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SCIENTIFIC ARTICLE

Quantitative magnetic resonance imaging in patellar tendon-lateral femoral condyle friction syndrome: relationship with subtle patellofemoral instability

Jia Li [1] · Bo Sheng [1] · Fan Yu [1] · Chunhua Guo [1] · Fajin Lv [1] · Furong Lv [1] · Haitao Yang [1]

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Abstract

Objective To investigate the correlation of patellar tendon-lateral femoral condyle friction syndrome (PTLFCFS) with subtle patellofemoral instability to explore its pathogenesis.

Materials and methods One hundred knees of 80 patients with PTLFCFS were analyzed retrospectively by retrieving magnetic resonance imaging (MRI) data over a 3-year period from our database. Seven quantitative parameters for evaluating patellofemoral stability were measured on MR images, including the Insall–Salvati ratio, tibial tuberosity–trochlear groove (TT–TG) distance, trochlear groove depth, medial trochlear/lateral trochlear length (MT/LT) ratio, medial trochlear/lateral trochlear height (MH/LH) ratio, lateral patellofemoral angle (LPA), and lateral trochlear inclination (LTI) angle. These patellofemoral parameters of the PTLFCFS group and the normal control group were compared ($n = 88$), and receiving-operator characteristic (ROC) curve analysis was conducted to determine the specificity and sensitivity of these parameters.

Results The trochlear depth, MT/LT, LPA, and LTI angle were significantly lower ($p < 0.001$) and the Insall–Salvati ratio was significantly higher ($p < 0.001$) in the PTLFCFS group. However, the TT–TG distance and MH/LH ratio showed no significant difference ($p = 0.231$ and 0.073 respectively). The area under the ROC curve of the Insall–Salvati ratio, trochlear depth, MT/LT, LPA, and LTI angle were 0.925, 0.784, 0.8, 0.731, and 0.675 respectively. The efficiency of the Insall–Salvati ratio was the highest among those five parameters.

Conclusion This study verified the presence of subtle patellofemoral instability by measuring various patellofemoral parameters in patients with PTLFCFS. It confirmed that PTLFCFS is associated with subtle patellofemoral instability and could largely explain the pathogenesis of PTLFCFS.

Keywords Knee joint · Magnetic resonance imaging · Patellar tendon · Hoffa's fat-pad edema · Patellofemoral instability

Introduction

The anterior aspect of the knee consists of muscles, aponeuroses, ligaments, and the joint capsule, which provide a stabilizing system for knee motion. The quadriceps muscles and aponeuroses are the main active soft-tissue stabilizers. The patellar tendon, medial and lateral patellofemoral ligament, and portions of the fascia lata comprise the passive soft-tissue stabilizers [1]. The infrapatellar (Hoffa's) fat pad is an intracapsular but extrasynovial structure underneath the patellar tendon and patella and in front of the femoral condyles and tibial plateau that provides mechanical cushioning and stabilizes the patella in extreme extension and flexion motions [2–4].

Anterior knee pain during motion, even in ordinary activities, is a common complaint among patients. Superolateral Hoffa's fat-pad (SHFP) edema is one of the causes of anterior knee pain, especially in young people [5], and it is known that the infrapatellar fat pad, which contains macrophages, lymphocytes, granulocytes, and nociceptive nerve fibers, can easily become edematous in the presence of an inflammatory reaction caused by impingement [6]. Subhawong et al. [7] found the incidence of 50% of SHFP edema in non-elderly patients presenting with knee pain and suggested that it might be an important indicator of underlying patellofemoral

✉ Haitao Yang
frankyang119@126.com

[1] Department of Radiology, The First Affiliated Hospital of Chongqing Medical University, 1 Youyi Road, Chongqing 400016, Yuzhong District, China

impingement in younger, symptomatic patients. In clinical practice, the signs and physical examination findings of SHFP edema are not specific and similar to those of patellar pain syndrome, and there is no clear boundary between patellar pain syndrome and potential patellar instability in some literature reports [8]. Magnetic resonance imaging (MRI) has shown excellent ability and plays an irreplaceable role in the observation of soft tissue. MRI can simultaneously assess all structures of the knee and help to comprehensively understand the causes of anterior knee pain. The MRI findings of SHFP edema are typical, and characterized by focal high signal intensity between the patellar tendon and lateral femoral condyle on fat-suppressed T2-weighted or proton density-weighted images [7, 9]. Chung et al. [10] first described edema within the SHFP as patellar tendon-lateral femoral condyle friction syndrome (PTLFCFS). Several studies have reported that SHFP edema may correlate with an underlying patellofemoral instability, such as maltracking and malalignment [9, 11–13]. The exact mechanism has not been clarified, and there has been no relevant study on Asian or Chinese patients. Therefore, we performed this study to investigate more PTLFCFS cases, to determine the incidence and clinical imaging findings of PTLFCFS, and to confirm whether there is a correlation between PTLFCFS and patellofemoral subtle instability.

