



Original Article

Determination of patellar tendon length for anterior cruciate ligament reconstruction using an anteroposterior knee radiograph

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ARTICLE INFO

Article history:

Received 7 August 2018

Received in revised form

8 December 2018

Accepted 10 December 2018

Available online 21 December 2018

Keywords:

Patellar tendon length

Anterior cruciate ligament reconstruction

Bone-patellar tendon-bone graft

Graft-tunnel length mismatch

Radiographic measurement

Anteroposterior knee radiograph

ABSTRACT

Background/Objective: Graft-tunnel length mismatch is a common intraoperative technical problem for anterior cruciate ligament reconstruction (ACLR) using a bone-patellar tendon-bone graft (BPTB). The patella-to-condyle and the patella-to-notch distances are two measurements in an anteroposterior knee radiograph. The objective of this study was to evaluate the sensitivities, specificities and reliabilities of those 2 measurements for detecting patients who had a patellar tendon length exceeding 45 mm.

Methods: Preoperative plain radiographs of patients who underwent ACLR with a BPTB graft were evaluated independently by two orthopaedic surgeons 3 times each at 2-weekly intervals. The sensitivities and specificities of the two measurements for detecting patients who have a patellar tendon length exceeding 45 mm were calculated. The optimal cutoff point was estimated using Youden index, and the receiver operating characteristic (ROC) curve and area under the curve (AUC) were evaluated with a 95% CI. As for the inter- and intra-rater reliabilities, intraclass correlation coefficients (ICC) were determined.

Results: One hundred and twenty-seven patients with an average age of 29.5 years old were evaluated. The mean patellar tendon length was 41.3 ± 5.0 mm. Patients with a length more than 45 mm (20 patients, 16%) had significantly higher patella-to-condyle and patella-to-notch distances, and more frequent use of bone staples for distal graft fixation than patients with a length ≤ 45 mm. To detect patients with a patellar tendon length over 45 mm, the optimal cutoff point for the patella-to-condyle distance was set at 14.5 mm, which had a sensitivity of 80%, specificity of 71%, and AUC of 0.76. In the case of the patella-to-notch distance, the cutoff point of 5.5 mm had a sensitivity of 80%, specificity of 66%, and AUC of 0.73. The intra- and inter-rater reliabilities of the two measurements were excellent, with ICCs of over 0.90.

Conclusions: Preoperative measurements of the patella-to-condyle and the patella-to-notch distances in AP knee radiographs can be valuable tools, with good sensitivities and specificities, for the determination of the patellar tendon length when using a BPTB graft for an ACLR. They had an acceptable level of discrimination capability and excellent reliability.

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Introduction

The bone-patellar tendon-bone (BPTB) graft is a common autograft used in anterior cruciate ligament reconstruction (ACLR), especially for athletes who participate in contact sports.¹ Bone blocks at both ends of the BPTB graft provide strong fixation

strength, which allows athletes to have faster progression in the early phase of rehabilitation than using a soft tissue graft.¹ Due to the fixed length of the patellar tendon, a graft-tunnel length mismatch is a common intraoperative technical problem. This situation is usually caused by the tendon length was excessive. The mismatch is encountered in approximately 13%–26% of ACLR using a BPTB graft.^{2–4} There are several methods to solve this problem, but they all increase the complexity of the surgery and the risk of complications.^{4–7} Therefore, the preoperative determination of the patellar tendon length is important when selecting this graft choice, and it aids in the preparation of alternative fixation devices,

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such as bone staples.

Several methods to determine the patellar tendon length have been investigated.^{8–10} The height of a patient is one of anthropometric measurements that have a weak correlation with the true patellar tendon length.^{8,9} Lateral knee radiographs, which usually require a specific knee position, have also been used to assess patellar height.¹⁰ However, the measurement of the patellar tendon length in a lateral knee radiograph is problematic as it is sometimes difficult to define the distal attachment point of the tendon at the tibial tubercle due to the variations in the bony morphology in this area.¹¹ In addition, magnetic resonance imaging (MRI) can be used to obtain the measurement, but this method is costly.¹²

An anteroposterior (AP) knee radiograph is a routine preoperative investigation that has less variation in position than a lateral radiograph. Radiographic measurements of the patella-to-condyle distance and the patella-to-notch distance were introduced to detect the condition of an excessive long patellar tendon. It was hypothesized that these radiographic measurements could be used to determine the patellar tendon length for the ACLR with a BPTB graft with good sensitivities, specificities, and reliabilities. The objective of this study was to evaluate the sensitivities, specificities and reliabilities of the patella-to-condyle distance and the patella-to-notch distance measurements on an AP radiograph in identifying patients who had a patellar tendon length over 45 mm.

