Hip Capsular Closure

A Biomechanical Analysis of Failure Torque

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Background: Hip capsulotomy is routinely performed during arthroscopic surgery to achieve adequate exposure of the joint. Iatrogenic instability can result after hip arthroscopic surgery because of capsular insufficiency, which can be avoided with effective closure of the hip capsule. There is currently no consensus in the literature regarding the optimal quantity of sutures upon capsular closure to achieve maximal stability postoperatively.

Purpose/Hypothesis: The purpose of this study was to determine the failure torques of 1-, 2-, and 3-suture constructs for hip capsular closure to resist external rotation and extension after standard anterosuperior interportal capsulotomy (12 to 3 o'clock). Additionally, the degree of external rotation at which the suture constructs failed was recorded. The null hypothesis of this study was that no significant differences with respect to the failure torque would be found between the 3 repair constructs.

Study Design: Controlled laboratory study.

Methods: Nine pairs (n = 18) of fresh-frozen human cadaveric hemipelvises underwent anterosuperior interportal capsulotomy, which were repaired with 1, 2, or 3 side-to-side sutures. Each hip was secured in a dynamic biaxial testing machine and underwent a cyclic external rotation preconditioning protocol, followed by external rotation to failure.

Results: The failure torque of the 1-suture hip capsular closure construct was significantly less than that of the 3-suture construct. The median failure torque for the 1-suture construct was 67.4 N·m (range, 47.4-73.6 N·m). The median failure torque was 85.7 N·m (range, 56.9-99.1 N·m) for the 2-suture construct and 91.7 N·m (range, 74.7-99.0 N·m) for the 3-suture construct. All 3 repair constructs exhibited a median 36° (range, 22°-64°) of external rotation at the failure torque.

Conclusion: The most important finding of this study was that the 2- and 3-suture constructs resulted in comparable biomechanical failure torques when external rotation forces were applied to conventional hip capsulotomy in a cadaveric model. The 3-suture construct was significantly stronger than the 1-suture construct; however, there was not a significant difference between the 2- and 3-suture constructs. Additionally, all constructs failed at approximately 36° of external rotation.

Clinical Relevance: Re-establishing the native anatomy of the hip capsule after hip arthroscopic surgery has been reported to result in improved outcomes and reduce the risk of iatrogenic instability. Therefore, adequate capsular closure is important to restore proper hip biomechanics, and postoperative precautions limiting external rotation should be utilized to protect the repair.

Keywords: hip capsule; hip; capsulotomy

Because of the recent growth in the number of hip arthroscopic procedures performed worldwide, there has been increasing interest in proper capsular management to prevent iatrogenic microinstability.[5,7,8,17] The capsule originates on the margin of the acetabular rim proximally, surrounds the femoral neck, and attaches anteriorly to the intertrochanteric line. The capsule attaches superiorly to the head-neck junction, posteriorly above the intertrochanteric crest, and inferiorly proximal to the lesser trochanter on the neck.[12,20,27]

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Four capsular ligaments (iliofemoral, ischiofemoral, pubofemoral, and zona orbicularis) compose the capsule and are known to provide stability to the hip.[8] Biomechanical and clinical studies have reported that the hip capsule plays an important role in maintaining biomechanical constraint to a variety of motions, including rotation and translation.[4,8,9,28] Moreover, in pathological situations such as in the case of dysplastic patients, secondary stabilizers, for example, the labrum or the capsule, are subjected to additional stress, and therefore, they become vital for joint stability.[13,24] Therefore, proper intraoperative management of the capsule is important to restore native biomechanics after injuries or capsulotomy.[8]

Hip capsulotomy is routinely performed during arthroscopic surgery for visualization of the intra-articular anatomy.

