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# Stress Radiography Is a Reliable Method to Quantify Posterior Cruciate Ligament Insufficiency: A Systematic Review



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**Purpose:** To perform a systematic review of posterior tibial stress radiography techniques and radiographic measurement methods to compare their accuracy and efficacy to aid clinicians in quantifying posterior cruciate ligament laxity. **Methods:** Electronic databases, including PubMed, MEDLINE, [Embase.com](https://pubmed.ncbi.nlm.nih.gov/) 1947- , Ovid Medline 1946- , Scopus 1823- , Cochrane Central Register of Controlled Trials (CENTRAL), and [Clinicaltrials.gov](https://www.clinicaltrials.gov/) 1997- were queried in December 2020. The abstracts of articles were reviewed by 2 authors for published studies comparing posterior tibial stress radiography techniques, describing, and comparing radiographic measurement methods, and comparing stress radiographs with instrumented knee testing. **Results:** The systematic review included 13 studies that satisfied the inclusion and exclusion criteria. There were 3 studies comparing stress radiography with instrumented knee devices, 6 studies comparing stress radiography techniques, and 5 studies evaluating the reliability of radiographic measurements. Stress radiography was more sensitive for detecting posterior tibial translation than KT-1000 and KT-2000 and was similar to the Rolimeter knee arthrometer. The majority of studies found TELOS stress radiography to be more sensitive than gravity or hamstring contraction stress views. Kneeling stress radiographs were found to be equivalent to TELOS in one study and superior in another. All reported methods of radiographic measurement for posterior tibial translation showed good-to-excellent intraobserver and interobserver reliability, and no single technique demonstrated clear superiority. **Conclusions:** The results of this systematic review indicate that posterior stress radiography with TELOS and kneeling stress radiography are the most reliable methods to evaluate posterior cruciate ligament laxity. Gravity stress and hamstring contraction can be used but may underestimate posterior tibial translation. Radiographic measurement methods are reliable and no single method is clearly superior. **Clinical Relevance:** This information will allow clinicians to use various radiographic methods to objectively measure posterior tibial translation to formulate a treatment plan.

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Posterior cruciate ligament (PCL) injuries are relatively uncommon in isolation, with an incidence of isolated PCL tears of 1.8 cases per year per 100,000 people, but are more common in the setting of

multiligamentous knee injuries.<sup>1</sup> The degree of posterior tibial translation at 80 to 90° of knee flexion is the primary factor in determining the need for surgical management of PCL injuries and is assessed through both the physical examination and radiographic imaging.<sup>2</sup> Grade 1 injuries ( $\leq 5$  mm of posterior tibial translation on stress radiography) and grade 2 injuries (6-10 mm of posterior tibial translation on stress radiography) are more commonly treated nonsurgically.<sup>2,3</sup> Grade 3 ( $\geq 10$  mm of posterior tibial translation on stress radiography) injuries are more commonly treated surgically, especially since they often occur in conjunction with other ligamentous knee injuries.<sup>2</sup> PCL deficiency also may lead to patellofemoral pain and patellofemoral and medial compartment osteoarthritis.<sup>1</sup> Also, isolated grade 2 PCL injuries have been shown to significantly alter knee mechanics during functional activities despite an absence of patient-reported symptoms.<sup>4</sup> Since operative intervention is indicated for

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greater-grade injuries based on stress radiographs, it is critical for surgeons to understand the accuracy and reproducibility of the radiographic techniques and measurement methods on the images.

Factors that may influence the reproducibility of the images are knee flexion angle, use of instrumentation or gravity for applied stress, and patient positioning. A number of stress radiographic techniques have been described, including gravity views (with<sup>5</sup> or without<sup>6-9</sup> weights), hamstring contraction views,<sup>7,9</sup> kneeling views,<sup>5,7,10,11</sup> and the TELOS device (TELOS Medical USA, Millersville, MD).<sup>6,7,9,10,12-16</sup> The optimal protocol for PCL stress radiography has not been established in the literature.<sup>5-8,10,17</sup> Likewise, measurement methods of the stress radiographs can be performed via several described techniques without a clear optimal method.

The purpose of this study is to perform a systematic review of posterior tibial stress radiography techniques and radiographic measurement methods to compare their accuracy and efficacy to aid clinicians in quantifying posterior cruciate ligament laxity. We hypothesized that the use of a TELOS device would provide the most reliable method for evaluating posterior tibia translation during stress radiography and the radiographic measurement methods for posterior tibial translation would yield similar inter- and intraobserver reliability.

## Methods

A systematic review was performed according to the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses. With the assistance of a medical librarian (L.H.Y.), search strategies were used in a combination of key words and controlled vocabulary in PubMed, MEDLINE, [Embase.com](http://Embase.com) 1947- , Ovid Medline 1946- , Scopus 1823- , Cochrane Central Register of Controlled Trials (CENTRAL), and [Clinicaltrials.gov](http://Clinicaltrials.gov) 1997- . Key search terms included "posterior cruciate ligament injury" or "rupture," "laxity," "instability," "stress radiography" or "X-ray." "arthrometer," "KT-1000" or "KT-2000," "Rolimeter," and "Telos." Fully reproducible search strategies for each database can be found in the [Appendix Table 1](#), available at [www.arthroscopyjournal.org](http://www.arthroscopyjournal.org). All search strategies were completed on December 22, 2020, with no added limits.

