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ABSTRACT

Background: The purpose of this study was to determine the inter- and intra-observer reliability of the patellotrochlear index (PTI) on magnetic resonance images (MRI) in patients with patellofemoral pain. The correlation between the PTI measured on MRI and the modified Insall–Salvati (MIS) ratio measured on radiographs was also assessed.

Methods: The PTI was assessed on MRI images and the MIS ratio on radiographs of 66 knees of 62 patients. Assessment was performed by two orthopaedic surgeons, one orthopaedic surgery registrar, two radiologists and one radiology registrar. Correlation coefficients, standard errors of measurement and limits of agreement were calculated for the PTI. To assess the association between the PTI and the MIS ratio, the Pearson's correlation coefficient was calculated.

Results: The PTI showed good interobserver reliability (intraclass correlation coefficient (ICC) 0.79; 95% confidence interval (CI) 0.73–0.85) and excellent intra-observer reliability (ICC 0.90; 95% CI 0.89–0.91). The standard error of measurement was 0.05 and limits of agreement with the mean ± 0.09. A very weak and not significant correlation was found between the PTI and the MIS ($r = 0.02$; $P = 0.77$).

Conclusions: The PTI showed good interobserver reliability and excellent intra-observer reliability. In order to conclude which measurement method of assessing patellar height is truly the most reliable, future studies should investigate agreement parameters (standard error of measurement, limits of agreement) besides solely correlation coefficients. We found a very weak correlation between the PTI and the MIS which suggests that at least one index has poor validity. Future validity studies on indices to assess patellar height are necessary.

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1. Introduction

Patients with patellofemoral pain (PFP) experience retro- or peri-patellar pain during knee loading activities (e.g., running, cycling, squatting, and stairclimbing) and during prolonged sitting with flexed knees. PFP is a common disorder, especially in female athletes. Its incidence varies with age and gender, and appears to be associated with an active lifestyle [1]. The aetiology of PFP is debated, but known associations are patella maltracking [2] and patellofemoral instability [3]. Patella alta is a cause of both patellar maltracking [2] and patellofemoral instability [3]; hence its identification is important when evaluating patients with PFP.

To correctly identify patella alta a reliable method for measuring patellar height is needed. Many measurement methods have been proposed [4], with older methods using conventional radiographs still being widely used in clinical practice. Examples include: the Insall–Salvati ratio (IS) [5]; the Blackburne–Peel ratio (BP) [6]; the Caton–Deschamps ratio (CD) [7]; and the modified Insall–Salvati ratio (MIS) [8]. There is no consensus on which technique is the most reliable or the most valid for measuring patellar height [4], with the literature showing conflicting outcomes regarding the reliability of these methods. In a previous study we suggested using the MIS above the other three measurement methods [9] as we found the MIS to have the second-best reliability after the IS, and previous studies have shown the MIS to have greater validity.

More recently, Biedert and Albrecht [10] introduced the patellotrochlear index (PTI) for the assessment of patellar height using magnetic resonance imaging (MRI). The PTI is a ratio that defines the position of the patella relative to the femoral trochlea in the sagittal plane of an MRI image. An MRI-based technique for assessing patellar height is likely to have better validity than a method using conventional radiographs as MRI can show cartilaginous landmarks and therefore permits assessment of the true cartilaginous articular surface. Meanwhile conventional radiographs only demonstrate bony landmarks which are subject to greater anatomical variation and can lead to inaccurate estimation of the patellofemoral contact surface. To justify the use of MRI to assess patellar height in clinical practice, the reliability of PTI must be equal or better than the conventional method, as MRI is more expensive and less available than conventional radiography. The reliability of PTI on MRI has been investigated in a few other studies and demonstrated good interobserver reliability and good to excellent intra-observer reliability, although studies used intraclass correlation coefficients (ICCs) only [10-12].

The primary aim of this study was to determine the reliability of PTI to assess patellar height on MRI in patients with patellofemoral pain with or without related instability. To assess inter- and intra-observer reliability, both ICC and agreement parameters were computed. The secondary aim was to assess the correlation between the outcomes of the PTI and the MIS.

