Orthopaedics & Traumatology: Surgery & Research (2013) 99S, S391—S398

Available online at
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com/en

ORIGINAL ARTICLE

The introduction of a new MRI index to evaluate sagittal patellofemoral engagement

D. Dejour[a,*], P. Ferrua[a], P.G. Ntagiopoulos[a], C. Radier[b], C. Hulet[c], F. Rémy[d], J. Chouteau[e], F. Chotel[f], P. Boisrenoult[g], A. Sebilo[c], S. Guilbert[h], D. Bertin[i], F.-P. Ehkirch[b], V. Chassaing[b], the French Arthroscopy Society (SFA)[j]

[a] *Clinique de la Sauvegarde, bâtiment Trait-d'union allée B, 29, avenue des Sources, 69009 Lyon, France*
[b] *Clinique Maussins-Nollet, 67, rue de Romainville, 75019 Paris, France*
[c] *Service d'orthopédie, CHU de Caen, avenue de la Côte-de-Nacre, 14033 Caen cedex 9, France*
[d] *Clinique de Saint-Omer, 71, rue Ambroise-Paré, 62575 Blendecques, Pas-de-Calais, France*
[e] *Cabinet de chirurgie orthopédique et de chirurgie du sport (Le Périclès B), allée de la Mandallaz, 74370 Metz-Tessy, Haute-Savoie, France*
[f] *Hopital universitaire Femme-Mère—Enfant de Lyon, 59, boulevard Pinel, 69677 Bron, Rhône, France*
[g] *Service d'orthopédie, centre hopsitalier de Versailles, 177, rue de Versailles, 78150 Le Chesnay, France*
[h] *Pôle santé Oréliance, 551, avenue Jacqueline-Auriol, 45770 Saran, France*
[i] *Centre médical Château-Galland, 33, chemin des Tilleroyes, 25000 Besançon, Doubs, France*
[j] *Cabinet médical, 18, rue Marbeuf, 75008 Paris, France*

Accepted: 9 October 2013

KEYWORDS
Patellofemoral engagement;
Patellar instability;
MRI

Summary
Introduction: Patella alta is one of the primary factors of patellofemoral instability and its importance lies in the reduced engagement between patella and trochlea during the early degrees of flexion. The evaluation of patellar height is based on conventional x-rays, CT scan and, more recently, MRI. The objective of this multicentric prospective study is to describe a novel index to assess in the sagittal plane the functional engagement between patella and trochlea.
Materials and methods: One hundred and thirty-five patients with objective patellar dislocation were prospectively enrolled between April 2010 and September 2011 and were compared with a second group of 45 controls. All patients underwent a standard MRI and a complete radiographic study. Sagittal engagement was measured as the ratio between the articular cartilage of the patella and the trochlear cartilage length measured on two different MRI slices.

* Corresponding author.
E-mail address: corolyon@wanadoo.fr (D. Dejour).

1877-0568/$ - see front matter
http://dx.doi.org/10.1016/j.otsr.2013.10.008

Results: The mean Sagittal Patellofemoral Engagement (SPE) index was 0.43 ± 0.18 and ranged from 0.02 to 0.913 in the Objective Patellar Dislocation group versus 0.42 ± 0.11 range 0.22 to 0.55 in controls. In the Patellar Dislocation group the mean Caton-Deschamps index was 1.18 ± 0.21 (range 0.71 to 1.91). There were 58 patients with patella alta, in whom the mean SPE was 0.39 ± 0.18 (range 0.02 to 0.87). Sagittal engagement was significantly higher when compared with patients in the Patellar Dislocation group who had no patella alta (mean 0.46 ± 0.16, range 0.1—0.913).
Discussion: The present study introduces a new method to measure the SPE with the use of MRI. The evaluation of the functional engagement of the patella with the femoral trochlea in the sagittal plane can serve as a supplementary tool to the existing methods of evaluating patellar height, and may help to better identify the cases where inadequate engagement is recorded despite the absence of patella alta, so that the need for tibial tuberosity osteotomy may be re-assessed.
Level of evidence: Level 3.

Introduction

Increased patellar height (patella alta) is a key factor causing patellar instability and is present in 30% of patients with recurrent patellar dislocation [1]. The importance of increased patellar height in the study of patellofemoral (PF) disorders lies on the reduced ''engagement'' between the two articulating bones: the patella and the femoral trochlea, which is necessary to provide to the patella the required mechanical stability throughout the range of motion [2]. Evaluation of patellar height in PF disorders is predominately based on imaging, such as x-rays [3—5] and computed tomography (CT) scan [1,6,7]. The combination of plain radiography and CT scans also provides a three-dimensional evaluation of the joint and allows surgeons to make reliable measurements and to give an objective definition of the underlying abnormalities (trochlear dysplasia, increased trochlear groove — tibial tuberosity distance (TT-TG), and patellar tilt) and compare them to their published thresholds [1,8—10].

