Is there enough evidence to support hip capsular reconstruction? A systematic review of biomechanical studies

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This study was performed in accordance with the ethical standards in the 1964 Declaration of Helsinki. This study was carried out in accordance with relevant regulations of the US Health Insurance Portability and Accountability Act (HIPAA). Details that might disclose the identity of the subjects under study have been omitted. This study was approved by the IRB (IRB ID: 5276).

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ABSTRACT

The aim of this study was to review and summarize the available biomechanical data on hip capsular reconstruction to guide clinical decision-making. A literature search was completed in December 2020 using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines to identify biomechanical cadaver studies on hip capsular reconstruction, hip capsulectomy or hip capsular defect. The investigated parameters included maximum distraction force, capsular state affecting range of motion (ROM), rotation and translation. Four studies met al. the inclusion–exclusion criteria. The median effective force for resisting maximum distraction for the reconstruction state, capsular defect state and the intact state was 171, 111 and 206 N, respectively. The defect capsule force was significantly lower ($P = 0.00438$) than the intact capsule force. The reconstruction state had a higher distraction force than that of the capsular defect, but due to heterogeneity, the overall effect size was not statistically significant. The capsular reconstruction state reduced excess motion and the degree of instability compared to the capsular defect state but restored the hip close to its native capsular state in the cadaveric model. When compared to capsulectomy/defect state, hip capsular reconstruction significantly improved the rotational stability and effective force at maximum distraction and minimized translation. However, no conclusions can be made regarding the most effective protocol due to the high heterogeneity between the four studies. Further biomechanical studies are needed to test various types of grafts under the same protocol.

INTRODUCTION

Capsuloligamentous structures are the fundamental stabilizers that prevent dislocating forces on the hip joint [1, 2]. After the suction seal of the chondrolabral junction against the femoral head, the capsule may be the most important structure that resists distraction [1–4]. Periportal capsulotomy, capsulotomy without closure, capsular release, repair, plication and reconstruction have all been presented in literature for addressing the resulting capsular defect during hip arthroscopy [5–11]. However, there have been reports of iatrogenic hip dislocation or recurrent instability following hip arthroscopy. This type of iatrogenic hip instability can possibly be attributed to the underlying damage to the hip joint capsule from aggressive capsular management strategies such as large capsulotomy with absent or inefficient repair methods [3, 12–15]. Microinstability and, sometimes, gross hip instability from iatrogenic capsular deficiency are a cause for recurrent symptoms following primary and revision hip arthroscopy [4, 16, 17]. However,

capsular reconstruction has been shown to restore joint kinematics and minimize instability-induced pain in such conditions [4, 16–19].

To date, there is no consensus regarding the best management approach for hip capsular deficiency [18–20]. Numerous techniques have been described for hip capsular reconstruction using varying graft choices including iliotibial band (ITB), Achilles tendon allograft and human dermal allograft—each having its own advantages and disadvantages [21–25]. The capsular reconstruction technique described using an ITB allograft showed short-term improvements in clinical outcomes [19]. However, this technique often required folding the graft multiple times to mimic the native capsular thickness, which potentially limited its use to only smaller capsular defects [19, 21]. Alternatively, the human dermal allograft also has comparable short-term clinical outcomes to that of ITB allograft but has similar size restrictions [19, 22, 23]. Conversely, larger capsular defects can be treated by using more robust capsular reconstruction techniques like the

Achilles tendon allograft [18, 24]. While this technique has been shown to result in a more anatomic reconstruction of the hip capsule, it cannot always be performed arthroscopically when the hip capsular defect is very large [18].

Previous biomechanical studies have reported on the importance of the hip joint capsule in controlling hip rotation and joint distraction under various loading conditions [2, 26–30]. However, few studies have actually examined the biomechanics of capsular reconstruction [29, 31–33]. In all studies, the different biomechanical effects of capsular reconstruction are compared against the intact and capsulectomy or capsular defect states in a cadaveric model [29, 31–33]. The limited kinematic data currently available from these studies do not support the use of any particular graft or technique over another [29, 31–33]. This discrepancy in the literature highlights the lack of compatibility and the need for an objective review of the available biomechanical data on the commonly performed capsular reconstruction procedures utilized during arthroscopic hip preservation surgery. The purpose of this study is to compare the biomechanical parameters among the different cadaveric studies that were available on the hip capsular reconstruction and to summarize the facts that are clinically relevant and would influence decision-making while treating hip instability.

