The Biomechanical Consequences of Arthroscopic Hip Capsulotomy and Repair in Positions at Risk for Dislocation

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Background: The effect of interportal (IP) capsulotomy, short T-capsulotomy, and long T-capsulotomy, and their repairs, on resistance to anterior and posterior "at risk for dislocation" positions has not been quantified.

Hypotheses: Our primary hypothesis was that an IP capsulotomy would have a minimal effect on hip resistive torque compared with both short and long T-capsulotomies in the at-risk dislocation positions. Our secondary hypothesis was that capsule repair would significantly increase hip resistive torque for all capsulotomies.

Study Design: Controlled laboratory study.

Methods: We mounted 10 cadaveric hips on a biaxial test frame in an anterior dislocation high-risk position (20° of hip extension and external rotation) and posterior dislocation high-risk position (90° of hip flexion and internal rotation). An axial force of 100 N was applied to the intact hip while the femur was internally or externally rotated at 15° per second to a torque of 5 N·m. The rotatory position at 5 N·m was recorded and set as a target for each subsequent condition. Hips were then sequentially tested with IP, short T-, and long T-capsulotomies and with corresponding repairs randomized within each condition. Peak resistive torques were compared using generalized estimating equation modeling and post hoc Bonferroni-adjusted tests.

Results: For the anterior position, the IP and long T-capsulotomies demonstrated significantly lower resistive torques compared with intact. For the posterior position, both the short and long T-capsulotomies resulted in significantly lower resistive torques compared with intact. Repairs for all 3 capsulotomy types were not significantly different from the intact condition at anterior and posterior positions.

Conclusion: An IP incision resulted in a decrease in capsular resistive torque in the anterior but not the posterior at-risk dislocation position, in which direction only T-capsulotomies led to a significant decrease. All capsulotomy repair conditions resulted in hip resistive torques that were similar to the intact hip in both dislocation positions.

Clinical Relevance: Our results suggest that it is biomechanically advantageous to repair IP, short T-, and long T-capsulotomies, particularly for at-risk anterior dislocation positions.

Keywords: capsulotomy; hip arthroscopy; hip dislocation; dislocation torque; hip biomechanics

The use of hip arthroscopic procedures continues to increase.[5] The size and geometry of the capsulotomy performed for joint access varies depending on surgical objectives and the degree of joint visualization required. The 2 most commonly used capsulotomies are the interportal (IP) capsulotomy and the T-capsulotomy, with recent studies reporting 80% of high-volume hip arthroscopy surgeons performing either of these variations.[4,11] The IP capsulotomy has a single transverse capsule incision between the anterolateral portal and midanterior portal distal to the acetabular labrum.[1] It can be expanded to a T-capsulotomy with an additional perpendicular incision from the midpoint of the IP capsulotomy extended to provide an improved view of proximal femoral head-neck junction, zona orbicularis, lateral and medial synovial folds, and lateral ascending vessels.[1,7,11] Systematic reviews of reported clinical practices and outcomes with arthroscopic procedures show that capsular management is varied; however, practice has shifted toward capsular repair.[8,18,27] One cause of variance is the type of capsulotomy: T-capsulotomies are repaired more often than IP capsulotomies.[27] Justifications for capsular repair include faster return to sports in higher level athletes, reduced risk of conversion to arthroplasty, and reduced concerns regarding hip subluxation, dislocation, or more subtle instabilities,[9,12,19,23,27,30] which can range from 0.3% to 1.5%.[8,14,15]

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Previous cadaveric studies have evaluated hip capsule contributions to stability in terms of internal and external ranges of motion and distraction. Several cadaveric models have investigated hip range of motion by applying fixed rotational torque, varying from 0.5 N·m to 5 N·m, to the femur in various positions of flexion/extension and abduction/adduction.[2,3,10,24] In a comprehensive study of 15 different hip positions, Baha et al[2] concluded that, across all conditions, capsular repair after IP and T-capsulotomy restored range of motion and joint translation to the native joint. These results contrasted slightly with those of Philippon et al,[24] who used an elegant robotic system to demonstrate that joint stability may not be restored completely with repair at time zero. Neither study examined hip positions associated with increased risk of dislocation, and they did not study common variations of IP and T-capsulotomies, such as the short T- or long T-capsulotomy. Finally, running each condition in torque control–that is, to a predefined torque for each condition–risks stretching the soft tissue structures of the joint with each sequential run.