Materials and methods

Subjects

This study was approved by the Committee for Human Research of our institution. We retrospectively reviewed patients with chronic anterior knee pain who underwent MRI between January 2014 and March 2017 by using the Picture Archiving and Communication Systems at our department. We included patients with an imaging diagnosis of increased signal changes on T2 or proton density-weighted MRI in the anterolateral patellofemoral joint interpreted as focal inflammatory edema. The inclusion criteria were anterior knee pain for >3 months and SHFP edema located between the patellar tendon and the lateral femoral condyle on MR images (Fig. 1) [7, 11–13]. The exclusion criteria were unknown patellofemoral history; absence of anterior knee pain; presence of internal meniscus lesions; and history of patellar dislocation, patellofemoral traumatism, or arthroscopy or surgery of the knee. All the clinical information was acquired by reviewing the electronic medical records or collected by telephone for medical history if uncertain on records. Subjects in the control group were selected from among patients without SHFP edema and other obvious detectable knee structural lesions on MRI during the same period and of a similar age

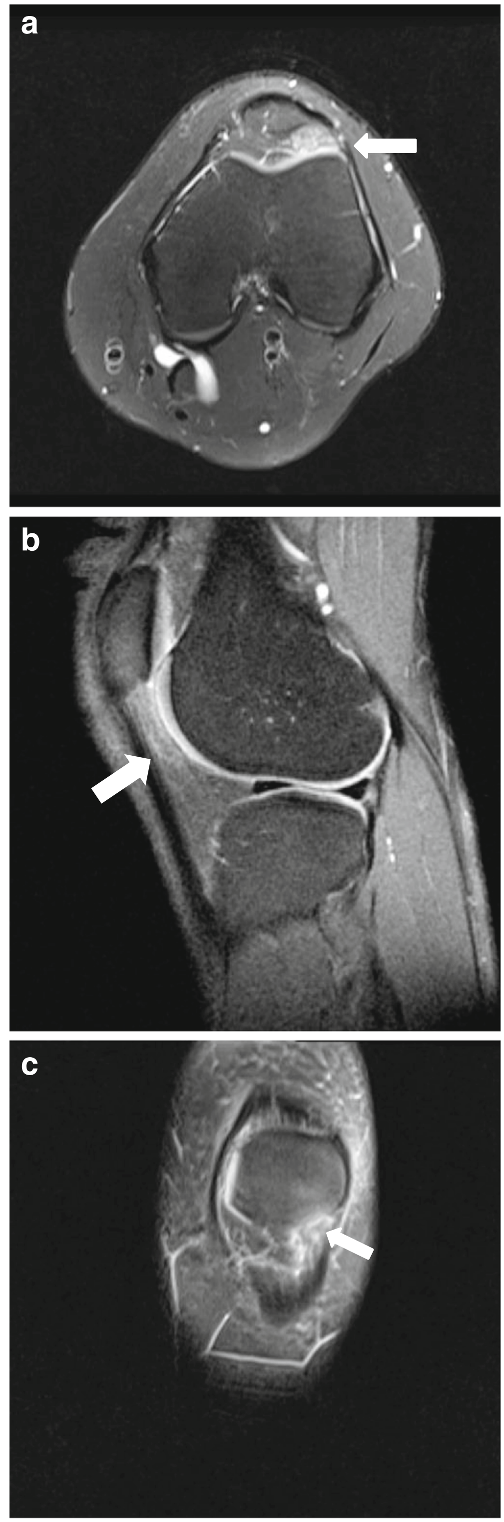


Fig. 1 Magnetic resonance imaging (MRI) findings in a patient with superolateral Hoffa's fat-pad (SHFP) edema. **a** MRI of a 24-year-old woman with bilateral knee pain for 5 months. The axial intermediate-weighted MRI with fat saturation of the left knee shows focal hyperintense edema-like signals within the SHFP (*white arrow*). **b** Sagittal intermediate-weighted MRI with fat saturation showing the same ill-defined edema-like zone with high signal intensity within the SHFP (*white arrow*). **c** Coronal intermediate-weighted MRI with fat saturation illustrating the same findings (*white arrow*)

range to the study group at our department, who met the exclusion criteria except for the absence of anterior knee pain.

