The Role of Imaging in the Evaluation of Patellar Instability

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Abstract

Patellar instability is a complex problem that requires a thorough evaluation and work up. A critical part of this work up is appropriate imaging. This article reviews key imaging techniques and important imaging findings in patellar instability patients. This includes the evaluation of patella alta, trochlear dysplasia, lateral patellar tilt, extensor mechanism alignment, valgus alignment, rotational alignment, and soft tissue injury. Effective management for patellar instability relies on a comprehensive approach where any of these elements are evaluated when necessary.

Keywords: Patellofemoral Instability, Patellar Instability, Patellar Dislocation, Imaging.

Introduction

The patellofemoral joint is a complex articulation stabilized by both soft tissue and bony constraints. Pathology of the anterior compartment encompasses a broad range from degenerative conditions to dysplasia and instability. A complete evaluation requires a structured and thorough imaging evaluation to complement the history and physical exam. Given the critical role osseous anatomy plays in treatment decisions, careful attention must be paid to imaging techniques and measurement methods [1,2].This article will review the main imaging modalities and key measurements in a comprehensive evaluation of the patellofemoral joint for patients with patellar instability.

Patella Alta

Assessment of patellar height is a critical portion of the evaluation of the patellofemoral joint as it relates directly to trochlear engagement in early flexion and, when elevated, is associated with patellar instability [2,3].Numerous indices have been developed to evaluate patellar height on both the lateral radiograph and slice imaging including computed tomography (CT) and magnetic resonance imaging (MRI) [1,4].The methods can be broadly categorized into those which relate the patellar position relative to the tibia and those which directly evaluate the position of the patella relative to the femur [5].Methods measuring the patella's position to the tibia have their broadest application in the clinic setting, with measurements made on the sagittal knee radiograph. The most common patellar-tibial indices include the Insall-Salvati (IS) ratio, modified IS (MIS), Caton-Deschamps (CD), and Blackburne-Peel [6].The first method to relate the patella to the femur for measuring patella height also used the sagittal knee radiograph [4],but its application in the clinical setting proved difficult. With the increasing use of MRI which details the cartilaginous surfaces, the patella trochlear index (PTI) has gained importance in defining patella-trochlear engagement [7].

The IS and the MIS compare the patella, either its entire length (IS) or simply the articular surface (MIS), to the length of the patellar tendon where it inserts on the tibial tubercle (TT) (Fig. 1) [6].The MIS method tried to overcome the variable length of the patella's non-articular surface (Fig. 2).These methods are common, but have a disadvantage of lack of utility in some post-operative procedures. Because the TT is used as the anatomic landmark for the patellar tendon, both indices do not allow for post-operative comparison following TT distalization; the IS ratios can also be significantly influenced by proximal tibial osteotomies when performed [6,8].The CD(Fig. 1) and Blackburne-Peelindices measure the articular surface of the patella directly and are unaffected by variations in morphology of the patella or patellar tendon. In these indices, it is possible to compare pre-operative and post-operative imaging regardless of concomitant osteotomies. These methods have been used on both plain radiographs and MRI, but it should be noted that they are not always equivalent depending on the imaging modality used [9].With the advent of digital imaging techniques measuring to 0.01 sensitivity in linear measurements and a lack of repeatability in defining the landmarks used for measurement on MRI, there is greater variability on MRI than was present in plain radiographs. A recent systematic review found that anatomic patellar instability risk factors on MRI show sensitivity without specificity in patients with patellofemoral instability [10].Measurements thresholds which indicate patella alta is defined for each measurement technique; what is less clear is the threshold to use when deciding to distalize the TT for surgical patellar stabilization. Typically values above 1.4 on IS or CD is something which should generate consideration for surgically lowering patellar height.

