Reliability and validity of quantitative ultrasound for evaluating patellar alignment: A pilot study

Abstract

Background: Patellar malalignment is a risk factor of patellofemoral pain. Evaluation of the patellar alignment have mostly used magnetic resonance imaging (MRI). Ultrasound (US) is a non-invasive instrument that can quickly evaluate patellar alignment. However, the method for evaluating patellar alignment via US has not been established. This study aimed to investigate the reliability and validity of evaluating patellar alignment via US.

Methods: The sixteen right knees were imaged via US and MRI. US images were obtained at two sites of the knee to measure US-tilt as the index of patellar tilt. Using a single US image, we measured US-lateral distance and US-angle as the index of patellar shift. All US images were obtained three times each by two observers to evaluate reliabilities. Lateral patellar angle (LPA), as the indicators of patellar tilt, and lateral patella distance (LPD) and bisect offset (BO), as the indicators of patellar shift, were measured via MRI.

Results: US measurements provided high intra- (within-day and between days) and interobserver reliabilities with exception of interobserver reliability of US-lateral distance. Pearson correlation coefficient indicated that US-tilt is significantly positively correlated with LPA ($r = 0.79$), and US-angle is significantly positively correlated with LPD ($r = 0.71$) and BO (r = 0.63).

Conclusion: Evaluating patellar alignment via US showed high reliabilities. US-tilt and US-angle showed moderate to strong correlation with MRI indices of patellar tilt and shift via MRI, respectively. US methods are useful for evaluating accurate and objective indices of patellar alignment.

Keywords: Ultrasonography; magnetic resonance imaging; patellar shift; patellar tilt

Introduction

Patellar malalignment is a potential risk factor of patellofemoral pain (PFP) [1–4] and many studies have investigated the association between patellar malalignment and PFP [5–8]. Excessive lateral alignment of the patella, a typical patellar malalignment, can lead to an increase in contact pressure in the patellofemoral joint [9,10], resulting in PFP and early degeneration of the patellofemoral joint [10]. Patellar tilt and shift are proxies for the lateral patellar alignment, and both are potentially related to PFP [5,6,11–14]. Thus, a quantitative evaluation of the patellar tilt and shift is necessary to evaluate knee condition [12,15–17].

PPatellar alignment is generally evaluated using X-ray, computed tomography, and magnetic resonance imaging (MRI) [5,18,19]. Although these instruments can accurately evaluate patellar alignment, they are disadvantageous because of factors such as radiation exposure and taking long time. In contrast, ultrasound (US) is a non-invasive instrument and can quickly obtain images. However, the method for evaluating patellar alignment via US has been challenging.

No study has reported the US method for the patellar tilt evaluation. The lateral patellar angle (LPA), which has been evaluated using the MRI, is used as the indicator of patellar tilt [20]. LPA is calculated from the patellar tilt with respect to the anterior condyle of the femur. Because US images at the anterior knee allow us to simultaneously capture both the patella and the anterior condyle of the femur, the US method equivalent to MRI measured LPA may be developed with two US images at the anterior knee.

A US method has been developed to determine patellar shift [21,22]. The distance between the lateral edge of the patella and anterior lateral condyle of the femur in a single US image (US-lateral distance), obtained at the anterior-lateral knee, was defined as the indicator of patellar shift. Herrington et al. [23] reported that the US-lateral distance shows high intraobserver reliability and a moderate correlation with lateral patella displacement (LPD1), as an indicator of patellar shift, measured via MRI at 20° knee flexion. Several previous studies investigated the association between patellar shift and soft tissue using this method (i.e. US-lateral distance) [24–26]. However, it has been unclear as to whether the method is valid at other knee angles (e.g., at 0° knee flexion). As per a recent systematic review, patellar alignment that is most related to PFP was patellar shift at 0° knee flexion [11]. Therefore, it is necessary to investigate whether the method can be applied at 0° knee flexion. Additionally, lateral patella displacement (LPD2) and bisect offset (BO), in addition to LPD1, are commonly used for evaluating the patellar shift [27,28]. However, it remains unclear whether US-lateral distance can correlate with these indicators (LPD2 and BO). Hence, it is crucial to explore the relations of LPD2 and BO with US-lateral distance and to establish the US method to evaluate the accurate patellar shift at 0° knee flexion.

This study aimed to investigate the reliability and validity of evaluating patellar tilt and shift using US images. We hypothesized that measuring the patellar tilt and shift with US images show correlations with the MRI measurements. In addition, we also hypothesized that the US measurement methods which most corelated to MRI indices of patellar shift are different for 0° and 20° knee flexions.

