Clinically Reliable Knee Flexion Angle Measured on Stress Radiography for Quantifying Posterior Instability in Posterior Cruciate Ligament Injury

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Background: After posterior cruciate ligament injury, stress radiography is a common method of quantifying posterior instability, defined as the side-to-side difference in posterior tibial displacement (PTD) between the injured knee and contralateral noninjured knee. However, no study has evaluated the reliability of PTD according to knee flexion angle (KFA) measurements on stress radiographs.

Purpose: To evaluate the test-retest reliability of stress radiographic measurements of the KFA in the noninjured knee. In addition, we established a reliable range of KFAs to indicate posterior instability by comparing results with the instability measured at a KFA of 90°, which is considered the gold standard.

Study Design: Cohort study (diagnosis); Level of evidence, 3.

Methods: We evaluated patients who had undergone bilateral stress radiographic examinations at least 5 times for ligament injuries between January 2013 and November 2019. All examinations were performed using a Telos device with a 150-N posterior load. A total of 120 knees and 644 stress radiographs were included. We measured the KFA and PTD on stress radiographs and evaluated the reliability of repeated PTD measurement and the correlation between KFA and PTD.

Results: The distribution of the actual noninjured knee KFA ranged from 56.9° to 106.7°. Among the 644 radiographs, 155 (24.1%) showed KFAs between 85° and 95°, and 287 (44.6%) showed KFAs between 80° and 85°. A significant correlation was found between KFA and PTD ($P < .001$), and the intrapatient intraclass correlation coefficient (ICC) was 0.788. A KFA range of 85° to 92° satisfied the criteria of high ICC (0.885) and nonsignificant correlation between KFA and PTD ($P = .055$) and thus was considered a reliable range of KFAs for quantifying posterior instability. We found no significant risk factors for measurement error, including age ($P = .674$), sex ($P = .328$), height ($P = .957$), weight ($P = .248$), or body mass index ($P = .257$).

Conclusion: We found high reproducibility of posterior displacement measurements on Telos stress radiography at a KFA of 85° to 92° in noninjured knees.

Keywords: posterior instability; posterior cruciate ligament injury; stress radiography; knee flexion angle; reliability

Although more information has become available on the anatomic and biomechanical characteristics of the posterior cruciate ligament (PCL), many variables and controversies remain regarding diagnosis and treatment options.[21,26] PCL injury is managed with nonoperative treatment at the acute phase in many cases, and if posterior instability remains, surgical treatment is indicated.[18] However, physical examination has been considered to have low reproducibility, low accuracy, and high subjectivity for assessing posterior knee instability.[6,11] Despite the numerous clinical tests that have been described for diagnosing posterior instability, objective clinical quantification of posterior laxity remains difficult.[1,4,26]

Several techniques to quantify posterior instability, including stress radiography using a stress device, kneeling position, supine lateral radiography, and arthrometry, are available.[11,12,14,15,19,24] In PCL injury, stress radiography is generally accepted to be superior in quantifying posterior instability.[10,12,22] However, the reliability of this measurement method has not been well-evaluated in a larger patient population, and no clear standard method has been established.[20,26]

On stress radiographs, posterior instability is defined as the side-to-side difference in posterior tibial displacement

The Orthopaedic Journal of Sports Medicine, 9(3), 2325967121989252
DOI: 10.1177/2325967121989252

(PTD) between the injured and contralateral noninjured knees, measured at a knee flexion angle (KFA) of 90°, which is considered the gold standard.[14,26] However, stress radiography performed in the clinic may yield varying results owing to inconsistent KFA,[7,16] patient guarding or muscle contraction secondary to pain, reliability of the device used, and technician experience.[12,16,26] Previous studies have evaluated posterior instability at KFAs of 70° to 90°.[7,14,15,24,26] In terms of KFA, a threshold should be set to secure the reliability of stress radiographic measurement. If there are differences in the measurement of KFA in the noninjured knee, the intertest reliability for the injured knee may be impaired.