The objective of this study was to quantify the effect of IP capsulotomy, short T- capsulotomy, and long T-capsulotomy, and their repairs, on resistance to anterior and posterior positions that are at risk for dislocation. We hypothesized that (1) an IP capsulotomy would have a minimal effect on resistive torques compared with the short T- and long T-capsulotomies in at-risk dislocation positions and that (2) repair would increase hip resistive torque significantly for all capsulotomies.

METHODS

Cadaveric Preparation and Testing

With institutional review board approval, 10 freshly frozen nonarthritic cadaveric hips (hemipelvis to midfemur; mean age 55 years [range, 35-65 years]; 6 male, 4 female; purchased from Anatomy Gifts Registry) were stripped of excess fat and soft tissue, leaving the joint capsule, labrum, and ligamentum teres intact. Specimens were evaluated with computed tomography for bony morphology examination to ensure there was no significant osteoarthritis or abnormality in acetabular and femoral radiographic factors (coronal and anterior center-edge angles, acetabular version, and alpha angles). Abnormal coronal and anterior center-edge angles were defined as $<20^\circ$, abnormal acetabular version was defined as $>30^\circ$ at the 3 o'clock position, and abnormal alpha angles were defined as $>50^\circ$.[17] Femoral version was not considered due to lack of distal femur.

The labrum was identified visually after the open capsulotomy was performed by a clinical sports medicine fellow (R.M.). Specimens were positioned at 0° hip flexion, neutral internal/external rotation, and neutral abduction/adduction following techniques used by Jackson et al[16] in which the position was estimated based on observed capsular ligament tensions and the positions that minimized visual capsular ligament tensions in multiple directions. Specimens were then pinned through the femoral head into the pelvis, and the pins were used to align the specimen within custom testing fixtures such that rotational axes were coincidental with the femoral head center. Pins were removed prior to testing.

Each hip was mounted on a servohydraulic biaxial load frame (MTS Systems), with a 22 kN, 282 N·m load cell, in fixtures that allowed for adjustable hip flexion/extension positioning. Two positions considered "at risk" for dislocation in the anterior and posterior positions were simulated, and a modified testing approach was adopted to prevent overloading of secondary stabilizing ligaments during repeated testing of capsulotomy and repair conditions. This approach involved applying an initial torque of 5 N·m to the intact hip,[24] then running subsequent conditions to the position corresponding to 5 N·m, and quantifying the resulting torque, as follows:

1. Anterior dislocation: The femur was positioned at 20° of hip extension. A compressive force of 100 N was applied across the joint, whereas the femur was externally rotated at 15°/s to a torque of 5 N·m (Figure 1A).[21] The position of the femur at the fifth cycle of 5 N·m was recorded as the target external position for subsequent displacement control tests of altered hip capsule conditions (Figure 1B).
2. Posterior dislocation: The femur was positioned at 90° hip flexion.[22,24] A compressive force of 100 N was applied to the intact joint while the femur was rotated internally at 15°/s to a torque of 5 N·m (Figure 1A).[21] The rotational position of the femur at the fifth cycle of 5 N·m was recorded as the target internal position for subsequent displacement control tests of altered hip capsule conditions (Figure 1B).

After intact testing, hip capsule conditions were tested in order of increasing violation to the capsule while randomizing the order of repair or capsulotomy for each incision (Figure 2). The first capsulotomy performed was a 3 cm midanterior IP incision. The IP incision was repaired using 2

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Ethical approval for this study was obtained from Hospital for Special Surgery (ref No. 14010).

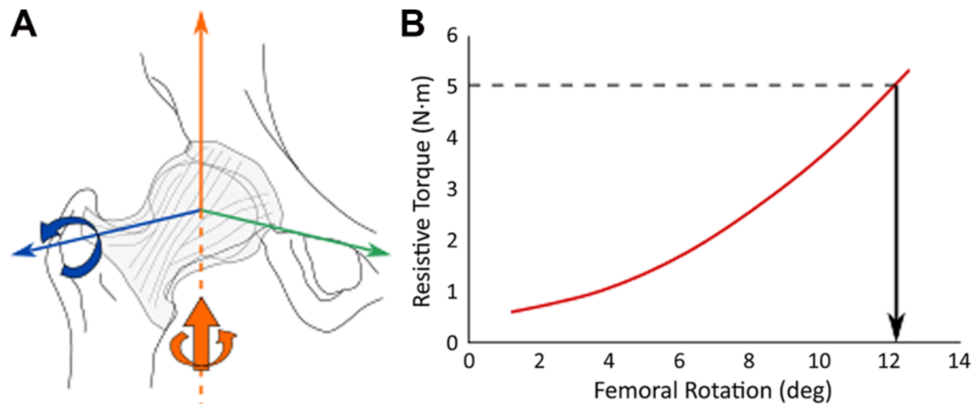

Figure 1. (A) Intact hips were mounted in a biaxial test frame and 100 N compressive force (orange axis) was applied to all hips. Hips were then tested in the high-risk condition of anterior dislocation (20° extension [about blue axis] and externally rotated [about orange axis] to 5 N·m) and then tested in the high-risk condition of posterior dislocation (90° flexion and internally rotated to 5 N·m). (B) The angle of rotation at ±5 N·m was the target rotation for all conditions.

