Hip Capsular Management in Patients with Femoroacetabular Impingement or Microinstability: A Systematic Review of Biomechanical Studies

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Purpose: To investigate the correlation between hip capsular management (repair or reconstruction) and biomechanical results in the setting of femoroacetabular impingement and microinstability. **Methods:** A search of the PubMed and Embase databases was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Included studies focused on hip biomechanics related to capsular release, repair of I- and T-capsulotomy, or capsular reconstruction. Studies were assessed for external/internal rotation of the femur, femoral head translation, rotational torque, and distraction force. Articles were excluded if they discussed treatment of the hip capsule related to surgical dislocation, mini-open surgery, arthroplasty, reorientation osteotomy, or traumatic dislocation. **Results:** Twenty-four biomechanical studies were included that evaluated rotation/translation (11 studies), distraction (3 studies), the capsular role in microinstability (simulated with anterior capsule pie crusting [2 studies] and cyclical loading [2 studies]), allograft reconstruction (3 studies), and anatomic properties (3 studies). Repair and reconstruction demonstrated improvements in maximum distractive force, total ROM, and torsional stability when compared to capsular release. Significant differences were observed between capsular repair and release in total ROM in the coronal plane with improved stability in the repair groups (standardized mean difference [SMD]: −1.3°, 95% confidence interval [CI] −1.68 , −0.854; $P < .001$). There was significantly increased total motion in the coronal plane in the capsular laxity state compared to the native state (SMD: 1.4° (95% CI 0.32, 2.49; $P = .012$). **Conclusions:** Biomechanical evidence supports closure of the capsule after hip arthroscopy to reverse the significant effects of capsulotomy. Simulated capsule laxity models created altered joint motion and translation. Capsule reconstruction appears to restore the hip to its native capsule state. **Clinical Relevance:** Investigating the biomechanical outcomes of capsular repair and reconstruction will help surgeons better understand the rationale and implications of these capsular management strategies.

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Hip arthroscopy has been increasingly used to treat hip pathology and is one of the most rapidly growing fields in orthopaedic surgery.[1] Hip arthroscopic procedures performed by American Board of Orthopaedic Surgery (ABOS) Part II examinees increased by more than 600% in 5 years from 83 in 2006 to 636 in 2010.[2] Capsular management remains a controversial topic for the hip arthroscopy surgeon and is relatively understudied compared to femoroacetabular impingement and labral tear management. With growing evidence of biomechanical data in the literature, hip preservation surgeons are increasingly performing a high number of capsular closures, guided by patient characteristics.[3]

Recently, there has been substantial research regarding capsular management and investigation into more complex topics such as capsular reconstruction and the role of the capsule in hip microinstability.[4-10] Despite ongoing outcome studies, there is still controversy regarding the mechanical effect of different capsular management modalities. The purpose of this review was to investigate the correlation between hip capsular management (repair or reconstruction) and biomechanical results in the setting of femoroacetabular impingement and microinstability. This study's hypotheses were that capsular repair/reconstruction would significantly improve hip biomechanical profiles compared to the capsular release/deficient state and that microinstability models would demonstrate significantly decreased hip joint stability compared to the native capsular state.

Methods

Study Identification and Search Strategy

A comprehensive literature search of the PubMed and Embase databases was performed in July 2020 using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines and checklist. The following keywords were used in the literature search for data extraction: hip arthroscopy, hip capsule, hip biomechanics, hip instability, hip microinstability, hip dislocation, hip subluxation, atraumatic hip instability, hip stability, hip capsule release, hip capsulotomy, hip capsulectomy, hip capsulorrhaphy, hip capsule repair, hip capsule closure, and hip capsule reconstruction.

Two orthopaedic surgeons (A.E.J. and B.R.S.) performed the search and independently reviewed the titles and abstracts to determine relevant articles to proceed onto full-text review. Reference lists from relevant articles were retrieved to identify additional studies. Differences in opinion were resolved by a third, senior orthopaedic surgeon (B.G.D.) to ensure that the studies met the inclusion and exclusion criteria. Studies were included only if all reviewers came to a consensus that they met the eligibility criteria.

Study Eligibility

Studies were included in this systematic review if they evaluated cadaveric specimens, were written in English, and focused on hip capsule biomechanics. Investigated parameters included rotation/translation, distraction, microinstability, allograft reconstruction, and anatomic properties. Articles were considered irrelevant to our topic and excluded if they discussed treatment of the hip capsule related to surgical hip dislocation, mini-open surgery of the hip, arthroplasty, reorientation osteotomy, or traumatic dislocation. Reviews, technique reports, opinion articles, articles written in a language other than English, clinical studies focusing on patient reported outcomes, or articles with no abstract available were also excluded.

Data Extraction

Data from all included studies were organized into Microsoft Excel (Microsoft Office 2011; Microsoft, Redmond, WA). Data included title, author, journal and date of publication, study design, number of cadaveric specimens, and outcomes.

Data Collection

The cadaveric biomechanical studies were assessed for several outcomes including maximum external rotation of the femur, maximum internal rotation of the femur, femoral head translation, maximal rotational torque, and maximum distraction force. Descriptive statistics were calculated from each included study. For continuous data, weighted means and standard deviations were calculated for all subjects and outcome parameters. Standardized mean differences (SMD) were calculated between the capsular release groups and the capsular repair/reconstruction groups in the native capsule studies. For studies investigating microinstability, SMDs were calculated between the intact group and the anterior capsular laxity groups.