Thus, an investigation using a large sample is needed to elucidate the optimal clinical setting for evaluating posterior instability using stress radiography. The purpose of this study was to evaluate the test-retest reliability of noninjured knee KFA measurements for calculating posterior instability on stress radiography. We conducted this investigation to establish a reliable range of KFAs for posterior instability measurement by comparing results with the value measured at the gold standard of 90°.

METHODS

Participants

This retrospective, institutional review board–approved study was conducted in patients who had undergone a bilateral stress radiographic examination for ligament injury between January 2013 and November 2019. Patients were included if they (1) were between 18 and 60 years old; (2) had confirmed isolated anterior cruciate ligament (ACL) or PCL injury by magnetic resonance imaging examination; and (3) had undergone stress radiography at least 5 times for posterior instability evaluation using a stress device in both knees (patients with ACL and PCL reconstruction underwent stress radiography at the preoperative point and at postoperative 6 months, 9 months, 1 year, and 2 years; patients with partial or stable PCL injury underwent stress radiography at the initial visit and at 3 months, 6 months, 1 year, and 2 years after trauma). Patients were excluded if (1) they had a bony abnormality or a history of previous fracture; (2) their noninjured side could not be assessed because of a history of knee ligament injury on both sides; (3) they had incurred an additional ligament injury on the noninjured side during the interval before the repeated test; and (4) they had general laxity (Beighton score of ≥4).[28] Overall, 120 patients (120 knees, total of 644 stress radiographic images of the noninjured side) were enrolled in this study.

Stress Radiographs

Stress radiographs of the noninjured knee were performed using the Telos GA II stress device (Telos, Weterstadt, Germany). A true lateral radiograph with overlapping of the posterior condyles was obtained at a KFA of 90° with the patient in the lateral decubitus position. A posterior load of 150 N[12] was applied to the proximal tibia at a level just below the tibial tubercle (Figure 1). All radiographs were performed by 1 of 3 experienced radiology technicians. The source film distance was always approximately 90 to 100 cm, and the cassette was positioned in direct contact with the examined knee.

Measurement of Posterior Instability

PTD measured on the Telos stress radiographs was evaluated using a technique described by Stäubli and Jakob.[29] After a line was drawn along the medial tibial plateau, perpendicular lines were drawn tangential to the midpoint between the most posterior contours of the medial and lateral femoral condyles and tibial plateau. This was also set as the midpoint of the posterior contours of the condyles to evaluate PTD on radiographs with rotational error. The distance between these 2 points was then measured to determine the PTD (Figure 1D).[14,26] KFA was defined as the angle between the extension line of the distal femoral posterior cortical line (Figure 1E) and the proximal tibial posterior cortical line (Figure 1F).[13]

The PTD and KFA were measured to the nearest 0.01 mm using a digitized picture archiving and communication system (PACS) (Centricity 6.0 SP9; GE Healthcare); a 5-cm bar was calibrated in the PACS system and measured as a reference value in the PACS program. Two trained orthopaedic surgeons (D.J.R. and K.B.K.) measured

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Final revision submitted September 16, 2020; accepted October 21, 2020.

One or more of the authors has declared the following potential conflict of interest or source of funding: This research was supported by a grant from the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health & Welfare, Republic of Korea (grant No. HI15C2424), and supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (NRF-2017R1A2B3007362). AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from Samsung Medical Center (IRB file No. 2019-11-180).

