The Functional Integrity of the Anterior Cruciate Ligament Can Be Objectively Assessed With the Use of Stress Radiographs

A Systematic Review

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Background: Stress radiography is a viable imaging modality that can also be used to assess the integrity of the anterior cruciate ligament (ACL) after primary or secondary injury. Because conventional radiography is relatively easy, affordable, and available worldwide, the diagnostic efficacy of ACL standing, lateral decubitus, and supine stress radiography should be evaluated.

Purpose: To examine the existing literature regarding the application of stress radiography in evaluating the integrity of the ACL.

Study Design: Systematic review; Level of evidence, 3.

Methods: Using the PubMed and MEDLINE databases for relevant articles published between 1980 and the present, a systematic review was conducted to identify evidence related to the radiographic diagnosis or assessment of ACL tears. The literature search was conducted in September 2022.

Results: Of 495 studies, 16 (1823 patients) were included. Four studies examined standing stress radiography, and 12 investigated lateral decubitus or supine stress radiography. Significant heterogeneity in imaging technique and recorded anterior tibial translation was identified. Anterior tibial translation for ACL-injured knees ranged from 1.2 to 10.6 mm for standing stress radiographs and 2.7 to 11.2 mm for supine stress radiographs, with high sensitivities and specificities for both.

Conclusion: Stress radiography was a dependable diagnostic method for identifying ACL rupture. Further research is necessary to determine the ideal anatomic landmarks, optimal patient positioning, and appropriate applied stresses to establish a standardized protocol for both assessing ACL tears and evaluating the postoperative integrity of ACL reconstruction using stress radiography.

Keywords: anterior cruciate ligament; assessment; diagnosis; stress radiography

While the history and physical examination certainly aid in the evaluation of a suspected tear of the anterior cruciate ligament (ACL), magnetic resonance imaging (MRI) has emerged as the conventional method for statically visualizing ACL tears, often being referred to as the gold standard for its high sensitivity and specificity.[22,26,27,32] However, it is important to delineate that the gold standard in this context refers to its capabilities in imaging rather than functional assessment. While MRI is proficient in depicting anatomic disruptions, it falls short in evaluating the dynamic functional integrity of the ACL, which is a critical aspect often assessed through stress radiography or instrumented measurement.[1,2,16,24,30] In addition, MRI is expensive,[4] and its associated cost leaves those in rural facilities or underdeveloped nations at a disadvantage in receiving timely diagnoses.[19,23] Furthermore, MRI is associated with some degree of subjectivity, which adds an important nuance to the high reported values for the

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sensitivity and specificity of MRI to detect an ACL tear.[20,29] This subjectivity in MRI evaluation can lead to discrepancies in reads and diagnoses, especially in the postoperative setting when assessing the integrity of an ACL reconstruction (ACLR) graft.

Stress radiography, although less commonly employed in the context of acute ACL injuries, plays a pivotal role in the functional assessment of ACL integrity.[7,8,10,14,24] This technique involves applying a standardized load to the knee, measuring the resulting displacement, and then comparing this to established normal ranges observed in uninjured individuals.[1,8,14,24] Tools such as the Telos device enhance the precision of these assessments, allowing for more accurate determinations of ACL-based instability.[2,8,24] Specific applied stress views that radiographically demonstrate ACL-based instability have been previously described. Given the relative ease, affordability, and availability of radiography worldwide, the diagnostic utility of ACL stress radiography must be assessed.

This systematic review aimed to review the literature on using stress radiography to assess ACL integrity. We sought to assess the clinical reliability and reproducibility of stress radiography in objectively quantifying instability associated with ACL injury. Furthermore, we aimed to determine what, if any, standardization currently exists for these radiographic techniques that could be readily implemented in the diagnostic workup of a new ACL injury.

METHODS

This study followed the 2009 PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) statement.[21] A systematic review of the literature for existing evidence of the radiographic diagnosis or assessment of ACL tears was performed using the PubMed and MEDLINE databases between 1980 and the present. The queries were performed in September 2022.

The literature search strategy included the following: ((Anterior Cruciate Ligament[Title])) OR (ACL[Title])) AND ((Diagnosis[Title]) OR (Assessment[Title]) OR (Postoperative[Title]) AND ((X-ray) OR (Radiograph))) AND ((ultrasound) OR (Sonograph)) and (((Anterior Cruciate Ligament[Title]) OR (ACL[Title]) OR (Anterior Knee[Title])) AND ((Diagnosis[Title]) OR (Diagnose[Title]) OR (Measure[Title]) OR (Stress[Title]) OR (Translation[Title]) OR (Measurement[Title]) OR (Assessment[Title]) OR (Assess[Title]) OR (Postoperative[Title]) OR (Laxity[Title])) AND (((X-ray) OR (Radiograph) OR (Radiography))). The inclusion criteria were as follows: use of conventional radiographs to diagnose initial ACL injury; assessment of ACL injury; or assessment of ACL graft failure after reconstruction procedures; English language; and human studies. The exclusion criteria were as follows: animal studies; basic science studies; cadaveric studies; reviews; editorials; expert opinions; surveys; special topics; letters to the editor; and correspondence. We also excluded all studies focusing on joints other than the knee joint and multiligament knee studies.