Materials and Methods

Participants

Sixteen young adults (n = 16, 8 males; 16 right knees) participated in this study. The mean age, height, and weight of the participants were 25.9 ± 3.3 years, 163.8 ± 6.4 cm, 56.9 ± 7.0 kg, respectively. All participants were more than 20 years old. Two out of 16 participants had knee pain. Furthermore, individuals that had a history of fractures or surgeries of the right leg and contraindications to undergoing MRI were excluded. The sample size was calculated using G*Power 3.1 (Heinrich Heine University, Düsseldorf, Germany) for correlation analysis (effect size: $r = 0.64$, α error: 0.05, power: 0.8), which showed that 14 participants were required. The effect size was determined based on a previous study in which correlation analysis was performed between patellar alignments that were evaluated using US and MRI [23]. Therefore, 16 participants were recruited in this study considering the measurement errors and omissions. Prior to this study, the procedures and goals of the study were verbally explained to the participants, and all the subjects provided written informed consent in accordance with the ethical standards of the 1964 Declaration of Helsinki. All procedures were approved by the Ethics Committee of our institution.

Protocol

The participants visited our laboratory on three separate days. MRI measurements were obtained on the first day and US measurements were obtained on the other two days. On the second day, US images were obtained by two observers (observer1 and observer2) to test interobserver reliability. One week later, similar US images were obtained by observer1 to test intraobserver reliability (between days). The measurements were performed while ensuring that the participants were relaxed. The two observers analyzed each of the US and MRI measurements respectively.

Ultrasound measurements

Patellar alignment was evaluated using US (Aixplorer; SuperSonic Imagine, Axi-en-Provence, France) with a linear probe (SL15-4, 4-15MHz, SuperSonic Imaging, Aix-en-Provence, France).

The participants were asked to lay in the supine position with their right knee at 0°

flexion. US images were obtained at two sites of the anterior surface of the knee (Fig. 1). One US image was obtained in such a way to satisfy two requirements: both superior-lateral edge of the patella and lateral condyle of the femur were captured, and the surface of the lateral condyle of the femur was put in a horizontal direction (US1, Fig. 2a), and the other was obtained in such a way to satisfy a requirement: superior-medial edge of the patella and medial condyle of the femur were captured (US2, Fig. 2b). The probe was placed softly on the skin to prevent any displacement of the patella as a result of the pressure of the probe. In addition, water-soluble transmission gel was applied on the scanning head to eliminate any gaps between the probe and skin. The participants were instructed to relax as much as possible during the ultrasound measurements. US images at each of the two sites were obtained three times.

By using the US1, we measured US-lateral distance [23] (Fig. 3a), and the angle between a line from the lateral edge of the patella to the most anterior of the anterior lateral condyle of the femur and the horizontal line of the anterior lateral condyle of the femur (US-angle) (Fig. 3b) as the indicator of patellar shift. In addition, by using the US2, we measured the distance between the medial edge of the patella and the most anterior of the anterior medial condyle of the femur (US-medial distance) (Fig. 3c), and calculated the ratio of US-medial distance and US-lateral distance (US-tilt) as the indicator of patellar tilt. US-tilt was calculated using the following equation:

US-tilt = US-medial distance / US-lateral distance

For further statistical analysis, we computed the average US-lateral distance, US-angle, and US-tilt across three US1 and US2 images, separately.

MRI measurements

Patellar alignment was evaluated from a proton density-weighted image (PD), which was obtained from a 3.0 T MRI scanner (Magnetom Verio, SIEMENS, Germany). The MRI sequence corresponded to 3D SPACE with PD variable contrast using a body matrix coil and a spine coil, and the parameters were set as follows: slice thickness: 0.7 mm, repetition time: 1000 ms, echo time: 35 ms, field of view: 150 mm × 150 mm, flip angle: 120°, voxel size: 0.59 mm × 0.59 mm × 0.7 mm. The images were evaluated using an image analysis software (version 9.0; Osirix, Geneva, Switzerland). LPA was used as the indicator of patellar tilt [28] (Fig. 4a), and LPD1 [23] (Fig. 4b), LPD2 [28] (Fig. 4c), and BO [28] (Fig. 4d) were used as the indicators of patellar shift. Measurements were performed as follows:

LPA

The angle formed between the line parallel to the lateral patella facet (line AB) and the line tangent to both the anterior femoral condyle was measured (line CD). A positive value indicated lateral tilt.

LPD1

A line was drawn tangent to both the anterior femoral condyles as a baseline (line AB). A perpendicular line was drawn passing through the highest point of the anterior lateral condyle of the femur (line CD). Then, the perpendicular distance from the lateral edge of the patella to the perpendicular line was measured (line EF). A positive value indicated that the lateral edge of the patella is lateral to the perpendicular line.

