Imaging of Individual Anatomical Risk Factors for Patellar Instability

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Abstract

This review article presents several pitfalls and limitations of image interpretation of anatomical risk factors for patellar instability. The most important imaging examinations for the work-up of patients with patellar instability are the true lateral radiograph and transverse computed tomography (CT) or MR images of the knee. Primary anatomical risk factors are an insufficient medial patellofemoral ligament (MPFL), patella alta, trochlear dysplasia, increased distance from the tibial tuberosity to the trochlear groove (TTTG), and torsional limb parameters.

Limitations of the Caton-Deschamps index are related to the clear identification of the patellar and tibial articular margin. Classification of trochlear dysplasia according to the Dejour system on radiographs and MR images revealed a weak reliability. The comparability of TTTG values obtained on CT and MR images at various flexion angles and different varus alignments of the knee is limited. Thus MRI performed with a dedicated knee coil may underestimate the TTTG distance compared with CT images.

Increased lateral patellar tilt is a consequence of primary anatomical risk factors rather than an independent anatomical risk factor for patellar instability. The pretest likelihood of a torn MPFL on MR images is very high after an acute episode of lateral patellar dislocation.

Keywords

► patellar instability
► risk factors
► trochlear dysplasia
► TTTG
► patellar tilt

Surgical restoration of the patellofemoral joint stability addresses the complex multifactorial biomechanics by a custom-made management such as MPFL reconstruction, sulcus-deepening trochleoplasty, as well as medialization and distalization of the tibial tubercle.

Quantification of anatomical risk factors for patellar instability in each person is important for highly individual treatment.

Lateral dislocations of the patella are frequent injuries in sports-active adolescents and young adults.\(^1\) The patellofemoral joint is stabilized by a complex multifactorial relationship of the osseous joint geometry and the force vectors resulting from the quadriceps muscle and capsuloligamentous stabilizers.\(^2\)\(^–\)\(^4\)

For appropriate treatment planning, the radiologic work-up after an episode of lateral patellar dislocation should assess both the injuries of the knee and the individual anatomical risk factors for patellar instability.\(^1\)\(^,\)\(^3\)\(^,\)\(^5\)\(^–\)\(^7\)

Dejour et al provided reference values for imaging analysis of four major risk factors for patellar instability: patella alta, trochlear dysplasia, increased tuberosity to the trochlear groove (TTTG) distance, and abnormal lateral tilt of the patella.\(^3\)\(^,\)\(^6\)\(^,\)\(^8\)

Additional anatomical risk factors for patellar instability are an insufficient medial patellofemoral ligament (MPFL), torsional limb malalignment, and genu valgum.\(^5\)\(^,\)\(^9\)\(^–\)\(^11\)

Conventional radiographs, computed tomography (CT), and MRI enable quantification of these predisposing anatomical risk factors for patellar instability.

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instability.6,9,13–17 Surgical restoration of the patellofemoral joint stability addresses the complex multifactorial biomechanics by a tailored treatment such as MPFL reconstruction, release or lengthening of the lateral patellar retinaculum, medialization and distalization of the tibial tubercle, sulcus-deepening trochleoplasty, and rarely femoral derotation osteotomy.6,8,13,14 This review article presents several pitfalls and limitations in the analysis of anatomical risk factors for patellar instability.

**Patellar Height**

Patella alta, or high-riding patella, is a major risk factor for recurrent lateral patellar dislocations.3,8 The trochlear groove is the most important osseous stabilizer of the patellofemoral joint.1 The patella slips into the trochlear groove at ~20 degrees of knee flexion.1,15 A high-riding patella requires higher flexion angles of the knee to slide into the trochlear groove and covers a higher range of motion without osseous stabilization of the trochlear groove.1,5 Numerous quantification techniques on radiographs were proposed for the diagnosis of a high-riding patella.16–21 The four most popular patellar height measurement techniques are the Insall-Salvati, Grelsamer-Meadows, Caton-Deschamps, and Blackburne-Peel indexes.21 Dejour and Le Coutil stated that any patellar height index can be used; however, the Caton-Deschamps index became the preferred standard for the Lyon school of knee surgery (Fig. 1).6,8 A main advantage of the Caton-Deschamps and Blackburne-Peel ratios is the ability to quantify patellar height changes after osteotomy of the tibial tubercle (Fig. 1).5 In addition, the Caton-Deschamps index allows simple and reliable patellar height measurements for various degrees of knee flexion, different physical sizes of the knee, variable skeletal maturation, patellar pole abnormalities, and unequal radiographic magnifications.6,13,22,23 Limitations of the Caton-Deschamps index are related to the clear identification of the patellar and tibial articular margin as well as its difficult application in osteoarthritic knees.21 The Caton-Deschamps index is determined by the ratio of the distance between the lowest point of the patellar articular surface and the anterior point of the tibial plateau as well as the patellar articular length (Fig. 1), whereas values >1.2 indicates a patella alta and values <0.6 represent a patella baja.5,17 However the suggested reference values for patella alta and patella baja vary slightly in the literature.