Materials and methods

This retrospective study was approved by the Siriraj Institutional Review Board (COA no. Si 493/2017). Medical records and preoperative radiographs of patients who had undergone an arthroscopic ACLR between January 2015 and August 2017 were reviewed. The inclusion criteria were patients who were older than 15 years and had undergone an arthroscopic ACLR using a BPTB graft, and who had all of the following data: an intraoperative record of the patellar tendon length, the type of graft fixation, and a preoperative AP plain radiograph of the affected knee. Patients who had an extension deficit of the knee of more than 10°, a previous

fracture of either patella or the femoral condyle were excluded.

The following demographic data were collected from the patients' records: age, sex, weight, height, body mass index (BMI), side of involvement, types of graft fixation, and the patellar tendon length. The patellar tendon length was obtained from the intraoperative measurement. After the BPTB autograft had been harvested, the tendinous portion of the graft was measured at its midline along its posterior surface to the nearest millimeter using a sterile ruler. The graft was longitudinally pulled to prevent graft redundancy.

During the ACLR, the femoral tunnel was drilled at the center of the femoral footprint of the anterior cruciate ligament using the transportal technique. The tibial tunnel was also drilled at the center of the tibial ACL footprint using an aiming device of 55–60°. The BPTB graft was usually fixed with a bioabsorbable interference screw on both sides. A bone staple was an alternative tibial fixation technique when there was less than 15 mm of bone block in the tibial tunnel. An excessive long patellar tendon in this study was defined as a BPTB graft with a tendinous portion exceeding 45 mm. In such cases, the graft might have required additional femoral bone block recession or the increased usage of staples for distal graft fixation.

The AP radiographs of the knees were measured using the picture archiving and communication system (PACS). Two methods were proposed by the authors to determine the patellar tendon length. The patella-to-condyle distance was defined as the distance between a line tangential to the most convex point of both the medial and lateral femoral condyles, and a parallel line at the inferior pole of the patella (Fig. 1A). The patella-to-notch distance was defined as the distance between the apex of the femoral notch and a line at the inferior pole of the patella (Fig. 1B). Using these two definitions, the distances were measured with the PACS, which was calibrated to reflect the actual distance. Two orthopaedic surgeons independently measured each radiograph; to assess the intra- and inter-rater reliabilities of the measurements, they were made 3 times by each surgeon, with a 2-week interval between each computation.

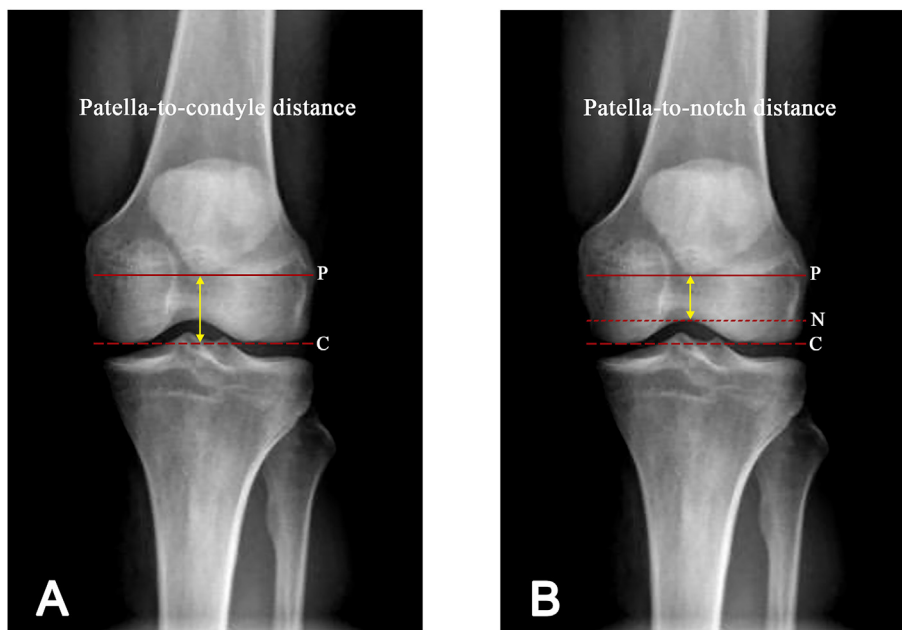


Fig. 1. Measurements were performed on an antero-posterior radiograph of the knee. A) Patella-to-condyle distance was the distance between a line draw at a tangent to the most convex point of both femoral condyles (line C), and a parallel line at the inferior pole of the patella (line P). B) Patella-to-notch distance was the distance between the apex of the femoral notch (line N) and a line at the inferior pole of the patella.