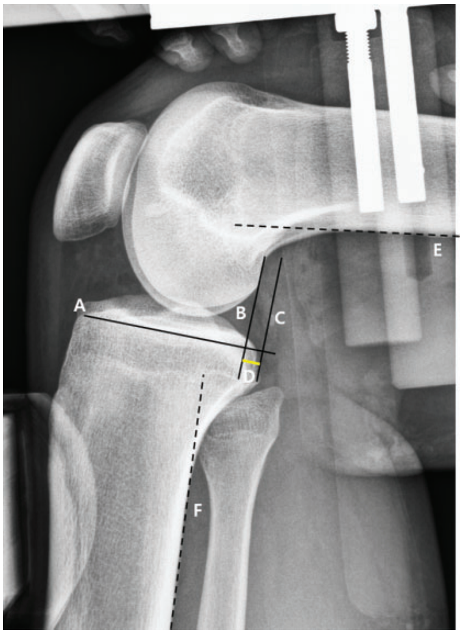

Figure 1. Measurement of posterior tibial displacement on posterior stress radiograph at a knee flexion angle (KFA) of 90°. Perpendicular lines from the reference line (solid black line *A*, parallel to the medial tibial plateau joint line) are drawn tangentially to the midpoint between the most posterior contours of the medial and lateral femoral condyles (solid black line *B*) and medial tibial plateau (solid black line *C*). If the femoral condyle is in an inappropriate rotation position, the midpoint between the most posterior contours of the medial and lateral femoral condyles is used. The distance between lines *B* and *C* is defined as the posterior tibial displacement (*D*, yellow line). The KFA is defined as the angle between the extension of the distal femoral posterior cortical line (dashed black line *E*) and the proximal tibial posterior cortical line (dashed black line *F*).

the PTD and KFA 2 times at a 2-week interval, and the intraobserver and interobserver reliabilities were evaluated.

Statistical Analysis

To evaluate the primary outcome of this study, after correcting the actual KFA using a linear mixed model, we evaluated the reliability of the multiple posterior instability measurements in each patient by calculating the intraclass correlation coefficient (ICC) and 95% CI. Before the study commenced, the sample size was calculated. The criteria were set as an ICC of 0.8 and a lower limit of 0.75 for the 95% CI of the ICC.[2] Results indicated that a sample size of 120 and repeated measurements at least 4 times were required.

By applying a linear mixed model with the participant as a random effect, we used the ICC to estimate the correspondence among the PTD values in each participant, and we analyzed the correlation between KFA and posterior instability. KFA that satisfied an ICC of >0.855 was set as a reliable KFA range, whereas the number of participants within the range was set as at least 80. Finally, we analyzed the risk factors[3,16] (age, sex, height, weight, and body mass index [BMI]) for the selected reliable KFA range by using a generalized linear mixed-effects model. The Bonferroni-corrected *P* value was used for post hoc analysis. All statistical analysis was performed using SPSS Version 25.0 (IBM Corp), and *P* values of <.05 were considered statistically significant.

TABLE 1
Patient Characteristics (120 participants, 644 radiographs)

Variable	Mean ± SD or No.
Age	32.26 ± 10.3
Sex, male:female	92:28
Height, cm	172.24 ± 7.38
Weight, kg	74.18 ± 13.22
Body mass index	25.17 ± 3.46
Frequency of stress radiography	
5 times	86
6 times	26
7 times	6
8 times	2

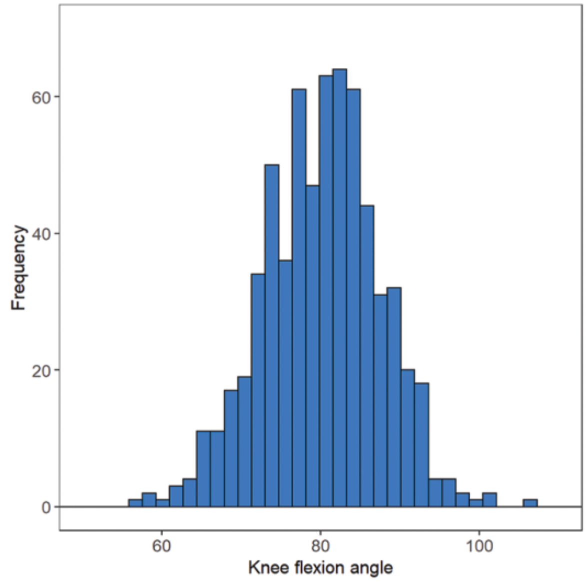

Figure 2. Distribution of actual knee flexion angle for the noninjured knee (N = 644 radiographs).

