

Is the Lind or LaPrade Technique Able to Control Anterior and Rotational Laxity in Medial-Side Knee Injuries?

A Controlled Laboratory Study of 18 Knees

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Background: Reconstruction of the medial collateral ligament (MCL) and posterior oblique ligament (POL) is necessary to restore stability in chronic lesions on the medial side of the knee. The Lind technique uses a single-strand, pedicled semitendinosus tendon autograft to perform continuous reconstruction of the MCL and POL. The LaPrade technique uses 2 free grafts: 1 graft for the MCL (double-strand semitendinosus tendon graft) and 1 graft for the POL (double-strand gracilis tendon graft).

Purpose: To investigate the LaPrade and Lind techniques in restraining tibial translation and rotation induced by MCL + POL transection, simulating a grade 3 medial-side injury.

Study Design: Controlled laboratory study.

Methods: A total of 18 fresh-frozen cadaveric lower limbs (mean age, 75 years [range, 62-94 years]; 14 men and 4 women), disarticulated at the hip, were examined. The MCL and POL of each knee were isolated. Each knee was subjected, at 30° of flexion, to anterior force up to 200 N and torque (internal and external tibial rotation) up to 5 N·m and measured with a laximeter (repeatability of motion within ± 0.1 mm and $\pm 0.1^\circ$) in the following states: intact knee, MCL Transection, MCL + POL transection, and finally MCL + POL reconstruction with either the Lind (9 knees) or LaPrade (9 knees) technique. The results were registered as laxity curves (in millimeters and degrees) after each state and then calculated as laxity increases (in millimeters and degrees) from the intact state. Residual laxity after reconstruction was presented as absolute values (Laxity Reconstructed – Laxity Intact [in millimeters or degrees]) and as relative values (Laxity Reconstructed – Laxity Intact / Laxity Transected – Laxity Intact $\times 100$ [in percentages]). The Shapiro-Wilk test of normality, analysis of variance with the post hoc Bonferroni correction for multiple comparisons, and the Student *t* test were used.

Results: In anterior tibial translation (ATT), the knees reconstructed with the Lind technique had a residual laxity of 0.70 ± 0.82 mm ($66.7\% \pm 36.8\%$) compared with 1.21 ± 1.12 mm ($78.1\% \pm 33.8\%$) using the LaPrade technique ($P < .05$). In internal rotation, the knees reconstructed with the Lind technique had a residual laxity of $0.92^\circ \pm 0.79^\circ$ ($32.5\% \pm 34.7\%$) compared with $0.98^\circ \pm 0.60^\circ$ ($35.9\% \pm 27.4\%$) using the LaPrade technique. In external rotation, the knees reconstructed with the Lind technique had a residual laxity of $0.48^\circ \pm 0.60^\circ$ ($17.8\% \pm 20.5\%$) compared with $1.21^\circ \pm 1.41^\circ$ ($30.3\% \pm 29.9\%$) using the LaPrade technique ($P < .05$).

Conclusion: MCL and POL reconstruction with either the Lind or LaPrade technique improved sagittal and rotatory stability compared with injured knees. The Lind technique had significantly less laxity in external rotation ($P < .001$) and ATT ($P = .012$) than the LaPrade technique. However, residual laxity in ATT and external rotation was low and may not be clinically significant. There was no significant difference in internal rotation ($P = > .05$). This is the first biomechanical study, to our knowledge, comparing these 2 “classic” techniques.

Clinical Relevance: The Lind and LaPrade techniques did not restore native stability in translation and rotation. We believe that technical improvements or new techniques are essential for better knee control.

Keywords: knee; ligaments; multiple ligament injuries; biomechanics of ligaments; MCL

Combined anterior cruciate ligament (ACL) and medial collateral ligament (MCL) injuries of the knee occur frequently.^{30,32} Willinger et al³² reported that 67% of presumed isolated ACL injuries were accompanied by an injury to the medial side (MCL, posteromedial complex [PMC], and medial meniscus) of the knee. Most medial ligament lesions are grade 1 and progress favorably because of their high self-healing potential. Some high-grade acute MCL injuries (grade 3) do need a primary surgical intervention. Nonsurgical treatment of a concomitant superficial and deep MCL (sMCL and dMCL, respectively) injury without complete healing increases the risk of ACL graft failure and chronic external rotation instability, especially in the sports-active population.^{1,27,31} In a comparison of loading on the ACL when the MCL is intact, the ACL load increased by 127% after a complete MCL injury.³

Slocum and Larson²⁹ identified the importance of a combined ACL and MCL injury and related it to the existence of abnormal anterior rotatory displacement of the medial tibial plateau, causing “anteromedial rotatory instability” (AMRI). They described the anteromedial drawer test, performed with the knee at 90° of flexion and the foot held in 15° of external rotation (Slocum test). The past lack of attention to rotatory laxity is reflected in the multitude of surgical reconstruction techniques that have been proposed to control mostly valgus stability (sMCL), disregarding the dMCL.^{9,15,30} Stannard³⁰ reported that repair of MCL tears had a failure rate of 20%, whereas reconstruction had a failure rate of only 4%.

The functions of each of these structures have been described extensively over time and confirmed recently.^{2,12,13,21,23,26,28,29} The sMCL is the primary passive restraint to valgus and an important medial restraint to external tibial rotation. The dMCL is a major restraint to external tibial rotation, and the PMC is the main restraint to internal tibial rotation.¹² Anatomic dissections have demonstrated that the PMC is composed of the posterior oblique ligament (POL), semimembranosus tendon, posteromedial joint capsule, and posterior horn of the medial meniscus.²²

Overall, 2 techniques have been proposed to address rotatory instability on the medial side of the knee: the Lind technique in 2009¹⁷ and the LaPrade technique in 2012.¹⁶ To the best of our knowledge, no biomechanical study comparing these 2 techniques has been reported.

