Many Radiographic and Magnetic Resonance Imaging Assessments for Surgical Decision Making in Pediatric Patellofemoral Instability Patients Demonstrate Poor Interrater Reliability

Peter D. Fabricant, M.D., M.P.H., Madison R. Heath, B.S., Douglas N. Mintz, M.D., Kathleen Emery, M.D., Matthew Veerkamp, B.A., Simone Gruber, B.A., Daniel W. Green, M.D., M.S., Sabrina M. Strickland, M.D., Eric J. Wall, M.D., JUPITER Study Group*, Beth E. Shubin Stein, M.D., and Shital N. Parikh, M.D.

Purpose: To evaluate the interrater reliability of several common radiologic parameters used for patellofemoral instability and to attempt to improve reliability for measurements demonstrating unacceptable interrater reliability through consensus training. **Methods:** Fifty patients with patellar instability between the ages of 10 and 19 years were selected from a prospectively enrolled cohort. For measurements demonstrating unacceptable interrater reliability (intraclass correlation coefficient [ICC]: <0.6), raters discussed consensus methods to improve reliability and re-examined a subset of 20 images from the previous set of images. If reliability was still low after the second round of assessment, the measure was considered unreliable. **Results:** Of the 50 included subjects, 22 (44%) were male and the mean age at the time of imaging was 14 ± 2 years. With 1 or fewer consensus training sessions, the interrater reliability of the following radiograph indices were found to be reliable: trochlea crossing sign (ICC: 0.625), congruence angle (ICC: 0.768), Caton-Deshamps index (ICC: 0.644), lateral patellofemoral angle (ICC: 0.768), and mechanical axis deviation on hip-to-ankle alignment radiographs (ICC: 0.665-0.777). Reliable magnetic resonance imaging (MRI) indices were trochlear depth (ICC: 0.743), trochlear bump (ICC: 0.861), sulcus angle (ICC: 0.684), patellar tilt (ICC: 0.841), tibial tubercle to trochlear groove distance (ICC: 0.706), effusion (ICC: 0.866), and bone marrow edema (ICC: 0.961). **Conclusions:** With 1 or fewer consensus training sessions, the interrater reliability of the following patellofemoral indices were found to be reliable for trochlear morphology: trochlea crossing sign and congruence angle on radiograph and trochlear depth, trochlear bump, and sulcus angle on MRI. Reliable patellar position measurements included: Caton-Deshamps index and lateral patellofemoral angle on radiograph and patellar tilt and tibial tubercle to trochlear groove distance on MRI. Additional global measurements (e.g., mechanical axis deviation on standing radiographs) and MRI assessments demonstrated acceptable reliability. **Level of Evidence:** II, prospective diagnostic study.

Patellofemoral instability in adolescent patients is a common problem that can cause functional limitations, pain, and poor quality of life.[1,2] Treatment of patellofemoral instability involves assessing and potentially correcting abnormal anatomy that may have caused the instability and/or restoring normal anatomy that was disrupted by a patellar dislocation.[3]

Determining the optimal treatment strategy relies heavily on radiologic assessments of an individual's pathoanatomy. Many imaging findings indicate

From the Hospital for Special Surgery, New York, New York (P.D.F., M.R.H., D.N.M., S.G., D.W.G., S.M.S., B.E.S.S.); and Cincinnati Children's Hospital, Cincinnati, Ohio (K.E., M.V., E.J.W., S.N.P.), U.S.A.

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anatomic risk factors for recurrence of patellofemoral instability, so radiologic assessments are important to determining whether a patient should have conservative or surgical treatment.[4,5] Surgically, there are a wide range of bony and soft-tissue procedures used for patellar instability, including tibial tubercle osteotomies, trochleoplasty, implant-mediated guided growth to correct coronal plane malalignment, and medial patellofemoral ligament (MPFL) reconstructions based on the underlying pathoanatomy identified on imaging.[3,6,7] Furthermore, unrecognized or unaddressed anatomic risk factors may be responsible for

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[*]*JUPITER Study Group: Jacqueline M. Brady, M.D. (Oregon Health and Science University Hospital, Portland, Oregon), Caitlin C. Chambers, M.D. (TRIA Orthopedic Center, Bloomington, Minnesota), Henry B. Ellis, M.D. (Texas Scottish Rite Hospital for Children, Dallas, Texas), Jack Farr, M.D. (OrthoIndy Hospital, Indianapolis, Indiana), Benton E. Heyworth, M.D. (Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts), Jason L. Koh, M.D. (NorthShore Skokie Hospital, Skokie, Illinois), Dennis E. Kramer, M.D. (Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts), Robert A. Magnussen, M.D. (Ohio State University Wexner Medical Center, Columbus, Ohio), Lauren H. Redler, M.D. (Columbia University Irving Medical Center, New York, New York), Seth L. Sherman, M.D. (Stanford Health Care, Redwood City, California), Marc A. Tompkins, M.D. (TRIA Orthopedic Center, Bloomington, Minnesota), and Philip L. Wilson, M.D. (Texas Scottish Rite Hospital for Children, Dallas, Texas).*

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Address correspondence to Peter D. Fabricant, M.D., M.P.H., Pediatric Orthopaedic Surgery & Sports Medicine, Hospital for Special Surgery, 535 East 70th St., New York, NY 10021. E-mail: fabricantp@hss.edu

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complications or failure of surgical treatments,[8] so imaging findings have prognostic significance. These radiologic assessments are essential to determining the optimal treatment for each patient.