Table 1
Demographic data.

Variables	All (n = 127)	Group I Patellar tendon > 45 mm (n = 20)	Group II Patellar tendon ≤ 45 mm (n = 107)	P-value
Age (yr)	29.5 ± 8.8	27.5 ± 7.6	29.9 ± 9.1	0.26
Sex (n, %)				
Male	121 (95%)	20 (100%)	101 (94%)	0.59
Female	6 (5%)	0 (0%)	6 (6%)	
Weight (kg)	72.5 ± 12.7	71.6 ± 11.9	72.6 ± 12.8	0.75
Height (cm)	170.7 ± 7.2	172.7 ± 5.6	170.3 ± 7.4	0.17
BMI (kg/m ²)	24.3 (17.5–36.8)	22.8 (19.8–31.6)	24.3 (17.5–36.8)	0.22
Side (n, %)				
Left	69 (54%)	9 (45%)	60 (56%)	0.47
Right	58 (46%)	11 (55%)	47 (44%)	

Table 2
Patellar tendon length, two radiographic measurements, and types of tibial fixation of the patients.

Variables	All (n = 127)	Group I Patellar tendon > 45 mm (n = 20)	Group II Patellar tendon ≤ 45 mm (n = 107)	P-value
Patellar tendon length (cm)	41.3 ± 5.0	49.5 ± 2.7	39.7 ± 3.6	<0.01*
Radiographic measurements				
Patella-to-condyle (mm)	13.2 ± 6.6	18.7 ± 6.9	12.1 ± 6.0	<0.01*
Patella-to-notch (mm)	3.8 ± 7.2	8.6 ± 7.7	2.9 ± 6.7	<0.01*
Tibial fixation (n, %)				
Interference screw	108 (85%)	10 (50%)	98 (92%)	<0.01*
Bone staple	19 (15%)	10 (50%)	9 (8%)	

* Statistically significant difference between the two groups with p-value less than 0.05.

The minimum sample size required for sensitivity and specificity testing was calculated using a formula to estimate a 95% CI for sensitivity (nQuery Advisor and nTerim sample size software, version 4.0). The value of the expected prevalence of a patellar tendon length exceeding 45 mm was set to be from 15%, which was obtained from operative records of 100 consecutive patients. Given that, having 126 participants would allow the achievement of a 95% CI for sensitivity.

Descriptive statistics were used to summarize the demographic data. All categorical data were reported as a number or percentage, while the continuous data were reported either as the mean and standard deviation if normally distributed, or as the median with a range if non-normally distributed. The Shapiro–Wilks test and visual inspection revealed if the data were sufficiently normal for the use of parametric statistics. Data were divided into two groups: patients with a patellar tendon length exceeding 45 mm, and patients with a tendon length less than or equal to 45 mm. A chi-squared or Fisher's exact test was used to test the differences between the 2 groups of categorical data. In the case of continuous data, the independent *t*-test or the Mann–Whitney *U* test was used, as appropriate, to find differences.

The sensitivities and specificities of the two radiographic measurements for detecting patients who have a patellar tendon length over 45 mm were conducted with a 95% CI for sensitivity and specificity. The optimal cutoff point was estimated using Youden index. The positive predictive value (PPV), negative predictive value (NPV) and positive/negative likelihood ratio (LR+/LR-) were also calculated with a 95% CI. Testing of the performance or accuracy of the potential new diagnostics test, the receiver operating characteristics (ROC) curve, and the area under the curve (AUC) were evaluated with a 95% CI, in accordance with Hosmer and Lemeshow's recommendations (discrimination of AUC: 0.50–0.60 = luck; 0.61–0.70 = low; 0.71–0.80 = acceptable; 0.81–0.90 = very good; and 0.91–1.0 = excellent).¹³

As for the inter- and intra-rater reliabilities, intraclass correlation coefficients (ICC) were determined. As a general rule, an ICC value over 0.75 is considered good.¹⁴ Standard errors of measurement and limits of agreement (LOA), using Bland–Altman plots, were presented as indicators of absolute reliability. Statistical

analyses were performed using STATA/SE version 14 (StataCorp LP, College Station, TX, USA) and NCSS version 10 (NCSS Statistical Software, Kaysville, UT, USA). A p-value of 0.05 was considered to be the threshold for significance.

