



# Suture Tape—Augmented Posterior Cruciate Ligament Repair Should Be Tensioned and Fixed at Approximately 100° Knee Flexion to Prevent Loss of Full Flexion

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**Purpose:** To evaluate the biomechanics of simulated posterior cruciate ligament injuries (SimPCL) with and without internal brace suture tape augmentation (IBSTA) in cadaver knees. **Methods:** A total of 20 cadaveric knees were used, all male, with an average age of  $65 \pm 18$  years. Femoral tunnel isometry was evaluated at the 1/11 o'clock and 2/10 o'clock femoral positions. SimPCL were created in 6 knees. IBSTA was performed, and load data were collected through knee range of motion. An additional 6 specimens were evaluated at the 1/11 femoral tunnel position, and load cell recordings were obtained at 10 different knee flexion angles. Cyclic displacement in 8 cadaver knees was assessed using an Instron machine. Load and displacement data were recorded. Testing was performed under 3 conditions for each specimen: intact PCL, SimPCL, and SimPCL/IBSTA using the 1/11 femoral tunnel position. **Results:** There was no difference in isometry when comparing the 1/11 o'clock ( $7.1 \pm 4.0$  ft\*lb) femoral position and the 2/10 o'clock ( $7.6 \pm 4.2$  ft\*lb) position ( $P = .467$ ). SimPCL/IBSTA suture tape tension gradually increased with progressive flexion to a peak at approximately 120° of knee flexion. For cycle 100 tibial displacement, there was no difference between intact (4.41 mm) and SimPCL/IBSTA (5.59 mm,  $P = .391$ ). There was a difference between intact (4.41 mm) and SimPCL (7.19 mm,  $P = .006$ ), but there was no significant difference between SimPCL/IBSTA (5.59 mm) and SimPCL (7.19 mm,  $P = .140$ ). There was a difference in cycle 1 stiffness between intact (62.3 N/mm) and Sim2PCL (37 N/mm,  $P = .005$ ). There was no difference between other groups. **Conclusions:** In this cadaver study, there was a 1.18-mm average difference in posterior tibial displacement when comparing intact and SimPCL/IBSTA. The internal brace construct should be tensioned and fixed at approximately 100° of knee flexion to prevent loss of full flexion. **Clinical Relevance:** The presented biomechanical data for internal bracing of PCL injuries may lead to improved surgical techniques.

Isolated posterior cruciate ligament (PCL) injuries are uncommon. Most PCL injuries are seen in combination with other knee ligament injuries.<sup>1</sup> The

PCL is an essential stabilizer of the knee, functioning as the primary restraint to posterior tibial translation and secondary restraint to rotation.<sup>2</sup> PCL-deficient knees develop abnormal kinematics and increased contact pressures within the medial and patellofemoral compartments, which lead to increased strain on both the chondral surfaces and posterolateral knee structures, placing them at risk for subsequent injury.<sup>3,4</sup> Surgical treatment has historically been reserved for complete symptomatic PCL injuries. Despite improving knee stability, varying degrees of laxity were often noted after these procedures, which lead to the development of more anatomic techniques<sup>5</sup> and augmentation with internal brace constructs.<sup>6</sup> Similarly, concerns exist after nonoperative treatment of PCL injuries both complete and incomplete due to persistent laxity.<sup>7,8</sup> Initially acceptable short-term outcomes<sup>8,9</sup> have given way to concern for accelerated development of osteoarthritis and declining functional subjective scores.<sup>10-13</sup>

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The decision to treat some complete and most incomplete PCL injuries nonoperatively can be attributed to the good short-term functional outcomes and the shortcomings of traditional surgical reconstructions, which often resulted in residual laxity.<sup>14,15</sup> The PCL also has been reported to have intrinsic healing ability after injury.<sup>16</sup> However, the injured ligament can heal in a lengthened position because of gravity induced posterior tibial sag during the early phases.<sup>17-19</sup> Dynamic bracing has been advocated for PCL postinjury and surgery but the efficacy in preventing tibial sag and laxity in clinical practice needs more study. There has been increased interest in using suture augmentation to protect repairs and reconstructions in a wide variety of ligament injuries.<sup>6</sup> The protective effect of suture augmentation in ACL reconstructions has been clinically demonstrated.<sup>20</sup> It is therefore natural to consider the potential for similar constructs to protect the injured posterior cruciate ligament during the healing phase to improve stability.