The Insall-Salvati and Blackburne-Peel indexes on radiographs were compared with the corresponding values on CT and MR images.24,25 A moderate inter-method reliability of patellar height assessment was found for radiographs and CT images as well as for radiographs and MRI for both indexes.25 The results show that reference values for patella alta and baja based on radiographs cannot be directly applied on CT and MR images.3 The authors suggested the addition of 0.09 to 0.13 to the so far established cut-off values derived from conventional radiographs for the diagnosis of patella alta and baja on CT and MRI images.25

**Trochlear Dysplasia**

Trochlear dysplasia is considered a developmental anomaly and is one of the most important risk factors for lateral patellar dislocation.3,5 A decreased depth, a flat or even a convex trochlear surface characterizes trochlear dysplasia (Figs. 2–6).3,8,9 Trochlea dysplasia can be diagnosed and classified according to the four types of David Dejour classification by the so-called crossing sign, a reference line along the anterior cortical border of the distal femur, the supratrochlear spur, and the double-contour sign on true lateral conventional radiographs, axial conventional radiographs,
The diagnostic accuracy of trochlear dysplasia is in accuracy and are more reliable for the diagnosis of trochlear dysplasia Dejour type B, C and D.\(^8,9\) These findings are the supratrochlear spur (also called supratrochlear bump) and the double-contour sign (\(\text{Figs. 1, 6}\)).\(^8,9\) The supratrochlear spur sign indicates an osseous prominence of the proximal part of the femoral trochlea, which is present if the height is \(\geq 3\) mm measured from a reference line along the anterior cortical border of the distal femur on true lateral radiographs.\(^3\) This reference line is usually anterior in relation to the sulcus of the trochlea in normal femoral trochlea (\(\text{Fig. 2}\)).\(^8,9\) The double-contour sign on lateral knee radiograph refers to a hypoplastic medial trochlear facet that represents a pronounced asymmetry of the height of the medial and lateral trochlear facets (\(\text{Figs. 5 and 6}\)).\(^8,9\) The double-contour sign of the hypoplastic medial trochlear facet on lateral knee radiographs is located posteriorly to the radiopaque line of the lateral trochlear facet (\(\text{Figs. 1, 5, and 6}\)).\(^8,9\)

Transverse CT or MR images in patients with trochlear dysplasia demonstrate a flattening or even an absent trochlear sulcus that might be assessed subjectively by the overall impression of the trochlear shape, by an trochlear sulcus angle \(> 145\) degrees, or a trochlear depth \(\leq 3\) mm on a transverse MR image 3 cm proximal to the femorotibial joint space.\(^8,9,27\) A marked ventral trochlear prominence \(\geq 7\) mm with a step-like transition zone between the anterior femoral cortex and the most ventral point of the trochlear floor on midsagittal MR images is an accurate criterion for trochlear dysplasia.\(^27\) A specific finding for trochlear dysplasia is a nipplelike anterior prominence at the most anterior and proximal part of the femoral trochlea on midsagittal MR images.\(^27\)

True lateral radiographs revealed a higher diagnostic accuracy and are more reliable for the diagnosis of trochlear dysplasia compared with axial radiographs obtained at 30 degrees of flexion of the knee (\(\text{Figs. 2–7}\)).\(^26\) True lateral radiographs allow assessment of the whole length of the trochlea. In contrast the evaluation of the trochlea on axial radiographs is limited to the small area viewed tangentially.\(^26\) The diagnostic accuracy of trochlear dysplasia is influenced by the degree of knee flexion. Axial views frequently enable radiologic assessment of the trochlea in its distal part,
groove (TTTG) distance of 22 mm (distance factor, 25 s acquisition time, 18-channel body array knee: 18 sections per slab, 5 mm section thickness, 50% intersection distance factor, 25 s acquisition time, spine matrix coil; parameters: femur: 25 sections per slab, 5 mm section thickness, 30% imaging MR technique (single-shot turbo spin-echo) with the following images over the proximal femur and knee are acquired by a fast the text and references 37, 74, and 75. These strictly transverse MR measurements are obtained in hip and knee extension as described in Figs. 2–6.