MedCalc (version 12.7) was used for data analysis. Forest plots were created for maximum range of motion comparing the capsular release to the capsular repair states and for comparing the intact state to the anterior capsular laxity state in the studies investigating microinstability (Figs 1 and 2). The I^2 index was used to measure heterogeneity of included studies.[11] Effect sizes were calculated using random effects models with the DerSimonian-Laird estimator, because high heterogeneity precluded use of a fixed effects model.[12,13] All outcomes of analysis were reported as the weighted average of SMD with a 95% confidence interval. An SMD score of 0.2 to 0.49 was considered weak, a score of 0.5 to 0.79 was moderate, and a score of $\geq$ 0.8 was considered large.[14]

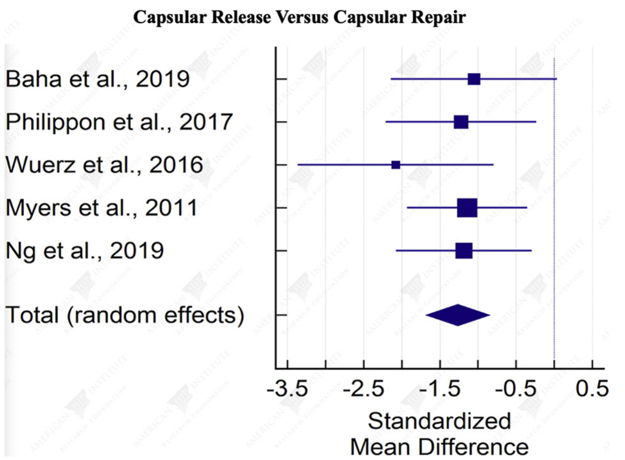

Fig 1. Forrest plot demonstrating change in total ROM (internal and external) between the capsular release and capsular repair states.

Results

Study Identification

After our initial search in PubMed and Embase with the selected keywords, this study identified 1445 studies (Fig 3). After removing review articles, duplicates, technique reports, case reports, clinical studies, and non-English studies, we obtained 899 total articles. We then evaluated abstracts and removed studies that were irrelevant on the basis of our inclusion criteria. We identified 46 articles for full-text review. An additional 22 studies were excluded, leaving 24 studies that were included. The included studies primarily evaluated rotation/translation in 11 studies,[5,10,15-23] distraction in 3 studies,[24-26] the capsular role in microinstability in 4 studies,[27-30] allograft reconstruction in 3 studies,[31-33] and anatomic properties in 3 studies.[8,9,34]

Multiple biomechanical cadaveric studies have been performed to assess hip instability and compare the profiles of the intact, released, repaired, and reconstructed capsule (Table 1). Eight biomechanical studies performed a capsular repair in comparison to a capsular release state.[15-17,21,22,24,25,33] A control group consisting of hips with intact capsules was used for comparison in all of these studies. Surgical technique and experimental scenarios varied among studies and included investigation of T-capsulotomy and T-capsulotomy repair in 3 of the 8 studies.[15,16,24] Two studies investigated resistance to torsional load applied to the hip joint, and 3 studies evaluated distractive stability of the hip joint.[16,17,24-26] Chahla et al.[15] sought to determine the failure torques of 1-, 2-, and 3-suture repair constructs for hip capsular closure to resist external rotation and extension after standard anterosuperior interportal capsulotomy (12 to 3 o'clock). Eighteen cadaveric specimens were tested in a dynamic biaxial testing machine and were externally rotated until they reached repair failure. The median failure torque was 67.4 N·m (range, 47.4-73.6 N·m) for the 1-suture construct, 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). They concluded that the 3-suture construct was significantly stronger than the 1-suture construct; however, there was no significant difference between the 2- and 3-suture constructs. All constructs failed at approximately 36° of external rotation (Fig 4). All studies reported improvements in rotational stability after capsular repair compared to a capsular release state.

Four studies evaluated capsular laxity and its effects on range of motion stability, and all demonstrated decreased biomechanical stability compared to a native capsular state.[27-30] Two studies simulated an attenuated anterior hip capsule with pie crusting, and 2 studies achieved this with cyclical loading. All 4 studies investigated stability as measured by internal and external range of motion, and 3 studies evaluated femoral head translation with a stereoscopic camera system as a measure of femoral head translation. All studies concluded that capsular laxity can lead to hip microinstability as evidenced by increased joint rotation and femoral head translation in the attenuated capsule state.

Three studies evaluated the effects of capsular reconstruction compared to a capsular defect state.[31-33] Two studies used an IT band allograft for reconstruction, and 1 study used a dermal allograft. Two studies evaluated distractive stability of the hip using materials testing systems (Fig 5), and 1 study used a 6-degree-of-freedom robot to test for rotational stability at various hip positions (Fig 6). All demonstrated improvements in rotational stability compared to an intact state.

Nine of the 24 biomechanical studies were included in the quantitative analysis.[5,15,16,21,27,27,29,30,33] Five studies were performed on native capsules, and 4

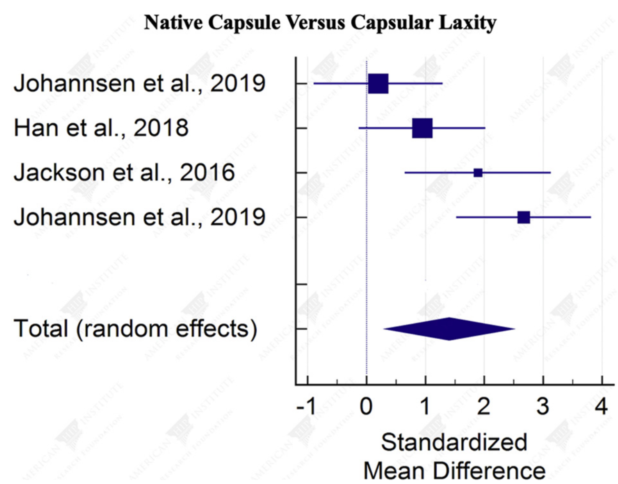

Fig 2. Forrest plot demonstrating change in total ROM (internal and external) between the native capsule and capsular laxity states.