Two investigators (J.S. and A.N.R.) independently reviewed the abstracts from all identified articles. When necessary, full-text articles were obtained for review to screen the full texts for the inclusion and exclusion criteria. All references from the included studies were also reviewed to ensure that there were no potentially relevant articles missing from this systematic review. The inclusion and exclusion criteria were used to systematically screen and identify relevant articles, as illustrated in the PRISMA flowchart (Figure 1).

Data Collection

The included studies were organized by level of evidence.[31] This information was organized by the data available in the abstracts. Information such as the study type, number of patients, imaging technique, patient positioning, anatomic landmarks used for measurements, sensitivity, specificity, positive potential value, and negative potential value, as well as controls, were extracted and recorded. A custom Excel spreadsheet (Microsoft Corp) was used to extract data into a modified information extraction table.[9]

Study Bias

Selection and performance bias can be present in studies with level 3 and 4 evidence. These forms of bias can result from a lack of randomization and a lack of prospective comparative control groups. The studies selected in this systematic review were subjectively reviewed based on their patient selection, measurement, and reporting methodologies to ensure that bias was minimized.

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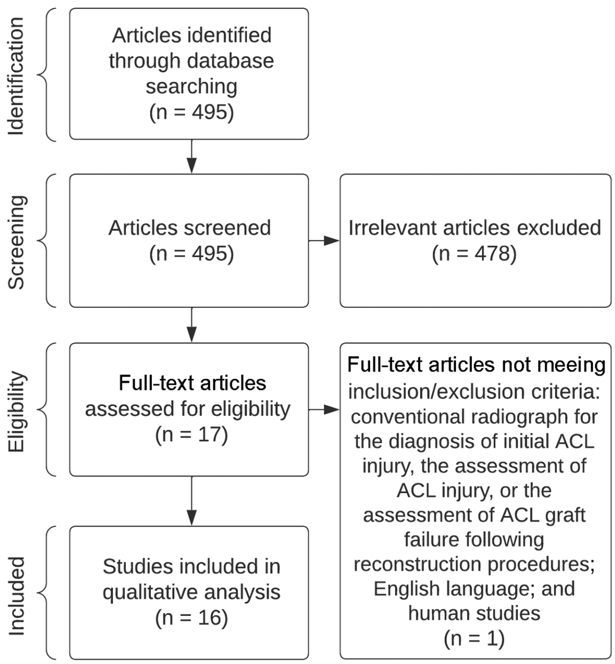

Figure 1. A PRISMA flowchart of the article selection with the inclusion and exclusion criteria. ACL, anterior cruciate ligament; PRISMA, Preferred Reporting Items for Systematic Review and Meta-Analyses.

RESULTS

The systematic search using the previously mentioned keywords yielded 495 studies without duplicates (Figure 1). Of these studies, 478 were unrelated to this topic, leaving 17 studies. Of the remaining 17 studies, 1 study was a review article and was excluded. After applying all exclusion criteria, 16 studies were included (Figure 1).[§] Four studies[6,12,18,30] examined the use of standing stress radiography, and 12 studies investigated the use of supine or lateral decubitus stress radiography.[‖] The included studies reported on a total of 1823 patients. For most of these patients, the injured knee was designated as the experimental knee, while the contralateral knee was designated as the normal control knee. Notably, despite the common methodologies employed, there was significant variability in the techniques used across these studies, highlighting the lack of standardization. A summary of the included studies is provided in Table 1.

Standing ACL Stress Radiographs

Patient positioning varied among the 4 studies[6,12,18,30] that examined the utility of standing stress radiographs for diagnosing ACL tears (Supplemental Tables S1 and S3). Lateral 1-legged standing (monopodal) stance testing was performed with the patient standing on 1 knee with the knee flexed at 20° and compared with a clinical Lachman test at 30° of flexion. The radiograph plate was placed along the medial knee and included 20 cm of the proximal tibia on the radiographic film.[6,18] Alternatively, another group had the patient stand with the injured knee fully extended and the opposite foot on a step. Bilateral lateral radiographs of each knee were obtained, and anterior tibial translation (ATT) was measured by drawing a line on the posterior aspect of the medial and lateral tibial plateaus, measuring the shortest distance from these lines to the most posterior aspect of the medial and lateral femoral condyles, and comparing the injured to the normal contralateral knee.[12] Wang et al[30] had patients obtain lateral radiographs before and after a 150-N force was placed posteriorly on the proximal tibia. Their mean flexion angle during stress testing was 38.47° ± 11.22°.

