

# The Supine Internal Rotation Test

## A Pilot Study Evaluating Tibial Internal Rotation in Grade III Posterior Cruciate Ligament Tears

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**Background:** Biomechanical studies have reported that the posterior cruciate ligament (PCL) functions as a restraint against excessive tibial internal rotation at higher degrees of knee flexion.

**Purpose:** To investigate the use of a supine internal rotation (IR) test for the diagnosis of grade III PCL injuries. The hypothesis was that internal rotation would be greater in patients with grade III PCL injuries compared with other knee injuries and that the supine IR test would demonstrate excellent diagnostic accuracy.

**Study Design:** Cohort study (diagnosis); Level of evidence, 2.

**Methods:** A consecutive series of 309 patients underwent arthroscopic and/or open knee ligament reconstruction surgery. Seven patients were excluded based on the inability to perform a side-to-side comparison of internal rotation. Tibial internal rotation was assessed bilaterally on 302 patients during examination under anesthesia by a single orthopaedic surgeon measuring tibial tubercle excursion (mm) while applying internal rotation torque. Internal rotation was graded from 0 to 4 at 60°, 75°, 90°, 105°, and 120° of knee flexion. Data were collected and stored prospectively. The optimal threshold for the supine IR test was chosen based on maximization of the Youden index. Diagnostic accuracy parameters were calculated. Multiple logistic regression models were constructed to assess the influence of other knee pathologies on diagnostic accuracy.

**Results:** Examination of the 22 PCL-deficient knees demonstrated an increase in tibial internal rotation at 60°, 75°, 90°, 105°, and 120° of knee flexion. The supine IR test had a sensitivity of 95.5%, a specificity of 97.1%, a positive predictive value of 72.4%, and a negative predictive value of 99.6% for the diagnosis of grade III PCL injuries. Posterolateral corner injury had a significant interaction with the supine IR test, increasing its sensitivity and decreasing its specificity.

**Conclusion:** PCL-deficient knees demonstrated an increase in the side-to-side difference in tibial internal rotation compared with other knee pathologies. The supine IR test offers high sensitivity and specificity for grade III PCL injuries and may represent a useful adjunct for diagnosing PCL injuries.

**Keywords:** posterior cruciate ligament; internal rotation; diagnostic accuracy; supine internal rotation test

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The posterior cruciate ligament (PCL) plays a pivotal role in the knee as the primary restraint against posterior tibial translation.<sup>2,8</sup> The incidence of PCL tears has been reported to vary widely from 1% to 44% of all acute knee injuries, although the reported incidence in the general population (3%) is lower than the 37% incidence in the traumatic setting of patients presenting with knee hemarthroses.<sup>17,27,30</sup> Injuries are often the result of acute sports trauma or motor vehicle accidents.<sup>24</sup> While the optimal reconstruction technique is still debated, nonsurgical management of isolated and combined grade III PCL injuries has been reported to lead to decreased knee function and early development of osteoarthritis.<sup>1,22</sup> Additionally, isolated PCL tears have been reported to alter gait patterns, which can lead to

degenerative changes and a decreased activity level in the long term.<sup>5,20</sup>