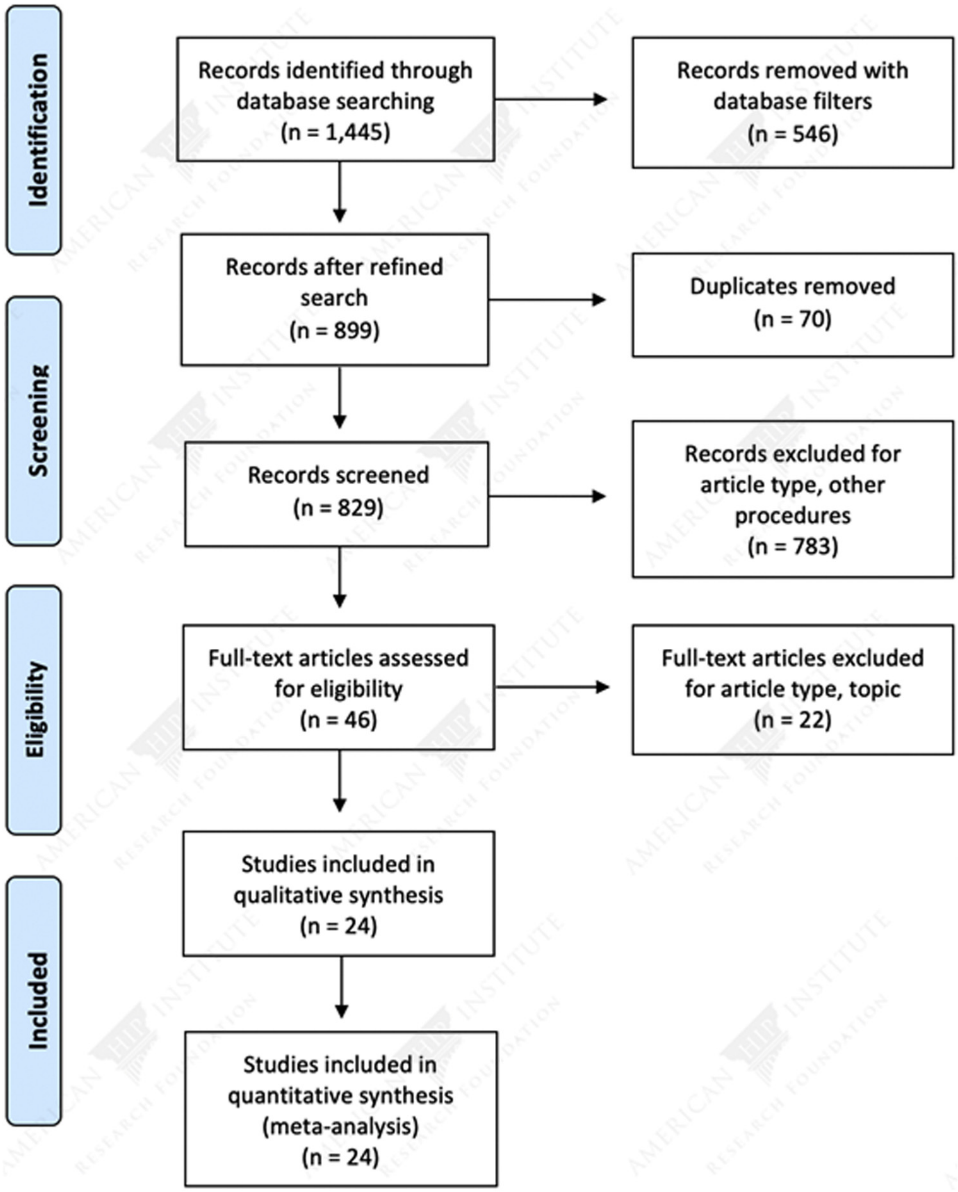

Fig 3. Preferred reporting items for systematic reviews and meta-analysis flow diagram for literature review.

studies were performed in an anterior capsular laxity model. All studies used similar experimental conditions. Fresh frozen cadaveric hips were mounted on custom hip testing systems and analyzed under various conditions of intact capsule, capsulotomy, and capsule repair states. For the studies investigating anterior capsular laxity, specimens were analyzed under intact, attenuated anterior capsule and capsular repair states. For total range of motion (internal and external), the SMD between experimental (capsular repair) and control (capsular release) was −1.3° (95% CI −1.68, −0.854; $P < .001$, $I^2 = 0\%$). In the capsular laxity studies, the anterior capsule was attenuated by either pie crusting or by cyclic stretching. For total range of motion (internal and external), the SMD between experimental (capsular laxity) and control (intact) was 1.4° (95% CI 0.32, 2.49; $P = .012$; $I^2 = 76.0\%$). The forest plots for total range of motion in the native capsule and capsular laxity settings are demonstrated in (Figs 1 and 2).

Discussion

The most important finding of the study was that capsular repair and capsular reconstruction improved hip stability compared to the capsulotomy and capsular deficiency states, respectively. In microinstability modes, anterior capsular laxity resulted in significantly decreased hip stability compared to the intact state. The hip capsule has a crucial role in native hip function, and both interportal capsulotomy and T-capsulotomy result in significant decreases in hip distractive force and increases in hip ROM compared to the intact state. Capsular repair demonstrated improvements in total