The objective of the present work was to investigate the differences between 2 classic techniques, the Lind and LaPrade techniques, in controlling knee joint laxity, especially tibial translation and rotation. It was hypothesized that there would be no statistically significant difference between the Lind and LaPrade techniques in controlling sagittal and rotatory laxity induced by transection of the medial plane (MCL + POL), resulting in a grade 3 medial injury.

METHODS

Specimen Preparation

A total of 18 nonpaired, fresh-frozen cadaveric lower limbs from 4 female and 14 male donors (mean age, 75 years [range, 62-94 years]) were examined in the Anatomy Laboratory of the Faculty of Medicine, University of Rennes. Written consent (donation to the university's anatomy program) from the donors for use in educational and research programs was obtained for each specimen. The lower limbs were collected by disarticulation at the hip and kept frozen at -20°C before testing. All specimens were thawed at room temperature (20°C) for 1 day before use. During testing, specimens were kept moist with water. The knees were mobilized 10 times in flexion, extension, and rotation to ensure that they were flexible and able to flex to at least 130°. The knees were stable during clinical testing in the frontal and sagittal planes. Inclusion criteria were stable and mobile knees, and exclusion criteria were signs of ligamentous injuries, bone anomalies, osteoarthritis, or scars indicating previous surgery. All the knees underwent radiography (coronal and sagittal planes) before dissection and were categorized according to the Ahlbäck classification (grades 1-4). Only knees with Ahlbäck grade ≤1 on radiography were chosen.

Overall, 2 orthopaedic surgeons, experienced in knee surgery, performed all the dissections (H.C. and H.R.). The technique has been precisely described in a previous article from our laboratory.¹³ A long medial arciform incision exposed the medial side, taking care to keep the ligaments and joint capsule intact. The skin and subcutaneous tissue were removed, leaving deep soft tissue intact. The medial aspect of the knee from the edge of the patellar

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Ethical approval was not sought for the present study.

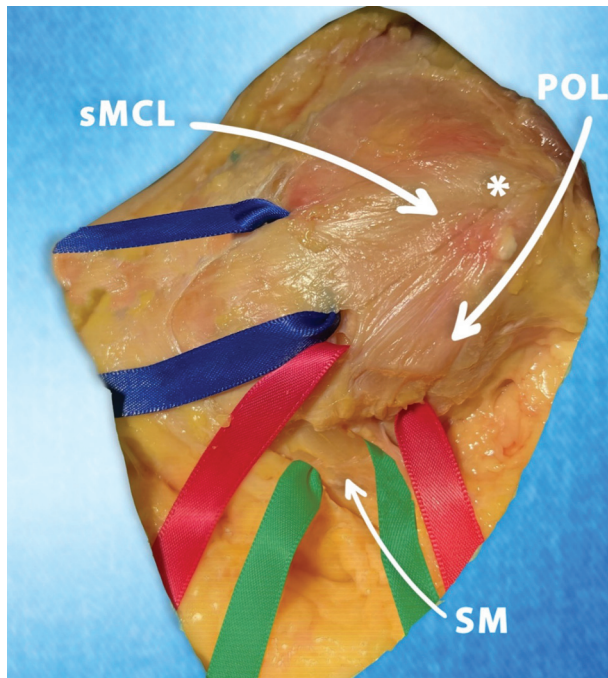


Figure 1. Medial view of a right knee at 30° of knee flexion. Identification started in the middle third (blue tape), as it represents the medial collateral ligament (MCL). The anterior margin of this structure was clearly defined by palpation of longitudinal fibers, but posteriorly, the margins were less clear. At the posterior margin of the middle section, the longitudinal fibers blended with oblique fibers from the posterior third. The posterior third (red tape) formed the posteromedial complex (PMC), and the localized thicker band in the PMC is the posterior oblique ligament (POL). The semimembranosus (SM) insertion was isolated (green tape). *Epicondyle.

tendon to the head of the medial gastrocnemius muscle was divided into 3 parts (Figure 1). The identification and separation of the 3 parts were performed above the medial joint line. Identification started in the middle third, as it represents the MCL divided into superficial (sMCL) and deep (dMCL) layers. The anterior third, named the anteromedial retinaculum, was left intact. For the posterior third, the localized thicker band in the PMC is the POL. No. 2 braided wire sutures were tied around both tested structures: sMCL + dMCL and PMC. The semimembranosus and the anterior capsule were left intact. Before reconstruction, the ligaments (sMCL, dMCL, and POL) were transected above the medial meniscus (to create a completely MCL-POL-deficient state) with No. 2 braided wire sutures, doubled up and used in the same manner as a Gigli saw.

The first reconstruction was performed in accordance with the technique described by Lind et al¹⁷ in 2009. The technique consists of reconstruction of the 2 main structures on the medial side (POL and MCL) of the knee using 1 graft and 2 tunnels. The semitendinosus tendon was harvested at the pes anserinus, and the insertion at the pes anserinus was kept intact. The tendon was sutured at

the free end using a No. 2 braided nonabsorbable suture (FiberWire; Arthrex). The medial femoral epicondyle was exposed, and the femoral MCL insertion site was identified. An isometric femoral location for placement of the tunnel close to the epicondyle was found with a double-point compass. When the proper femoral position was found, a socket was drilled according to the measured diameter of the double-looped tendon. The semitendinosus tendon was then passed under the fascia and inserted in the tunnel but not tightened. A tibial tunnel was drilled from the anterior to posterior corner of the medial tibial plateau. The drill hole was aimed to exit 10 mm below the tibial plateau, posterior and lateral to the semimembranosus insertion. The tunnel diameter was the size of the semitendinosus tendon graft, which typically was 5 to 6 mm. The free end of the semitendinosus tendon graft was passed from the femoral condyle through the posterior tibial tunnel opening. The graft was secured with a metallic bicortical screw at the anterior tibial exit (Figure 2). After transection of the MCL + POL, the loop of the semitendinosus tendon engaged in the femoral socket was fixed with a metallic bicortical screw at the lateral femoral cortex. The reconstruction construct was tightened under maximal manual traction on each strand of the tape, with the knee at 30° of flexion and neutral rotation. The reconstruction site appeared as an inverted “V” on the medial aspect of the knee.

