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Objective patellar instability: MR-based quantitative assessment of potentially associated anatomical features

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Abstract To evaluate and compare the diagnostic utility of multiple quantitative parameters as measured on knee magnetic resonance (MR) examinations of patients suffering objective patellar instability (OPI). We performed a retrospective evaluation of knee MR examinations in a group of 46 patients (59 knees) with clinically proven OPI, and in a control group of 69 patients (71 knees). Multiple quantitative parameters in both groups were statistically evaluated and compared for their association with OPI. OPI patients tend to present shallower trochlear groove (<5 mm), larger Insall-Salvati index (>1.2), shorter patellar nose (<9 mm), smaller morphology ratio (<1.2), and larger patellar tilt (>11°) than control patients. The best sensitivities were those of the lateral patellar tilt (92.7%), the trochlear groove depth at the roman arch level (85.7%) and the Insall-Salvati index (78%). The best specificities were those of the morphology ratio (86.9%), the patellar nose (84.5%) and the patellar tendon length (84.5%). Shallow trochlear groove may be confidently identified at the roman arch view in OPI patients. Patella alta may be more reliably detected by the Insall-Salvati index in OPI patients. Patellar nose and morphology ratio are very specific indicators of OPI. A short patellar nose (that is to say, a patellar nose ratio of <0.25) has a high association with OPI. Lateral patellar tilt remains the single feature with the highest sensitivity and specificity for identifying OPI patients.

Keywords Knee · Abnormalities · Anatomy · MR · Femur · Dysplasia · Patella

Introduction

Objective patellar instability (OPI) most commonly occurs in young, physically active individuals. Diagnosis of OPI is based on the documented evidence of single or repetitive lateral patellar dislocation. Alternatively, a convincing history of prior patellar dislocation following a suggestive traumatic mechanism should be appropriate for the diagnosis of OPI when effusion, tenderness along the medial retinaculum, or sensation of impending dislocation on manual lateral displacement of the patella are present [6].

It has been suggested that morphological features of the distal femur, proximal tibia and patella may be involved in the pathogenesis of patellar instability and patellofemoral maltracking. There are four main abnormalities: femoral trochlear dysplasia, patella alta, increased lateral patellar tilt, and accentuated tibial tubercle offset [3, 5, 6, 9, 13, 23].

Although radiographs are still valid for initially evaluating OPI, in many practices computed tomography (CT) scans and, in particular, magnetic resonance (MR) imaging are increasingly used [4, 11, 31]. Numerous studies have investigated the value of MR imaging for detecting lesions derived from prior patellar dislocations [14, 17, 30]. The utility of MR imaging for detecting predisposing anatomic features, either quantitatively or qualitatively, has also been addressed [2, 7, 15, 24, 26, 28]. The importance of kinematic MR imaging for evaluating the first phase of knee flexion has been extensively tested, although this is not available in most institutions [22, 29].

Our purpose was to perform a non-kinematic MR-based quantitative anatomical study to evaluate the utility of multiple measurements and indices that may have an association with OPI. We also emphasized on the evaluation of the patellar nose morphology and its related parameters. In this way, we aimed to establish quantitative MR criteria for diagnosing OPI.

Materials and methods

Patients

MR examinations of 59 knees in 46 patients (27 male patients, 32 female patients; mean age, 24 years; age range, 16–45 years) suffering OPI and 71 knees in 69 patients (29 male patients, 40 female patients; mean age, 26.5 yeas; age range, 15–45 years) without anterior knee pain were included in this study. The OPI and control groups were matched for sex and age.

The OPI knees were retrospectively retrieved from the patient population of a dedicated orthopaedic institution during a period of 10 years. Most cases presented with recurrent transient dislocation (>2 episodes). All OPI cases had a firm clinical diagnosis of prior patellar dislocation, documented by reduction in the emergency department or by a convincing history of dislocation associated with the suggestive clinical or radiographical signs. These included tenderness along the medial retinaculum, positive apprehension test or osteochondral fracture on the medial aspect of the patella.

The control cases were consecutively selected from the ordinary referral for knee MR examinations in a university hospital. In all the control cases, anterior cruciate ligament tear, patellofemoral disabilities, fractures or a history of prior surgery were systematically ruled out. Patients with previous history of anterior knee pain were discarded.

Because of the characteristics of the study and in accordance with the research policy of our institution, informed consent and institutional review board approval were not obtained.