Table 1. Summary of Included Biomechanical Studies

Title	Author	Year	Purpose, Results, and Conclusions	Limitations
Biomechanical Response to Distraction of Hip Capsular Reconstruction With Human Acellular Dermal Patch Graft	Jacobsen et al.	2020	Jacobsen et al. wanted to quantify the biomechanical properties of the hip capsule with human dermal allograft reconstruction to determine whether a dermal patch restored capsular resistance to distraction. The mean distractive force requirements in each condition were as follows: intact (228 N), capsulotomy (208 N), capsulectomy (159 N), and patch (217 N). They found that human dermal allograft provides restoration of distractive strength for use during hip capsule reconstruction with acetabular anchor fixation and distal soft-tissue fixation after capsulectomy in a cadaveric model.	Small sample size; all other soft tissues were removed from the specimens; advanced mean age of specimens; no screening of specimens for arthritic changes; time-zero collection of data
Complete Capsular Repair Restores Native Kinematics After Interportal and T-Capsulotomy	Baha et al.	2019	Baha et al. investigated the biomechanical effect of capsulotomy and capsular repair techniques on hip joint kinematics in varying combination of sagittal and coronal joint positions. The mean IR/ER range of motion values at neutral in the T-capsulotomy condition was 55.96° ± 6.11°, 44.92° ± 7.35° in the intact state, 60.09° ± 6.82° in the interportal capsulotomy state, and 60.09° ± 6.82° in the portal state. They found that across all conditions, complete capsular repair after interportal or T-capsulotomy restored rotational range of motion and joint translation to values observed in the native joint.	Small sample size, multiple comparisons, and reduced power; use of elderly specimens; time-zero kinematics; testing order not randomized; no dynamic muscle loading or physiological joint loading
Contributions of the Capsule and Labrum to Hip Mechanics in the Context of Hip Microinstability	Johannsen et al.	2019	Johannsen et al. wanted to determine the relative role of anterior capsular laxity and labral insufficiency in atraumatic hip microinstability. The mean increases in IR-ER values at neutral in each condition were as follows: capsule intact + labral insufficiency (1.3° ± 0.6°, capsular laxity (4.7° ± 1.7° relative to vented state), capsular laxity + labral insufficiency (0.6° ± 0.9° relative to laxity state). They found that both the anterior capsule and labrum played a role in hip stability. The anterior hip capsule was the primary stabilizer to femoral head translation, but labral tears in the setting of capsular laxity produced the most significant increases in femoral head translation.	The effect of venting was not reported; testing was only performed in 0° extension and maximal extension; capsulotomy was performed in labral insufficiency state.
The Role of Anterior Capsular Laxity in Hip Microinstability: A Novel Biomechanical Model	Johannsen et al.	2019	Johanssen et al. wanted to determine the role of capsular laxity in atraumatic hip microinstability. The mean increase in IR-ER at neutral in the capsular laxity state compared to the vented state was 4.5° ± 1.7°. They found that the anterior hip capsule played an important role in controlling hip rotation and femoral head displacement. Capsular laxity increased hip IR-ER range of motion and femoral head displacement.	Did not address condition that may alter pelvic tilt and hip biomechanics; cumulative forces from weightbearing, muscle contraction, and gravity may be different than forces applied in testing; extension torque determined before stretching as a firm endpoint but was not quantified
Hip Joint Torsional Loading Before and After Cam Femoroacetabular Impingement Surgery	Ng et al.	2019	Ng et al. examined the contributions of the capsule and cam deformity to hip joint mechanics by testing the effects of the surgical capsulotomy, cam resection, and capsular repair on passive range of motion and resistance of applied torque. The mean increase in IR at neutral after capsulotomy was 5° compared with intact hip. They found that the capsule played a predominant role in joint constraint; however, the cam deformity was responsible for a substantial amount of torsional resistance during hip flexion and internal rotation by pressing on the chondrolabral junction. The cam deformity provided 21% to 27% of the intact hip's resistance to torsional load in flexion and internal rotation. Resecting the deformity removed this loading on the chondrolabral junction.	Only young male specimens; muscles not included in experiments; unknown if specimens had clinical symptoms of FAI that qualified them as candidates for surgery; performed T-capsulotomy instead of an interportal-only capsulotomy; small compressive load applied during testing; time-zero analysis

(continued)

Table 1. Continued

Title	Author	Year	Purpose, Results, and Conclusions	Limitations
Effects of Capsular Reconstruction With an Iliotibial Band Allograft on Distractive Stability of the Hip Joint: A Biomechanical Study	Fagotti et al.	2018	Fagotti et al. evaluated the biomechanical effects of capsular reconstruction of distractive stability of the hip joint. The median force at maximum distraction was 156 N in the capsular reconstruction state, 89 N in the capsular defect state, and 218 N in the intact state. The found that capsular reconstruction with an ITB allograft significantly increased the force required to distract the hip compared with a capsular defect. Capsular reconstruction with an ITB allograft significantly increased distractive stability and should be considered an effective treatment option for patients with symptomatic capsular deficiency.	Small sample size; time-zero analysis; initial positioning of 15° static flexion may have affected capsular resistance to distraction; repeated distraction of capsule
Does Capsular Laxity Lead to Microinstability of the Native Hip?	Han et al.	2018	Han et al. wanted to determine the relationship between capsular laxity and abnormal rotation and translation of the hip. The overall increases in IR and ER were 3.1° ± 1.6° and 4.1° ± 2.7°, respectively. They found that the native hip approximates a concentric ball-and-socket within 30° of flexion; however, beyond 30°, the femoral head translation reached as high as 4 mm. Capsular laxity leads to microinstability of the hip as indicated by significantly increased joint rotations and femoral head translations and an abnormal movement path of the femoral head center. There was no correlation between rotational laxity and the increase in femoral head translation.	Unknown whether pie-crusting technique used leads to same distribution of tissue properties observed in patients with increased joint laxity; muscles and other soft tissues around hip were removed from specimens; role of labrum was not analyzed
Vertical Extension of the T-Capsulotomy Incision in Hip Arthroscopic Surgery Does Not Affect the Force Required for Hip Distraction: Effect of Capsulotomy Size, Type, and Subsequent Repair	Weber et al.	2018	Weber et al. wanted to quantify how increasing interportal capsulotomy size, conversion to T-capsulotomy, and subsequent repair affect the force required to distract. The mean distractive forces were as follows: intact state (274.6 ± 71.2 N), capsular repair (331.7 ± 103.7 N), 2-cm interportal state (209.7 ± 73.2 N), 4-cm interportal state (160.4 ± 79.8 N). They found that conversion of interportal capsulotomy to T-capsulotomy did not significantly affect the force required to distract the hip. Larger interportal capsulotomies resulted in significant stepwise decreases in distraction force. When performing interportal or T-capsulotomy, the iliofemoral ligament strength is significantly decreased. Complete capsular repair demonstrated the ability to restore joint stability to the native, intact hip.	Pure axial distraction; use of older specimens; did not test the repair groups to failure; subtle differences in body morphology not assessed; possible exhaustion of capsular tissue
The Effect of Capsulectomy on Hip Joint Biomechanics	Bakshi et al.	2017	Bakshi et al. evaluated anterior hip stability in capsular sectioned states with a labral injury to test whether the load required for anterior translation would decrease with greater capsular injuries. The mean loads for each condition were as follows: all-intact (160.8 N); sutured-intact (160.2 N), sutured-labrectomy (158.3 N), partial capsulectomy (122.8 N), total capsulotomy (99.3 N). They found that the capsule/labrum played an important role in anterior hip stability and the iliofemoral ligament was crucial for preventing anterior translation in labral-injured states. The ischiofemoral and pubofemoral ligaments provided resistance to anterior translation in iliofemoral- and labral-deficient states. Intraoperative capsulectomy should be avoided in patients with large, irreparable labral tears to prevent postoperative anterior hip instability.	Small sample size; specimens had normal hip morphology and joint surfaces; time-zero evaluation; total capsulectomy state unlikely and may not be clinically relevant; role of ischiofemoral and pubofemoral ligaments not evaluated individually