Measurements were obtained by various methods between author groups. Two groups obtained measurements by comparing the distance between lines tangential to each posterior femoral condyle and each tibial plateau (Figures 2 and 3). Measurements were recorded for medial anterior tibial translation (M-ATT) and lateral anterior tibial translation (L-ATT).[6,18] Wang et al[30] specifically compared 4 sets of anatomic landmarks for the measurement of ATT (Table 1 and Figure 4). The sensitivity of these 4 methods ranged from 62% to 82.2%, and the specificity ranged from 56.3% to 79.2%.[30] Method A had the highest sensitivity (82.2%), while method C had the lowest sensitivity (62%). Method C had the highest specificity (79.2%), while method A had the lowest specificity (56.3%).

The mean standing ATT for knees with ACL tears ranged from 1.2 ± 4.1 mm to 10.6 ± 4.83 mm in 2 studies.[12,30] One group reported a mean ATT side-to-side difference of 2.7 ± 3.6 mm in ATT.[18] Another study stratified ATT into medial and lateral, and reported mean side-to-side differences of 3.5 ± 3.2 mm for M-ATT and 3.7 ± 5.8 mm for L-ATT. The same study compared standing stress radiographs versus a clinical Lachman test and reported that the side-to-side difference for the Lachman M-ATT was 5.6 ± 5.8 mm, while the side-to-side difference for the Lachman L-ATT was 6.5 ± 4.4 mm.[6] The authors reported that M-ATT was measured more reliably when compared with L-ATT for diagnosing ACL tears.[6]

Supine Stress Radiographs With or Without KT-1000 Arthrometer

Twelve studies utilized a form of supine or lateral decubitus stress imaging to assess the presence of an ACL tear (Supplemental Tables S2 and S4).[¶] The degree of force used to evaluate functional status varied between studies. Hooper[10] examined 70 patients using a sandbag applied directly to the anterior distal thigh, with the patient positioned supine and the knee flexed to 20°. The author compared this technique to anterior drawer and pivot-shift tests. The author did not report the amount of knee flexion

[§]References 1,2,5-8,10-14,16,18,24,28,30.
[‖]References 1,2,5,7,8,10,11,13,14,16,24,28.
[¶]References 1,2,5,7,8,10,11,13,14,16,24,28.

TABLE 1
Summary of the Included Studies[a]

Lead Author (Year)	Position	Technique	Flexion Angle	Anatomic Landmarks
Hooper[10] (1986)	Supine	Flexed knee stressed with a 3-kg sandbag on the distal thigh, compared with anterior drawer and pivot shift.	20°	PMTP, PLTP, PMFP, PLFP
Franklin[7] (1991)	Supine	Fully extended knee, 66.7-N downward force at the ankle with 6.8-kg weight suspended from ankle, compared with the KT-1000 arthrometer.	30°	PMTP, PLTP, PMFP, PLFP
Stäubli[28] (1991)	Supine	An 89-N anterior force applied by the KT-1000 arthrometer and a simultaneous lateral radiograph was taken with the knee flexed.	20°	PMTP, PLTP, PMFP, PLFP
Kobayashi[14] (1993)	Supine	A portable stress-applying device was used to apply 100 N to the distal femur at 20° and 90° of flexion.	20° and 90°	PMTP, PLTP, PMFP, PLFP
Dejour[6] (1994)	Standing	The lateral monopodal stance test was performed where the patient stood on 1 knee with the knee slightly flexed. The radiograph plate was placed on the medial knee and included 20 cm of the upper tibia on the film. The radiograph source was placed 1 m from the knee and aligned perpendicular to the long axis of the limb. An image intensifier was used to achieve superimposition of the femoral condyles.	20°	PMTP, PLTP, PMFP, PLFP
Garcés[8] (1995)	Supine	A Telos device was used to apply 137 N to the proximal tibia with the knee flexed.	20°	PMTP, PLTP, PMFP, PLFP
Beldame[1] (2011)	Supine	A Telos anterior drawer was performed with 250 N vs Franklin extension stress with a 7-kg weight at the ankle.	20°	PMTP, PLTP, PMFP, PLFP
Beldame[2] (2012)	Supine	The 250-N GNRB arthrometer was compared with the 250-N Telos and Lerat stress radiography.	20°	PMTP, PLTP, PMFP, PLFP
Panisset[24] (2012)	Lateral decubitus	Bilateral Telos stress radiography, in which 15 kg of posteriorly directed force was applied on the anterior proximal tibia.	20°	PMTP, PLTP, PMFP, PLFP
Dejour[5] (2013)	Lateral decubitus	A Telos 15-kg force was applied with the knee flexed.	20°	PMTP, PLTP, PMFP, PLFP
Jenny[11] (2013)	Supine	GNRB was preoperatively compared with a stress lateral radiograph using 250 N of anterior traction and a KT-2000 arthrometer with knee flexed. Control was intraoperative navigation using the OrthoPilot Navigation System (Aesculap).	25°	PMTP, PLTP, PMFP, PLFP
Kim[13] (2020)	Lateral decubitus	Telos with 250-N force was used to obtain lateral radiographs taken with the knee flexed.	30°, 45°, 60°, and 90°	PMTP, PLTP, PMFP, PLFP
Lee[16] (2019)	Lateral decubitus	Telos with 250-N force was used to obtain lateral radiographs taken with the knee flexed.	30°, 45°, 60°, and 90°	PMTP, PLTP, PMFP, PLFP
Kim[12] (2021)	Standing	The patient stood on a step with the uninjured knee and the opposite knee fully extended. A lateral radiograph of each leg was taken.	0°	PMTP, PLTP, PMFP, PLFP