METHODS
Study identification and search strategy

In December 2020, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used to find articles using PubMed and Embase. The following keywords were used in the literature search for data extraction: hip arthroscopy, hip capsule, cadaver hip, hip biomechanics, hip microinstability, hip gross instability, hip capsulectomy, hip capsular defect and hip capsule reconstruction. Two orthopedic surgeons (X.X.X. and Y.Y.Y.) 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 orthopedic surgeon (Z.Z.Z.) to ensure that the studies met the inclusion and exclusion criteria. Studies were included only if all reviewers came to a consensus.

Study eligibility

Studies were included in this systematic review if they evaluated cadaveric specimens, were written in English and focused on hip capsule biomechanics looking specifically into hip capsular reconstruction. The primary outcome variable was the maximum force required for distraction (N). Other investigated variables included ROM and rotation/translation as the secondary outcome variable. The graft type including technique, testing zig method and probe/optical tracker position were considered as independent variables. Articles were 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 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, USA). Data included title, author, journal and year of publication, study design, number of cadaveric specimens, outcomes and limitations.

Data collection and statistics

Biomechanical studies specifically looking at capsular reconstruction were grouped into two categories, looking at either the effective distraction force (N), which was the primary outcome variable, or the effect on the degree of ROM (°), which was the secondary outcome variable for this review. For studies that looked at effective distraction force, the standard mean differences (SMDs) were calculated between the experimental and control groups. The I^2 index was used to measure the heterogeneity of included studies [34]. Effect sizes were calculated using random-effects models with the DerSimonian–Laird estimator, as high heterogeneity precluded use of a fixed effects model [35, 36]. All outcomes of the analysis were reported as the weighted average of SMD with a 95% confidence interval (95% CI). SMD values ranging from 0.2 to 0.49 were considered weak, 0.5–0.79 were moderate and a score of $\geq$0.8 was considered large [37]. The Review Manager (RevMan, Version 5.4, The Cochrane Collaboration, 2020) was used for all data analysis regarding SMDs. The median and interquartile ranges (IQRs) were calculated for studies that only reported means with the assumption that the data followed a log-normal distribution using the method detailed by Johnson *et al.* [38]. Similarly, for studies that only reported median and IQRs, the mean and standard deviations were computed using the method detailed by Hozo *et al.* [39]. For studies that reported ROM, the percent increase was calculated from the mean and standard deviation of groups [29, 33]. All computations for *P* values were carried out using a linear random effect model using the log scale data. For this study, the threshold for statistical significance was set to $P < 0.05$. All other calculations described were performed in R (Version 3.4.0; R Foundation for Statistical Computing, Vienna, Austria).

RESULTS
Study identification

Our initial search in PubMed and Embase with the selected keywords identified 830 studies (Fig. 1). After removing articles that did not meet the database filter, there were 47 full-text articles that were reviewed for eligibility. We evaluated the abstracts and removed studies based on our inclusion criteria and found 25 biomechanical studies available for full-text review. An additional 21 studies were excluded based on the topic, leaving a total of four studies that specifically looked into evaluating hip capsular reconstruction, to be included for review in this study. All included studies primarily assessed the effect of hip capsular reconstruction on either the effective distraction force or the degree of ROM of the hip compared to the intact and capsulectomy or defect state (Table I). The four studies reviewed had a large variation among the extent of capsular defect, type and size of graft, reconstruction technique utilized and methodology. Considering this, the four studies show high heterogeneity,
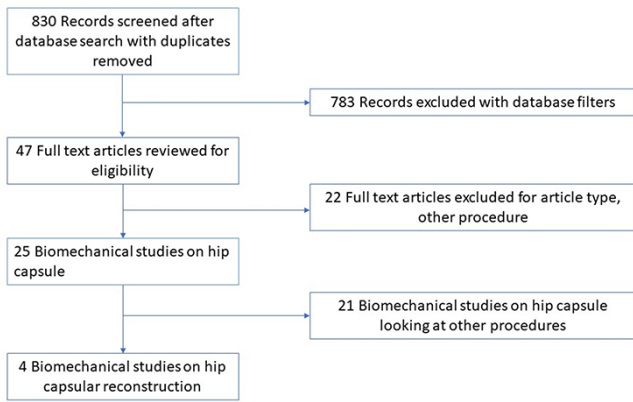
Fig. 1. PRISMA flow diagram for literature review.

which precluded us from a more in-depth analysis of the data, limiting our meta-analysis.