(continued)

Table 1. Continued

Title	Author	Year	Purpose, Results, and Conclusions	Limitations
Hip Capsular Closure: A Biomechanical Analysis of Failure Torque	Chahla et al.	2017	Chahla et al. wanted to determined the failure torques of 1-, 2-, and 3-suture constructs for hip capsular close to resist external rotation and extension after standard anterosuperior interportal capsulotomy (12 to 3 o'clock). The median failure torque in each construct was a follows: 1-suture construct (67.4 N·m), 2-suture construct (85.7 N·m), 3-suture construct (91.7 N·m). They found that the 2- and 3-suture constructs resulted in comparable biomechanical failure torques when external rotation forces were applied to conventional hip capsulotomy. The 3-suture construct was significantly stronger than the 1-suture construct; however, there was no significant difference between the 2- and 3-suture constructs. All constructs failed at approximately 36° of external rotation.	Time-zero analysis; all other soft tissues removed from specimens; used dynamic testing machine, and its maximal torque of 100 N·m did not accommodate failure for some 2- and 3-suture constructs.
Effects of Hip Joint Transverse Plane Range of Motion With a Modeled Effusion and Capsular Tear: A Cadaveric Study	Herbert et al.	2017	Herbert et al. wanted to determine the effect of multiple portals piercing the capsule during hip arthroscopy or the residual effects of an effusion on the hip joint and transverse plane limits of motion. The modeled effusion had 4.1° less external rotation at 0° flexion. They found that in hips with traumatic capsular tears or arthroscopic portals, an effusion may decrease the rotation of the hip, and a capsular tear may increase its rotation. Transverse plane rotation decreased with 10 mL joint effusion. Capsular incision at the 12 o'clock position may release the intra-articular negative pressure effect and allow increased rotation in 0° and 90° of flexion.	Capsular venting and transection of surrounding capsule
The Effect of Capsulotomy and Capsular Repair on Hip Distraction: A Cadaveric Investigation	Khair et al.	2017	Khair et al. wanted to quantify how increasing interportal capsulotomy size affects the force required to distract the hip and also wanted to biomechanically compare simple side-to-side suture repair to acetabular-based suture anchors as capsular techniques. The distractive forces for each condition were as follows: side-to-side suture repair (257.0 ± 82.2 N), suture anchor-based repair (302.8 ± 68.8 N), repaired capsule (279.9 ± 76.1 N), intact state (301 ± 100 N). They found that an interportal capsulotomy significantly affected the force required to distract the hip, with the larger the size of the capsulotomy resulting in less force required to distract the hip.	Pure axial distraction; use of older specimens; did not test the repair groups to failure; capsular redundancy; subtle differences in body morphology not assessed; possible exhaustion of capsular tissue
Biomechanical Assessment of Hip Capsular Repair and Reconstruction Procedures Using a 6 Degrees of Freedom Robotic System	Philippon et al.	2017	Philippon et al. biomechanically evaluated the effects of several arthroscopically relevant conditions of the capsule through robotic, sequential section. They found that common hip arthroscopic capsulotomy procedures can result in increases in external, internal, abduction, and adduction rotations throughout a full range (−10° to 90°) of hip flexion. Capsular repair and reconstruction succeeded in partially reducing this increased rotational ROM. Thus consideration should be allotted toward capsular repair or reconstruction in cases with an increased risk of residual instability.	Small sample size; only male specimens with increased age and BMI used; pure rotation simulated examinations

(continued)