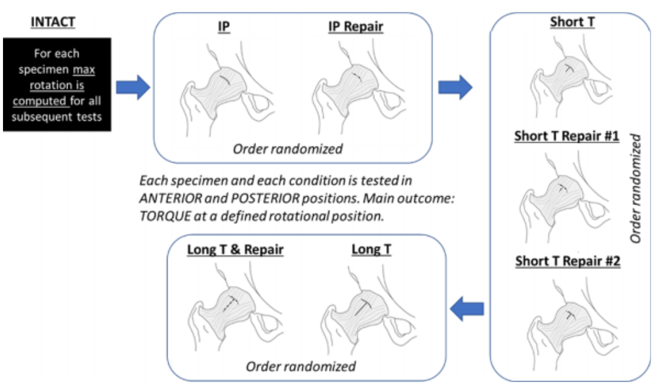

Figure 2. The intact hip was used to define the maximum rotation for all subsequent tests. Hip capsulotomies (interportal [IP], short T, long T) and corresponding repair techniques were randomized within groups. Each specimen and each condition were tested in the anterior and posterior positions.

simple stitches with suture (No. 2 Fiberwire; Arthrex). The second capsulotomy condition was a short T-capsulotomy, with a 2-cm incision perpendicular to the IP incision to the level of the zona orbicularis but not transecting it. Two common repair techniques were included, with 1 or 3 sutured simple stitches across the T incision, with the IP incision closed with 2 sutures for each. The last capsulotomy condition was the long T-capsulotomy, lengthening the T incision to 4 cm, transecting the zona orbicularis down to the level to the intertrochanteric line, which is just proximal to the vastus lateralis proximal attachment. Testing in both anterior and posterior positions was done for each hip capsule condition.

Outcomes

The resistive torque at the fifth loading cycle was averaged across the 10 specimens. A generalized estimating equation modeling was used to compare resistive torque between capsulotomy conditions and intact, and between repair conditions and intact. The P values (significance level $\alpha = .05$) in the post hoc tests were Bonferroni-adjusted to account for multiple comparisons.

RESULTS

All hips were tested successfully. For the anterior dislocation risk condition, the IP and long T-capsulotomy resistive torques were lower than intact ($P = .01$ and $P < .001$, respectively) (Figure 3). The short T-capsulotomy did not show a significant difference from intact resistive torque ($P = .358$). For the posterior dislocation risk condition, the short T- and long T-capsulotomy resistive torques were lower than intact ($P = .009$ and $P = .018$, respectively) but the IP was not significantly different from intact. All capsulotomy repair techniques demonstrated a return of resistive torque to that of the intact capsule at both dislocation-risk positions ($P > .3$ for all conditions) (Figure 4). The status of the labral tissue in each specimen was tested in gross dislocation position at the end of testing and was deemed to be intact with an adequate suction seal.

DISCUSSION

In our controlled biaxial testing of cadaveric hips joints, we quantified the resistance of capsulotomies and their repairs to high-risk anterior and posterior dislocation positions. We observed a decrease in capsular resistive torque in the anterior at-risk dislocation position with the IP incision and long T incision. Both kinds of T-capsulotomy incisions (short and long) resulted in a decrease in capsular resistive torque in the posterior at-risk dislocation condition, but the IP incision had no effect. It is conjectured that any capsulotomy puts the hip at risk for anterior dislocation due to the minimal osseous constraints of the anterior acetabulum, while only T-capsulotomies put the hip at risk for posterior dislocation due to the enhanced osseous constraint of