MR imaging technique

The MR imaging studies of the 59 selected knees suffering OPI were performed in a 0.5-T imager (General Electric Medical Systems, Milwaukee, WI, USA). A dedicated knee coil was used. The knees were positioned in a minimal flexion (15°) and neutral rotation of the hip. Axial and sagittal spin-echo T1-weighted MR imaging were performed (repetition time millisecond/echo time millisecond, 550/15 ms; field of view, 160×160 mm, two signal acquired; matrix, 204×256; section thickness, 4.0 mm; intersection gap, 0.4 mm).

The MR imaging studies of the 71 control knees were performed in either a 1.5-T (Signa, General Electric Medical Systems) or a 1.0-T imager (Harmony, Siemens Medical Systems, Erlangen, Germany). Dedicated send-receive extremity coils were used, with the knee positioned in almost full extension and neutral rotation of the hip, to obtain several sequences. Slightly different MR protocols were used, although most patients underwent axial spin-echo T1-weighted MR imaging (repetition time msec/echo time msec, 505–550/15–16 ms; field of view, 131×150 mm, 1 signal acquired; matrix, 224×256; section thickness, 4.0 mm; intersection gap, 0.8 mm), or axial gradient-recalled-echo MR imaging (repetition time millisecond/echo time millisecond, 1,100–1,116/17–31 ms; field of view, 160×160 mm, 1 signal acquired; matrix, 184×256; section thickness, 4.0 mm; intersection gap, 0.8 mm, flip angle, 30°); and sagittal fast proton-density-weighted MR imaging (repetition time msec/echo time millisecond, 3,150–3,350/15 ms; field of view, 150×150 mm, 1 signal acquired; matrix, 256×256; section thickness, 4.0 mm; intersection gap, 0.8 mm). When available, axial gradient-recalled-echo MR imaging was preferred to axial T1-weighted MR imaging.

Analysis of MR images

Multiple parameters were quantitatively assessed on the knee MR imaging studies of all selected patients. MR examinations were retrospectively analyzed on film hard-copies by a senior orthopaedic surgeon who was blinded to the initial MR imaging interpretations and clinical charts. The knee MR examinations belonging to both groups of patients were randomly mixed for imaging review. Various categories of quantitative parameters were evaluated in a single measurement using rulers, scales, squads and a hand-held goniometer. Where necessary, the contour of the articular cartilage was systematically used as the reference plane [33, 34].

Several quantitative parameters were evaluated in a midsagittal oblique MR section, which was defined as the MR image in which the deepest point of the trochlear groove could be seen. This MR section was selected using the information provided by cross-referenced axial MR images. The midsagittal MR section most commonly corresponded to the MR section where the anterior cruciate ligament was completely visualized. In those patients with lateralized patella, an MR section lateral to the midsagittal section was used. Among the quantitative parameters evaluated in the sagittal MR sections were the ventral trochlear prominence (VTP) [6], the intercondylar distance (ID) [6], the ventral trochlear prominence ratio (VTPR) [6], the patella-tibia distance (PTD) [3], the craniocaudal patellar facet (CPF) [3], the Caton-Deschamps index (CDI) [3], the patellar tendon length (PTL) [12], the craniocaudal patellar distance (CPD) [12], the Insall-Salvati index (ISI) [12], the patellar nose (PN) [10], the patellar nose ratio (PNR) [10], the morphology ratio (MR) [10], the patellofemoral contacting surface (PCS) [24], and the patellofemoral contacting surface ratio (PCSR) [24] (Fig. 1, Table 1).