The second reconstruction was performed in accordance with the technique described by LaPrade and Wijdicks¹⁶ in 2012. The technique consists of anatomic reconstruction of the 2 main structures on the medial side of the knee using 2 free grafts and 4 tunnels. The sMCL's distal tibial attachment site was identified deep to the sartorius tendon, and a 7-mm reamer was used to create a tunnel to a depth of 25 mm. Then, a 25 mm-deep closed socket tunnel was drilled with a 7-mm reamer at the POL's tibial attachment site, slightly anterior to the semimembranosus tendon's direct arm. The anatomic femoral and tibial attachment points of the sMCL and POL were located isometrically with the use of a compass. The sMCL's femoral attachment was slightly proximal and posterior to the medial epicondyle. The POL's femoral attachment was distal and anterior to the adductor tubercle. Once the sMCL and POL attachment sites were identified, 2 socket tunnels (depth of 25 mm, diameter of 7 mm) were reamed at the POL site and the sMCL site, maintaining a sufficient bone bridge between sites. It was critical to avoid tunnel convergence during medial knee reconstruction. The sMCL was reconstructed with the semitendinosus tendon cut to a minimum of 16 cm in length, and the POL was reconstructed with the gracilis tendon cut to a minimum of 12 cm in length. The graft was double stranded and whipstitched using No. 2 sutures (Ultrabraid; Smith & Nephew). Each lead suture of the sMCL and POL was tied at the medial tibial cortex with a metallic bicortical screw. Next, fixation of both the sMCL and POL on the lateral femoral cortex with bicortical screws was performed after transection of the MCL + POL at 30° of flexion under maximal manual traction. The order of reconstruction (Lind or LaPrade) performed was alternated each day to avoid any bias due to the order of testing.

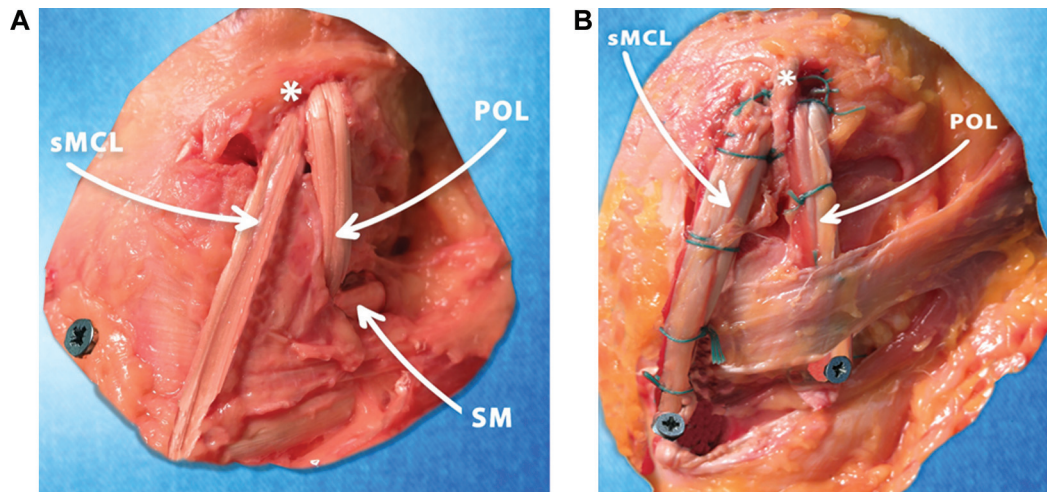


Figure 2. (A) The Lind technique on a right knee. The semitendinosus tendon (ST) was harvested at the pes anserinus, and the insertion at the pes anserinus was kept intact. The ST loop was inserted in the femoral socket but not tightened. The free end of the ST was then passed from the femoral condyle through the posterior tibial tunnel opening. The graft was secured with a metallic bicortical screw at the anterior tibial exit. After transection of the medial collateral ligament (MCL) + posterior oblique ligament (POL), the sutured loop of the ST was inserted in the femoral tunnel and fixed with a metallic bicortical screw at the lateral femoral cortex. *Epicondyle. (B) The LaPrade technique on a right knee. The superficial MCL (sMCL) was reconstructed with the ST cut to a minimum of 16 cm in length, and the POL was reconstructed with the gracilis tendon cut to a minimum of 12 cm in length. Each lead suture of the sMCL and POL was tied at the medial tibial cortex with a metallic bicortical screw. Next, fixation of both the sMCL and POL on the lateral femoral cortex with bicortical screws was performed after transection of the MCL + POL at 30° of flexion under maximal manual traction. *Epicondyle.

Laximeter Testing

We used a noninvasive and static translational and rotational knee laximeter: the Dyneelax (Genourob) (Figure 3). To our knowledge, there is no laximeter that has previously been described in the literature to measure both anterior tibial rotation (ATT) and tibial rotation with one device.^{18,25} The Dyneelax has been validated and widely used in biomechanical works and clinical practice.^{8,20} The Dyneelax allows ATT under forces up to 250 N and torques (internal rotation [IR] and external rotation [ER]) up to 8 N·m independently from translation. The lower limb was placed on a thermoformed support at 30° of knee flexion. The femoral head was secured horizontally by a transverse rod (8-mm diameter) to prevent any rotation of the femur. The foot and ankle were attached to a dual bootstrap, providing a stationary block under the tibia. The initial knee position (position zero) was defined as the “patella at the zenith,” and the foot-ankle block was in a natural resting position of the leg (usually in slight ER) controlled by the absence of constraint on the boot sensors. The initial position of the lower limb after complete stabilization was not further modified during all the testing conditions. Therefore, any change in translation or rotation was caused by surgical alteration of the joint. The induced ATT (force up to 200 N) and rotation (torque up to 5 N·m) were measured from this neutral position (femur fixed) and were recorded. All specimens were subjected first to the anterior load (200 N) and secondarily to the torque (5 N·m). The system allows for the repeatability of motion within ± 0.1 mm in translation and $\pm 0.1^\circ$ in rotation.⁸