2. Material and methods

2.1. Study design and study population

A retrospective study was conducted. We collected MRIs and radiographs of knees from patients registered in the hospital information system who visited our outpatient clinic with symptoms of patellar maltracking, with or without related instability, between May 2009 and October 2013. Patients with a radiograph and MRI taken within 1 year were included. Patients were excluded if epiphyseal closure had not completely occurred, or if morphological bone abnormalities of the knee or trochlear dysplasia were diagnosed in the radiology report. Institutional review board approval was obtained. Given the retrospective design, patients' informed consent was not considered necessary.

2.2. Image acquisition and assessment

MRI scans were performed using a 1.5 Tesla scanner (Siemens Magnetom Symphony, Siemens Magnetom Avanto, or Siemens Magnetom Espree). Patients were positioned at rest in a 16-channel coil with the knee in approximately 15° flexion, 0° rotation and relaxed extensor mechanism. Standard weight bearing lateral knee radiographs in approximately 30° flexion were used to measure the MIS. A goniometer was not used when obtaining the lateral knee radiographs. For both the MRI and radiograph, the patellar height was determined using the built-in ruler of our picture archiving and registration system (IMPAX 6.4, Agfa HealthCare N.V.). The PTI was assessed using a T1 weighted midsagittal sequence through the patella. The sagittal image used to assess the patellar height was selected by the examiner according to usual clinical practice.

All observers measured the PTI and MIS as originally described [8,10]. Fig. 1 shows the two methods for assessing patellar height. The PTI was obtained on the sagittal MRI image with the thickest patellar articular cartilage and maximal length of the patella. The PTI is defined as baseline trochlea:baseline patella (A:B). Where baseline trochlea (A) is defined as the distance between the most superior aspect of the trochlear articular surface to the most inferior aspect of the patellar articular cartilage. Baseline patella (B) is defined as the distance between the most superior aspect of articular cartilage to the most inferior aspect of articular cartilage of the patella. For the MIS (C:D), the distance from the inferior edge of the patellar articular surface to the insertion of the patellar tendon (C) and the length of the patellar articular surface (D) were assessed.

The diagnostic images were independently interpreted in an identical sequence by two orthopaedic surgeons specialized in knee surgery, one orthopaedic surgery registrar, two radiologists specialized in musculoskeletal radiology, and one radiology registrar specializing in musculoskeletal radiology. The orthopaedic surgeons and the radiologists had a minimum of 9

Fig. 1. (a) Measurement methods for the patellotrochlear index (PTI; A:B). A: distance between the most superior aspect of the trochlear articular surface to the most inferior aspect of the patellar articular cartilage. B: distance between the most superior aspect of articular cartilage to the most inferior aspect of articular cartilage of the patella. (b) Measurement methods for the modified Insall–Salvati index (MIS; C:D). C: distance from the inferior edge of the patellar articular surface to the insertion of the patellar tendon. D: length of the patellar articular surface.

and 7 years of experience including their training, respectively. All radiographs were assessed followed by the MRI images. The examiners were blinded to the patients' data and the other examiners results. To assess intra-observer reliability, two examiners assessed the same diagnostic images independently on two occasions separated by an interval of at least 4 weeks. The sequence of the radiographs was changed for the second assessment.

2.3. Statistical analysis

Statistical analyses were performed with IBM SPSS Statistics version 25 (IBM Corporation, Armonk, NY, USA). The data were normally distributed. The interobserver reliability and the intra-observer reliability was calculated using ICC for single measures. The ICC estimates the average correlation among pairs of data and is expressed in a value between 0 (totally unreliable) and 1 (perfectly reliable). ICC and 95% confidence intervals (CIs) were based on a two-way random model utilizing absolute agreement. Interobserver reliability was calculated for six observers using data from the first measurement only. Intra-observer reliability was calculated for two observers using data from two measurements of both observers. Scores were interpreted as described by Portney et al. [13], with a score of 0–0.50 indicating poor reliability, 0.50–0.75 indicating moderate reliability, 0.75–0.90 indicating good reliability, and a score higher than 0.90 indicating excellent reliability.

The standard error of measurement (SEM) was calculated to quantify the level of measurement error. It is defined as standard deviation (SD) $\times$ ($\sqrt{}$1 - reliability). A high SEM score indicates lower reliability and vice versa [14].

The limits of agreement (LoA) were also calculated to quantify the level of measurement error, as proposed by Bland and Altman [15]. The LoA evaluates the mean difference between two measurements of one observer and a range of agreement within which 95% of the differences between the measurements are included. It is defined as the mean difference ±1.96 $\times$ the SD of the difference.