MRI protocol

Magnetic resonance imaging was performed using 1.5-T MRI equipment (Magnetom Essenza; Siemens Healthcare, Munich, Germany) with an extremity matrix knee coil (a Tim coil). The imaging protocol was as follows: sagittal and coronal T1 fast spin-echo (repetition time/echo time 306/12 ms, field of view 16 cm, matrix size 320 × 320, slice thickness 4 mm), sagittal T2 turbo spin-echo (repetition time/echo time 3,220/99 ms, field of view 16 cm, matrix size 320 × 320, slice thickness 4 mm), sagittal and coronal intermediate-weighted fast spin-echo with fat saturation (repetition time/echo time 2,800/38 ms, field of view 16 cm, matrix size 256 × 256, slice thickness 4 mm), and axial intermediate-weighted fast spin-echo with fat saturation (repetition time/echo time 2,800/51 ms, field of view 16 cm, matrix size 232 × 256, slice thickness 4 mm).

Image analysis

All MRI images were independently reviewed by two musculoskeletal radiologists (Guo and Sheng, with 6 and 10 years of clinical experience respectively), and the presence of SFHP edema was determined as focal high signal intensity with ill-defined margins on T2-weighted or proton density-weighted fat-suppressed MR images between the patellar tendon and the lateral femoral condyle. It must be observed on at least two consecutive slices and simultaneously displayed in the axial, coronal, and sagittal positions according to published criteria [7]. Patellofemoral MRI parameters were quantitatively measured by two other fellowship-trained musculoskeletal radiologists (Li and Yu, with 4 and 15 years of clinical experience respectively), who were both blinded to the diagnoses. First, they did not know the specific research content of this study and the inclusion criteria of the study group. Second, all of the data, both the study and the control group, were mixed, then the mixed ID numbers were distributed to them for measurement. All measurements were repeated by one of the radiologists (Li), and the interval between the first and second reading was 4 weeks.