Because of the importance of radiologic assessments for the treatment of patellofemoral instability, these assessments must be evaluated consistently and reliably amongst radiologists and surgeons to be clinically useful. The purpose of this study was to evaluate the interrater reliability of several common radiologic parameters used for patellofemoral instability and to attempt to improve reliability for measurements demonstrating unacceptable interrater reliability through consensus training. We hypothesized that at the conclusion of this study, a list of radiologic patellofemoral instability measurements with acceptable reliability would successfully be generated.

Methods

Before beginning this study, institutional review board approval was obtained at each participating institution. In the absence of traditional comparative statistical hypothesis testing, performing a power analysis is not possible.[9] Therefore, 50 subjects were used for the investigation, given precedent in the medical literature for reliability studies. Subjects were selected from a prospective cohort of patients with patellofemoral instability who were between the ages of 10 and 19 years, based on the adolescent age range as defined by the World Health Organization.[10,11] Study participants who met the inclusion criteria were pooled by a study coordinator, and then 25 male and 25 female subjects were selected at random to equally include patients by sex. All patients enrolled in the study had been diagnosed with patellar instability by a study group surgeon. The preoperative anteroposterior, lateral, and axial (Merchant) views on radiographs and the coronal, sagittal, and axial proton density magnetic resonance imaging (MRI) sequences of each selected patient were reviewed. Lateral radiographs were taken in approximately 30° of flexion and MRI were taken with the leg in extension or mild flexion and at rest.

Two fellowship-trained musculoskeletal radiologists who were trained and employed at separate institutions examined the radiographs and MRIs for each included patient. Each radiologist was sent a deidentified set of images that was imported into their hospital's research picture archiving and communication system for analysis. The radiologists had 1 month to complete all assessments and record their responses in the secure online database (REDCap, Nashville, TN).

Based on previous literature of common patellofemoral instability assessments and clinical relevance, radiologists were asked to make 20 assessments on radiographs and/or MRI

(Table 1). For the initial rating, radiologists' measurements were based on guidelines generated from current literature that were compiled into a PowerPoint file (Microsoft Office; Microsoft, Redmond, WA). The PowerPoint contained illustrations, measurement

Table 1. Variables (With Radiograph Views and Units) Assessed by Each Radiologist on Each Patient

Variables	View	Units/Categorical Choices
Trochlea crossing sign	Lateral radiograph	Present or absent
Trochlear bump	Lateral radiograph	Millimeters
Double contour sign	Lateral radiograph	Present or absent
Caton-Deschamps index	Lateral radiograph	Number without units
Medial patella avulsion fracture	Axial radiograph	Present or absent
Lateral patellofemoral angle	Axial radiograph	Degrees
Lateral patellofemoral tilt	Axial radiograph	Angle opens laterally (no tilt), Angle opens medially (tilt present), Lines are parallel (tilt present)
Congruence angle	Axial radiograph	Degrees
Mechanical axis (left and right leg)	Standing AP, hips to ankles	Varus 1, varus 2, varus 3, neutral, valgus 1, valgus 2, valgus 3
Effusion	MRI	Present or absent
Bone edema	MRI	None, Lateral femoral condyle, medial patellar facet, multiple locations
Trochlear bump	MRI	Millimeters
Location of MPFL Injury	MRI	None, patella, femur, mid, combined
Tibial tubercle to trochlear groove distance (TT-TG)	MRI	Millimeters
Sulcus angle	MRI	Degrees
Trochlear dysplasia: Dejour classification	MRI	Type A, Type B, Type C, Type D
Patellar tilt	MRI	Degrees
Patellar subluxation distance	MRI	Millimeters
Cartilage injury	MRI	None, patella, trochlea, both, other
Trochlear depth	MRI	Millimeters

AP, anteroposterior; MPFL, medial patellofemoral ligament; MRI, magnetic resonance imaging.

criteria, and a link to original description of the measurement for reference purposes. The responses from each radiologist were compiled and imported into SPSS, version 22 (IBM., Armonk, NY) for data analysis. Interrater reliability was calculated using a 2-way random intraclass correlation coefficients (ICCs) with absolute agreement. If either of the radiologists was unable to make an assessment based on low-quality imaging, that patient was removed for that particular measurement analysis. While this decreased the number of included images for an analysis, it ensured the results were not confounded by poor or inadequate radiographs (Landis and Koch).[12] established the following cutoffs for interrater agreement: 0.0 to 0.20 for slight agreement, 0.21 to 0.40 for fair agreement, 0.41 to 0.60 for moderate agreement, 0.61 to 0.80 for substantial agreement, and 0.81 to 1.0 for almost-perfect agreement. Based on these cutoffs, an ICC score less than 0.6 for any given assessment was considered unacceptably low agreement.