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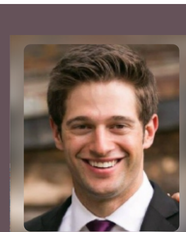

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Insall-Salvati ratio	Measure on sagittal cut with greatest patellar length. Line (B) from most superior subchondral bone to point of tendon insertion on inferior patella; line (A) from lower point of line (B) to superior aspect of insertion of patellar tendon on tibial tuberosity. IS = A ÷ B
Caton-Deschamps index	Measure on sagittal cut with greatest patellar length. Line (D) measurement of cartilage articular surface; line (C) to the anterior corner of the superior tibial joint surface. CD = C ÷ D

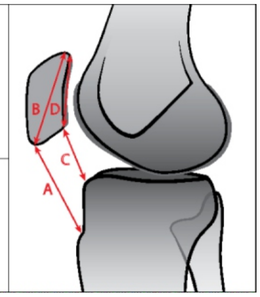


Figure 1: Insall-Salvati and Caton-Deschamps(Copyright© Regents of the University of Minnesota). All rights reserved.

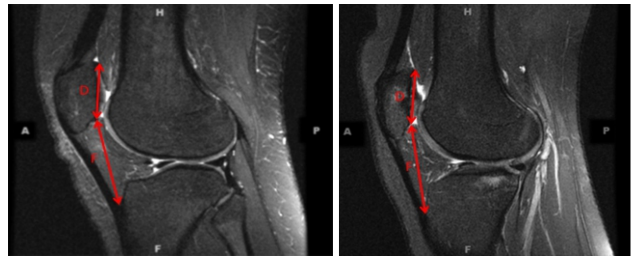


Figure 2: The modified insall-salvatiis measuredon the sagittal cut with greatest patellar length. Line (D) measurement of cartilage articular surface; line (F) from lower point of line (D) to superior aspect of insertion of patellar tendon on tibial tuberosity. MIS = F ÷ D.

Despite the common use of patellar-tibial indices, they do not directly describe the relationship of the patellar and trochlear articular surfaces. The PTI does directly assess the articular congruency on sagittal MRI and in particular the engagement of the patellar articular surface with the trochlear articular surface [7].If the overlap of the patella and trochlea is <1/8, then there is poor functional engagement of the patella in the trochlea (Fig. 3).It is also the only technique that takes into consideration the length of the trochlea, as a short trochlea can lead to "relative" patella alta despite a normal measurement on tibial based methods (Fig. 4). There are limitations, however, even with the PTI measurement. Because it is made on slice imaging, a single slice may not contain both the patella and the trochlear groove (TG), particularly in the setting of a large effusion or significant patellar lateral tilt (Fig. 5).The PTI can also be sensitive to knee flexion and quadriceps activation at the time images are taken, so a complete evaluation of patellar height should include a combination of all of the above techniques to completely evaluate for trochlear engagement of the patella bearing in mind the strengths and limitations of each technique.

Trochlear Dysplasia

The morphology of the trochlea plays a critical role in patellofemoral contact forces and the tracking of the patella. Therefore, imaging assessment of the trochlea is necessary for a thorough evaluation of the patellofemoral joint. Evaluating trochlear dysplasia, in particular, is crucial, especially in the setting of patellar instability [2].To precisely analyze the trochlear morphology on plain radiographs, strict attention must be paid to obtaining a true lateral radiograph with the femoral condyles overlapped; there can be limitations to this, however, especially in trochlear dysplasia if the condyles are dysplastic (Fig. 6) [11].Careful review of the lateral radiograph can provide a wealth of information regarding trochlear shape and the degree of dysplasia. The key radiographic landmarks to consider are the outlines of the medial, central, and lateral trochlea as well as their relationships to the anterior femoral cortex. The normal trochlea will have no overlap of the central groove with the medial and lateral trochlea [11].

Trochlear dysplasia occurs along a spectrum and was classified, on the true lateral knee radiograph, by Dejour et al. into four types based on the presence of the supratrochlear bump, crossing sign, and double contour sign (Fig. 7) [12].Identification of these four types of dysplasia is not only helpful in identifying the degree of pathology but also can direct treatment.

Dejour Type A dysplasia the trochlea is shallow and represented radiographically by the crossing sign, i.e., the central groove meeting the outline of the femoral condyles distal to the proximal-most aspect of the trochlea.This often means that the proximal aspect of the central TG is level with the anterior femoral cortex, indicating a shallow or flat groove.