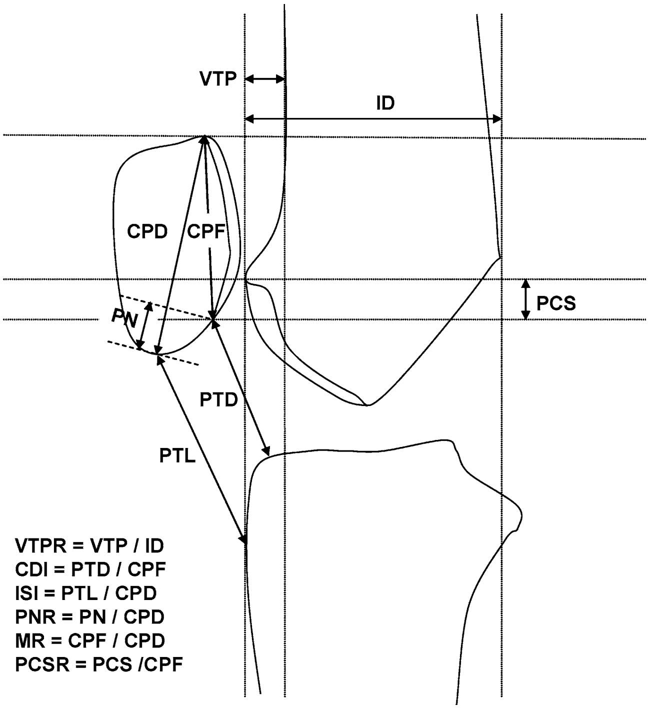

Fig. 1 Diagram of measurements and indexes obtained in a midsagittal MR image, including the ventral trochlear prominence (*VTP*), the intercondylar distance (*ID*), the ventral trochlear prominence ratio (*VTPR*), the patella-tibia distance (*PTD*), the craniocaudal patellar facet (*CPF*), the Caton-Deschamps index (*CDI*), the patellar tendon length (*PTL*), the craniocaudal patellar distance (*CPD*), the Insall-Salvati index (*ISI*), the patellar nose (*PN*), the patellar nose ratio (*PNR*), the morphology ratio (*MR*), the patellofemoral contacting surface (*PCS*), and the patellofemoral contacting surface ratio (*PCSR*)

Several quantitative parameters were also evaluated in the axial plane. Two basic MR sections were used for these measurements, which included the section through the most cranial aspect of the trochlear groove (that in which the articular cartilage was first visualized on both trochlear facets), and the plane in which the intercondylar tunnel was visualized with the semi-circumferential shape of a roman arch. The quantitative parameters assessed in these two axial MR sections were the lateral condyle distance (LCD1, LCD2) [16], the medial condyle distance (MCD1, MCD2) [16], the trochlear groove distance (TGD1, TGD2) [16], the trochlear groove depth (TGDE1, TGDE2) [16, 22, 28], and the lateral trochlear inclination (LTI1, LTI2) [2, 7]. Finally, using a proximal axial MR section (the one in which the widest transverse diameter of the patella was seen, most commonly coincident with that in which the articular cartilage was first visualized on both trochlear facets), the lateral patellar tilt (LPT) [8, 18, 27, 29] was measured (Fig. 2a, b; Table 1).

The search for bone and soft tissue abnormalities deriving from the prior episodes of subluxation and dislocation was omitted, as this was not the purpose of the study.

Statistical analysis

All the quantitative parameters assessed in both groups of patients were evaluated and compared for their association with OPI. For descriptive analysis, the quantitative parameters were evaluated by calculating the mean value and range. The categorical parameters consisted of absolute and relative frequencies. The most suitable threshold values were calculated by univariant logistic regression analysis. The sensitivity, specificity and *P* value for all the calculated threshold values were determined. The level of accepted statistical significance was $P <$ or $=$ 0.05. The quantitative parameters of both groups were compared by using the Student *t* test. The categorical parameters of both groups were compared by using the Chi-square test. The association of selected parameters with OPI was investigated by using multivariant logistic regression analysis, in order to calculate their odds ratios. The diagnostic utility of the Caton-Deschamps or Insall-Salvati indexes in association with the patellar nose was also investigated by using multivariant logistic regression analysis. Statistical analyses were performed with commercially available software, including SPSS 6.1 (SPSS, 1990) and BMDP 8.1 (Dixon, 1991).

Results

Table 2 summarizes the mean values and ranges of all the quantitative parameters evaluated in both groups of

Table 1 Quantitative parameters

Quantitative parameters and indexes measured and calculated in the midsagittal MR sections[a]	
Ventral trochlear prominence (VTP)	Distance between the line tangential to the anterior femoral cortex and its parallel line tangential to the most ventral point of the trochlear groove [6]
Intercondylar distance (ID)	Distance between the line tangential to the most ventral point of the trochlear groove and its parallel line tangential to the most posterior aspect of the intercondylar roof [6]
Ventral trochlear prominence ratio (VTPR)	VTP/ID [6]
Patella-tibia distance (PTD)	Distance between the inferior aspect of the patellar articular surface and the most anterior aspect of the intercondylar eminence [3]
Craniocaudal patellar facet (CPF)	Craniocaudal length of the patellar articular surface [3]
Caton-deschamps index (CDI)	PTD/CPF [3]
Patellar tendon length (PTL)	Length of the patellar tendon, measured following the reference plane that is tangential to the posterior aspect of the tendon [12]
Craniocaudal patellar distance (CPD)	Longest craniocaudal longest dimension of the patella [12]
Insall-Salvati index (ISI)	PTL/CPD [12]
Patellar nose (PN)	Distance between the inferior patellar pole and the perpendicular line traversing the most inferior aspect of the patellar articular surface [10]
Patellar nose ratio (PNR)	PN/CPD [10]
Morphology ratio (MR)	CPF/CPD [10]
Patellofemoral contacting surface (PCS)	Distance between a horizontal line tangential to the most ventral point of the trochlear groove and its parallel tangential to the most distal aspect of the patellar articular surface [24]
Patellofemoral contacting surface ratio (PCSR)	PCS/CPF [24]
Quantitative parameters measured in axial MR sections	
Lateral condyle distance LCD[b, c]	Distance between the lines tangential to the most posterior and anterior aspects of the lateral femoral condyle [16]
Medial condyle distance (MCD)[b, c]	Distance between the lines tangential to the most posterior and anterior aspects of the medial femoral condyle [16]
Trochlear groove distance (TGD)[b, c]	Distance between the lines tangential to the deepest aspect of the trochlear groove and tangential to the most posterior aspect of both femoral condyles [16]
Trochlear groove depth (TGDE)[b, c]	LCD [1, 2] – TGD [1, 2] [16, 22, 28]
Lateral trochlear inclination (LTI)[b, c]	Angle formed by the lines tangential to the lateral trochlear facet and tangential to the posterior aspect of both femoral condyles [2, 7]
Lateral patellar tilt (LPT)[d]	Angle formed by the lines tangential to the longest transverse dimension of the patella and tangential to the most posterior aspect of both femoral condyles [29]