There were no disagreements regarding studies that fit inclusion and exclusion criteria. The systematic review included published studies comparing posterior tibial stress radiography techniques, describing and comparing radiographic measurement methods, cadaveric evaluation of stress radiography after sequential ligament resection, and comparing stress radiographs with instrumented knee testing. Non-English-language articles, abstracts, and studies reporting techniques without meaningful data were

excluded. Two authors (J.J.G. and R.G.S.) independently executed the search protocol to evaluate studies for inclusion or exclusion, with complete agreement on eligibility.

## Results

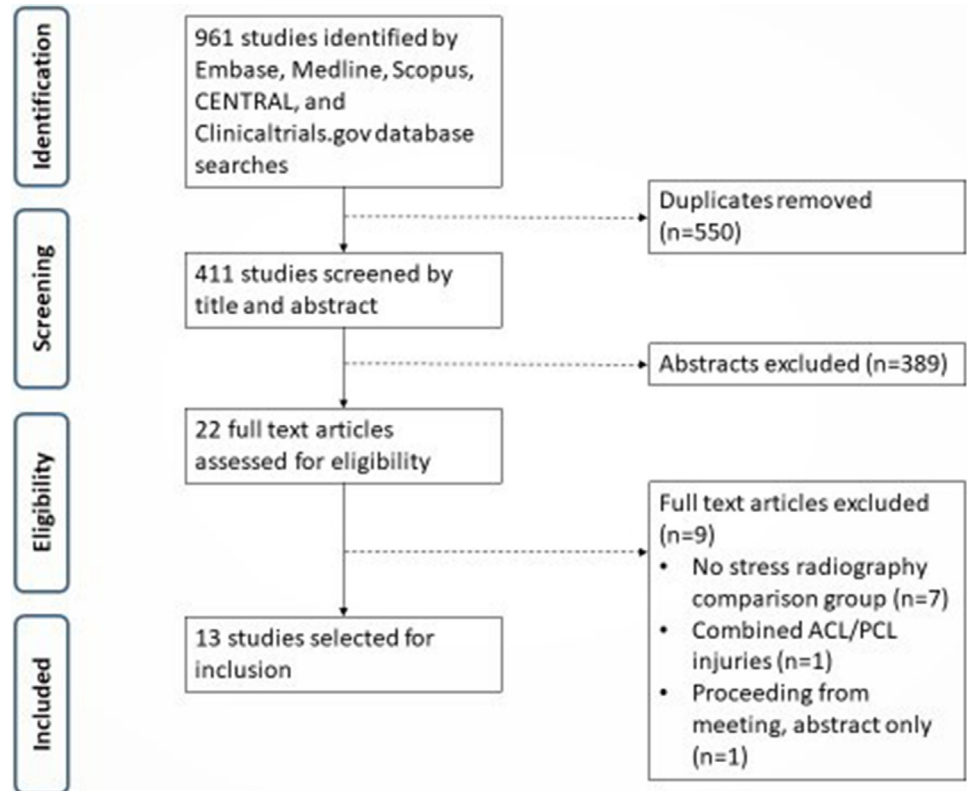
A total of 961 results were found. Five-hundred fifty duplicate records were deleted after using the deduplication processes described in "De-duplication of database search results for systematic reviews in EndNote," resulting in a total of 411 unique citations included in the project library.<sup>18</sup> Thirteen articles were ultimately included in the study ([Fig 1](#)). There were no disagreements between the reviewers regarding the application of the inclusion and exclusion criteria.

Included studies examined posterior tibial translation in both cadaveric and clinical settings. Most techniques were reported in awake patients, but one study reported outcomes in patients under anesthesia.<sup>19</sup> Patients were positioned in the supine, lateral decubitus, and kneeling positions. Methods of applying stress included gravity, hamstring contraction, accessory weights, examiner-applied manual force (stress), or with the patient's applied body weight. One-hundred fifty newtons (N) was the applied force most commonly used, with a range of 89 to 200 N ([Table 1](#)).<sup>5-11,13-16,19,20</sup> Locations of applied stress were reported in relation to the joint line or the tibial tubercle, with most studies reporting force application either 10 cm distal to the joint line or directly over the tibial tubercle. With regard to specialized equipment, 9 studies reported stress radiography using a TELOS device.<sup>6,7,9,10,12-16</sup> For studies reporting kneeling stress radiography, a padded bench<sup>5,7,10</sup> was used in 3 studies and a custom support jig for another study.<sup>11</sup> Techniques to obtain both lateral and axial radiographs were described. Two studies reported pain visual analog score differences and time required for stress radiography between various methods.<sup>5,7</sup> One study reported differences in femoral condyle rotation for various radiographic methods,<sup>7</sup> and another study reported patient preferences between stress methods.<sup>5</sup>