(continued)

TABLE 1
(continued)

Lead Author (Year)	Position	Technique	Flexion Angle	Anatomic Landmarks
Wang[30] (2021)	Standing	Lateral projection views were obtained before and after a 150-N force was placed posteriorly on the tibia. Images were processed to clarify and establish defined anatomic landmarks, including the femoral axis, femoral condyles, and tibial axis. The tibial position was defined as the distance between the tibial axis and the femoral reference.	38.47° ± 11.22°	Four methods: (A) The intersection of the femoral and tibial axes was used as the femoral reference point for measurement. (B) The midline of lines tangential to the posterior femoral condylar edges and parallel to the tibial axis was used as the femoral reference line. (C) The femoral reference point was used as the midpoint between the posterior femoral condylar edges and parallel to the femoral axis. (D) The midpoint of the center points of the medial and lateral femoral condyles was the femoral reference point.
Macchiarola[18] (2022)	Standing	The lateral monopodal stance test was performed where the patient stood on 1 knee with the knee slightly flexed. The radiograph plate was placed on the medial knee and included 20 cm of the upper tibia on the film. The radiograph source was placed 1 m from the knee and aligned perpendicular to the long axis of the limb.	20°	PMTP, PLTP, PMFP, PLFP

[a]PLFP, posterior lateral femoral plateau; PLTP, posterior lateral tibial plateau; PMFP, posterior medial femoral plateau; PMTP, posterior medial tibial plateau.

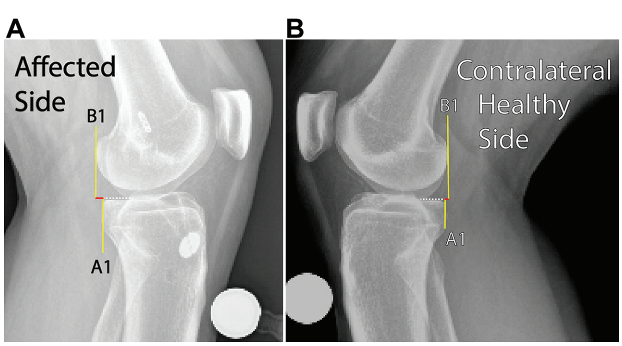

Figure 2. Radiographs of (A) injured and (B) healthy knees illustrating the measurement method used to assess anterior tibial translation by Dejour and Bonnin.[6] A line is drawn parallel to the tibial plateau (white dotted line), and a second line is drawn perpendicular to this line at the posterior aspect of the medial tibial plateau (line *A1*). A third line is drawn parallel to *A1* and tangential with the posterior aspect of each femoral condyle (line *B1*). The distance between *A1* and *B1* (red line) is measured as the amount of anterior tibial translation.

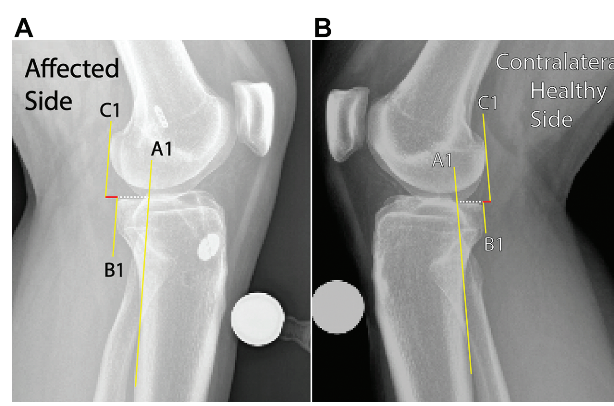

Figure 3. Radiographs of (A) injured and (B) healthy knees illustrating the measurement method used to assess anterior tibial translation by Macchiarola et al.[18] A line is drawn along the posterior tibial cortex (line *A1*). A line is drawn parallel to the tibial plateau (white dashed line), and a second line is drawn parallel to A1 at the posterior aspect of the medial tibial plateau (line *B1*). A third line is drawn parallel to *A1* and *B1* and tangential with the posterior aspect of each femoral condyle (line *C1*). The distance between *B1* and *C1* (red line) is measured as the amount of anterior tibial translation.