To calculate the limits of agreement of all six observers, an adapted Bland–Altman method proposed by Jones et al. was used [16]. This evaluates how different a measurement of an individual observer can be compared with the mean measurement of all observers for this patient.

To examine the association between PTI and MIS the Pearson's correlation coefficient (r) was calculated. Correlations of 0–0.19, 0.20–0.39, 0.40–0.59, 0.60–0.79 and 0.80–1.0 were labelled 'very weak', 'weak', 'moderate', 'strong' and 'very strong', respectively.

A *P*-value of 0.05 was considered significant.

3. Results

Within the study period, 62 patients aged 17–40 years visited the outpatient clinic with symptoms of patellar maltracking, with or without related instability. Four patients had bilateral symptoms, therefore a total of 66 MRI scans and 66 radiographs were assessed.

3.1. Reliability of PTI on MRI

Outcomes of inter- and intra-observer reliability of PTI are presented in Table 1 and Table 2. The interobserver agreement is plotted in Fig. 2. The limits of agreement with the mean are −0.09 to 0.09, which means that the PTI measured by different observers can be discordant with a patient's mean by up to 0.09.

3.2. Reliability of PTI on MRI versus MIS on conventional radiograph

The interobserver reliability of PTI was good and that of MIS was moderate. The intra-observer reliability of PTI was good to excellent and that of MIS was moderate to good (Table 3).

3.3. Outcomes of PTI on MRI versus MIS on conventional radiograph

The mean PTI measured on MRI was 0.28 (SD ± 0.10). The mean MIS measured on conventional radiograph was 1.70 (SD ± 0.17). The correlation between PTI and MIS was very weak and not significant (r = 0.02, *P* = 0.77, Fig. 3).

4. Discussion

This study investigated the reliability of PTI in assessing patellar height on MRI in patients with patellofemoral pain due to patellar maltracking with or without related instability. We found good interobserver reliability (ICC 0.79; 95% CI 0.73–

Table 1
Inter- and intra-observer reliability of patellotrochlear index (PTI) on magnetic resonance imaging (MRI).

	ICC	SEM	Lower LoA	Upper LoA
Interobserver reliability	0.79 (0.73–0.85)	0.05	−0.09	0.09
Intra-observer reliability				
Orthopaedic surgery registrar	0.89 (0.82–0.93)	0.04	−0,11	0.09
Musculoskeletal radiologist	0.90 (0.84–0.94)	0.04	−0.09	0.10

ICC intraclass correlation coefficients (95% confidence intervals in parentheses); LoA, limits of agreement; SEM, standard error of measurement.

Table 2
Interobserver reliability for patellotrochlear index (PTI) on magnetic resonance imaging (MRI) in intraclass correlation coefficients (ICC) (95% confidence intervals in parentheses).

	Orthopaedic surgeon 1	Orthopaedic surgeon 2	Orthopaedic registrar	MSK radiologist 1	MSK radiologist 2
Orthopaedic surgeon 2	0.83 (0.73–0.89)				
Orthopaedic registrar	0.85 (0.76–0.90)	0.81 (0.70–0.88)			
MSK radiologist 1	0.90 (0.82–0.94)	0.79 (0.66–0.87)	0.83 (0.71–0.90)		
MSK radiologist 2	0.89 (0.83–0.93)	0.80 (0.69–0.87)	0.84 (0.75–0.90)	0.84 (0.71–0.91)	
Radiology registrar	0.75 (0.62–0.84)	0.64 (0.47–0.76)	0.65 (0.48–0.77)	0.74 (0.60–0.83)	0.69 (0.55–0.80)

MSK, musculoskeletal. All correlation coefficients were significantly correlated ($P < 0.01$).