[a]In those patients with lateralized patella, an MR section lateral to the midsagittal section was used for some of the measurement
[b]Measured where the most cranial aspect of the cartilaginous trochlear groove could be seen
[c]Measured where the intercondylar tunnel was visualized as a roman arch
[d]Measured where the widest diameter of the patella could be seen [9]

patients, as well as their most appropriate cut-off values, and their resulting sensitivities, specificities and p values. The sensitivities of the lateral patellar tilt, the trochlear groove depth at the roman arch view, and the Insall-Salvati index were 92.7, 85.7, and 78%, respectively. The specificities of the morphology ratio, the patellar nose and the patellar tendon length were 86.9, 84.5 and 84.5%, respectively.

The reliability of various associations of quantitative parameters for diagnosing OPI was evaluated. A total of 33 OPI knees (60%) were positive for the Caton-Deschamps index and the patellar nose. The combination of these two parameters reached a sensitivity of 88% and a specificity of 82%, an improvement on the 69.5 and 60.6% obtained by the index alone. A total of 43 OPI knees (73%) were positive for the Insall-Salvati index and the patellar nose. The combination of these two parameters reached a sensitivity of 81.4% and a specificity of 83%, an improvement on the 78.0 and 67.6% obtained by the index alone.

Multivariant logistic regression analysis was used to assess the association of selected parameters with OPI by calculating their corresponding odds ratio. The parameters which showed the strongest associations with OPI were the lateral patellar tilt (odds ratio 8.7) and the trochlear groove depth measured at the roman arch axial view (odds ratio 7.7). The patellar nose ratio (odds ratio 4.7) and the Insall-Salvati index (odds ratio 4.5) also showed a strong association with OPI (Fig. 3).

Discussion

In our study, all the knee MR studies were performed in complete extension or minimal degree of flexion. This is believed to be important, as the congruence of the