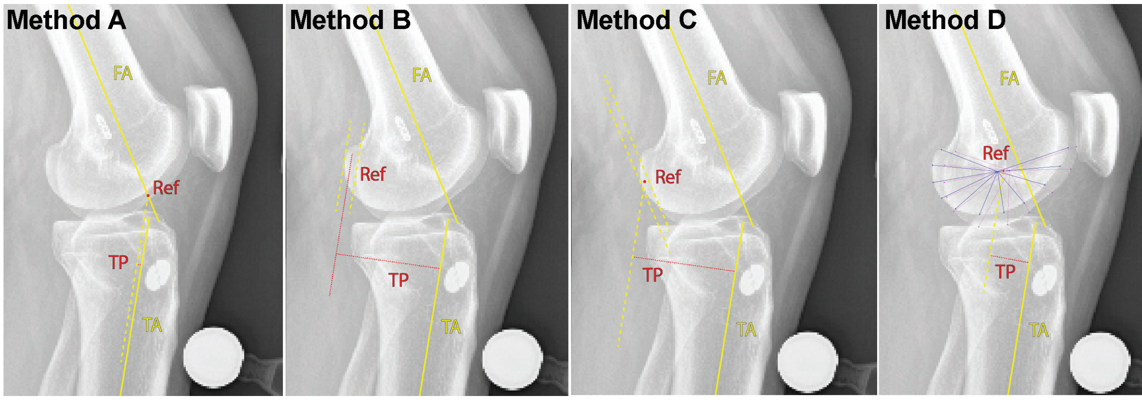

Figure 4. Radiographs illustrating the 4 methods used for measurement of anterior tibial translation by Wang et al.[30] The details of each method and the anatomic landmarks used are presented in Table 1. FA, femoral axis; Ref, reference;TA, tibial axis; TP, tibial position.

used when performing anterior drawer tests. Franklin et al[7] examined 60 patients positioned with the knee at 30° and with a 6.8-kg weight applied to the ankle. Patients were then instructed to extend their knee maximally while cross-table lateral radiographs were taken. Stäubli and Jakob[28] placed patients in a supine position, and a KT-1000 arthrometer was used to apply an 89-N anteriorly directed force on the tibia with the knee flexed to 20°. A lateral radiograph was taken when 89 N of anterior force was achieved. Kobayashi and Terayama[14] used a portable device to apply a 100-N force to the distal femur at 20° and 90° of knee flexion.

The positions of the posterior femoral condyles were measured relative to the posterior aspects of the medial and lateral tibial plateaus to measure ATT.[7,10,14,28] Hooper[10] reported a mean M-ATT of 8.3 mm and a mean L-ATT of 10.3 mm in ACL-injured knees. The mean ATT in ACL tears ranged from 7 mm to 11.9 ± 3.1 mm.[14,28] Kobayashi and Terayama[14] reported the specificity, sensitivity, and accuracy of their portable stress device to be 100%, 94%, and 97%, respectively, with the knee flexed at 20°. The specificity, sensitivity, and accuracy for the Lachman test by the same group were all 100%, respectively.[14]

Supine Stress With or Without Telos Device and Other Devices

Many studies used the Telos device and compared it with other modalities of assessing ATT—including the Franklin quadriceps contraction technique,[1,7] the Lerat technique,[2,17] the GNRB arthrometer,[2,11] and the KT-1000 arthrometer.[7,16,28] Garcés et al[8] used a Telos device to apply a 137-N load to the tibia with the knee at 20° of flexion. Displacement was measured by 3 independent observers using the method of Franklin et al[7] (Table 2). Lee et al[16] investigated imaging obtained at multiple angles of knee flexion: 30°, 45°, 60°, and 90°. They reported that 30° of knee flexion was the best angle for measuring ATT with stress radiography.[16] The posterior aspects of the medial and lateral tibial plateaus were measured relative to the posterior aspect of the medial and lateral femoral condyles to calculate ATT in most of these studies.[#]

Garcés et al[8] found that with Franklin quadriceps contraction stress testing,[7] the mean displacement for the medial and lateral compartments of the injured knees were 5.8 mm and 10.2 mm, respectively, and the mean displacement in the intact contralateral control knees was 1.07 mm for the medial compartment measurement and 3.5 mm for the lateral compartment measurement. The authors reported that the sensitivity and specificity for manual examination utilizing the Franklin quadriceps contraction technique (Table 3) was 70.2% and 98.5%, respectively, while these values were 67% and 100%, respectively, for stress imaging using the Telos device.[8] Beldame et al[1] reported that the Telos device was superior to the Franklin technique, with a mean side-to-side ATT difference of 5.90 ± 5.20 mm versus 3.84 ± 3.45 mm. The authors reported that a medial compartment stress measurement technique was more reliable than a lateral or central compartment stress measurement technique.[1] The Telos device was reported to have a sensitivity ranging from 88% to 95% and a specificity ranging from 80.7% to 96%, compared with the KT-1000 arthrometer, which had a sensitivity of 72.1% and specificity of 91.9%.[6,16] Kim et al[13] 1.1 further stratified the sensitivities and specificities of the Telos device by comparing medial and lateral compartment ATT values. They reported that measuring the medial compartment had a sensitivity of 94.6% and a specificity of 81.1% while measuring the lateral compartment had a sensitivity of 94.6% and a specificity of 80.7%. The Telos technique was reported to have a lower specificity (75.9%) for measuring ATT on stress radiographs when compared with the Lerat technique (Table 3), which had a specificity of 82%.[2,11]

Panisset et al[24] compared the Telos device to a Rolimeter device in evaluating 177 patients. The Telos and Rolimeter devices were compared both in isolation and in

[#]References 1,2,5-8,10-14,16,18,24,28.