Two biomechanical cadaveric studies have been performed to assess the primary outcome variable, effective force at maximum distraction in capsular reconstruction state in comparison to an intact and a capsular defect state. Fagotti et al. studied eight fresh frozen cadaveric hip specimens that were distracted at 6 mm relative to the neutral position at a rate of 0.5 mm/s [31]. They studied three capsular states: intact, partial defect in the proximal and anterior aspects of the capsule and reconstruction with an ITB allograft. Similarly, Jacobsen et al. studied nine cadaveric hip specimens that were distracted at 5 mm relative to the neutral position [32]. However, Jacobsen et al. looked at four capsular states, including the intact capsule, inter-portal capsulotomy, capsulectomy to the zona orbicularis and capsular reconstruction

with a human dermal allograft [32]. Surgical techniques varied between the two studies [31, 32]. The overall median force for resisting maximum distraction for the reconstruction state, capsular defect state and the intact state was 171, 111 and 206 N, respectively (Table II).

For the overall median force difference between the two studies, when compared to the intact capsule, the effective distraction force of the defect capsule was statistically significantly lower ($P = 0.00438$) while the effective distraction force of the reconstructed capsule was different but not statistically significant enough when compared to intact state (Table III). The effective force recorded at maximum distraction for all capsular conditions from both Fagotti et al. and Jacobsen et al. are shown in Fig. 2.

Additionally, the SMD of distraction force for each capsular state from Fagotti et al. and Jacobsen et al. was calculated and shown in Fig. 3a and b. For distraction force, the SMD between the reconstruction state (experimental) and intact state (control) was −1.12 N (95% CI = −3.26, 1.02; $P = 0.31$; $I^2 = 86.0\%$). Likewise, the SMD between the capsular defect state (experimental) and the intact state (control) was −2.33 N (95% CI = −6.01, 1.35; $P = 0.21$; $I^2 = 91.0\%$). The reconstruction state was found to have a higher force when compared to the capsular defect state. However, the overall effect size was not found to be statistically significant, likely due to high heterogeneity.

The other two studies evaluated the secondary outcome variable, the effect on the degree of ROM in capsular reconstruction state compared to intact and capsular defect states. Philippon et al. studied 10 human cadaveric unilateral hip specimens on internal, external, abduction and adduction rotation torques throughout different degrees of hip flexion in reconstructed,

Table I. Summary of the included biomechanical studies

Authors	Purpose and conclusions	Limitations
Philippon et al. [29]	Philippon et al. biomechanically evaluated the effects of several arthroscopically relevant conditions of the capsule through a robotic, sequential sectioning study	-Time-zero cadaveric study -Limited sample of specimens tested -Simulated examinations of the hip may not be exact replicas of manual clinical examinations -Pure rotation simulated examinations may not be fully effective in characterizing hip stability
Fagotti et al. [31]	Fagotti et al. evaluated the biomechanical effects of capsular reconstruction on distractive stability of the hip joint	-Small sample size and study representing time-zero joint biomechanics -Lack of muscle forces to replicate in vivo picture and repeat testing leading to elastic tissue deformation
Jacobsen et al. [32]	Jacobsen et al. quantified biomechanical properties of the hip capsule with human dermal allograft reconstruction to determine whether a dermal patch restored capsular resistance to distraction	-Specimens were not screened for arthritis -Time-zero testing condition
Pasic et al. [33]	Pasic et al. compared the kinematic effect of two capsular reconstruction techniques (ITB graft and Achilles tendon graft) verifying rotational ROM as well as joint translation in the coronal, sagittal and axial planes	-Elderly cadaveric specimens, small sample size and study representing time-zero joint biomechanics limit generalizability -Differences in ITB elastic properties noted across specimens -Large standard deviations suggesting a high degree of inter-specimen variability -Distractive testing not done and likewise the testing protocol did not include/consider hip in extension