Increased femoral antetorsion of 39 degrees (Fig. 8) corrected by an osteotomy and subsequent medial transfer in lateral patellar dislocations, which may be surgically underestimated the degree of trochlear dysplasia according the Dejour classification compared with transverse MR images.29 It was also shown that lateral radiographs classify trochlear dysplasia correctly on lateral radiographs.28

Quantitative parameters such as the depth of the trochlear groove, condyle asymmetry, trochlear facet asymmetry, lateral trochlear inclination, lateralization of the patella, the height of the medial and lateral condyle, and the central trochlear height in relation to the width of the distal femur were evaluated on MR images to discriminate a normal and a dysplastic trochlea.30 The authors found that these quantitative measurements on MR images are of limited value for the assessment of trochlear dysplasia.30 In addition, measurements on transverse MR images of the femoral trochlea were not reliable to classify trochlear dysplasia type B, C, and D according to Dejour.30 The weak reliability in classification of trochlear dysplasia according to Dejour on radiographs and on CT and MR images suggest inconsistent treatment planning and a limited comparability of clinical outcomes in studies addressing trochlear dysplasia.

**Tuberosity to the Trochlear Groove Distance**

An increased lateralization of the tibial tubercle in relation to the trochlear groove lateralizes the force vector of the extensor mechanism of the knee. Lateralization of the tibial tubercle in relation to the trochlear groove can be quantified as the TTTG distance. The TTTG distance measurements were initially described on plain radiographs; today the TTTG distance is measured on CT and MR images.31,32 It was shown that an increased lateralized TTTG distance is an important risk factor in lateral patellar dislocations, which may be surgically corrected by an osteotomy and subsequent medial transfer of the tibial tubercle (Figs. 1 and 8).3,5,33–35 Conventional axial radiographs at 30 degrees of knee flexion revealed a large measurement error for the TTTG distance quantification compared with CT images.36 Thus conventional axial radiographs are not appropriate anymore for TTTG distance measurements.36 In contrast, cross-sectional modalities, either CT or MRI, are suitable for measurement of the TTTG distance.32 The following TTTG distance measurement technique is used.
Patellar Tilt

An easy and fast patellar tilt measurement on axial radiographs is the lateral patellofemoral angle, formed by a line between the femoral condyles anteriorly and a line between the margins of the lateral facet of the patella (Fig. 9). The lateral patellofemoral angle was open laterally in 97% and with parallel lines in 3% of 100 normal control patients on axial radiographs with a knee flexion between 20 and 30 degrees. In contrast, the lateral patellofemoral angle was open medially in 20% and with parallel lines in 80% of patients with recurrent symptomatic patellar subluxations.

On transverse CT images, a reference line through the transverse axis of the patella and a line tangential along the femoral condyles posteriorly determine the lateral patellar tilt angle (Fig. 9). The mean lateral patellar tilt angle on transverse CT with the knee in extension without quadriceps contraction was significantly higher in patients with patellar instability (28.8 ± 10.5 degrees) compared with the control group (10 ± 5.8 degrees). Quadriceps contraction increased the lateral patellar tilt by a mean of 6 degrees in patients with patellar instability, whereas the control group demonstrated an increase of 1.5 degrees. The authors suggested a threshold value of 20 degrees for lateral patellar tilt on transverse CT images with the knee in extension without quadriceps contraction. Similar lateral patellar tilt characteristics on transverse CT images with and without quadriceps contraction were noted in further studies.

Thus prominent lateral patellar tilt was assessed as a major anatomical risk factor for patellar instability. Extensor apparatus insufficiency, in particular quadriceps dysplasia and vastus medialis dysplasia, was considered as the etiologic factor of prominent lateral tilt in the past.

However, the current literature has shown that increased lateral patellar tilt is rather a consequence of an increased TTTG distance, patella alta, trochlear dysplasia, insufficient MPFL, and various flexion angles of the femorotibial compartments than an independent anatomical risk factor for patellar instability. In addition, it was hypothesized that a severe knee effusion could increase or diminish patellar tilt. Finally, it has to be noted that a meta-analysis revealed insufficient evidence to determine the reliability, validity, sensitivity, or specificity of lateral patellar tilt as a radiologic assessment parameter for patellar instability.

