Meta-Analysis

Nonanatomic and Suture-Based Coracoclavicular Joint Stabilization Techniques Provide Adequate Stability at a Lower Cost of Implants in Biomechanical Studies When Compared With Anatomic Techniques: A Systematic Review and Meta-Analysis

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Purpose: To compare the stability and cost of the used implants in nonanatomic and anatomic acromioclavicular joint repair/reconstruction (ACCR) techniques tested in cadaveric shoulder biomechanical studies during the last decade. **Methods:** A systematic review and meta-analysis were performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines and prospectively registered in PROSPERO. Two independent reviewers searched PubMed, Embase, and Virtual Health Library databases. Studies evaluating 3-direction stability under 70-N loads and load-to-failure protocols with servohydraulic testing systems were included. A meta-analysis of the mean differences of anterior, posterior, and superior direction; relative stability value in 3 directions; superior direction load-to-failure; stability/cost index; and load-to-failure/cost index was performed using a continuous random-effects model and 95% confidence interval. **Results:** Eighteen articles were included. Both non-ACCR and ACCR techniques exceeded the minimum acceptable threshold of stability and load-to-failure. ACCR techniques were biomechanically better in terms of anterior stability ($P = .04$) and relative stability value (mean difference 64.08%, $P = .015$). However, supraphysiological stability and failure loads were achieved with non-ACCR techniques at a lower cost of implants. Techniques combining 2 clavicular tunnels separated by at least 10 mm, a mean of 2 sutures, and/or suture tapes had the greatest stability/cost index and load-to-failure/cost index among the included techniques (confidence interval 99%). **Conclusions:** Non-ACCR and ACCR techniques exceeded the minimum acceptable threshold of stability and failure loads in controlled biomechanical testing. However, non-ACCR and techniques combining 2 clavicular tunnels separated by at least 10 mm, a mean of 2 sutures, and/or suture tapes provide supraphysiologic stability and failure loads at a lower cost of implants. **Clinical Relevance:** Non-ACCR and suture-based techniques may provide more cost-effective and greater value treatment for acromioclavicular joint injury and could be considered in the surgical management of normal activity individuals and cost-sensitive populations.

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Acromioclavicular (AC) joint injuries are one of the most common in the young athlete's shoulder.[1-4] The typical injury mechanism is a direct trauma from falling onto the shoulder's superior aspect with the arm in adduction and the subsequent medial and inferior translation of the acromion, which jeopardizes the joint ligament's complex and stability.[5,6]

AC joint ligament's complex comprises intrinsic structures such as the AC capsule; anterior, posterior, superior, and inferior ligaments; and the extrinsic coracoclavicular (CC) ligaments, named the conoid and trapezoid ligament.[5] The conoid ligament arises from the coracoid process base and inserts in the conoid tubercle, spanning 3 to 5 cm medial from the clavicle's lateral edge. Conversely, the trapezoid ligament arises from the coracoid process's superior aspect and inserts in the trapezoid ridge at 1.5 to 3 cm medial from the clavicle's lateral edge.[7]

From a biomechanical standpoint, the intrinsic ligaments assist in posterior clavicle translation and posterior axial rotational stability.[5,8,9] Likewise, the conoid ligament resists anterior and superior clavicle translation, and the trapezoid ligament contributes to the horizontal and vertical stability, especially during acromial compression.[5,8,9]

Several factors, such as the severity of the injury, chronicity, sports activities, and rehabilitation compliance, are considered when deciding the treatment option.[5,10] Conservative treatment is the most common approach and has been recommended for Rockwood I and II AC joint injuries, whereas the surgical approach has been advocated for Rockwood type IV and VI.[5,11] However, it is still controversial for type III and V injuries.[5,10,12-14]

New studies have challenged the current algorithms, as conservative treatment has shown faster recovery and similar pain outcomes than surgical treatment,[15] even in high-grade injuries.[14,16] In addition, surgical treatment is reportedly associated with prolonged hospitalizations and recovery but with greater reoperation rates due to implant-related complications.[16]

Also, interrogations about standard treatment still arise when considering that at least one half of the world's population does not have access to quality essential services to protect and promote health.[17] It seems from an economic standpoint that conservative management is the most cost-effective treatment; however, no study has been conducted on this topic.