Standard anterosuperior interportal capsulotomy for hip arthroscopic surgery (12 to 3 o'clock) sacrifices the integrity of the iliofemoral ligament (ligament of Bigelow),[1] which provides rotational stability in both flexion and extension.[14] Failure to restore the anatomic and biomechanical properties of the iliofemoral ligament after arthroscopic surgery has been reported to increase the likelihood of microinstability or dislocations.[10] The consequences of a deficient capsule can result in iatrogenic instability, producing potential adverse outcomes such as persistent pain, subluxation symptoms, and accelerated cartilage wear.[3,15]

Previous literature investigating the arthroscopic management of hip pathological conditions has understated the importance of proper capsular management.[8] Recent evidence has suggested that repairing the capsule restores near native hip joint stability.[2,8,11] In addition to capsular shift or capsulorrhaphy, as many as 6 sutures have been reported to be used for capsular closure[1,8-11,15] or plication to improve stability when performing either interportal or T capsulotomy.[11,18] However, there is currently no consensus regarding the optimal number of sutures for hip capsular closure after arthroscopic capsulotomy to provide a biomechanical strength similar to that of the native capsule.

The purpose of this study was to determine the failure torque of 1-, 2-, and 3-suture constructs for hip capsular closure to resist external rotation and extension after standard anterosuperior interportal capsulotomy (12 to 3 o'clock) in cadaveric specimens. Additionally, the degree of external rotation at which each of the suture constructs failed was recorded. The null hypothesis of this study was that no significant failure torque differences would be found among the 3 repair constructs.

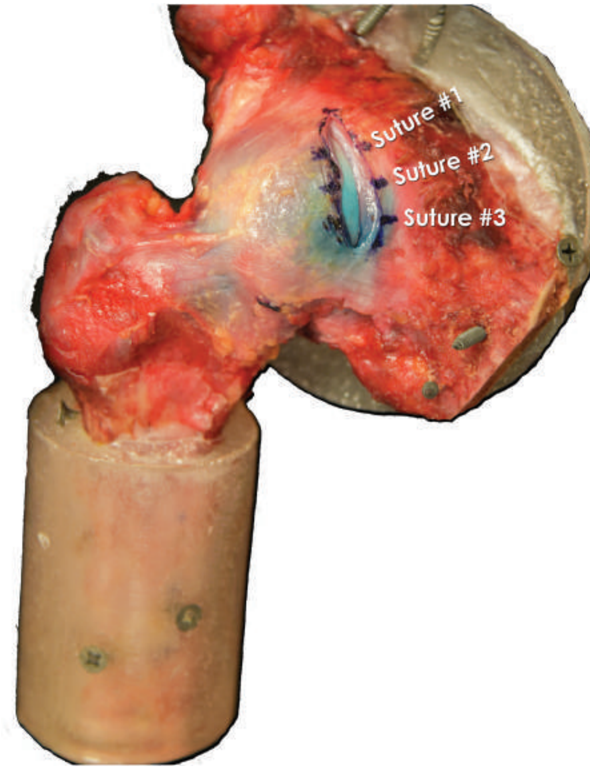

Figure 1. Anterosuperior interportal capsulotomy on a potted right hemipelvis. The incision was made parallel to the labrum from a point 1 cm distal to the acetabular rim from the ''psoas-u'' position (3 o'clock) to the stellate crease (12 o'clock). The capsule was demarcated with a pen before performing capsulotomy to ensure anatomic locations for capsular closure. Each suture was placed 1 cm apart (suture locations for a 3-suture construct are shown).

METHODS

Cadaveric Specimens

Nine pairs (n = 18) of male fresh-frozen human cadaveric hemipelvises with femurs (mean age, 51.3 years; range, 26-65 years) and no prior injury, surgical history, or gross anatomic abnormality were dissected free of all skin and surrounding soft tissues, leaving the bone and capsular structures intact. The hips were examined for range of motion, crepitus, or any other sign of occult bony abnormalities. The proximal femur and pelvis were potted in polymethyl methacrylate (PMMA; Fricke Dental) (Figure 1).

