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SCIENTIFIC ARTICLE

Reliability of patellotrochlear index in patellar height assessment on MRI—correction for variation due to change in knee flexion

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Abstract

Objectives To assess the reliability of patellotrochlear Index (PTI) in patellar height assessment on successive MRI scans in asymptomatic patients.

Materials and methods Sixty-four patients with two successive MRI scans (128 studies) of the same knee for non-patellofemoral joint symptoms were identified retrospectively. PTI and knee flexion angle were assessed independently by three observers to assess interobserver reliability. The effect of knee flexion on PTI was assessed by comparing the change in values of PTI in each patient correlated with change in knee flexion.

Results Sixty-four MRIs of patients (M:F) aged between 18 and 35 years (mean 24.6) years were assessed. The mean PTI for initial scan group was 0.33% (95% CI: 0.29–0.37; SD: 0.15) and consecutive scan group was 0.30% (CI: 0.27–0.33; SD: 0.3). The difference was not significant ($p = 0.097$ using a paired t test) with high inter-observer correlation (0.9) in both sets. Spearman's rho for knee flexion angle and PTI was found to be positive and statistically significant (0.41; $p = 0.001$). A linear regression model was derived using a scatter chart of change in PTI with change in knee flexion for each patient. The gradient of the linear regression line was used to estimate a cPTI (corrected PTI) value (corrected to 0 degrees of knee flexion), defined as cPTI = PTI – 1.3a (a = knee flexion angle).

Conclusions This study demonstrates high inter-observer correlation of PTI on MRI and high test–retest reliability indicating unconscious quadriceps contraction does not change the index sufficiently. Knee flexion significantly alters PTI, increased patellotrochlear engagement with flexion increases the index. We propose use of the formula cPTI = PTI -1.3a to correct the index to 0 degree knee flexion in clinical practice.

Keywords Patellofemoral joint · Patella alta · MRI · Patellotrochlear index

Introduction

Patellar alta has been associated with patellofemoral disorders like chondromalacia, patellar pain, and maltracking [1–3]. Increased patellar height (patella alta) can contribute to patellar instability, found in 30% of patients with recurrent patellar dislocation [1]. Reduced engagement of patellar articular surface with the trochlear groove can compromise mechanical stability needed to allow a full range of patellofemoral motion [4, 5]. Radiographic indices define patellar height with reference to landmarks on the bony tibia, which results in variable classification of patellar height due to anatomical differences in landmarks used. Biedert et al. have described the patellotrochlear index as a measure of patellar height based on true patellotrochlear cartilage congruence, instead of bony landmarks on MRI to overcome this variation [1].

Patellotrochlear index (PTI) is defined as a ratio of the length of trochlear cartilage overlapping the patella and the patellar cartilage length on a midsagittal MR image of the knee [6]. Values of less than 12.5% suggest patella alta and more than 50% indicates patella infera [6]. Our study assesses the reliability of PTI in assessing patellar height on MRI, by identifying if the index varies on successive MRI

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examinations of the same patient. We also assess how the degree of knee flexion during MRI in clinical practice changes patellar height assessment using this index.

We propose a method to correct this index to 0 degree knee flexion (corrected PTI) to reduce variability due to variation in knee flexion at MRI.

Materials and methods

In this retrospective cohort study, 64 consecutive patients who underwent two successive MRI scans of the same knee for non-patellofemoral joint symptoms were identified from the Radiology Information System (CRIS) of a tertiary teaching hospital between 2012 and 2015. Suspected meniscal or anterior cruciate ligament pathologies were the common indications for knee MRI in the selected cohort.