Table II. Summary of median and interquartile range (IRQs) for different capsular conditions (capsular reconstruction, capsulectomy/defect and intact states) for the two studies that were compared

Capsular reconstruction					
Study	*n*	*Q1*	*Median force (N)*	*Q3*	*Weight*
Fagotti, 2018 [31]	8	76	156	179	0.471
Jacobsen, 2020	9	129	187	270	0.529
Overall [32]	17		171		1.000
Capsular defect					
	n	*Q1*	*Median force (N)*	*Q3*	*Weight*
Fagotti, 2018	8	18	89	120	0.471
Jacobsen, 2020	9	93	136	198	0.529
Overall	17		111		1.000
Intact					
	n	*Q1*	*Median force (N)*	*Q3*	*Weight*
Fagotti, 2018	8	158	218	263	0.471
Jacobsen, 2020	9	135	196	284	0.529
Overall	17		206		1.000

Table III. Comparing overall median force (N) difference between Fagotti et al.'s [31] and Jacobsen et al.'s [32] studies

Comparison	*Median force difference (N)*	*P value[a]*
Reconstruction—capsular defect	60	0.1601
Reconstruction—intact	−34	0.3364
Capsular defect—intact	−95	0.0438

[a]Based on log-normal distribution.

intact and capsular defect states [29]. Philippon *et al.* used an ITB allograft to reconstruct the capsule [29]. Pasic *et al.* investigated eight paired, cadaveric pelvises and recorded rotational ROM and joint translation in the coronal, sagittal and axial planes while applying internal–external rotation and abduction–adduction rotation torques at different degrees of flexion [33]. Pairs were randomly allocated to either ITB or Achilles reconstruction and were compared to intact and capsulectomy conditions [33]. Philippon *et al.* reported that the defect state had higher percent increases than that of the reconstruction state at all flexion points for both external and adduction rotations (Figs 4 and 5).

Similarly, Pasic *et al.* found that both the reconstructed and capsular defect states had increased ROM at 45° and 90° flexion when compared to the intact state. At 90° flexion, the capsular reconstruction state showed a much lower increase in ROM than that of the defect state (Fig. 6). While both studies showed that the capsular reconstruction and defect states increased ROM at all flexion ranges, the reconstruction state performed the closest to the native intact state.

DISCUSSION

Hip capsular reconstruction fared close to the intact state in cadaver specimens regardless of graft type. Our analysis of the available biomechanical studies suggests that hip capsular

reconstruction performed kinematically better than the capsular defect state. However, we were unable to draw a meaningful conclusion as to the tested parameters, graft type or a specific reconstruction method since our meta-analysis relied on the included study data that is largely heterogenic.

Fagotti *et al.* noted a significantly higher median distractive force at 6 mm of hip distraction in the capsular reconstruction state compared to the capsular defect state [31]. Capsular reconstruction with an ITB allograft significantly increased distractive stability of the hip joint by 76% compared to the capsular defect in their study [31]. Notably, the distractive force of capsular reconstruction was 37% less than the intact state but 44% more than the capsular defect state [31]. In a similar manner, Jacobsen *et al.* demonstrated that the mean force required to resist 5 mm of distraction for the capsulectomy state was 30% lower than the intact state, while the mean force for capsular reconstruction with a dermal allograft patch was only 5% lower [32]. Comparing between two studies [31, 32], the overall median effective force (N) for resisting maximum distraction for the reconstruction state, capsular defect state and the intact state was 171, 111 and 206 N, respectively. Also, by comparing the SMDs, the reconstruction state was found to require a higher distraction force than the capsular defect state (−1.12 N vs −2.33 N), although the overall effect size was not statistically significant. These findings not only signify the role played by the intact hip capsule but also reiterate the need for capsular reconstruction in restoring gross hip stability [31, 32].