For assessments with unacceptably low interrater reliability, the participating radiologists discussed consensus methods to improve reliability. First, the radiologists reviewed criteria for slice selection on MRI and acceptable image quality on radiographs and agreed on a common standard. Then, they discussed their approach to making each assessment. If their approaches were different, they reviewed existing literature and clarified their approach as needed to ensure similarity and clinical relevance. After a consensus was reached, 20 patients were selected from the original 50 patients by a study coordinator to review again. Patients were selected to maximize the number of instances the raters disagreed on initially to ensure the radiologists had a chance to reach a consensus on a case they previously disagreed upon. For example, all patients with differing trochlear dysplasia assessments between the radiologists were included in the second assessment. Radiologists assessed the 20 patients for variables with low reliability using their new consensus methods, blinded to their original answers. The radiologists had 1 month to submit their responses, then responses were compiled, and their interrater reliability was analyzed a second time. Radiologic assessments with acceptable reliability after discussion were considered reliable with training, while assessments with unacceptable reliability were considered poor radiologic assessments for patellofemoral instability.

Results

Of the 50 included patients, 22 (44%) were male, and the mean age at the time of imaging was 14 ± 2 years. Interrater reliability for 3 radiographic and 7 MRI assessments was initially acceptable, 3 radiographic and 2 MRI assessments improved after consensus training,

Table 2. Interrater Reliability of First- and Second-Round Assessments of Clinically Relevant Patellofemoral Instability Parameters by Two Fellowship-Trained Musculoskeletal Radiologists

	First Assessment		Second Assessment		Reliability		
Variables	N	ICC	N	ICC	Initially Reliable	Reliable with Training	Unreliable
Radiograph							
Trochlea crossing sign	33	0.455	10	0.625		X	
Trochlear bump	34	0.205	7	0.435			X
Double contour sign	34	0.38	10	-0.2			X
Caton-Deschamps index	47	0.644	–	–	X		
Medial patella avulsion fracture	50	0.43	18	0.779		X	
Lateral patellofemoral angle	44	0.768	–	–	X		
Lateral patellofemoral tilt	50	0.256	18	0			X
Congruence angle	44	-0.133	18	0.768		X	
Mechanical axis: left	49	0.777	–	–	X		
Mechanical axis: right	50	0.665	–	–	X		
MRI							
Effusion	46	0.866	–	–	X		
Bone edema	45	0.961	–	–	X		
Location of MPFL injury	43	0.639	–	–	X		
TT-TG distance	44	0.706	–	–	X		
Trochlear bump	20	0.861	–	–	X		
Trochlear dysplasia: Dejour classification	42	0.174	19	0.211			X
Sulcus angle	11	0.339	20	0.684		X	
Patellar tilt	44	0.841	–	–	X		
Patellar subluxation distance	44	0.552	19	0.561			X
Cartilage injury	38	0.245	20	0.686		X	
Trochlear depth	20	0.743	–	–	X		

ICC, intraclass correlation coefficient; MPFL, medial patellofemoral ligament; MRI, magnetic resonance imaging; TT-TG, tibial tubercle to trochlear groove distance.

Table 3. Assessment Method for Initially Reliable Radiologic Measurements

Variables	Imaging Modality	Assessment Methodology
Caton-Deschamps index	Lateral radiograph	The ratio between the articular facet length of the patella (AFP) and the distance between the articular facet of the patella and the anterior corner of the superior tibial epiphysis (AT). CDI = AT/AFP.[13] See Figure 1.
Lateral patellofemoral angle	Axial radiograph	Draw line connecting the summits of the femoral condyles. Draw line between the limits of the lateral patellar facet. Angle between these lines.[14] See Figure 4.
Mechanical axis	Standing AP, hips to ankles radiograph	Draw line from center of femoral head to the center of the tibial plafond. See Figure 5.
Effusion	MRI	Synovial fluid visualized superior to the patella.
Bone edema in knee	MRI	high signal intensity on fat suppressed sequence on the lateral femoral condyle, medial patellar facet, or other location in the knee. See Figure 6.
Location of MPFL Injury	MRI	High signal on the MPFL at the site of the patella, femur, mid-substance, or a combination from an acute injury with an MRI completed within 1 month of dislocation
TT-TG	MRI	Find most distal/caudal femoral slice with complete Roman arch and subchondral bone visible. The trochlear groove location is the apex of the groove on this slice. Draw a line along the posterior condyles of the femur and stay parallel to this line for this measurement (may require a piece of paper to hold the place). Select the slice of tibia where the patellar tendon starts inserting on to the tibial tubercle. Measure the distance between the center of the patellar tendon attachment on the tibial tubercle and the trochlear groove as measured on the chosen femoral slice.[15]
Trochlear Bump	MRI	Line is drawn along the anterior femoral cortex. Bump (supratrochlear spur) is the distance between anterior femoral line and the most anterior point of trochlea.[16] See Figure 2.
Patellar tilt angle	MRI	Draw a line across the posterior condyles at the most inferior level of full posterior articular cartilage. Draw another line at the greatest patellar width through bony medial/lateral patella midpoint (may be on another MRI slice). Find the angle between these 2 lines.[16,17] See Figure 3.
Trochlear depth	MRI	Choose the axial slice closest to a point 3cm proximal to the tibiofemoral joint line. Then, measure the maximal anteroposterior distance of the medial femoral condyle (d) and the lateral femoral condyle (b) and the minimal anteroposterior distance between the deepest point of the trochlear groove (c), all perpendicular to a posterior condylar reference line (a). Trochlear depth was calculated according to the formula $([b + d]/2 - c)$.[18] All measurements include cartilage thickness. See Figure 3.