LPD2

A line was drawn tangent to both the posterior femoral condyles as a baseline (line AB). A perpendicular line was drawn passing through the highest point of the anterior medial condyle of the femur (line CD). Then, the perpendicular distance from the medial edge of the patella to the perpendicular line was measured (line EF). A negative value indicated that the medial edge of the patella is medial to the perpendicular line.

BO

A line was drawn tangent to both the posterior femoral condyles as a baseline (line AB). A perpendicular line was drawn passing through the deepest point of the trochlear groove (line CD). Then, the ratio of medial to lateral displacement of the patella relative to the perpendicular line was measured (length FG / length EF ×100%). A high ratio indicated that patella is displaced laterally.

Statistical analysis

Statistical analysis was performed using IBM SPSS statistic software (version 22; IBM, Armonk, NY, USA). Shapiro–Wilk test confirmed that the data exhibit a normal distribution.

The intraobserver (within-day), interobserver, and intraobserver (between days) reliability were evaluated using intraclass correlation coefficient (ICC) (1,1), ICC (2,1), and ICC (1,1), respectively. Additionally, the standard error of measurement (SEM) and minimal detectable change (MDC_{95}) were calculated for evaluating the measurement error. SEM and MDC_{95} were calculated as follows: $SEM = SD_d / \sqrt{2}$, and $MDC_{95} = 1.96 \times SD_d$, where SD_d denotes the standard deviation (SD) of the difference in scores.

Pearson correlation coefficient was used to evaluate the validity between US and MRI. A confidence level of 0.05 was set in all statistical tests. Reliability thresholds for ICC values were defined as almost perfect (> 0.81) [29].

Results

Figure. 5 showed the MR and ultrasound image of the same participant. Table 1 shows the results with respect to the evaluation of patellar alignment using US and MRI. No participant had patellar malalignment [30,31].

Intraobserver (within-day), interobserver, and intraobserver (between days) reliabilities of US-lateral distance were 0.93 (95% CI: 0.85–0.97), 0.58 (95% CI: 0.11–0.84), and 0.88 (95% CI: 0.69–0.95), respectively. Thus, reliabilities of US-lateral distance were almost perfect with the exception of interobserver reliability. With respect to interobserver, SEM was 1.1 mm and MDC_{95} was 3.0 mm, and for intraobserver (between days), SEM was 0.7 mm and MDC_{95} was 1.9 mm.

Intraobserver (within-day), interobserver, and intraobserver (between days) reliabilities of US-angle were 0.86 (95% CI: 0.71–0.95), 0.89 (95% CI: 0.72–0.96), and 0.88 (95% CI: 0.69–0.96), respectively. Thus, reliabilities of the US-angle were almost perfect. With respect to interobserver, SEM was 3.6° and MDC_{95} was 10.1°, and for intraobserver (between days), SEM was 4.2° and MDC_{95} was 11.6°.

Intraobserver (within-day), interobserver, and intraobserver (between days) reliabilities of US-tilt were 0.84 (95% CI: 0.66–0.94), 0.79 (95% CI: 0.51–0.92), and 0.89 (95% CI: 0.70–0.96), respectively. Thus, reliabilities of the US-tilt were almost perfect. With respect to interobserver, SEM was 0.14 and MDC_{95} was 0.32, and for intraobserver (between days), SEM was 0.12 and MDC_{95} was 0.35.

The Pearson correlation coefficient showed that US-tilt exhibits a significant positive correlation with LPA (r = 0.79, p < 0.01). The US-angle exhibits a significant positive correlation with LPD1 (r = 0.65, p < 0.01), LPD2 (r = 0.71, p < 0.01), and BO (r = 0.63, p = 0.01) (Table 2; Fig. 6). The US-lateral distance was not significantly correlated with all indices of patellar alignment, which was measured via MRI.

Discussion

This study aimed to investigate the reliability and validity of evaluating patellar tilt and shift using US images. US-tilt measured from two US images showed high reliability and a strong correlation with LPA, an indicator of patellar tilt via MRI. To the best of our knowledge, this is the first study to establish an original US method for evaluating patellar tilt. Additionally, US-angle measured from a single US image showed high reliability and a significant correlation with the patellar shift, which was measured via MRI. However, the US-lateral distance that was used in a previous study [23] did not exhibit a significant correlation with the patellar shift. These findings indicated that the novel US methods (US-tilt and US-angle) are useful in evaluating accurate and objective indices for patellar alignment.