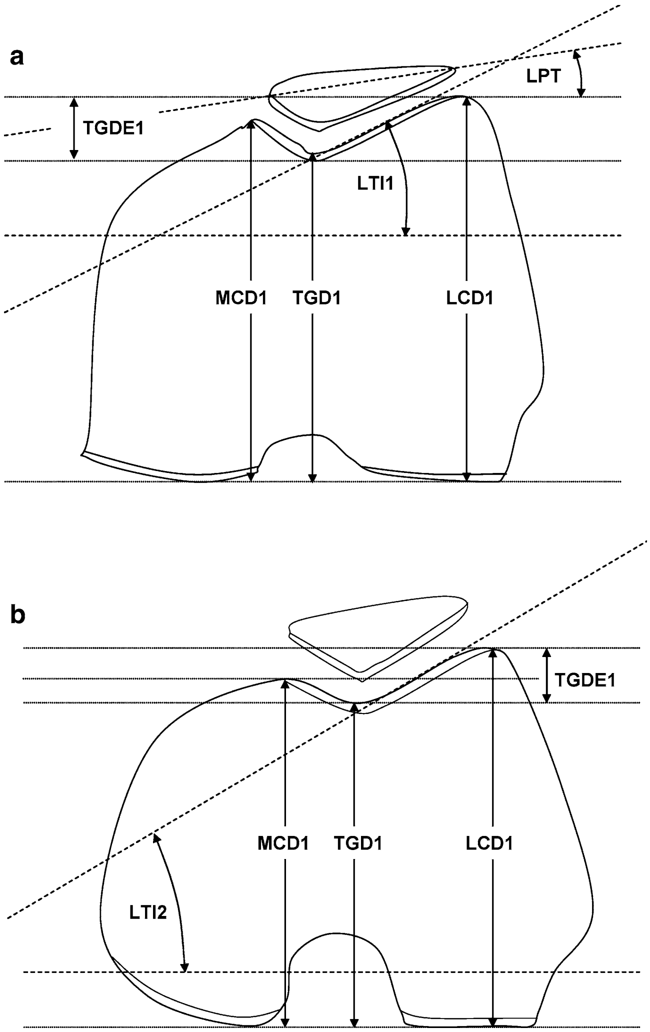

Fig. 2 a, b Diagram of parameters measured in the axial MR sections through the most cranial aspect of the femoral trochlea (**a**) and through the ''Roman arch'' section (**b**), including the lateral condyle distance (*LCD1*, *LCD2*), the medial condyle distance (*MCD1*, *MCD2*), the trochlear groove distance (*TGD1*, *TGD2*), the trochlear groove depth (*TGDE1*, *TGDE2*), the lateral trochlear inclination (*LTI1*, *LTI2*) and the lateral patellar tilt (*LPT*)

proximal aspect of the patellofemoral joint is considered the crucial zone for patellar maltracking [15, 25, 35].

Whenever possible, the distances, angles and indexes were obtained using reference lines tangential to the chondral surfaces. As suggested by Staubli et al. [33, 34] this may be crucial, as the chondral surface of the trochlear groove and patellar facets do not coincide with the contour of the subchondral bone.

Femoral trochlear dysplasia is believed to be the most important anatomic predisposing factor in patellar instability and patellofemoral maltracking. It is still difficult to diagnose radiographically because optimal positioning is difficult and because the chondral surfaces are ignored [6, 18]. In view of these limitations, MR imaging has been proposed for diagnosing femoral trochlear dysplasia [25, 32]. A quantitative MR-based diagnosis of femoral trochlear dysplasia may consider evaluating the ventral trochlear prominence, the femoral trochlear groove depth, and the lateral trochlear inclination [5, 28, 33].

In our study, the ventral trochlear prominence averaged 4.8 mm in OPI knees (Fig. 4a) and 4.2 mm in control knees. The resultant cut-off value, >4 mm, was found to be statistically significant, and is close to the admitted radiographic threshold, which is >3 mm [5]. This difference may reflect the inclusion of chondral thickness in our measurements. Less likely, it may result from the slight obliquity in which the sagittal MR section was obtained. In another MR-based study, Pfirrmann et al. [28] found a cut-off value of >6.9 mm to be useful for diagnosing trochlear dysplasia. This discrepancy may reflect the differences in the inclusion criteria, while we focused on patients suffering OPI, Pfirrmann et al. [28] chose to study patients with femoral trochlear dysplasia, whether they had suffered patellar dislocation or not. In any case, the diagnostic value or the ventral trochlear prominence for predicting OPI, according to our own data, seems to be relatively low.

In our population, the trochlear groove depth averaged 3.3 mm in the proximal view and 4.2 mm in the distal view in OPI patients (Fig. 4c). In a previous MR-based study [28], the average proximal trochlear groove depth (3 cm above the joint line) was −0.6 mm, and 3.6 on a more distal axial view (2 cm above the joint line). The discrepancy may reflect the different MR sections selected and our own difficulties in making accurate measurements in the uppermost section where the trochlear cartilage was visible. Nevertheless, our data suggest that the trochlear groove in OPI patients is shallower on its cranial aspect, as previously demonstrated [33, 34]. In addition, we found that the sensitivity and specificity of the femoral trochlear depth are greater at the roman arch level than in a more cranial axial view, which probably reflects the greater reliability of the lower measurements.

In our study, the proximal aspect of OPI patients' lateral trochlear facet was more horizontally oriented (Fig. 3c). We found $<12°$ to be an adequate threshold value for discriminating OPI. In a study performed on 30 patients suffering OPI [2], the most appropriate threshold value was $<11°$. However, the range of values obtained in our two groups of patients was significantly wide. As stated by Elias et al. [7] measurement of the lateral trochlear facet inclination may not be entirely reliable, due to difficulties in identifying the most superior transverse image in which the trochlear cartilage is visible. Our results also indicate that measuring the lateral trochlear inclination at the roman arch view is not a reliable test for identifying OPI.