Philippon *et al.* noted that at different degrees of hip flexion, capsular reconstruction significantly reduced rotational ROM (external rotation and adduction rotation, in particular) in comparison to the defect state but remained higher than the intact state [29]. These authors theorized that while it was possible to decrease residual joint microinstability via reconstruction of the capsular defect, it is unknown if the observed rotational differences will be clinically relevant [29]. Likewise, Pasic *et al.* showed that at 90° of hip flexion, both reconstruction techniques utilizing ITB and Achilles tendon had significantly lower degrees of total rotation than the capsulectomy state with values similar to the intact state [33]. Increased coronal plane stability in the
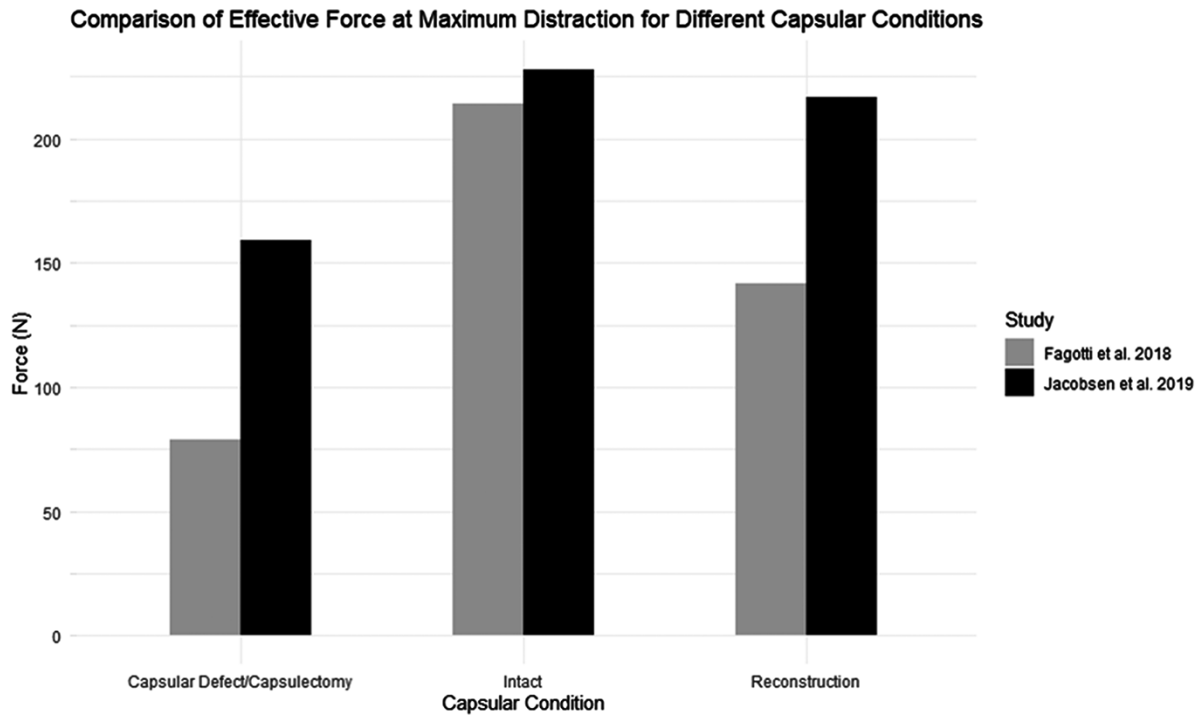
Fig. 2. Comparison of effective force recorded at maximum distraction (6 mm vs 5 mm) for different capsular conditions.
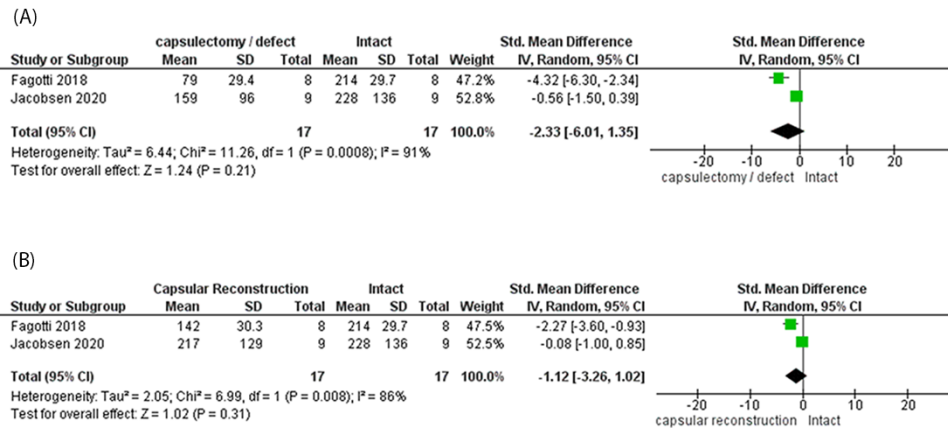