Table 1. Continued

Title	Author	Year	Purpose, Results, and Conclusions	Limitations
Contribution of the Pubofemoral Ligament to Hip Stability: A Biomechanical Study	Martin et al.	2017	Martin et al. wanted to determine the isolated function of the pubofemoral ligament of the hip capsule and its contribution to hip stability in external/internal rotational motion during flexion greater than 30° and abduction. Hip IR was increased up to 438.9% when the pubofemoral ligament was released and 412.9% when the pubofemoral and teres ligaments were released. They found that the pubofemoral ligament maintains a key function in limiting internal rotation in the position of increasing hip flexion beyond 30° and abduction.	Human error during may have affected positions during testing; less-than-ideal measures regarding femoral and acetabular version
Capsulotomy Size Affects Hip Joint Kinematic Stability	Wuerz et al.	2016	Wuerz et al. evaluated the effect of capsulotomy size and subsequent repair on the biomechanical stability of the hip joint through external rotation of a hip in neutral flexion. The findings for ROM were as follows: intact (1000%), 4-cm capsulotomy (107.42%), 6-cm capsulotomy (113.4%), and repair (99.78%). They found that larger sized capsulotomies were accompanied by increases in 3 measures of joint mobility: range of motion, hysteresis area, and neutral zone. Complete capsular closure effectively restored these measure when compared with the intact condition.	Advanced mean age of cadavers; mini-open dissection as opposes to an arthroscopic procedure; only analyzed movements in pure external and internal rotation; specimens not tested in hyperextension; underpowered for some comparisons
Biomechanical Effects of Capsular Shift in the Treatment of Hip Microinstability: Creation and Testing of a Novel Hip Instability Model	Jackson et al.	2016	Jackson et al. created a cadaveric model of hip capsule laxity and evaluated the biomechanical effects of a capsular shift to treat instability in this model. They found that interportal capsulotomy increased total range of motion, external rotation, and extension compared with the intact condition. In addition, capsule repair restored internal rotation, but not to the intact state, at 0° and 5° of extension; restored external rotation at all degrees of ROM; restored distraction, but not to the intact state; and restored extension. Finally, the greatest effects of capsular shift were seen with internal rotation, maximum extension, and distraction, with minimal effect of external rotation compared with side-to-side repair.	Time-zero collection of data; small sample size; no radiographic data of specimens
Biomechanical Evaluation of Capsulotomy, Capsulectomy, and Capsular Repair on Hip Rotation	Abrams et al.	2015	Abrams et al. wanted to determine the effect of different types of capsulotomies on hip rotational biomechanical characteristics. The mean external rotation at neutral flexion in each condition was as follows: T-capsulotomy (91.1° ± 19.6°), intact (83.2° ± 20.5°), and complete repair (87.4° ± 20.6°). They found that a T-capsulotomy showed significantly increased external rotation versus the intact and interportal capsulotomy states. The repaired T-capsulotomy restored the rotational profile back to the native state. Capsulotomy and capsulectomy did not restore the external rotation restraint of the hip to its native state.	Bony morphology not addressed; testing order not randomized; neutral position only; underpowered
Effect of Capsulotomy on Hip Stability—A Consideration During Hip Arthroscopy	Bayne et al.	2014	Bayne et al. wanted to see the effect of capsulotomy on hip joint stability. They evaluated rotation and translation after capsulotomy in neutral and in flexion. Neutral showed more translation than rotation. Flexion showed more rotation than translation.	Small sample size; bony morphology not addressed

(continued)

Table 1. Continued

Title	Author	Year	Purpose, Results, and Conclusions	Limitations
Role of the Acetabular Labrum and the Iliofemoral Ligament in Hip Stability: An In Vitro Biplane Fluoroscopy Study	Myers et al.	2011	Myers et al. wanted to determine the relative contributions of the labrum and iliofemoral ligament in maintaining hip joint stability as measured by external rotation, internal rotation, and anterior translation of the femur relative to the center of the acetabulum. They found that the iliofemoral ligament had a significant role in limiting external rotation and anterior translated of the femur. The labrum provided a secondary stabilizing role in limiting external rotation and anterior translation of the femur. No difference in external rotation or anterior translation was found between the intact and repaired capsule. Careful repair of an arthroscopic capsulotomy should be performed to avoid increased external hip rotation and anterior translation after arthroscopy.	No compression applied to cadavers during testing; only male specimens
The Proximal Hip Joint Capsule and the Zona Orbicularis Contribute to Hip Joint Stability in Distraction	Ito et al.	2009	Ito et al. wanted to evaluate the contribution of the zona orbicularis in the hip joint in distraction. They found that the proximal to middle part of the capsule, which includes the zona orbicularis, appeared grossly and biomechanically to act as a locking ring wrapping around the neck of the femur and was a key structure for hip stability in distraction.	Small sample size; only male specimens
The Function of the Hip Capsular Ligaments: A Quantitative Report	Martin et al.	2008	Martin et al. wanted to analyze the anatomy and quantitative contributions of the hip capsular ligaments. The major increases in internal and external rotation ROM occurred when the hip was in 90° or 120° of flexion. They found that the ischiofemoral ligament controlled internal rotation in flexion and extension. The lateral arm of the iliofemoral ligament had dual control of external rotation in flexion and both internal and external rotation in extension. The pubofemoral ligament controlled external rotation in extension with contributions from the medial and lateral arms of the iliofemoral ligament.	Analysis of 4 *df*; testing not randomized
Spatial Distribution of Hip Capsule Structural and Material Properties	Stewart et al.	2002	Stewart et al. wanted to describe the mechanical properties of the hip capsule. They found that the hip capsule was an irregular structure composed of mostly dense tissue, with its 3 major thickened regions (ligaments) containing layers of fibers each oriented in generally the same direction. The posterior capsule was the weakest, and the anterior portion was the strongest.	Some fibers were cut across rather than parallel; small sample size
The Mechanical Properties of the Human Hip Capsule Ligaments, Regional Material Properties of the Human Hip Joint Capsule Ligaments	Hewitt et al.	2002, 2001	Hewitt et al. wanted to provide information about the mechanical properties of the hip capsule. They found that the anterior ligaments, consisting of the 2 arms of the iliofemoral ligament, were much stronger than the posterior ischiofemoral ligament, withstanding greater force at failure and exhibiting greater stiffness.	Small sample size

ER, external rotation; FAI, femoroacetabular impingement; IR, internal rotation; ITB, Iliotibial band.