We hypothesized that measuring the patellar tilt and shift with US images show correlations with MRI. Our results indicated a strong correlation between US-tilt and patellar tilt measured via MRI (i.e. LPA), and indicated moderate to strong correlation between US-angle and patellar shift measured via MRI (i.e. LPD1, LPD2, and BO). These results was consistent with our hypothesis. The association between the LPA and US-tilt can be explained by the change in patellar and femoral position with patellar tilt. For example, a greater lateral tilt results in a greater distance between the medial patella and medial femoral condyle, or a smaller distance between the lateral patella and lateral femoral condyle. A greater medial tilt results in an inverse change to the lateral tilt. These relative positions between the patella and femur resulting from patellar tilt can be accurately captured by the equation for US tilt; therefore, we consider it rational that the US tilt is associated with LPA, the gold standard for patellar tilt.

US-tilt and US-angle can be measured quickly and conveniently, therefore, these methods are useful in clinical and sports settings.

In addition, we also hypothesized that the US measurement methods which were most corelated to MRI indices of patellar shift are different for 0° and 20° knee flexions. At 0° knee flexion, US-angle show high reliability and a significant correlation with the patellar shift measured via MRI. Conversely, the US-lateral distance exhibited low interobserver reliability and no significant correlation with LPD1, unlike that in a previous study [23]. These results were consistent with our hypothesis. The difference of the results of this study and the previous study can be due to the knee angle. The measurement was performed at 20° knee flexion in the previous study, while it was performed at 0° knee flexion in this study. In other words, the US-angle can be evaluate patellar shift at 0° knee flexion, the US-lateral distance can be evaluate patellar shift at 20° knee flexion. A recent systematic review reported that patellar alignment that is most related to PFP was patellar shift at 0° knee flexion [11]. Therefore, the evaluation of patellar shift at 0° knee flexion can be clinically important. The patellar shift at 0° knee flexion exhibited a higher correlation with US-angle than with US-lateral distance. These results indicated that US-angle is useful to evaluate patellar shift at 0° knee flexion which is most related to PFP.

This study established US methods for evaluating patellar alignment. By using these methods, the patellar tilt and shift can be evaluated simultaneously and non-invasively. Given that patellar tilt and shift can be related to PFP [5,6,11,12], our original methods can potentially be applied to reveal the characteristics of PFP patients during muscle activity or loading in future studies. In particular, using these methods, it is possible to simultaneously evaluate the patellar alignment and muscle activity using electromyography, which is not possible with X-ray or MRI. In addition, these methods can be used multiple times for one participant (e.g. to evaluate the patellar alignment at different quadriceps contraction conditions), without radiation exposure unlike X-ray. Moreover, in clinical setting, these US methods can be used to evaluate the immediate and/or long-term effects of conservative treatment. Frequent measurements of patellar alignment using X-ray and MRI are not feasible due to their high cost and unnecessary radiation exposure. In sports settings, these US methods can be used to easily evaluate patellar alignment in athletes who have little to no pain, and if the athletes have abnormal patellar alignment, appropriate interventions (e.g., exercise and movement guidance) can be provided. This may be useful in preventing the onset and/or exacerbation of PFP.

There are a few limitations of this study. First, this study involved only young adults. It is unclear whether the results of this study can be applied to older patients or patients with knee osteoarthritis, and thus, further investigation is required for generalizing the methods to broader populations. Second, although patients with patellar malalignment often have abnormal patellar and condylar morphologies, no participants in this study had such issues. It is unclear whether the results of this study can be applied to the patients who have abnormal patellar and condylar morphologies. Third, although patellar malalignment and patellofemoral pain are common in women, half of the participants in this study were men. Further research is required to examine the differences across sexes.

Conclusion

In this study, we investigated the reliability and validity of evaluating patellar alignment via US. US-tilt measured from two US images and the US-angle measured from a single US image showed high reliabilities, and showed moderate to strong correlation with the patellar tilt and patellar shift measured via MRI, respectively. These US methods provide accurate and objective indicators for evaluating patellar alignment.

Ethical statement

The participants were informed that data from the research would be submitted for publication, and gave their consent.

Conflict of interest

None.

References

1. Fulkerson JP. The etiology of patellofemoral pain in young, active patients: a prospective study. Clin Orthop Relat Res [Internet]. 1983 Oct;(179):129–33. Available from: http://www.ncbi.nlm.nih.gov/pubmed/6617004
2. Werner S. Anterior knee pain: an update of physical therapy. Knee Surgery, Sport Traumatol Arthrosc. 2014;22(10):2286–94.
3. Afridi A, Rathore FA. Is neuromuscular electrical stimulation effective for management of patellofemoral pain syndrome? A Cochrane Review summary with commentary. Musculoskelet Sci Pract [Internet]. 2019;44:102059. Available from: http://www.ncbi.nlm.nih.gov/pubmed/31550621
4. Zikria B, Rinaldi J, Guermazi A, Haj-Mirzaian A, Pishgar F, Roemer FW, Hakky M, Sereni C, Demehri S. Lateral patellar tilt and its longitudinal association with patellofemoral osteoarthritis-related structural damage: Analysis of the osteoarthritis initiative data. Knee [Internet]. 2020 Nov 24;27(6):1971–9. Available from: https://doi.org/10.1016/j.knee.2020.11.002
5. Esfandiarpour F, Lebrun CM, Dhillon S, Boulanger P. In-vivo patellar tracking in individuals with patellofemoral pain and healthy individuals. J Orthop Res. 2018;36(8):2193–201.
6. Salsich GB, Perman WH. Tibiofemoral and patellofemoral mechanics are altered at