Patients with anterior knee or patellofemoral symptoms mentioned in the clinical details of the imaging request were excluded from the study to allow assessment of the index in a normal population. MR examinations were performed on either a 1.5-Tesla (Magnetom Avanto/Aera, Siemens) using proton density fat-saturated sequence with TR range/TE range 3500–4000/12–35 ms; matrix size, 256 × 192–224; FOV, 16 × 16 or 18 × 18 cm; slice thickness, 3 mm) or a 3.0 Tesla (Verio, Siemens) with TR range/TE range 2500–3000/18–50; matrix size, 384 × 256; FOV, 16 × 16 cm; slice thickness, 3 mm). A standard knee coil was used for MRI, with knee in near neutral position as in routine practice, with relaxed quadriceps. Each MRI was retrospectively analyzed and PTI was measured independently by three musculoskeletal radiologists (10 years, 7 years, and 1 year experience in musculoskeletal radiology), blinded to each other's readings. On a sagittal proton density–weighted fat-suppressed fast spin-echo sequence, the mid-patellar section was identified with the help of axial cross reference, where the patellar articular cartilage was thickest corresponding to the junction of the lateral and medial patellar facet and patellar length was maximum, as described by Biedert et al. (4) (Fig. 1a, b). Ratio caliper tool on a standard PACS workstation ('Agfa Impax') was used to measure PTI, defined as the length of patellar cartilage overlapping the trochlear cartilage (A-B) divided by length of patellar cartilage (C-B), expressed as a percentage. The methodology was agreed by all observers prior to the blinded analysis.

In clinical practice, the knee is held in near neutral position in the knee coil for a MRI examination. A small variation in degree of knee flexion is unavoidable, depending on the patient's habitus and position of comfort. In this study, we assessed if this variation in knee flexion in routine clinical practice significantly alters patellar height assessment using PTI. The angle of knee flexion at MRI was measured on the mid-sagittal localizer image. Measurement was performed on 'Agfa Impax' using the angle tool, by drawing lines parallel to the posterior margin of the included shafts of femur and tibia (Fig. 2). Patients with hyperextended knees were noted as a negative angle value. The effect of knee flexion on PTI was assessed by comparing the change in PTI for each patient correlated with change in knee flexion.

Statistical analysis was performed on Stata software (StataCorp 2015. Stata Statistical Software: Release 14. College Station, TX, USA, StataCorp LP). Inter-observer reliability of PTI was analyzed for each MRI. To assess the reliability of PTI on successive MRI studies of the same knee, which would also assess the effect of unconscious quadriceps contraction (if any, although this was not objectively measured given the retrospective nature of this study). The mean PTI measured by the three radiologists for each patient on the initial MRI was compared to the mean PTI on the consecutive MRI of the same patient. Intraclass correlation coefficients were calculated to determine the inter-observer and inter-group variation.

To investigate the relation of PTI with knee flexion angle, the Pearson correlation coefficient was calculated between the knee flexion angle and average PTI score measured by the three radiologists on consecutive MRI scans on each patient. To correlate change in PTI with change in knee flexion for each patient, the mean of three PTI values for the initial scan and three PTI values for the subsequent MRI scan was calculated. The difference between these paired mean PTI values, as well as the difference of flexion angles for initial and subsequent scans was calculated for each patient and tabulated (Table 1). A scatter plot of these two variables was used to derive a linear regression model. The gradient of this line was used to apply a correction to estimate the PTI values that would have been obtained if the flexion angles had been zero in all cases. To test the validity of the formula derived to correct PTI for knee flexion, three knees of asymptomatic volunteers were scanned with varying knee flexion. Informed consent according to Trust guidelines were obtained from each volunteer.

Sagittal proton density fat-saturated images of the knee were obtained with knee in neutral position (with two pads placed under the ankle to prevent knee flexion), a position of mild flexion and moderate flexion of the knee in the knee coil (achieved by sequentially removing one and both pads from under the ankle). The angle of knee flexion was assessed on localizer images, and PTI was measured on the sagittal images obtained (Fig. 3a, b, c). The corrected PTI (cPTI) formula was used to calculate a predicted PTI for the given knee flexion angle, and results were compared to actual measured PTI for each flexion angle (Table 2). To test this hypothesis, three healthy volunteer knees were scanned in 2018, at three positions of knee flexion. The PTI was measured at each knee flexion angle, and this was compared to the 'predicted PTI' derived by using the formula.