All surgical procedures were performed by a single orthopaedic surgeon (J.C.). Standard 4 cm–long anterosuperior interportal capsulotomy was performed from 12 to 3 o'clock on the acetabular clockface,[19] 1 cm distal to the hip labrum and parallel to it (Figures 1 and 2). Before capsulotomy, closure locations between the capsuloligamentous flaps were demarcated with a surgical marking pen at 3 equidistant intervals to ensure anatomic closure of the capsule (Figure 1).

To determine the position of capsulotomy in an extra-articular fashion, the psoas-u (3-o'clock position) was visually identified during hip flexion.[19] The incision was initiated at the psoas-u position (3 o'clock) 1 cm distal from the acetabular rim and continued parallel with the labrum to the stellate crease (12 o'clock), which can be visualized with slight subluxation of the femoral head (Figure 2). The

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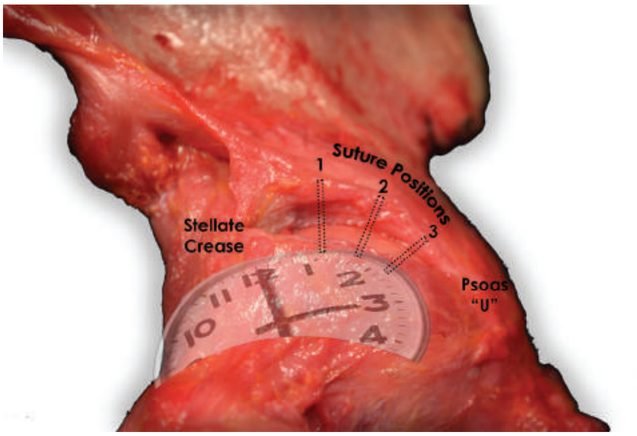

Figure 2. Image of a right cadaveric hip demonstrating a schematic disposition of standard capsulotomy and the consistent equidistant locations of sutures 1, 2, and 3. When 1 suture was utilized, it was placed in the middle of the capsulotomy site (position 2), and when 2 sutures were utilized, they were positioned equidistant from the ends of the capsulotomy site.

capsule was closed in a side-to-side fashion between the proximal and distal segments of the capsuloligamentous flaps with 1, 2, or 3 No. 2 Vicryl sutures (Ethicon Inc) using our previously described capsular closure technique.[16] When 1 suture was utilized, it was placed in the middle of the capsulotomy site (position 2), and when 2 sutures were utilized, they were positioned equidistant from both ends of the previously performed capsulotomy site (Figure 2).

Biomechanical Testing

Each potted hemipelvis was securely fixed in hip extension within a dynamic biaxial testing machine (ElectroPuls E10000; Instron) for in vitro testing (Figure 3).

The hip was subjected to a cyclic external rotation preconditioning protocol, with the hip oriented in 10° of extension and under a constant axial compressive load of 5 N. The preconditioning protocol consisted of 100 cycles between 1 and 5 N·m of external rotation torque, followed by 100 cycles between 1 and 10 N·m of external rotation torque, oscillating at 0.5 Hz. A 5-N·m torque has been reported to correspond to the torque required to produce a typical internal/external full range of motion.[17] After cyclic loading, the hip was realigned to its starting position and was externally rotated to failure (Figure 4) or, if the sutures did not fail, to the rotational limit of the testing machine (~130° of rotation or 100 N·m of torque) at a rate of 10 deg/s.

Data Collection and Statistical Analysis

Each of the 9 matched pairs were randomly assigned 2 of the 3 closure techniques, and each closure technique was randomly assigned to the left and right specimens of each pair to constitute a balanced incomplete block design (BIBD) (Table 1).[30] This design dictated that each suture

Figure 3. Photograph of the mechanical testing setup for a left hip (inverted). The potted hemipelvis was securely fixed in 10° of hip extension to the base of a dynamic biaxial testing machine to be subsequently tested in external rotation and extension of the hip joint.