Dejour Type B dysplasia represents a flat trochlea with the crossing sign and the addition of a supratrochlear spur.

Figure 3: Patellotrochlear index (PTI): Measure on sagittal cut with greatest patellar length. Line (D) measure length of cartilage articular surface. Strike a reference line at 90° to inferior end of line (D). Line (E) parallel to line (D), length of femoral articular cartilage superior to reference line.PTI = E ÷ D.

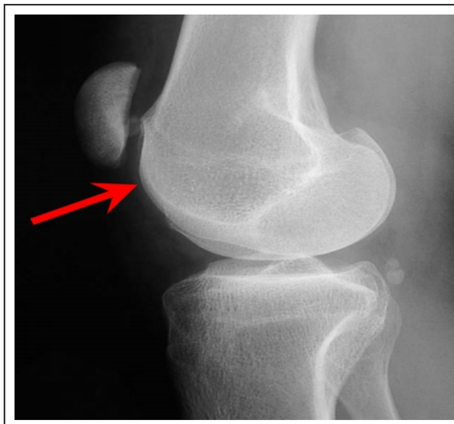


Figure 4: Sagittal knee radiograph illustrating a short trochlea. C/D ratio = 1.2, which is theupper limit of normal, however, due to the short trochlea, there is no engagement of the patella with the trochlea.

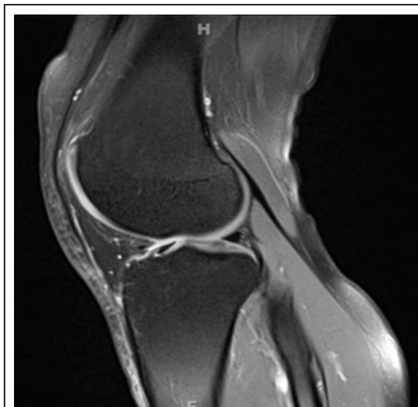


Figure 5: Patella and trochlear cartilage are not present on thesame slice, precluding measurement of PTI.

Figure 6: Evidence of condylar dysplasia which can make obtaining a true lateral radiograph challenging.

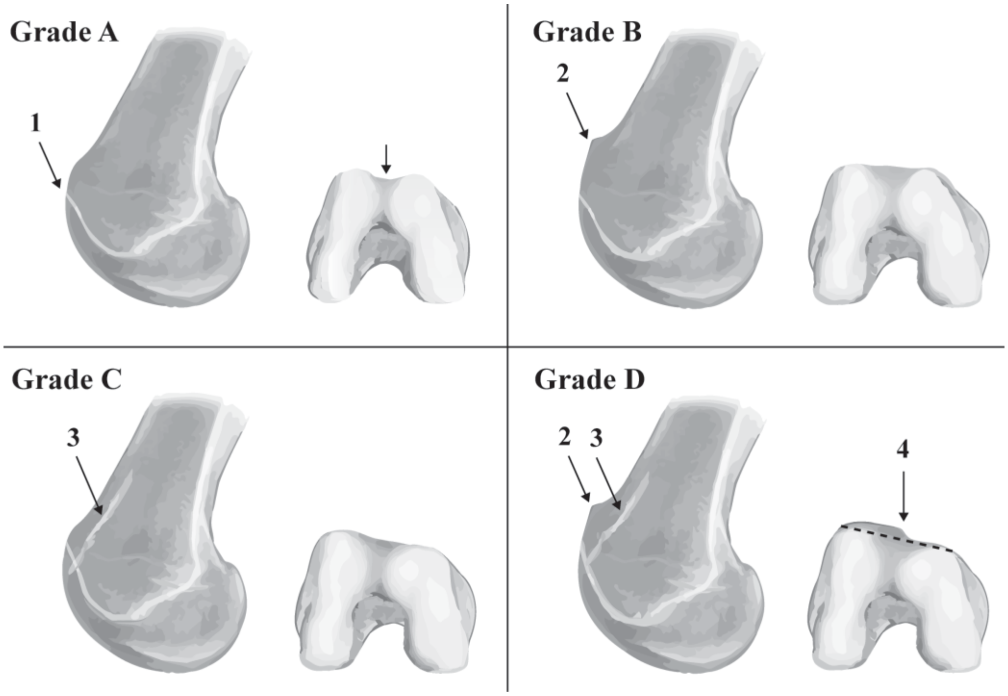
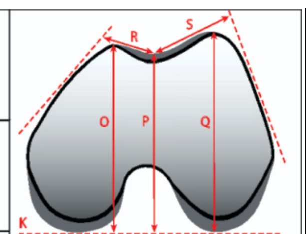