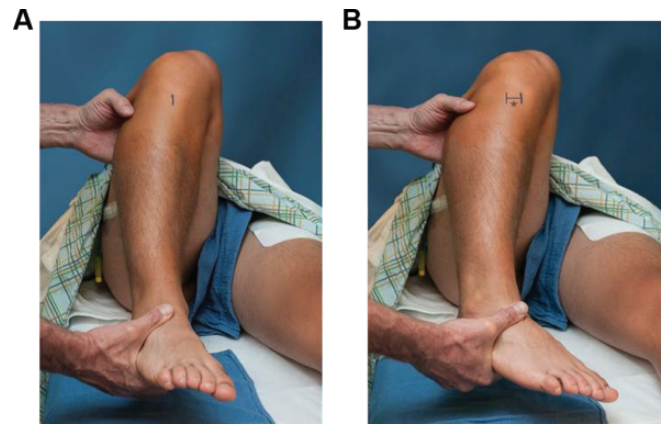
Accurate assessment of PCL integrity is an essential component of evaluating patients with acute or chronic knee injury. A typical clinical evaluation requires synthesis of data obtained on history, physical examination, and imaging. On history, patients may report falling on a flexed knee or the classic “dashboard” mechanism of injury.<sup>15</sup> Physical examination tests for assessing PCL integrity include the posterior drawer test, quadriceps active test, and posterior sag sign. In a systematic review of PCL physical examination maneuvers, Kopkow et al<sup>11</sup> concluded that no single test could be deemed the most useful due to the lack of unbiased data on reported diagnostic accuracies. However, the diagnostic accuracy of physical examination for PCL injuries could be increased when examination maneuvers were used in combination. For this reason, development of additional physical examination maneuvers to assess PCL integrity would be useful to further improve the cumulative diagnostic accuracy of physical examination for PCL injuries.

Previous biomechanical sectioning studies have investigated the role of the PCL in limiting rotational laxity of the knee.<sup>3,4,9,13,16,26</sup> In 1982, Fukubayashi et al<sup>3</sup> noted that there was a rotational component to a PCL-deficient knee with the increase in posterior translation. In a recent cadaveric study, Kennedy et al<sup>9</sup> investigated the functional contributions of the anterolateral bundle (ALB) and the posteromedial bundle (PMB) of the PCL across a range of knee flexion angles. Results indicated that, in addition to restraint against posterior tibial translation, both the ALB and PMB resisted tibial internal rotation at higher degrees of flexion.<sup>9</sup>

While previous biomechanical studies have demonstrated increases in tibial internal rotation in PCL-deficient knees,<sup>3,9</sup> increased tibial internal rotation on physical examination has been largely overlooked as a diagnostic tool for evaluating PCL integrity. Therefore, the purpose of this study was to translate prior biomechanical findings into clinical research by grading the side-to-side difference in internal rotation in a prospective evaluation of PCL-deficient knees compared with other ligamentous, chondral, and meniscal knee injuries. In addition, we wanted to assess the diagnostic accuracy of a supine internal rotation (IR) test for diagnosing grade III PCL tears, including evaluating the significance of other ligamentous injuries on the diagnostic accuracy of this test. We hypothesized that PCL-deficient knees would have an increase in internal rotation at 60°, 75°, 90°, 105°, and 120° of knee flexion compared with other knee injuries, and that a supine IR test would accurately diagnose PCL-deficient knees. It was anticipated that this information would potentially add diagnostic value as well as a greater understanding of the rotational significance of the PCL.

## MATERIALS AND METHODS

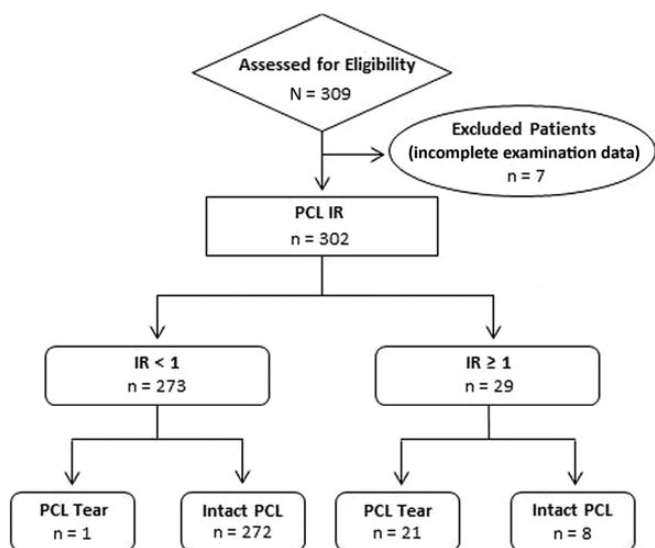
This study was approved by an institutional review board. A consecutive series of 309 patients underwent arthroscopic



