# Biomechanical Analysis of Internal Bracing for Treatment of Medial Knee Injuries

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## abstract

The internal brace technique uses a high-strength suture tie to augment injured tissues or a primary repair, allowing early rehabilitation. Anatomic repair with internal bracing is a novel and promising treatment for femoral-sided medial knee avulsion injuries of the medial collateral ligament and posterior oblique ligament. Unfortunately, biomechanical and clinical data are lacking. To evaluate this technique compared with other treatment options, 3 assays of 9 cadaveric matched pairs (54 knees) were tested to failure at 30° under valgus load in a biomechanical testing apparatus. The primary outcome measure was moment at failure (Nm), with secondary outcome measures of stiffness (Nm/°), valgus angulation at 10 Nm (°), and valgus angulation at failure (°). Repair with internal bracing was compared with the intact state, repair alone, and allograft reconstruction. The mean moment to failure (62.5±24.9 Nm) for internal bracing was significantly lower than that for intact specimens (107.2±39.7 Nm) ($P$=.009). Mean moment to failure and valgus angle at failure were significantly greater for internal bracing (95±31.9 Nm) than for repair (73.4±27.6 Nm) ($P$=.05). Internal bracing was similar to reconstruction for the primary outcome measure (53.5±26.3 Nm vs 66.9±28.8 Nm) ($P$=.227) and for all secondary outcome measures. These findings indicate that posteromedial knee repair with internal bracing for femoral-sided avulsions is superior to repair alone and is similar to allograft reconstruction for all parameters measured; however, this technique did not re-create biomechanical properties equivalent to the intact state. [*Orthopedics*. 2016; 39(3):e532-e537.]

**M**edial-sided ligamentous knee injuries are common, and the majority of medial-sided ligament injuries heal with nonoperative treatment.[1,2] However, severe (grade 3) or combined (multiligament) injuries may require surgical intervention to stabilize the joint.[3-7] Treatment technique and timing of surgical intervention remain controversial, and postoperative stiffness is

the most common complication.[6-8] Anatomic reconstruction of the superficial and deep portions of the medial collateral ligament (MCL) and the posterior oblique ligament (POL) using soft tissue grafts, bone sockets, and interference screw fixation has been shown to result in nearly normal knee stability without biomechanical overconstraint and may be considered the gold standard.[9] However, anatomic reconstruction autografts have associated morbidity, and allografts have risks.[10-12] Therefore, the goal of any operative technique for injuries to the posteromedial knee is to restore anatomy and stability, minimize patient morbidity and risk, and allow for immediate range of motion to prevent postoperative stiffness.

An alternative surgical technique for severe and combined medial knee injuries is posteromedial corner reconstruction using a technique combining repair[13-15] with internal bracing.[16] The purpose of this study was to compare posteromedial anatomic repair with internal bracing to the intact state, to anatomic repair alone,[13-15] and to anatomic allograft reconstruction.[9] The hypothesis for the study was that the biomechanical properties of anatomic repair with internal bracing would be superior to repair alone and similar to reconstruction and the intact state.

## MATERIALS AND METHODS

Twenty-seven matched pairs of cadaver knees were used in the study and divided into 3 assays of 9 pairs per assay. Assay 1 compared repair with internal bracing with the intact state, assay 2 compared repair alone with repair with internal bracing, and assay 3 compared anatomic repair with internal bracing with allograft reconstruction. For each specimen donor number (to ensure matched pairs) side, age, and sex were recorded.

### Specimen Preparation

Twenty-seven cadaveric fresh-frozen knee matched pairs with no evidence of previous injury or disease were identified
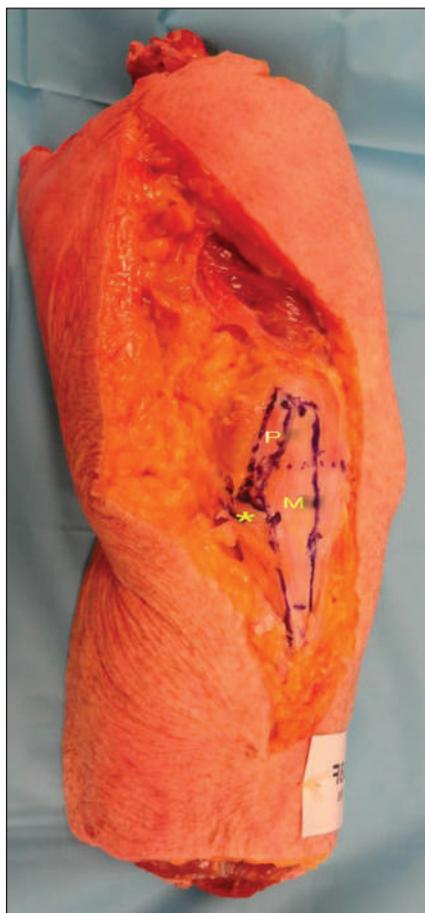


