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SCIENTIFIC ARTICLE

Magnetic resonance imaging-based morphological and alignment assessment of the patellofemoral joint and its relationship to proximal patellar tendinopathy

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Abstract

Objective To assess the differences in morphology and alignment of the knee between patients with proximal patellar tendinopathy (PPT) and a control group, using MRI and focusing on the patellofemoral joint.

Methods We retrospectively included 35 patients with clinically diagnosed and unequivocal findings of PPT on knee MRI, the case group. For the control group, we included 70 patients who underwent knee MRI for other reasons, with no clinical or MRI evidence of PPT. Patients and controls were matched for age and gender, with all subjects reporting frequent physical activity. MRIs were evaluated by two musculoskeletal radiologists, who assessed parameters of patellar morphology, trochlear morphology, patellofemoral alignment, and tibiofemoral alignment. The differences in parameters between cases and controls were assessed using Student's t test. Logistic regression was applied to assess the associations between the MRI parameters and the presence of PPT.

Results The patellar height Insall–Salvati ratio was different between cases and controls (1.37 ± 0.21 vs. 1.24 ± 0.19; $p = 0.003$). The subchondral Wiberg angle was higher in cases than controls (136.8 ± 7.4 vs. 131.7 ± 8.8; $p = 0.004$). After applying logistic regression, significant associations with PPT were found [odds ratios (95% CI)] for patellar morphology [1.1 (1.0, 1.2)] and patellar height [1.3 (1.0, 1.7)].

Conclusions Patellar height and the subchondral patellar Wiberg angle were greater in patients with PPT and significantly associated with PPT.

Keywords MRI · Patellar tendinopathy · Patellofemoral alignment · Jumper's knee

Introduction

Overuse tendon injuries are common not only in elite athletes but also in the general population, mainly in those participating in frequent physical or athletic activities [1, 2]. Patellar tendinopathy usually affects the proximal aspect of the patellar tendon at its insertion at the distal aspect of the patellar bone, affecting athletes in sports that demand repetitive straining of the tendon, mainly from repeated quadriceps muscle eccentric contractions [3, 4], as well as sudden knee extension [3]. Proximal patellar tendinopathy (PPT), also known as patellar tendinitis or "jumper's knee" [5], is widely considered to be an overuse pathology, representing one of the numerous pathologies associated with anterior knee pain, and is a risk in activities that include running, kicking, and especially jumping [6–9]. The etiology of PPT is probably multifactorial,

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with factors related to the type, amount, intensity, and conditions of training or practice [3, 10, 11]. However, since not all athletes exposed to the same extrinsic factors will develop PPT, there are probably other factors related to the subjects themselves that might be contributory. A few studies have attempted to evaluate the relationship of intrinsic factors with proximal patellar tendinopathy, demonstrating that factors such as lower flexibility of the quadriceps and hamstring muscles [11], ilio-tibial band or shank-forefoot alignment above the clinically relevant cut-off [12], and a greater volume of the infrapatellar fad pad [13] may be associated with PPT.

Altered knee morphology and alignment, especially if the patellofemoral joint is involved, may affect load distribution to the extensor mechanism, including the patellar tendon [14, 15]. Malalignment has been hypothesized as a factor for overuse tendinopathy [16], and yet despite the availability of advanced cross-sectional imaging for the assessment of several joint-alignment parameters, no previous work has attempted to evaluate in depth the relationship between such factors and PPT. Magnetic resonance imaging (MRI) allows assessment of several morphological and alignment parameters regarding the patellofemoral joint [17], and we aimed to test our hypothesis that differences in some MRI-detected patellofemoral morphology and alignment parameters exist between patients with and without PPT.

Methods

Subjects

This retrospective and cross-sectional study was approved by the local institutional review board, which also waived the requirement for signed informed consent due to the retrospective nature of the study. We searched for the clinical and radiological records of patients who had undergone MRI of the knee in our department from 2012 to 2014. To select cases with PPT, we searched for reports of knee MRIs in our Radiological Information System (RIS) where at least one of the following keywords was present: "patellar tendinopathy", "proximal patellar tendinopathy", "jumper's knee". For the case group, we included patients from 18 to 50 years of age presenting clinical features of PPT, including pain, tenderness, with or without associated swelling at the inferior pole of the patella, and with symptoms that worsened with physical activity. All cases reported frequent physical activity (at least three times per week), and underwent a knee MRI that showed unequivocal MRI features of PPT (see MRI assessment below). For the control group, we included patients from 18 to 50 years of age with no clinical features of PPT who had been referred to our institution for other reasons (to rule out internal derangements of the knee). They also reported frequent physical activity (at least three times per week) but their patellar tendons appeared normal on MRI. Patients with a history of knee surgery, a history of recent knee trauma, exhibiting severe artifacts on MRI, advanced knee osteoarthritis, equivocal findings of PPT on MRI, or a complete tear of the quadriceps or the patellar tendons were excluded. We finally included 35 patients (one knee per patient) with a clinical and MRI diagnosis of PPT. We calculated that, by including twice as many controls as cases (thus 35 cases, 70 controls), we would be capable of identifying an association between a continuous variable (alignment and morphology MRI parameters assessed) and PPT with a statistical power of 80%. The flow chart of patient selection is represented in Fig. 1.