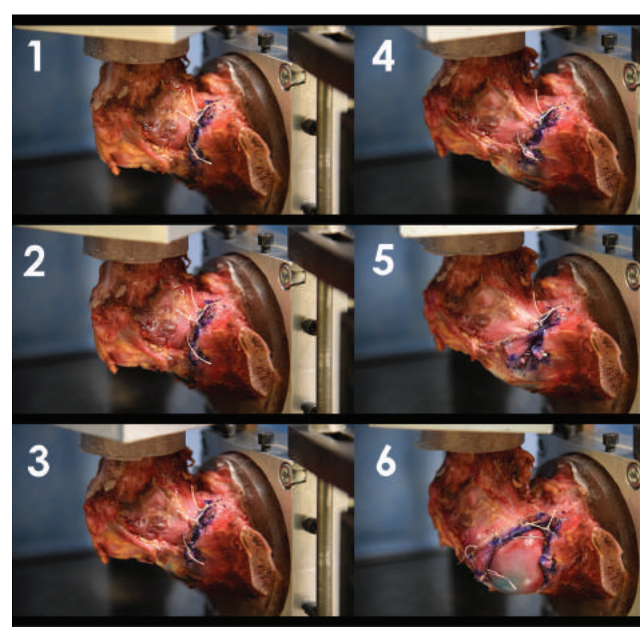

Figure 4. External rotation to failure was applied at a rate of 10 deg/s. Images 1 to 6 document the sequence of the failure mechanism of a 2-suture capsular closure construct mounted in the machine. This sequence demonstrates the effects of progressive external rotation of the hip until failure of the capsule sutures (image 6).

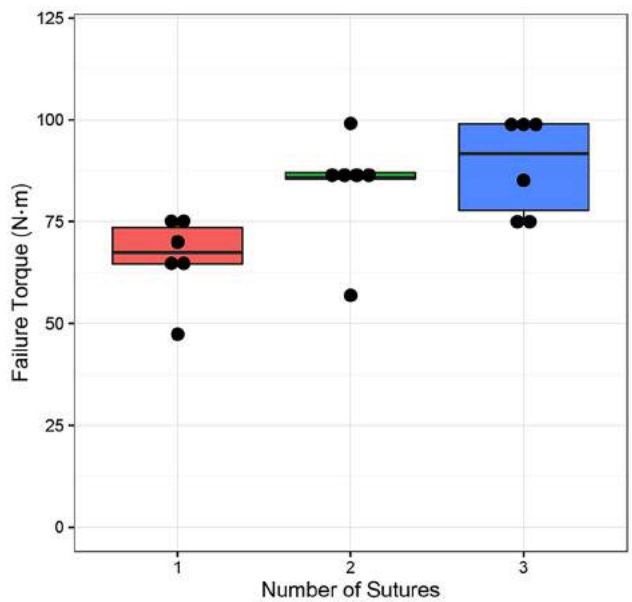

Figure 5. Boxplots of failure torques for the 3 different constructs (1, 2, and 3 sutures). Dark horizontal lines represent the median, with the box representing the 25th and 75th percentiles.

number shared a paired specimen with each of the other suture groups 3 times. Torque (N·m) and external rotation (degrees) were collected using computer software (Wave Matrix; Instron). Within the experiment, there was a maximal torque of 100 N·m. This ceiling effect led us to utilize rank-based statistical testing methods. The nonparametric version of the BIBD analysis of variance (ANOVA) is the Durbin test, which was used to assess the primary hypothesis that different suture numbers are associated with the failure torque. When the omnibus Durbin test was statistically significant, post hoc comparisons were made using the Conover method, and the Holm-Bonferroni method was used to control the type I error. Group medians and ranges were reported. External rotation at failure was assumed to follow a normal distribution, analyzed with the standard parametric BIBD ANOVA and reported using least-squares means. Significance was set at $P < .05$. All analyses were conducted using the statistical programming language R[23] with packages PMCMR[22] and ggplot2.[29]