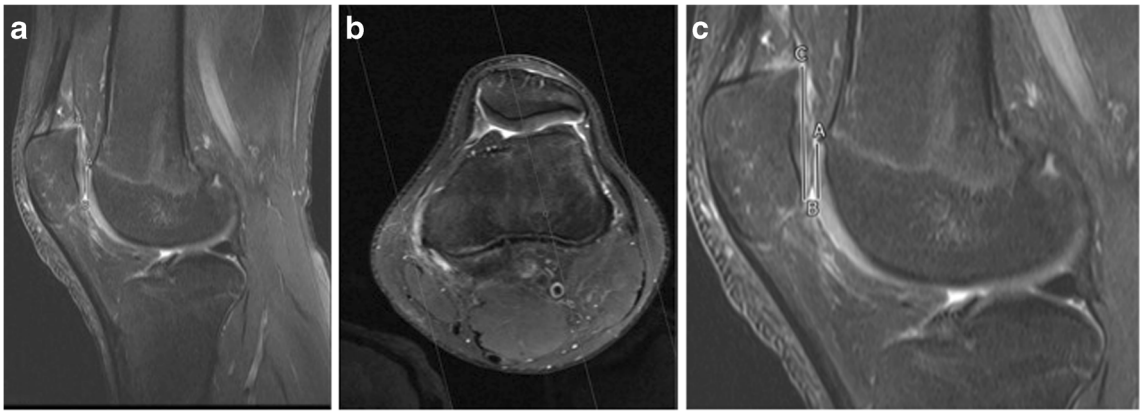

Fig. 1 **a** Midsagittal proton density fat-saturated image of the knee through mid-patella is identified with the help of axial cross reference image (**b**). Measurements of patellotrochlear index using ratio caliper tool (Impax 6, Agfa Healthcare), magnified view of the same (Fig. 1c)

Results

Reliability of PTI on successive same knee MRI studies

Sixty-four patients (128 MRI scans) who underwent two consecutive MRI examinations of the same knee were identified from the Radiology Information System. Patients were aged between 18 and 35, mean age was 24.6 years (95% CI: 19.2–32.6). Seventeen out of 64 patients (27%) included in the study were females.

Mean PTI for the initial MRI scan group was 0.33% [95% CI: 0.29–0.37] and the subsequent MRI scan group was 0.30% [CI: 0.27–0.33]. Inter-observer correlation was high (0.9) in both sets indicating high interobserver reliability. The individual test–retest reliabilities for the three readers were 0.436, 0.546, and 0.298 respectively ($p < 0.001$, $p < 0.001$, and $p = 0.008$) between consecutive MRI scans on the same knee, indicating the index was reliable on successive same knee MRI studies, with little effect of unconscious quadriceps contraction. There was no subjective difference in measuring the patellotrochlear index on 3 T when compared to 1.5-T scanners due to variable spatial resolution. However, a different study design will be required to scientifically answer this particular question, which would involve measuring the index on the same knee with different scanning parameters.

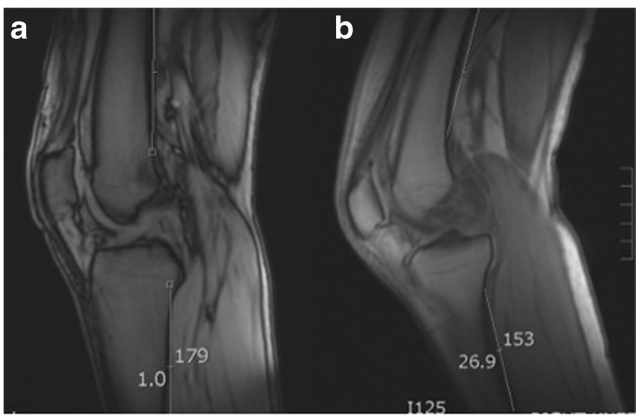

Fig. 2 **a, b** Use of localizer images for measurement angle of knee flexion on the mid-sagittal image, knee is held at 1 degree flexion (**a**); **b** demonstrates a significantly flexed knee at 27°, which increases patellotrochlear engagement and therefore the patellotrochlear index. Angle caliper on PACS used for this measurement (Impax 6, Agfa Healthcare)

Effect of knee flexion on PTI

The degree of knee flexion during MRI in routine clinical practice varied from − 6.0 to + 19.6 degrees. A consistent increase in the mean PTI with increasing knee flexion angle was demonstrated (Fig. 4). Pearson's correlation coefficient was used to calculate the correlation between mean PTI measurement across the three observers and knee flexion angle. A moderate positive correlation was reported (0.67; $p < 0.005$).