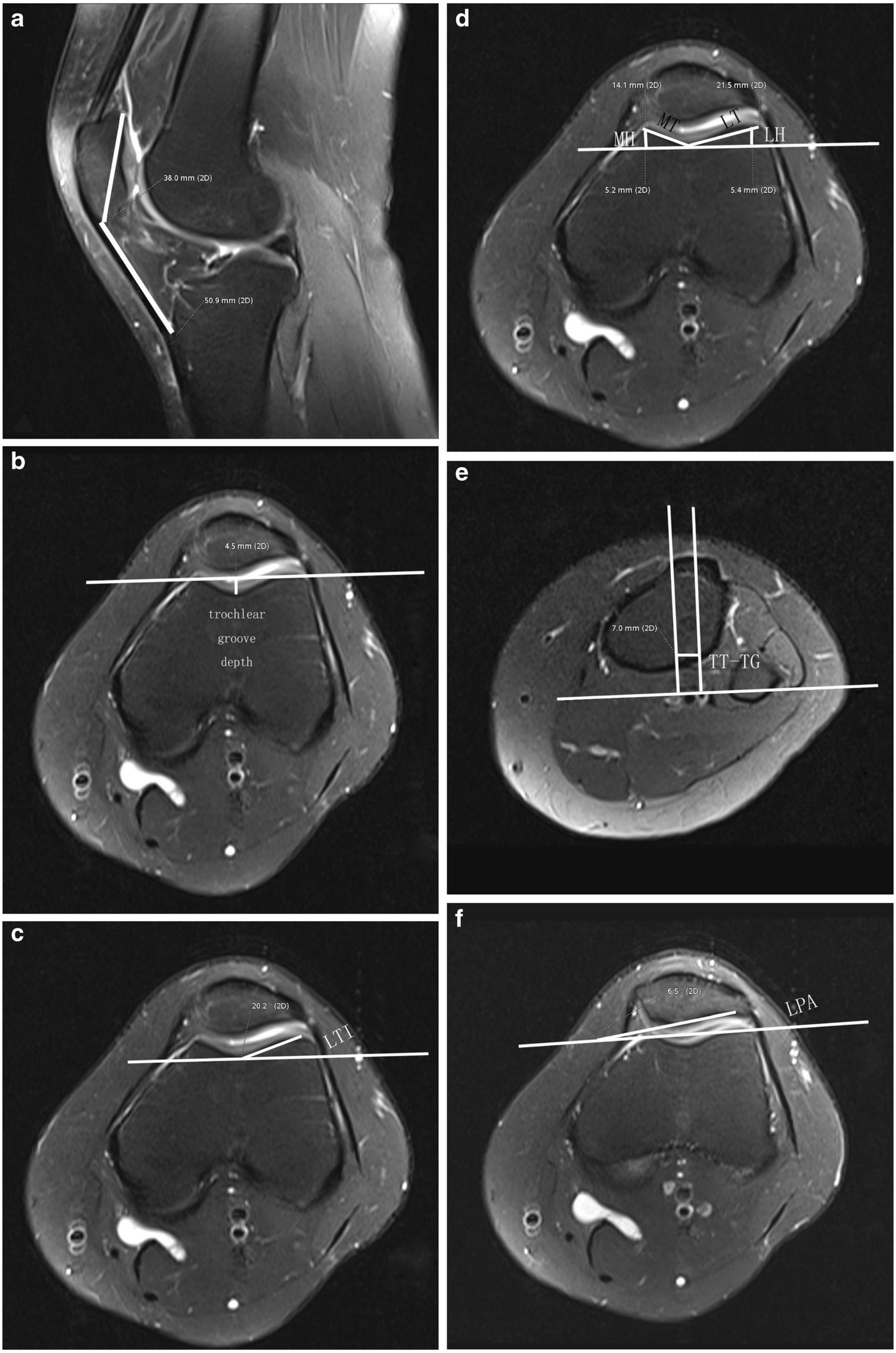
A total of seven quantitative parameters for evaluating patellofemoral stability and their relations were calculated at each MRI examination, including the Insall–Salvati ratio, tibial tuberosity–trochlear groove distance (TT–TG), trochlear groove depth, medial trochlear/lateral trochlear length (MT/LT) ratio, medial trochlear/lateral trochlear height (MH/LH) ratio, lateral patellofemoral angle (LPA), and lateral trochlear inclination (LTI) angle. The Insall–Salvati ratio [14] was calculated as the patellar tendon length divided by the maximum patellar length on sagittal MRI (Fig. 2a). If the Insall–Salvati ratio was >1.2, we considered it to be patella alta. Trochlear measurements (including trochlear groove depth, MT/LT, MH/LH, and LTI angle) were performed on axial proton density-weighted fast spin-echo MRI at the closest to 3 cm above the joint line, based on reference lines measured on coronal images (Fig. 2b–d) [7, 12, 13]. The trochlear groove depth was measured as the perpendicular distance between deepest point of the trochlear groove and the line tangent to the anterior aspect of the femoral condyles, and a trochlear depth of >3 mm was defined as normal [7]. The LTI was measured as the angle between the bony lateral trochlear facet and the tangent of the posterior femoral condyles. The normal LTI angle was >11° [15]. To measure the TT–TG distance, a reference line was first drawn tangentially to the posterior femoral condyles at the deepest point of the trochlear groove; then, two lines perpendicular to the reference were drawn at the deepest point of the trochlear groove and the anterior-most point of the tibial tuberosity respectively (Fig. 2e). The distance between the two lines represented the TT–TG distance, and a TT–TG distance >20 mm was considered abnormal [16–18]. The LPA was used to survey the lateral patellar tilt and was measured at axial slices where the patella was the widest on intermediate-weighted fast spin-echo MRI (Fig. 2f). It was the angle between two lines: one line drawn along the lateral patellar facet and another line drawn along the anterior aspect of the femoral condyles. An LPA >8° was defined as normal [19].

Statistical tests

The subjects were categorized, according to the inclusion and exclusion criteria, into the SHFP edema-positive group and the control group. Intraclass correlation coefficients (ICCs) were used to assess the intra- and inter-reader reliability of MRI quantitative measures. Continuous variables with a normal distribution were expressed as mean ± standard deviation, and Student's *t* test was used to detect the difference. On the other hand, continuous variables with an abnormal distribution were expressed as median (quartile) and analyzed using Wilcoxon test for all values of the quantitative MRI patellofemoral parameters of the two groups. The diagnostic efficiency of various patellofemoral measurements for PTLFCFS was determined using receiving-operator characteristic (ROC) curve analysis. All statistical analyses were performed using SPSS for Windows software (version 17.0; SPSS, Chicago, IL, USA), and the significance level was set at 0.05.