RESULTS

The demographic data of the included patients are shown in Table 1. Although the goal of KFA measurement was for the technician to have the patient's knee positioned at 90° during stress radiography, the distribution of actual KFAs ranged from 56.9° to 106.7° (Figure 2). When a linear mixed model was applied in all 120 participants, a statistically significant correlation was found between KFA and PTD (*P* < .001), and the intrapatient ICC value was 0.788

TABLE 2
Results of Linear Mixed-Model Analysis (N = 120 participants)[a]

Effect	Estimated Value	SE	*t* Value	*P* Value	ICC	95% CI
Intercept	10.264	0.473	21.700	<.001	0.788	
Angle	–0.076	0.006	–13.710	<.001		
Knee flexion angle						
Intraobserver				<.001	0.993	0.991-0.994
Interobserver				<.001	0.985	0.980-0.989
Posterior tibial displacement						
Intraobserver				<.001	0.992	0.990-0.993
Interobserver				<.001	0.974	0.967-0.979

[a]A statistically significant correlation was found between knee flexion angle and posterior tibial displacement ($P < .001$). ICC, intraclass correlation coefficient.

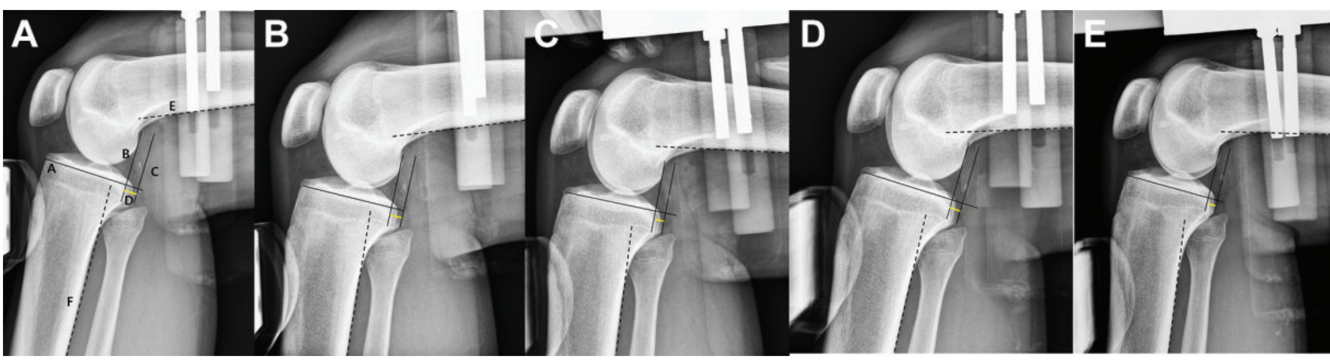

Figure 3. A representative case of a 24-year-old man with a posterior cruciate ligament injury. The noninjured left knee had undergone repeated radiographic examinations to compare side-to-side difference during nonoperative management. (A) The first examination, at a knee flexion angle (KFA, the angle between the extension line of the dashed black lines of 73.3°), resulted in a posterior tibial displacement (PTD, yellow line) measurement of 6.58 mm. (B) KFA of 76.8° and PTD of 4.9 mm. (C) KFA of 90.7° and PTD of 3.98 mm. (D) KFA of 79.5° and PTD of 5.48 mm. (E) KFA of 88.5° and PTD of 4.37 mm.

(Table 2, Figures 2 and 3). The ICCs value are shown in Table 2.

To set the reliable KFA range that satisfied the predetermined criteria, we applied a linear mixed model for each KFA pair. KFAs ranging from 85° to 92° satisfied the criteria regarding the ICC (0.885), minimum number of participants within the range (n = 80), and nonsignificant correlation between KFA and PTD ($P = .055$) (Appendix Table A1); the KFAs in 22.8% of the 644 radiographs were in this range.

Figure 4 shows the results comparing the KFA values within the reliable range (85°-92°) with those in the other KFA ranges after the linear mixed model was applied. All differences were statistically significant ($P < .001$).

To analyze the risk factors of test error, we used a generalized linear mixed-effects model. Results indicated there were no statistically significant differences in results when comparing by age ($P = .674$), sex ($P = .328$), height ($P = .957$), weight ($P = .248$), or BMI ($P = .257$).