Fig. 3. Forest plot comparing the effective force recorded at maximum distraction (6 mm vs 5 mm) between Fagotti *et al.*'s study and Jacobsen *et al.*'s study, respectively. (A) Capsulectomy/defect vs intact state. (B) Capsular reconstruction vs intact state.

hip was also observed with capsular reconstruction, especially with the Achilles tendon allograft [33]. When comparing the two different allograft types, they found no significant differences in total internal rotation - external rotation (IR-ER) or abduction–adduction ROM or joint translation in the coronal, sagittal or axial planes at any given flexion angle [33]. Comparing effect on ROM between these two studies [29, 33]; the capsular reconstruction reduced the excess ROM and the degree of instability (translation in three different planes) when compared to the capsular defect. Even though both the reconstruction and defect states were inferior to the intact capsular condition; the defect state had higher percent increases in both external and adduction rotations at all flexion points, while the capsular reconstruction state showed a much lower increase in ROM at 90° flexion when compared to the defect state. Both these studies supported the

idea that capsular reconstruction minimized joint translation and is efficient in treating microinstability [29, 33].

Biomechanical data have been incredibly important in the advancements of hip arthroscopy, especially regarding hip capsular treatment. In summary, all studies presented in this systematic review demonstrated that hip capsular reconstruction significantly improved stability and hip ROM with testing values closest to the native intact state. This study supports the idea that there is a definitive role for capsular reconstruction in hip instability treatment, which has been previously backed by clinical studies [18–20].

This systematic review is based on the premise that the variables included in the individual studies had few comparable data points and all used differing graft types and methodology for their hip capsular reconstruction. There is a need for
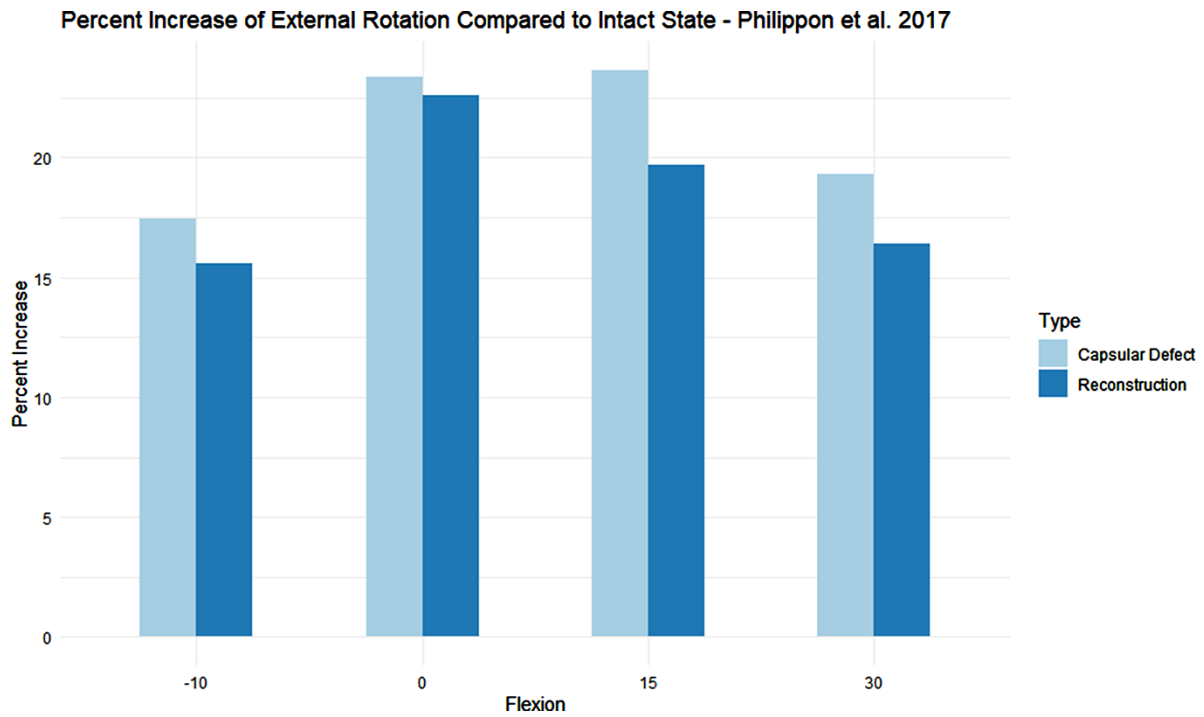
Percent Increase of External Rotation Compared to Intact State - Philippon et al. 2017