MRI technique

All the knees were examined on a high-field 1.5-T MRI (Signa HDXT 1.5 T, GE Healthcare, Milwaukee, WI, USA), using a dedicated standard knee coil with the patients supine. Our routine MRI of the knee protocol included intermediate-weighted fast spin-echo sequences with fat suppression (FS) acquired in the axial, coronal, and sagittal planes (TR = 3600 ms, TE = 35 ms, slice thickness = 3 mm, matrix = 512 × 512, FOV = 18), a sagittal proton density-weighted fast spin-echo sequence (TR = 2000 ms, TE = 15 ms, slice thickness = 3 mm, matrix = 512 × 512, FOV = 18), a coronal T1-weighted sequence (TR = 550 ms, TE = 12 ms, slice thickness = 4 mm, matrix = 512 × 512, FOV = 18), as well as a coronal-oblique T2-weighted sequence (for anterior cruciate ligament assessment, performed routinely in our institution but not used for patellar tendon assessment).

MRI assessment

The patellar tendon was evaluated in consensus by two musculoskeletal radiologists, with 2 and 8 years of experience using sagittal and axial intermediate-weighted FS images. The patellar tendon was assessed in consensus since its appearance was used to define patients as cases or controls. MRI findings of PPT included unequivocal thickening of the proximal aspect of the patellar tendon, in comparison to the mid- and distal aspects of the tendon, with unequivocal intrasubstance signal changes of the proximal patellar tendon on intermediate-weighted FS images (Fig. 2), predominantly in the deep portion of the tendon. These findings could be associated with one or more of the following features: infiltration of the adjacent Hoffa's fat pad, bone marrow edema at the inferior pole of the patella, and a partial-thickness tear of the proximal patellar tendon at its deep aspect. The presence of equivocal or mild intrasubstance signal changes of the proximal patellar tendon without associated tendon thickening was not considered, for the present study, as an unequivocal MRI feature of PPT. Thus, all cases exhibited unequivocal MRI features of PPT and all controls exhibited strictly normal