AP, anteroposterior; MPFL, medial patellofemoral ligament; MRI, magnetic resonance imaging; TT-TG, tibial tubercle to trochlear groove distance.

and 3 radiographic and 2 MRI assessments remained unacceptably unreliable even after consensus training (Table 2). Initial methodology, methods for improvement, and explanations for lack of improvement are listed in Tables 3-5.[13-23] Methods for image quality assessment are listed in Table 6.

A total of 15 assessments were determined to be reliable before or after consensus training (Table 7). For describing trochlear dysplasia, the trochlear crossing sign (ICC: 0.625) was reliable on radiographs and the trochlear bump (ICC: 0.861), trochlear depth (ICC: 0.743), and sulcus angle (ICC: 0.684) were reliable on MRI (Figs 1-3). For assessing axial alignment, the lateral patellofemoral angle (ICC: 0.768) was reliable on radiographs and patellar tilt (ICC: 0.841) and tibial tubercle to trochlear groove distance (TT-TG) (ICC: 0.706) were reliable on MRI (Figs 3-4). For assessing patellar height, the Caton-Deschamps index (CDI) (ICC: 0.644) was reliable on radiographs (Fig 1). Mechanical axis deviation (ICC: 0.777 left leg and 0.665 right leg) was reliable on radiographs (Fig 5). Assessing the presence of the medial patella avulsion fracture (ICC: 0.779) on radiographs and the location of the MPFL injury on MRI (ICC: 0.639) were reliable for describing injuries to the medial patellofemoral complex (Fig 4). Finally, effusion (ICC: 0.866), bone edema (ICC: 0.961), and cartilage injuries (ICC: 0.686) were all reliably identified on MRI (Fig 6).

Table 4. Initial Assessment Methodology and Methods for Reliability Improvement for Radiologic Measures That Improved After Consensus Training

Variable	Imaging Modality	Initial Assessment Methodology	Method for Improvement
Trochlea crossing sign	Lateral radiograph	Present if there is crossing of sulcus (trochlear) line and lateral condylar line.[16] See Figure 1.	Only assessed on true laterals (less than 5 mm of posterior condyle overlap).
Medial patella avulsion fracture	Axial radiograph	An avulsion fracture involving variable-sized fragments from the medial patellar margin.[19] See Figure 4.	Differentiate from osteochondral fractures which are intra-articular fractures.
Congruence angle	Axial radiograph	Draw the sulcus angle. Then, create a line that bisects the sulcus angle. Create another line from the lowest point of the intercondylar sulcus to the lowest point on the articular ridge of the patella. Find the angle between these 2 lines.[20] See Figure 7.	Defined the sulcus angle points more clearly (i.e., the most anterior part of medial and lateral trochlear facets).
Sulcus Angle	MRI	Draw lines from the highest points of the medial and lateral femoral condyles to connect at the lowest point of the intercondylar sulcus. All measurements are from cartilage surfaces. The axial slice is cross-referenced from the coronal image, 3 cm above the joint line, or on the most cranial trochlear slice which is covered with articular cartilage.[18,20] See Figure 3.	Clarified proper axial slice determination and that the most anterior aspect of the trochlear facet rather than the curve of the trochlea should be used for this measurement.
Cartilage Injury	MRI	Any grade of cartilage injury (superficial fibrillation through defect down to deep subchondral bone) visualized on the patella or femur.[21]	Disregarded the odd facet osteochondral injuries since they are almost always present.

MRI, magnetic resonance imaging.

Discussion

This study determined that many (10 of 20) assessments were initially reliable between fellowship-trained attending radiologists, including CDI, lateral patellofemoral angle, and mechanical axis deviation on radiograph and effusion, bone edema, location of MPFL injury, TT-TG distance, trochlear bump, patellar tilt, and trochlear depth on MRI. However, 5 assessments (trochlea crossing sign, medial patella avulsion fracture, and congruence angle on radiograph and sulcus angle and cartilage injury on MRI) required consensus training to be reliable and 5 assessments remained unreliable even after consensus training. Although several of these measures are reliable, they may not be useful or clinically relevant in daily practice, which is a separate question and an area of active investigation. Only reliable assessments should be used for diagnosis, prognostication, and surgical planning in pediatric patients with patellofemoral instability and the lack of reliability for several common radiologic assessments is concerning since these are often used as indications to address specific components of patellofemoral instability.[3,24] Based on these results, this study determined which assessments and measurements should be used and validated in future research to diagnose and treat several aspects of patellofemoral pathoanatomy. Also, an accurate and precise description or refinement of the definition used to measure a variable may help in the future to improve the reliability of measurements that have remained unreliable in the current study.