TABLE 2
The Franklin et al[7] Technique for Measuring Anterior Tibial Translation

Step	Description
Line 1	A fine line is drawn parallel to the subchondral plate of the medial tibial plateau.
Line 2, medial and lateral	Using the posterior medial and lateral condyles as tangential landmarks, a second line is drawn perpendicular to line 1 so that the medial line intersects with the posterior medial tibial condyle and the lateral line intersects with the posterior lateral tibial condyle.
Line 3, medial and lateral	After identifying the posterior subchondral surface of the medial and lateral femoral condyle, a tangential line is drawn parallel to line 2 for each respective femoral condyle.
Line 4, medial and lateral	The distance between lines 2 and 3 for each knee compartment is now measured to assess the amount of anterior tibial translation.

TABLE 3
The Franklin[7] and Lerat[17] Manual Stress Techniques

Technique	Description
Franklin	With the knee flexed to 30°, a 15-kg weight is placed around the ankle, and the patient is instructed to straighten the knee as much as possible during imaging.
Lerat	With the knee flexed to 20°, a 9-kg loading strap is placed on the anterior aspect of the femur to induce femoral posterior translation relative to the tibia.

TABLE 4
Correlation of the Pivot-Shift Grade to the Amount of Anterior Tibial Translation on Telos and Rolimeter Devices[24]

	Anterior Tibial Translation, mm	
Pivot-Shift Grade	Telos	Rolimeter
0	1.2	2.8
1	4.3	2.7
2	7.3	5.6
3	10.4	6.4

combination with a clinical pivot-shift test. The posterior aspect of the medial tibial plateau was measured relative to the posterior aspect of the superimposed medial and lateral femoral condyles to calculate ATT. For each device, the magnitude of ATT was correlated with the grade of pivot-shift testing observed (Table 4). The pivot-shift test combined with stress radiography had the highest sensitivity and specificity (88% and 94.6%, respectively). Stress radiography alone had a sensitivity of 80.9% and a specificity of 81.8%.[24]

DISCUSSION

The most important finding of this systematic review was that bilateral ACL stress radiographs were reliable and reproducible diagnostic tests for assessing ACL integrity. Stress radiographs were reliable in diagnosing ACL tears, with high sensitivities and specificities.[1,2,5,8,13,14,16,24] Furthermore, this review found 30° of knee flexion optimal for assessing ACL integrity through stress radiography. In addition, standing stress radiography was reliable in diagnosing ACL tears, particularly secondary failures, failures >4 years, and injuries with associated meniscal injuries. However, there was a lack of consistency in the methodology used to perform standing stress radiographs and the landmarks used to assess ATT.

Regarding the method in which forces were applied, using a Telos device was associated with higher sensitivity and specificity. We theorize that this was due to the ability to control the magnitude and directionality of force applied to the knee when inducing ATT. However, the difference between manual stress testing and instrumented stress testing was not significant in the context of the clinical setting because many authors felt that both were effective in combination with a history and physical examination.[10,11,14,28] The combination of both clinical assessment and instrumented knee laxity measurements increased the sensitivity and specificity compared with isolated instrumented measurement of the knee with a Rolimeter device.[24] Stress radiograph may be superior to the GNRB arthrometer in cases where patients are obese and excess tissue may impact the accuracy of the translation sensor.[2] Moreover, where the GNRB is inaccessible, and considering the inadequacy of MRI for evaluating the functional integrity of the ACL, adopting a standardized stress radiography for ATT assessment could be advantageous for both patients and health care providers.

Several studies utilized similar anatomic landmarks to measure ATT. The anatomic landmarks commonly mentioned included the most posterior aspects of the medial and lateral femoral condyles, the most posterior aspects of the medial and lateral tibial plateaus, the posterior cortex of the tibia, and the femoral and tibial axes. Stäubli and Jakob[28] used the posterior border of the medial and lateral tibial plateaus and the most posterior aspect of the medial and lateral subchondral femoral condyles to measure ATT in both compartments of the knee. This was similar to the landmarks used in several other studies, which measured the distance between a line parallel to the tibial cortex and tangent to the posterior contour of the medial tibial condyle and the posterior aspect of the medial femoral condyle.[5,13,16] These anatomic landmarks are demonstratively effective in accurately measuring the extent of ATT in patients with both partial and complete ACL tears.