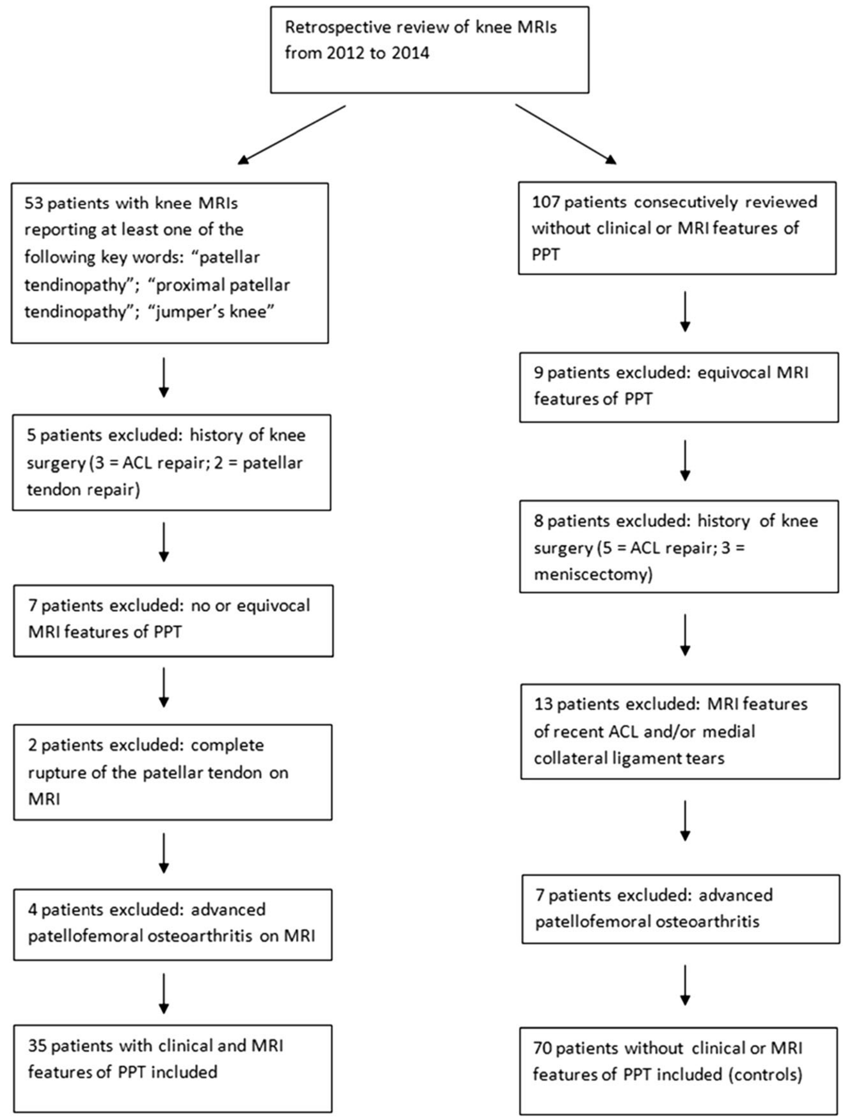

Fig. 1 Flow chart of patients included in the analysis

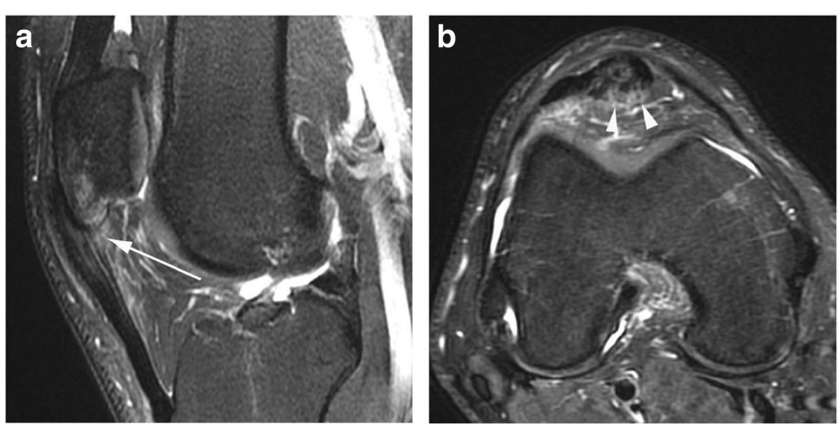

Fig. 2 A 28-year-old man with proximal patellar tendinopathy (PPT). MRI findings of PPT: **a** Sagittal and **b** axial intermediate-weighted FS images show thickening of the proximal aspect of the patellar tendon, with intrasubstance signal changes of the proximal patellar tendon, predominantly in the deep portion of the tendon (*arrow* – **a**; *arrowheads* – **b**) Note the infiltration of the adjacent Hoffa’s fat pad, as well as bone marrow edema at the inferior pole of the patella

morphology and signal of the patellar tendon on MRI. Further, ten MRI-based parameters related to patellar and trochlear morphology, as well as to patellofemoral alignment, were assessed independently by two other musculoskeletal radiologists with 2 years of experience each. The patellar morphology parameters included both Wiberg's subchondral angle and index (Fig. 3). Trochlear morphology parameters included the trochlear sulcus angle, the medial-lateral trochlear facets length ratio, and lateral inclination angle (Fig. 4). Patellofemoral alignment parameters included the Insall–Salvati and Caton–Deschamps ratios for patellar height (Fig. 5), the tibial tuberosity – trochlear groove distance (Fig. 6), as well as the patellar tilt and lateral patellar displacement (Fig. 7). For all patellar and trochlear measurements made using the axial plane, marginal osteophytes present at the medial and lateral aspects of the patella and/or the trochlea were not considered and were excluded from measurements. Enthesophytes present at the proximal patellar tendon insertion or osteophytes present at the proximal or distal aspect of the patellar subchondral bone were not considered when assessing patellar height and were excluded from measurements. Since femorotibial alignment may influence patellofemoral alignment, we also assessed the femorotibial angle on the coronal T1-weighted sequence, as the angle formed between the long shaft axis of the distal femur and proximal tibia at the midline of the femorotibial compartments (Fig. 8). Detail on how measurements were performed for each MRI-based variable assessed is found in the figure legends. To assess the reproducibility of measurements of the MRI-based parameters, both radiologists independently re-evaluated 30 knees randomly selected from the whole sample of knees. To avoid recognition bias, the MRIs were re-assessed 1 month after both radiologists finished the initial readings. To respect the proportion of cases and controls included, we randomly selected ten cases and 20 controls for re-assessment. We selected one for each three cases in the list of patients with PPT until completing ten cases; then one for each three cases in the list of patients without PPT (controls) until completing 20 cases.