Despite the results favoring nonoperative treatment, some populations may benefit from surgical intervention, especially those with high functional demands and athletes.[16,18] A plethora of techniques have been described for this sole joint stabilization.[4,15,19] Nevertheless, the orthopaedic community has not found a standard technique.[4,5] With the introduction of anatomic principles in the repair/reconstruction of CC ligaments[20] and the findings of AC capsule and intrinsic ligament's role, multiple studies about anatomic acromioclavicular joint repair/reconstruction (ACCR) techniques were conducted in the last decade.[21,22] Accordingly, several implants were developed to meet those purposes.[5,6,23]

Although the ligaments' biomechanical specificity motivated the reproduction of the native anatomy during these novel repair/reconstruction techniques, their clinical advantage has not met the expectations.[24,25] Recent evidence reveals similar clinical outcomes, complications, failure, and return to sports rates between techniques,[4,18,21,26] which may imply that it is not clinically relevant to recreate both ligaments.

Thus far, some authors have expressed their concern about the cost of the implants,[27-32] surgical technique,[23] surgical approach,[33-35] total surgery costs,[34] and postoperative recovery.[36] However, only a few studies have evaluated the cost of the AC joint repair/reconstruction surgery, and those comparing the cost-effectiveness between techniques reveal significant differences in consumables and materials among them.[27,33,37] Abdelrahman et al.,[37] in a randomized controlled study, reported significant differences in the cost of consumables (arthroscopic $1729.95 vs open $851.7) but no differences in terms of the operation room and hospital charges. Similarly, significantly greater material costs were found when comparing the cortical button system and Kirschner wire fixation (€340 ±123.7 vs. €4)[27] and cortical button system versus Kirschner wire combined with suture tape (€400 vs €82.5-85), without significant differences in other items.[33]

The purpose of this study was to compare the stability and cost of the used implants in non-ACCR and ACCR techniques tested in cadaveric shoulder biomechanical studies during the last decade. We hypothesized that non-ACCR techniques would provide adequate stability at a lower cost of implants.

Methods

This systematic review and meta-analysis were conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and were prospectively registered in PROSPERO.

Search Strategy

Two independent reviewers (T.M., V.R.) searched PubMed, EMBASE, and Virtual Health Library databases up to March 25, 2020. The following terms, "acromioclavicular," "acromioclavicular joint," "AC joint," "coracoclavicular," "coraco clavicular," "repair," "reconstruction," "biomechanical testing," "biomechanical test," "biomechanical comparison," "biomechanical analysis," "biomechanical study," and "biomechanics," were used alone and in combination with Boolean operators AND caraco OR. Filters were applied to screen only investigations in the last 10 years. Inclusion and exclusion criteria were established before the search and were used to identify the potentially eligible studies by title and abstracts screening. Disagreements between reviewers were carried through the next round of screening for full-text assessment in potential eligible studies for inclusion. If any, the senior author (J.K.) resolved disagreements in article inclusion.

Eligibility Criteria

Controlled laboratory studies evaluating AC joint stability with different repair/reconstruction techniques in shoulder cadaveric specimens with servohydraulic testing systems were screened for inclusion. Studies were considered eligible for this systematic review if they fulfilled all the following predefined criteria: (1) controlled laboratory studies written in English and Spanish; (2) a minimum of 6 shoulder specimens per group; (3) reporting anterior, posterior, and superior translation in millimeters with loads of 70 N in native joints and after the proposed repair/reconstruction technique; and/or reporting superior direction failure load in Newtons; (4) disclosing with detail the implants used in the repair/reconstruction technique; and (5) published in the last 10 years.

Three-direction biomechanical protocols under 70-N loading were preferred because they are representative of shoulder forces during postoperative physical therapy.[38] Excluded studies met at least 1 of the following criteria: (1) evaluated biomechanical properties of the AC joint without comparing CC repair/reconstruction with/without AC repair/reconstruction technique, (2) tested risk of clavicle or coracoid process fracture, or (3) were conducted in artificial models.

Data Extraction

Two reviewers independently reviewed the included studies, and data were extracted and presented in a table. All disagreements were resolved by consensus by a discussion with a third individual. Data extraction was based on a predefined Excel spreadsheet (Microsoft, Redmond, WA) with the following variables: (1) first author, (2) year of publication, (3) number of specimens, (4) surgical technique, (5) biomechanical protocol, (5) post-loading translational testing results of native and described technique, (6) load-to-failure results, and (7) implants involved in the technique.

Methodologic Quality Assessment

The quantitative content assessment was performed using the STROBE Statement checklist (SSc), identifying individual studies bias risk. The Pearson test was employed to evaluate the possible association with the year of publication of the studies and highlight any possible improvement of the methodology through the years.

Statistical Analysis

Cohen's kappa (κ) was calculated for title and abstract screening interrater reliability. We designed 2 indexes to assess the correlation between stability and implants' cost for this study: the stability/cost index (SCI) and the load-to-failure/cost index (LtFCI). SCI value can be interpreted as the percentage of 3-direction stability per dollar, or when multiplied per 100, the percentage of 3-direction stability per every $100. Correspondingly, LtFCI relates to the number of Newtons to failure per dollar.