Data Acquisition

Laxity of the knees was registered in the following 4 states: intact knee, MCL transection, MCL + POL transection, and finally MCL + POL reconstruction with either the Lind or LaPrade technique. To account for any viscoelastic effects of tissue, all measurements were recorded 5 times, and the mean data were taken as the result in each test. The results were recorded as translation laxity curves (in millimeters) and rotational laxity curves (in degrees) for IR and ER, representing absolute motion of the tibia relative to the femur. Calculations of residual laxity were based on 2 formulas:

$$\text{Residual laxity (mm)} = \text{Laxity Reconstructed} - \text{Laxity Intact}$$

$$\begin{aligned} \text{Residual laxity (\%)} &= \text{Laxity Reconstructed} \\ &\quad - \text{Laxity Intact} / \text{Laxity Transected} \\ &\quad - \text{Laxity Intact} \times 100 \end{aligned}$$

Statistical Analysis

Statistical analyses were performed using Python (Python Software Foundation) and XLSTAT (Addinsoft), a software suite for data analysis and statistics in Excel (Microsoft). The laxity data were examined for a normal distribution with the Shapiro-Wilk test. First, results were compared between each state of transection/reconstruction for both the Lind and LaPrade techniques using repeated-

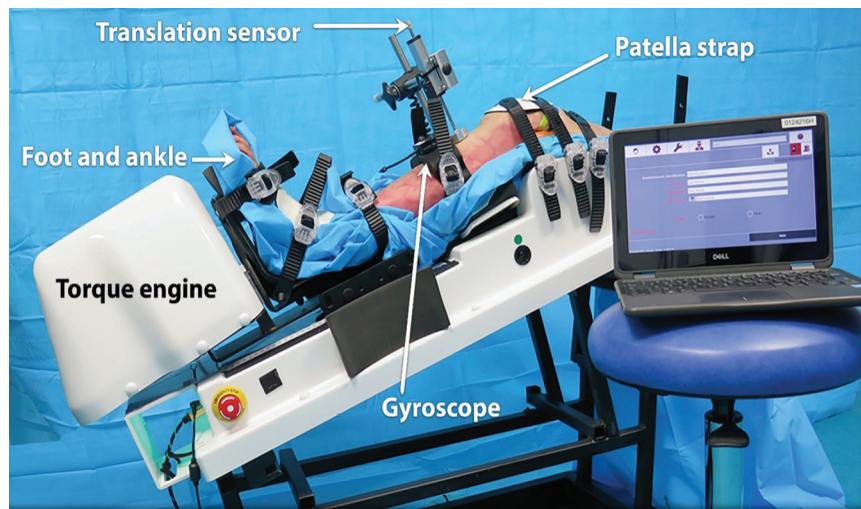


Figure 3. The Dyneelax allows anterior tibial translation (ATT) under loads up to 250 N and rotation (internal rotation [IR] and external rotation [ER]) up to 8 N·m separately. The lower limb was placed on a thermoformed support at 30° of flexion. The femoral head was secured horizontally by a transverse rod. The foot and ankle were attached to a dual bootstrap, providing a stationary block under the tibia. ATT was produced with a linear jack and axial torque (IR and ER) with a rotation engine. ATT was registered using a translation sensor and rotation (ER and IR) using a gyroscope.

measures 1-way analysis of variance with the post hoc Bonferroni correction for multiple comparisons.

Residual laxity was established after each reconstruction compared with the intact state of the knee. The Student *t* test was used to compare Lind and LaPrade reconstructions to assess which technique restored greater translational as well as internal and external rotational stability.

The sample size was calculated by power analysis using G*Power (Version 3.1.9.7; Heinrich Heine University Düsseldorf). Laxity results at 30° of knee flexion were used, as reported in recent publications on medial-side reconstruction^{3,21} to align Dyneelax positioning parameters. It was found that 8 specimens per group were enough to detect a significant change of 2° in IR and ER, and 2 mm in ATT, between the 2 techniques with 80% power and 95% confidence. A *P* value <.05 was considered statistically significant.

RESULTS

Laxity data at 200 N for ATT and at 5 N·m for IR/ER in the intact state, transection states (MCL, then MCL + POL), and reconstruction state between the Lind and LaPrade techniques are summarized in Table 1 and Figures 4 to 6.

In the Lind series, the mean increases in ATT, IR, and ER after transection of the sMCL and dMCL were 0.51 ± 0.53 mm, $1.38^\circ \pm 0.61^\circ$, and $1.75^\circ \pm 1.35^\circ$, respectively. In the same series, the mean increases in ATT, IR, and ER after transection of the MCL + POL were 1.05 ± 0.60 mm, $2.83^\circ \pm 2.37^\circ$, and $2.70^\circ \pm 0.98^\circ$, respectively. In this series, residual laxity after Lind reconstruction was 0.70 ± 0.82 mm (66.7% $\pm$ 36.8%) in ATT, $0.92^\circ \pm 0.79^\circ$

TABLE 1
Laxity Measurements^a

	Lind	LaPrade
Anterior tibial translation at 200 N, mm		
Intact	8.12 ± 1.41	8.32 ± 1.52
MCL transected	8.63 ± 1.78	9.23 ± 1.54
MCL+ POL transected	9.17 ± 1.83	9.87 ± 1.86
Reconstructed	8.82 ± 2.11	9.53 ± 1.59
Residual laxity	0.70 ± 0.82	1.21 ± 1.12
Internal rotation at 5 N·m, deg		
Intact	11.38 ± 3.83	11.04 ± 3.82
MCL transected	12.75 ± 4.22	12.58 ± 4.96
MCL + POL transected	14.21 ± 4.62	13.77 ± 5.29
Reconstructed	12.30 ± 4.07	12.02 ± 5.56
Residual laxity	0.92 ± 0.79	0.98 ± 0.60
External rotation at 5 N·m, deg		
Intact	9.76 ± 3.46	12.25 ± 3.97
MCL transected	11.51 ± 4.23	15.08 ± 4.69
MCL + POL transected	12.46 ± 4.03	16.24 ± 5.22
Reconstructed	10.24 ± 4.90	13.46 ± 5.18
Residual laxity	0.48 ± 0.60	1.21 ± 1.41

^aData are shown as mean $\pm$ SD. MCL, medial collateral ligament; POL, posterior oblique ligament.