**Figure 1:** Photograph showing a left knee specimen with the medial collateral ligament (M), posterior oblique ligament (P), and semimembranosus tendinous insertion on the posteromedial proximal tibia (*) identified. The dotted blue ink line (above M) represents the medial joint line, and the horizontal dash (below M) represents the distal attachment of the superficial medial collateral ligament 6 cm distal to the joint line.

for testing. In all of the knees, superficial soft tissue was dissected, and particular care was taken to identify the entire MCL and POL, the femoral medial epicondyle and adductor tubercle, and tibial insertion of the semimembranosus (**Figure 1**).

### Testing Protocol

Specimens were mounted on an Instron 8871 Electromechanical Dynamic Testing System (Instron, Norwood, Massachusetts) with a 5-kN load cell secured to the cross-head. The specimens were positioned at 30° of knee flexion with the
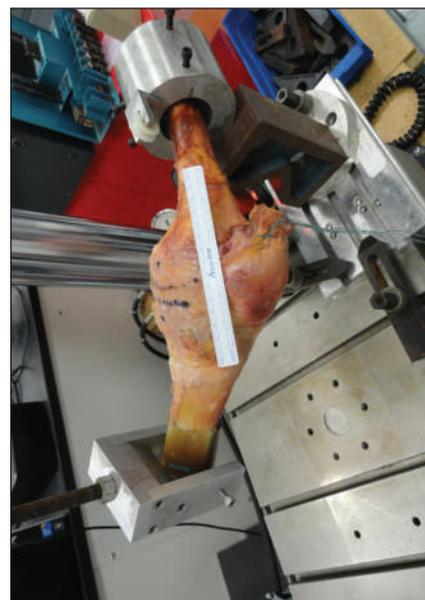


**Figure 2:** Photograph showing a left knee mounted in the testing apparatus in an anteromedial view (rotated 90° left to orient the femur above and the tibia below). The white plastic ruler delineates the patella (right) from the medial side (left), where the femoral condyle and joint line are marked horizontally in ink, and the medial collateral ligament is marked with ink above and below the femoral condyle and joint lines.

long axis of the femur positioned perpendicular to the direction of the applied valgus load to prevent internal and external rotation. The proximal end of the femur and the distal ends of the tibia and fibula were potted in fiberglass resin. A valgus preload of 5 N was applied to the potted portion of the tibia followed by loading at 20 mm/minute until failure (**Figure 2**).

The mode of failure was recorded. Failure was defined as the point at which a change in displacement no longer exhibited concomitant force increases.[17] Moment, stiffness, and valgus displacement angle at 10 Nm and at failure were recorded using Instron Systems software (WaveMaker, version 7.1). Moment is a measure of force over a given distance (Nm). Moment was used to standardize force measurements about the knee because of differences between cadaver specimens. Differences in tibia length and the bone cuts for each specimen re-

**Figure 3:** Photograph showing dissection of a left knee. In this medial view, the medial collateral ligament (right) and posterior oblique ligament (left) can be seen after scalpel release from the femur.



**Figure 4:** Photograph showing repair of the posteromedial corner of a left knee. In this medial view, the medial collateral ligament (distal blue ink) and anteromedial joint line (blue dots to right) are marked. The medial collateral ligament (upper right) and posterior oblique ligament (upper left) are anatomically repaired to the femur. Suture anchors loaded with high-strength suture at the anatomic medial collateral ligament and posterior oblique ligament femoral footprints secure the ligament. The repair is secured at 30° of knee flexion for the medial collateral ligament and at full extension for the posterior oblique ligament, with varus stress.