Results

There were 135 eligible patients. Eight were excluded because of a knee extension deficit of more than 10°. Of the remaining 127 patients, 121 were male, with an average age of 29.5 years. The mean patellar tendon length was 41.3 ± 5.0 mm. The patients were divided into 2 groups using a tendon-length cutoff point of 45 mm. Twenty patients (16%) had a length more than 45 mm. The demographic data of the two groups were compared (Table 1); there were no significant differences in their average age, weight, height or BMI.

Regarding the distal graft fixation, 108 patients (85%) had interference screw fixation, whereas 19 patients (15%) required bone staple fixation. Patients with a patellar tendon length over 45 mm had significantly higher patella-to-condyle and patella-to-notch distances. This group also required bone staple fixation more often than those patients with a patellar tendon length

Table 3
Sensitivities and specificities of different cutoff points.

Distance (mm)	Sensitivity (%) (95% CI)	Specificity (%) (95% CI)
Patella-to-condyle distance		
13.5	80.0 (56.3–94.3)	62.6 (52.7–71.8)
14.0	80.0 (56.3–94.3)	67.3 (57.5–76.0)
14.5#	80.0 (56.3–94.3)	71.0 (61.5–79.4)
15.0	70.0 (45.7–88.1)	72.9 (63.4–81.0)
15.5	65.0 (40.8–84.6)	73.8 (64.4–81.9)
Patella-to-notch distance		
4.5	85.0 (62.1–96.8)	60.7 (50.8–70.0)
5.0	80.0 (56.3–94.3)	62.6 (52.7–71.8)
5.5#	80.0 (56.3–94.3)	66.4 (56.6–75.2)
6.0	70.0 (45.7–88.1)	68.2 (58.5–76.9)
6.5	65.0 (40.8–84.6)	69.2 (59.5–77.7)

The optimal cutoff point with the highest Youden index.

Table 4

Predictive values, likelihood ratios, and area under the curve of different cutoff points.

Distance (mm)	PPV (95%CI)	NPV (95%CI)	LR+ (95%CI)	LR- (95%CI)	AUC (95%CI)
Patella-to-condyle distance					
13.5	28.6 (17.3–42.2)	94.4 (86.2–98.4)	2.1 (1.5–2.9)	0.3 (0.1–0.8)	0.7 (0.6–0.8)
14.0	31.4 (19.1–45.9)	94.7 (87.1–98.5)	2.5 (1.7–3.5)	0.3 (0.1–0.7)	0.7 (0.6–0.8)
14.5#	34 (20.9–49.3)	95 (87.7–98.6)	2.8 (1.9–4.0)	0.3 (0.1–0.7)	0.8 (0.7–0.8)
15.0	32.6 (19.1–48.5)	92.9 (85.1–97.3)	2.6 (1.7–3.9)	0.4 (0.2–0.8)	0.7 (0.6–0.8)
15.5	31.7 (18.1–48.1)	91.9 (83.9–96.7)	2.5 (1.6–3.9)	0.5 (0.3–0.8)	0.1 (0.6–0.8)
Patella-to-notch distance					
4.5	28.8 (17.8–42.1)	95.6 (87.6–99.1)	2.2 (1.6–2.9)	0.3 (0.1–0.7)	0.7 (0.6–0.8)
5.0	28.6 (17.3–42.2)	94.4 (86.2–98.4)	2.1 (1.5–3.0)	0.3 (0.1–0.8)	0.7 (0.6–0.8)
5.5#	30.8 (18.7–45.1)	94.7 (86.9–98.5)	2.4 (1.7–3.4)	0.3 (0.1–0.7)	0.7 (0.6–0.8)
6.0	29.2 (17.0–44.1)	92.4 (84.2–97.2)	2.2 (1.5–3.3)	0.4 (0.2–0.9)	0.7 (0.6–0.8)
6.5	28.3 (16.0–43.5)	91.4 (83.0–96.5)	2.1 (1.4–3.2)	0.5 (0.3–0.9)	0.7 (0.5–0.8)

The optimal cutoff points with the highest Youden index and area under the curve.