(32.5% $\pm$ 34.7%) in IR, and $0.48^\circ \pm 0.60^\circ$ (17.8% $\pm$ 20.5%) in ER (Tables 2 and 3).

In the LaPrade series, the mean increases in ATT, IR, and ER after transection of the sMCL and dMCL were 0.91 ± 0.57 mm, $1.54^\circ \pm 0.95^\circ$, and $2.83^\circ \pm 1.06^\circ$, respectively. In the same series, the mean increases in ATT, IR, and ER after transection of the MCL + POL were 1.55 ± 0.89 mm, $2.73^\circ \pm 1.64^\circ$, and $4.00^\circ \pm 1.91^\circ$,

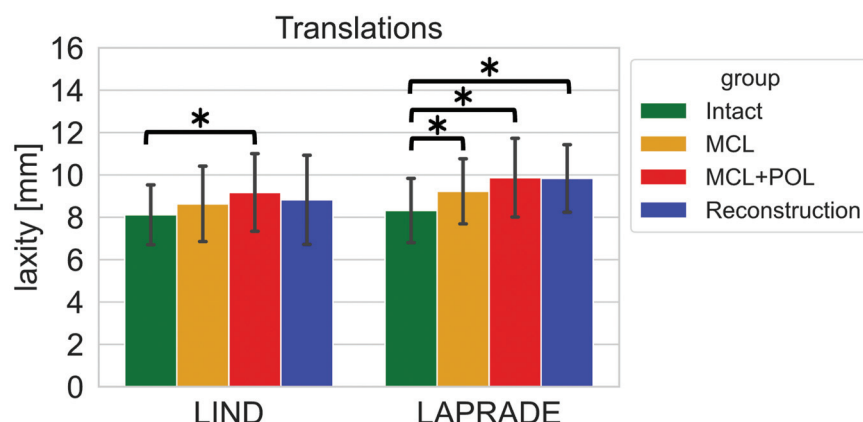


Figure 4. Data presenting laxity, expressed as mean $\pm$ SD, measured at 200 N for anterior tibial translation testing. Results are presented after each cutting state and after the Lind or LaPrade technique. Statistically significant differences compared with the previous states are indicated by an asterisk ($P < .05$).

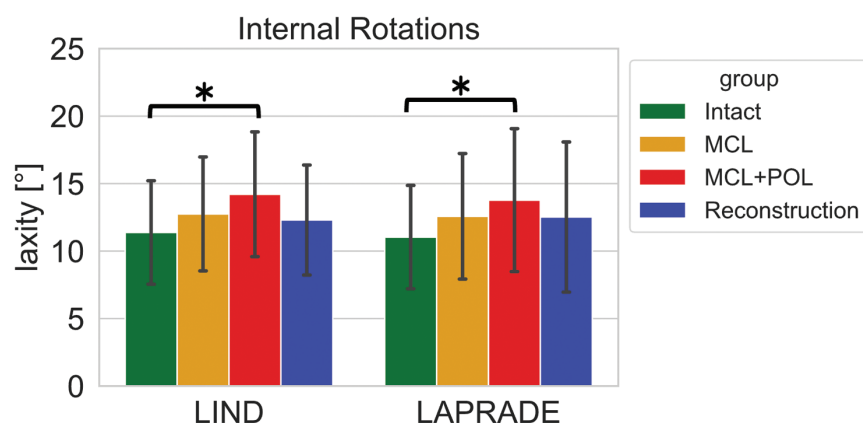


Figure 5. Data presenting laxity, expressed as mean $\pm$ SD, measured at 5 N·m for internal rotation testing. Results are presented after each cutting state and after the Lind or LaPrade technique. Statistically significant differences compared with the previous states are indicated by an asterisk ($P < .05$).

respectively. In this series, residual laxity after LaPrade reconstruction in ATT, IR, and ER was 1.21 ± 1.12 mm ($78.1\% \pm 33.8\%$), $0.98^\circ \pm 0.60^\circ$ ($35.9\% \pm 27.4\%$), and $1.21^\circ \pm 1.41^\circ$ ($30.3\% \pm 29.9\%$), respectively (Tables 2 and 3).

Residual laxity in absolute values (in millimeters and degrees) for ATT and ER was significantly less with the Lind technique versus the LaPrade technique but not in relative values (in percentages).

DISCUSSION

The main finding was that residual laxity in absolute values was significantly lower for ATT and ER with the Lind technique than with the LaPrade technique but not in relative values. Both techniques were able to reduce most of the laxity induced by a grade 3 injury on the medial side in IR and ER but to a lesser extent in ATT. In relative values, residual laxity was always lower for ATT, IR, and ER

with the Lind technique compared with the LaPrade technique but without a statistically significant difference (Table 3). In the current study, there was some residual laxity in ATT, ER, and IR with both the Lind and LaPrade techniques. At time zero, no reconstruction technique completely restored the knee's native stability, although the Lind technique performed better. These results confirmed the study's hypothesis. Residual laxity was $<1.5^\circ$ and <1.5 mm, which is probably not detectable by a clinical examination, hence the importance of using a laximeter for measurements. Testing was performed with a force of 200 N and torque of 5 N·m, significantly lower than the stresses that knees undergo during sports activities. It is possible that under much higher stress conditions, such as in soccer, football, skiing, or rugby, residual laxity will increase and could likely be perceived by the athlete as sagittal or rotatory instability.