small knee flexion angles in people with patellofemoral pain. J Sci Med Sport. 2013;16(1):13–7.

7. Draper CE, Besier TF, Fredericson M, Santos JM, Beaupre GS, Delp SL, Gold GE. Differences in patellofemoral kinematics between weight-bearing and non-weight-bearing conditions in patients with patellofemoral pain. J Orthop Res [Internet]. 2011 Mar;29(3):312–7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20949442

8. Verhulst F V., van Sambeeck JDP, Olthuis GS, van der Ree J, Koëter S. Patellar height measurements: Insall–Salvati ratio is most reliable method. Knee Surgery, Sport Traumatol Arthrosc [Internet]. 2019;(0123456789). Available from: https://doi.org/10.1007/s00167-019-05531-1

9. Clark D, Stevens JM, Tortonese D, Whitehouse MR, Simpson D, Eldridge J. Mapping the contact area of the patellofemoral joint: the relationship between stability and joint congruence. Bone Joint J. 2019;101-B(5):552–8.

10. Elias DA, White LM. Imaging of patellofemoral disorders. Clin Radiol. 2004;59(7):543–57.

11. Drew BT, Redmond AC, Smith TO, Penny F, Conaghan PG. Which patellofemoral joint imaging features are associated with patellofemoral pain? Systematic review and meta-analysis. Osteoarthr Cartil. 2016;24(2):224–36.

12. Pal S, Besier TF, Draper CE, Fredericson M, Gold GE, Beaupre GS, Delp SL. Patellar

tilt correlates with vastus lateralis: vastus medialis activation ratio in maltracking patellofemoral pain patients. J Orthop Res [Internet]. 2012 Jun;30(6):927–33. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22086708

13. Peng H Te, Song CY. Predictors of treatment response to strengthening and stretching exercises for patellofemoral pain: An examination of patellar alignment. Knee [Internet]. 2015;22(6):494–8. Available from: http://dx.doi.org/10.1016/j.knee.2014.10.012

14. Biedert RM, Gruhl C. Axial computed tomography of the patellofemoral joint with and without quadriceps contraction. Arch Orthop Trauma Surg [Internet]. 1997;116(1–2):77–82. Available from: http://www.ncbi.nlm.nih.gov/pubmed/9006771

15. Biyani R, Elias JJ, Saranathan A, Feng H, Guseila LM, Morscher MA, Jones KC. Anatomical factors influencing patellar tracking in the unstable patellofemoral joint. Knee Surgery, Sport Traumatol Arthrosc. 2014;22(10):2334–41.

16. Zaffagnini S, Colle F, Lopomo N, Sharma B, Bignozzi S, Dejour D, Marcacci M. The influence of medial patellofemoral ligament on patellofemoral joint kinematics and patellar stability. Knee Surgery, Sport Traumatol Arthrosc. 2013;21(9):2164–71.

17. Stephen J, Alva A, Lumpaopong P, Williams A, Amis AA. A cadaveric model to evaluate the effect of unloading the medial quadriceps on patellar tracking and patellofemoral joint pressure and stability. J Exp Orthop. 2018;5(1).

18. MacIntyre NJ, Hill NA, Fellows RA, Ellis RE, Wilson DR. Patellofemoral joint kinematics in individuals with and without patellofemoral pain syndrome. J Bone Joint Surg Am [Internet]. 2006 Dec;88(12):2596–605. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17142409

19. Kim TH, Sobti A, Lee SH, Lee JS, Oh KJ. The effects of weight-bearing conditions on patellofemoral indices in individuals without and with patellofemoral pain syndrome. Skeletal Radiol [Internet]. 2014 Feb;43(2):157–64. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24221139

20. Song CY, Lin JJ, Jan MH, Lin YF. The role of patellar alignment and tracking in vivo: the potential mechanism of patellofemoral pain syndrome. Phys Ther Sport [Internet]. 2011 Aug;12(3):140–7. Available from: http://dx.doi.org/10.1016/j.ptsp.2011.02.008

21. Shih YF, Bull AMJ, McGregor AH, Humphries K, Amis AA. A technique for the measurement of patellar tracking during weight-bearing activities using ultrasound. Proc Inst Mech Eng H [Internet]. 2003;217(6):449–57. Available from: http://www.ncbi.nlm.nih.gov/pubmed/14702982

22. Shih YF, Bull AMJ, McGregor AH, Amis AA. Active patellar tracking measurement: A novel device using ultrasound. Vol. 32, American Journal of Sports Medicine. 2004. p. 1209–17.