Several methods were described to measure posterior tibial translation radiographically ([Table 2](#)). Intrarater and inter-rater reliability were reported in several studies for both varying stress radiography techniques as well as radiographic measurements. Studies also compared stress radiography with instrumented knee arthrometer testing.<sup>9,13,14</sup>

## Cadaveric Studies

Two studies evaluating posterior tibial translation in cadaveric specimens provided a baseline to better understand clinical findings on stress radiography.<sup>6,16</sup> Garavaglia et al.<sup>6</sup> reported increased posterior tibial translation on lateral radiographs using multiple stress



**Fig 1.** Flowchart demonstrating results of the systematic review. (ACL, anterior cruciate ligament; posterior cruciate ligament.)

techniques with arthroscopic sectioning of the PCL compared to the intact specimen. The mean posterior tibial translation increased across all techniques with successive sectioning of the lateral collateral ligament and the posterolateral corner, as well as the medial collateral ligament and the posteromedial corner. Similarly, Sekiya et al.<sup>16</sup> reported similar sequential increases in posterior tibial translation on stress radiography with PCL resection followed by osteotomy of the femoral attachments of the lateral collateral ligament and popliteus tendon. The cadaveric studies suggest that larger displacement measurements on posterior tibial stress radiography should raise suspicion for a multiligamentous knee injury.

## Stress Radiography Techniques

### Gravity Stress Views

Stress radiography for PCL injuries has been most frequently described in awake patients; however, intraoperative assessment under anesthesia was studied by Staubli and Jakob.<sup>19</sup> Multiple stress methods have been described with varying amounts of force applied to the proximal tibia (Table 1). Kim et al.<sup>8</sup> reported that supine gravity lateral radiographs at 90° of knee flexion (Fig 2) were found to have greater than 90% sensitivity and specificity to detect a 3-mm side-to-side difference in posterior tibial translation, and, as such, were

recommended as a reasonable alternative to TELOS stress radiographs. Jung et al.<sup>7</sup> reported that the gravity view underestimated posterior tibial displacement as well differences in posterior tibial translation between the healthy and injured knee in patients with unilateral PCL deficiency compared with the TELOS device and kneeling stress radiographs. Garavaglia et al.<sup>6</sup> also found that a gravity view demonstrated good discrimination between partial and complete PCL lesions but less sensitivity to identify additional ligamentous injuries compared with TELOS stress radiographs. Two additional studies evaluated axial knee radiographs at 70 to 100° of flexion and without additional stress to the proximal tibia.<sup>7,9</sup> These studies found that gravity stress views without supplemental weight may underestimate posterior tibial translation, and thus may not provide accurate objective data to determine operative indications.

### Hamstring Contraction Stress Views

Two studies reviewed the efficacy of using active hamstring muscle contraction (Fig 3) as a means of producing posterior tibial stress. Margheritini et al.<sup>9</sup> found equivalent side-to-side differences in posterior tibial translation compared with TELOS stress radiography (89 N), whereas Jung et al.<sup>7</sup> found dissimilar results when compared with TELOS stress radiography at higher posterior forces (150 N) at the same knee

**Table 1.** Stress Radiography Techniques for Posterior Tibial Translation

Study	Stress Method	Force Applied	Patient Position	Knee Flexion Angle, °	Findings
Garavaglia et al. <sup>6</sup>	TELOS	180 N	Lateral decubitus	30	TELOS most sensitive to detect PCL injury
	TELOS	180 N	Lateral decubitus	80	LOE: controlled cadaveric laboratory study
	Gravity	—	Supine	90	
Garofalo et al. <sup>10</sup>	PCL press	180 N	Supine	100	
	TELOS	147 N	Lateral decubitus	90	Kneeling stress produces larger posterior tibial displacement than TELOS
	Kneeling board	—	Kneeling	90	LOE: Level III
Hewett et al. <sup>13</sup>	Manual	89 N	Supine	70	Stress radiography is superior to KT-1000
					LOE: Level III
Höher et al. <sup>14</sup>	TELOS	150 N	Lateral decubitus	90	Similar posterior tibial displacement compared with Rolimeter
					LOE: Level II
Holliday et al. <sup>5</sup>	Kneeling board	—	Kneeling	90	Equivalent posterior tibial translation
	Weighted gravity	20 lb	Supine	90	LOE: Level III
Jackman et al. <sup>11</sup>	Kneeling board	—	Kneeling	90	Kneeling stress radiography is reliable and reproducible
					LOE: Level IV
Jung et al. <sup>7</sup>	Gravity	—	Supine	70	TELOS and kneeling stress radiography superior to gravity and hamstring contraction
	Gravity	—	Supine	90	
	Hamstring contraction	—	Seated	90	LOE: Level III
	TELOS	150 N	Lateral decubitus	90	
Kim et al. <sup>8</sup>	Kneeling board	—	Kneeling	90	
	Gravity	—	Supine	30	Supine gravity stress radiography equivalent to TELOS
	Gravity	—	Supine	90	
Lee et al. <sup>20</sup>	TELOS	134 N	Lateral decubitus	90	LOE: Level IV
	TELOS	150 N	Lateral decubitus	90	TELOS stress radiography is reliable and reproducible for numerous measurement methods
					LOE: Level II
Margheritini et al. <sup>9</sup>	Gravity	—	Supine	70	Stress radiography superior to KT-2000;
	Hamstring contraction	—	Lateral decubitus	90	hamstring contraction stress radiography equivalent to TELOS
	TELOS	89 N	Lateral decubitus	25	
Schulz et al. <sup>15</sup>	TELOS	89 N	Lateral decubitus	90	LOE: Level II
	TELOS	150 N	Lateral decubitus	90	TELOS stress radiography is reliable and reproducible for numerous measurement methods
					LOE: Level II
Sekiya et al. <sup>16</sup>	TELOS	200 N	Lateral decubitus	90	TELOS stress radiography predictably evaluates severity of PCL injury
					LOE: Controlled cadaveric laboratory study
Staubli and Jakob <sup>19</sup>	Manual	25-30 kg	Supine	Near full extension	Manual stress radiography under anesthesia is effective to diagnose PCL injuries
					LOE: Level III