Figure 4. Posterior tibial displacement (PTD) values measured at a knee flexion angle (KFA) within 85° to 92° compared with those measured at KFAs within the other ranges after application of a linear mixed model. *Significant difference compared with the other KFA ranges ($P < .001$, Bonferroni corrected).

DISCUSSION

The most important finding of this study was the statistically significant correlation between noninjured knee KFA and posterior instability ($P < .001$), with an intrapatient ICC value of 0.788. Even if we examined only the noninjured knee, the ICC was <0.8 in the repeated measurement in the same patient. Among all 644 radiographs, 155

(24.1%) showed a KFA between 85° and 95° and 287 (44.6%) showed a KFA between 80° and 85° (Figure 2). In many cases, the examination tended to yield an insufficient KFA. We found that the clinically reliable noninjured KFA range that satisfied an ICC of >0.855 was 85° to 92°. The values measured in this range had a nonsignificant error between the repeated measurements in the noninjured knee. After a stress radiographic examination, the accuracy of the rotation as well as the KFA should be checked, and if the KFA results are not within the reliable range, the examination should be performed again.

Although new measurement methods without a stress device are being introduced, such as the kneeling position suggested by Louisia et al[19] and supine lateral radiography as described by Kim et al,[15] stress radiography using a Telos device remains the most frequently used method for assessing PCL injuries, grading instability, and evaluating treatment outcomes owing to its reproducibility, quantifiability, and easy application in daily clinical settings.[14,20] However, no consensus has been reached regarding the posterior drawer force (89-150 N)[12,14] position that provides the optimal method to measure instability.[12,14,15,17] Kim et al and Schulz et al[26] suggested that 90° of knee flexion would be a more appropriate KFA for measuring posterior instability than 30° knee flexion, which is similar to the posterior drawer test. However, in clinical settings, no study has suggested that a range of KFAs that includes 90° is acceptable for obtaining good test-retest reliability. Previous studies have reported that a 1.5-mm difference on stress radiographs is clinically relevant for determining significant instability.[15,31] In our study, the PTD differed from the set reliable range by 1.98 mm in the section less than 70° and 1.476 mm in the section between 70° and 80°. For this reason, this study has important implications for improving the accuracy of examinations in clinical settings.

In the clinical setting, many factors influence the results of stress radiographic measurement, including patient knee position, acute injury pain, muscle tone, technician experience, and amplitude of the force applied.[14,22] In fact, many patients report discomfort and pain during examination, especially in the acute injury phase.[15] Wroble et al[31] reported that the first-day measurements were significantly lower than measurements made on succeeding days, suggesting that patient and examiner adjust to the testing procedure. Technician skill and experience are important. Schulz et al[26] reported that PTD measurement using a Telos device had a relatively low intertester reliability. No significant difference was found between experienced testers, but a significant change was observed between experienced and novice testers. To enhance intertester reliability, accurate settings must be used with a prepared goniometer instead of relying on visual inspection.[16]

Measurement errors may also occur because of the patient's age and thigh circumference due to a high BMI.[30] In middle-aged or female patients with examination anxiety and subsequent quadriceps muscle contraction, the KFA may be reduced.[15] Assessing the KFA clinically during the radiographic examination could be difficult, especially in obese or muscular patients with large thighs and calves. Also, in such patients, it would be difficult to apply a Telos device while maintaining a KFA of 90°. However, using a generalized linear mixed-effects model in this study, we found no statistically significant differences when accounting for age ($P = .674$), sex ($P = .328$), or BMI ($P = .257$).