A linear regression model was derived using a scatter chart of change in PTI with change in knee flexion for each patient (Fig. 5). The gradient of the linear regression line was used to estimate a cPTI (corrected PTI) value (corrected to 0 degrees of knee flexion). This is defined as cPTI = PTI-(1.327a + *0.5683)* (where a = the knee flexion angle). The correction to the PTI value to derive cPTI can be a subtraction (if knee is held flexed on MRI) or an addition (if knee is hyperextended on MRI). This can be further simplified to cPTI = PTI - 1.3a, as the constant term (0.5683) in the linear regression equation is not significantly different from 0 (the p value is 0.7), if no constant term is included in the model the linear regression equation is 1.3a instead of 1.327a + 0.5683.

To test the hypothesis, three knees of asymptomatic volunteers were scanned in neutral (no flexion) and varying degrees of knee flexion. The corrected PTI (cPTI) formula was used to calculate a predicted PTI for the given knee flexion angle, and results were compared to actual measured PTI (Table 2). The results showed good correlation of the measured PTI on the knee scanned at a given flexion angle, with the predicted PTI

Table 1 Table showing mean PTI in relation to change in flexion angle of the knee on paired same knee MRI scans of each patient

S. no.	Mean of initial PTI	Mean of follow-up PTI	Change in flexion angles between initial and follow-up (degrees)	Mean PTI change
1.	40.3	32.3	− 1.5	− 8.0
2.	25.3	39.3	− 1.7	14.0
3.	32.3	23.3	− 5.0	− 9.0
4.	37.3	32.0	3.4	− 5.3
5.	55.3	33.3	2.0	− 22.0
6.	55.3	44.0	− 2.8	− 11.3
7.	91.0	52.7	− 6.4	− 38.3
8.	42.3	49.7	2.9	7.3
9.	59.0	41.0	0.0	− 18.0
10.	19.0	20.7	1.0	1.7
11.	28.3	14.7	− 2.5	− 13.7
12.	34.7	15.3	− 12.8	− 19.3
13.	19.3	44.3	11.3	25.0
14.	29.7	28.7	− 0.8	− 1.0
15.	14.3	16.7	− 3.9	2.3
16.	45.7	42.3	− 2.5	− 3.3
17.	26.0	35.0	3.4	9.0
18.	36.3	32.0	− 7.5	− 4.3
19.	23.0	13.3	− 0.8	− 9.7
20.	30.0	33.3	0.1	3.3
21.	25.3	24.0	1.5	− 1.3
22.	58.7	28.0	− 16.2	− 30.7
23.	22.3	20.3	2.9	− 2.0
24.	11.3	47.3	10.8	36.0
25..	39.3	51.0	17.5	11.7
26.	49.3	25.3	− 6.4	− 24.0
27.	11.0	12.3	− 6.0	1.3
28.	23.0	48.0	9.9	25.0
29.	14.3	14.0	− 6.6	− 0.3
30.	38.0	64.7	5.7	26.7
31.	40.7	34.0	0.3	− 6.7
32.	25.7	15.7	− 0.3	− 10.0
33.	26.7	36.7	11.7	10.0
34.	52.3	33.3	− 17.8	− 19.0
35.	22.3	25.3	2.5	3.0
36.	30.3	26.3	− 2.8	− 4.0
37.	36.0	43.0	2.6	7.0
38.	23.7	34.7	− 2.7	11.0
39.	15.0	29.0	− 10.9	14.0
40.	23.3	23.0	0.1	− 0.3
41.	24.3	26.3	− 3.8	2.0
42.	35.7	26.7	1.2	− 9.0
43.	15.0	15.0	2.1	0.0
44.	25.7	15.0	− 5.8	− 10.7
45.	22.0	31.7	− 1.5	9.7
46.	35.3	49.3	− 2.9	14.0
47.	20.0	27.0	1.1	7.0
48.	33.0	40.3	− 1.2	7.3
49.	32.0	33.0	5.2	1.0
50.	31.0	38.0	− 4.6	7.0
51.	23.0	29.7	1.9	6.7
52.	28.3	17.0	− 6.6	− 11.3
53.	9.7	8.0	− 5.8	− 1.7
54.	33.0	23.3	− 4.4	− 9.7
55.	27.7	20.0	− 2.4	− 7.7
56.	65.3	22.7	− 10.1	− 42.7
57.	22.3	19.0	− 5.5	− 3.3
58.	25.7	31.0	5.5	5.3
59.	33.0	29.7	− 1.3	− 3.3
60.	49.7	42.7	0.9	− 7.0
61.	27.3	19.7	0.2	− 7.7
62.	40.7	51.0	− 2.5	10.3
63.	43.0	62.0	0.7	19.0
64.	18.3	29.3	− 10.0	11.0