More recently, magnetic resonance imaging (MRI) gained popularity in the imaging of PF disorders, due to its superiority in the evaluation of associated cartilage defects and ligamentous anatomy [11—13], such as the medial patellofemoral ligament rupture [14—17] and the aspect of the lateral retinaculum. The reproducibility of radiologic and CT cutoff values has been tested on MRI [16—25], often highlighting incongruences [26], while additional MRI thresholds or new imaging parameters have been described [14,15,27—29]. Several authors have focused on the study of the sagittal position of the patella with the use of MRI or have introduced novel MRI measurements for patients with PF disorders. This is mainly due to the fact that the existing traditional methods of measuring patellar height [3—5,30] use bony and not cartilaginous landmarks, and because the different variations on the morphology of the PF joint, such as small patellar articular surface or a short trochlea, are not well represented in these indexes [29,31,32].

The use of the MRI in the evaluation of PF disorders and the introduction of new imaging methods started with Carillon et al., who presented the ''lateral inclination index'' of less than 11° as a feature observed in patients with patellar dislocation [14]. Neyret et al. found that the insertion of the patellar tendon is a constant value and in patients with patellar dislocation and patella alta, the patellar tendon length was more than 53 mm [27]. Lippacher et al. found that the classification of trochlear dysplasia in 4 distinguished types can be reproduced with the use of MRI [19]. Biedert et al. set the ''lateral condyle index'' by measuring the ratio of the anterior cartilaginous trochlear length to the posterior aspect of the lateral femoral condyle in MRI, and found it reduced in patients with patellar dislocation [15]. They also focused on the proximal extension of the dysplastic trochlea and found a new type of dysplasia where the trochlear is ''too short'' and is not extending proximally enough in order to engage with the patella [15]. Biedert and Albrecht described another MRI method for evaluating the relationship between the patella and the trochlea and for assessing patellar height using MRI: the ''patellotrochlear index'' [29]. This is a ratio between the maximum length of patellar articular cartilage and the length of trochlear articular cartilage, that Barnett et al. found it significantly lower in patients with PF disorders (15%) than in controls (32%) [33].

All these data, along with numerous other measurements obtained with MRI in patients with PF disorders [16,17], show the need to better identify pathological values of anatomic features and to better describe PF morphology in patients and controls. It is well known that during early flexion, the patella must be positioned anteriorly to the trochlea and so that it is introduced and ''engaged'' into a deep groove in order to avoid lateral dislocation [2,9,10]. Factors that influence this ideal ''functional engagement'' between the two articulating bones have been described separately: patella alta, trochlear dysplasia, increased patellar tendon length or a trochlea that does not extent sufficiently proximally. The study of an imaging feature that describes this ''functional engagement'' of the patella with the trochlea in the sagittal plane is new in the literature. The purpose of this study is to introduce and describe a novel imaging parameter using two different static MRI views on the sagittal plane to assess and measure the patellar position regarding the trochlea. The authors tested the hypothesis that this new index could be a useful tool to evaluate and quantify the articular patellar engagement in the trochlea on the sagittal plane, and could further identify the cases where the patella is engaged in the trochlea from the cases that the patella is not engaged. Furthermore, this new method of measuring

sagittal engagement on MRI could act as an additional tool for radiologic methods that are already in use, such as the ''patellotrochlear index'', which is not possible to measure if the patella is positioned lateral to the trochlea.

Materials and methods

This is a multicentre prospective study that took place between April 2010 and September 2011, and involved 9 different institutions affiliated with the French Arthroscopic Society (SFA). The study was approved by the hospitals' Ethical Committees. Two distinctive groups were set: the first group consisted of patients with a history of more than 2 episodes of documented lateral patellar dislocation (Objective Patellar Dislocation) and no previous knee surgery. A second group of patients undergoing MRI for a isolated meniscus tear without any history of PF disorder, knee surgery, anterior knee pain or patellar dislocation was set (Control). Exclusion criteria for both groups were the presence of femoro-tibial, PF arthritis or ligament injuries.

All patients underwent a standard non-weight bearing MRI (1.5 Tesla) with the knee close to full extension, and 2-mm sagittal cuts were made. MRI measurements were performed using Osirix® freeware DICOM viewer (www.osirix-viewer.com). All patients had also conventional monopodal weight bearing x-rays including anterior-posterior view, lateral x-rays with the posterior femoral condyles superimposed with the knee flexed at 30° and lateral x-rays in full extension, and axial views at 30° of flexion. Patellar height was measured using the Caton-Deschamps Index [4].