Table 2 All distances are expressed in millimeters. All angles are expressed in degrees. Sensitivity and specificity are expressed in percentages

	OPI patients		Control patients		Cut- off value	Sensitivity	Specify	*P*
	Average	Range	Average	Ranges				
VTP	4.8	0.8–8.9	4.2	1.7–7.3	> 4 mm	67.8	52.1	0.0346
ID	41.4	33.5–52.0	40.4	30.0–54.5	–	52.5	59.2	0.1278
VTPR	0.11	0.02–0.21	0.10	0.04–0.19	–	64.4	49.3	0.1243
PTD	36.9	25.0–48.3	31.9	23.3–44.0	> 34	71.2	73.2	0.0001
CPF	32.2	25.0–46.7	30.1	29.2	> 31	59.3	59.2	0.0016
CDI	1.16	0.71–1.60	1.07	0.77–1.43	> 1.1	69.5	60.6	0.0010
PTL	51.8	34.3–70.0	44.4	21.8–61.4	> 50	52.5	84.5	0.0001
CPD	39.1	26.7–55.7	40.3	26.0–54.5	–	42.4	40.8	0.1173
ISI	1.35	0.85–2.20	1.11	0.60–2.10	> 1.2	78.0	67.6	0.0001
PN	7.8	0.8–14.3	11.9	4.0–21.7	< 9	66.1	84.5	0.0001
PNR	0.20	0.02–0.36	0.3	0.15–0.56	< 0.25	74.6	66.2	0.0001
MR	1.22	0.70–1.69	1.35	0.81–2.14	< 1.2	44.1	86.9	0.0010
PCS	8.3	1.7–16.0	8.1	0.9–16.7	–	35.6	57.7	0.9664
PCSR	0.27	0.05–1.00	0.27	0.02–0.50	–	35.6	53.5	0.5572
LCD1	66.8	48.6–80.0	68.4	58.5–86.0	–	47.2	41.9	0.4130
LCD2	69.0	54.3–8.7	69.2	47.7–90.0	–	60.7	51.7	0.9339
MCD1	63.9	44.3–78.3	64.8	53.8–80.0	–	52.8	44.2	0.7148
MCD2	66.1	48.6–78.3	66.4	46.1–86.0	–	44.6	56.7	0.9934
TGD1	63.5	42.9–78.3	62.1	49.2–78.0	–	49.1	53.5	0.1806
TGD2	64.7	47.1–78.3	63.0	43.1–80.0	–	48.2	70.0	0.0803
TGDE1	3.3	−1.6/8.3	5.3	1.7–11.4	< 4	77.4	60.5	0.0001
TGDE2	4.21	1.2–13.3	6.4	2.9–10.0	< 5	85.7	71.7	0.0001
LTI1	9.6	0.0–23.0	16.5	7.0–30.0	< 12	71.2	76.7	0.0001
LTI2	12.5	1.0–24.0	18.0	3.0–32.0	< 14	62.5	71.7	0.0001
LPT	21.7	2.0–45.0	9.2	0.0–20.0	> 11	92.7	63.3	0.0001

Patella alta is another major predictor of OPI (Fig. 4a). In our study, we evaluated the height of the patella by measuring the patella–tibia distance or the patellar tendon length, and by calculating the Caton-Deschamps index and the Insall-Salvati index [3, 13].

In our study, the patellar tendon was significantly longer in OPI knees. At a threshold value of > 50 mm, the patellar tendon length reached a sensitivity of 52.5%

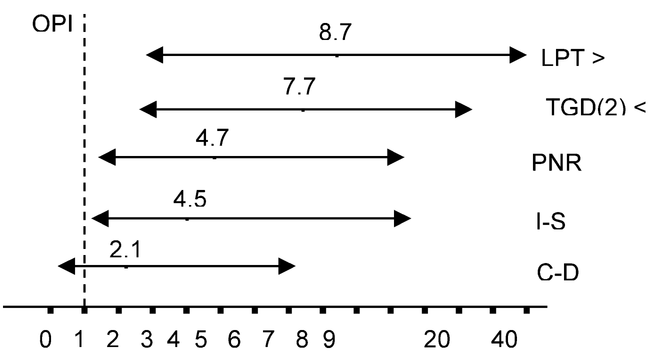

Fig. 3 The odds ratio of several parameters are displayed. The parameters with the strongest associations with OPI were the lateral patellar tilt (odds ratio 8.7) and the trochlear groove depth measured at the roman arch axial view (odds ratio 7.7). The patellar nose ratio (odds ratio 4.7) and the Insall-Salvati index (odds ratio 4.5) also showed a strong association with OPI

and a specificity of 84.5% for predicting OPI. This is in accordance with the previous studies [16, 24, 26], although the resulting sensitivity is lower than expected.