Results

A total of 100 knees (31 left, 29 right, and 20 bilateral) of 80 patients (22 men, 58 women, age range 16–61 years, mean


a
38.0 mm (2D)
50.9 mm (2D)
b
4.5 mm (2D)
trochlear
groove
depth
c
20.2 (2D)
LTI
d
14.1 mm (2D)
21.5 mm (2D)
MT
LT
MH
LH
5.2 mm (2D)
5.4 mm (2D)
e
7.0 mm (2D)
TT–TG
f
6.5 (2D)
LPA

◀ **Fig. 2** Methods for determining the seven quantitative patellofemoral parameters and calculating their relations using MRI. **a** MRI of the same patient as that in Fig. 1. The Insall–Salvati ratio was measured on the sagittal intermediate-weighted MRI and calculated as the patellar tendon length/maximum patellar length. **b** The trochlear groove depth was measured as the perpendicular distance between the deepest point of the trochlear groove and the line tangent to the anterior aspect of the femoral condyles. **c** The lateral trochlear inclination (*LTI*) was the angle between the bony lateral trochlea facet and the tangent of the posterior femoral condyles. **d** The medial trochlear/lateral trochlear (*MT/LT*) and medial trochlear/lateral trochlear (*MH/LH*) ratios were calculated from the length and height of the medial and lateral trochlea. **e** The tibial tuberosity–trochlear groove (*TT–GG*) distance was measured as the line drawn from the deepest point of the trochlear groove to the anterior-most point of the tibial tuberosity. **f** The lateral patellofemoral angle (*LPA*) was the angle between two lines: one line drawn along the lateral patellar facet and another line drawn along the anterior aspect of the femoral condyles

age 38 ± 9 years) with a diagnosis of PTLFCFS were included in this study of 9,029 knees with MRI during that period. The control group (normal group) included a total of 88 knees (30 left, 34 right, 12 bilateral) of 76 patients (46 men, 30 women, age range 20–50 years, mean 35 ± 8 years) with normal knees. The incidence rate of PTLFCFS at our institution was about 1.1%. When we restricted the age range from 16 to 61 years for the PTLFCFS group, the incidence rate of PTLFCFS was about 1.8% among 5,488 knees with MRI.

Seven patellofemoral parameters for detecting subtle patellofemoral instability were compared between the PTLFCFS group and the control group. The intra-reader ICCs for these quantitative measurements ranged from 0.951 to 0.987, whereas the inter-reader ICCs ranged from 0.893 to 0.969, as shown in Table 1, indicating good intra- and inter-reader reliability. The trochlear depth, MT/LT, LPA, and LTI angle were all significantly lower ($p < 0.001$) and the Insall–Salvati ratio was significantly higher ($p < 0.001$) in the PTLFCFS group (Table 2). There were no significant differences in both TT–TG distance and MH/LH ratio between the two groups ($p = 0.231$ and 0.073 respectively).

Table 1 The intra- and inter-observer agreement between two radiologists of patellofemoral measurement parameters

	Intra-observer ICCs	Inter-observer ICCs
Insall–Salvati ratio	0.983	0.899
TT–TG	0.987	0.966
Trochlear groove depth	0.967	0.932
MT/LT ratio	0.951	0.898
MH/LH ratio	0.958	0.969
LPA	0.986	0.962
LTI	0.982	0.893

TT–GG tibial tuberosity–trochlear groove, *MT/LT* medial trochlear/lateral trochlear length, *MH/LH* medial trochlear/lateral trochlear height, *LPA* lateral patellofemoral angle, *LTI* lateral trochlear inclination, *ICCs* intraclass correlation coefficients