To calculate the proposed SCI, the relative stability of the technique was divided by the cost of the implants used in the technique. Likewise, the for suggested LtFCI, the superior direction load-to-failure was divided by the cost of the implants used in the technique.

Relative stability value (RSV) was computed for every surgical technique tested in 3-direction protocols under 70 N. RSV was considered as the resulting stability after a repair/reconstruction technique (dividend) compared with the native joint stability (divisor) in the form of a percentage (per 100). Being (1) the dividend, the stability of the repaired/reconstructed joint was calculated based on the sum of mean post-loading translations (mm) after 70-N loading in anterior, posterior, and superior direction; and (2) the divisor, the sum of the superior standard deviation (SD) of native post-loading translation (millimeter) of the joint after 70-N loading in anterior, posterior, and superior direction in the native specimen.

According to the reference prices obtained from 4 manufacturers' sales representatives from America and Europe, the implants' costs were estimated. According to their type, average prices were given to implants regardless of the specific manufacturer (Table 1). Allografts were not considered for cost estimation since autologous tissue could be substituted.

Three independent investigators carried out the SCI and LtFCI calculation. Results were averaged, and indexes were assigned for every technique accordingly. Techniques were grouped following a modification of the Beitzel et al.[39] categorization in (1) non-ACCR, in which the CC ligaments repair/reconstruction was performed without considering their native anatomic positioning (including hook plate osteosynthesis) and/or involving CA ligament transfer; (2) ACCR, in which the CC ligaments repair/reconstruction was performed restoring their anatomic position; and (3) ACCR + AC cerclage (ACCR + AC), in which the anatomically restored CC ligaments were accompanied with AC ligament cerclage (Table 2).

Correlations between year and (1) stability under 70-N loads in 3 directions, (2) superior direction load-to-failure, and (3) cost of implants were calculated using Pearson's coefficient, looking for statistical significance. Statistical significance was calculated using $P < .1$, .05, .01, and .001.

A meta-analysis of mean difference (MD) of (1) anterior, posterior, and superior direction under 70-N loads; (2) stability relative value in 3 directions under 70-N loads; (3) superior direction load-to-failure;

Table 1. Mean Cost of Implants for Acromioclavicular Joint Repair/Reconstruction

Implants	Cost, $
Locking hook plate	750
Synthetic ligament system	800
Sutures	40
Suture tapes, fiber mesh, braided cords	85
Cortical buttons	85
Two-cortical button systems	350
Three-cortical button systems	850
Interference screws	215
Suture anchors	285

(4) SCI; and (5) LtFCI was performed using a continuous random-effects model and 95% CI. Heterogeneity was calculated with the I^2 test. Forest plot graphics were generated for each condition. Adjustments using Bonferroni method (alpha = 0.05) were made for multiple comparisons. Statistical analysis was performed using OpenMetaAnalyst[40] and Microsoft Excel 2016 (Microsoft, Redmond, WA).

Results

Search Results

The initial literature search yielded 376 potentially relevant records after the removal of duplicates. After we screened titles and abstracts, 56 articles were retrieved for full-text evaluation (κ = 0.91). Twenty-one biomechanical controlled laboratory studies met the predetermined eligibility criteria, and 18 were eventually included with a total agreement in the systematic review, as shown in the PRISMA flow diagram (Fig 1).

A total of 41 AC joint repair/reconstruction techniques were examined. From the 18 included studies, 6 consisted of 70-N testing protocols in anterior, superior, and posterior direction[28,41-45] and 16 superior direction load-to-failure protocols.[23,30,31,41,42,44-54]

Synthesis of Results

Stability Meta-Analysis

Stability meta-analysis of 5 studies showed that both non-ACCR and ACCR techniques met or exceeded physiologic stability. ACCR showed statistically significant superiority of anterior stability than non-ACCR techniques (weighted mean: 5.16 mm ± 1.85 vs 10.45 mm ± 2.11, $P = .04$) (Fig 2A). The pooled weighted mean of the available native anterior translation under 70-N loads of 68 specimens among 5 studies[41-45] was 6.90 ± 2.42 mm. Posterior and superior translations under 70 N were not statistically different between groups (Fig 2 B and C). Similarly, when we compared RSV, ACCR techniques had greater stability, showing a mean of 64.08% more stability (weighted mean: 194.26 ± 23.51% vs 137.81 ± 25.49%, $P = .015$) (Fig 2D).