23. Herrington L, McEwan I, Thom J. Quantification of patella position by ultrasound

scanning and its criterion validity. Ultrasound Med Biol [Internet]. 2006 Dec;32(12):1833–6. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17169695

24. Park JH, Kang SY, Choung SD, Jeon HS, Kwon OY. Effects of tibial rotation on Ober's test and patellar tracking. Knee [Internet]. 2016 Aug;23(4):600–3. Available from: http://www.ncbi.nlm.nih.gov/pubmed/27242281

25. Kang SY, Choung SD, Park JH, Jeon HS, Kwon OY. The relationship between length of the iliotibial band and patellar position in Asians. Knee [Internet]. 2014 Dec;21(6):1135–8. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25311516

26. Herrington L, Law J. The effect of hip adduction angle on patellar position measured using real time ultrasound scanning. Knee [Internet]. 2012 Oct;19(5):709–12. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22306212

27. Wilson T. The measurement of patellar alignment in patellofemoral pain syndrome: are we confusing assumptions with evidence? J Orthop Sports Phys Ther [Internet]. 2007 Jun;37(6):330–41. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17612360

28. Ye Q, Yu T, Wu Y, Ding X, Gong X. Patellar instability: the reliability of magnetic resonance imaging measurement parameters. BMC Musculoskelet Disord [Internet]. 2019 Jul 6;20(1):317. Available from: http://www.ncbi.nlm.nih.gov/pubmed/31279345

29. Landis JR, Koch GG. The measurement of observer agreement for categorical data.

Biometrics [Internet]. 1977 Mar;33(1):159–74. Available from: http://www.ncbi.nlm.nih.gov/pubmed/843571

30. Pal S, Besier TF, Beaupre GS, Fredericson M, Delp SL, Gold GE. Patellar maltracking is prevalent among patellofemoral pain subjects with patella alta: An upright, weightbearing MRI study. J Orthop Res. 2013;31(3):448–57.

31. Becher C, Fleischer B, Rase M, Schumacher T, Ettinger M, Ostermeier S, Smith T. Effects of upright weight bearing and the knee flexion angle on patellofemoral indices using magnetic resonance imaging in patients with patellofemoral instability. Knee Surgery, Sport Traumatol Arthrosc. 2017;25(8):2405–13.

Table

Table 1. Patella alignment as measured using US and MRI.

	US			MRI
	Day1		Day2	
	Observer1	Observer2	Observer1	
US-tilt	2.0 ± 0.3	2.2 ± 0.4	2.0 ± 0.4	—
US-lateral distance (cm)	1.1 ± 0.2	0.9 ± 0.2	1.1 ± 0.2	—
US-angle (°)	40.0 ± 9.9	40.8 ± 9.4	40.6 ± 9.8	—
LPA				-0.5 ± 4.1
LPD1 (mm)	—	—	—	5.3 ± 2.6
LPD2 (mm)	—	—	—	-6.6 ± 2.8
BO (%)	—	—	—	51.0 ± 6.9

Values are expressed as mean ± standard deviation.

US = ultrasound; MRI = magnetic resonance imaging; LPA = lateral patellar angle; LPD = lateral patella displacement; BO = bisect offset.

Table 2. Pearson correlation (*r*) of US-tilt, lateral distance, and angle versus LPA, LPD1, LPD2, and BO.

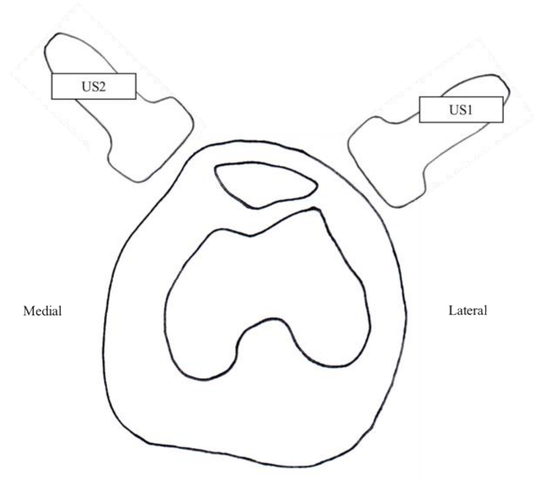
		MRI			
		LPA	LPD1	LPD2	BO
US	Tilt	**0.79***	0.13	0.17	0.43
	Lateral distance	-0.13	0.49	0.24	0.26
	Angle	0.31	**0.65***	**0.71***	**0.63***

* Significant correlation between US and MRI ($p < 0.05$).