Several authors have compared different reconstruction techniques, with results similar to ours.^{21,24,33} In fact, 3

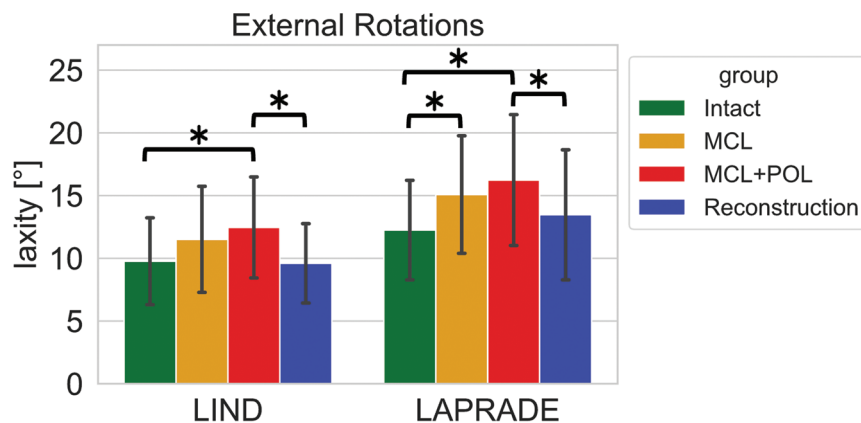


Figure 6. Data presenting laxity, expressed as mean $\pm$ SD, measured at 5 N·m for external rotation testing. Results are presented after each cutting state and after the Lind or LaPrade technique. Statistically significant differences compared with the previous states are indicated by an asterisk ($P < .05$).

TABLE 2
Absolute Residual Laxity After Reconstruction^a

	Lind	LaPrade	Difference	P
Anterior tibial translation at 200 N, mm	0.70 $\pm$ 0.82	1.21 $\pm$ 1.12	0.51	.012 ^b
Internal rotation at 5 N·m, deg	0.92 $\pm$ 0.79	0.98 $\pm$ 0.60	0.06	>.05
External rotation at 5 N·m, deg	0.48 $\pm$ 0.60	1.21 $\pm$ 1.41	0.73	<.001 ^b

^aData are shown as mean $\pm$ SD.

^bStatistical significance ($P < .05$).

TABLE 3
Relative Residual Laxity After Reconstruction^a

	Lind	LaPrade	Difference	P
Anterior tibial translation at 200 N, %	66.7 $\pm$ 36.8	78.1 $\pm$ 33.8	11.4	>.05
Internal rotation at 5 N·m, %	32.5 $\pm$ 34.7	35.9 $\pm$ 27.4	3.4	>.05
External rotation at 5 N·m, %	17.8 $\pm$ 20.5	30.3 $\pm$ 29.9	12.5	>.05

^aData are shown as mean $\pm$ SD.

independent biomechanical studies showed that single-bundle reconstruction (sMCL) without specific reconstruction of the dMCL (anteromedial reconstruction) was unsuitable in restoring native anteromedial kinematics. Zhu et al³³ compared double-bundle reconstruction (LaPrade technique) and a single-bundle triangular technique (Lind technique) using a robotic system on 10 cadaveric knees. They concluded that double-bundle MCL reconstruction (with single-bundle ACL reconstruction) and modified triangular MCL reconstruction (with single-bundle ACL reconstruction) does not restore knee kinematics.³³ Miyaji et al²¹ examined double-strand suture tapes used as grafts to mimic anatomic reconstruction of the sMCL and POL after transection of the sMCL and POL (grade 3 medial-side injury). An optical tracking system measured motion (ATT, IR, and ER) of the tibia

relative to the femur. At 30° of flexion, the double-strand tapes partly restored stability of the native knee.²¹ Richter et al²⁴ compared the LaPrade technique and the MARCI (MCL anatomic reconstruction with capsular imbrication) technique. There was no difference between the MARCI and LaPrade techniques for IR. For ER and for flexion $\leq 30^\circ$, knees using the MARCI technique more closely resembled the intact cadaveric knee.²⁴

The 2 techniques tested in the present work involving 2 graft strands to mimic the sMCL and the POL did not restore initial stability of the native knee at 30° of flexion. These techniques underestimated the importance of the dMCL as a primary restraint to tibial ER.^{2,13}

Preservation or reconstruction of the dMCL makes it possible to reproduce knee kinematics, particularly in ER, as shown by the following 2 studies. Coobs et al⁹

examined knee stability with buckle transducers after transection of the sMCL (not the dMCL) and POL as well as after LaPrade reconstruction. With the LaPrade technique, a proximal tibial attachment point was re-created by suturing the sMCL graft to the anterior arm of the semimembranosus muscle. Each knee was tested with 5-N·m ER and IR torque and with 88-N ATT. The anatomic, medial reconstructed knee restored near-normal stability to the 10 knees while avoiding overconstraint of the ligament grafts. These results may be explained by consideration for the dMCL, an important stabilizer of the knee.⁹ Miyaji et al²¹ proposed a novel 2-strand anteromedial reconstruction technique with semitendinosus tendon autografts. In 12 cadaveric knees, the sMCL, dMCL, and PMC were transected to induce a grade 3 injury. Joint motion was measured using optical trackers. By reproducing both the sMCL and the dMCL, anteromedial reconstruction was able to restore native laxity in ATT, ER, and combined ATT + ER loading, which simulated AMRI.²¹

New MCL reconstruction techniques are being proposed to better restore the dMCL, in addition to sMCL reconstruction. Some surgeons have proposed reinforced reconstruction of the sMCL and dMCL in the form of a “short isometric construct” for AMRI.^{6,7,11,19,27} The protocol is to repair the native MCL structures and to protect them while healing with a short isometric ligament, not necessarily anatomic. This short, slightly oblique graft (autograft or synthetic graft) is stiff and resists valgus at 30° of flexion and ER.