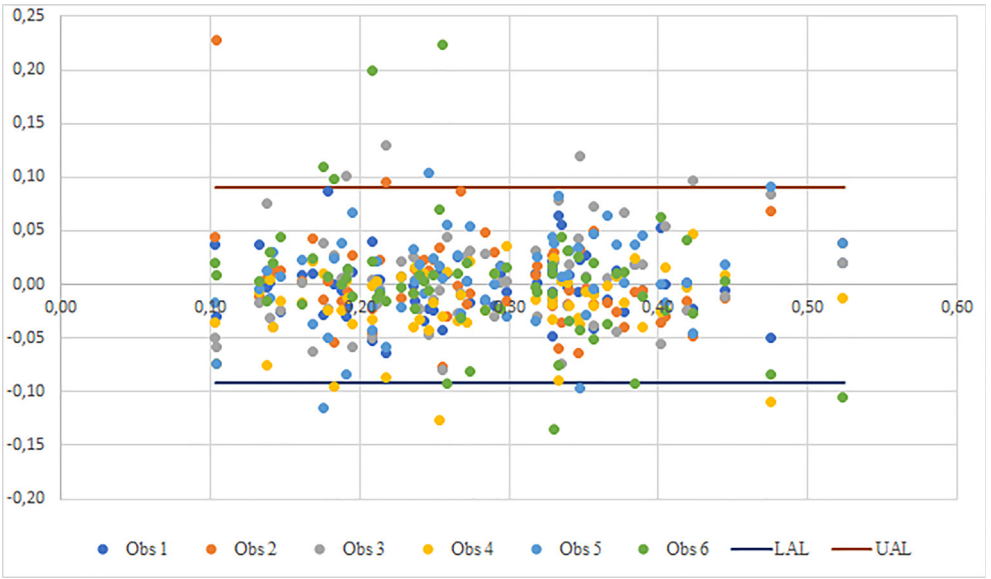

Fig. 2. Bland–Altman plot for interobserver agreement analysis between six observers. Each colour represents a different observer. Each patient's mean patellotrochlear index (PTI; *x*-axis) is plotted against the differences of each measurement with the patients mean PTI (*y*-axis). The lines indicate the limits of agreement with the mean of the six observers and ranged from −0.09 to 0.09. LAL, ???; UAL, ???.

Table 3
Inter- and intra-observer reliability of patellotrochlear index (PTI) on magnetic resonance imaging (MRI) versus modified Insall–Salvati ratio (MIS) on conventional radiograph in intraclass correlation coefficients (ICC) (95% confidence intervals in parentheses).

	PTI on MRI ICC		MIS on conventional radiograph ICC	
Interobserver reliability	0.79 (0.73–0.85)	Good	0.58 (0.47–0.69)	Moderate
Intra-observer reliability*	0.90 (0.89–0.91)	Excellent	0.71 (0.61–0.81)	Moderate
Orthopaedic surgery registrar	0.89 (0.82–0.93)	Good	0.78 (0.67–0.86)	Good
Musculoskeletal radiologist	0.90 (0.84–0.94)	Excellent	0.64 (0.46–0.76)	Moderate

0.85) and excellent intra-observer reliability (ICC 0.90; 95% CI 0.89–0.91). The secondary aim was to assess the correlation between the outcomes of PTI on MRI and MIS on conventional radiograph. We found a very weak and not significant correlation (r = 0.02, $P = 0.77$), which implies that one index (or both) has poor validity.

The ICC of PTI found in this study is comparable with previous studies that reported interobserver correlations of 0.78–0.80 and intra-observer correlations of 0.80–0.90 [10-12]. Previous studies that examined PTI and other measurement methods to assess patellar height have primarily used the ICC to assess reliability. The ICC has its own limitations, and additional information about the reliability of a test can be obtained from agreement parameters (e.g., SEM, LoA) [17]. Reliability parameters (e.g., ICC) are highly dependent on the population being studied and are therefore only generalizable to samples with a similar variation. In contrast, agreement parameters are more stable over different population samples and are more a characteristic of the measurement instrument itself [17]. For example, if two different studies found similar correlation coefficients, the SEM could still vary: a low SEM if the population studied is very heterogenic or a high SEM in the case of an homogenic population [14].