The ROC curves of the Insall–Salvati ratio, trochlear depth, MT/LT, LPA, and LTI angle were generated (Fig. 3, Table 3). The area under the curve (AUC_1) of the Insall–Salvati ratio was 0.925 (95% confidence interval [CI], 0.882–0.967; Youden's index, 0.786; cutoff value, 1.203; estimated sensitivity and specificity: 0.82 and 0.966 respectively). The AUC_2 of trochlear depth was 0.784 (95% CI, 0.718–0.850; Youden's index, 0.55; cutoff value, 4.96; sensitivity and specificity: 1 and 0.55 respectively). The AUC_3 of MT/LT was 0.8 (95% CI, 0.738–0.862; Youden's index, 0.461; cutoff value, 0.636; sensitivity and specificity: 0.761 and 0.70 respectively). The AUC_4 of LPA was 0.731 (95% CI, 0.658–0.805; Youden's index, 0.447; cutoff value, 9.14; sensitivity and specificity: 0.818 and 0.629 respectively). The AUC_5 of the LTI angle was 0.675 (95% CI, 0.599–0.752; Youden's index, 0.309; cutoff value, 16.245; estimated sensitivity and specificity: 0.989 and 0.32 respectively). The efficiency of the Insall–Salvati ratio was highest among the five patellar maltracking parameters.

Discussion

Patellar tendon-lateral femoral condyle friction syndrome has been described in some literature reports [8, 10]. Anterior knee pain is the very common clinical presentation that typically occurs with activity, and treatment is generally similar to that for other patellofemoral pain syndromes, including a variety of therapeutic methods such as cold, ultrasound, electrotherapy modalities, exercise therapy [20]. However, overall, there has been little research on its outcome and prognosis. In this study, we enrolled a large sample to systematically evaluate the potential association by comparing the anatomical and morphological MRI parameters of the patellofemoral joint of patients with SHFP edema with those of the normal group, confirming the presence of a correlation between PTLFCFS and patellofemoral instability.

The prevalence of SHFP edema in the general population is unclear. In this study, we retrospectively reviewed the records of 9,029 knees during a 3-year period at our institution, and 100 cases of PTLFCFS were found, suggesting an incidence of about 1.1–1.8% in Chinese patients. Few studies have discussed the prevalence of PTLFCFS, and several studies reported the prevalence of SHFP edema in the USA and Europe, which ranged widely from 4% to 50% [7, 12]. Mehta et al. [3] reported that the prevalence of SHFP edema in female volleyball players was 50% (all had bilateral disease), which is very high. The incidence rate in our study was much lower, and this might be related to our longer study period and higher number of samples.

The utility of various patellofemoral measurements is slightly controversial in the literature. The results of our study confirmed the association between PTLFCFS and some

Table 2 Comparison of magnetic resonance imaging (MRI) quantitative patellofemoral parameters between the patellar tendon-lateral femoral condyle friction syndrome (*PTLFCFS*) and control groups

	PTLFCFS group	Control group	*t/z*	*p*
Insall–Salvati ratio	1.340 ± 0.144	1.104 ± 0.156	10.729	<0.001
TT–TG distance	7.951 ± 3.043	7.227 ± 3.052	1.202	0.231
Trochlear groove depth	4.819 ± 1.454	6.197 ± 0.942	−7.8	<0.001
MT/LT	0.571 ± 0.115	0.698 ± 0.087	−8.575	<0.001
MH/LH*	0.61 (0.41–0.83)	0.70 (0.57–0.86)	−1.792	0.073
LPA*	8.02 (4.71–11.66)	11.93 (10.17–14.22)	−5.432	<0.001
LTI	19.773 ± 5.477	23.014 ± 3.586	−4.825	<0.001

*From the Wilcoxon test; statistical results are expressed as median (percentile) and statistical values are expressed by *z*

commonly measured parameters for detecting subtle patellofemoral instability. Moreover, our results were generally concordant with those of previous studies, despite some small differences.

Patellar height has been shown to correlate with patellofemoral instability, pain, chondromalacia, and arthrosis [21, 22]. Our study showed that the Insall–Salvati ratio was significantly higher in the PTLFCFS group and 82% knees had patella alta (82 out of 100), which coincided with the results of Matcuk et al. [13]. In addition, the efficiency of the Insall–Salvati ratio in our study was the highest among other patellar maltracking parameters, which means that patella alta could be the most important risk factor for PTLFCFS. A higher patella may not be able to engage the trochlear groove early in knee flexion, and the patellar tendon would generate tension if the knee was positioned with a flexion of 20° [14]. In patellofemoral motion in patients with patella alta, a straightened and elongated patellar tendon could more easily mechanically impinge the fat pad between the lateral femoral condyle and the patellar tendon, leading to edema and pain in Hoffa's fat pad between them. Moreover, patella alta is an important factor related to recurrent patellar instability [23], which results in excessive patellar lateral motion by reducing the joint contact between the patella and trochlea in flexion; thus, it is probably a strong risk factor for SHFP edema.