**Figure 5:** Photograph showing the repair of a left knee in concert with structural internal bracing of the posteromedial corner. This medial view shows anatomic repair of the medial collateral ligament(upper right) and posterior oblique ligament (upper left) to the femur with structural ties. Repair of the posteromedial corner in concert with structural ties is secured at 30° of knee flexion for the medial collateral ligament and full extension for the posterior oblique ligament, with varus stress.

sulted in loads being generated at different distances from the joint. Therefore, the moment arm (cm) was measured for every sample and was multiplied to the maximum load (N) to provide the moment (Nm) about the joint. Stiffness is a measure of the extent to which a material resists deformation in response to an applied force. Constructs with a greater stiffness demonstrate less deformity under a given force. For the purpose of this study, the force represented by moment (Nm) was divided by the change in angulation (°) to yield a measure of stiffness (Nm/°).

**Surgical Technique**

In all repair, internal brace, and reconstruction specimens, a scalpel was used to release the MCL and POL directly off the femur to simulate a femoral-sided avulsion injury (**Figure 3**). Repair was performed using 2 suture anchors (SwiveLock 4.75-mm diameter PEEK [polyether ether ketone] anchor; Arthrex Inc, Naples, Florida) loaded with high-strength suture (#2 FiberWire; Arthrex Inc) at the anatomic MCL and POL femoral footprints[18] (**Figure 4**). Each of the 2 anchors were predrilled to a depth

of 20 mm using a 4.5-mm diameter bit. A drill with stop was used to standardize the depth of drilling and depth of anchor insertion. Suture limbs from the implanted anchors then were used to secure the ligament ends of the MCL and POL to the anatomic footprints with a Krackow suture technique.

Internal bracing was performed by loading an additional high-strength suture tie (FiberTape; Arthrex Inc) into each of the anchors at the femoral MCL and POL footprints. Repair was performed as above using the #2 eyelet sutures. After repair, the suture tie from the MCL anchor was secured to the anatomic tibial insertion of the MCL. The suture tie from the POL anchor was secured to the anatomic tibial footprint of the POL. In both cases, the end of a small surgical instrument (hemo-

stat) measuring 2 mm was placed under the suture tie to prevent overtensioning during anchor implantation (**Figure 5**). This technique has been described previously in detail by Lubowitz et al.[16]

Reconstruction was performed using two bovine tendon allografts with 7-mm biocomposite interference screws (Arthrex Inc) placed after reaming and tapping 7-mm bone tunnels at the MCL and POL femoral and tibial footprint (4 tunnels with 4 screws) plus suture of the MCL graft to periosteum at the deep tibial footprint as previously described by LaPrade and Wijdicks[9] (**Figure 6**).

Tensioning for all groups was performed at 30° of knee flexion and in neutral rotation, with the knee held in varus to

**Figure 6:** Photograph showing anatomic reconstruction of the posteromedial corner in a left knee. This medial view shows the medial collateral ligament (right) and posterior oblique ligament (left) soft-tissue grafts fixed with biocomposite interference screws. Reconstruction of the posteromedial corner is secured at 30° of knee flexion for the superficial and deep medial collateral ligament, and at full extension for the posterior oblique ligament, with varus stress.

Table 1

### Results of Biomechanical Testing

| Testing Assay | Mean±SD | | P |
| --- | --- | --- | --- |
| | Experiment | Control[a] | |
| Assay 1 | | | |
| Moment, Nm | 62.5±24.9 | 107.2±39.7 | .009 |
| Stiffness, Nm/° | 3.8±1.5 | 6.1±2.1 | .003 |
| Valgus angle at 10 Nm | 4°±2° | 3°±1° | .133 |
| Valgus angle at failure | 21°±5° | 21°±3° | .949 |
| Assay 2 | | | |
| Moment, Nm | 95.0±31.9 | 73.4±27.6 | .05 |
| Stiffness, Nm/° | 4.6±1.4 | 4.4±1.1 | .636 |
| Valgus angle at 10 Nm | 3°±1° | 3°±1° | .528 |
| Valgus angle at failure | 22°±4° | 17°±6° | .014 |
| Assay 3 | | | |
| Moment, Nm | 53.5±26.3 | 66.9±28.8 | .227 |
| Stiffness, Nm/° | 3.2±1.0 | 4.4±1.5 | .099 |
| Valgus angle at 10 Nm | 5°±1° | 6°±1° | .545 |
| Valgus angle at failure | 19°±5° | 19°±6° | .958 |

[a]*For assay 1, this is intact. For assay 2, this is repair. For assay 3, this is reconstruction.*

prevent gapping of the joint medially for the MCL. For the POL, tensioning was performed in full extension and in neutral rotation, with the knee held in varus.