derived using the proposed formula for the same flexion angle. This confirms the regression line can reliably predict change of PTI with knee flexion angle.

The test–retest reliability improved on correcting the PTI for knee flexion. The test–retest reliabilities for the three readers were 0.551, 0.642, and 0.409 for the corrected PTI values (all $p < 0.001$).

Discussion

The patellofemoral joint has gained attention in osteoarthritis research due to the substantial prevalence of patellofemoral OA [7]. A high-riding patella contributes to symptoms of patellar maltracking, chondromalacia and anterior knee pain [1].

Measures of patellofemoral congruence are therefore relevant and have therapeutic implications. Different methods for assessing patellar height have been described.

Radiographic indices utilize bony landmarks and anatomy, which introduces variation due to patellar shape and tibial tuberosity anatomy [8]. There is significant disparity between cartilaginous and bony anatomy of the patellofemoral joint [9]. Various radiographic indices like Caton–Deschamps, Insall–Salvati, modified Insall–Salvati and Blackburne–Peel correlate well with MRI [10–15]. However, Seil et al. and Ali et al. demonstrated a high degree of variation in the results of various indices leading to differences in patellar height classification, mostly due to variation in the osseous anatomy

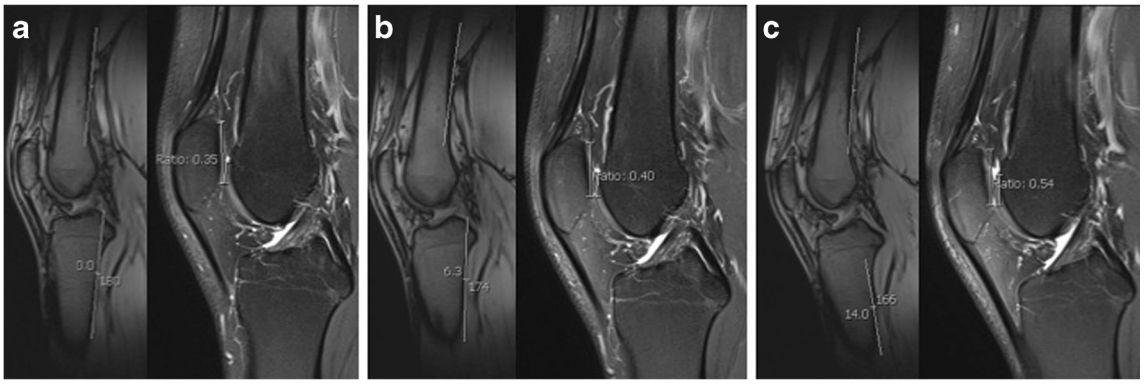

Fig. 3 **a, b, c** Series of sagittal proton density fat-saturated MRI images with patello-trochlear index measured in an asymptomatic volunteer, at neutral (**a**), 6 degrees (**b**), and 14 degrees (**c**) knee flexion

and also weight-bearing and knee flexion [1, 13, 16, 17]. They recommended the use of an index based on the patellofemoral articular surface.