Evaluating the morphology of the femoral condyles has been found to be important in patients with anterior knee pain. The result of our study revealed that the femoral trochlear groove depth, MT/LT ratio, and LTI angle were significantly decreased in the PTLFCFS group, which further shows that PTLFCFS is closely related to patellofemoral instability. The trochlear groove depth in the PTLFCFS group was >3 mm but <5 mm (55 out of 100), suggesting the possibility of femoral trochlear dysplasia. The depth and steepness of the trochlear groove affects the stability of the patellofemoral joint, and a reduction in trochlear groove depth could increase the patellar height [24]. The LTI angle was significantly lower in the PTLFCFS group, similar to the findings of some previous reports. Keser et al. [25] found that the LTI angle was significantly lower in the anterior knee pain group than in the control group, and revealed that the frequency of trochlear dysplasia in patients with anterior knee pain was also considerably high. Carrillon et al. [15] reported that subtle patellofemoral instability without any patellar dislocation or subluxation may lead to anterior knee pain. In our study and some other studies [13, 15, 25] of patients with anterior knee pain or PTLFCFS, the average LTI angles were all significantly lower in the patient group, but was >11° (the cutoff value in cases with trochlear dysplasia is 11°). We speculated that there was a risk of or already subtle patellofemoral joint instability in these patients.

In addition, although the TT–TG distance is an important parameter for the evaluation of patellofemoral instability in addition to patellar height and trochlear depth, an increased TT–TG distance has been reported to indicate an increased risk for patellar subluxation [26, 27]. However, in our study, the TT–TG distance did not show a statistically significant difference between the two investigation groups, which is concordant with the study of Subhawong et al. [7]. In contrast, Matcuk et al. [13] found that the TT–TG distance was significantly higher in the SHFP edema group than in the normal group. The lack of a statistical difference in TT–TG distance in our study could be related to subtle patellofemoral instability without any patellar dislocation or subluxation in the PTLFCFS group; otherwise, the TT–TG distance is related to individual knee size and different somatometric values. These factors may have caused the different results from those of other studies, and the association between TT–TG distance and PTLFCFS remains to be investigated in depth.

Fig. 3 Receiving-operator characteristic (*ROC*) curves of the quantitative patellofemoral parameters in the patellar tendon-lateral femoral condyle friction syndrome (PTLFCFS) group. **a** ROC curve of the Insall–Salvati ratio (area under curve [AUC] = 0.925). **b** ROC curve of the trochlear depth (AUC = 0.784). **c** ROC curve of the MT/LT ratio (AUC = 0.800). **d** ROC curve of the LPA (AUC = 0.731). **e** ROC curve of LTI (AUC = 0.675)