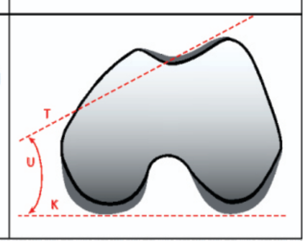
Figure 7: Trochlear dysplasia four types per DejourCopyright©Regents of the University of Minnesota. All rights reserved.

Dejour Type C dysplasia has a hypoplastic medial condyle in addition to a shallow central groove. Radiographically this manifests as a crossing sign with the addition of the double contour sign representing the hypoplastic medial condyle relative to the lateral condyle. In Dejour Type C dysplasia, the supratrochlear spur is absent.

Dejour Type D dysplasia includes all three pathologic signs: Crossing sign, supratrochlear spur, and double contour sign; Type D represent the greatest degree of dysplasia [12,13]. With a heavier reliance on slice imaging, measurements have been put forward to analyze the trochlea on MRI. Initial measurements made were found to be most reliable 3 cm above the joint line, with trochlear depth<3cm, and medial to lateral facet ratio of <2:5 indicating trochlear dysplasia [14].Other measurements made on MRI include sulcus angle (SA), condyle asymmetry, and lateral trochlear inclination angle (Fig. 8). There are limitations in evaluating trochlear dysplasia with MRI slice imaging. Due to the varying sizes and shapes of the trochlea, measurements made 3 cm above the joint line may be above the entire trochlea, especially in children. Most current conventions utilize the most proximal slice in which the trochlear articular cartilage spans the entire medial to lateral trochlear surface [3,15].This can sometimes be vague; however, so different reviewers may choose different slices. In addition, it should

Sulcus angle (degrees)	Measure cartilage surface, beginning at deepest part of trochlear groove and extending to highest points of lateral and medial cartilage. Measure angle between the slopes of the medial (R) and lateral (S) trochlea.
Trochlear facet asymmetry	Measure on full articular cartilage across anterior femur from groove to edge of subchondral bone. Calculate the ratio of medial trochlear facet length (R) to lateral trochlear facet length (S). FA = R ÷ S
Trochlear depth (mm)	Drop lines at 90° to baseline (K) along posterior condyles at most inferior level of full posterior articular cartilage (may need to visualize on > 1 axial slice, as full cartilage may not correlate over anterior and posterior femur). Average the lengths of the medial (O) and lateral (Q) trochlear facets, and subtract the length of the trochlear groove (P). TD = [(O + Q) ÷ 2] – P
Trochlear condyle asymmetry	Drop lines at 90° to baseline (K) along posterior condyles at most inferior level of full posterior articular cartilage (may need to visualize on > 1 axial slice, as full cartilage may not correlate over anterior and posterior femur). Divide the length of the lateral (Q) by the medial (O) trochlear facet, as a percentage. CA = Q ÷ O x 100%
Lateral trochlear inclination angle (degrees)	Baseline (K) tangential to subchondral bone of posterior aspect of femoral condyle at most posterior height of full articular cartilage. Line (T) on slice with full articular cartilage anteriorly across lateral and medial facets. Angle (U) measured between lines (K) and (T). LTI = U°