RESULTS

The failure torque for the 1-suture construct was 67.4 N·m (range, 47.4-73.6 N·m). For 2 sutures, the failure torque was 85.7 N·m (range, 56.9-99.1 N·m), and for 3 sutures, the failure torque was 91.7 N·m (range, 74.7-99.0 N·m). Two specimens in the 2-suture group and 3 specimens in the 3-suture group reached the maximal torque (100 N·m) of the testing machine. No significant differences were found between 1 and 2 sutures (P = .072) or 2 and 3 sutures (P = .538). However, the 3-suture construct withstood a significantly higher torque than the 1-suture construct (P = .043) (Figure 5). There was not a consistent pattern of failure for any group or between groups.

For the 1-suture construct, the least-squares mean external rotation of the hip at failure was 34.0° (95% CI, 30.7° -37.3°); for 2 sutures, the external rotation at failure was 44.3° (95% CI, 41.0°-47.6°); and for 3 sutures, the external rotation was 30.3° (95% CI, 27.0°-33.6°). The 2-suture construct failed at a significantly greater degree of external rotation than the 1- (P = .002) and 3-suture ($P < .001$) constructs. However, no significant differences were found between 1 and 3 sutures (P = .124) (Figure 6).

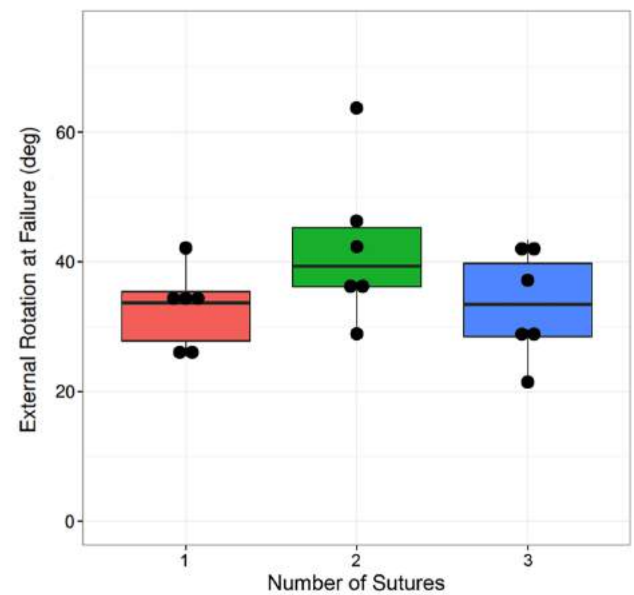

Figure 6. Boxplots of external rotation at failure for the 3 different constructs (1, 2, and 3 sutures). Dark horizontal lines represent the median, with the box representing the 25th and 75th percentiles.

TABLE 1
Randomized Closure Technique Assignment Constituting a Balanced Incomplete Block Design[a]

	Specimen No.								
	1	2	3	4	5	6	7	8	9
Left hip	2S	2S	2S	3S	3S	1S	1S	1S	3S
Right hip	3S	3S	1S	1S	2S	3S	2S	2S	1S

[a]1S, 1 suture; 2S, 2 sutures; 3S, 3 sutures.

DISCUSSION

The most important finding of this study was that the 2- and 3-suture constructs resulted in comparable biomechanical failure torques when external rotation forces were applied to conventional hip capsulotomy in a cadaveric model. The 3-suture construct was significantly stronger than the 1-suture construct; however, there was not a significant difference between the 2- and 3-suture constructs. Additionally, all constructs failed at approximately 36° of external rotation.