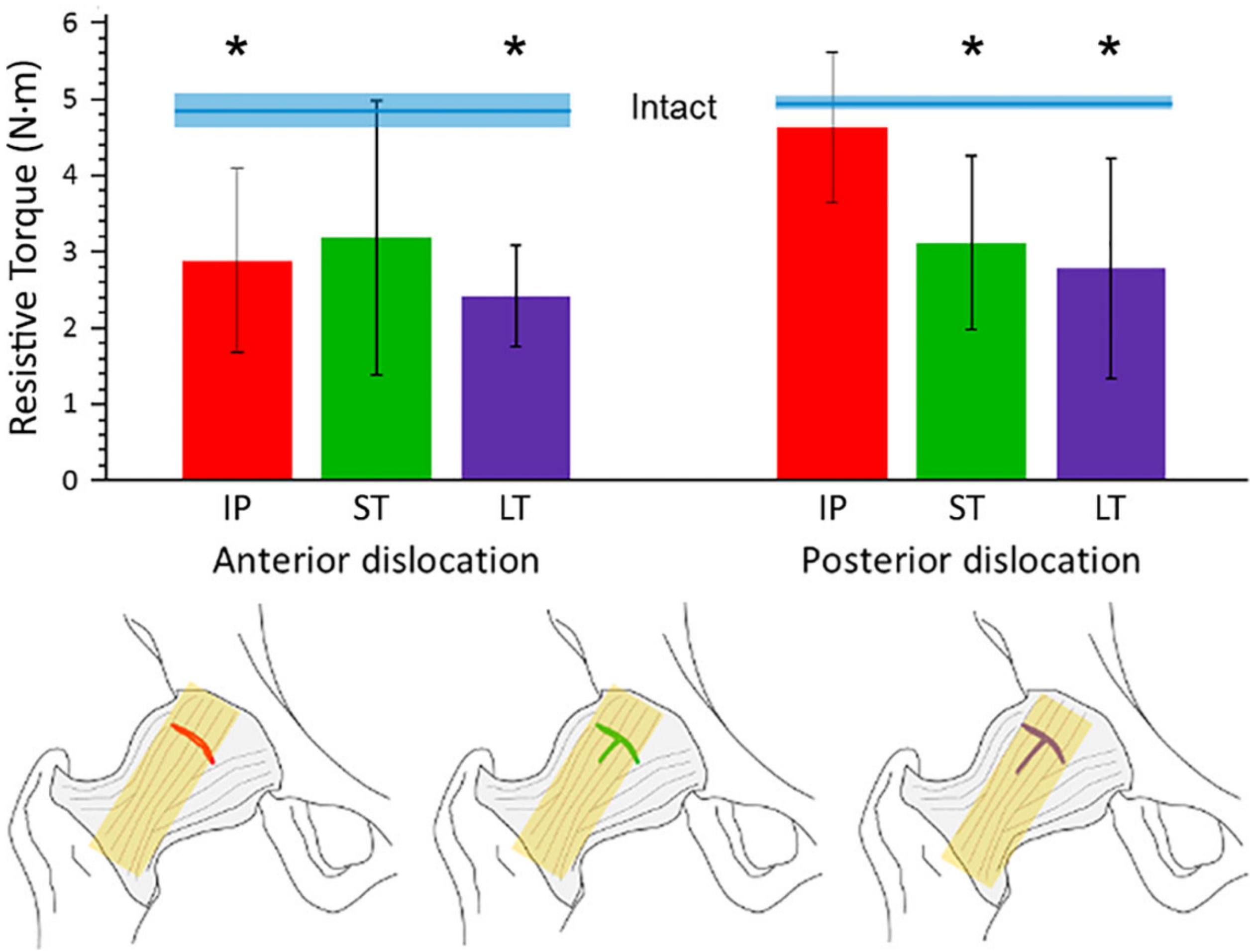

Figure 3. Resistive torques of each open capsulotomy condition compared with intact (blue band) with 95% CIs. *Significant difference from intact ($P < .05$). IP, interportal; LT, long T-capsulotomy; ST, short T-capsulotomy.

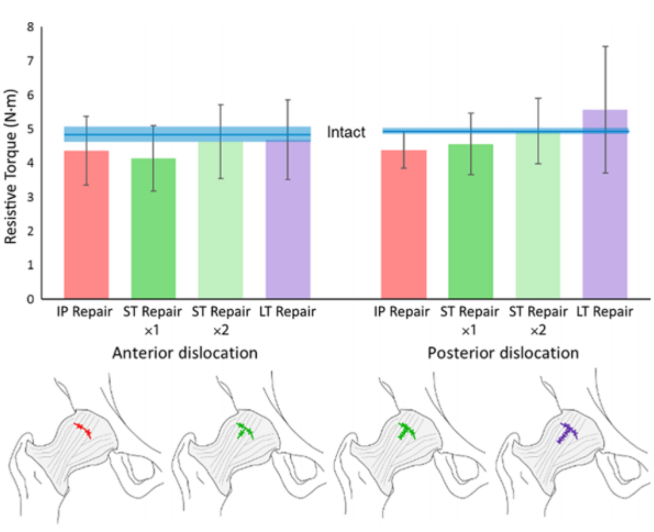

Figure 4. Resistive torques of each capsulotomy repair condition compared with intact (blue band) with 95% CIs. IP, interportal; LT, long T-capsulotomy; ST, short T-capsulotomy.

the posterior wall. All capsulotomy repair conditions had a hip resistive torque that was not significantly different than that of the intact condition in both anterior and posterior at-risk dislocation positions.