Positive predictive value (PPV), negative predictive value (NPV), positive likelihood ratio (LR+), negative likelihood ratio (LR-) and area under the curve (AUC).

≤45 mm (50% and 8%, respectively; Table 2).

The optimal cutoff point for the patella-to-condyle distance with the highest Youden index was 14.5 mm, which had a sensitivity of 80% and a specificity of 71% (Table 3). This value had a PPV of 34% and an NPV of 95% (Table 4). The area under the curve was 0.76, which represents an acceptable level of discrimination capability (Fig. 2).

As for the patella-to-notch distance measurement, the optimal

cutoff point of 5.5 mm had a sensitivity of 80% and a specificity of 66% (Table 3). This value had a PPV of 31% and an NPV of 95% (Table 4). The area under the curve for this method was 0.73, which was an acceptable level (Fig. 3).

The intra- and inter-rater reliabilities of the two measurements are at Table 5. Both methods had excellent reliabilities, with ICCs of more than 0.90. The differences between the observers are also illustrated by Bland-Altman plots, which plot the mean value of

Patella-to-condyle distance

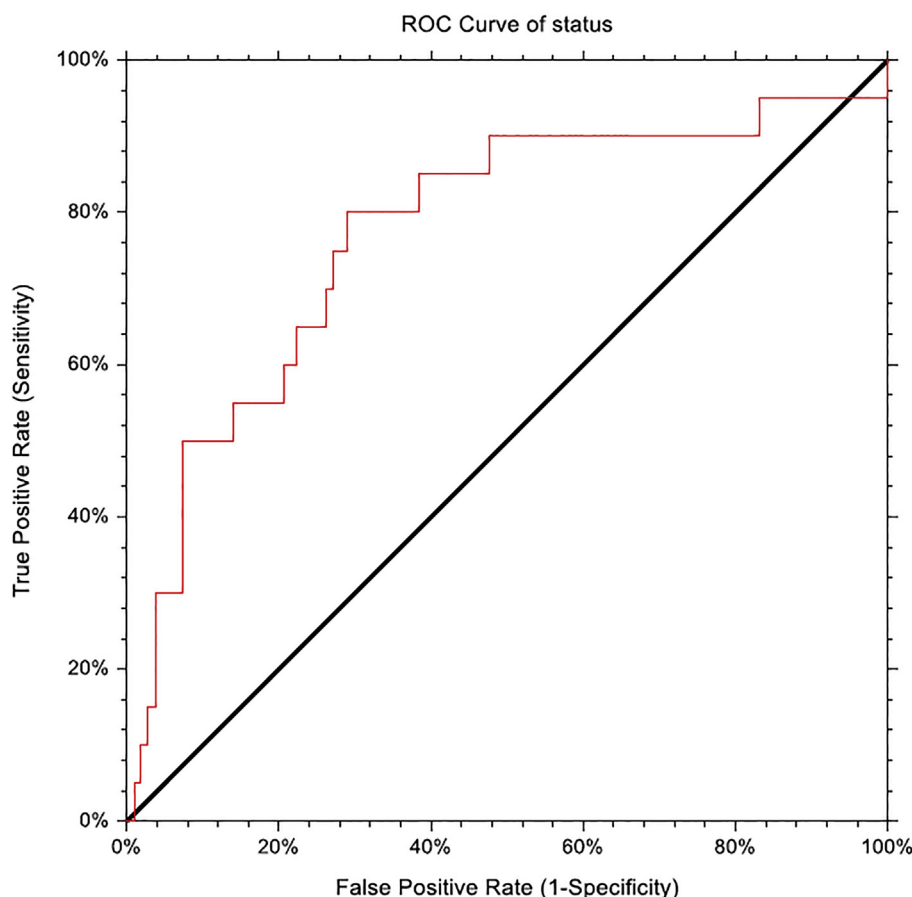


Fig. 2. The ROC curve of the patella-to-condyle distance was obtained after empirical estimation. The area under the curve was 0.76 (0.66–0.85), which represents an acceptable level of discrimination capability.