Fig. 4. Percent increase of external rotation compared to intact state (Philippon *et al.*'s study [29]).

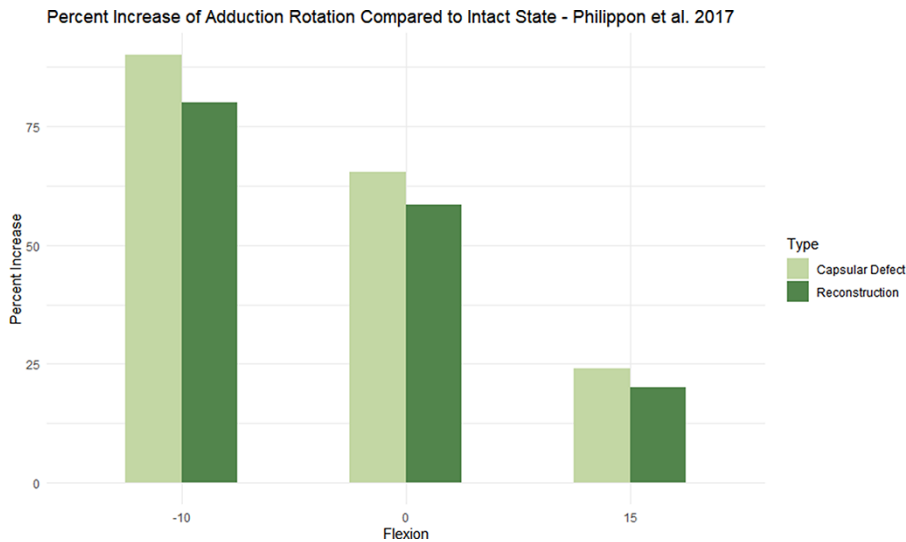Percent Increase of Adduction Rotation Compared to Intact State - Philippon et al. 2017

Fig. 5. Percent increase of adduction rotation compared to intact state (Philippon *et al.*'s study [29]).

further research with larger specimen numbers comparing different techniques and graft types using the same protocol as either cases or controls, while including the different parameters that were reviewed here. Future directions could focus on specific variables such as force required for a constant distraction distance, effect of different graft dimensions and effectiveness of different methods of capsular reconstruction. This would enable us to draw more meaningful conclusions that may be relevant to clinical practice.