**Figure 1.** The internal rotation test is performed with the patient in the supine position at each flexion angle (60°, 75°, 90°, 105°, and 120°). The clinician applies an internal rotation torque to the patient’s foot. The amount of tibial internal rotation (°) is assessed by grading the location of the tibial tubercle in neutral position (A) versus the point of maximal internal rotation (B) based on increases in millimeters. A side-to-side comparison is performed to account for physiologic laxity, which may vary between patients.

or open knee surgery between December 2013 and August 2014. Tibial internal rotation was measured bilaterally during examination under anesthesia using a supine IR test performed by a single orthopaedic surgeon. Examination under anesthesia was chosen over examination in the clinic to perform the test under ideal conditions by minimizing the effect of patient pain and guarding. Seven patients were excluded based on the inability to perform the supine IR test on both knees. Five of these patients had a preoperative diagnosis of arthrofibrosis, 1 patient had a body mass index >45 kg/m<sup>2</sup> and was unable to be evaluated, and 1 patient had bilateral ligamentous pathology, which precluded performing a side-to-side comparison.

Internal rotation was graded from 0 to 4 and recorded at 60°, 75°, 90°, 105°, and 120° of knee flexion. Internal rotation was assessed by measuring tibial tubercle excursion (mm) while applying internal rotation torque using neutral knee position as the reference point (Figure 1). The internal rotational torque was performed to the point where further rotation did not occur, at an estimated 5 N·m of force based on previous biomechanical assessments of internal rotation.<sup>9</sup> Grade 0 was defined as 0 mm of excursion, grade 1 as excursion between 0 and <3 mm, grade 2 between 3 and <6 mm, grade 3 between 6 and <9 mm, and grade 4 as ≥9 mm of excursion. A total of 302 patients were categorized according to the side-to-side differences in the grade of internal rotation and the diagnosis of knee ligament injury confirmed by subsequent arthroscopic or open knee surgery. Data collection and analysis were organized based on the Standards for the Reporting of Diagnostic accuracy studies (STARD) guidelines to ensure proper methodology.<sup>10</sup> The study flow diagram is depicted in Figure 2.



**Figure 2.** Flow diagram depicting patients included in this study and results of the side-to-side difference in grade on the supine internal rotation (IR) test. Patients with a side-to-side difference in IR of  $<1$  or  $\geq 1$  were further subdivided into those with grade III posterior cruciate ligament (PCL) tears and those with an intact PCL.

**Statistical Analysis**

The main goal of this study was to assess the diagnostic accuracy of the supine IR test. To address this, several variants of the test were compared, including using the injured side only versus using the side-to-side difference in internal rotation grade and using individual flexion angles versus using the maximum among all 5 tested flexion angles. For all candidate diagnostic tests, the optimal threshold for each test scale was chosen based on maximization of the Youden index (sensitivity + specificity - 1), which places equal importance on sensitivity and specificity.

The secondary goal of the study was to determine whether injury to other knee stabilizing structures, including the anterior cruciate ligament (ACL), medial collateral ligament (MCL), fibular collateral ligament (FCL), posterolateral corner (PLC), or meniscal roots influenced the diagnostic accuracy of the supine IR test. To test this, multiple logistic regression models (using the Firth bias-reduced approach) were constructed separately to predict PCL injury using the supine IR test and the ACL, MCL, FCL, PLC, and meniscal roots as predictors. Interaction terms between the supine IR test and presence or absence of injury to the other knee structure were modeled to test whether the diagnostic accuracy of the supine IR test differs when concomitant knee injury exists. For a given concomitant injury, a significant interaction effect led to the interpretation that this injury was a confounder of the internal rotation–PCL association and that diagnostic accuracy could be improved with knowledge of the presence or absence of this injury. The interaction term was removed from the model when not