One other reason for residual laxity after these 2 classic reconstruction techniques (Lind and LaPrade) may be that a round-bundle graft (cord-like) may not reproduce the flat appearance and complex behavior of the broad sMCL. Behrendt et al⁵ demonstrated that a more anatomic, flat sMCL was more effective in controlling valgus and ER laxity but was unable to fully restore stability after AMRI. In a similar article, the addition of an anteromedial bundle that simulated the dMCL to the flat sMCL was able to restore intact knee kinematics.⁶ Their results were better than those obtained with an anatomic sMCL plus an anteromedial cord-like bundle by Beel et al.⁴ Further investigations need to be performed to define the ideal proximal tibial fixation for anteromedial reconstruction while avoiding overconstraint.

The 2 techniques examined are aimed at complex laxity involving the entire medial plane (MCL and POL) and that go beyond AMRI.¹⁴ POL damage combined with MCL damage is found in 4.7%, in association with ACL damage.¹⁰ On the other hand, damage to the POL is mainly found in posterior cruciate ligament ruptures as part of posteromedial rotatory instability.³⁰ A clinical examination is essential to differentiate between these different types of combined rotatory laxity and to guide the patient toward a targeted and individualized reconstruction technique.

The highlight of the study was the number of knees, exceeding the power analysis threshold (16 cases). The ACL was left intact; thus, this work only examined reconstruction of the MCL and POL, excluding variability among ACL reconstruction cases. Additional transection and reconstruction of the ACL might be closer to clinical

situations, but the interpretation of the results may be more difficult. Moreover, other recent experimental studies on MCL reconstruction have chosen not to perform ACL reconstruction.^{4,19} All measurements were performed objectively using the same Dyneelax laximeter without any mobilization after its initial setup.

Limitations

Our study has several limitations. Specimen age and reduced bone quality may have negatively affected rigid fixation of the reconstruction sites. The mean age of the donors was not very close to the age of the population targeted by the applications of this study. The ranges of translation and rotation in participants with a mean age of 22 years are higher in Mihalinec et al's²⁰ work than those recorded in our study, which is typical in cadaveric studies. In the study by Mihalinec et al,²⁰ rotational amplitudes were slightly higher in women compared with men, as also observed in our study. We chose not to transect the ACL to reduce confounding variability related to ACL reconstruction, which could make the interpretation of the results more difficult. To decrease the risk of graft slippage in porotic bone, the grafts were fixed with bicortical screws on both the femur and the tibia. For each knee, only 20 repetitive tests at 30° of flexion were performed, without modification of the position, which avoids the potential for failure of the fixation construct and slippage or stretching of the grafts. Some authors have reported the need for graft retension before proceeding with the next flexion angle for testing.²¹ We did not suture the sMCL graft up to the tibial joint line as LaPrade and Wijdicks¹⁶ recommended. The present study concerns only reconstruction of the passive medial ligamentous restraints, excluding the dynamic stability provided by surrounding muscles (semimembranosus and hamstring tendons). Sims and Jacobson²⁸ reported that the most common abnormality found during AMRI surgery was a rupture of the semimembranosus tendon attached to the posteromedial capsule. The loads applied were not as high as those encountered during sports activities but were similar to those that occur during clinical testing. Higher loads have the potential to stretch the remaining intact structures, leading to uncontrolled ligament and joint laxity. A tensiometer or other force gauge was not used to standardize the amount of initial tension on the grafts, and thus, there may be bias introduced by different initial manual tensions. The knees were tested only at 30° of flexion; the total arc of flexion (0°-90°) was impossible with the Dyneelax. The knees were not tested in valgus for the same reason.

CONCLUSION

In this in vitro cadaveric study, reconstruction with the Lind technique provided better knee stability compared with the LaPrade technique. However, the gold-standard techniques of Lind and LaPrade were unable, in our work, to restore stability in translation and rotation to intact values after transection of the medial side. These

results should be confirmed by other biomechanical studies and possibly by clinical series.