Medial Patellofemoral Ligament

The MPFL is consistently found in anatomical dissection with a mean width of 1.9 cm and a mean length of 5.3 cm. Most of the MPFL fibers originate close to the adductor tubercle of the femur, distal to the attachment of the adductor magnus tendon and proximal to the origin of the medial collateral ligament.
Anatomical Risk Factors for Patellar Instability

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Torsional Limb Alignment

Thirty patients with a history of recent patellar dislocation demonstrated significant higher mean values compared with asymptomatic volunteers for femoral antetorsion (20.3 ± 10.4 degrees versus 13.0 ± 8.4 degrees), knee rotation (9.4 ± 5.0 degrees versus 5.7 ± 4.3 degrees) and genu valgum (0.81 ± 0.75 mm versus – 0.28 ± 0.87 mm) on MR images. The corresponding tibial torsion values did not differ significantly. In addition, quantitative values for trochlear dysplasia, patellar height, and TTTG distance served for the assessment of standard anatomical risk factors for patellar instability and were compared with the torsional alignment values. These standard anatomical risk factors did not correlate significantly with the obtained torsional alignment parameters. The authors concluded that torsional malalignment might be a so far underestimated primary risk factor in patellar dislocation.

Gender-Specific Differences

Females, in particular between 10 and 17 years of age, have a higher risk for patellofemoral instability. A 33% higher frequency for acute patellar dislocations was reported in female compared with male adolescents with a three times higher risk for recurrent patellar dislocations. The very high pretest probability of 54 to 46% for first-time patellar dislocations, analyzed the distribution of no-risk pivoting activities (e.g., swimming, cycling), low-risk pivoting activities (e.g., hiking, jogging, dancing), and high-risk pivoting activities (e.g., football, basketball, soccer) for first-time patellar dislocations and found significant gender differences. The authors reported that low-risk and no-risk pivoting activities were more frequent in females with first-time patellar dislocations, whereas high-risk pivoting activities were more common in males. The authors also found that trochlear dysplasia and the TTTG distance is more pronounced in women who dislocate the patella compared with men. Thus it was concluded that the more excessive trochlear dysplasia and the higher TTTG distance in female patients with patellar instability might contribute to an increased risk of lateral patellar dislocations for females compared with males.

In contrast, the TTTG distance and the patellar height did not differ significantly between males and females in the overall study population of Balcarek et al consisting of 100 patients with lateral patellar instability and 157 patients without patellar instability (p value = 0.94).

Current Therapeutic Concepts at Our Institution

Patellar instability is multifactorial; thus imaging and therapeutic strategies have to address several anatomical variants in patients with lateral dislocations of the patella. Conservative and operative treatment strategies for patellar instability are highly individual.

Recurrent symptomatic patellar dislocations are much more frequent in patients with previous multiple patellar instability episodes (49%) compared with first-time patellar dislocation patients (17%). Thus a conservative therapy is usually chosen for first-time patellar dislocation patients at our institution. Conservative treatment includes physiotherapy, bracing, weight reduction, and pain medication.

In contrast, recurrent lateral patellar dislocations usually undergo surgical interventions such as MPFL reconstruction, sulcus-deepening trochleoplasty, and distalization and medialization of the tibial tubercle. Lateral retinaculum release or shortening is an uncommon procedure for cases with patellar tilting and the clinically diagnosed severe lateral patellar...
compression syndrome.\textsuperscript{7,14,72} The indication for femoral derotation osteotomy is reserved for rare occasions.\textsuperscript{7,14}

MPFL reconstruction is performed in most of the patients with recurrent patellar dislocations.\textsuperscript{7} Distalization of the tibial tubercle is done in patients with prominent patella alta with a Caton-Deschamps index > 1.3 with a goal index close to 1.0. Medialization of the tibial tubercle is indicated for a TTTG distance ≥ 20 mm.\textsuperscript{3,7,73} A TTTG distance ~12 mm should be achieved postoperatively.

Trochlear dysplasia severe type B and type D have showed a significantly better subjective outcome compared with type A and mild type B.\textsuperscript{14,7} Thus a stricter indication for trochleoplasty was accepted at our institution than is commonly indicated for type D and severe type B trochlear dysplasia and usually not for type A and mild type B.\textsuperscript{14} Type C can be treated by trochleoplasty in cases with relevant dysmorphic changes. Trochleoplasty also lateralizes the sulcus, which indirectly corrects an increased TTTG distance by lowering the lateral vector force of the patellar tendon.\textsuperscript{14} Thus additional medialization osteotomy of the tibial tubercle is less frequently indicated in trochleoplasty patients.\textsuperscript{14}

**Summary**

The most important imaging examinations for the work-up of patients with patellar instability are the true lateral radiograph and transverse CT or MR images of the knee. The pretest likelihood of a torn MPFL on MR images is very high after a lateral patellar dislocation. Increased lateral patellar tilt is rather a consequence of primary anatomical risk factors than an independent anatomical risk factor for patellar instability. Radiologic reports should provide details about the individual and independent main anatomical risk factors for patellar instability such as patella alta, trochlear dysplasia, increased TTTG distance, and torsional limb parameters.

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