### Data Analysis

The primary outcome measure was moment at failure (Nm). Secondary outcome measures were valgus angulation at 10 Nm (°), which represents knee laxity with the knee at 30° flexion, valgus angulation at failure (°), and stiffness (Nm/°). Mode of failure, moment arm (mm), and maximum load (N) also were recorded. One matched pair from assay 2 (a 76-year-old man) was excluded from analysis because of premature failure of the femoral bone for both specimens presumably due to osteoporosis.

### Statistical Methods

Significance was determined as $P<.05$. Statistical analysis was performed with Systat software (SigmaPlot version 11.0; Systat Software Inc, San Jose, California). Paired *t* tests were used to compare means between the 2 techniques in each assay. A 1-way ANOVA was used to compare internal bracing groups from each assay, and pairwise multiple comparisons were performed using the Holm-Sidak method to identify differences between internal brace groups.

### RESULTS

Results are summarized in **Table 1**. For assay 1, mean moment for internal bracing (62.5±24.9 Nm) was significantly less than for the intact state (107.2±39.67 Nm) ($P=.009$). Mean stiffness for internal bracing (3.8±1.5 Nm/°) was significantly less than for the intact state (6.1±2.1 Nm/°) ($P=.003$). Mean valgus angle at 10 Nm (4°±2°) was not significantly different than for the intact state (3°±1°) ($P=.133$). Mean valgus angle at failure (21°±5°) was not significantly different than for the intact state (21°±3°) ($P=.949$).

For assay 2, mean moment for internal bracing (95±31.9 Nm) was significantly greater than for repair (73.4±27.6 Nm) ($P=.05$). Mean stiffness (4.6±1.4 Nm/°) was not significantly different than for repair (4.4±1.1 Nm/°) ($P=.636$). Mean valgus angle at 10 Nm (3°±1°) was not significantly different than for repair (3°±1°) ($P=.528$). Mean valgus angle at failure (22°±4°) was significantly greater than for repair (17°±6°) ($P=.014$).

For assay 3, mean moment for internal bracing (53.5±26.3 Nm) was not significantly different than for reconstruction (66.9±28.8 Nm) ($P=.227$). Mean stiffness (3.2±1 Nm/°) was not significantly different than for reconstruction (4.4±1.5 Nm/°) ($P=.099$). Mean valgus angle at 10 Nm (5°±1°) was not significantly different than for reconstruction (6°±1°) ($P=.545$). Mean valgus angle at failure (19°±5°) was not significantly different than for reconstruction (19°±6°) ($P=.958$).

Comparison of means for internal brace specimens from each assay revealed no significant difference for moment ($P=.064$), stiffness ($P=.107$), or valgus angle at failure ($P=.526$). A significant

| Table 2 |
| :---: |
| **Results of 1-Way ANOVA for Internal Brace Groups** |

| Parameter | P |
| :--- | :--- |
| Moment | .064 |
| Stiffness | .107 |
| Valgus angle at 10 Nm | .011[a] |
| Valgus angle at failure | .526 |

*Abbreviation: ANOVA, analysis of variance.*
*[a]Pairwise multiple comparison. Holm-Sidak method: assays 2 and 3 significantly different (P=.009).*

difference was observed for valgus angle at 10 Nm (*P*=.011). Further pairwise analysis (comparing specimens from assay 1 with assay 2, assay 2 with assay 3, and assay 1 with assay 3) revealed a significant difference between internal brace specimens in assay 2 and assay 3 (*P*=.009) (**Table 2**).