LOE, Level of Evidence; PCL, posterior cruciate ligament.

flexion angle. It is unclear what role patient position or amount of stress applied with the TELOS device accounted for these discrepancies.

### Kneeling Stress Views

Kneeling stress radiographs require patients to kneel on a padded apparatus providing a posteriorly directed force along the proximal tibia (Fig 4). Jung et al.<sup>7</sup> found equivalent posterior displacement compared with TELOS radiographs, whereas Garofalo et al.<sup>10</sup> demonstrated greater posterior tibial displacement with kneeling stress radiography. While kneeling stress radiography is seemingly at least as sensitive as TELOS stress radiographs, the protocol requires patients to

apply body weight to the affected knee and may be limited by pain or associated injuries. Holliday et al.<sup>5</sup> reported significantly greater visual analog scale pain scores with kneeling stress radiography compared with weighted gravity stress views, and almost all patients preferred the weighted gravity stress view (Fig 5). A specialized kneeling apparatus is also required, although relatively simple and low-cost methods have been described.<sup>7,10,11</sup>

### TELOS Stress Views

Stress radiography using the TELOS device is the method reported most frequently in the literature.<sup>6-10,12,14-16,20</sup> Novel stress methods often are

**Table 2.** Radiographic Measurement Techniques for Posterior Tibial Translation

Study	Measurement Technique	Stress Method	Intraobserver Reliability (ICC)	Interobserver Reliability (ICC)
Garavaglia et al. <sup>6</sup>	Staubli	TELOS (30°)	—	0.981
		TELOS (80°)	—	0.966
		Gravity	—	0.863
Jackman et al. <sup>11</sup>	Novel	Kneeling	0.973	0.955
Kim et al. <sup>8</sup>	Staubli	TELOS, gravity	0.859	0.827
Lee et al. <sup>20</sup>	MM	TELOS	0.736	0.871
	LL		0.685	0.803
	Mid-Mid		0.883	0.894
	PC		0.754	0.872
	BAT		0.894	0.943
Schulz et al. <sup>15</sup>	Staubli	TELOS	0.95	0.91

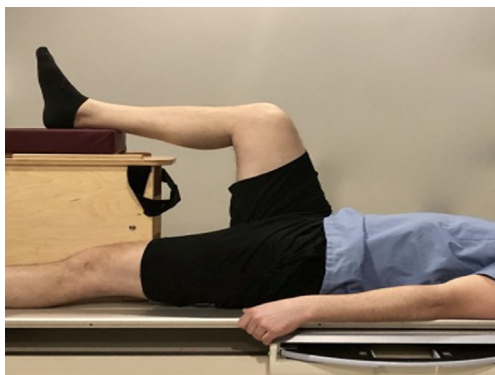
BAT, posterior Blumensaat line to anterior tibia; ICC, intraclass correlation coefficient; LL, lateral femoral condyle to lateral tibial plateau; Mid-Mid, midpoint of femoral condyles to midpoint of tibial plateau; MM, medial femoral condyle to medial tibial plateau; PC, posterior femoral condyle to tibial axis.

compared with TELOS stress radiography, and thus TELOS may be considered the de facto gold standard for evaluating posterior tibial translation due to its ability to accurately quantify the degree of knee flexion and posterior stress applied. Although Garavaglia et al.<sup>6</sup> found equivalent posterior tibial displacement in cadavers using TELOS stress radiographs at both 30 and 80° of knee flexion, Margheritini et al.<sup>9</sup> found superior posterior displacement at 90° of knee flexion compared with 25°. There is little continuity in the literature regarding the appropriate force required using the TELOS device to accurately assess posterior tibial translation. Sekiya et al.<sup>16</sup> reported posterior tibial displacement in cadavers using the TELOS device at 90° of knee flexion and a 200 N force. Margheritini et al.<sup>9</sup> studied the lowest reported posterior force with 89 N. While this study reported the average posterior tibial displacement with this protocol, it is difficult to compare these results with other studies due to the fact that nearly one-half of the patients (27 of 60) had multiligamentous injuries.