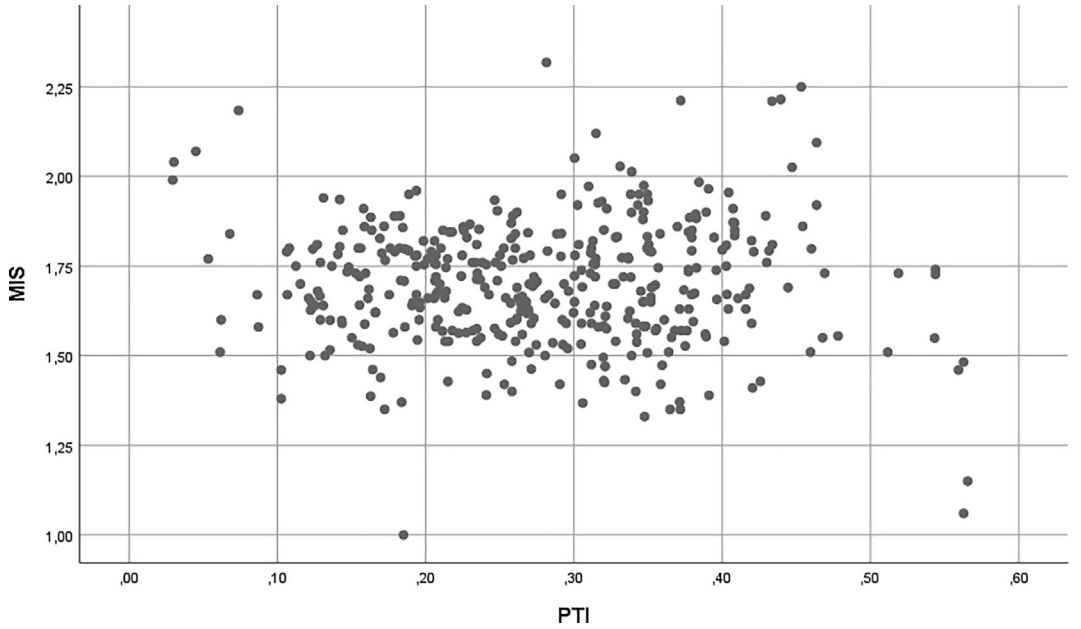

Fig. 3. Very weak and not significant correlation between patellotrochlear index (PTI) and modified Insall–Salvati index (MIS) (r = 0.02; *P* = 0.77).

This is the first study that investigated both SEM and LoA as agreement parameters for the PTI. The mean SEM of six observers was 0.05. SEM is a measure of how much an individual's measured PTI result is spread around his "true" score. An individual's 95% confidence interval around his measured PTI result is defined as: PTI ± (1.96*SEM). If the test was perfectly reliable and always gave the patient's 'true' score, the SEM would be zero. The measurement unit of the SEM is the same as the original test scores. At this point it is hard to assess an SEM of PTI as most clinicians are not familiar with the use and the interpretation of the outcomes of PTI. Still, an SEM of 0.05 seems to be fairly high given the mean PTI of 0.28 in the present study. Unfortunately, the found SEM cannot be compared to SEMs of other measurement methods for assessing patellar height as they are not investigated in other studies yet.

We found the LoA with the mean PTI to range from −0.09 to 0.09. This means that 95% of future measurements of the PTI lie within plus or minus 0.09 of the patient's mean PTI result. One previous study has investigated LoA of PTI and found the LoA between three pairs of observers to be slightly worse (±0.13, ±0.14 and ± 0.15) [12].

In addition to reliability, the validity of indices to assess patellar height is also important when assessing their clinical utility. We found no correlation between PTI measured on MRI and MIS measured on conventional radiographs. This implies that one instrument (or both) has poor validity. Several theoretical explanations for this lack of correlation can be given. First, both measurement methods use different radiographic modalities. On MRI, the bony landmarks can slightly differ on each sagittal image. The measurements on MRI are therefore dependent on the chosen sagittal image. As a result, these landmarks are not expected to be identical to the bony landmarks of a lateral radiograph. This potential confounder has been further investigated using the same sagittal MRI image to measure both the PTI and MIS, which from a theoretical standpoint at least, could be expected to produce measurements with a greater correlation between them. In the work of Barnett et al. [11], they found only a weak correlation between PTI and traditional measurement methods of assessing for patella alta (IS, BP and CD ratios), despite using the same sagittal MRI image to measure the indices. Ali et al. [18] also found no correlation between the PTI and IS ratio when using the same method to measure PTI and MIS as Barnett et al. Second, the lack of correlation between PTI and MIS can be explained by the difference between a direct (i.e. PTI) and indirect (i.e. MIS) assessment of the patella-trochlear relationship. The goal of patellar height measurement is to assess the relationship between the patella and the trochlea. When this relationship is assessed using anatomic landmarks other than located at the patella or trochlea, it is an indirect measurement. In case of the MIS, the tibial tubercle and the inferior edge of the patellar articular surface are used. Variability in the position of the tibial tubercle and patellar length can potentially influence the ratio without necessarily influencing the patella-trochlear relationship. For example, a low position of the tibial tubercle and a long patellar tendon will lead to a high value of MIS. However, the patella-trochlear relationship can be normal in this case, as will be the PTI. This disadvantage was also discussed by Ali et al. [18].