The Caton-Deschamps index evaluates the height of the patellar articular facet independently of the patellar tendon length. In our study, the Caton-Deschamps index was slightly larger in OPI knees. At a most appropriate threshold value of > 1.1, the Caton-Deschamps index reached a sensitivity of 69.5% and a specificity of 60.6%. Our results are similar to those obtained by Neyret et al. [26], who first proved the feasibility of the Caton-Deschamps index in MR imaging. However, they found that the patellar tendon length was more sensitive at predicting OPI, while we found that the Caton-Deschamps index is superior to the patellar tendon length in this regard.

The Insall-Salvati index was originally conceived as a radiographic indicator of patellar height independent of the degree of knee flexion and of the individual's constitution. In our study, the Insall-Salvati index was slightly larger in OPI knees. At a most appropriate threshold value of > 1.2, the Insall-Salvati index reached a sensitivity of 78% and a specificity of 67.6%. Our results are in accordance with those obtained by Miller et al. [24], who first proved the feasibility of the Insall-Salvati index in MR imaging, and with those of Elias et al. [7]. By using multivariant logistic regression anal-

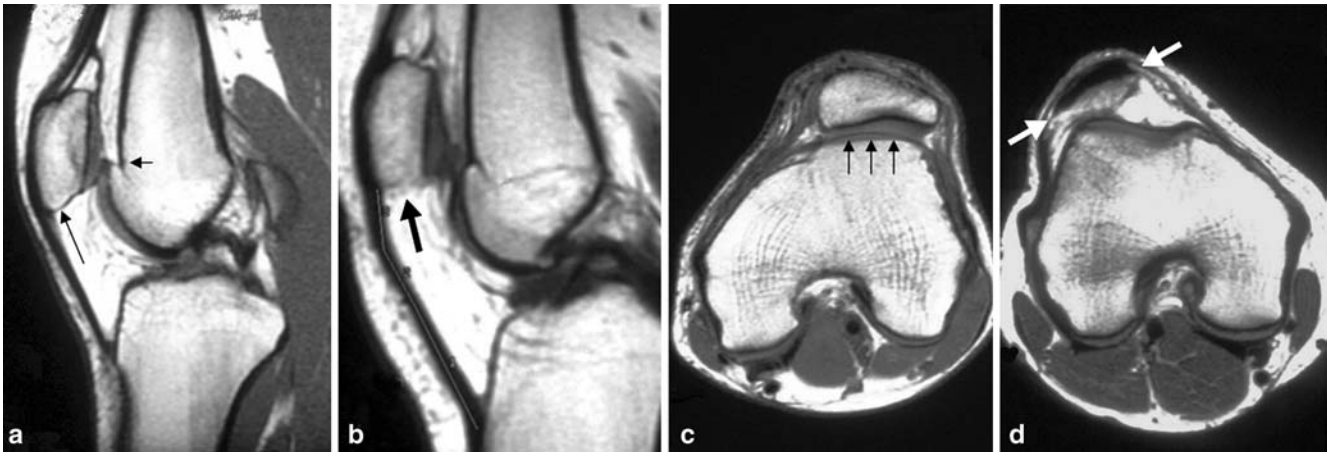

Fig. 4 MR imaging in four different patients suffering OPI. **a** Sagittal T1-weighted image reveals patella alta (*long arrow*) and positive ventral trochlear prominence (*short arrow*). **b** Sagittal T1-weighted image reveals a short patellar nose (*arrow*). **c** Axial T1-weighted image shows a shallow (*almost convex*) trochlear groove (*arrows*). **d** Axial T1-weighted image shows marked lateral patellar tilt (*arrows*)

ysis, we also found the Insall-Salvati index to have a more statistically significant association with OPI (odds ratio: 4.5) than the Caton-Deschamps index (odds ratio 2.1). Therefore, in our MR-based study, the Insall-Salvati was a more reliable indicator of patella alta than the Caton-Deschamps index, thus enabling better prediction of OPI.

Initial concern about the relevance of the patellar shape focused on variations in the retropatellar surface as seen on axial radiographs [36]. However, variations in patellar size and shape as seen on a lateral view have also been studied. Grelsamer et al. [10] suggested that the conventional Caton-Deschamps and Insall-Salvati indexes may only be useful for determining the existence of patella alta in patients with type 1 patella. However, in those patients with large patellar nose (patella type 2) and short patellar nose (patella type 3), these indexes may fail to detect abnormal values.

In our study, we found that OPI patients tend to have shorter patellar nose (<9 mm), smaller patellar nose ratio (<0.25) and smaller morphology ratio (<1.2). Forty six percent of OPI patients showed a short patellar nose (type 3), which was only present in 14% of the control group. In our MR-based study, the patellar nose ratio reached an acceptable sensitivity (78%), while the morphology ratio and the patellar nose reached the greatest specificities (86.9 and 84.5%, respectively). In other words, patients showing a large patellar nose in a midsagittal MR section are unlikely to suffer OPI. Conversely, patients with short patellar nose (especially those whose patellar nose ratio is <0.25) may be considered to have a dysplastic patellar morphology with a strong association with OPI. We wish to emphasize the importance of the patellar nose and patellar nose ratio, the specificities of which are higher than those of the Insall-Salvati index.