In this study, despite the individual differences, the PTD tended to decrease when the KFA increased from 70° to 90°. Owing to the high variability of the reported PCL load data, the detailed biomechanical parameters of PCL remain controversial.[10] Shelburne and Pandy[27] calculated the PCL force up to 90° of flexion and reported no PCL force until 10° of knee flexion but a steadily increasing force thereafter to a peak at 80°. The estimated PCL force decreased slightly between 80° and 90° of flexion. Hosseini Nasab et al[10] reported that the application of posterior drawer force produced higher PCL forces than did passive flexion, with the greatest difference at 60° to 80° of midflexion. Moreover, as mentioned earlier, the muscle tone of the hamstring could have a significant effect on PTD. In a biomechanical study, the hamstring muscle torque gradually decreased from 60° to 90° of flexion.[8] The hamstring muscle torque would have a greater effect on PTD at midflexion angle. Accordingly, tibial posterior translation may occur. During knee flexion, femoral rollback occurs. The position of the femoral condyle is relatively posterior to the tibial plateau; accordingly, the PTD would be decreased.[5,23]

This study has several limitations. First, it enrolled all of the radiographs, including slightly rotated images, to represent a clinical setting. To reduce measurement error, we used the midpoint between the most posterior contours of the medial and lateral femoral condyles.[12] However, the measurement changed according to anatomic landmark, and the results might also have changed.[25,26] Nevertheless, there was high reliability in intra- and interobserver measurements in this study. Second, this was a retrospective study design, and there were no comparative participants with another posterior stress examination technique. Third, we measured noninjured knees to establish test reliability criteria. When these criteria are applied to injured knees, the measurement may differ by a large value. However, to validate objective measurement in surgical decision making and postoperative assessment,[22] the intertest reliability on the noninjured side is important because it is determined by calculating the side-to-side differences. Further study is needed to apply the set reliable range for the injured knee. Fourth, we did not evaluate the reproducibility of the measurement between sides in patients with 2 noninjured knees. Fifth, although patients were allowed to relax as much as possible during the tests, there was no way to ensure relaxation. Sixth, if the patients had a large medial tibial plateau, this may have led to an overestimation of posterior laxity.[9,20]

CONCLUSION

We found high reproducibility of posterior displacement measurements on Telos stress radiography at a KFA of 85° to 92° in noninjured knees.

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APPENDIX

TABLE A1
Evaluation of Test Reliability for Each Section When a Linear Mixed Model Was Applied[a]

Knee Flexion Angle			Estimated Value	SE	*t* Value	*P* Value	ICC	No. of Participants
From	To							
80°	91°	Intercept	14.464	1.514	9.554	<.001	0.853	114
		Angle	–0.128	0.018	–7.162	<.001		
81°	91°	Intercept	16.309	1.753	9.301	<.001	0.852	112
		Angle	–0.149	0.021	–7.260	<.001		
82°	91°	Intercept	15.995	2.181	7.335	<.001	0.853	110
		Angle	–0.146	0.025	–5.729	<.001		
83°	91°	Intercept	14.020	2.462	5.694	<.001	0.869	95
		Angle	–0.123	0.028	–4.306	<.001		
84°	91°	Intercept	13.659	3.336	4.094	<.001	0.868	83
		Angle	–0.118	0.038	–3.093	.003		
85°	91°	Intercept	13.725	3.673	3.737	<.001	0.923	76
		Angle	–0.118	0.042	–2.831	.007		
85°	92°	Intercept	10.747	3.769	2.851	.006	0.885	80
		Angle	–0.084	0.043	–1.963	.055		
85°	93°	Intercept	11.421	2.821	4.409	<.001	0.893	82
		Angle	–0.092	0.032	–2.877	.005		
85°	94°	Intercept	11.605	2.664	4.357	<.001	0.885	83
		Angle	–0.094	0.03	–3.127	.003		
85°	95°	Intercept	8.391	2.781	3.017	.003	0.863	84
		Angle	–0.057	0.031	–1.82	.073		
85°	96°	Intercept	8.035	2.735	2.938	.004	0.865	84
		Angle	–0.053	0.031	–1.719	.090		
86°	91°	Intercept	6.887	5.926	1.162	.249	0.929	67
		Angle	–0.041	0.067	–0.605	.551		
87°	91°	Intercept	3.428	9.279	0.369	.713	0.914	56
		Angle	–0.002	0.104	–0.017	.986		
88°	91°	Intercept	–10.274	10.882	–0.944	.351	0.966	43
		Angle	0.151	0.122	1.238	.256		

[a]ICC, intraclass correlation coefficient.