Patella-to-notch distance

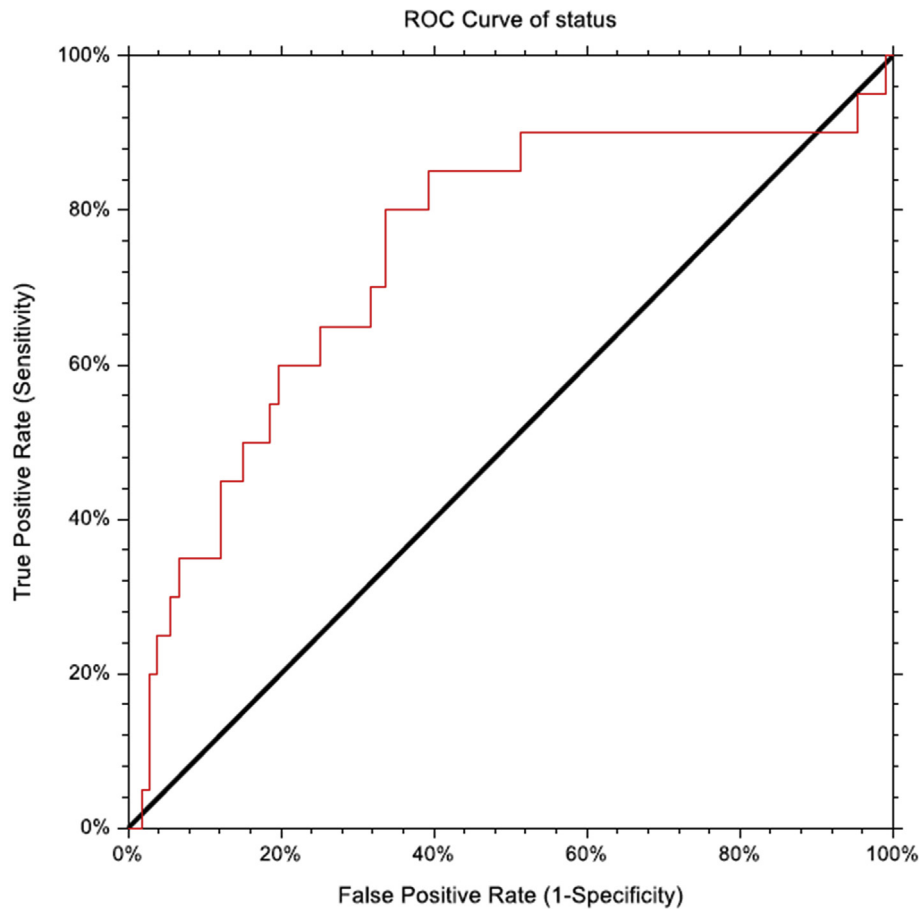


Fig. 3. The ROC curve of the patella-to-notch distance was obtained after empirical estimation. The area under the curve was 0.73 (0.63–0.83), which signifies an acceptable level of discrimination capability.

Table 5

The intra- and interrater reliabilities of the patella-to-condyle and the patella-to-notch distance measurements.

	ICC (95%CI)	SEM (mm)	LOA (mm)
Intra-rater reliability			
Patella-to-condyle distance	0.98 (0.97, 0.99)	0.92	–2.8 to 2.3
Patella-to-notch distance	0.98 (0.97, 0.99)	0.89	–2.5 to 2.4
Inter-rater reliability			
Patella-to-condyle distance	0.96 (0.94, 0.98)	1.24	–3.2 to 3.6
Patella-to-notch distance	0.95 (0.92, 0.97)	1.51	–3.2 to 4.6

ICC intraclass correlation coefficients, SEM standard error of measurement, and, LOA limit of agreements.

both observers for both methods of measurement (Figs. 4 and 5).

Discussion

In this study, the length of the tendinous portion of the BPTB graft was determined using 2 measurement methods on a preoperative AP radiograph of the knee. The condition of an excessive long patellar tendon—one longer than 45 mm—could be predicted when the patella-to-condyle distance was more than 14.5 mm (a sensitivity of 80% and a specificity of 71%) or the patella-to-notch distance was more than 5.5 mm (a sensitivity of 80% and a specificity of 66%). Both measurements had an acceptable level of

discrimination capability, with excellent intra- and inter-rater reliabilities. However, regarding the optimal cutoff point, the patella-to-condyle distance had the higher area under the curve (AUC) comparing to the patella-to-notch distance of 0.8 (95% CI of 0.7–0.8) over 0.7 (95% CI of 0.6–0.8). Therefore, the patella-to-condyle distance may be a more reliable and preferred method to detect the condition of an excessive long patellar tendon (patellar tendon length more than 45-mm).