Also following Grelsamer's [10] suggestions, we aimed to evaluate the diagnostic value of the Caton-Deschamps and Insall-Salvati indexes in association with the patellar nose. In our study, the combination of positive Caton-Deschamps index (>1.1) and short patellar nose (<9 mm) reached a sensitivity of 88% and a specificity of 82%, an improvement on the data obtained by the Caton-Deschamps index as a separate parameter. What is more, the combination of positive Insall-Salvati index (>1.2) and short patellar nose reached a sensitivity of 81.4% and a specificity of 83%, which also improved individual data. Therefore, the Caton-Deschamps and Insall-Salvati indexes were more sensitive and specific in those patients with short patellar nose. The greater improvement in sensitivity obtained by the association of a short patellar nose and a positive Caton-Deschamps index seem to reflect the fact that the Caton-Deschamps per se ignores the contour of the patellar nose.

In our study, a lateral patellar tilt >11° reached the highest sensitivity for predicting OPI (92.7%). Our results are in agreement with previously published data by Ward et al. [35], who found a good sensitivity for a threshold value of 13.5°. In a kinematic MR study [29], Powers found that the lateral patellar tilt is highly dependent on the degree of knee flexion. Because of the different patient populations and methodological aspects, it is difficult to compare our results with those from the previous studies.

The other parameters assessed in our study did not reveal any statistically significant association with OPI, and may thus be obviated in the routine assessment of knee MR examinations.

According to our results, different anatomical variations and possibly biomechanical abnormalities may be present in OPI knees. In our study, consisting of 59 OPI knees from 46 patients, shallow trochlear groove, increased lateral patellar tilt and patella alta only coexisted in one patient. However, the predisposing role of each anatomical parameter remains unclear. The fact that a number of anatomical variations may be found in OPI patients does not mean that these features are the cause of the instability in all cases. They indeed may even be the consequence of such instability.

Given the potentially multifactorial nature of OPI, the role of quantitative MR imaging may be that of identifying the specific geometrical predisposing factors that are involved for each patient. If it can do this, quantitative MR imaging may prove useful in the preoperative evaluation of OPI. For adequate management of OPI patients, various treatment options may be considered. If a patella alta is present, a patellar descent may be indicated. If the trochlear groove is shallow, a trochleoplasty may be performed [1, 20]. If the lateral patellar tilt is especially accentuated, a plastia of the vastus medialis may prove useful [12, 27]. Finally, in those individuals with marked lateral patellar offset, the tibial tubercle should be medially reinserted [9].

We are aware that our study has several drawbacks. The investigation was retrospective, partly reflecting the difficulties in gathering a large group of true OPI patients. Because of its retrospective nature, three different MR units and slightly different protocols were used, although a minimum of homogeneity in all the studies was assured. In addition, no gradient-echo 3D-sequence was used. The lack of thin contiguous slices may have negatively influenced the identification of cartilage at the proximal trochlea and the accuracy of some measurements in the axial view. In addition, intra and interobserver variability could not be calculated, and the technology used was not digital. While this may have diminished the reproducibility of the test, we wish to emphasize that many of our results are in agreement with those of some previously published studies. Finally, our inclusion criteria may have resulted in a selection bias, which may difficult the extrapolation of results to the general population potentially exposed to incidental traumatic patellar dislocation. In this regard, consideration to damaged medial retinaculum may add value to future prospective studies, given the fact that some OPI patients may not have any of the associated anatomical features that we evaluated.

In conclusion, non-kinematic MR-based quantitative assessment may enable to identify anatomical features associated with OPI to be recognized. Objective patellar instability patients tend to present shallower trochlear groove, which may be confidently evaluated at the roman arch view. Objective patellar instability patients tend to present patella alta, which may be more reliably detected with the Insall-Salvati index. The patellar nose and the morphology ratio are very specific indicators of OPI. We wish to emphasize that a short patellar nose (one with a patellar nose ratio of <0.25) may be considered dysplastic and has a remarkable association with OPI. Finally, the lateral patellar tilt is still the single most sensitive parameter for identifying OPI. Owing to the potentially multifactorial nature of OPI and to the variability of available surgical approaches, the contribution of an MR-based quantitative assessment may be most efficient in the pre-operative planning of these patients by identifying a determinant anatomical feature.

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