**TABLE 1**  
Supine Internal Rotation Test: Side-to-Side Difference in Grade at Each Measured Angle of Flexion<sup>a</sup>

Flexion Angle, deg	PCL Injury	Difference in IR Grade, n						
		-3	-2	-1	0	1	2	3
60	Present	0	0	0	5	9	5	3
	Absent	0	1	11	263	4	1	0
75	Present	0	0	0	4	9	6	3
	Absent	0	1	12	262	4	1	0
90	Present	0	0	0	4	8	7	3
	Absent	0	1	15	259	4	1	0
105	Present	0	0	0	3	11	6	2
	Absent	1	1	23	249	6	0	0
120	Present	0	0	0	3	10	6	3
	Absent	1	1	25	247	6	0	0

<sup>a</sup>IR, internal rotation; PCL, posterior cruciate ligament.

statistically significant, and the main effect of the concomitant injury was interpreted as the association with PCL injury, independent of the supine IR test.

Diagnostic accuracy metrics included sensitivity, specificity, positive and negative predictive values, and positive and negative likelihood ratios. All metrics were reported with 95% confidence intervals. The statistical computing package R (R Development Core Team) was used for all analyses.<sup>7,14,21</sup>

**RESULTS**

There were 170 males and 132 females included in this study. Mean age ( $\pm$ SD) was  $38.5 \pm 15.9$  years. Among the 302 patients, grade III PCL injury was found in 7% of patients, ACL injury in 43% of patients, MCL injury in 11% of patients, PLC (fibular collateral ligament, popliteus, and popliteofibular ligament) injury in 10% of patients, FCL injury in 10% of patients, and meniscal root tears in 9% of patients. Isolated PCL injuries accounted for 23% of all PCL injuries, while 77% of patients with a PCL injury had concomitant injury to at least 1 other knee structure listed above.

Grade III PCL-deficient knees had an increase in internal rotation at each tested angle of knee flexion (60°, 75°, 90°, 105°, and 120°). The side-to-side difference in internal rotation grade determined using the supine IR test performed at 60°, 75°, 90°, 105°, and 120° of knee flexion in patients with grade III PCL injuries versus those without a PCL injury is reported in Table 1.

Diagnostic accuracy results for different knee flexion angles of the supine IR test are reported in Table 2. Using the side-to-side difference in internal rotation grade provided equally accurate or more accurate diagnosis of PCL injury at all tested knee flexion angles and with respect to all diagnostic accuracy metrics. Moreover, the maximum side-to-side difference among the 5 flexion angles produced an optimal balance of sensitivity and specificity. The supine IR test had a sensitivity of 95.5% (95% CI, 77.2%-99.9%), a specificity of 97.1% (95% CI, 94.4%-98.8%), a positive predictive value (PPV) of 72.4% (95% CI, 56.8%-99.1%), and a

TABLE 2  
Supine Internal Rotation Test: Injured Knee Only Versus Side-to-Side Difference<sup>a</sup>

Flexion angle, deg	Injured Knee						Side-to-Side Difference					
	60	75	90	105	120	Max	60	75	90	105	120	Max
Cutoff grade <sup>b</sup>	2	2	2	3	3	3	1	1	1	1	1	1
Sensitivity	0.682	0.773	0.818	0.591	0.636	0.636	0.773	0.818	0.818	0.864	0.864	0.955
Specificity	0.936	0.929	0.879	0.961	0.950	0.950	0.982	0.982	0.982	0.979	0.979	0.971
PPV	0.455	0.459	0.346	0.542	0.500	0.500	0.773	0.783	0.783	0.760	0.760	0.724
NPV	0.974	0.981	0.984	0.968	0.971	0.971	0.982	0.986	0.986	0.989	0.989	0.996
DLR–Pos	10.6	10.8	6.74	15.0	12.7	12.7	43.3	45.8	45.8	40.3	40.3	33.4
DLR–Neg	0.340	0.245	0.207	0.426	0.383	0.383	0.231	0.185	0.185	0.139	0.139	0.047
False positives, n	18	20	34	11	14	14	5	5	5	6	6	8
False negatives, n	7	5	4	9	8	8	5	4	4	3	3	1

<sup>a</sup>DLR–Neg, negative diagnostic likelihood ratio; DLR–Pos, positive diagnostic likelihood ratio; Max, maximum internal rotation test result among all 5 flexion angles; NPV, negative predictive value; PPV, positive predictive value.