Statistical analysis

The reproducibility of measurements of the different MRI-based parameters by the two radiologists was assessed by applying intraclass coefficient correlations. Then, we assessed the differences in MRI-based parameters measurements between cases and controls using Student's t test method. We further applied a logistic regression model [18] to assess the associations between the MRI-based parameters and PPT. Only those MRI-based parameters exhibiting differences between cases and controls with a p value < 0.1 (Student's t test) were selected for the logistic regression model. Multi-adjustments were performed when considering these parameters as potential confounders, and the quality of these adjustments was measured using C-statistics and Nagelkerke R^2 statistics.

Statistical significance was set at 0.05. All analyses were performed using SAS software version 9.4 (SAS Institute, Cary, NC, USA).

Results

There were no significant differences between the groups in terms of age (Student's t test; mean 31.7 years ± 8.7 standard deviation (SD) for cases vs. mean 33.1 years ±

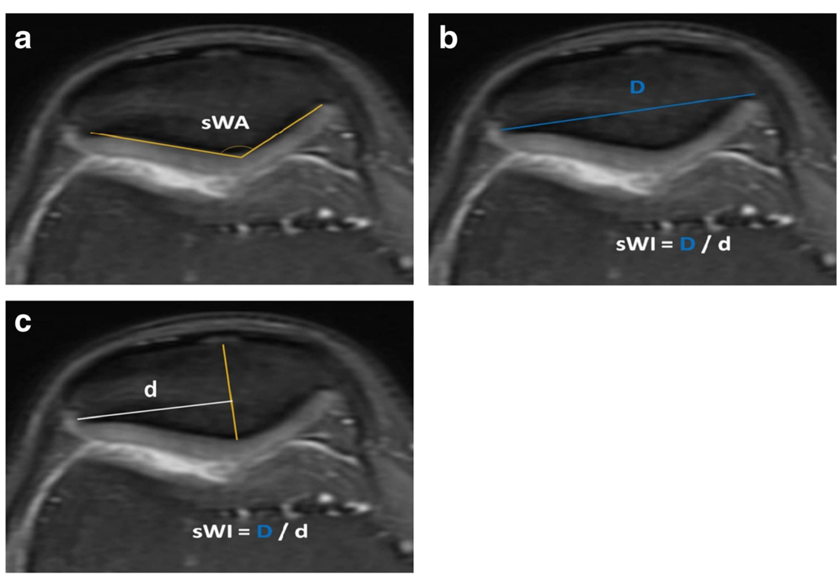

Fig. 3 Axial MR images were used to assess the patellar subchondral Wiberg angle (sWA, **a**) and subchondral Wiberg index (sWI, **b**, **c**), parameters related to patellar morphology. The axial image displaying the largest patellar width, measured from the most lateral aspect to the most medial aspect of the patella (distance "D", **b**) was used for assessing both parameters. Distance "d" (**c**) is measured from the most lateral aspect of the patella to a perpendicular line at the mid portion of the medial patellar ridge