US = ultrasound; MRI = magnetic resonance imaging; LPA = lateral patellar angle; LPD = lateral patella displacement; BO = bisect offset.

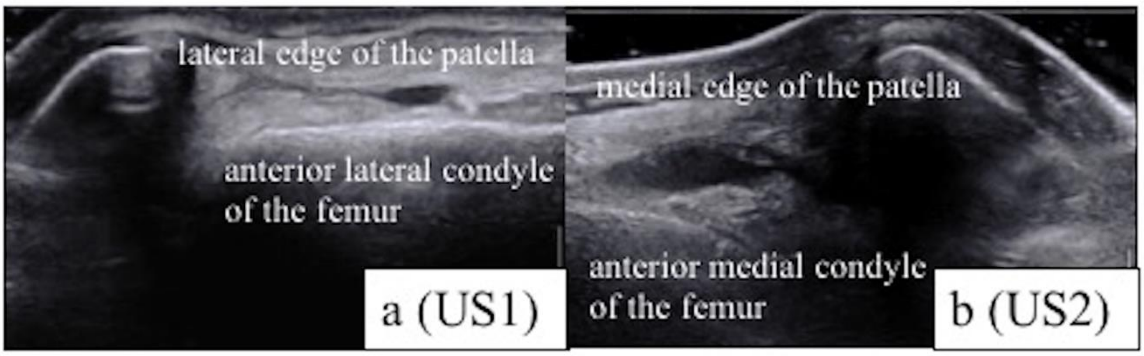
Figure

Figure. 1



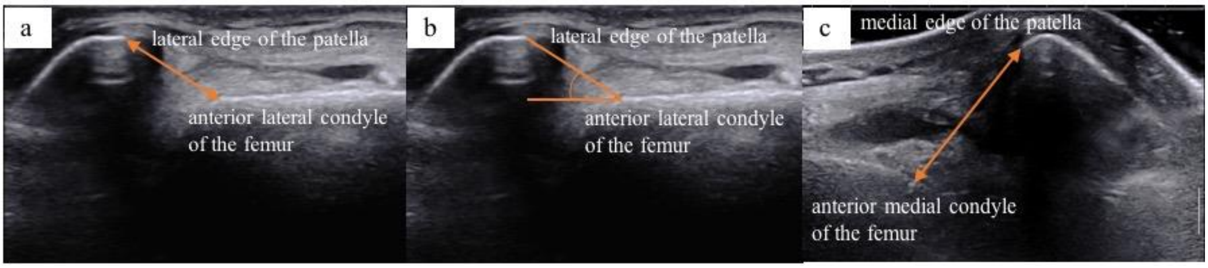
Position of the ultrasound probe to obtain the two ultrasound images.

Figure. 2



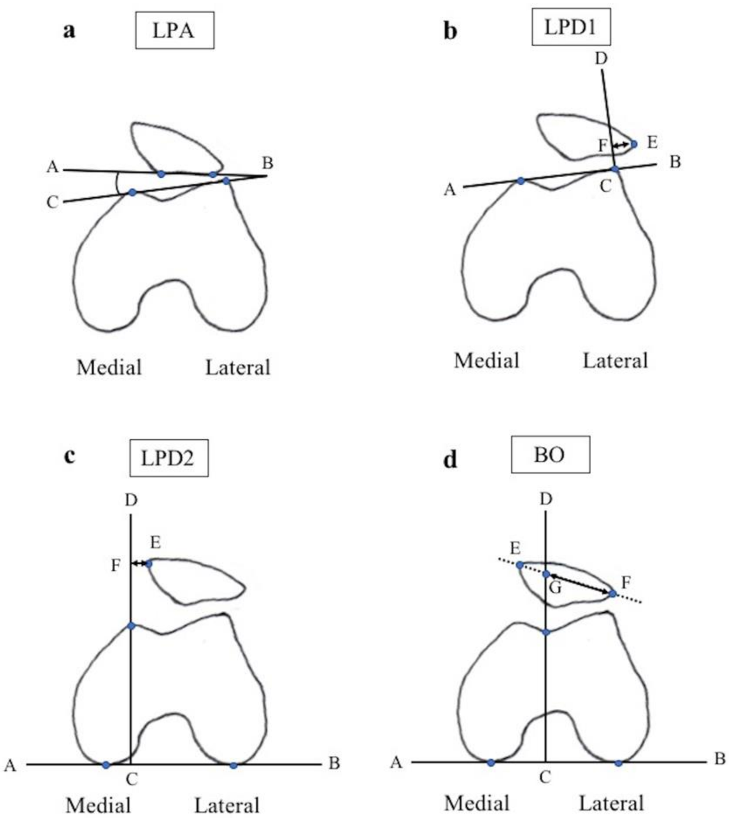
Ultrasound (US) images obtained at the two sites of the knee. **a**, The lateral edge of the patella and lateral condyle of the femur. **b**, The medial edge of the patella and medial condyle of the femur. US = ultrasound.