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REFERENCES

- Alm L, Krause M, Frosch KH, Akoto R. Preoperative medial knee instability is an underestimated risk factor for failure of revision ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2020;28(8):2458-2467.
- Ball S, Stephen JM, El-Daou H, Williams A, Amis AA. The medial ligaments and the ACL restrain anteromedial laxity of the knee. *Knee Surg Sports Traumatol Arthrosc.* 2020;28(12):3700-3708.
- Beel W, Doughty C, Vivacqua T, Getgood A, Willing R. Load sharing of the deep and superficial medial collateral ligaments: the effect of a partial superficial medial collateral injury and implication on ACL load. *Am J Sports Med.* 2024;52(8):1960-1969.
- Beel W, Vivacqua T, Willing R, Getgood A. Double-bundle medial collateral ligament reconstruction improves anteromedial rotatory instability. *Am J Sports Med.* 2024;52(8):1970-1978.
- Behrendt P, Herbst E, Robinson JR, et al. The control of anteromedial rotatory instability is improved with combined flat sMCL and anteromedial reconstruction. *Am J Sports Med.* 2022;50(8):2093-2101.
- Borque KA, Ball S, Sij E, et al. A "short isometric construct" reconstruction technique for the medial collateral ligament of the knee. *Arthrosc Tech.* 2023;12(2):e167-e171.
- Borque KA, Shuyand H, Dunbar NJ, et al. Single-strand "short isometric construct" medial collateral ligament reconstruction restores valgus and rotational stability while isolated deep MCL and superficial MCL reconstruction do not. *Am J Sports Med.* 2024;52(4):968-976.
- Cojean T, Batailler C, Robert H, Cheze L. Sensitivity, repeatability and reproducibility study with a leg prototype of a recently developed knee arthrometer: the Dyneelax®. *Med Nov Technol Devices.* 2023;19:100254.
- Coobs BR, Wijdicks CA, Armitage BM, Spiridonov S, Engebretsen L. An in vitro analysis of an anatomical medial knee reconstruction. *Am J Sports Med.* 2010;38(2):339-347.
- Cristiani R, van de Bunt F, Kvist J, Ståhlman A. High prevalence of meniscal ramp lesions in anterior cruciate ligament injuries. *Knee Surg Sports Traumatol Arthrosc.* 2023;31(1):316-324.
- Gilmer BB, Crall T, DeLong J, Kubo T, Mackay G, Jani SS. Biomechanical analysis of internal bracing for treatment of medial knee injuries. *Orthopedics.* 2016;39(3):e532-e537.
- Griffith CJ, Wijdicks CA, LaPrade RF, Armitage BM, Johansen S, Engebretsen L. Force measurements on the posterior oblique ligament and superficial medial collateral ligament proximal and distal divisions to applied load. *Am J Sports Med.* 2009;37(1):140-148.
- Guegan B, Drouineau M, Common H, Robert H. All the meniscologamentary structures of the medial plane play a significant role in controlling anterior tibial translation and tibial rotation of the knee: cadaveric study of 29 knees with the Dyneelax® laximeter. *J Exp Orthop.* 2024;11(3):e12038.
- Herbst E, Muhmann RJ, Raschke MJ, et al. The anterior fibers of the superficial MCL and the ACL restrain anteromedial rotatory instability. *Am J Sports Med.* 2023;51(11):2928-2935.
- Kitamura N, Ogawa M, Kondo E, Kitayama S, Tohyama H, Yasuda K. A novel medial collateral ligament reconstruction procedure using semitendinosus tendon autograft in patients with multiligamentous knee injuries: clinical outcomes. *Am J Sports Med.* 2013;41(6):1274-1281.
- LaPrade RF, Wijdicks CA. Surgical technique: development of an anatomic medial knee reconstruction. *Clin Orthop Relat Res.* 2012;470(3):806-814.
- Lind M, Jacobsen BW, Christiansen SE, et al. Anatomical reconstruction of the medial collateral ligament and posteromedial corner of the knee in patients with chronic medial collateral ligament instability. *Am J Sports Med.* 2009;37(6):1116-1122.
- Magdić M, Dahmane RG, Vauhnik R. Intra-rater reliability of the knee arthrometer GNRB® for measuring knee anterior laxity in healthy, active subjects. *J Orthop.* 2023;39(39):7-10.
- Mehl JT, Kia CM, Murphy M, Imhoff FB, Imhoff AB. Posteromedial ligament repair of the knee with suture tape augmentation: a biomechanical study. *Am J Sports Med.* 2019;47(12):2952-2959.
- Mihalinec K, Martinez-Cepa CB, Juan C, Zuñi-Escobar JC, Nataša Kežar N, Vauhnik R. Intra-rater and inter-rater reliability of robotic arthrometer Dyneelax®. *J Exp Orthop.* 2024;11(3):e70026.
- Miyaji N, Holthof SR, Bastos RPS, et al. A triple-strand anatomic medial collateral ligament reconstruction restores knee stability more completely than a double-strand reconstruction: a biomechanical study in vitro. *Am J Sports Med.* 2022;50(7):1832-1842.
- Müller W. *The Knee: Form, Function, and Ligament Reconstruction.* Springer; 2012.
- Peltier A, Lording T, Maubisson L, Ballis R, Neyret P, Lustig S. The role of the meniscotibial ligament in posteromedial rotational knee stability. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(10):2967-2973.
- Richter DL, McIver ND, Sapradi T, et al. A biomechanical comparison of the LaPrade technique versus a novel technique for reconstruction of medial-sided knee injuries. *Am J Sports Med.* 2022;50(8):2083-2092.
- Robert H, Nouveau S, Gageot S, Gagnière B. A new knee arthrometer, the GNRB: experience in ACL complete and partial tears. *Orthop Traumatol Surg Res.* 2009;95(3):171-176.
- Ruiz N, Filippi GJ, Gagnière B, Bowen M, Robert H. The comparative role of the anterior cruciate ligament and anterolateral structures in controlling passive internal rotation of the knee: a biomechanical study. *Arthroscopy.* 2006;32(6):1053-1062.
- Shatrov J, Bartolin PB, Holthof SR, Ball S, Williams A, Amis A. Comparative biomechanical study of alternative medial collateral ligament reconstruction techniques. *Am J Sports Med.* 2024;52(6):1505-1513.
- Sims WF, Jacobson KE. The posteromedial corner of the knee: medial sided injury patterns revisited. *Am J Sports Med.* 2004;32(2):337-345.
- Slocum DB, Larson RL. Rotatory instability of the knee: its pathogenesis and a clinical test to demonstrate its presence. *J Bone Joint Surg Am.* 1968;50:211-225.
- Stannard JP. Medial and posteromedial instability of the knee: evaluation, treatment and results. *Sports Med Arthrosc Rev.* 2010;18(4):263-268.
- Svantesson E, Senorski EH, Alentorn-Geli E, et al. Increased risk of ACL revision with non-surgical treatment of a concomitant medial collateral ligament injury: a study on 19457 patients from the Swedish National Knee Ligament Registry. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(8):2450-2459.
- Willing R, Balendra G, Pai V, et al. High incidence of superficial and deep medial collateral ligament injuries in 'isolated' anterior cruciate ligament ruptures: a long-overlooked injury. *Knee Surg Sports Traumatol Arthrosc.* 2022;30(1):167-175.
- Zhu W, Zhu J, Marshall B, Linde MA, Smolinski P, Fu FH. Single-bundle MCL reconstruction with anatomic single-bundle ACL reconstruction does not restore knee kinematics. *Knee Surg Sports Traumatol Arthrosc.* 2020;28(8):2687-2696.