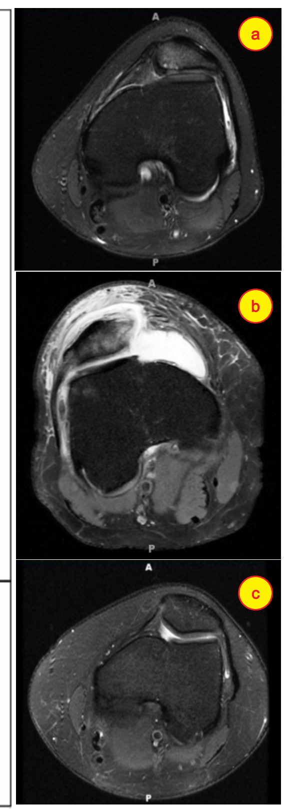


Figure 8: (a) Measurements made on magnetic resonance imaging include sulcus angle, condyle asymmetry, and lateral trochlear inclination angle(Copyright©Regents of the University of Minnesota). All rights reserved.(b-d)Examples of trochlear dysplasia on axial slice imaging

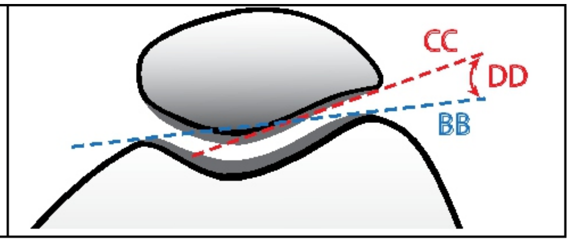
Angle of Laurin (degrees)	Line (BB) is drawn across the anterior margin of the medial and lateral trochlea. Line (CC) is drawn tangential to the slope of the lateral facet of the patella. A positive angle (DD) is one that opens up laterally. Parallel lines or converging lines are considered (+) tilt.	

Figure 9: (a) Lateral patellofemoral angle as described by Laurin.Copyright©Regents of the University of Minnesota. All rights reserved.(b)Example of Laurin axial radiograph in 20° of knee flexion. The right patella has diverging lines (no lateral tilt). The left patella has parallel lines, and therefore, is (+) for lateral tilt based on Laurin's criteria.

also be noted that since these measurements are made on axial slices, they cannot evaluate the length of the trochleaor the depth of the trochlea in a more distal segment of the trochlea.

The SA is formed from the angle between the medial and lateral trochlea; trochlear dysplasia is manifested by a larger angle. It reflects the structural constraint of the trochlea but importantly exhibits significant variability based on the level of the measurement and the imaging modality [4,16].Studies of patellar instability using MRI have shown larger values on average with instability patients having mean SA of 168 in one series [4].In a recent systematic review of MRI measurements in control versus PF instability patients, mean SA ranged from 143° to 156° in the control group and 147° to 169° in the PF instability group [10].

Trochlear depth is measured in the axial plane as the mean of the medial and lateral trochlear height minus the height at the center of the TG. Decreased trochlear depth is a manifestation of trochlear dysplasia with values <3.00 being considered pathologic on radiographs and CT [14]. As with other trochlear measures, variability exists with imaging modality and a higher threshold may be appropriate when the cartilage is measured on MRI versus osseous measurement on CT.

Lateral trochlear inclination angle is another measure of trochlear dysplasia and quantifies the angle of the lateral trochlea. The angle is measured between a reference line drawn along the posterior border of the femoral condyles and a line along the lateral trochlear slope [17].Patellar instability patients generally have lower LTI values than controls, with means usually between 10° and 15° for patellar instability patients [4,17].

Facet asymmetry compares the ratio of medial trochlear facet length to lateral trochlear facet length, as measured from the central TG to the edge of the articular cartilage. A ratio of 2:5, medial:lateral, is a defined as trochlear dysplasia [14].