STRENGTHS

This systematic review not only provided a brief overview of the biomechanical cadaver studies available on hip capsular reconstruction but also generated a relevant meta-analysis for the comparable parameters and summarized the available biomechanical evidence. The biomechanical evidence presented in this review shows that hip capsular reconstruction significantly improved the stability and the hip ROM and performed close to the native intact state.
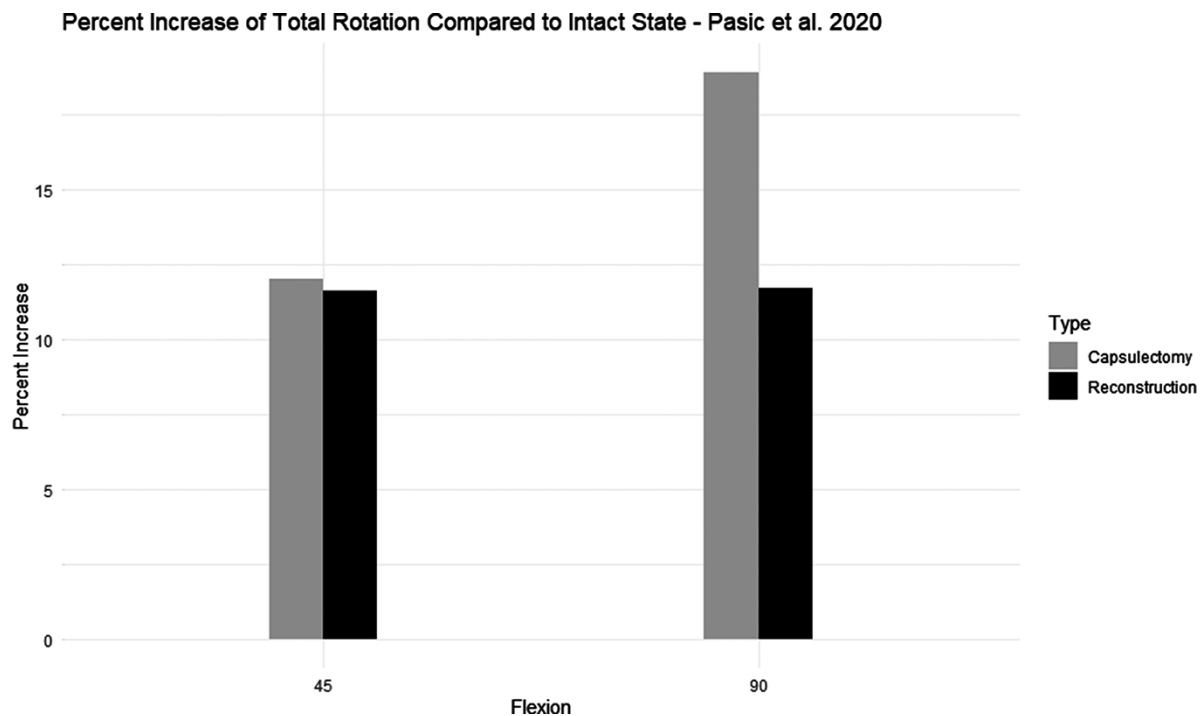
Fig. 6. Percent increase of total rotation compared to intact state (Pasic *et al.*'s study [33]).

LIMITATIONS

There are few limitations to this systematic review, some being inherent limitations of the included biomechanical studies and the heterogeneity between them. One major limitation is that only four studies qualified for inclusion in this review, all of which had differences in study methodology and biomechanical parameters that required calculations to be made in order to statistically compare them. There was also high heterogeneity among the studies that were reviewed. Additionally, it is important to consider that repeat testing of the same cadaver would impact the mechanical behavior of a given tissue, which could explain the observed differences in outcomes. Furthermore, the nature of biomechanical studies eliminates the possibility of any biological healing, postoperative rest or brace protection that would have an impact on the postoperative hip stability in the clinical setting.

CONCLUSION

Hip capsular reconstruction significantly improved the rotational stability and effective force at maximum distraction while minimizing translation when compared to the capsulectomy/defect state. Capsular reconstruction appeared to restore the hip close to its native capsular state in the cadaveric model. While the included biomechanical studies had differing methodologies, all support the use of capsular reconstruction to treat capsular defects.

DATA AVAILABILTY

We confirm that all the relevant data and any required links or identifiers for our data are present within the manuscript.

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CONFLICT OF INTEREST STATEMENT

Dr Domb reports grants and other from American Orthopedic Foundation, during the conduct of the study; personal fees from Amplitude, grants, personal fees and non-financial support from Arthrex, personal fees and non-financial support from DJO Global, grants, personal fees and non-financial support from Medacta, grants, personal fees, non-financial support and other from Stryker, grants from Breg, personal fees from Orthomerica, grants and non-financial support from Medwest Associates, grants from ATI Physical Therapy, personal fees and non-financial support from St. Alexius Medical Center, grants from Ossur, non-financial support from Zimmer Biomet, outside the submitted work; In addition, Dr Domb has a patent 8920497 - Method and instrumentation for acetabular labrum reconstruction with royalties paid to Arthrex, a patent 8708941 - Adjustable multi-component hip orthosis with royalties paid to Orthomerica and DJO Global, and a patent 9737292 - Knotless suture anchors and methods of tissue repair with royalties paid to Arthrex and Dr Domb is a board member of American Hip Institute Research Foundation, AANA Learning Center Committee, the Journal of Hip Preservation Surgery, the Journal of Arthroscopy; has had ownership interests in the American Hip

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