Importantly, optimal image acquisition is a prerequisite for reliable radiographic measurements. It was noted that several images were suboptimal and not all parameters were able to be measured in all subjects, which was particularly true for parameters measured on lateral radiographs. This underscores the presence of variability in image acquisition (due to both patient and institutional parameters) and highlights the importance of ensuring optimal image acquisition when measuring and interpreting radiographic parameters.

Trochlear Dysplasia

Several trochlear dysplasia assessments were reliable in this study. Although previous studies have reported mixed reliability and clinical usefulness of trochlear depth and bump,[18,25-27] this study found both were reliable when assessed on axial and sagittal MRI, respectively. In addition, the crossing sign was reliable when assessed on perfect lateral radiographs. Rotations of just 5 mm in the lateral view can generate false results when assessing trochlear dysplasia on lateral radiographs,[28] so properly performed lateral radiographs

Table 5. Initial Assessment Methodology and Reasons for Low Reliability for Radiologic Measures That Did Not Improve After Consensus Training

Variable	Imaging Modality	Assessment Methodology	Reason for Low Reliability
Trochlear bump	Lateral radiograph	Line is drawn along the anterior femoral cortex. Bump (supratrochlear spur) is the distance between anterior femoral line and the most anterior point of trochlea.[16]	Difficult to delineate where to draw the anterior cortical line on femur when the femoral bow extends distally.
Double contour sign	Lateral radiograph	Radiographic line ending below the crossing sign. Represents the subchondral condensation of hypoplastic medial condyle.[16]	Difficult assessment and susceptible to rotation.
Lateral patellofemoral tilt	Axial radiograph	Based on the lateral patellofemoral angle, the angles were categorized as no tilt if the angle opens laterally or tilt present if angle opens medially or lines are parallel.[14]	Disagreement on definition cutoffs.
Trochlear dysplasia: Dejour classification	MRI	Type A: shallow trochlea (>145°) and crossing sign. Type B: Flat trochlea and supratrochlear spur. Type C: lateral convexity and medial hypoplasia, double contour sign and crossing sign. Type D: cliff and supratrochlear spur, double contour sign, and crossing sign.[22] See Figure 3.	Could not agree on the shape of the trochlea on axial MRI image and lack of correlation between lateral radiograph and axial MRI at times.
Patellar subluxation distance	MRI	Measure absolute patellar lateralization. From line tangent to posterior part of condyles, a perpendicular line is projected anteriorly through most anterior point of medial condyle at the level the TT-TG was measured. Distance from this line to the most medial edge of patella (may be a different slice) is expressed either positively or negatively in millimeters, depending on lateral or medial position, respectively, of medial patellar edge to perpendicular line.[23]	Could not agree on determining the anterior part of medial condyle as the trochlea may not be completely covered with cartilage on the selected axial image.

MRI, magnetic resonance imaging; TT-TG, tibial tubercle to trochlear groove distance.

are essential for the accurate and reliable assessment of the presence of dysplasia. Finally, the sulcus angle was reliable on MRI after consensus training and agreement regarding the axial slice and the part of the trochlear facet to measure the angle from. Toms et al.[29] demonstrated that the sulcus angle could be measured reliably on MRI when measuring the most anterior portions of the trochlear margins, so the radiologists in this study adopted these methods and improved their reliability. Pfirrmann et al.[18] had reported high specificity and sensitivity for the diagnosis of trochlear dysplasia based on a trochlear depth measurement of less than 3 mm. The current study found the trochlear depth measurement to be reliable as well.

Several of the unreliable assessments in this study are commonly used to evaluate trochlear dysplasia, including trochlear bump and double contour sign on lateral radiographs, condylar height on axial MRI, and the Dejour classification.[16,24,25] Trochlear dysplasia is a major risk factor for recurrent patellofemoral instability and may need surgical correction by a trochleoplasty procedure,[3] so assessments of trochlear dysplasia must be reliable. Previous studies have found mixed reliability in trochlear dysplasia assessments.[25,27,30,31] Lippacher et al.[30] found poor to moderate reliability amongst raters on Dejour's 4 classifications using radiographs or MRI, which improved when a 2-part classification (low grade vs high grade dysplasia) was used. A systematic review by Smith et al.[25] indicated that the reliability and validity of trochlear dysplasia assessments were poor. In support of previous literature, this study found that the lack of precise

Table 6. Methodology for Image Quality Assessment

Image	Quality Checks
Lateral radiograph	
	Knee flexed to 30°
	Condyles should overlap (<5 mm)
Merchant/axial view[20]	Knee flexed to 45° (if Merchant view)
	Angle between femur and x-ray tube is 30°
AP radiograph	Rotation should be minimal
MRI	Varies by institution, but motion degradation prevents measurement making and low resolution prevents accurate cartilage assessments

AP, anteroposterior; MRI, magnetic resonance imaging.

measurement instructions (e.g., drawing a straight line along the curved anterior cortex of femur for trochlear bump or choosing the optimal axial MRI sequence) in addition to their technical difficulty made these measurements unreliable, even after consensus training, and therefore not clinically useful for identifying the pathoanatomy of patients with patellofemoral instability. Therefore, trochlear depth should be used for assessment of trochlear dysplasia. Other reliable measurements that could be used for assessment of trochlear dysplasia were the crossing sign on perfect lateral radiographs and trochlear bump and sulcus angle on MRI.