motion in the coronal plane, maximum distractive force, and torsional stability compared to a capsular release. Capsular reconstruction demonstrated improvement in total motion in the coronal plane and maximum distractive force compared to a capsular deficient state. Capsular laxity resulting from anterior capsule attenuation resulted in increased femoral head translation and increased coronal plane motion

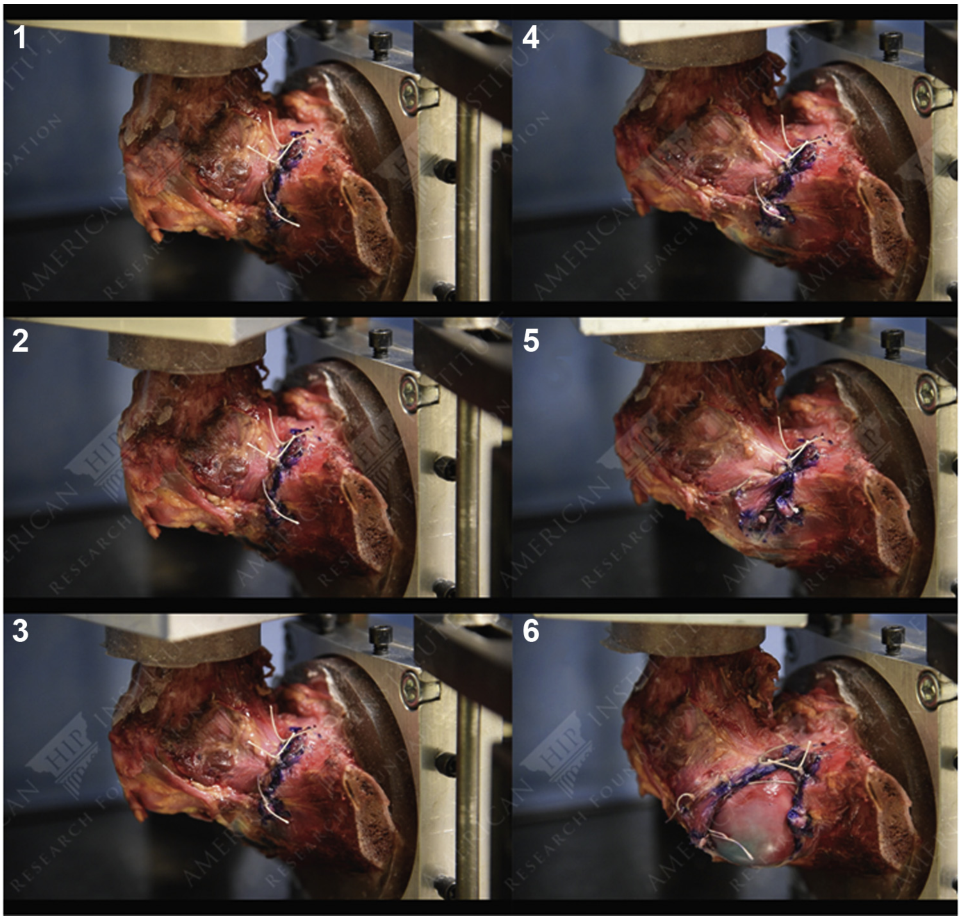

Fig 4. Annotated experimental image from Chahla et al.[15] demonstrating the sequence of failure mechanism of a 2-suture capsular closure construct on a left hip. The sequence demonstrates progressive external rotation until failure of the capsule sutures (progressive external rotation in images 1 through 6).

compared to the native capsule. Pooled analysis of the available biomechanical studies demonstrated significantly improved stability in coronal plane range of motion in the capsular repair group compared to a capsular release group.

The results suggest that from a biomechanical standpoint, repairing the capsule provides better biomechanical results, specifically maximum distractive force, torsional stability and coronal plane range of motion, than leaving it unrepaired.[5,8-10,15-34] Eight biomechanical studies performed a capsular repair in comparison to a capsular release state.[15-17,21,22,24,25,33] A control group consisting of hips with intact capsules was used for comparison in all of these studies. T-capsulotomy and T-capsulotomy repair were investigated in 3 of the 8 studies.[15,16,24] Two studies reported resistance to torsional load applied to the hip joint and three studies evaluated distractive stability of the hip.[16,17,24-26] This correlates with comparative clinical outcome studies by Frank et al.[35] and more recently Domb et al.[36] in which patients who had unrepaired capsules had deterioration in mHHS as well as a higher rate of conversion to arthroplasty compared to a matched repair group at midterm follow up.

Even in the absence of a capsulotomy, anterior capsule attenuation results in an altered biomechanical profile of the hip and plays a major role in hip microinstability. Cases of dislocation or subluxation after hip

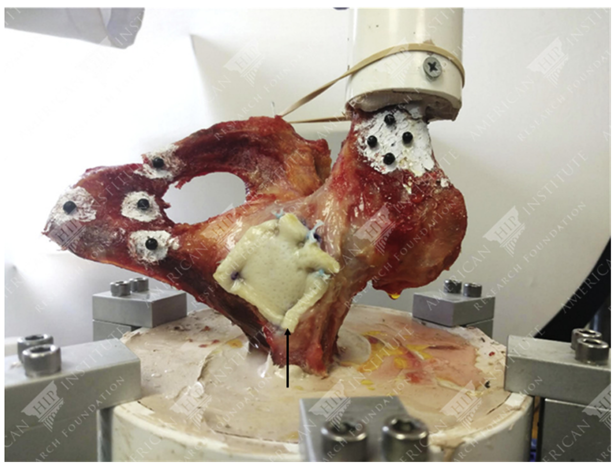

Fig 5. Experimental photograph from Jacobsen et al.[23] demonstrating their reconstruction of a right hip capsule after capsulectomy using dermal allograft patch (black arrow), camera markers, and biomechanical testing set up.