Ideal tibiofemoral flexion angle was another variable assessed in several studies included in this review. Many studies[1,2,5,8,10,14,24,28] have examined ATT with the knee flexed to 20°. Two studies[13,16] specifically examined the optimal amount of knee flexion to assess rotatory laxity and anterior instability. These 2 studies agreed on 30° of knee flexion as the ideal positioning for using stress radiography to assess ACL integrity. However, these authors did not compare the efficacy of stress radiography at 30° of knee flexion to that of stress radiography at 20°. The comparison between these 2 angles of knee flexion for stress radiography may be an area for future investigation.

The financial burden of a stress radiograph is much lower than that of a knee MRI.[3,25] It has been reported that the out-of-pocket cost of a knee MRI ranges from $459 to $2042 in the United States,[15,25] while the average cost of a 3-view knee radiograph is $282 (in 2021).[3] The difference in cost between stress radiographs and MRI for assessing anterior knee laxity is substantial for patients and the health care system. Stress radiography may also better evaluate the degree of ATT compared with other modalities in certain situations, such as in cases of posterior subluxation with posterior cruciate ligament deficiency and pseudo-Lachman. Stress radiography also provides the benefit of better visualizing signs of concomitant pathology—such as increased posterior slope, hypermobility, and other soft tissue ligamentous and meniscal deficiencies—which may contribute to the degree of translation and can significantly impact surgical planning. The main downside to stress radiography is the added risk of radiation exposure to patients, which does not exist with MRI. This further underscores the clinical importance of recognizing the affordability, efficiency, and accuracy of dynamic stress radiography and supports establishing a standardized stress radiograph protocol for evaluating patients in the setting of a suspected ACL injury.

Limitations

Some limitations are present in the current study. First, most studies included in this systematic review were of level 3 or 4 evidence in case series and diagnostic accuracy studies. Moreover, a standardized, validated risk of bias or quality assessment tool was not used for screening articles. This methodology relied on a more subjective analysis, which, despite allowing for nuanced interpretation, may introduce elements of bias and variability not present when using established, systematic assessment tools. In addition, not all of these studies controlled for variability in intertechnician imaging techniques to reduce the incidence of rotational or positional differences. These studies did not assess the posterior tibial slope as an additional risk factor for increased ATT. Given the known relationship between slope and native and ACL graft forces, this could be a factor in the amount of anterior translation, especially in the standing studies. Additional limitations exist with respect to chronicity of the injury or hyperlaxity of the patient, which can produce confounding biases regarding ATT in the knee.

CONCLUSION

Stress radiographs provide a low-cost, reliable, reproducible diagnostic modality for diagnosing ACL tears. Future studies should further investigate ideal anatomic landmarks, optimal patient positioning, and ideal applied stresses to establish a standardized protocol for evaluating ACL tears and assessing the postoperative integrity of ACLR using stress radiography.

Supplemental Material for this article is available at https://journals.sagepub.com/doi/full/10.1177/23259671241246197#supplementary materials

REFERENCES

1. Beldame J, Bertiaux S, Roussignol X, et al. Laxity measurements using stress radiography to assess anterior cruciate ligament tears. *Orthop Traumatol Surg Res*. 2011;97(1):34-43.
2. Beldame J, Mouchel S, Bertiaux S, et al. Anterior knee laxity measurement: comparison of passive stress radiographs Telos® and ''Lerat'', and GNRB® arthrometer. *Orthop Traumatol Surg Res*. 2012;98(7):744-750.
3. Birir A, Amen TB, Varady NH, Chen AF. Clinical efficacy and cost-effectiveness of postoperative radiographs after total knee arthroplasty. *Knee*. 2021;32:97-102.
4. Carbone AD, Wang K, Tiao J, et al. Trends in health care expenditures and patient out-of-pocket expenses in primary anterior cruciate ligament reconstruction. *Am J Sports Med*. 2022;50(10):2680-2687.
5. Dejour D, Ntagiopoulos PG, Saggin PR, Panisset J-C. The diagnostic value of clinical tests, magnetic resonance imaging, and instrumented laxity in the differentiation of complete versus partial anterior cruciate ligament tears. *Arthroscopy*. 2013;29(3):491-499.
6. Dejour H, Bonnin M. Tibial translation after anterior cruciate ligament rupture. Two radiological tests compared. *J Bone Joint Surg Br*. 1994;76(5):745-749.
7. Franklin JL, Rosenberg TD, Paulos LE, France EP. Radiographic assessment of instability of the knee due to rupture of the anterior cruciate ligament. A quadriceps-contraction technique. *J Bone Joint Surg Am*. 1991;73(3):365-372.
8. Garcés GL, Perdomo E, Guerra A, Cabrera-Bonilla R. Stress radiography in the diagnosis of anterior cruciate ligament deficiency. *Int Orthop*. 1995;19(2):86-88.
9. Harris JD, Quatman CE, Manring MM, Siston RA, Flanigan DC. How to write a systematic review. *Am J Sports Med*. 2014;42(11):2761-2768.
10. Hooper GJ. Radiological assessment of anterior cruciate ligament deficiency. A new technique. *J Bone Joint Surg Br*. 1986;68(2):292-296.
11. Jenny J-Y, Arndt J, Surgery-France CAO. Anterior knee laxity measurement using stress radiographs and the GNRB® system versus intraoperative navigation. *Orthop Traumatol Surg Res*. 2013;99(suppl 6):S297-S300.