Axial and Coronal Plane Deformity Evaluation

Similar to previous studies,[32,33] this study found that assessment of mechanical axis deviation was reliable on anteroposterior hip-to-ankle radiographs. In addition, although this study found good interrater reliability for the lateral patellofemoral angle on axial radiographs and patellar tilt angle on axial MRI, reliability for the categorization or presence of lateral patellofemoral tilt on radiographs was poor. While some studies have reported good reliability between raters on the presence of lateral patellofemoral tilt,[34] a systematic review by

Table 7. Summary of Radiologic Parameters of Patella Instability That Were Reliable Based on Clinical Application Category and Imaging Modality

	Radiograph	MRI
Trochlear dysplasia	Trochlear crossing sign	Trochlear bump Trochlear depth Sulcus angle
Axial and coronal plane deformity	Lateral patellofemoral angle Congruence angle Mechanical axis	Patellar tilt TT-TG
Patellar height	Caton-Deschamps index	None
Medial patellofemoral complex	Medial patella avulsion fracture	Location of MPFL injury
MRI findings	None	Effusion Bone edema Cartilage injury

MPFL, medial patellofemoral ligament; MRI, magnetic resonance imaging; TT-TG, tibial tubercle to trochlear groove distance.

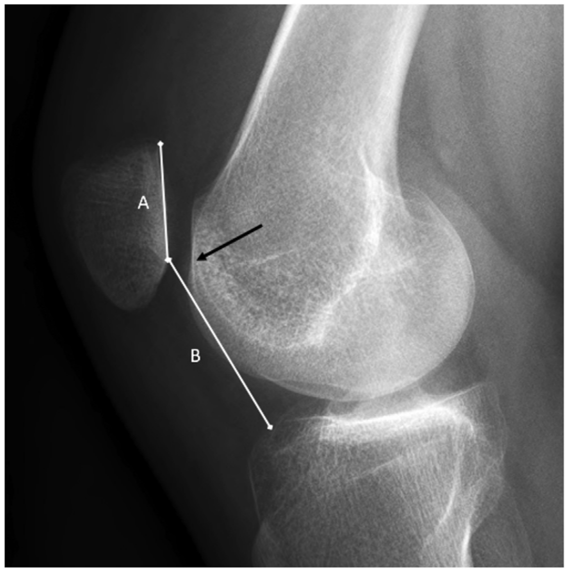

Fig 1. Sagittal radiograph depicting a crossing sign (black arrow). Caton-Deschamps index is equal to the magnitude of distance B divided by distance A.

Fig 2. Sagittal magnetic resonance image depicting the trochlear bump (arrows) between the anterior femoral cortex (white line) and anterior most aspect of cartilaginous trochlea.

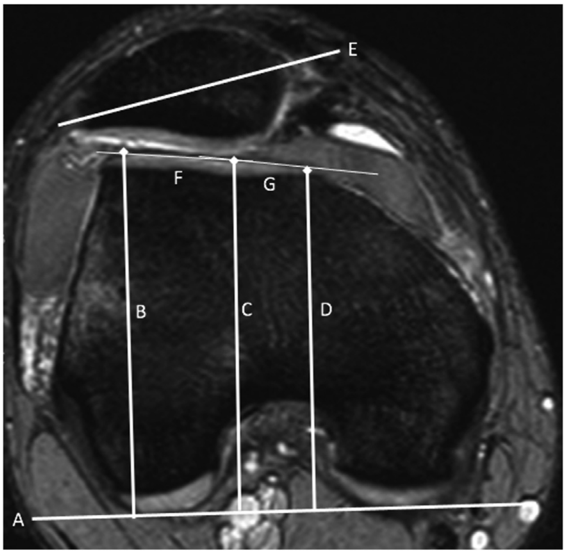

Fig 3. Axial magnetic resonance image depicting a Dejour C flat trochlea. Line A is a tangent along the posterior femoral condyles. Lines B, C and D are perpendicular to A and connect to the highest point of the lateral femoral condyle (B) and medial femoral condyle (D) and lowest point of the trochlea (C). Trochlear depth is $(B + D)/2 - C$. Sulcus angle is between the lines along the lateral trochlear facet (F) and medial trochlear facet (G). Patellar tilt is the angle between line A and the line along the maximum width of the patella (E).

Smith et al.[25] concluded that there was not enough evidence to demonstrate the lateral patellofemoral tilt assessment was reliable. One major problem with lateral patellofemoral tilt is there is no consensus on the cutoff values that would constitute malalignment.[24] However, the patellar tilt angle has established cutoffs and has been shown to be reliable in previous studies.[24,35] Similar to previous literature, radiologists in this study reported low reliability for the presence of lateral patellofemoral tilt due to unclear cutoffs, but good reliability on the actual degrees of the lateral patellofemoral angle and patellar tilt angle.