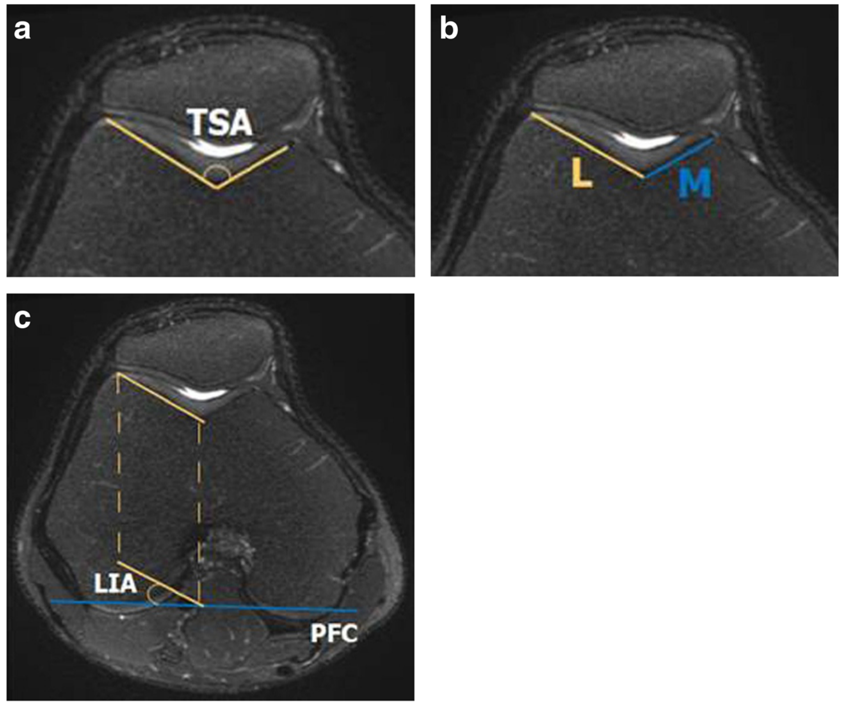

Fig. 4 Axial MRI displaying the trochlear sulcus and the posterior aspects of the femoral condyles was used to assess (**a**) the trochlear sulcus angle (TSA), which is the angle formed between the slopes of the medial and lateral trochlea; (**b**) the medial (M) / lateral (L) trochlea length ratio; and (**c**) the lateral trochlea inclination angle (LIA), which is the angle formed between the lateral slope of the trochlea (*yellow line*) and the line drawn across the posterior cortical (and not chondral) margins of the medial and lateral femoral condyles (PFC, *blue line*)

9.1 SD for controls; $p = 0.46$) or gender (Chi-square test; 29 men (82.9%) for cases vs. 54 men (77.1%) for controls; $p = 0.67$).

The differences in the MRI-based parameters of patellofemoral morphology and alignment between cases and controls (Student's *t* test) are presented in Table 1. The Insall–Salvati ratio, a measure of patellar height, was greater in patients with PPT vs. controls (1.37 ± 0.21 vs. 1.24 ± 0.19; $p = 0.003$). Further, we found that the subchondral Wiberg angle, a measure of patellar morphology, was greater in patients with PPT vs. controls (136.80° ± 7.37 vs. 131.73° ± 8.84; $p = 0.004$). Finally, we found that the femorotibial valgus (angle) was greater in patients with PPT vs. controls (4.73° ± 2.49 vs. 2.49° ± 3.77: $p = 0.002$). None of the other MRI-based parameters showed significant differences between cases and controls.

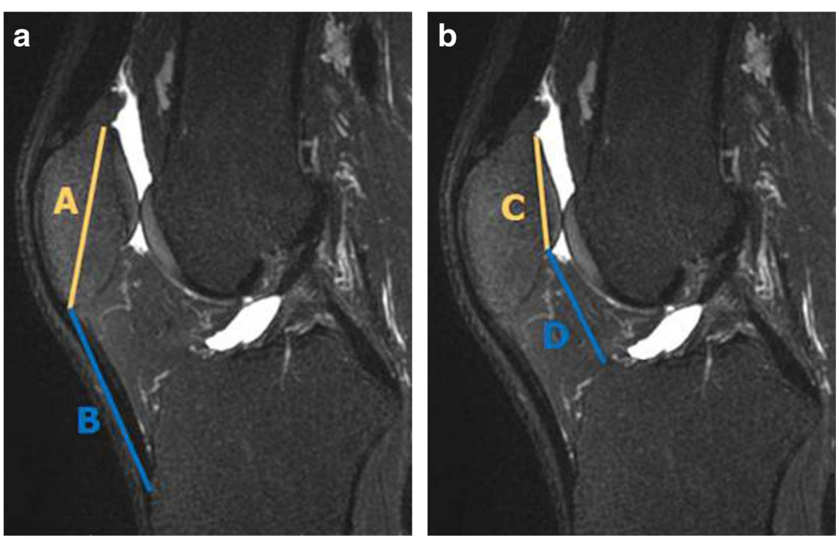

Fig. 5 Mid-line sagittal MRI sections through the patella were used to assess patellar height. "A" represents the measurement from the most proximal articular margin of the patella to the most distal (non-articular) aspect of the patella. "B" represents the measurement from the most distal (non-articular) aspect to the distal insertion of the patellar tendon at the tibial tuberosity. "C" represents the measurement from the most proximal to the most distal articular margin of the patella. "D" represents the measurement from the most distal articular margin of the patella to the anterior aspect of the articulating surface of the tibia. Insall–Salvati ratio = B/A; Caton-Deschamps ratio = D/C