Condyle asymmetry is a related concept to facet asymmetry but attempts to identify whether the center of the TG is elevated or if either of the facets are hypoplastic. The ratiois

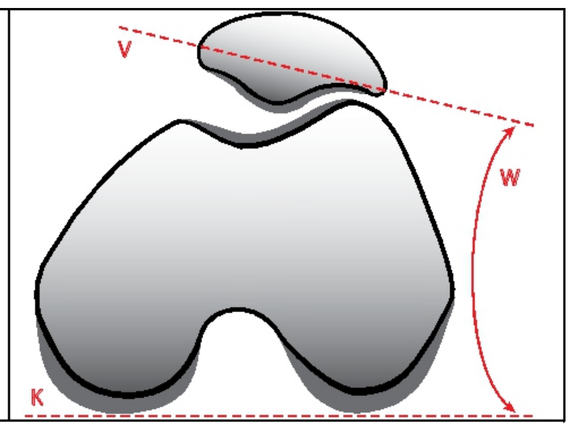
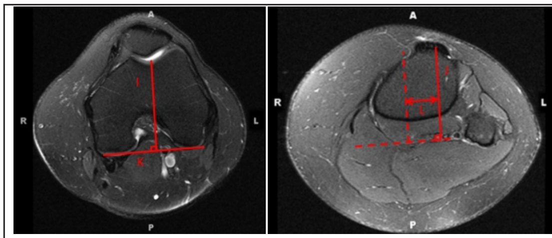
Patellar tilt (degrees)	Measure on axial view (may require two slice imaging views). Baseline (K) across posterior condyles at most inferior level of full posterior articular cartilage. Line (V) at greatest patellar width through bony medial / lateral patella midpoint (may be on another MR slice). PT = W°	

Figure 10: Measuring patellar tiltCopyright© Regents of the University of Minnesota. All rights reserved.



Tibial tubercle – trochlear groove distance (mm)

Measure on axial view (requires two slice imaging views). Baseline (K) across posterior condyles at most inferior level of full posterior articular cartilage; line (I) at 90° to baseline through lowest point of trochlear groove cartilage. Superimpose a second image of tibial tubercle; line (J) parallel to line (I) at midline of patellar tendon insertion onto tibia. Measure distance (L) between lines (I) and (J). TT-TG = L

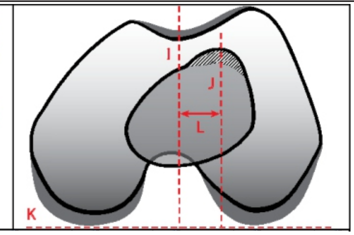


Figure 11: The tibial tubercle-trochlear groove distance is measured on the axial view (requires two slice imaging views). (a) Slice image representing the full cartilage coverage of the trochlea. Line (I) represents the center of the trochlea at this level. (b) Superimposed line (I) from panel A onto a second image of the tibial tubercle insertion; the distance (L) represents the TT-TG distance measured in mm.(c)Tibial tubercle-trochlear groove distance.Copyright©Regents of the University of

obtained on axial MRI slices by measuring the maximum height of the lateral and medial condyles from anterior to posterior on the first slice containing cartilage across the entirety of the trochlea. The values are expressed as a percentage of total femoral width across the epicondylar axis [18].The value in measuring the condyles in this manner is to establish a more objective assessment of the trochlear morphology. Most often pathology is located in the center and/or medial trochlea [18], and when present in patellar instability patients, a deepening trochleoplasty may be indicated to correct dysplasia and help stabilize the patella.

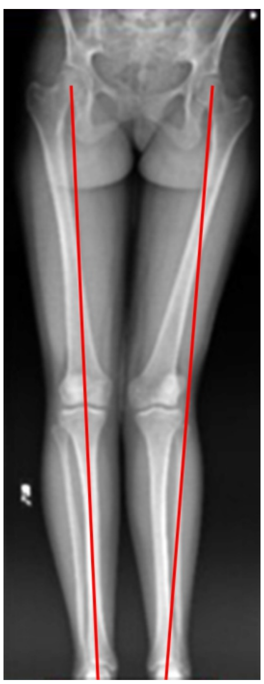


Figure 12: Mechanical alignment and lower extremity valgus can contribute to patellofemoral instability. Alignment with the weight-bearing axis at or outside of the lateral compartment may alter the quadriceps vector and affect patellofemoral mechanics.

Lateral Patellar Tilt

Abnormal lateral patellar tilt is a manifestation of quadriceps dysplasia, lateralretinacular tightness, and/ormedial soft tissue laxity. Excessive lateral patellar tilt is not necessarily a cause of patellar instability, but can be informative of underlying pathology and is often seen in patients with patellar instability. As such, it is an important component of the imaging evaluation. This can be measured on axial radiographs as well as MRI [1,19,20].