Sagittal Patellofemoral Engagement (SPE) Index measurement

The previously published method of ''patellotrochlear index'' of Biedert and Albrecht [29] measures the sagittal position of the patella, but there is a key limitation of the method because by measuring both patella and trochlea in a single slice, this index is not always measurable in cases of dislocated patella, [33]. In the present method, two distinctive sagittal cuts were selected because of the different and inconsistent position of the patella in the axial plane in patients with patellar dislocation and in controls. The first cut was the sagittal MRI section where the patella showed the longest articular cartilage. On this image, a patellar length (PL) line was drawn, that measured the entire length of the patellar articular cartilage (Fig. 1). The second cut was the sagittal section where the femoral trochlear cartilage extended more proximally. On this slice, the PL line that had been copied, wasinserted (Fig. 2). A second line was then drawn parallel to the PL, which started from the most proximal articular trochlear cartilage and finished at the distal end of the PL, providing the Trochlear Length (TL) line (Fig. 3). The SPE was calculated as the ratio between TL and PL. Patellar tendon length was also measured in sagittal MRI slices. All MRI measurements were performed by the different teams involved in the multicentre study. The control group was measured by two senior orthopaedic surgeons independently.

Figure 1 For the measurement of the Sagittal Patellofemoral Engagement (SPE) Index, the first cut is where the patella shows its largest sagittal articular cartilage. The patellar length (PL) is measured.

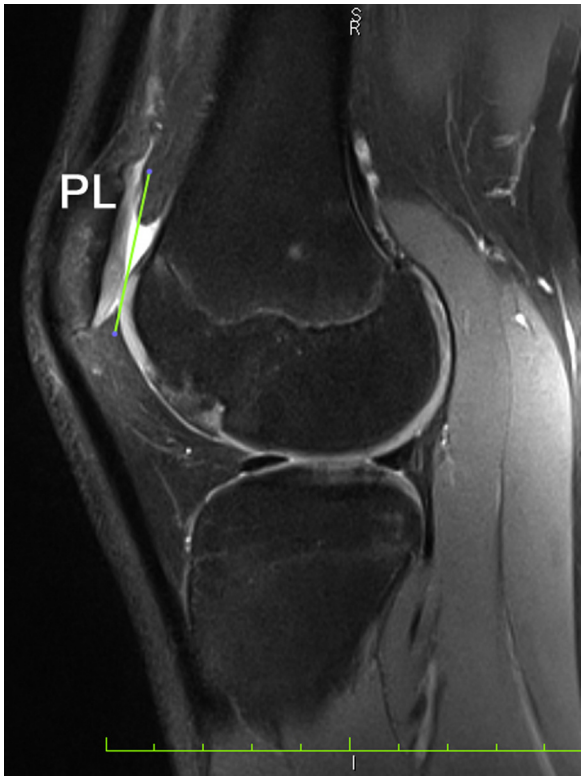

Figure 2 The second cut is where the articular cartilage of the femoral trochlea extends more proximally. On this slice the previously measured patellar length (PL) is pasted.

Figure 3 The SPE is completed by measuring the length of the femoral trochlea that is engaged with the patella (TL).

Statistical analysis

Statistical analysis was performed using the ''Graphpad'' software (http://www.graphpad.com). Comparisons of two means were performed using the Welch paired *t* test for numerical variables. The degree of correlation for pairs of numeric variables was assessed by the Spearman correlation coefficient. The hypothesis that this coefficient was equal to 0 was tested. Level of statistical significance was set at $p < 0.05$.

Results

Objective Patellar Dislocation group: epidemiological data are shown in Table 1. Mean patellar tendon length was 51.2 ± 6.76 mm (36.0—68.1 mm). Mean patellar length (PL) was 31.4 ± 3.8 mm (23—41 mm) and mean trochlear length (TL) was 13.4 ± 5.5 mm (0.5—26.8). Mean SPI was 0.439 ± 0.18 and ranged from 0.01 to 0.913 (95% C.I. = 0.42—0.48). Mean Caton-Deschamps ratio on x-rays in the same group was 1.18 ± 0.21 and ranged from 0.71 to 1.91. Fifty-eight patients had patella alta with Caton-Deschampsindex ≥ 1.2. Mean patellar tendon length in them was 53.1 ± 7.1 mm (36—68 mm). In these patients, mean SPE was 0.39 ± 0.18 and ranged from 0.01 to 0.87 (95% C.I. = 0.36—0.45). Seventy-seven patients had no patella alta with Caton-Deschamps index of < 1.2. Mean patellar tendon length was 49.3 ± 6.1 mm (33.5—65 mm). In these patients, mean SPE was 0.46 ± 0.16 (range = 0.1—0.913, 95% C.I. = 0.45—0.52), ($p < 0.01$, when compared to SPE with patella alta). Correlation between Caton-Deschamps index and SPE in all cases of the Patellar Dislocation Group was non-significant.

Control group: epidemiological data are shown in Table 1. Mean patellar tendon length was 44.6 ± 7.5 mm (35.9—59.1 mm). Mean PL was 32.3 ± 2.7 mm (27.4—36.4 mm) and mean TL was 15.2 ± 3.1 mm (7.5—21.8 mm). Mean SPE was $0.42 \pm 0.11$and ranged from 0.22 to 0.55 (95% C.I. = 0.43—0.49). Mean Caton-Deschamps ratio in the control group was 0.93 ± 0.14 and ranged from 0.66 to 1.19. There were no cases with patella alta in our control population.