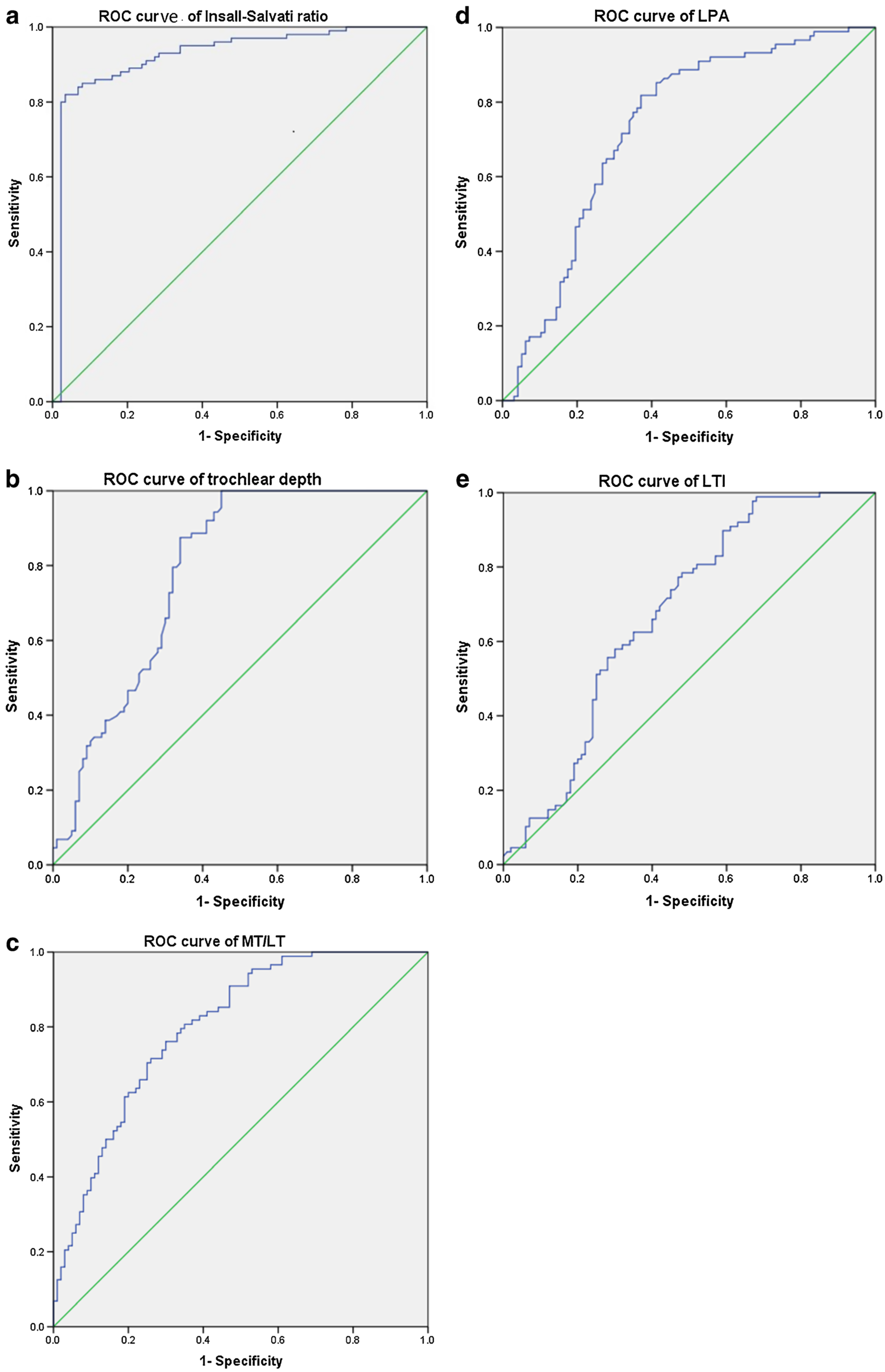

a
ROC curve of Insall-Salvati ratio
b
ROC curve of trochlear depth
c
ROC curve of MT/LT
d
ROC curve of LPA
e
ROC curve of LTI
Sensitivity
1- Specificity
0.0
0.2
0.4
0.6
0.8
1.0

Table 3 Results of receiving-operator characteristic analysis of the Insall–Salvati ratio, trochlear depth, medial trochlear/lateral trochlear length ratio, lateral patellofemoral angle, and lateral trochlear inclination angle in the PTLFCFS group

	PTLFCFS group	Control group	*t/z*	*p*
Insall–Salvati ratio	1.340 ± 0.144	1.104 ± 0.156	10.729	<0.001
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Our study has several limitations. First, the selection of patients with PTLFCFS was based on MR images, and histological or pathological evidence was lacking. The clinical symptoms of this syndrome are relatively mild and subtle, and conservative treatment is given priority; thus, a pathological diagnosis is difficult to obtain. Second, we evaluated only bony morphology without considering the cartilaginous contour, which showed a different form from that of the underlying bone. The influence of PTLFCFS on the cartilage within the patellofemoral joint should also be considered and measured. Third, this was a cross-sectional retrospective study lacking longitudinal data. Future work should include continuous dynamic images to follow up the outcome and prognosis of PTLFCFS, to develop appropriate MRI grading of the SHFP edema so as to reflect the severity of the illness and guide the management of patients, and to quantitatively subcategorize subtle patellofemoral instability so as to accurately elucidate the mechanism of PTLFCFS.

In conclusion, our study identified the presence of subtle patellofemoral instability by quantitatively measuring patellofemoral parameters on MRI of patients with PTLFCFS, and the results confirmed that PTLFCFS is associated with subtle patellofemoral instability, which could largely explain the pathogenesis of PTLFCFS. In fact, the subclinical forms of patellofemoral instability are frequently overlooked in daily clinical practice. Moreover, there is also insufficient understanding of PTLFCFS, despite its high prevalence. We hope that the results of this study can be applied to real clinical practice to help identify patients susceptible to PTLFCFS, so as to enable early monitoring or intervention.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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