Load-to-Failure Meta-Analysis

Seven studies were available for superior direction load-to-failure comparison. Superiority was found in

Table 2. Categorization of AC Joint Repair/Reconstruction Techniques

Non-ACCR	ACCR	ACCR + AC Cerclage
• Banffy's SCT[41] • Beitzel's SCT[42] • Beitzel's mWD[42] • Clevenger's CC reconstruction + CA ligament transfer[53] • Hislop's SCT[43] • Struhl's Dog Bone button construct[47] • Li's mWD[45] • Lobao's synthetic ligament technique[46] • Nüchtern's locking hook plate[52] • Weiser's single TR + AC[50] • Zooker's mWD by Le Hanneur[44] • Zooker's mWD augmented with fiber mesh cerclage[28] • Zooker's mWD augmented with a 2-cortical button system[28]	• Abat's DCT[49] • Abat's "V" configuration repair[49] • Banffy's DCT[41] • Beitzel's DCT[42] • Clevenger's CC reconstruction[53] • Grantham's double ENDOBUTTON technique[23] • Grantham's coracoid cerclage technique[23] • Hislop's DCT[43] • Le Hanneur's triple-bundle reconstruction[44] • Lee's modified knot fixation technique by Staron[54] • Li's triple ENDOBUTTON technique[45] • Lobao's CC suspensory construct[46] • Mazzocca's modified anatomical double-bundle technique with interference screws by Staron[54] • Naziri's augmented graft[48] • Naziri's graft[48] • Nüchtern's TR[52] • Nüchtern's bone anchor systems[52] • Shin's coracoid cerclage reconstruction[30] • Struhl's double ENDOBUTTON construct[47] • Tashjian's interference screw fixation method[31] • Tashjian's side-to-side suturing[31] • Tashjian's square knot[31] • Weiser's double TR[50]	• Hislop's DCT + AC suture[43] • Martetschläger's PDS cerclage reconstruction[51] • Shin's single-tendon anatomic AC-CC reconstruction[30] • Weiser's double TR + AC[50] • Weiser's PDS sling + AC[50]

AC, acromioclavicular; ACCR, anatomic acromioclavicular joint repair/reconstruction; CA, coraco-acromial; CC, coracoclavicular; DCT, double clavicular tunnel; mWD, modified Weaver-Dunn; PDS, polidioxanone; SCT, single clavicular tunnel; TR, TightRope.

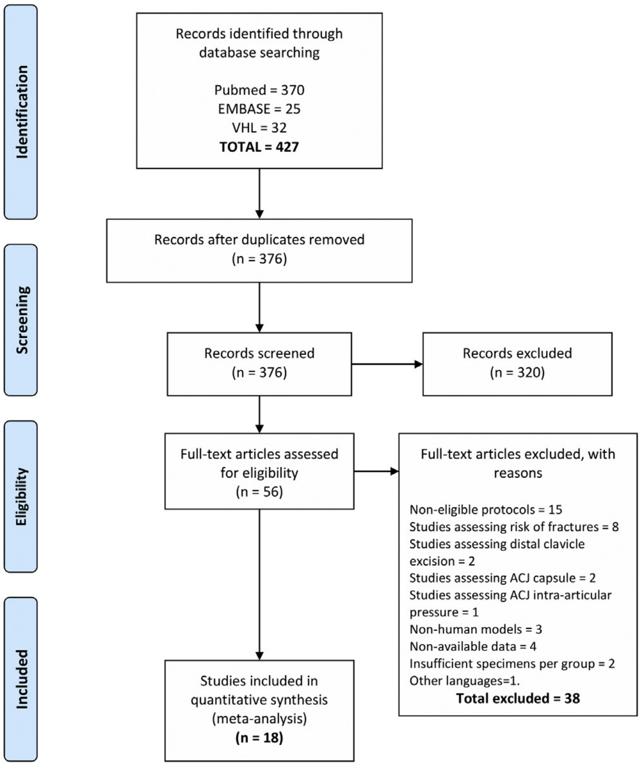

Fig 1. Search strategy and study selection process using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses methodology.

the ACCR group, showing a mean of 185.83 N more than the non-ACCR group (weighted mean: 591.72 ± 154.12 N vs 425.31 ± 138.42 N, $P = .07$) (Fig 3A). The pooled weighted mean of the available native failure loads of 65 specimens among 5 studies[42,45,49,51,54] was 538.13 ± 114.48 N. The lower SD (423.66 N) was considered as the minimum physiologic failure load. Only 2 studies were available for comparison between ACCR and ACCR + AC techniques for superior direction load-to-failure, favoring ACCR + AC techniques without statistical significance (Fig 3B).

Stability and Cost Behavior Over the Last Decade

A total of 41 techniques were evaluated for SCI and/or LtFCI. Among 14 techniques (6 studies) assessing stability in anterior, posterior, and superior direction under 70-N loads, the Pearson coefficient revealed an improvement of the RSV of the AC joint over the last decade ($P = .026$), with a negative correlation for superior direction load-to-failure improvement in 36 techniques (16 studies), although not statistically significant. In contrast, there was an increase in the implants' cost in 41 techniques (18 studies) over the last decade ($P = .08$).