The purpose of this study is to evaluate the biomechanics of simulated PCL (SimPCL) injuries with and without internal brace suture tape augmentation (IBSTA) in cadaver knees. We hypothesized that IBSTA would restore stability and kinematics similar to that of the native PCL.

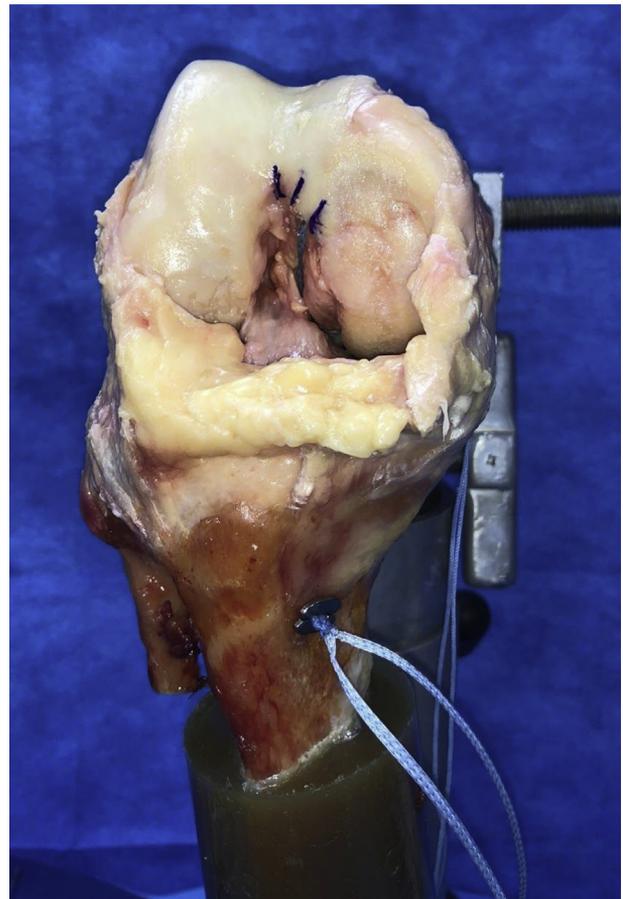
## Methods

This study contained 2 arms, with the initial arm aimed at evaluating the isometry of femoral tunnel position for suture tape augmentation of SimPCL injuries. The second arm was designed to determine whether suture tape augmentation can recreate native PCL stability kinematics by limiting posterior tibial displacement and recreating a stiffness similar to a native PCL. In total, 12 cadaver knees were used for the isometry assessments and 8 cadaver knees for the mechanical cyclic displacement. For the isometry assessment, 12 cadaver knees were used, all male with an average age of  $64 \pm 18$  years. The specimens were dissected of all soft tissue, save the primary ligaments, and potted for testing.

### PCL-Augmentation Procedure

A 4-mm spade tip guide pin was used to drill a femoral tunnel at the articular margin of the medial femoral condyle adjacent to the anterolateral PCL bundle in the desired position. The exact entry point into the femur was located at either the 11-o'clock or 10-o'clock position for a left knee and the 1-o'clock to 2-o'clock position for a right knee, depending on the specific testing cycle. A shuttle suture was placed through the tunnel for later suture tape passage. A small posteromedial arthrotomy was created to visualize the PCL tibial insertion. A standard arthroscopic tibial PCL guide was then introduced through the

intercondylar notch and visualized from the posterior arthrotomy. The guide was positioned on the posterior tibia just adjacent to the medial aspect of the PCL insertion. A 3.5-mm guidewire was then advanced through the drill guide from the anteromedial border of the tibia and out through the posterior tibia. A suture shuttling device was used to place a shuttle suture through the tibia for later suture tape passage. A free Arthrex TightRope RT femoral button loaded with Arthrex SutureTape (Arthrex, Naples, FL) was shuttled through the femur using the previously placed shuttle stitch and seated on the medial aspect of the femoral condyle. The suture tape was then shuttled through the tibial tunnel exiting the anteromedial tibia. The suture was tensioned with the knee at 90° of flexion with the tibia held in a reduced position with respect to the femur by applying an anterior drawer. The suture tape limbs were tied over an ABS Cortical Button (Arthrex) at the anteromedial tibia for fixation. Fig 1 displays the gross appearance of the final construct. For the isometry arms of the study, a 50-lb capacity donut load cell (Transducer Techniques, LLC, Temecula, CA) was