Several studies have reported the mean patellar tendon length.^{9,12} McAllister et al.¹² found it averaged at 45.2 mm, whereas Yoo et al.⁹ described a length of 40.2 mm. In the present study, the mean was 41.3 mm, which was close to the results of Yoo et al., whose study was also done on an Asian population. Shaffer et al.² demonstrated that the incidence of graft tunnel mismatch is higher when the tendinous portion of the graft is more than 50 mm. In the current study, there was a significantly increased use of bone staple fixation among the group of patients with a patellar tendon length exceeding 45 mm. Therefore, this length was used to define the condition of the excessive long patellar tendon to raise the awareness of surgeons.

Several methods to predict the tendon length of a BPTB graft have been investigated. Yoo et al.⁹ showed there was a poor correlation between anthropometric parameters and patellar tendon length. Brown et al.¹⁵ also demonstrated that the length of the patellar tendon did not have a significant correlation with the

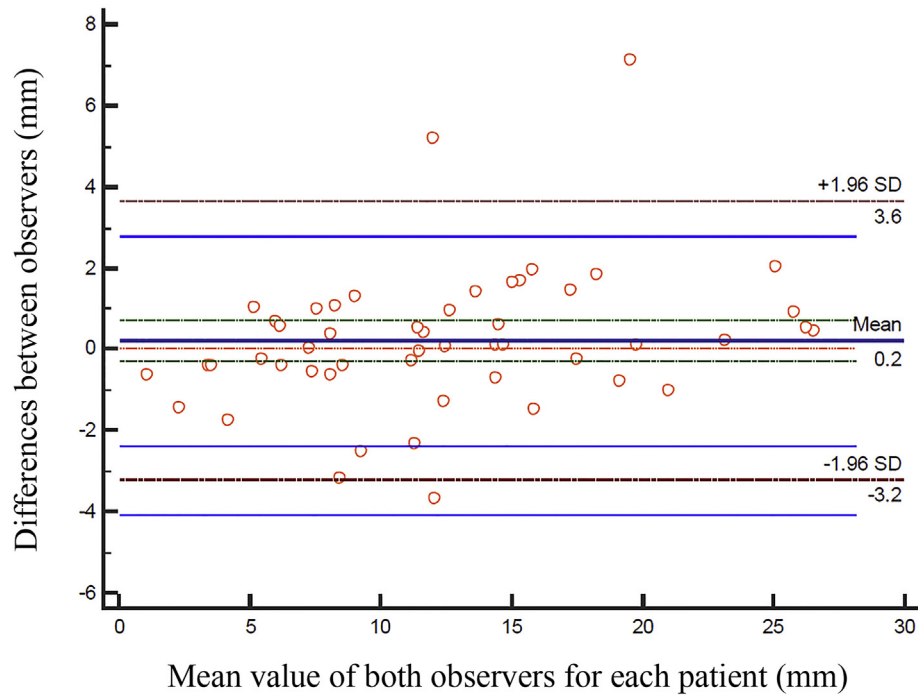


Fig. 4. Bland–Altman plots of the patella-to-condyle distance measurement demonstrated differences between the 2 observers, plotted against the mean value of both observers for each patient.