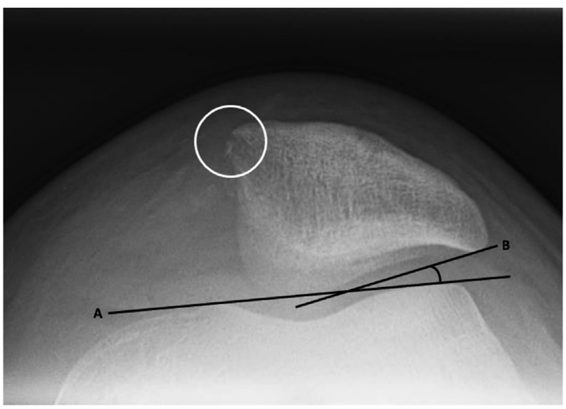

Fig 4. Axial radiograph depicting a medial rim avulsion fracture (white circle). The lateral patellofemoral angle is the angle between lines A and B.

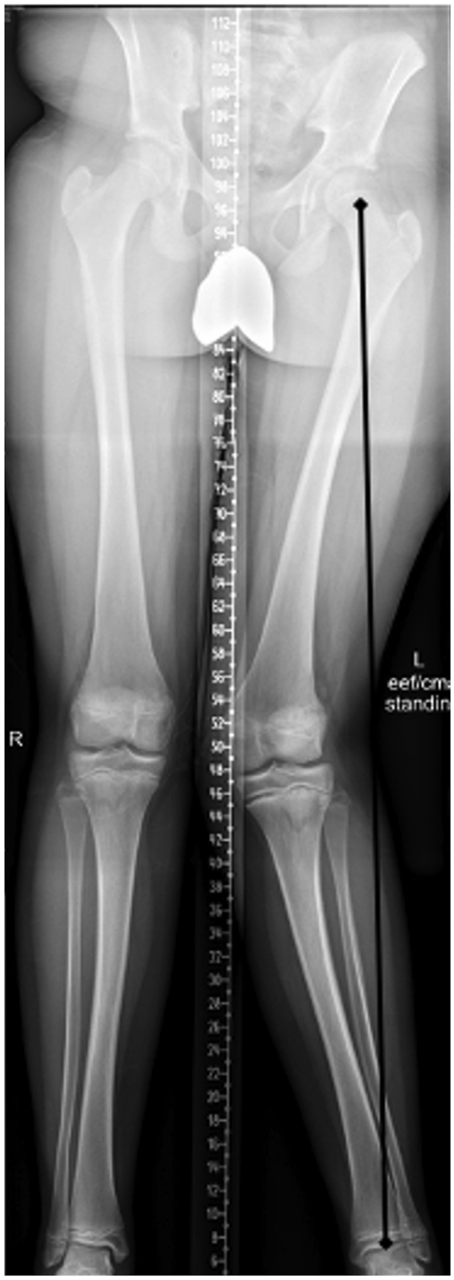

Fig 5. Anteroposterior hip-to-ankle radiograph depicting the mechanical axis, which is drawn from the center of the femoral head to the center of the ankle.

Congruence angle demonstrated poor interrater reliability initially in this study but improved with consensus training (Fig 7). Congruence angle was initially complicated by the difficulty in determining the patellar apex, similar to issues identified in previous studies.[35] Reliability for assessing the sulcus angle improved when consensus was met regarding image slice selection and landmark measurement. In addition,

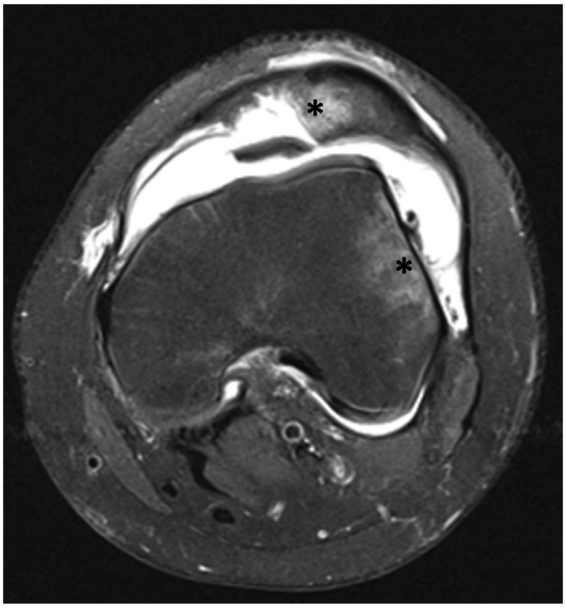

Fig 6. Axial magnetic resonance image depicting edema over the medial patella and lateral femoral condyle (asterisks) and effusion.

patellar subluxation distance (also known as lateral patellar displacement) demonstrated poor interrater reliability in this study. Previous studies have demonstrated that this measurement varies significantly based on knee flexion angle and muscle contracture during imaging.[24,25,35,36] Therefore, this measurement should be used with caution, if at all.