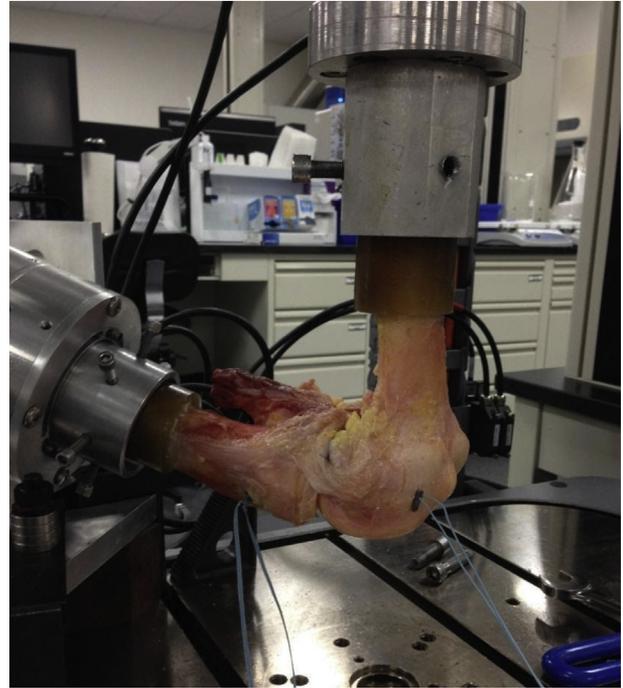
**Fig 1.** Gross appearance of final construct for internal brace suture tape augmentation of simulated posterior cruciate ligament injury in a right cadaveric knee specimen with cortical buttons on the femur and tibia for fixation.



**Fig 2.** Gross picture of a left knee showing a vertical orientation line and two hash marks drawn on the lateral aspect of the medial femoral condyle for the 2 positions used for isometry evaluation (10 o'clock and 11 o'clock in left knees).

loaded onto the suture tape and secured to the distal tibia beneath the tibial button.

The femur was clamped horizontally to the specimen tray, allowing the tibia to rest at 90° of flexion. A posterior drawer was applied, confirming an intact PCL. A knife was then used to sequentially section portions of the PCL in its midsubstance until the medial femoral condyle was flush with the medial tibial plateau with posterior drawer testing, consistent with grade II PCL laxity. Augmentation with suture tape was then performed as previously described with a 50-lb capacity donut load cell (Transducer Techniques, LLCCA) secured to the distal tibia beneath the suture button. Transducer Techniques reports 0.25% accuracy for the donut load cell. While recording load data at 100Hz with Transducer Techniques software, the knee was manually cycled from full extension to 135° of flexion. The flexion–extension regimen was repeated 3 additional times for each sample. Excluding the first flexion–extension cycle as a preconditioning load, the difference between the maximum and minimum loads of the three subsequent cycles was calculated and averaged. Six specimens were first tested using a femoral tunnel at the 2/10 position (2 o'clock for a right knee, 10 o'clock for left). Testing was then repeated



**Fig 3.** Testing setup for cyclic displacement of cadaveric specimens. The femur and tibia were potted in plasticized molds and loaded into an ElectroPuls Instron Machine with a 1-kN cell (Instron Corp, Norwood, MA). Specimen oriented such that motion of femur relative to tibia simulates a posterior drawer test.

using suture tape augmentation with the femoral tunnel at the 1/11 position (1 o'clock for a right knee, 11 o'clock for left) (Fig 2). A paired *t* test was used to compare the 2/10 and 1/11 femoral tunnel positions. Six specimens were then evaluated at the 1/11 femoral tunnel position since it's traditionally used as the location for femoral tunnel placement during PCL reconstruction<sup>21,22</sup> and load cell recordings were obtained at 10 different knee flexion angles. Starting from full extension and verified with a goniometer, the knee samples were moved in 15° increments to 135° of flexion, with load cell readings recorded at each increment. The first flexion–extension cycle was excluded as a preconditioning load. The results of each sample were averaged and a curve of suture tension per angle of flexion was developed.