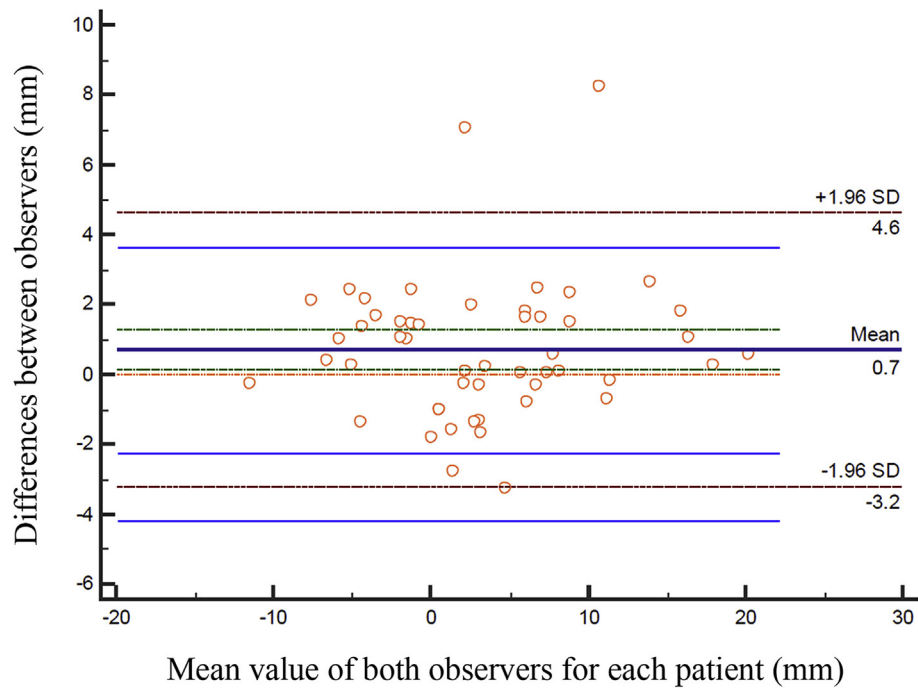


Fig. 5. Bland–Altman plots of the patella-to-notch distance measurement demonstrated differences between the 2 observers, plotted against the mean value of both observers for each patient.

patient's height. The current study revealed that there were also no statistically significant differences in weight, height and BMI of the two groups of the patients.

Radiographic measurements, such as plain radiography, sonography or MRI, may aid in the prediction of patellar tendon length. McAllister et al.¹² compared the efficacy of lateral radiographs taken at 30° of knee flexion with both a standard MRI and an

MRI with supplemental, three-dimensional reconstructions, to predict the patellar tendon length of 14 cadaveric knees. They found that the radiographs were the most accurate predictor of the actual patellar tendon length. The standard MRI protocol was probably less accurate because of the obliquity of the imaging plane relative to the patellar tendon plane. In contrast, Chang et al.¹⁶ found that an MRI assessment provided satisfactory accuracy and

reliability when estimating the patellar tendon dimension. Those outcomes may be attributable to advances in MRI technology and more precise methods of measurement. However, many patients who have sufficient clinical information might not require an MRI for their preoperative planning. Besides, it could reduce the treatment cost of the patient. Robert et al.¹⁷ showed a good agreement of ultrasonography when determining patellar tendon thickness, but a poor agreement for patellar tendon's width and length. They concluded that sonography could not be recommended for the measurement of the length because of its limited accuracy.

Lateral radiographs have also been used to predict patellar tendon length.^{14,18} In clinical practice, the inaccuracy of patellar tendon length measurements obtained from lateral radiographs might be affected by differences in the knee positions and variations of the bony morphology around the tibial tubercle.

An AP radiograph is another routine preoperative imaging for an arthroscopic ACLR. The present study demonstrated that the patella-to-condyle distance and the patella-to-notch distance in this routine radiograph can be used to provide additional information regarding the length of the tendinous part of the BPTB graft in an ACLR. This could help surgeons to be more aware of a potential graft-tunnel mismatch and prepare for technical adjustments, which sometimes require special instruments.

This study had some limitations. Most of patients in this study were male. During the intraoperative measurement of the tendon length, the authors did not use a tensioning device to control the tension force on the BPTB graft. However, the grafts were manually pulled to eliminate redundancy of the tendon during the measurement. In addition, the patella was superimposed on the distal femur in the AP radiograph, which caused some difficulties with defining the inferior pole of the patella of some patients. This can be solved by using the contrast adjustment facility of the digital PACS system. Although both measurements in this study were useful for detecting the condition of an excessive long patellar tendon, these measurements could not directly estimate the actual length of the patellar tendon.

In summary, this study demonstrated that the preoperative measurements of the patella-to-condyle distance and the patella-to-notch distance on AP radiographs of the knee could be used to determine the patellar tendon length of those patients who were undergoing an ACLR using a BPTB graft, and with good sensitivities and specificities. Those measurements also had acceptable levels of discrimination capability and excellent reliability.

Funding/Support Statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors, and no material support of any kind was received.

Conflict of interest

The authors declare that there are no conflicts of interest related to this study.

Acknowledgement

The authors gratefully acknowledge Miss Nichakorn Khomawut for data collection, and Miss Waraporn Chalermasuk for manuscript preparation.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.asmart.2018.12.001>.

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