Resistance to dislocation is influenced by a number of anatomical factors: the stiffness of the soft tissue envelope,[13] the attachment points of the ligamentous structures that span the hip,[20] the status of the labrum, the displacement path of the hip to the dislocation point,[22] and the osseous support provided by the acetabulum.[25] To account for specimen-specific variations in soft tissue envelope and the attachment points of the ligamentous structures, all hips were tested initially in the intact condition, then capsulotomy and repair data were compared with intact data. A significant strength of our model is the shift from the torsional target of previous studies to a positional target to prevent damage of the capsular structures that may affect subsequent capsule conditions tested. This approach may contribute to our finding of all repaired conditions returning intact capsular strength, which was not shown in prior studies.[3,16,24] By mimicking both anterior and posterior at-risk dislocation positions, our model adds to the data generated from other biomechanical test models used to study hip dislocation[2,3,21,24,29] and provides important observations at the extrema of patient exertion for a larger variety of capsulotomy and repair techniques.

The anterior at-risk position simulates a common situation of dislocation: a standing pivot where the torso and contralateral limb are rotated away from a planted foot, causing hip extension and external rotation.[22] The posterior at-risk position recreates a similarly common dislocation situation: a seated position with the torso bending over to tie one's shoe with feet planted on the floor, causing hip flexion and internal rotation.[22] The biomechanical consequences of type of capsulotomy were different depending on whether an anterior or posterior dislocation position was modeled. The IP capsulotomy exhibited a reduction in resistive torque in the anterior dislocation position, but not in the posterior dislocation position. This result is not surprising, given that the IP capsulotomy transects the iliofemoral ligament, previously reported as a dominant restraint to external rotation,[20,21,28] which was studied in our anterior at-risk dislocation position. This result can be explained further by the minimal osseous constraints of the anterior acetabulum, which places greater mechanical demand on the ability of the anterior soft tissue structures to resist dislocation. Interestingly, the short T-capsulotomy resulted in more variable torque for anterior dislocation position and was not significantly different from the intact condition. Upon further inspection, this result appears to be driven by an outlier specimen. It should be noted that capsulotomies do not cut across the ischiofemoral ligament, which is why posterior dislocation is rarer after capsulotomy.

The benefits of hip capsulotomy and repair are still debated; however, the use of capsulotomy and repair seem to be increasing.[8,11,27] The repair of hip capsulotomies and documentation of motivation behind this decision is highly variable in sizable practices.[8,18,27] Our finding that all capsulotomy repair conditions improved hip resistive torque, and that those torques were not significantly different from the intact conditions, suggest that regardless of the level of exposure needed, repair is advocated. This finding is also supported by the cadaveric study of Baha et al[2] and short- and mid-term clinical studies that point to improved patient-reported outcomes,[6,9,26] and more predictable and reliable hip function,[8] after capsule repair. Our findings differ from the conclusions of Bayne et al,[3] who saw no biomechanical effect of capsulotomy in hip extension with external rotation, under torques of approximately 0.6 N·m. It is possible that the applied torque, which is substantially lower than our applied torque of 5 N·m, did not lead to sufficient forces across the incision.

This study had several limitations. Our model did not emulate a frank dislocation; rather, we calculated the resistive torque as the femur was rotated to positions that are known to be at high risk for dislocation. Other parameters including anteroposterior wall relationship and femoral version were not identified because of a lack of distal femurs and radiographs, which also limited our ability to define neutral position from bony geometry. Finally, we did not perform a detailed analysis of hip kinematics as conducted by Baha et al[2] and Philippon et al,[24] which are important analyses when microinstability is being studied.

CONCLUSION

We rejected our study hypothesis: a decrease in capsular resistive torque in at-risk anterior dislocation positions can occur with the IP incision, but not with posterior at-risk dislocation positions. Repair improved hip resistive torque to that of the intact condition in both anterior and posterior dislocation positions, suggesting that it is biomechanically advantageous to repair even the most minimal capsulotomy, particularly in the anterior at-risk position.

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