### Radiographic Measurement Techniques

Methods to measure posterior tibial translation have been reported on both axial and lateral radiographic views. Puddu et al.<sup>17</sup> described measuring a line parallel to the trochlea from the anterior-most aspect of the femoral condyles to the anterior-most aspect of the tibial tubercle on an axial view (Fig 6). This method was evaluated by Margheritini et al.,<sup>9</sup> Jung et al.,<sup>7</sup> and Garavaglia et al.<sup>6</sup> Garavaglia et al.<sup>6</sup> reported interobserver reliability in the form of intraclass correlation coefficients and found excellent reliability. The axial stress view measured using the technique by Puddu et al.<sup>17</sup> demonstrated excellent interobserver reliability between 3 observers.

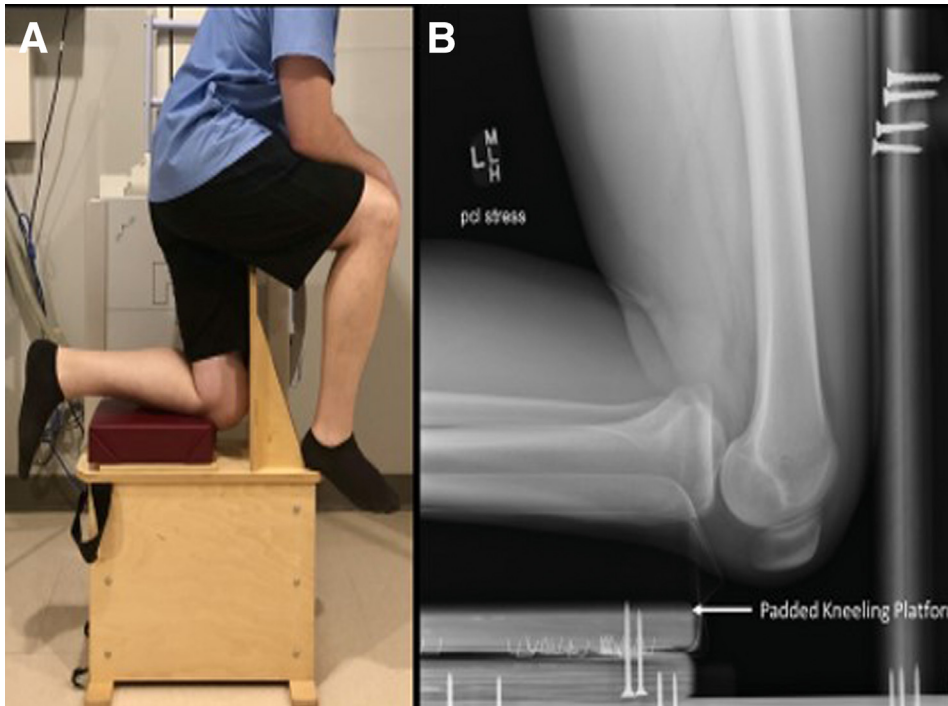
Many measurement techniques have been reported on a lateral radiographic view. Staubli and Jakob<sup>19</sup> initially described a measurement method for both medial and lateral tibiofemoral compartments. The posterior-most aspect of the tibial plateau and femoral condyle of each compartment were identified, and lines through each point were made parallel to the posterior



**Fig 2.** Clinical photograph demonstrating positioning for a right knee posterior tibia gravity stress radiography.



**Fig 3.** Clinical photograph demonstrating positioning for a right knee hamstring contraction stress radiography.



**Fig 4.** Clinical photograph (A) and lateral radiograph (B) performed with a padded kneeling platform designed for kneeling stress views with the right tibia resting on the platform distal to the knee.

cortex of the tibial shaft (Fig 7). This technique was used in seven studies.<sup>6,9,10,12,14-16</sup> The reported intra- and interobserver reliability for this method has been reported as good or excellent for this measurement method across all of these studies. Jackman et al.<sup>11</sup> described a novel measurement technique with measurements taken from the posterior tibial cortex to the most posterior point along Blumensaat's line (Fig 8). Three observers measured 132 kneeling posterior tibial stress radiographs 4 weeks' apart and found excellent intraobserver reliability in detecting a difference in mean posterior tibial displacement less than 0.3 mm between trials. In addition, excellent interobserver reliability was reported.