The most common radiographic measures of patellar tilt include.

Lateral patellofemoral angle was described by Laurin and is measured on a 20° axial radiograph (Fig. 9) [21],The image is taken in early flexion to display the anatomy of the proximal trochlea as the patella enters the groove. This is important so that the patella is not fully engaged within the deep portions of the more distal trochlea, which can normalize the tilt. The angle is measured between a line drawn across the highest points of the medial and lateral facets of the trochlea and a second line parallel with the lateral patellar facet. The angle normally opens laterally with abnormal being parallel or convergent lines.

Congruence angle is a measure of patellar displacement and is obtained on a Merchant axial radiograph at 45° of knee flexion [19].First, the SA is drawn, and two lines are extended from its apex in the trochlea; a line bisecting the SA and a second line to the median ridge of the patella. The angle between the two lines from the trochlear apex establishes the congruence angle with values more than 16° being abnormal[19].

MRI allows evaluation of patellar tilt by referencing the posterior femoral condyles and has the advantage of the knee in near full extension which minimizes the passive correction from early trochlear engagement (Fig. 10) [2,20].External patellar tilt is measured on axial slice imaging as an angle between a reference line along the posterior femoral condyles and a second line along the transverse axis of the patella [2].In general, >20° is felt to be a modifiable factor when approaching patellar stabilizing surgery [22].

Extensor Mechanism Alignment

To fully evaluate the patellofemoral joint attention must be turned to an evaluation of the entire limb including coronal alignment and axial rotation. The relationship between the quadriceps (extensor) mechanism and the TG is a factor in patellofemoral mechanics and is most commonly measured on imaging using the TT-TG distance [22,23].TT-TG distance utilizes axial slices from CT or MRI to measure the relative distance between the TT and the center of the TG. It was initially described using CT slices but has been validated using MRI [4].The distance is measured from lines

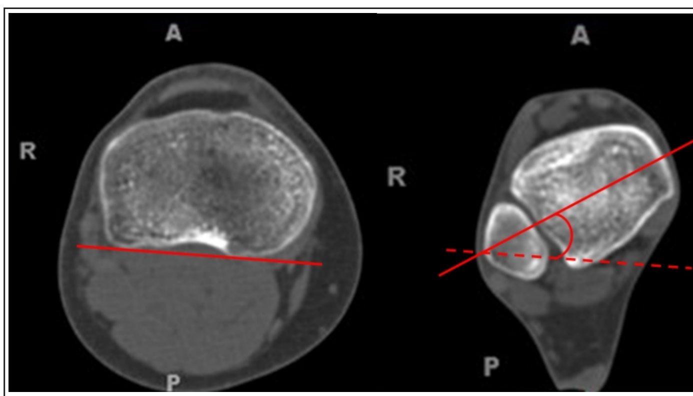


Figure 13: Tibial torsion. (a) Reference line along the posterior border of the proximal tibia. (b)The proximal tibial reference line is then compared to the bimalleolar axis to establish tibial torsion.

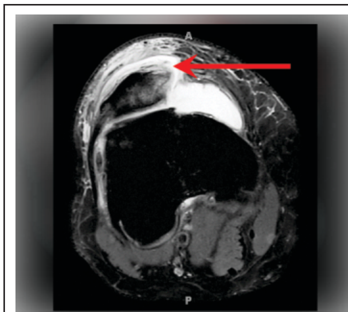


Figure 14: Medial patellofemoral ligament injury can be visualized on axial magnetic resonance imaging images with increased signal and disruption of the medial retinacular structures (arrow).

drawn on two distinct axial slices. The first slice, using CT, is through the proximal trochlea at the level of the "Roman arch" appearance of the intercondylar notch posteriorly [20].The first slice on MRI is the most proximal slice in which the trochlear articular cartilage spans the entire medial to the lateral trochlear surface [4].From these slices, a line is drawn a perpendicular to the axis of the posterior condyles through the center of the TG. The second axial slice is through the proximal portion of the TT, best seen on MRI where the patellar tendon begins to insert on the TT. The TT-TG distance is measured from the center point of the tubercle to the line through the center of the TG (Fig. 11).Although some variation between CT and MRI values exists, a distance of 15–20 mm is considered borderline while distances>20 mm are associated with patellar instability [4,20].