SCI Meta-Analysis

SCI meta-analysis was conducted in 5 studies[41-45] comparing non-ACCR versus ACCR techniques (Fig 4A). Non-ACCR techniques had favorable results, with 10.2% more stability per every $100 (weighted mean: SCI 0.465 ± 0.121 vs 0.328 ± 0.037, cost of implants $348.29 vs $666.5).

Overall mean SCI was 0.424 ± 0.251 (range 0.148-1.137) of 14 eligible techniques. Techniques denoted with an asterisk (*) exceeded the minimum acceptable threshold of stability (Table 3). The greatest indexes (CI 99%) were found in Beitzel et al.'s modified Weaver-Dunn, Hislop et al.'s single clavicular tunnel, and Hislop et al.'s double clavicular tunnel (SCI 1.137, 0.671, and 0.657, respectively).[43,44]

LtFCI Meta-Analysis

LtFCI meta-analysis of 7 studies[41-46,52] revealed favorable results for ACCR techniques, with 21.2 N more to failure per every $100 (weighted mean: SCI 1.361 vs 1.304, cost of implants $444.71 vs $612.30) (Fig 4B). Overall mean LtFCI was 2.473 SD ± 3.287 (range 0.220-15.370) of 36 eligible techniques. Techniques denoted with an asterisk (*) exceeded the minimum acceptable threshold of load-to-failure (Table 4). The techniques with the greatest indexes (CI 99%) were Tashjian et al.'s ACCR with graft square knot, Tashjian et al.'s ACCR with graft side-to-side suturing, Clevenger et al.'s ACCR reconstruction, Clevenger et al. 's ACCR reconstruction + coracoacromial (CA) ligament transfer, Weiser et al. 's ACCR polidioxanone + AC cerclage, Lobao et al.'s ACCR suspensory construct, and Beitzel et al.'s modified Weaver—Dunn (LtFCI 15.370, 12.768, 8.086, 5.954, 4.512, 4.413, and 3.889, respectively).[31,42,46,50,53]

Common Aspects Among Greatest SCI and LtFCI Surgical Techniques

From the 9 surgical techniques with the greatest SCI and LtFCI, all of them used a mean of 2 sutures and/or suture tapes,[31,42,43,46,51,52] 8 included 2 clavicular tunnels separated by at least 10 mm,[31,42,43,46,50,53] 5 had distal clavicle excisions,[31,41,42] 4 implemented grafts,[31,53] and 2 CA ligament transfer.[42,54] Beitzel et al.'s[42] modified Weaver—Dunn technique was the only technique showing high SCI and LtFCI, but with suboptimal RSV (90.95%) and failure load (311.13 N).

Methodologic Evaluation

The SSc was used to assess the quality of the report of the studies included in the present systematic review and meta-analysis (Table 5). The average SSc value was 29.11 of 32 (range 28-31), demonstrating a high methodologic quality level. However, of the items that compose the SSc: (1) 10 studies failed to report "how the sample size was arrived at" and the "description of analytical methods that took account of sampling strategy"[23,28,41,42,45,48-52] (2) 4 studies failed to report the mean age of the cadaveric specimens,[31,43,52,53]