### Cyclic Displacement

Eight cadaver knees were assessed, all male, with an average age of  $66 \pm 3$  years. The proximal femur and distal tibia were fixated into round epoxy molds. Mechanical testing of the specimens was performed using an ElectroPuls machine with a 1-kN cell (Instron Corp., Norwood, MA). Instron reports 0.5% accuracy of its load cells above loads of 10 N for the 1-kN load cell. Samples were oriented in the testing machine such that a compressive load could be applied in line with the

long axis of the femur. The tibia was fixed to the testing surface, creating a  $100^\circ$  angle of knee joint flexion, producing a system where the motion of the femur relative to the tibial plateau is equivalent to a posterior drawer test (Fig 3), similar to what has been described previously.<sup>23,24</sup>

To precondition each sample, a compressive preload of 50 N was applied and then released back to zero load, at which point the digital position control was balanced to zero; this was followed by a compressive displacement of 2.5 mm and 50 position control cycles between 0 and 2.5 mm at 1 Hz. Following preconditioning, each sample was subjected to 100 load control cycles between 10 and 250 N of compressive loading at 1 Hz. Load and displacement data were recorded at 1,000 Hz using Instron software. Total cyclic displacement (creep) was measured between the first 130 N load and final 130 N load that occurred during cycling. The total translational motion experienced between the femur and tibia during the first 250 N load was determined from the load-displacement curve, and the stiffness of that motion was measured as the slope of the first cycle load-displacement curve between 100 and 200 N. The translation and stiffness were also measured at the 100th cycle. Testing was repeated under 3 conditions for each specimen; intact PCL (intact), SimPCL injury, and PCL suture tape augmentation of simulated injury (SimPCL/IBSTA) using the 1/11 femoral tunnel position. The 1/11 o'clock position was used for biomechanical testing, since it is traditionally used as the location for femoral tunnel placement during PCL reconstruction.<sup>21,22</sup> One-way repeated-measures analyses of variance (ANOVAs) were performed using SigmaPlot software (Systat Software, Inc., version 14, San Jose, CA) with an  $\alpha = 0.05$  to compare the displacement, translation, and stiffness of the intact, resected, and repaired sample groups. A post-hoc

**Table 1.** Results of the Isometry Assessment of for the Vertical or 1/11 Position (1 o'clock for a Right Knee, 11 o'clock for Left), Which Showed a Mean First Peak Load of  $7.1 \pm 4.0$  ft\*lb Whereas the Horizontal or 2/10 Position (2 o'clock for a Right Knee, 10 o'clock for Left) Showed a Mean First Peak Load of  $7.6 \pm 4.2$  ft\*lb.

Sample	First Peak Load (lbf)	
	1/11 Position	2/10 Position
1	13.9	14.8
2	6.5	5.5
3	2.2	4.0
4	9.1	9.4
5	5.6	8.1
6	5.3	3.8
Average	7.1	7.6
Standard deviation	4.0	4.2

NOTE.  $P = .467$ .

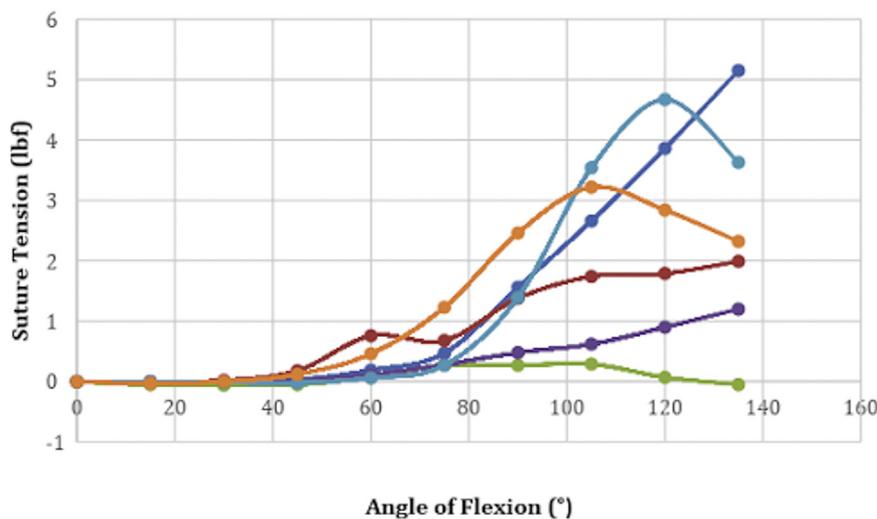
analysis of the data demonstrated that three of the 4 repeated-measures ANOVAs on cyclic displacement and stiffness had a power greater than 0.8, indicating that the sample size tested was sufficient to detect differences.