When mean values of SPE index from Objective Patellar Dislocation and Control groups were compared, no statistically significant difference was found. Correlation between Sagittal Position Index and Caton-Deschamps index in the Objective Patellar Dislocation Group was also non-significant. Sagittal patellofemoral engagement of patients with Objective Patellar Dislocation and patella alta was significantly lower than SPE of patients with Objective Patellar Dislocation and no patella alta.

Table 1 Epidemiologic data for the two groups.

	Objective Patellar Dislocation Group	Control Group
Number	135	45
Female to male ratio	1.29	1.3
Age	24.5 ± 9 (10—56)	29 (16—61)
Trochlear dysplasia	No dysplasia = 17 (12,5%) Type A = 36 (26.6%) Type B = 32 (23.7%) Type C = 19 (14%) Type D = 31 (22.9%)	No dysplasia = 45 (100%)

Discussion

The PF articulation is a three-dimensional anatomical structure whose morphology is difficult to evaluate on plain x-rays or CT scan that either show one plane or fail to show cartilage and soft-tissue pathology [34]. There is significant mismatch between the osseous landmarks observed in radiographs or CT scans, and the articular cartilage of patella and trochlea obtained by MRI [35]. Additionally, patellar position in the sagittal plane has been evaluated with the use of different indexes, such as the Caton-Deschamps [4], the Insall-Salvati [5], the modified Insall-Salvati [30] and the Blackburne-Peel [3], which have been also reproduced with MRI [23,24]. The variety of these methods to measure patellar position in the sagittal plane leads to lack of agreement among surgeons in the diagnosis of PF disorders, but their common feature is that they use osseous landmarks and they refer the position of the patella in relationship to the tibia. Although some methods of measuring patellar height refer to the femur [36,37], the most popular refer it to the tibia, because the surgical method of correcting increased patellar height involves tibial tuberosity osteotomy with distalization.

But in the study of PF disorders, the clinical importance of patella alta in the fact that the patella is not positioned in front of the trochlea. Thus, identifying and quantifying a normal or a pathological relationship between the patella

Figure 4 Bernageau's index consists of a distance between two lines: the first line is drawn perpendicular to the most proximal point of the Blumensaat's line, the second line lies parallel to the first tangent at the distal point of the patellar articular cartilage. If the second line lies distally to the first of more than 6 mm, patella infera is defined; if the patellar line lies proximally to the trochlea more than 6 mm, patella alta is defined.

and the femoral trochlea (and not the tibia) may be of greater significance. This has been first introduced by other authors who, very interestingly, studied this ''functional engagement'' between the two articulating bones of the PF joint. Bernageau and Goutallier pioneered in the radiological diagnosis of PF disorders, by evaluating the position of the patella in relationship to the femoral trochlea in the sagittal plane [38]. They measured the articular patellar length and the articular trochlear length in x-rays, and they evaluated if there is an overlap of them or not, in order to provide positive or negative values of this sagittal PF engagement (Fig. 4). But the application of the method in simple x-rays where all osseous landmarks are superimposed, failed to provide additional information of the position of the patella in the axial plane or the abnormal morphology of the trochlea in cases of dysplasia. Dejour and Walch, in their first trochlear dysplasia classification, categorized three different types according to the level of the crossing sign in lateral x-rays, thus, determining the level of proximal extension of the femoral trochlea, but did not correlate their findings with the position of the patella [1]. Later, Seil et al. emphasized that the most important factor in determining the position of the patella in the sagittal plane is to refer the articular surface of the patella according to the articular surface of the trochlea [39].

Finally, Biedert and Albrecht studied this engagement of the patella into the trochlea by introducing the ''patellotrochlear index'' [29]. They improved the method of Bernageau and Goutallier by performing the measurement in MRI and by identifying the cartilaginous surface of the two articulating bones. But the authors studied this sagittal engagement only in knees with ''no PF pathology'' and by performing the measurement ''in a single slice''. This may facilitate the method but the measurement may be inapplicable in cases of patellar dislocation or subluxation, where the patella is not positioned in front of the most proximal part of the trochlea. Furthermore, as Barnett et al. showed [33], in cases of trochlear dysplasia or increased TT-TG distance, common features in patients with patellar dislocation, the measurement is not always possible, because the most proximal part of the trochlea is not always positioned in the same slice that Biedert et al. used to measure the patellar length [29]. Also, both these methods did not provide threshold values for normal knees or knees with patella alta or patellar dislocation, and therefore cutoffs for their surgical correction were not introduced.