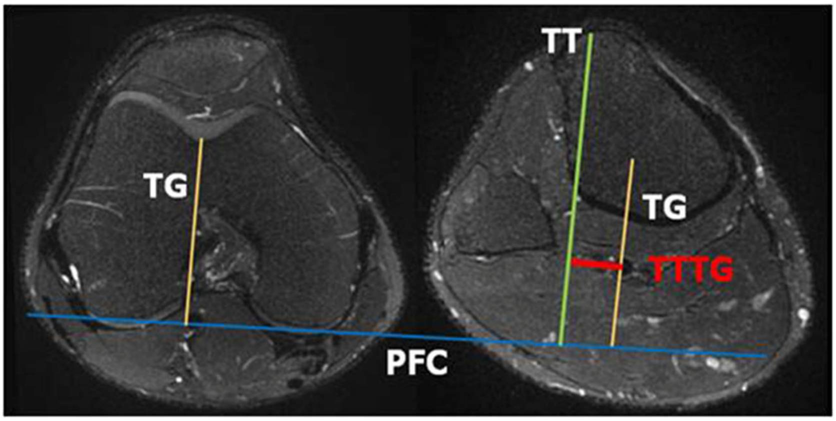

Fig. 6 Tibial tuberosity – trochlear groove distance (TTTG) assessment. Two sets of measurements are made. The first is made on the axial slice showing the trochlear groove and the posterior cortical margins of the femoral condyles. The second is made on the axial slice exhibiting the anterior tibial tuberosity. Line 1 is drawn across the posterior cortical (and not chondral) margins of the medial and lateral condyles (PFC) and will be applied to the distal image as well. Line 2 is perpendicular to line 1 and crosses the center of the trochlear groove (TG) in the first axial slice. Line 3 is perpendicular to line 1 and runs through the most anterior aspect of the tibial tuberosity (TT) on the distal axial slice. The difference in the distance of lines 2 and 3 to a fixed point on the image is the TTTG distance

All MRI-based parameters exhibiting differences between cases and controls with a p value < 1.0 were introduced in the logistic regression analysis to assess the associations with PPT. After adjustments, we found three MRI-based parameters that were associated with PPT in the final logistic regression model: the Insall–Salvati ratio (odds ratio (OR) of 1.3 (95% CI 1.0, 1.7); $p = 0.04$), the femorotibial angle (OR = 1.2 (95% CI 1.1, 1.5); $p = 0.01$), and the subchondral Wiberg angle (OR = 1.1 (95% CI 1.0, 1.1); $p = 0.02$). Reproducibility (intraclass coefficient correlations) of MRI-based measurements by both radiologists is presented in Table 2.

Discussion

In this retrospective case-control study, we demonstrated that some MRI-based parameters regarding patellar height (Insall–Salvati ratio) and morphology (subchondral Wiberg angle), and also femorotibial alignment, showed statistically significant differences between patients with PPT and controls, and were also associated with PPT.

The major known and described factors potentially related to PPT in athletes are considered as extrinsic or external factors, such as sports activities at risk [6–9], the amount and intensity of training – especially a sudden increase in the frequency and intensity of activities, the training surfaces (mainly hard), changing from one sport to another, environmental conditions, footwear and equipment, and related improper movements and actions while training [3, 10, 11]. Many intrinsic factors could be potentially responsible for altered load applied to the extensor mechanism and to the patellar tendon and their relationship with PPT would merit study. To date, the presence of altered patellofemoral morphology and alignment has been little explored as a factor for PPT.

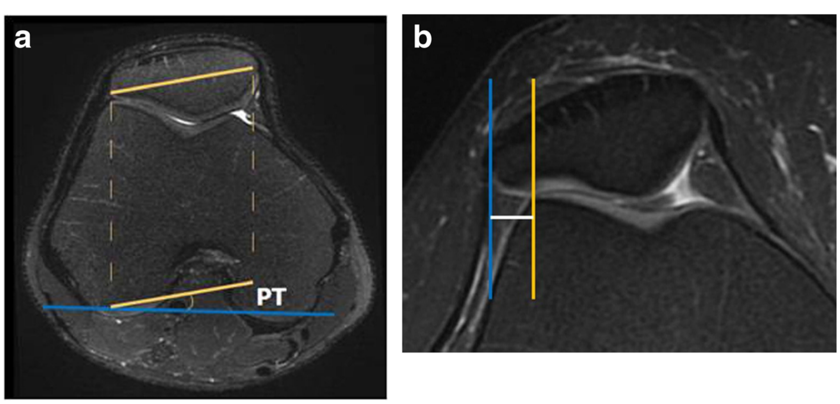

Fig. 7 Axial MR images passing through the mid-portion of the patella. **a** Patellar inclination angle or patellar tilt (PT): the angle formed between the blue line drawn across the posterior cortical (and not chondral) margins of the medial and lateral condyles and the yellow line drawn through the transverse axis of the patella (between the medial and lateral articular margins of the patella). **b** Lateral patellar displacement was assessed as the shortest distance between the lateral articular margins of the trochlea (*yellow line*) and the patella (*blue line*)