### Stress Radiography Versus Instrumented Knee Arthrometry

Hewett et al.<sup>13</sup> found a statistically significant increase in posterior tibial translation on stress radiography compared with KT-1000 arthrometer testing. Similarly, Margheritini et al.<sup>9</sup> found that the KT-2000 arthrometer underestimated posterior tibial translation in PCL-deficient knees compared to stress radiography. Specifically, stress radiography using the TELOS device with 90° of knee flexion and hamstring contraction demonstrated greater posterior tibial translation in PCL-deficient knees than the KT-2000. Höher et al.<sup>14</sup> quantified posterior tibial translation of the Rolimeter (Aircast Europa, Neubeuern, Germany) instrumented drawer test compared with TELOS stress radiography. These authors found similar posterior tibial translation

differences between intact and PCL-deficient knees and concluded that the Rolimeter was a viable alternative to stress radiography to determine posterior tibial translation. Potential advantages of the Rolimeter included lack of radiation exposure as well as low cost. However, no specific costs were cited to substantiate this claim.

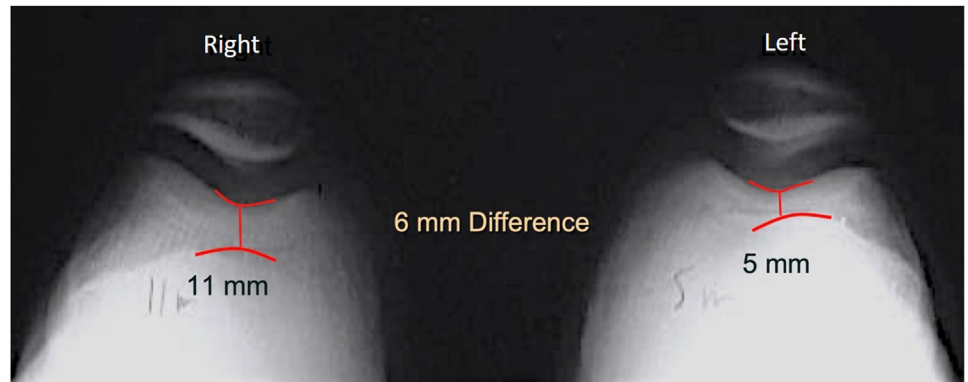
### Discussion

Our review of the literature suggests that the optimum stress technique has not been established. Stress radiographs are more reliable than instrumented devices for quantifying posterior tibial translation and are more practical in most clinical settings. TELOS and kneeling stress radiography are the most reliable methods to evaluate PCL laxity. The TELOS device is a



**Fig 5.** Clinical photograph demonstrating positioning and technique for a right knee weighted axial stress radiography.

**Fig 6.** Radiographs demonstrating the measurement technique of Puddu et al.<sup>17</sup> of posterior tibial translation on the axial view. A line is drawn parallel to the femoral condyles along the trochlea and along the anterior tibial plateau. The side-to-side difference can be measured from the anterior tibial plateau or the parallel line across the trochlea.

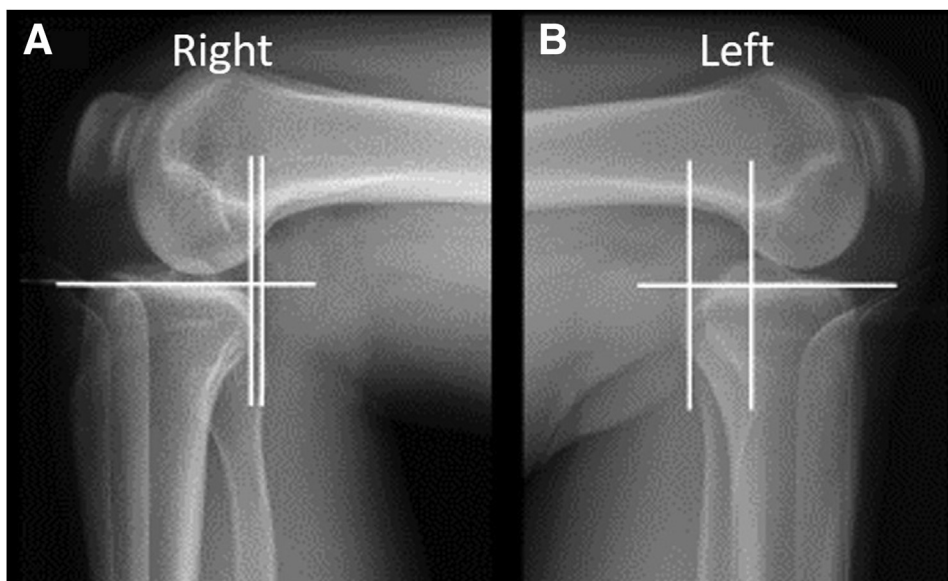


reliable method to provide uniform posterior tibial translation during stress radiography. Kneeling stress radiographs are at least equivalent to the TELOS method and may be cost-effective option for many clinicians. No clear operative threshold has been established based on side-to-side differences in posterior tibial translation for gravity stress radiographs, but these views tend to underestimate injury severity compared to TELOS and kneeling stress radiographs.