<sup>b</sup>Cutoff grade (grades 0–4) indicates the optimal threshold, as determined by the Youden index, for which an equal to or higher graded test predicts injured posterior cruciate ligaments.

TABLE 3  
Predictive Models of PCL Injury: Influence of Concomitant Knee Pathology<sup>a</sup>

	Concomitant Injury Included in Model				
	ACL	MCL	FCL	PLC	Root
Baseline <sup>b</sup>	–5.20 (<.001)	–6.55 (<.001)	–6.24 (<.001)	–6.28 (<.001)	–5.30 (<.001)
Positive IR test	6.05 (<.001)	6.76 (<.001)	7.07 (<.001)	7.13 (<.001)	6.05 (<.001)
Concomitant injury	0.164 (.830)	3.85 (<.001)	3.35 (.027)	4.98 (.003)	1.47 (.262)
Interaction <sup>c</sup>	ns	ns	ns	–4.73 (.015)	ns

<sup>a</sup>Results reported as  $\beta$  ( $P$  value), where the coefficient  $\beta$  is the estimated change in the log(odds) of posterior cruciate ligament (PCL) injury associated with presence of the given variable. ACL, anterior cruciate ligament; FCL, fibular collateral ligament; IR, internal rotation; MCL, medial collateral ligament; ns, not significant; PLC, posterolateral corner; root, meniscus root injury.

<sup>b</sup>Baseline, both concomitant injury and PCL IR test are negative.

<sup>c</sup>Interaction, both concomitant injury and PCL IR test are positive.

negative predictive value (NPV) of 99.6% (95% CI, 97.8%–99.8%) for the diagnosis of grade III PCL injury. The positive likelihood ratio was 33.4 (95% CI, 16.8–66.5), and the negative likelihood ratio was 0.047 (95% CI, 0.007–0.318).

With a maximum side-to-side difference of grade 1 as a cutoff point for diagnosing a grade III PCL tear, 29 patients had an internal rotation of  $\geq 1$ , which included 21 confirmed grade III PCL tears and 8 intact PCLs. There were 273 patients with an internal rotation of  $< 1$ , which included 272 intact PCLs and 1 confirmed PCL tear (Figure 2).

A summary of the multiple logistic regression models used to assess the effect of various concomitant knee injuries on the supine IR test is provided in Table 3. The low prevalence of PCL injury in our group is represented by the low baseline likelihood of PCL injury in each of the models. In each model, a positive IR test reflects a significant increase in the likelihood of PCL injury (log-odds range [5.03, 5.86]; all  $P < .001$ ). Anterior cruciate ligament, MCL, FCL, or meniscus root injuries did not have significant interaction effects with the supine IR test when predicting

PCL injury. Medial collateral ligament injury ( $\beta = 3.85$ ,  $P < .001$ ) and FCL injury ( $\beta = 3.35$ ,  $P = .027$ ) were significantly associated with higher probability of PCL injury, but ACL and meniscus root injuries were not. Posterolateral corner injury had a significant interaction with the supine IR test, indicating that the presence of either a positive supine IR test or a concomitant PLC injury increases the likelihood of a PCL injury. However, the negative interaction term indicates that these conditions do not increase the likelihood of a deficient PCL additively when both a positive supine IR test and a concomitant PLC injury are present. By accounting for PLC injuries with the supine IR test, the sensitivity and specificity of the prediction model were 1.0 and 0.954, respectively (Table 4). Specifically, zero false negatives were found when using the interaction model.

