145° on MRI. At a threshold of 151° on MRI, agreement was poor for pre- and postoperative sulcus angle (kappa, 0.117 and 0.095, respectively). Pre- and postoperative patella tilt (kappa, 0.421 and −0.044, respectively) and preoperative LPFA (kappa, 0.132) additionally demonstrated poor agreement (Figure 3). Postoperative LPFA did, however, demonstrate excellent agreement between MRI and M-XR measurements (kappa, 1.00). A total of 32 patients had preoperative patella alta (CDI ≥ 1.3). When analyzing preoperative measures of this group in isolation, agreement was not demonstrably different. Agreement between preoperative sulcus angle on MRI and M-XR was 0.066 (P = .58). Agreement between preoperative LPFA on MRI and M-XR was 0.314 (P = .03). Agreement could not be calculated for patellar tilt as all patients had tilt >0.

DISCUSSION

The major findings in our study demonstrated that MRI and M-XR show poor correlation and agreement in the assessment of patellofemoral morphology in pediatric patients with patellofemoral instability, both before and after MPFL reconstruction. Across all parameters analyzed, radiographic measurements were consistently less severe (closer to normal) than MRI measurements, in relation to the pathological cutoff. MRI measurements were always larger. These findings highlight that the 2 imaging modalities cannot be used interchangeably for diagnostic or follow-up purposes in this patient population.

Across all 3 key parameters—sulcus angle, LPFA, and patellar tilt—statistical agreement between MRI and M-XR was consistently poor with only weak to moderate correlations. Our findings are consistent with previous reports highlighting significant modality-related differences in patellofemoral measurements.[7,22,24] MRI provides multiplanar, high-resolution imaging that allows for the comprehensive assessment of both osseous and cartilaginous anatomy, as well as soft tissue structures, which are not visible on radiographs. Moreover, while MRI remains more expensive and less readily available in some settings, its superiority in evaluating cartilaginous morphology is particularly relevant in skeletally immature patients, in whom bony landmarks may not yet be fully ossified.[11] For example, Tan et al[22] demonstrated that the cartilaginous sulcus angle is consistently larger than the bony sulcus angle, a distinction particularly relevant in patients with PFI, as the cartilaginous contour more accurately reflects patellar engagement within the trochlea. This intrinsic difference likely contributes to the systematic underestimation observed with radiographic measurements in our study.

In addition, knee positioning differs substantially between MRI and M-XR. Conventional MRI is typically performed in the supine position with the knee fully extended and the quadriceps relaxed, whereas M-XRs are obtained at approximately 45° of flexion under weightbearing conditions. Previous studies have shown that axial patellofemoral indices vary with flexion angle and loading,[2,15] emphasizing the importance of methodological consistency, both in knee positioning and in the reference thresholds applied, when comparing or interpreting patellofemoral measurements across different imaging modalities.

Despite their historical and widespread use, M-XRs have several inherent limitations compared with MRI.[21] They are restricted to bony contours, are susceptible to variations in knee flexion and patient positioning, and provide no information about cartilage or soft tissue structures.[20,24] These limitations align with the poor agreement demonstrated in our study and with prior findings of low interobserver reliability for radiographic measures in PFI.[7] Gobbi et al[8] reported that MRI-based measurements of patellar tilt have high diagnostic reliability for instability, further reinforcing the role of MRI as the preferred modality, as radiographic measurements show greater interrater variability and may be less sensitive in detecting abnormal tilt.

Notably, our analysis showed that even after surgical stabilization, the discordance between MRI and radiographs persisted. This suggests that postoperative morphologic changes may be interpreted differently depending on the imaging modality used. A key finding was that some patients achieved the established normal threshold on one imaging modality but not on the other, highlighting a potential source of diagnostic and management discordance. These findings highlight the critical importance of consistently using the same imaging modality for both initial diagnosis and postoperative follow-up. Interestingly, we observed excellent agreement in the postoperative LPFA correction, a result that stands in contrast to the poor agreement observed for all other parameters. However, given the relatively small postoperative subgroup with both MRI and M-XR, this finding should be interpreted with caution and warrants further investigation.

Finally, we evaluated whether the presence of patella alta influenced the agreement between MRI and radiographs. Patella alta complicates the assessment and interpretation of imaging findings by reducing the engagement of the patella within the trochlear groove, particularly in early knee flexion.[3] A high-riding patella may only engage the trochlea at greater flexion angles compared with the usual ~30° position used in imaging, potentially altering patellofemoral relationships.[13] On M-XR, this proximal and lateral positioning can lead to an overestimation of patellar tilt and an underestimation of the true patellofemoral engagement.[3] Given that these measurements are dependent on patient positioning and are limited to bony contours, the radiographic assessment may not accurately reflect the functional relationship between the patella and