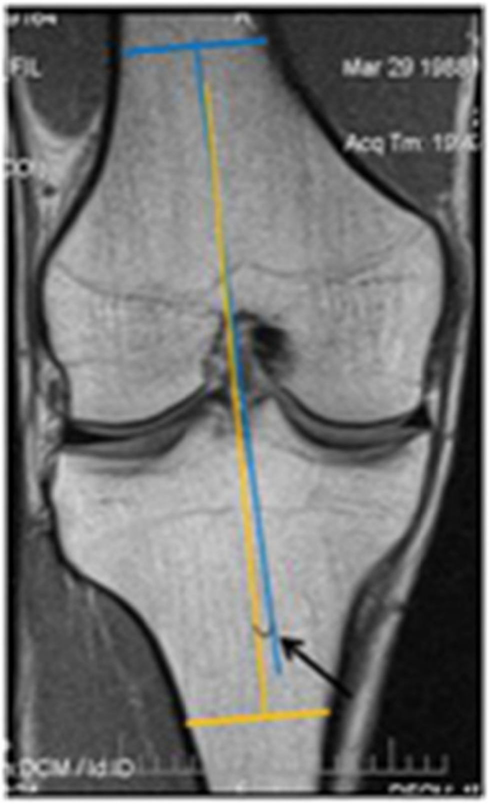

Fig. 8 The femorotibial angle was assessed using coronal T1-weighted images at the mid-line of the knee joint. The angle is formed between the distal axis of the femur (*blue line*) and the proximal axis of the tibia (*yellow line*)

A previous longitudinal study of male and female physical education students evaluated risk factors for PPT [11]. The leg-length discrepancy, the Q-angle, and the medial tibial intercondylar distance were the only leg alignment parameters included and were evaluated clinically, but not with imaging. The authors found that only lower flexibility of the quadriceps and hamstring muscles at baseline was associated with the development of PPT. A recent cross-sectional study that included male basketball and volleyball athletes assessed the relationships among clinically assessed lower limb alignment parameters, as well as muscular variables including range of motion, flexibility, and strength, and patellar tendon abnormalities evaluated with ultrasound [12]. The authors found that athletes exhibiting iliotibial band and shank-forefoot alignment above the clinically relevant established cut-off had a greater chance of concomitant patellar tendon abnormalities on ultrasound, but with no significant associations reported for knee alignment parameters. We found only one previous cross-sectional case-control study that assessed a few MRI-based parameters of patellofemoral alignment as factors for patellar tendinopathy confirmed clinically and with ultrasound [13]. The authors found that none of the patellofemoral alignment parameters (Insall–Salvati ratio, lateral patellar displacement, lateral patellar tilt angle, and trochlear sulcus angle) were associated with patellar tendinopathy.

MRI has been demonstrated to be a valuable technique for the assessment of several patellofemoral alignment and morphology parameters that may be implicated in the pathogenesis of patellofemoral instability [17]. Regarding patellofemoral alignment, the only factor that showed an association with PPT in our sample was patellar height, measured by the Insall–Salvati ratio. This ratio was significantly greater in patients with PPT than in controls. The Insall–Salvati ratio is usually assessed in lateral radiographic views, but it was recently demonstrated that, in comparison to radiographic measurements, there was excellent reproducibility when performing MRI measurements of patellar height [19]. We hypothesize that altered patellar height, mainly patella alta, may alter the load transmitted to the proximal patellar tendon, probably due to patellar and patellar tendon maltracking, ultimately leading to PPT. However, based on our results, it is not possible to affirm if a greater mean of the Insall–Salvati ratio in patients with PPT was due to an

Table 1 Differences in MRI-based parameters between patients with PPT and controls

MRI-based variable	Control Mean ± SD	PPT Mean ± SD	Total Mean ± SD	*p* value
Subchondral Wiberg index	0.58 ± 0.04	0.59 ± 0.06	0.58 ± 0.05	0.222
Subchondral Wiberg angle (°)	131.73 ± 8.84	136.8 ± 7.37	133.42 ± 8.68	**0.004**
Trochlear sulcus angle (°)	133.37 ± 7.73	132.28 ± 7.47	133.01 ± 7.63	0.49
Medial/lateral trochlea length ratio	1.56 ± 0.24	1.56 ± 0.24	1.56 ± 0.24	0.924
Lateral trochlea inclination angle (°)	22.29 ± 4.29	21.96 ± 4.92	22.18 ± 4.49	0.721
Insall–Salvati ratio	1.24 ± 0.19	1.37 ± 0.21	1.29 ± 0.2	**0.003**
Caton–Deschamps ratio	1.09 ± 0.13	1.14 ± 0.17	1.1 ± 0.14	0.09
TTTG (cm)	1.07 ± 0.33	1.02 ± 0.46	1.06 ± 0.36	0.663
Patellar tilt (°)	9.59 ± 5.99	11.89 ± 8.5	10.36 ± 6.97	0.112
Lateral patellar displacement (cm)	0.26 ± 0.2	0.31 ± 0.31	0.27 ± 0.24	0.33
Femorotibial angle (°)	2.49 ± 3.77	4.73 ± 2.49	3.27 ± 3.53	**0.002**