Figure. 3



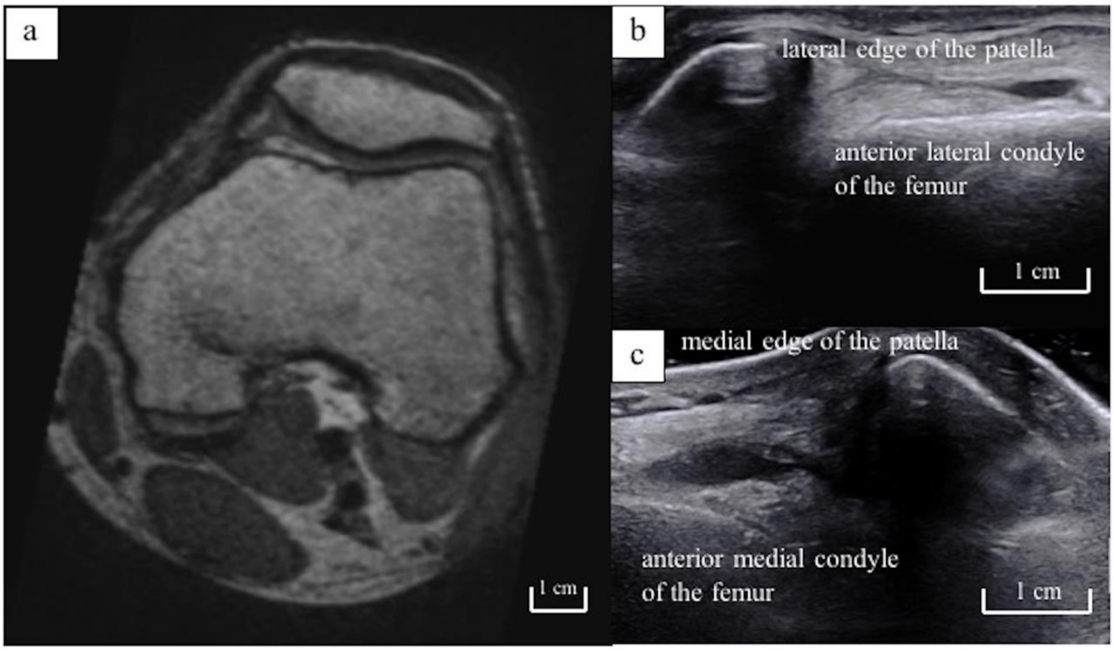
Methods for measuring US-lateral distance (a), US-angle (b), and US-medial distance (c). US = ultrasound.

Figure. 4



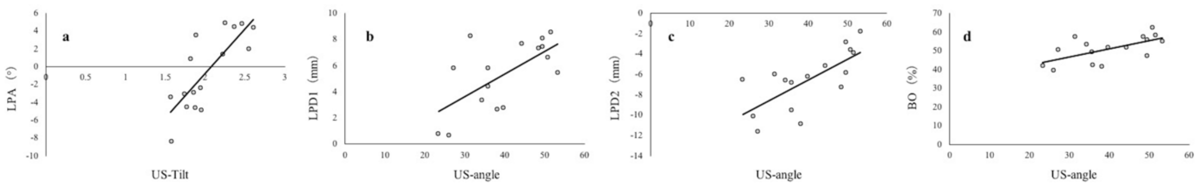
Methods for measuring LPA (a), LPD1 (b), LPD2 (c), and BO (d). LPA = lateral patellar angle; LPD = lateral patella displacement; BO = bisect offset.

Figure. 5



Representative images of MRI (a) and lateral (b) and medial (c) US images of the same participant. **a** Axial image of the right knee at the point of superior-lateral edge of the patella.

Figure. 6



Relationship between US and MRI. **a** US-Tilt and LPA. **b** US-angle and LPD1. **c** US-angle and LPD2. **d** US-angle and BO. LPA = lateral patellar angle; LPD = lateral patella displacement; BO = bisect offset.