Following the basis set by the previous methods of evaluating sagittal PF engagement by Bernageau-Goutallier and Biedert-Albrecht, in the present study the authors evaluated the sagittal engagement of the patella with the trochlea in MRI, using two distinguish slices and performing them in a group with patellar dislocation and in a control group. From the results of the present study, the mean SPE was not significantly different between Objective Patellar Dislocation and Control Group, but there was statistically significant difference between the SPE recorded for patients with patella alta and patients with no patella alta in the Dislocation Group. With the use of the SPE described in this study, the articulating surfaces of both patella and trochlea can be measured even in cases of patellar dislocation, since the authors use two distinctive slices to obtain them. Another interesting finding from our results, is the absence of correlation between the Caton-Deschamps ratio and the SPE recorded in the Objective Patellar Dislocation Group. A similar finding was also supported by Barnett et al. who found poor correlation between the patellotrochlear index and Caton-Deschamps, Insall-Salvati and Blackburne-Peel indexes [33]. This may sound an alarm of caution that in cases of increased patellar height, the functional PF engagement may still be sufficient, so the need for distalization osteotomy may be alleviated, despite an ''abnormal'' patellar height index. In our study population, we observed outliers of patients with patellar dislocation, where there was patella alta but a sufficient sagittal PF engagement (e.g. SPE = 0.88), (Table 2, Fig. 5). On the contrary, there were cases in the Objective Patellar Dislocation Group where the recorded Caton-Deschampsindex was within normal values and had no patella alta, but the sagittal PF engagement was reduced (e.g. SPE = 0.19) (Table 2), so the need for a tibial tuberosity distalization may be considered as necessary despite a ''normal'' patellar height index (Fig. 6). Further analysis of our results, showed that the confidence intervals

Table 2 Statistical relationships between the different groups for sagittal patellofemoral engagement.

Sagittal Patellofemoral Engagement (SPE) Index	Control Group	Objective Patellar Dislocation Group	Objective Patellar Dislocation Group: patients with patella alta	Objective Patellar Dislocation Group: patients with no patella alta
Mean	0.46[a]	0.43	0.39	0.46[b]
SD	0.11	0.18	0.18	0.16
N	45	135	58	77
95% C.I.	0.43—0.49	0.42—0.48	0.36—0.45	0.45—0.52
Range	0.22—0.94	0.02—1.0	0.02—0.88	0.17—1.0

[a] p = non-significant, when compared to Objective patellar dislocation group.
[b] $p < 0.01$, when compared to Objective patellar dislocation group with patella alta.

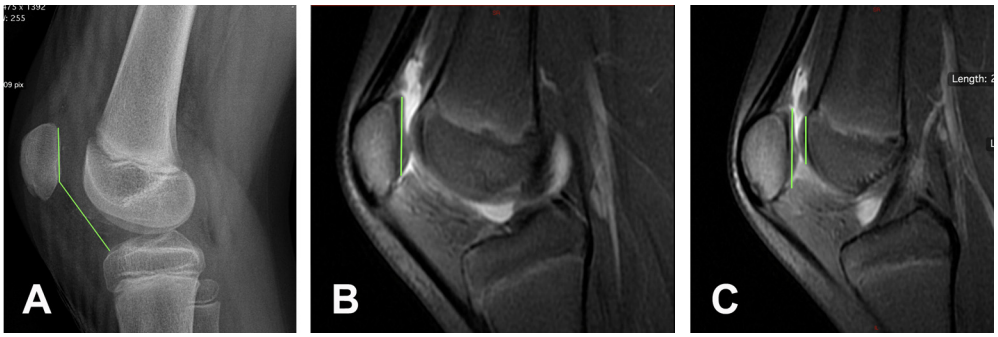

Figure 5 Example of a patient with patellar dislocation and (A) patellar alta in the lateral x-ray (Caton-Deschamps index = 1.66), but (B, C) sufficient patellofemoral engagement in the sagittal MRI views (SPE = 0.88).

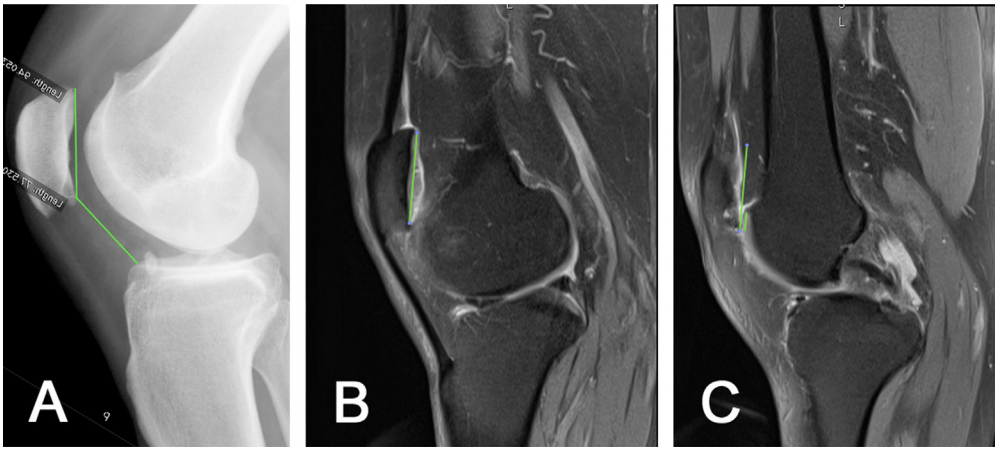

Figure 6 Example of a patient with patellar dislocation and (A) normal patellar in the lateral x-ray (Caton-Deschamps index = 0.81), but (B, C) reduced patellofemoral engagement in the sagittal MRI views (SPE = 0.19).