The consequences of a deficient or damaged hip capsule resulting in iatrogenic instability after hip arthroscopic surgery have been reported. These cases emphasize the potential adverse outcomes due to instability after hip arthroscopic surgery without attention to adequate closure and protection of the capsule. Matsuda[15] described the case of an acute anterior hip dislocation in a patient who had undergone hip arthroscopic surgery for femoroacetabular impingement without capsular closure. Mini-open capsulorrhaphy was subsequently performed and successfully restored hip stability. Benali and Katthagen[3] similarly described a case of a 49-year-old female patient who underwent hip arthroscopic surgery at an outside hospital without documented closure of the capsule. The patient later presented to their institution with hip subluxation and progressive osteoarthritis, both of which were not present on preoperative radiographs. Because of the noted subluxation and degenerative changes that resulted from the patient's iatrogenic instability, the patient was treated with total hip arthroplasty.

Previous studies have detailed the anatomic properties of the native hip capsule with relevance to hip arthroscopic surgery. Telleria and colleagues[26] described the normal anatomic intra-articular locations of the hip capsular ligaments in the central and peripheral compartments. They reported that the iliofemoral ligament ran from 12:45 to 3 o'clock and was punctured by the anterolateral and anterior portals within its lateral and medial borders, respectively. The iliofemoral ligament has been reported to be the most important stabilizer for hip extension and external rotation,[20] which is commonly incised when performing standard capsulotomy (12 to 3 o'clock). Additionally, the fibers of the zona orbicularis and anterior capsule are arranged in a spiral configuration.[8,25] The spiral orientation results in the ligaments tightening in a screw-home mechanism during hip extension and external rotation, which further stabilizes the hip joint. Loss of the screw-home mechanism places the hip at risk of instability.

A number of studies have demonstrated arthroscopic capsular closure and plication to be successful; however, they can be technically challenging. Philippon and colleagues[21] reported on a cohort of 37 patients who underwent revision hip arthroscopic surgery. They found that 35% of revision cases were caused by unaddressed instability, and postoperative outcomes were significantly improved after capsular plication and/or thermal capsulorrhaphy. Domb et al[9] evaluated the role of capsular plication in patients with borderline hip dysplasia. Their results demonstrated favorable outcomes at 2-year follow-up for an arthroscopic approach that included labral repair augmented by capsular plication with inferior shift for those patients at a greater risk of instability because of borderline dysplasia. Although the aforementioned studies highlight the importance of adequate capsular management during hip arthroscopic surgery, there is no consensus in the literature on the optimal closure technique or construct.

Currently, there is a paucity of literature on postoperative guidelines to protect the capsular repair construct. Cheatham et al[6] performed a systematic review to evaluate the evidence on postoperative rehabilitation programs after hip arthroscopic surgery. They found that while prior studies supported restrictions on weightbearing and hip mobility in the early postoperative period, specific protocols were widely variable and limited to case series or case reports. The biomechanical results of the present study demonstrate that all capsular repair constructs failed at approximately 36° of external rotation, indicating that postoperative protocols should include this important guideline to protect the capsular repair. However, future clinical trials are warranted to further support the inclusion of this postoperative protocol for hip arthroscopic surgery.

We recognize that the present study has some limitations inherent to the biomechanical cadaveric study design. Our model is representative of the immediate postoperative period before healing occurs, when patients are most reliant on the strength of the capsular repair construct. The cadaveric specimens cannot take into account the capsular healing process after surgery, which would likely improve the failure torque of the repair with time. Likewise, removal of the soft tissue could yield different final failure torques of the constructs; however, because this variable was kept consistent throughout testing, it is likely that the differences observed between the constructs would remain unaffected. Finally, the biomechanical properties were evaluated on a dynamic testing machine, which may not be identical to normal physiological loading conditions, and the testing machine's maximal torque of 100 N·m did not accommodate failure for some of the 2- and 3-suture constructs.

CONCLUSION

The most important finding of this study was that the 2- and 3-suture constructs resulted in comparable biomechanical failure torques when external rotation forces were applied to conventional hip capsulotomy in a cadaveric model. The 3-suture construct was significantly stronger than the 1-suture construct; however, there was not a significant difference between the 2- and 3-suture constructs. Additionally, all constructs failed at approximately 36° of external rotation.

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