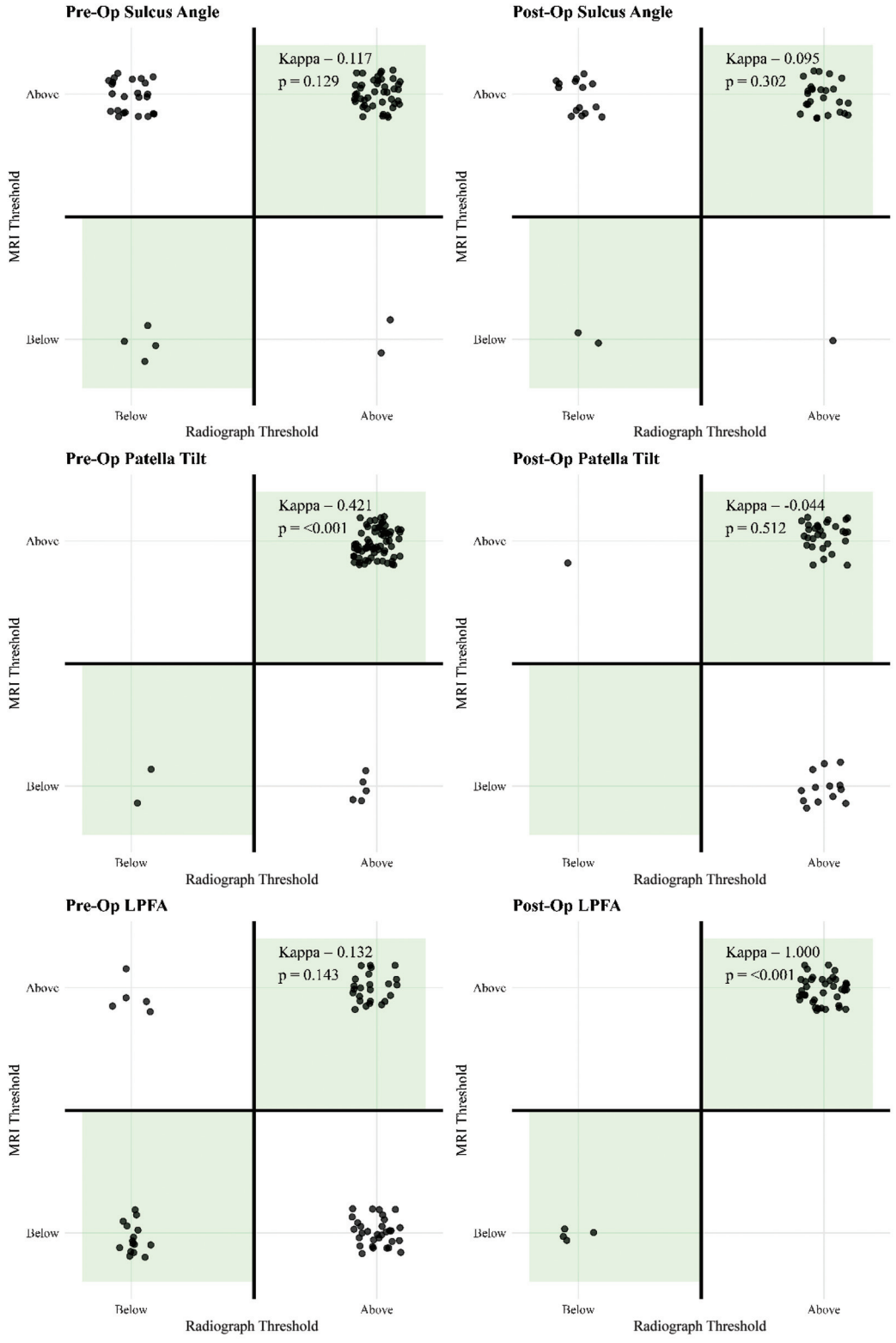


Figure 3. Agreement of binary classification utilizing established threshold values for normal and abnormal sulcus angle, patellar tilt, and lateral patellofemoral angle (LPFA) between magnetic resonance imaging (MRI) and Merchant radiography pre- and postoperatively.

trochlea in the presence of patella alta. Although we hypothesized that patients with patella alta might demonstrate greater discrepancies between the imaging modalities, our data did not support this, as the agreement between MRI and radiographic measurements remained consistently poor regardless of patellar height. These findings suggest that the lack of agreement is intrinsic to the imaging techniques themselves rather than being substantially affected by the presence of patella alta.

From a clinical perspective, M-XR and MRI should not be considered interchangeable for the assessment of patellofemoral morphology in pediatric patients with patellofemoral instability undergoing MPFL reconstruction. When MRI is used for surgical planning, measurements should be interpreted according to MRI-specific thresholds rather than radiographic reference values, both in the preoperative setting and in the postoperative follow-up. Although MRI is a second-level imaging modality with more limited availability, it may offer important advantages because it provides 3-dimensional evaluation of osseous, osteochondral, and soft tissue anatomy, whereas radiographs, despite their greater accessibility, are limited to osseous landmarks. At the same time, these findings underscore the importance of optimizing and standardizing imaging acquisition techniques to improve measurement reliability and comparability.

Limitations

This study has several limitations. First, its retrospective design introduces potential selection bias, as only patients who underwent MPFL reconstruction were included; as such, the findings may not be generalizable to all patients with PFI, including those managed nonoperatively who may be presumed to have more normal radiologic indices. We felt, however, that it was important to focus on the population in whom the measurements were more relevant, which is the group with severe instability in whom surgery is indicated. Second, the postoperative cohort was relatively small compared with the preoperative group, which limited the statistical power of some subgroup analyses, particularly those exploring agreement in patients with patella alta. Third, imaging was obtained as part of routine clinical care, without standardized protocols for knee flexion angle or patient positioning, which may have influenced the reproducibility of the radiographic measurements. Finally, we applied the most widely used cutoff values reported in the literature to classify measurements as normal or abnormal; the use of different thresholds might have altered the binary classification agreement between modalities and, therefore, may influence the generalizability of our findings.

CONCLUSION

Our study demonstrated that MRI and Merchant radiographs show poor correlation and agreement in the assessment of patellofemoral morphology in pediatric patellofemoral instability, both pre- and postoperatively. These differences are not influenced by surgical correction or the presence of patella alta, indicating that they are intrinsic to the imaging modalities. For this reason, the 2 modalities should not be considered interchangeable, and careful attention is needed when interpreting results, particularly in the context of preoperative evaluation and longitudinal follow-up.

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