between the Patellar Dislocation subgroups of patella alta (e.g. 0.36—0.45) and no patella alta (e.g. 0.45—0.52) were not overlapping (Table 2). This resulted to a 95% probability that a patient with patellar dislocation and SPE < 0.45 had patella alta and insufficient functional sagittal PF engagement, and to another 95% probability that a patient with patellar dislocation and SPE > 0.45 did not have patella alta and had adequate functional sagittal PF engagement.

Similarly to the work of Biedert and Albrecht [29], the authors support that the imaging evaluation of patients with PF disorders must include MRI for the evaluation not only of the exact patellar height, but also for the determination of the functional engagement of the two articulating bones in the sagittal plane. Normal patellar height ratios, according to any method, must not exclude the need to distalize the patella or to perform lateral facet-elevating trochleoplasty [40], in cases of a ''short'' trochlea that does not extend proximally enough to engage the patella [15]. On the other hand, the SPE is not an alternative method of measuring patellar height, but an additional tool to well-established methods of evaluating patellar position. The position of the patella must be identified in the sagittal, as well in the axial plane. Normal radiological or MRI variables of patellar height and sagittal patellofemoral engagement cannot exclude a

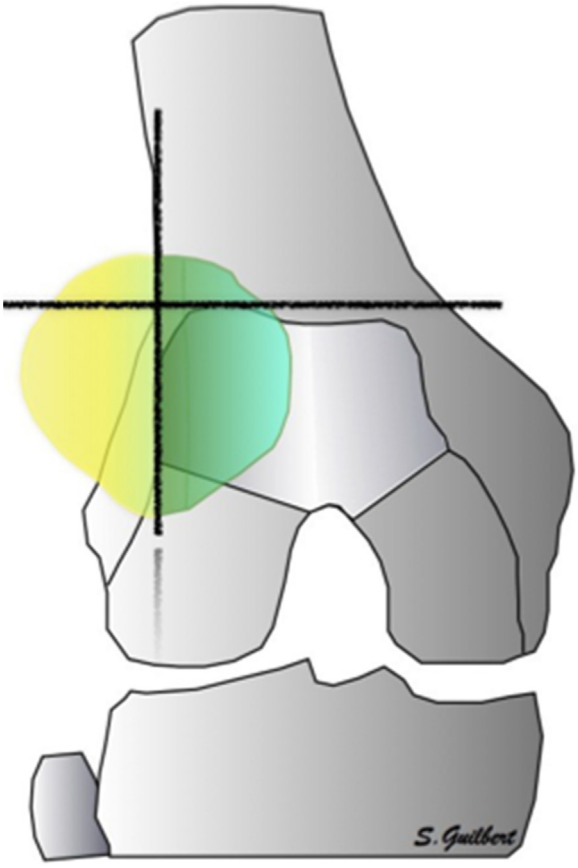

Figure 7 The position of the patella must be evaluated in the sagittal, as well in the axial plane, because normal radiological or MRI variables of patellar height and sagittal patellofemoral engagement cannot exclude a pathological position of the patella in the axial plane.

pathological position of the patella in the axial plane, and cannot exclude the need to surgically correct it (Fig. 7). Similar protocols of evaluating the combined engagement of the patella with the trochlea in two planes are probably required, to better evaluate and treat PF instability. No inter or intra-observer reliability was tested in the present study. Further limitations of the study are that MRI measurements were performed in full knee extension, in a non-weight bearing fashion and without quadriceps contraction. All these are factors that may affect the static position of the patella in relationship to the trochlea.

In conclusion, the present study introduces a new method to measure the SPE with the use of MRI. The evaluation of the functional engagement of the patella with the femoral trochlea in the sagittal plane can serve as a supplementary tool to the existing methods of evaluating patellar height, and may help to better identify the cases where inadequate engagement is recorded despite the absence of patella alta, so that the need for tibial tuberosity osteotomy may be re-assessed.

Disclosure of interest

D. Dejour: royalties from Tornier and SBM companies.

The other authors declare that they do not have any conflict of interest in relation to this article.