12. Kim SG, Kobayashi K, Uchino S, Nozawa M. Radiographic assessment of the tibiofemoral relationship in anterior cruciate ligament deficient knees. *J Orthop*. 2021;23:256-258.
13. Kim SH, Park Y-B, Ham D-W, Lim J-W, Lee H-J. Stress radiography at 30° of knee flexion is a reliable evaluation tool for high-grade rotatory laxity in complete ACL-injured knees. *Knee Surg Sports Traumatol Arthrosc*. 2020;28:2233-2244.
14. Kobayashi S, Terayama K. Quantitative stress radiography for diagnosis of anterior cruciate ligament deficiency. *Arch Orthop Trauma Surg*. 1993;112(3):109-112.
15. Koenig S, Morcos G, Gopinath R, et al. Is MRI overutilized for evaluation of knee pain in veterans? *J Knee Surg*. 2023;36(3):305-309.
16. Lee H-J, Park Y-B, Kim SH. Diagnostic value of stress radiography and arthrometer measurement for anterior instability in anterior cruciate ligament injured knees at different knee flexion position. *Arthroscopy*. 2019;35(6):1721-1732.
17. Lerat JL, Moyen B, Jenny JY, Perrier JP. A comparison of preoperative evaluation of anterior knee laxity by dynamic X-rays and by the arthrometer KT 1000. *Knee Surg Sports Traumatol Arthrosc*. 1993;1(1):54-59.
18. Macchiarola L, Jacquet C, Dor J, et al. Side-to-side anterior tibial translation on monopodal weightbearing radiographs as a sign of knee decompensation in ACL-deficient knees. *Knee Surg Sports Traumatol Arthrosc*. 2022;30(5):1691-1699.
19. Mariani G, Kasznia-Brown J, Paez D, et al. Improving women's health in low-income and middle-income countries. Part II: the needs of diagnostic imaging. *Nucl Med Commun*. 2017;38(12):1024-1028.
20. Marshall T, Oak SR, Subhas N, Polster J, Winalski C, Spindler KP. Can the anterolateral ligament be reliably identified in anterior cruciate ligament–intact and anterior cruciate ligament–injured knees on 3-T magnetic resonance imaging? *Orthop J Sports Med*. 2018;6(9):2325967118796452.
21. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009;6(7):e1000097.
22. Moore SL. Imaging the anterior cruciate ligament. *Orthop Clin North Am*. 2002;33(4):663-674.
23. Ogbole GI, Adeyomoye AO, Badu-Peprah A, Mensah Y, Nzeh DA. Survey of magnetic resonance imaging availability in West Africa. *Pan Afr Med J*. 2018;30:240.
24. Panisset JC, Ntagiopoulos PG, Saggin PR, Dejour D. A comparison of Telos™ stress radiography versus Rolimeter™ in the diagnosis of different patterns of anterior cruciate ligament tears. *Orthop Traumatol Surg Res*. 2012;98(7):751-758.
25. Pasalic D, Lingineni RK, Cloft HJ, Kallmes DF. Nationwide price variability for an elective, outpatient imaging procedure. *J Am Coll Radiol*. 2015;12(5):444-452.
26. Shantanu K, Singh S, Srivastava S, Saroj AK. The validation of clinical examination and MRI as a diagnostic tool for cruciate ligaments and meniscus injuries of the knee against diagnostic arthroscopy. *Cureus*. 2021;13(6):e15727.
27. Shu HT, Wegener NR, Connors KM, et al. Accuracy of magnetic resonance imaging in predicting anterior cruciate ligament tear location and tear degree. *J Orthop*. 2021;25:129-133.
28. Stäubli H-U, Jakob RP. Anterior knee motion analysis: measurement and simultaneous radiography. *Am J Sports Med*. 1991;19(2):172-177.
29. Thomas S, Pullagura M, Robinson E, Cohen A, Banaszkiewicz P. The value of magnetic resonance imaging in our current management of ACL and meniscal injuries. *Knee Surg Sports Traumatol Arthrosc*. 2007;15(5):533-536.
30. Wang CK, Lin LC, Sun YN, et al. Computer-assisted system in stress radiography for anterior cruciate ligament injury with correspondent evaluation of relevant diagnostic factors. *Diagnostics (Basel)*. 2021;11(3):419.
31. Wright JG, Swiontkowski MF, Heckman JD. Introducing levels of evidence to the journal. *J Bone Joint Surg Am*. 2003;85(1):1-3.
32. Zhao M, Zhou Y, Chang J, et al. The accuracy of MRI in the diagnosis of anterior cruciate ligament injury. *Ann Transl Med*. 2020;8(24):1657.