The TT-TG demonstrated substantial reliability on MRI in this study. Previous studies have found good reliability for TT-TG for several imaging modalities[15,37]; however, other studies have indicated that TT-TG is less accurate in patients with severe trochlear dysplasia.[5,24] This study did not examine the TT-TG distance in patients with different types of trochlear dysplasia, so future studies should determine how reliability and validity of TT-TG changes with other patellofemoral morphologies.

Patellar Height

This study examined patellar height using the CDI. While the Insall–Salvati ratio is also used to assess patellar height,[24,38,39] the CDI was chosen for this study because it has been extensively validated in patients with patellofemoral instability,[24,25,38] particularly those who are skeletally immature in whom determination of the distal insertion of the patellar tendon on the tibia is unreliable.[13] Furthermore, because it is measured using the articular surface of the patella rather than the entire patella, it is not affected by nonarticular portions of the patella (e.g., falsely decreased in the setting of a large nonarticular inferior patellar pole). This study demonstrated that the CDI is a reliable assessment of patellar height on plain radiographs. Neyret et al.[40] demonstrated that the CDI is also reliable on MRI with good sensitivity and specificity, but may not be necessary in many patients due to the good reliability of the CDI on radiographs.

Medial Patellofemoral Ligament Injury

The MPFL is frequently injured in patellofemoral dislocations at the level of the patellar insertion, the femoral origin, mid-substance, or their combination.[19] Some evidence suggests that femoral avulsion fractures can predict chronic instability, making the location of the MPFL injury important for surgical planning.[5,41] This study found that the location of the MPFL injury and the presence of a medial patella avulsion fracture could be identified reliably with careful vigilance. This study focused on identifying acute injuries caused by recent dislocations, but evidence of previous avulsion fractures or MPFL injuries may still be important findings to confirm a patient's medical history or decide on a proper treatment.

Osteochondral Injury and General MRI Findings

Patellofemoral injuries frequently present with bone edema of the patella or femur, effusion, and other cartilage injuries.[5] This study found that identifying the location of bone edema (contusion) and the presence or absence of effusion was initially reliable between the radiologists; however, the location of a cartilage injury was not reliable. Most patellar instability patients have cartilage injuries,[42,43] but further research is necessary to determine which injuries affect outcomes in patients. After disregarding the almost always present odd facet osteochondral injuries, reliability improved for this assessment.

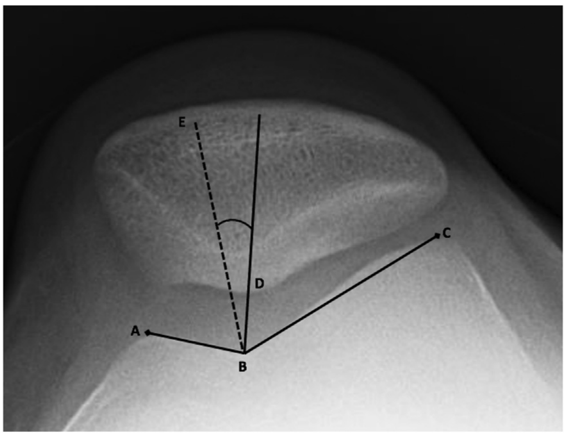

Fig 7. Axial radiograph depicting the congruence angle is between points D, B, and E. A and C are the highest points of femoral condyle. D is the lowest point of articular ridge of the patella. Line BE is the bisector of the angle between points A, B, and C.

Limitations

This study has several limitations. First, only 2 radiologists were raters, and they may not be representative of the general population of radiologists. Therefore, these results may not be generalizable to orthopaedic surgeons attempting these assessments who have not been comparably trained. Second, it is possible that some of the unreliable measures may have become reliable with a second round of consensus training, but that was not performed in this study. If more than one round of consensus training is required for musculoskeletal fellowship-trained radiologists, the investigators felt that it would be unlikely that those measures would be generally reliable in the hands of radiologists and surgeons alike. In addition, intrarater reliability was not performed in this study because assessment methodology was improved if it was initially unreliable. Furthermore, some included images were taken incorrectly. For example, not all axial radiographs followed the merchant guidelines, so knee flexion angle varied between patients. Some lateral radiographs were not "true laterals" with overlapping femoral condyles, which initially reduced the reliability of the trochlea crossing sign. Because of variation in image quality, this also led to the inability to perform some assessments in all patients. Finally, a control group was not used in this study, so it is difficult to assess whether these measurements are valid for diagnosing patellar instability, even if they are reliable.

Conclusions

With 1 or fewer consensus training sessions, the interrater reliability of the following patellofemoral indices were found to be reliable for trochlear morphology: trochlea crossing sign and congruence angle on radiograph and trochlear depth, trochlear bump, and sulcus angle on MRI. Reliable patellar position measurements included: CDI and lateral patellofemoral angle on radiograph and patellar tilt and TT-TG on MRI. Additional global measurements (e.g., mechanical axis deviation on standing radiographs) and MRI assessments demonstrated acceptable reliability.

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