While the TELOS device is clearly reliable, there are still limitations with its use. There is no clear consensus on the optimal amount of posterior applied force. Furthermore, the TELOS device is not widely available in many practice settings due to the relatively low incidence of PCL injuries and the cost of the device. A kneeling board is relatively inexpensive and bilateral radiographs can be obtained quickly. However, kneeling stress radiographs also have limitations, including the ability and/or willingness of patients to allow body weight stress through the affected knee, as

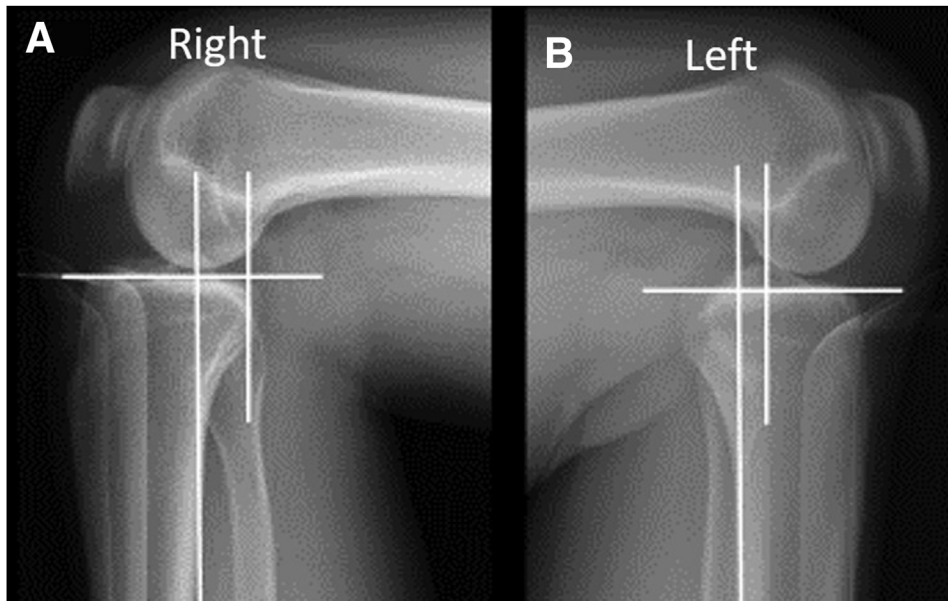
well as possible weight-bearing or knee flexion limitations secondary to additional injuries. In the scenario that a TELOS device is unavailable and the patient is unable to adequately kneel for stress radiographs, hamstring contraction or gravity stress views may still be valuable to clinicians. As such, if gravity stress radiographs are obtained to aid in surgical decision-making, practitioners should consider the expected smaller side-to-side differences and have a lower threshold to suspect additional ligamentous knee injury when a large difference is observed.

Posterior tibial stress radiography has been described with a myriad of techniques, varying by patient positioning, knee and hip flexion angle, and method and amount of force application. Patient positioning has been described in supine, lateral decubitus, or kneeling positions. Posterior tibial translation is commonly measured from lateral radiographs at 90° of flexion. Ryu et al.<sup>21</sup> recently reported that the knee flexion angle of 85 to 92° resulted in a high reproducibility of



**Fig 7.** Lateral radiograph demonstrating measurement of posterior tibial translation using the Staubli method. A horizontal line is drawn along the tibial articular surface. Two perpendicular lines are drawn through the posterior-most aspect of the femoral and tibial condyles, respectively. The distance between these lines is measured. Uninjured right (A) and injured left (B) knees are shown.





**Fig 8.** Lateral radiograph demonstrating measurement of posterior tibial translation using the Jackman method. A horizontal line is drawn along the tibial articular surface. One perpendicular line is drawn in line with the posterior-most aspect of the tibial cortex. Another perpendicular line is drawn by intersecting the posterior-most aspect of Blumensaat's line. The distance between these lines is measured. Uninjured right (A) and injured left (B) knees are shown.

posterior tibial displacement measurement. Assuming a proper lateral view is obtained, all of these measurement techniques have excellent inter- and intra-observer reliability. The studies reviewed do not support any specific measurement method over the others provided that high-quality radiographs are obtained; therefore, the limiting factor in accurately measuring posterior tibial translation on stress radiographs is primarily related to the technique used to obtain the images. Consultation with the radiology technician is recommended prior to obtaining stress radiographs to optimize image quality so that the amount of posterior tibial translation can be accurately calculated irrespective of the chosen measurement method.

While PCL stress views have been commonly used as a key indicator for surgical intervention, there is very little, if any, data on whether stress radiography predicts the need for surgical intervention or outcomes following treatment. PCL-reconstruction techniques have been evaluated by the change in stress radiography as an objective outcome measure to assess the integrity of the graft but have not been correlated to subjective patient-reported outcomes.<sup>22</sup> As such, understanding how to interpret the imaging findings based on the radiographic technique assists treatment decision-making and are a necessary objective measure for any clinical PCL research study. Ideally, prospective studies with larger number of patients with limited associated injuries are needed to advance our understanding of the utility of these techniques as diagnostic, therapeutic and prognostic aids in the treatment of patients with PCL injuries.