The TT-posterior cruciate ligament(TT-PCL) measurement [24] attempts to address some of the concerns with the TT-TG by measuring the lateralization of the TT relative to a fixed point on the tibia rather than the trochlea to eliminate the effect of tibial rotation at the knee joint level. A recent study comparing the TT-PCL to TT-TG in a patellar instability population, however, found both to have excellent interobserver reliability, but the TT-PCL measurement was less predictive of recurrent instability [25].

Valgus and Rotational Alignment

Valgus knee alignment can have a negative impact on patellofemoral mechanics and can be evaluated using standing long leg alignment films (Fig. 12).The degree of valgus predisposing to patellar instability is not well elucidated, but any alignment with the weight-bearing axis in the lateral compartment should be considered as potentially increasing the lateral quadriceps vector.

Femoral anteversion and tibial torsion can play an important role in patellar instability by influencing the overall rotational alignment of the patella with the trochlea.CT imaging is best utilized to quantify both the femoral version and tibial torsion [26].Utilizing CT slices through the femoral neck and distal femur, femoral version can be calculated by the angle between a line tangent to the posterior femoral condyles and a second line parallel to the femoral neck [11].With CT slices through the proximal tibia and ankle, tibial torsion is measured by an angle parallel to the posterior border of the proximal tibia compared to the bimalleolar axis (Fig. 13) [11]. Abnormal values for version and torsion in patellofemoral pathology are also not well defined but should be considered with values<30°[27].

More recently femoral anteversion has been evaluated by assessing the rotation at the neck, mid-shaft, and distal segments [28], with all 3 levels of the femur contributing to the total femoral version. As this is increasing understood, it is likely that different patterns will be identified among patients with high femoral version and patellar instability.

Ligamentous Injury/Instability

Finally, a complete evaluation of the patellofemoral articulation requires evaluation of the soft tissues and ligamentous restraints. The medial patellofemoral ligament (MPFL) is the primary restraint to lateral translation in early flexion and is a crucial stabilizer of the patellofemoral joint; injury to the MPFL can be visualized on MRI and in patellar instability patients (Fig. 14) [29].In some circumstances, injury to the MPFL/medial retinacular complex can avulse a fragment from the medial patella, which may be visualized on MRI or plain radiographs; this is most commonly from the inferomedial patella in the region of the medial patellotibial ligament[30].In addition to ligamentous injury, MRI allows identification of associated cartilage lesions, which may coincide with acute or chronic patellar instability. Finally, there is a consistent pattern of bone bruising following patellar instability, with increased signal on the medial patellar facet and lateral femoral trochlea.

Conclusions & Keypoints

- Patellar instability is a complex and multifactorial issue, which requires a thoughtful and structured imaging evaluation to complement the history and physical examination.
- Patella Alta can be measured using many methods with IS and CD being most common. The CD ratio can be used to compare pre-operative and post-operative imaging following distalization of the TT. Measurement of patellar height and evaluation of trochlear engagement is crucial in assessing instability patients.
- Trochlear dysplasia occurs along a spectrum and careful evaluation of the lateral radiograph and MRI can yield crucial information regarding trochlear morphology and the degree of trochlear pathology.
- Lateral patellar tilt can be evaluated on a low-flexion axial radiograph or MRI.
- TT-TG distance helps describe the relationship between the trochlea and the tibial insertion of the extensor mechanism and can be measured on CT or MRI.
- Long leg standing alignment radiographs complement knee radiographs by identifying valgus alignment.
- Axial slice imaging, most commonly CT imaging, can be used to evaluate for femoral anteversion and tibial torsion.
- MRI is highly sensitive for MPFL disruption and allows for the identification of the characteristic bone contusion patterns in patellar instability patients.

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