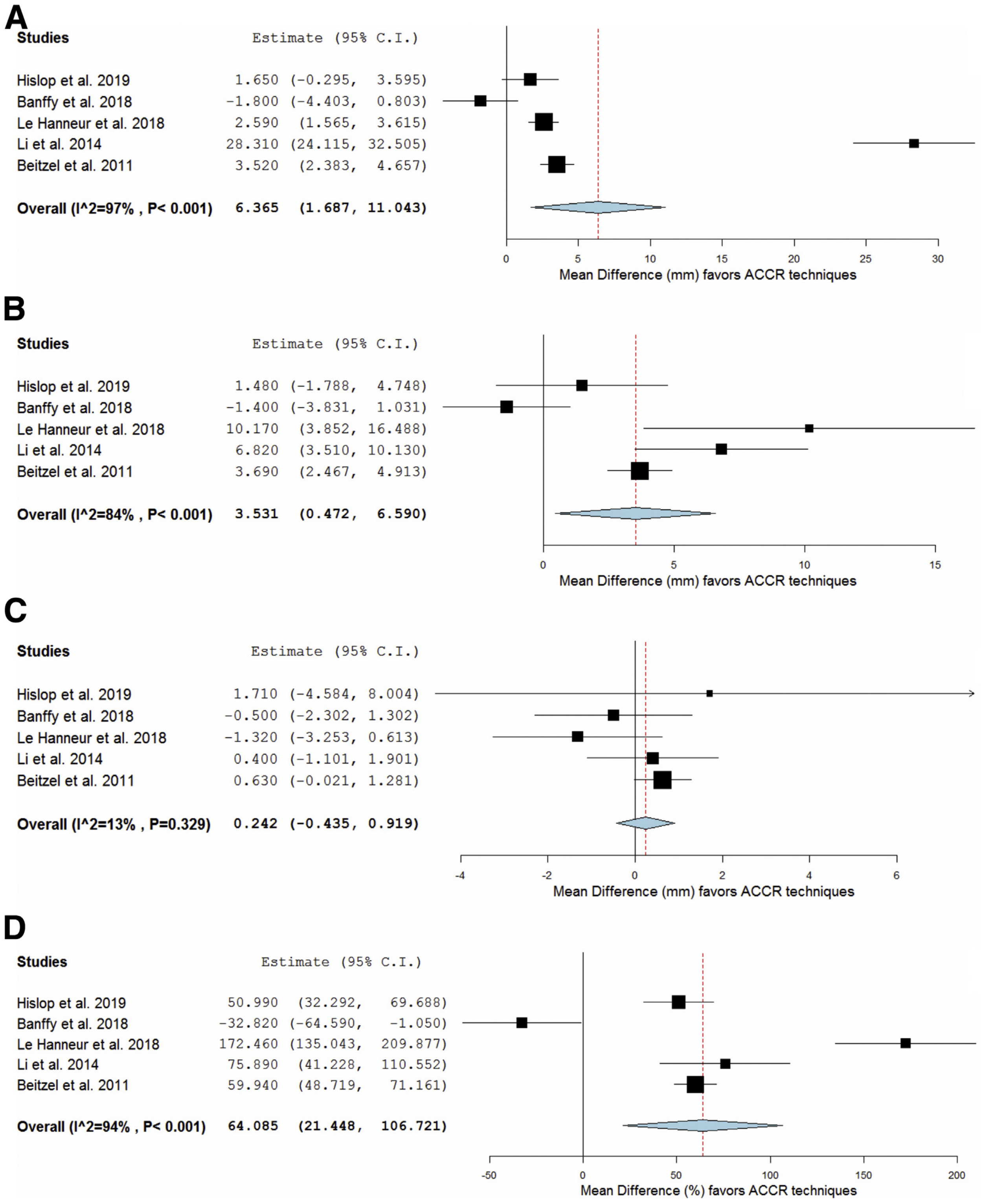

Fig 2. Meta-analysis on translation in 70-N biomechanical protocols comparing acromioclavicular joint anatomic vs. non-anatomic repair/reconstruction techniques during the last decade: (A) anterior translation (mm), (B) posterior translation (mm), (C) superior translation (mm), and (D) relative stability value (%). (ACCR, anatomic acromioclavicular joint repair/reconstruction; CI, confidence interval.)

(3) 3 studies did not clearly define failure,[30,42,45] and (4) one did not report the mm/min rate for load-to-failure testing.[41] It is also important to point out that only 3 studies performed bone mineral density and/or computed tomography analysis on the specimens.[50,52,54]