## DISCUSSION

The most important findings from this study were that PCL-deficient knees had a significant increase in the side-to-side difference of internal rotation and that a supine IR

TABLE 4  
Diagnostic Accuracy Metrics of the Confounding Effect  
of PLC Injuries (95% CI)<sup>a</sup>

Model	IR Test Only	IR Test + PLC
Cutoff (prob) <sup>b</sup>	0.717	0.214
Sensitivity	0.955 (0.772-0.999)	1.000 (0.846-1.000)
Specificity	0.971 (0.944-0.988)	0.954 (0.922-0.975)
PPV	0.724 (0.568-0.991)	0.629 (0.493-1.0)
NPV	0.996 (0.978-0.998)	1.000 (0.985-1.000)
DLR-Pos	33.4 (16.8-66.5)	21.5 (12.7-36.6)
DLR-Neg	0.047 (0.007-0.318)	0.000 (0.000-1.000)
False positives, n	8	13
False negatives, n	1	0

<sup>a</sup>Both tests use maximum (among flexion angles) side-to-side difference in internal rotation (IR) grade. Values in parentheses are 95% CIs. DLR-Neg, negative diagnostic likelihood ratio; DLR-Pos, positive diagnostic likelihood ratio; NPV, negative predictive value; PLC, posterolateral corner; PPV, positive predictive value.

<sup>b</sup>Cutoff (prob) is the optimal threshold on the probability scale as determined by the Youden index.

test was both highly sensitive and specific for diagnosing grade III PCL tears.

One important finding of this study was the side-to-side difference in internal rotation on physical examination in PCL-injured versus non-PCL-injured knees. Patients were found to have variable amounts of internal rotation when comparing only 1 leg regardless of the injured state of the knee. The grade of internal rotation for the injured leg was less sensitive and specific compared with the side-to-side difference because of the variability of internal rotation between patients. This is supported by previous studies where knee rotational laxity among healthy subjects has been reported to be highly variable and dependent on body mass index and sex.<sup>19</sup> However, there was no significant difference found in the side-to-side comparison of rotational laxity for patients with healthy knees.<sup>18</sup>

It is also useful to compare the diagnostic accuracy of the supine IR test to other physical examination maneuvers for the diagnosis of PCL injuries. Rubinstein et al<sup>25</sup> reported in 75 knees that the posterior drawer test was the most sensitive (90%) and specific (99%) for diagnosing chronic PCL tears. In comparison, we found that in 302 patients, the supine IR test was 95.5% sensitive and 97.1% specific for diagnosing grade III PCL tears. Differences do exist between the 2 studies; most notably, Rubinstein et al<sup>25</sup> utilized 5 orthopaedic surgeons whereas the present study involved only 1 orthopaedic surgeon.

A systematic review of physical examination tests for diagnosing posterior cruciate ruptures demonstrated that classical maneuvers such as the posterior drawer test and the posterior sag sign have a wide range of reported sensitivities, minimal reports of specificity, and the majority of the studies have a high risk of bias.<sup>11</sup> This led Kopkow et al<sup>11</sup> to conclude that there is no one maneuver that can be deemed more appropriate for diagnosing PCL tears; however, in combination, the accuracy of diagnosis increases.

With the uncertainty of the diagnostic accuracy of standard physical examination maneuvers, the supine IR test can be beneficial in diagnosing PCL-deficient knees.

Increased sensitivity of the supine IR test was found by selecting the maximum difference in internal rotation among the different angles of flexion. Meanwhile, specificity was not substantially reduced compared with testing at individual flexion angles. This increased accuracy may be attributable to searching for increased laxity among a range of flexion angles or simply to more opportunity for detection by performing repeated testing. Regardless, our findings strongly suggest that searching for the maximum side-to-side differences in IR test grade among a range of relevant flexion angles is optimal.