The patellotrochlear index (PTI), described by Biedert and Albrecht, addresses this limitation of radiographic indices, as a measure of engagement of cartilaginous articulating surfaces of patella and trochlea [6]. The cartilaginous patellotrochlear overlap is a functionally relevant parameter that accounts for variations in trochlear length and shape and is unaffected by differences in patellar anatomy, such as long distal non-articulating facet, or by physical variations in the tibial tubercle [16]. PTI is also unaffected by variations of the patellar tendon origin and attachment sites as seen in Sinding–Larson–Johansson, Osgood–Schlatter disease, or post-surgery [18].

In this study, we addressed the limitations of previous studies on reliability of PTI, examining test–retest reliability by measuring the PTI on two MRI examinations on the same knee for each patient [6, 19]. In addition, to our knowledge, this study is the first to examine the relationship between angle of knee flexion in the knee coil for MRI and PTI.

We confirmed high interobserver correlation between observations of three radiologists blinded to each other's findings, by analyzing reproducibility in patients who had two successive MRIs of the same knee. We used successive examinations as a control group to evaluate the effect of involuntary quadriceps contraction on PTI, as followed by other authors [19]. The test–retest reliability was 0.46 ($p = 0.0001$) between consecutive MRI scans on the same knee, indicating insignificant variation of PTI due to involuntary quadriceps contraction.

Secondly, influence of knee flexion on PTI was evaluated, by assessing change in PTI for each patient with change in degree of knee flexion. We found significant variation of PTI with change of knee flexion. A linear regression model with these variables was used to derive a formula to correct the measured PTI to a value at neutral knee flexion (corrected PTI or cPTI). This should prove useful in clinical practice, as there is an unavoidable variation in the degree of flexion of the knee joint in the knee coil for MRI. Further assessing implications on clinical practice, it can be predicted that a variation of knee flexion between +4 and − 4 degrees, would result in an error of 5 in the PTI value [cPTI-PTI = 5 = 1.3a]. This would be an acceptable difference if PTI is well within the normal range (PTI values ranging from15 to 45), but will make a difference at values which suggest patella alta, patella baja or borderline values (< 15, > 55), when angle of knee flexion should be assessed and the index should be corrected using the proposed formula. The variation in PTI can also be significant at large knee flexion values (> = 15 degrees), when the difference between measured and corrected PTI is nearly 20 or more.

Table 2 PTI assessed on neutral and two flexion angles in asymptomatic knees, compared to predicted PTI derived from proposed formula

	Knee flexion angle (A degrees)	PTI on image (%)	Predicted PTI derived as Predicted PTI = PTI+(1.3 × A)
Knee A	0.3 (neutral)	35	
	6	40	42.8
	14	54	53.2
Knee B	0.1 (neutral)	30	
	4	37	35.2
	15	50	49.5
Knee C	1.2	30	28.4 (corrected for 0 flexion)
	8	37	38.8
	9	44	40.1

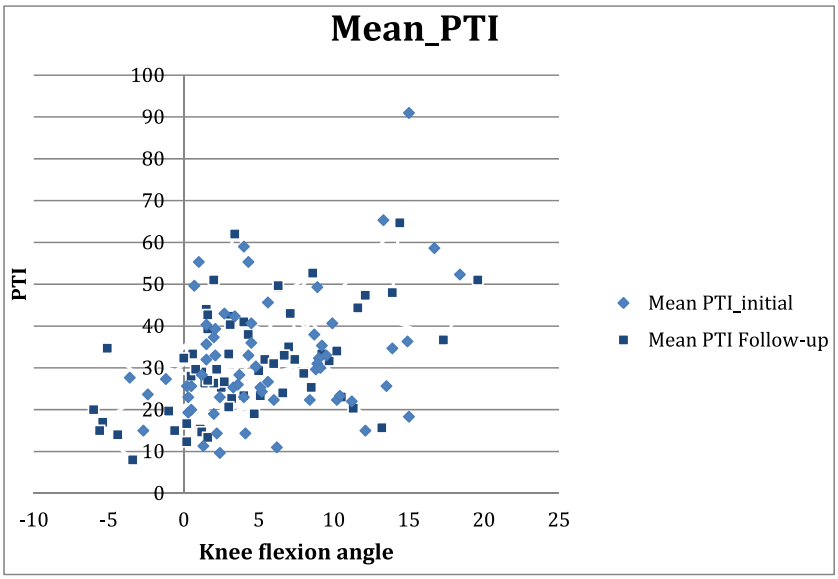

Fig. 4 Scatter diagram showing correlation of the angle of knee flexion and PTI on consecutive MRI scans