PTI has several limitations. As Biedert et al. [10] originally described, PTI should be measured on a sagittal MRI image with the knee in full extension, without quadriceps activation and non-weight bearing; these conditions may be difficult to accomplish in patients with patellofemoral symptoms. Becher et al. compared patellar height ratios measured on MRI during upright weight bearing and supine non-weight bearing positions at full extension (0° flexion) and at 15°, 30°, and 45° flexion in patients with and without patellar instability [19]. Upright weight bearing and the knee flexion angle affected patellofe-

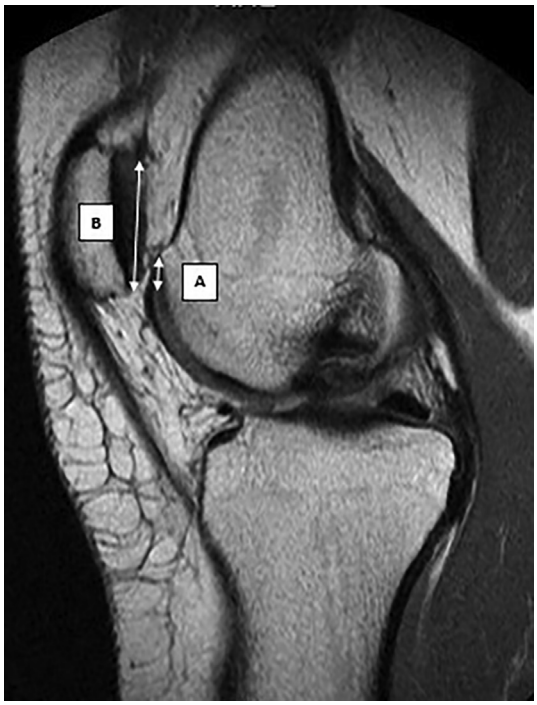

Fig. 4. Measurement of the patellotrochlear index (PTI) when a different, 'wrong' sagittal MRI image is chosen in the same patient as in Fig. 1(a), resulting in an incorrect PTI outcome.

moral MRI indices in patients with patellar instability, with significantly increased ratios at full extension. Although this does not affect this reliability study, clinicians should be warned that the PTI could be underestimated in patients with patellofemoral instability when the MRI is obtained with a certain degree of flexion or quadriceps tension. It would be useful to investigate the validity of PTI at different flexion angles. Furthermore, PTI is difficult to measure in tilted patellae and severe patellar subluxation [20]. Finally, considering that many patients affected by patellofemoral pain present with patella maltracking and chondropathy with thinning of the cartilage at midline or at the lateral patellar facet, it may be difficult for clinicians to select one image in which both criteria are met: i.e. maximal length of patellar bone and thickest articular cartilage. This may result in clinicians choosing different images to measure the PTI which may affect its reliability and/or validity. Fig. 4 is an example of how the measurements of the PTI look when choosing a different sagittal image.

One limitation of this study was its moderate sample size. Secondly, the quality of the radiographs (e.g., not perfectly lateral) and MRIs (e.g., motion artefacts) varied. However, we consider the images used in this study to be representative of those seen in routine clinical practice.

5. Conclusion

In this study we demonstrated that the PTI measured on MRI to assess patellar height has good interobserver reliability and excellent intra-observer reliability. With regards to reliability, PTI is the preferred measurement method in comparison with the MIS measured on conventional radiograph which demonstrated moderate inter- and intra-observer reliability. In the future, when studying the reliability of measurement methods to assess patellar height we recommend that agreement parameters (e.g., SEM, LoA) be reported in addition to the widely used correlation coefficients; this will allow a more thorough assessment of reliability.

We also emphasized that in addition to reliability, validity is an important factor that contributes to the clinical utility of any index to assess patellar height. In this study we found a poor correlation between the outcomes of PTI on MRI and MIS on conventional radiograph. Several potential explanations for this finding were discussed. Future validity studies on measurement methods to assess patellar height are necessary.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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