### Limitations

Limitations of this systematic review include the small numbers of patients and the retrospective nature of the studies. Selection and information bias may exist in the reviewed studies. Results across reviewed studies were unable to be synthesized due to differences in methodology across the studies. Not all techniques were included in every paper. It is unknown what effect injury chronicity has on the degree of posterior tibial translation documented in these studies. Lastly, there are limited studies available over the last 5 years evaluating stress radiography techniques indicated a few advancements in measurement techniques or better comparisons to clearly define the best techniques currently used.

### Conclusions

The results of this systematic review indicate that posterior stress radiography with TELOS and kneeling stress radiography are the most reliable methods to evaluate PCL laxity. Gravity stress and hamstring contraction can be used but may underestimate posterior tibial translation. Radiographic measurement methods are reliable and no single method is clearly superior.

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**Appendix Table 1.** Full Search Strategies

## Embase

Date Searched: 12/22/2020

Applied Database Supplied Limits: none

Number of Results: 315

Full Search Strategy:

('posterior cruciate ligament injury'/exp OR 'posterior cruciate ligament rupture'/exp OR (('posterior cruciate' OR 'posterior knee') NEAR/4 (injur\* OR rupture\* OR reconstruction\* OR laxity OR instability\* OR insufficienc\* OR lesion\*)):ti,ab,kw OR (posterior NEAR/3 knee NEAR/3 instability):ti,ab,kw) AND ('stress radiography'/exp OR 'stress radiograph'/exp OR (stress NEAR/3 (radiograph\* OR 'X ray\*' OR 'X-ray\*')):ti,ab,kw OR ((arthrometer/exp OR arthrometer:ti,ab ) OR ('GNRB (device)':tn,ti,ab OR 'KT 1000':tn,ti,ab OR 'KT-2000':tn,ti,ab OR 'Rolimeter':tn,ti,ab OR 'Telos (device)':tn,ti,ab OR 'arthrometer':tn,ti,ab OR 'arthrometers':tn,ti,ab)))

## Ovid Medline

Date Searched: 12/22/2020

Applied Database Supplied Limits: none

Number of Results: 287

Full Search Strategy:

((exp Posterior Cruciate Ligament/ AND exp Knee Injuries/) OR ((posterior cruciate OR posterior knee) ADJ4 (injur\* OR rupture\* OR reconstruction\* OR laxity OR instability\* OR insufficienc\* OR lesion\*)):ti,ab,kf. OR (posterior ADJ3 knee ADJ3 instability):ti,ab,kf.) AND ((stress ADJ3 (radiograph\* OR X ray\* OR X-ray\*)):ti,ab,kf. OR KT 1000.ti,ab. OR KT-2000.ti,ab. OR Rolimeter.ti,ab. OR Telos.ti,ab. OR arthrometer\*.ti,ab.)

## Scopus

Date Searched: 12/22/2020

Applied Database Supplied Limits: none

Number of Results: 344

Full Search Strategy:

((TITLE-ABS-KEY(("posterior cruciate" OR "posterior knee") W/4 (injur\* OR rupture\* OR reconstruction\* OR laxity OR instability\* OR insufficienc\* OR lesion\*))) OR (TITLE-ABS-KEY(posterior W/3 knee W/3 instability))) AND ((TITLE-ABS-KEY(stress W/3 (radiograph\* OR "X ray\*" OR "X-ray\*"))) OR (TITLE-ABS-KEY("KT 1000" OR "KT-2000" OR "Rolimeter" OR Telos OR "arthrometer" OR "arthrometers"))))

## The Cochrane Library

Date Searched: 12/22/2020

Applied Database Supplied Limits: none

Number of Results:

CENTRAL 15

CDSR 0

Full Search Strategy:

(([mh "Posterior Cruciate Ligament"] AND [mh "Knee Injuries"]) OR (("posterior cruciate" OR "posterior knee") NEAR/4 (injur\* OR rupture\* OR reconstruction\* OR laxity OR instability\* OR insufficienc\* OR lesion\*)):ti,ab,kw OR (posterior NEAR/3 knee NEAR/3 instability):ti,ab,kw) AND ((stress NEAR/3 (radiograph\* OR "X ray\*" OR "X-ray\*")):ti,ab,kw OR ("KT 1000":ti,ab OR "KT 2000":ti,ab OR "Rolimeter":ti,ab OR Telos:ti,ab OR "arthrometer":ti,ab OR "arthrometers":ti,ab))

## ClinicalTrials.gov

Date Searched: 12/22/2020

Number of Results: 0

Full Search Strategy:

(posterior cruciate ligament injur\*) AND (stress radiography)