A similar study assessed the effect of flexion on parameters for measuring trochlear dysplasia [20]. Becher et al. demonstrated significant variation of patellofemoral indices due to knee flexion and weight bearing [17]. Our study moves a step further by providing a potential solution to neutralize the variability of patellar height assessment with variation of knee flexion.

A limitation of this study is the lack of standardized knee flexion angles for the MRI study. We have also not compared the index with other measures of patellar height.

The flexion angle was measured on mid-sagittal localizer images of the MRI, given this was a retrospective cohort study, which reflects true clinical practice. The paired MRI examinations of the same knee, however, allowed derivation of a linear regression model to allow a correction factor for flexion to be derived.

Conclusions

A reliable method of patellar height assessment is important for treatment planning in patients with patellar maltracking. The patellotrochlear index is a method for assessing patellar height based on patellotrochlear cartilage congruence on MRI.

Our study demonstrates high interobserver and test–retest reliability of patellotrochlear index (PTI) in assessing patellar height on MRI. The study demonstrated significant variation

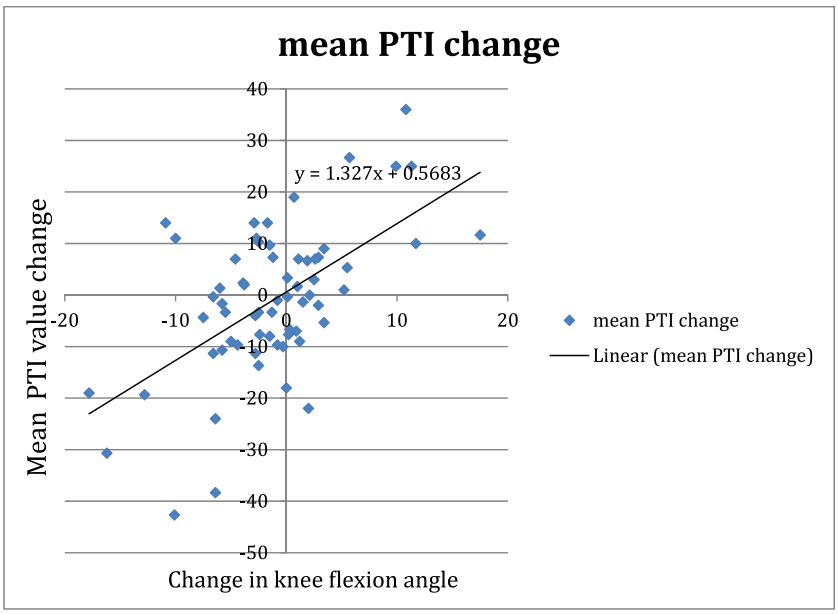

Fig. 5 Graph showing the mean PTI value change vs. flexion angle change and the derived linear regression model with equation $y = 1.327 \times + 0.5683$ (where y = PTI change, x = flexion change)

of the index with degree of knee flexion, which limits its reliability, given the inevitable small variation in knee positioning for MRI. Increased patellotrochlear engagement with flexion increases the index. We propose a formula derived from a linear regression model to correct the PTI to 0 degree knee flexion to improve its reliability in clinical practice, as cPTI = PTI - 1.3a (a = knee flexion angle, cPTI = corrected PTI). In clinical practice, applying the correction factor can prove useful when measured PTI shows borderline patella alta or baja, or when the knee flexion angle is 15 degrees or more at MRI.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The authors confirm this work complies with ethical principles regarding content of work. 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 Helsinki Declaration and its later amendments or comparable ethical standards.

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