## Results

### Isometry Assessment

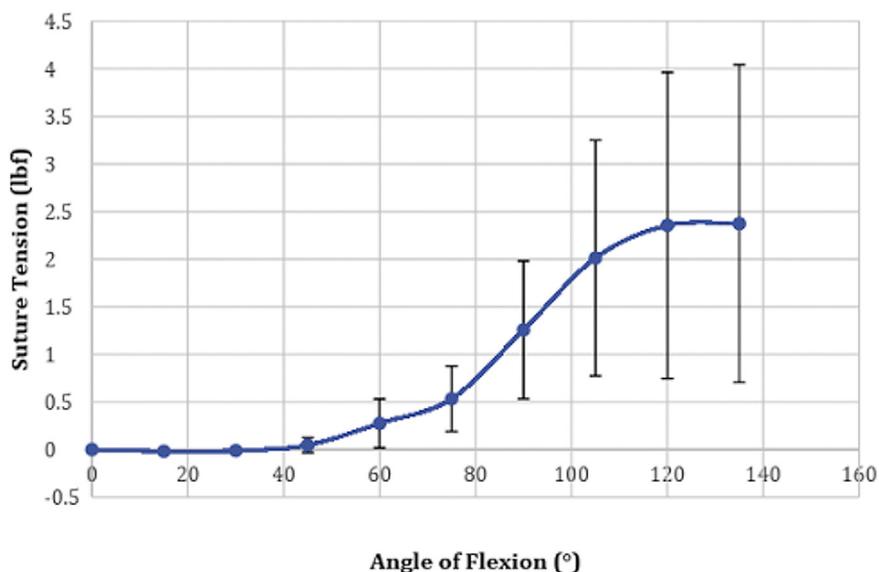
Isometry curves for the 1/11 position (1 o'clock for a right knee, 11 o'clock for left) showed a mean first peak load of  $7.1 \pm 4.0$  ft\*lb whereas the 2/10 position (2 o'clock for a right knee, 10 o'clock for left) showed a mean first peak load of  $7.6 \pm 4.2$  ft\*lb. There was no difference in peak load when comparing the 2 femoral tunnel positions ( $P = .467$ ). The data are displayed in Table 1.

Results of the suture tension versus flexion angle testing were normalized to begin with zero load at  $0^\circ$  flexion, and the results for each sample are shown in



**Fig 4.** Graph showing the suture tension as determined from the load cell placed beneath the tibial button throughout the range of motion for a suture tape –augmented posterior cruciate ligament injury.

**Fig 5.** Combined and averaged results of suture tension as determined from load cell placed beneath tibial button throughout range of motion for suture tape augmented posterior cruciate ligament injury. Bars represent standard deviation.



**Fig 4.** Three of the samples reached a maximum tension at or before 120° of flexion, whereas the other 3 samples continued to increase with increased flexion. The combined results are shown in Fig 5.

**Cyclic Displacement**

Cycle 1 mean displacement for the Intact PCL was  $4.69 \pm 1.22$  mm. Cycle 1 mean displacement for SimPCL was  $8.58 \pm 2.51$  mm. Cycle 1 mean displacement for SimPCL/IBSTA was  $5.63 \pm 1.55$  mm. Cycle 1 mean stiffness for the intact PCL was  $62.3 \pm 12.4$  N/mm. Cycle 1 mean stiffness for SimPCL was  $37.0 \pm 13.7$  N/mm. Cycle 1 mean stiffness for SimPCL/IBSTA was  $52.9 \pm 22.1$  N/mm (Table 2).