The primary mode of failure for intact specimens was a partial tear of the ligament at the femoral origin (16 of 18 specimens). The primary mode of failure for the repair specimens was tearing of the ligament (16 of 17 specimens). The primary mode of failure for the internal brace specimens was anchor pullout from the bone at the femoral origin (23 of 27 specimens). The primary mode of failure for the reconstruction specimens was graft slippage from the femoral or tibial interference screw (6 of 9 specimens).

## DISCUSSION

Treatment of medial-sided knee injuries is challenging. Although the capacity for healing of nonoperatively treated grade 1 and 2 MCL injuries has been well documented, nonoperatively treated grade 3 injuries yield poorer results.[19-23] Timing and management of higher grade MCL injuries is controversial particularly when there is injury to the anterior cruciate ligament (ACL) because the MCL may or may not heal reliably and collateral insuf-

ficiency results in higher stress to the ACL graft and risks failure. Therefore, some authors recommend initial nonoperative treatment of the MCL with delayed ACL reconstruction and MCL reconstruction only if indicated.[7,24-26] Anatomic repair with internal bracing has the potential benefit of allowing for early combined treatment of all injuries using native tissues while still providing a biomechanical environment conducive to early rehabilitation.

The current findings support the hypothesis that the biomechanical properties of anatomic repair with internal bracing are adequate for stabilizing the medial knee in this time zero cadaveric study. When comparing internal bracing with repair alone, the moment to failure was significantly greater for internal bracing and the valgus angle at failure was significantly less, suggesting the ability of the knee to resist deformity was improved even at higher loads. Internal bracing was similar to allograft reconstruction for all parameters tested, suggesting similar biomechanical properties in this testing model.

Analysis of variance analysis of internal brace specimens from each assay demonstrated significant differences between groups 2 and 3. The reason for this is unclear, but this could be related to differences in the specimens themselves or to an unintentional variation in technique.

Posteromedial knee repair with internal bracing is a novel technique with little existing literature to evaluate its biomechanical properties. Coobs et al[4] performed a similar cadaveric biomechanical study of a medial knee reconstruction technique comparing the intact state, sectioned state, and anatomic reconstruction. In their study, the values obtained for valgus angulation at 10 Nm at 30° of flexion were no different between their reconstruction and the intact state. These values were similar to values obtained in the current study for this measure in the internal brace, reconstruction, and intact states. This may validate the current test-

ing model with regard to this specific parameter.

One concern with internal bracing is that suture ties may overconstrain the medial knee. Compared with the intact state, valgus angle at 10 Nm and failure were similar, suggesting there was not overconstraint at this flexion angle because the tissues behaved similarly. Moment to failure and stiffness were significantly less for internal bracing compared with the intact state, indicating that mechanical strength and ability of the repaired tissue to resist load is not restored to the native state.

### Limitations

One limitation is that other knee flexion angles may yield different results. In this study, 30° was selected because the MCL is the primary component of the knee posteromedial corner, and the MCL is clinically tested at 30° when the cruciate ligaments are intact. Previous studies have confirmed that the POL experiences load sharing with the MCL at 30°; thus, the POL component of all studied techniques was tested indirectly in the current model.[27,28] Load-to-failure testing has the limitation that testing cannot be performed at other angles of knee flexion, and testing at other angles may reveal additional findings.

Mode of failure was predominantly at the suture-tissue interface for the repair group and predominantly at the femoral bone-implant interface for the internal brace and reconstruction groups. This may be related to bone quality in these cadaveric specimens as the femoral origin sites are located in cancellous bone of the distal femur whereas the tibial insertion is located in more distal cortical bone. Bone density and the presence of osteoarthritis may differ between sides, between matched pairs, or between assays, and this is a limitation.

An important limitation of repair with internal bracing is that moment to failure is significantly less than that in the intact state. Previous studies do not report mo-

ment to failure for soft tissue graft reconstruction, but cyclical submaximal loading demonstrated that the construct had sufficient stability to allow early preoperative rehabilitation.[29] Future study using cyclical testing at submaximal loads may yield additional information about the internal brace construct. Unfortunately, time-zero cadaveric analysis does not demonstrate clinical outcome in vivo or biomechanical qualities over time.

## Conclusion

Posteromedial knee repair with internal bracing is superior to repair alone and is similar to allograft reconstruction for all parameters measured. However, this technique did not recreate biomechanical properties equivalent to the intact state.

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