References

[1] Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc 1994;2(1):19—26.
[2] Monk AP, Doll HA, Gibbons CL, Ostlere S, Beard DJ, Gill HS, et al. The patho-anatomy of patellofemoral subluxation. J Bone Joint Surg Br 2011;93(10):1341—7, http://dx.doi.org/10.1302/0301-620X.93B10.27205 [PII:93-B/10/1341].
[3] Blackburne JS, Peel TE. A new method of measuring patellar height. J Bone Joint Surg Br 1977;59(2):241—2.
[4] Caton J, Deschamps G, Chambat P, Lerat JL, Dejour H. Patella infera. Apropos of 128 cases. Rev Chir Orthop Reparatrice Appar Mot 1982;68(5):317—25.
[5] Insall J, Salvati E. Patella position in the normal knee joint. Radiology 1971;101(1):101—4.
[6] Sasaki T, Yagi T. Subluxation of the patella. Investigation by computerized tomography. Int Orthop 1986;10(2):115—20.
[7] Walker C, Cassar-Pullicino VN, Vaisha R, McCall IW. The patello-femoral joint — a critical appraisal of its geometric assessment utilizing conventional axial radiography and computed arthro-tomography. Br J Radiol 1993;66(789):755—61.
[8] Dejour D, Le Coultre B. Osteotomies in patello-femoral instabilities. Sports Med Arthrosc 2007;15(1):39—46, http://dx.doi.org/10.1097/JSA.0b013e31803035ae [PII:00132585-200703000-00006].
[9] Bollier M, Fulkerson JP. The role of trochlear dysplasia in patellofemoral instability. J Am Acad Orthop Surg 2011;19(1):8—16 [PII:19/1/8].
[10] Colvin AC, West RV. Patellar instability. J Bone Joint Surg Am 2008;90(12):2751—62, http://dx.doi.org/10.2106/JBJS.H.00211 [PII:90/12/2751].
[11] Brossmann J, Muhle C, Schroder C, Melchert UH, Bull CC, Spielmann RP, et al. Patellar tracking patterns during active and passive knee extension: evaluation with motion-triggered cine MR imaging. Radiology 1993;187(1):205—12.
[12] Balcarek P, Jung K, Ammon J, Walde TA, Frosch S, Schuttrumpf JP, et al. Anatomy of lateral patellar instability: trochlear dysplasia and tibial tubercle-trochlear groove distance is more pronounced in women who dislocate the patella. Am J Sports Med 2010;38(11):2320—7, http://dx.doi.org/10.1177/0363546510373887 [PII: 0363546510373887].
[13] Gold GE, Hargreaves BA, Stevens KJ, Beaulieu CF. Advanced magnetic resonance imaging of articular cartilage. Orthop Clin North Am 2006;37(3):331—47, http://dx.doi.org/10.1016/j.ocl.2006.04.006 [vi. PII:S0030-5898(06)00023-X].
[14] Carrillon Y, Abidi H, Dejour D, Fantino O, Moyen B, Tran-Minh VA. Patellar instability: assessment on MR images by measuring the lateral trochlear inclination-initial experience. Radiology 2000;216(2):582—5.
[15] Biedert RM, Netzer P, Gal I, Sigg A, Tscholl PM. The lateral condyle index: a new index for assessing the length of the lateral articular trochlea as predisposing factor for patellar instability. Int Orthop 2011;35(9):1327—31, http://dx.doi.org/10.1007/s00264-010-1142-1.
[16] Escala JS, Mellado JM, Olona M, Gine J, Sauri A, Neyret P. Objective patellar instability: MR-based quantitative assessment of potentially associated anatomical features. Knee Surg Sports Traumatol Arthrosc 2006;14(3):264—72, http://dx.doi.org/10.1007/s00167-005-0668-z.
[17] Charles MD, Haloman S, Chen L, Ward SR, Fithian D, Afra R. Magnetic resonance imaging-based topographical differences between control and recurrent patellofemoral