Cycle 100 mean displacement for the intact PCL was  $4.41 \pm 0.92$  mm. Cycle 100 mean displacement for SimPCL was  $7.19 \pm 1.83$  mm. Cycle 100 mean displacement for SimPCL/IBSTA was  $5.59 \pm 1.49$  mm. Cycle 100 mean stiffness for the intact PCL was

$59.5 \pm 17.1$  N/mm. Cycle 100 mean stiffness for SimPCL was  $42.9 \pm 6.2$  N/mm. Cycle 100 mean stiffness for SimPCL/IBSTA was  $54.8 \pm 18.8$  N/mm (Table 3). One-way repeated-measures ANOVA results for displacement and stiffness are demonstrated in Table 4.

**Discussion**

In this study, we found that there was no difference in the isometry of the 1/11 o'clock versus the 2/10 o'clock position for femoral tunnel placement for IBSTA in a simulated PCL injury model. Isometric testing revealed that as the knee goes from extension to flexion, the tension on the internal brace increases, with some variability in the absolute numbers at greater flexion angles between specimens. The change in tension is relatively small (<2 lbs), but based on these findings, we feel that the internal brace should be tensioned at 100° of knee flexion to avoid potential loss of full flexion. We

**Table 2.** Cyclic Displacement and Stiffness for the First Cycle of Intact, Simulated PCL Injury, and Simulated PCL Injury With Suture Tape—Augmented Cadaveric Knees

Sample	Cycle 1 Tibial Displacement, mm			Cycle 1 Stiffness, N/mm		
	Intact	PCL Injury	Augmented	Intact	PCL Injury	Augmented
1	7.37	11.02	6.86	35.6	12.1	38.6
2	4.99	9.22	6.75	57.0	30.3	36.6
3	4.09	5.64	4.15	67.5	48.1	65.3
4	5.07	7.20	5.82	62.3	47.5	55.1
5	4.48	13.01	2.49	74.2	32.9	102.0
6	3.97	8.24	6.92	62.9	36.8	38.6
7	4.20	8.41	6.06	64.1	31.8	43.1
8	3.31	5.87	5.95	75.0	56.1	43.8
Average	4.69	8.58	5.63	62.3	37.0	52.9
Standard deviation	1.22	2.51	1.55	12.4	13.7	22.1

PCL, posterior cruciate ligament.

**Table 3.** Cyclic Displacement and Stiffness for the Final (100th) Cycle of Intact, Simulated PCL Injury, and Simulated PCL Injury With Suture Tape Augmented Cadaveric Knees

Sample	Cycle 100 Tibia Displacement, mm			Cycle 100 Stiffness, N/mm		
	Intact	PCL Injury	Augmented	Intact	PCL Injury	Augmented
1	6.15	7.05	5.80	44.4	43.0	47.7
2	4.95	6.23	6.81	57.7	45.4	52.5
3	3.26	6.36	4.51	84.4	46.0	60.4
4	4.83	5.47	6.19	64.6	46.5	42.6
5	4.16	8.04	2.65	67.1	39.6	97.5
6	4.11	10.94	6.96	29.6	32.0	43.3
7	4.37	8.04	4.92	54.6	38.2	55.9
8	3.45	5.35	6.86	73.5	52.1	38.1
Average	4.41	7.19	5.59	59.5	42.9	54.8
Standard deviation	0.92	1.83	1.49	17.1	6.2	18.8

PCL, posterior cruciate ligament.

found that suture augmentation of simulated PCL injuries resulted in stiffness and tibial displacement similar to an intact PCL before and after cyclic testing.

The current gold standard for surgical treatment of PCL injuries is reconstruction, with multiple techniques described in the literature.<sup>25-27</sup> Historically, PCL injuries were repaired using an open approach and with mixed results.<sup>28-30</sup> More recently, the idea of PCL repair has been revisited, using arthroscopic techniques,<sup>31,32</sup> with promising results.<sup>33</sup> However, there is concern post-operatively that gravity pulling posterior on the tibia can compromise the repair resulting in persistent laxity.<sup>34</sup> To address this issue, Van der List and DiFelice<sup>35</sup> described a technique for PCL repair in patients with proximal avulsions using suture anchors and suture augmentation to protect the PCL, allowing it to heal without excess stress on the native ligament.<sup>35</sup> Hopper et al.<sup>36</sup> also described a technique using IBSTA and repair for grade III PCL tears. Trasolini et al.<sup>37</sup> described their use of internal brace suture augmentation for partial PCL injuries in the multiple ligament injured knee. However, further clinical studies are necessary to determine the outcomes of these techniques.