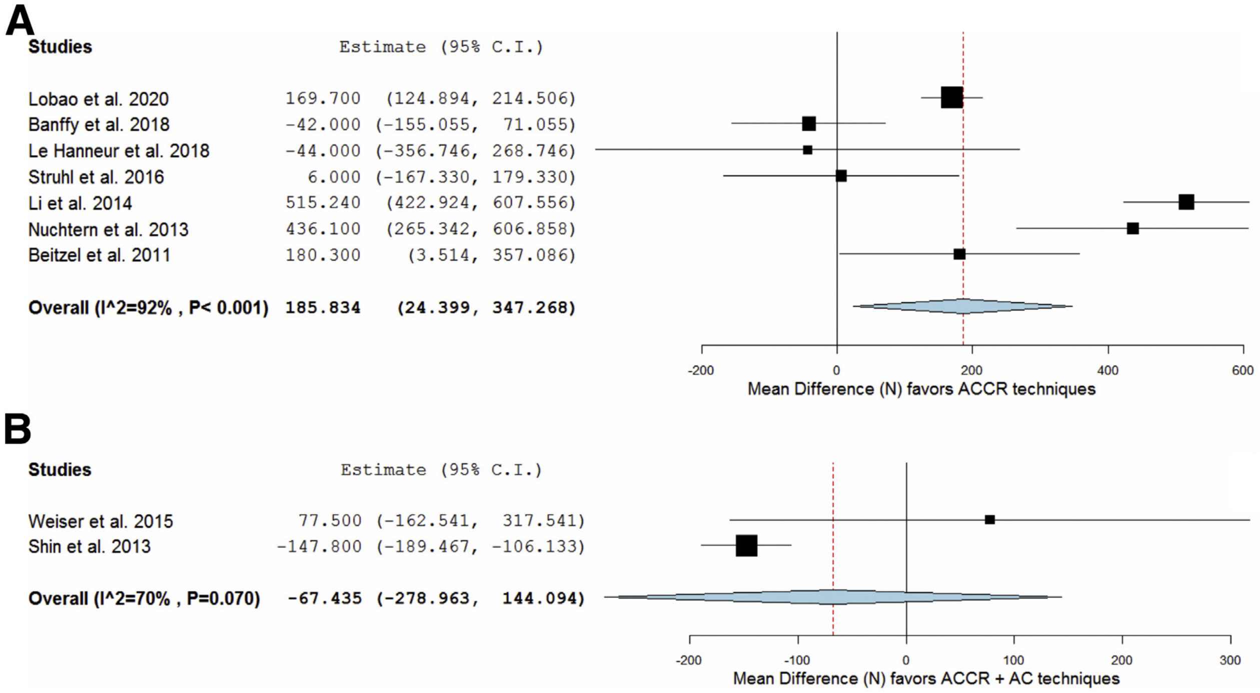

Fig 3. Meta-analysis on superior direction load-to-failure (N) biomechanical protocols comparing acromioclavicular joint repair/reconstruction techniques during the last decade: (A) anatomic versus nonanatomic techniques, (B) anatomic versus anatomic + AC cerclage techniques. (AC, acromioclavicular; ACCR, anatomic acromioclavicular joint repair/reconstruction; CI, confidence interval.)

Association analysis of the SSc score and year of publication with Pearson's coefficient showed a significant positive association (*P* = .047).

Assessment of Publication Bias

Evaluation of the included studies' publication bias was performed using the ROBIS tool[55] (Fig 5). The risk of bias in the review was found to be low. Nevertheless, concerns regarding the standardization of implants' cost and heterogeneity of surgical techniques and measurement methods should be noted. Heterogeneity tests were conducted and interpreted as follows: $I^2 \leq 25\%$, low heterogeneity; from 26% to 74%, moderate heterogeneity; and ≥75%, high heterogeneity. A high heterogeneity level was identified, ranging in most comparison groups between 70% and 99%.

Discussion

The most important finding of this study is that ACCR techniques were biomechanically better than the non-ACCR in terms of anterior stability (*P* = .04), RSV (MD 64.08%, *P* = .015), and failure loads (MD 185.83 N, *P* = .07). However, supraphysiological stability and failure loads can be achieved with non-ACCR techniques at a lower cost of implants, as originally hypothesized.

ACCR techniques have failed to demonstrate clinical superiority over non-ACCR techniques, as reported by several authors.[4,18,21,26] A systematic review of 34 studies by Moatshe et al.[21] showed comparable patient-reported outcomes measures (PROM) regardless of the surgical technique. Reconstruction techniques involving free graft scored the highest PROM and fewest complications than those involving a hook plate or K-wires. Also, Gowd et al.[4] conducted a systematic review composed of 58 articles collecting the complication profiles of open and arthroscopic surgical techniques. No differences were found in the complication rate, revision rate, and loss of reduction among them. Similarly, in a systematic review including 28 studies, Xará-Leite et al.[26] reported comparable postoperative outcomes, pooled failure, and reoperation rates between non-ACCR and ACCR techniques in managing chronic AC joint injuries.

It was theorized that the improvement of PROM in the surgical treatment of AC joint dislocations with non-ACCR and ACCR techniques is attributable to the supraphysiological RSV that can be achieved with both techniques in the biomechanical laboratory setting (weighted mean: 194.26% ± 23.51 vs 137.81% ± 25.49, *P* = .015). Even when ACCR techniques provide significantly greater stability (MD 64.08%, *P* = .015) and greater failure loads (MD 185.83 N, *P* = .07), they do not seem to translate into significantly better outcomes or fewer complication rates according to previously reported systematic reviews.[4,5,10,14,21,22]