PPT proximal patellar tendinopathy, *SD* standard deviation, *TTTG* tibial tuberosity – trochlear groove distance

Table 2 Reproducibility of measurements of MRI-based parameters

MRI-based variable	ICC	*p* value	95% CI	
			Inf	Sup
Subchondral Wiberg index	0.40	0.037	−0.04	0.71
Subchondral Wiberg angle	0.34	0.066	−0.11	0.67
Lateral patellar displacement	0.84	< 0.001	0.65	0.94
Patellar tilt	0.98	<0.001	0.94	0.99
Insall–Salvati ratio	0.92	< 0.001	0.82	0.97
Caton–Deschamps ratio	0.71	< 0.001	0.40	0.87
TTTG	0.91	<0.001	0.79	0.96
Femorotibial angle	0.73	< 0.001	0.44	0.88
Medial/lateral trochlea length ratio	0.75	< 0.001	0.47	0.89
Lateral trochlea inclination angle	0.91	< 0.001	0.78	0.96
Trochlear sulcus angle	0.83	< 0.001	0.62	0.93

ICC intraclass coefficient correlations, *CI* confidence interval, *Inf* inferior, *Sup* superior, *TTTG* tibial tuberosity – trochlear groove distance

increase in patellar tendon length or a decrease in patellar bone length. The same hypothesis could be raised for altered patellar morphology, as demonstrated in our study when assessing the patellar subchondral Wiberg angle. The angle was higher in patients with PPT than in controls, meaning that patients with PPT had a flattened and potentially unstable patella, which could lead to altered load applied to the patellar tendon during physical activity. Patellar height and morphology assessment, representing potential factors for altered load applied to the patellar tendon and ultimate PPT, should be considered in future prospective investigations, as well as in the development of rehabilitation and preventive programs.

We also demonstrated differences in femorotibial angles between patients with PPT and controls with valgus angles higher in patients than in controls. Valgus malalignment could be responsible for lateral dislocating forces applied to the patella and subsequently to the patellar tendon, which might alter the load applied to the extensor mechanism and lead to PPT [20]. However, in our study, the femorotibial angle was assessed with the subjects in a supine (and not weight-bearing) position, taking into account the axes of the distal femur and the proximal tibia in the coronal plane, which we acknowledge is not ideal for femorotibial alignment assessment. Furthermore, the standard deviation values found after statistical analysis indicate substantial overlap in femorotibial angles between cases and controls. Thus, based on our results, the femorotibial angle cannot be used to discriminate patients with PPT from controls.

Some limitations to this study need mentioning. First, due its retrospective nature, we were not able to control for the specific physical activities of the subjects. Only the mention of “practicing of frequent physical activity” was available in the clinical records, which we acknowledge is not sufficient to control for activities potentially related to PPT, especially those involving jumping, kicking, and running. Also, we did include symptomatic patients in the control group, and the presence of knee symptoms could impact in physical activity levels of controls, potentially reducing the likelihood of PPT. Second, we did not consider the presence of moderate to large joint effusion as an exclusion criterion, which could potentially impact measurements of some patellofemoral alignment parameters. Third, there was limited reproducibility for the assessment of patellar morphology parameters (subchondral Wiberg index and angle), making it difficult to interpret the relationships between them and PPT. Fourth, it was not possible to blind the radiologists who assessed the MRI-based parameters for alignment and morphology from the presence or absence of PPT, since the patellar tendon is obvious on the sagittal and axial images used for measurements. Finally, we did not have enough power to assess the relationship between the tibial tuberosity – trochlear groove distance and PPT, since many of the axial scans did not fully cover the anterior tibial tuberosity.

In conclusion, patellar height and the subchondral patellar Wiberg angle were greater in patients with PPT and significantly associated with PPT. We encourage the assessment of such features in future prospective case-control studies to confirm the relationships, which would help in planning rehabilitation and preventive strategies for athletes at risk of developing PPT.

Compliance with ethical standards

Conflict of interest Author MDC is vice president “musculoskeletal” and shareholder of Boston Imaging Core Lab (BICL), LLC. The remaining authors declare that they have no conflicts of interest.

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