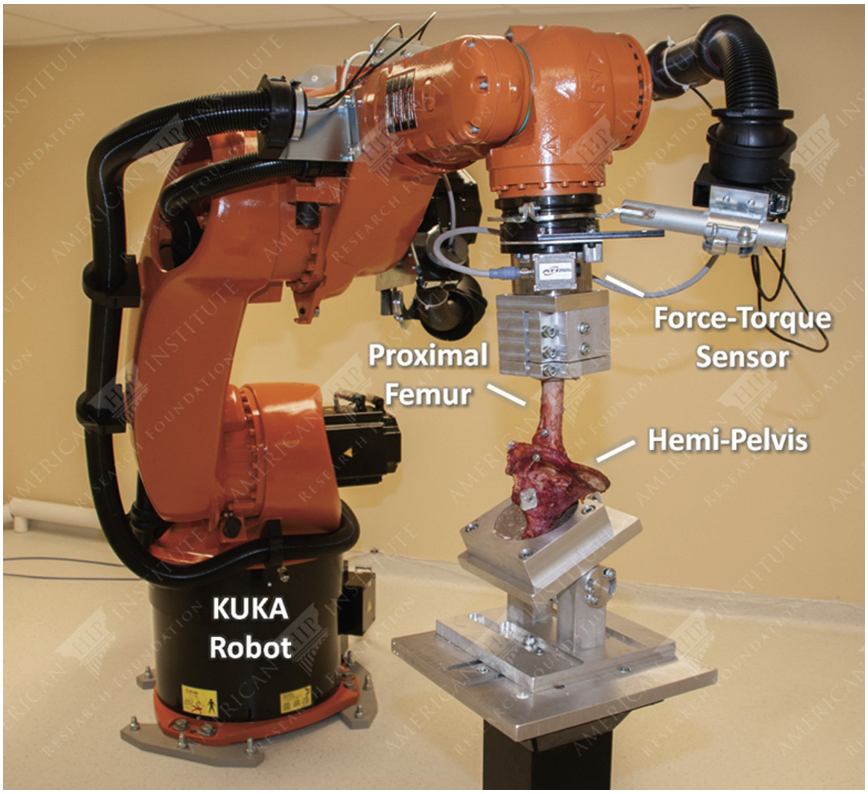

Fig 6. Annotated experimental photograph from Philippon et al.[20] showing biomechanical testing setup for a right hip using a 6-degrees-of-freedom robotic system.

arthroscopy raise concerns about postoperative or even iatrogenic instability, especially given the rapid increase of hip arthroscopic procedures being performed. Capsular release was performed in several case reports of postoperative instability, and hip capsule release should be considered a risk factor for instability after hip arthroscopy.[37-40] Additionally, 2 systematic reviews concluded that postarthroscopic hip instability was observed in patients with acetabular undercoverage (including iatrogenic resection), labral debridement, capsular insufficiency, or iliopsoas tenotomy which can all serve as potential indications for capsular repair.[41,42] Capsular laxity was implicated as a major contributor to microinstability in 4 biomechanical articles included in this review. Their analysis demonstrated decreased rotational stability and increased femoral head translation of the tested hips when the anterior capsule was attenuated. Two studies attenuated the capsule with pie crusting, and 2 studies attenuated the anterior capsule with cyclical loading. This corroborates clinical outcomes studies of 2 patient populations who would be at risk of having attenuated anterior capsules. The first is patients who had failure of their primary surgery and required arthroscopic revision. In these patients, capsular repair or plication has been found to be a significant predictor of better outcomes.[43-45] The second involves patients with borderline dysplasia where outcome studies have strongly supported capsular closure or plication.[46-48] Quantitative analysis of the studies investigating microinstability demonstrated significantly increased coronal plane range of motion and femoral head translation in the capsular laxity group compared to a native capsule group.

Literature on capsular reconstruction has started to emerge in recent years. Different techniques for capsular reconstruction have been described using iliotibial band allograft, Achilles allograft, and human dermal allograft.[49-52] In this review, two studies investigated the biomechanical results of an iliotibial band allograft and tested them for maximum distractive force in a materials testing system. One study tested a human dermal allograft using a 6-degree-of-freedom robot and was able to test for total coronal plane ROM at varying levels of hip flexion. These studies found that capsular reconstruction significantly improved rotational stability and restored distractive stability. The promising biomechanical data on capsular reconstruction has been supported by early outcomes data in the literature.[53]

Biomechanical studies have been important in the progression of hip preservation surgery and provide valuable information about the capsular anatomy and function. They allow for testing the performance of innovative techniques such as capsular reconstruction and help to provide clarity to complex conditions such as hip microinstability. Biomechanical studies are not without limitations. In all studies, surrounding soft tissues were dissected and removed from the specimens. This allowed for testing of the capsular structures, but the removed tissue may have a synergistic role with the capsule in maintaining hip joint stability. Another inherent limitation to biomechanical studies is that they do not take into account progressive degeneration or healing and do not necessarily correlate with clinical outcomes.

Limitations

The limitations of this systematic review mainly stem from the heterogeneity among the included studies. There was significant variability related to the type of capsulotomy, capsular repair technique, biomechanical testing setup, outcomes evaluated in the studies, and all of the studies tested specimens who were regarded as older than the typical hip preservation patient. Furthermore, the nature of instability created in the biomechanics model was iatrogenic in nature and different from in vivo instability seen in patients. Last, biomechanical studies of the hip capsule not related to hip arthroscopy were excluded from the present study. Despite these limitations, the current biomechanical evidence supports routine capsular closure in most cases and provides kinematic data to support capsular reconstruction techniques. Limitations of the individual studies included in this review can be found in Table 1.

Conclusions

Biomechanical evidence supports closure of the capsule after hip arthroscopy to reverse the significant effects of capsulotomy. Simulated capsule laxity models created altered joint motion and translation. Capsule reconstruction appears to restore the hip to its native capsule state.

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