While improved and minimally invasive arthroscopic techniques now exist for PCL repair,<sup>31,32</sup> there is currently limited clinical or biomechanical evidence to support these techniques. Current indications for surgical repair include avulsion injuries. Although clinical outcome studies are needed, internal brace augmentation and protection may improve outcomes by reducing postoperative laxity. PCL injuries with grade II laxity on posterior drawer are typically treated nonoperatively due to good short-term functional outcomes<sup>7-9</sup> and failure of more invasive reconstructions to completely eliminate posterior laxity.<sup>7,8</sup> The PCL has intrinsic healing potential, but due to gravity's posterior pull on the tibia, the PCL typically heals in an elongated fashion, resulting in persistent laxity.<sup>34</sup> Natural history studies have demonstrated that persistent laxity can lead to the development of pain and osteoarthritis of the knee.<sup>3,4,38</sup> If a minimally invasive technique can be performed that holds the tibia in a reduced position, protecting the ligament and allowing it to heal at the correct length, there is potential to improve long term outcomes. This is obviously speculation, and clinical studies for arthroscopic augmentation of PCL injuries are needed.

In this controlled laboratory study with cadaver knees, we have laid the foundation for understanding the

**Table 4.** One-Way Repeated ANOVA Values for Comparison of Intact PCL, Simulated PCL injury (Injury), and Simulated PCL Injury with Suture Tape Augmentation (Augmented) of Both Displacement and Stiffness at First Cycle and Final (100th) Cycle

	One-Way Repeated Measures ANOVA					
	Cycle 1 Displacement			Cycle 100 Displacement		
	Intact	Injury		Intact	Injury	
Resected	$P = .002$	X	Resected	$P = .006$	X	
Augmented	$P = .899$	$p = 0.013$	Augmented	$P = .391$	$P = .140$	
	Cycle 1 Stiffness			Cycle 100 Stiffness		
Resected	Intact	Injury	No differences found between groups ( $P = .071$ )			
	$P = .005$	X				
Augmented	$P = .511$	$p = 0.086$				

ANOVA, analysis of variance; PCL, posterior cruciate ligament.

biomechanics of PCL injury internal brace augmentation with suture tape. Future clinical studies are needed to determine whether protecting PCL repairs with IBSTA will allow the PCL to heal in a less-attenuated position, reducing residual PCL laxity and improving long-term outcomes. A clinical study to evaluate this is currently underway at our institution.

### Limitations

We acknowledge some limitations to this study. To perform biomechanical testing, the knees were stripped of the majority of their soft tissue envelope. Although the ligaments were preserved, the eliminated soft tissues may provide some secondary restraints to tibial displacement. A posterior drawer test was used to standardize the amount of PCL laxity generated for testing. This test is somewhat subjective and the degree of translation can vary among clinicians.<sup>39</sup> Following the generation of simulated PCL injury, the laxity that was perceived on posterior drawer testing was greater than measured with our biomechanical testing, potentially from a lack of tibial rotation standardization in this cadaver model.<sup>23,39</sup> This resulted in a lower-than-expected difference in tibia translation when comparing the intact and simulated injury specimens and a higher than desired standard deviation with the data. Looking at the isometry data we found relatively high standard deviation at high flexion angle, most likely the result of expected anatomic variations in a cadaver model. Although the described technique can be performed arthroscopically in a clinical situation, to provide more consistent and reproducible data and to accommodate the testing apparatus, the study was done in an open fashion. In addition, specimens used in this study were older than the average age of a patient treated for a PCL injury.

### Conclusions

In this cadaver study, there was a 1.18-mm average difference in posterior tibial displacement when comparing intact and SimPCL/IBSTA. The internal brace construct should be tensioned and fixed at approximately 100° of knee flexion to prevent loss of full flexion.

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