The supine IR test was 95.5% sensitive and 97.1% specific in diagnosing a grade III PCL tear in the 302 patients. Concomitant ACL tears, MCL tears, or FCL tears did not confound the sensitivity and specificity of the supine IR test. However, there was a significant effect of a PLC injury in diagnosing PCL tears with the supine IR test. While the sensitivity (100%) increased when accounting for the PLC, this should be regarded solely as a confounder. The confounding effect of the PLC potentially explains the notably lower PPV of 77.4%. While this was an unexpected finding, prior PLC sectioning and animal studies have reported increased internal rotation at lower degrees of knee flexion (0°-90°).<sup>6,12</sup> Additionally, the MCL and ACL have been reported to resist internal rotation at extension and lower degrees of flexion.<sup>4,23,28</sup> It is important to note that while the effect of each additional ligament injury on the supine IR test was assessed, the possible interaction effect of combined ligament injuries cannot be ruled out.

Furthermore, results of this study are consistent with previous reported biomechanical data. A cadaveric sectioning study performed by Kennedy et al<sup>9</sup> reported a significant increase in internal rotation in completely sectioned PCL knees compared with intact knees at higher degrees of flexion. The maximal increase in international rotation occurred at 105° of flexion.<sup>9</sup> The biomechanical results demonstrate a similar trend of increased internal rotation at higher degrees of flexion as the clinical findings found in this study. However, the values are not identical due to the significant differences of biomechanical and clinical studies. The biomechanics study used a reproducible 5-N·m robotic force, which is impossible to reproduce consistently clinically. The actual force applied clinically is unknown. In addition, internal rotation was calculated from a central point on tibial plateau in the study by Kennedy et al,<sup>9</sup> whereas internal rotation in this study was evaluated from the tibial tuberosity.

The side-to-side increase in internal rotation associated with PCL-deficient knees also further demonstrates the rotational significance of the PCL found previously in biomechanical studies.<sup>3,4,13,16,26</sup> The restraint against excessive internal rotation has clinical implications. First, in patients with a positive Lachman test, the supine IR test could differentiate a posteriorly displaced PCL-deficient knee producing a false positive Lachman test and a true ACL tear. Second, surgical reconstruction of the PCL, including graft selection and tunnel placement, needs to

account for internal rotation in addition to posterior translation. An anatomic double-bundle PCL reconstruction has been reported biomechanically to decrease the amount of internal rotation at higher degrees of flexion compared with anatomic single-bundle reconstructions.<sup>29</sup>

The strengths of this study include the prospective nature of examining 302 consecutive patients using intraoperative diagnosis as a reference standard. The 302 patients included a wide variety of ligamentous, meniscal, and chondral pathologies tested with the supine IR test.

This study had some limitations. First, patients were evaluated by a single orthopaedic surgeon who was not blinded to the clinical diagnosis. Physical examination and magnetic resonance imaging precluded the perioperative supine IR test, introducing potential bias to the study. Further studies are needed to investigate the interobserver reliability of the supine IR test across multiple blinded examiners, examiners with varying levels of training, and examiners across medical specialties. Second, only 22 of 302 patients examined were confirmed during surgery to have a grade III PCL knee injury. Additional research is needed to increase the sample size of PCL tears to further investigate the diagnostic accuracy of the supine IR test. Future randomized studies are needed to compare the supine IR test to other PCL tests such as the posterior drawer test and to assess the added utility of the supine IR test when used in combination with other tests. Finally, all examinations were performed under anesthesia and therefore results may not be generalizable and require additional investigation in a clinical setting, particularly when patient pain and guarding limits physical examination.

## CONCLUSION

This study demonstrates that grade III PCL tears have an increase in tibial internal rotation on the supine IR test performed during examination under anesthesia between 60° and 120° of flexion compared with other knee ligament injuries. The clinical findings in this study are consistent with previous biomechanical data reporting an increase in internal rotation between 60° and 120° of flexion with a sectioned PCL. The supine IR test is highly sensitive and specific for diagnosing grade III PCL injuries during examination under anesthesia.

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