instability patients. Am J Sports Med 2013;41(2):374—84, http://dx.doi.org/10.1177/0363546512472441 [PII: 41/2/374].
[18] van Huyssteen AL, Hendrix MR, Barnett AJ, Wakeley CJ, Eldridge JD. Cartilage-bone mismatch in the dysplastic trochlea. An MRI study. J Bone Joint Surg Br 2006;88(5):688—91, http://dx.doi.org/10.1302/0301-620X.88B5.16866 [PII: 88-B/5/688].
[19] Lippacher S, Dejour D, Elsharkawi M, Dornacher D, Ring C, Dreyhaupt J, et al. Observer agreement on the Dejour trochlear dysplasia classification: a comparison of true lateral radiographs and axial magnetic resonance images. Am J Sports Med 2012;40(4):837—43, http://dx.doi.org/10.1177/0363546511433028 [PII:0363546511433028].
[20] Balcarek P, Jung K, Frosch KH, Sturmer KM. Value of the tibial tuberosity-trochlear groove distance in patellar instability in the young athlete. Am J Sports Med 2011;39(8):1756—61, http://dx.doi.org/10.1177/0363546511404883 [PII:0363546511404883].
[21] Pandit S, Frampton C, Stoddart J, Lynskey T. Magnetic resonance imaging assessment of tibial tuberosity-trochlear groove distance: normal values for males and females. Int Orthop 2011;35(12):1799—803, http://dx.doi.org/10.1007/s00264-011-1240-8.
[22] Schoettle PB, Zanetti M, Seifert B, Pfirrmann CW, Fucentese SF, Romero J. The tibial tuberosity-trochlear groove distance; a comparative study between CT and MRI scanning. Knee 2006;13(1):26—31, http://dx.doi.org/10.1016/j.knee.2005.06.003 [PII:S0968-0160(05)00076-1].
[23] Miller TT, Staron RB, Feldman F. Patellar height on sagittal MR imaging of the knee. AJR Am J Roentgenol 1996;167(2):339—41, http://dx.doi.org/10.2214/ajr.167.2.8686598.
[24] Shabshin N, Schweitzer ME, Morrison WB, Parker L. MRI criteria for patella alta and baja. Skeletal Radiol 2004;33(8):445—50, http://dx.doi.org/10.1007/s00256-004-0794-6.
[25] Berruto M, Marinoni E, Chirico G, Vanzulli A, Usellini E, Marelli B. MRI analysis of patella instability factors. In: Zaffagnini S, Dejour D, Arendt E, editors. Patellofemoral pain, instabilty, and arthritis, vol. 1. Berlin, Heidelberg: Springer-Verlag; 2010. p. 79—89.
[26] Ali SA, Helmer R, Terk MR. Patella alta: lack of correlation between patellotrochlear cartilage congruence and commonly used patellar height ratios. AJR Am J Roentgenol 2009;193(5):1361—6, http://dx.doi.org/10.2214/AJR.09.2729 [PII:193/5/1361].
[27] Neyret P, Robinson AH, Le Coultre B, Lapra C, Chambat P. Patellar tendon length — the factor in patellar instability? Knee 2002;9(1):3—6 [PII:S0968016001001363].
[28] Biedert RM, Bachmann M. Anterior-posterior trochlear measurements of normal and dysplastic trochlea by axial magnetic resonance imaging. Knee Surg Sports Traumatol Arthrosc 2009;17(10):1225—30, http://dx.doi.org/10.1007/s00167-009-0824-y.
[29] Biedert RM, Albrecht S. The patellotrochlear index: a new index for assessing patellar height. Knee Surg Sports Traumatol Arthrosc 2006;14(8):707—12, http://dx.doi.org/10.1007/s00167-005-0015-4.
[30] Grelsamer RP, Meadows S. The modified Insall-Salvati ratio for assessment of patellar height. Clin Orthop Relat Res 1992;282:170—6.
[31] Fucentese SF, von Roll A, Koch PP, Epari DR, Fuchs B, Schottle PB. The patella morphology in trochlear dysplasia — a comparative MRI study. Knee 2006;13(2):145—50, http://dx.doi.org/10.1016/j.knee.2005.12.005 [PII:S0968-0160(05)00187-0].
[32] Servien E, Ait Si Selmi T, Neyret P. Study of the patellar apex in objective patellar dislocation. Rev Chir Orthop Reparatrice Appar Mot 2003;89(7):605—12, doi:MDOI-RCO-11-2003-89-7-0035-1040-101019-ART4.
[33] Barnett AJ, Prentice M, Mandalia V, Wakeley CJ, Eldridge JD. Patellar height measurement in trochlear dysplasia. Knee Surg Sports Traumatol Arthrosc 2009;17(12):1412—5, http://dx.doi.org/10.1007/s00167-009-0801-5.
[34] Saggin PR, Saggin JI, Dejour D. Imaging in patellofemoral instability: an abnormality-based approach. Sports Med Arthrosc 2012;20(3):145—51, http://dx.doi.org/10.1097/JSA.0b013e3182553cfe [PII:00132585-201209000-00004].
[35] Staeubli HU, Bosshard C, Porcellini P, Rauschning W. Magnetic resonance imaging for articular cartilage: cartilage-bone mismatch. Clin Sports Med 2002;21(3):417—33 [viii—ix].
[36] Chareancholvanich K, Narkbunnam R. Novel method of measuring patellar height ratio using a distal femoral reference point. Int Orthop 2012;36(4):749—53, http://dx.doi.org/10.1007/s00264-011-1340-5.
[37] Laurin CA. The investigation of the patello femoral joint. J Bone Joint Surg Br 1977;59:107.
[38] Bernageau J, Goutallier D. Examen radiologique de l'articulation fémoro-patellaire. In: de Sèze S, Ryckewaert A, Kahn MF, Le-Maire V, editors. L'actualité rhumatologique. Paris: Expansion scientifique française; 1984.
[39] Seil R, Muller B, Georg T, Kohn D, Rupp S. Reliability and interobserver variability in radiological patellar height ratios. Knee Surg Sports Traumatol Arthrosc 2000;8(4):231—6.
[40] Biedert R. Trochlear lengthening osteotomy with or without elevation of the lateral trochlear facet. In: Zaffagnini S, Dejour D, Arendt E, editors. Patellofemoral pain, instabilty, and arthritis, vol. 1. Berlin, Heidelberg: Springer-Verlag; 2010. p. 209—15.