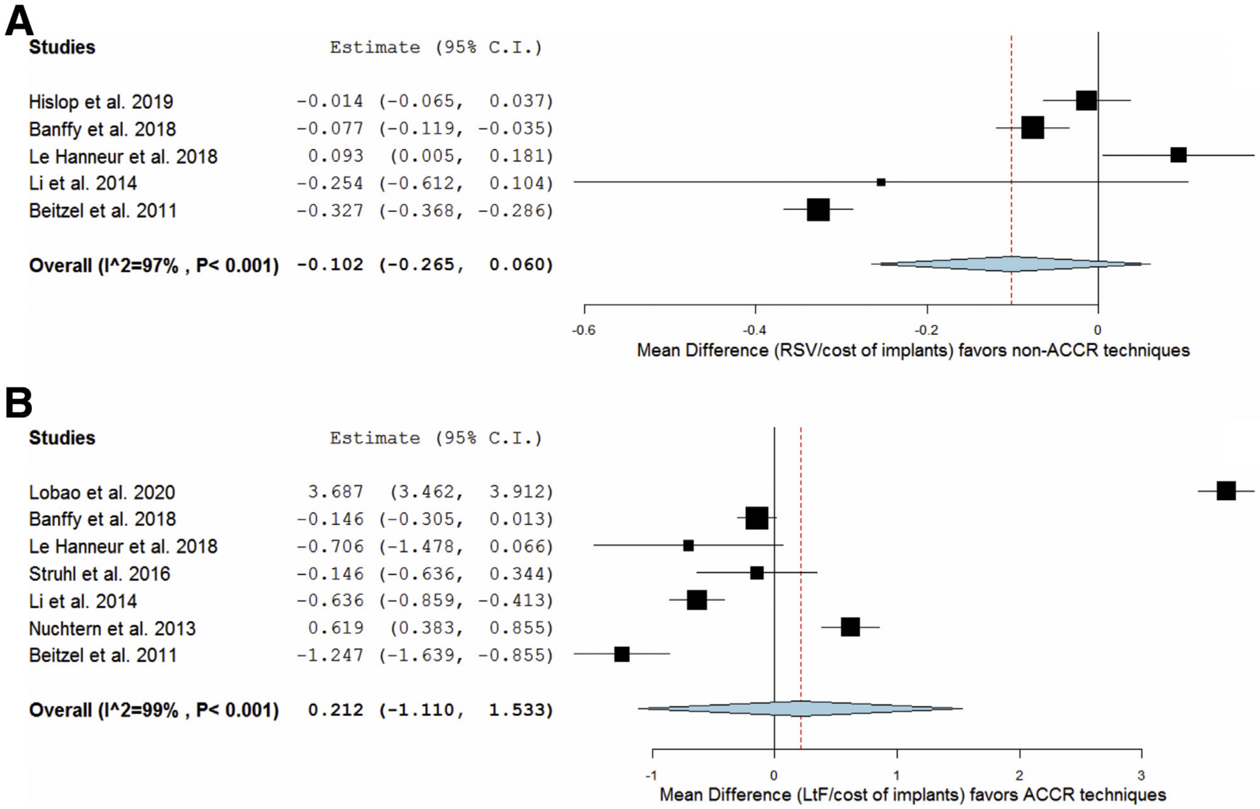

Fig 4. Meta-analysis comparing acromioclavicular joint anatomic versus nonanatomic repair/reconstruction techniques in biomechanical experiments during the last decade on: (A) stability/cost index, (B) load-to-failure/cost index. (ACCR, anatomic acromioclavicular joint repair/reconstruction; CI, confidence interval; RSV, relative stability value.)

All societies are interested in high-quality health care at a lower cost and are particularly crucial in cost-sensitive situations. According to the Tokyo Declaration on Universal Health Coverage, at least one half of the world's population still does not have access to quality essential services to protect and promote health, and 800 million people are spending at least 10% of their household budget on out-of-pocket health care expenses. Nearly 100 million people are being pushed into extreme poverty each year due to health care costs.[17] Although access to surgical care and cost-effectiveness of AC joint dislocations treatment is out of the scope of this systematic review and meta-analysis, our evaluation of 3-direction stability and the cost of implants suggests better indexes for the non-ACCR techniques. Moreover, the presented experimental evidence suggests the lack of clinical benefit from extra stability despite the trend toward the increment in 3-direction stability ($P = .026$) and the cost of used implants in the last decade ($P = .08$).

Our findings also endorse the techniques combining 2 clavicular tunnels separated by at least 10 mm, a mean of 2 sutures, and/or suture tapes as those to have the greatest SCI and LtFCI among all the included techniques (CI 99%). The equivalent loss of reduction between suture-only fixation versus cortical button systems compared with all other reconstruction techniques reported by Gowd et al.[4] supports our results in favor of suture-based fixation, considering its lower costs.

Beitzel et al.'s modified Weaver–Dunn was the only technique having high SCI and LtFCI, but with suboptimal RSV (90.95%) and failure load (311.13 N). Furthermore, it joined with four other techniques comprising distal clavicle excision[31,42,53] among the 9 displaying the greatest indexes. Distal clavicle excision techniques have been related to significantly greater horizontal instability[56-59] and modified Weaver–Dunn, with fewer load-to-failure than native specimens.[28,42,45] However, another biomechanical study of the modified Weaver–Dunn procedures shows contrasting results.[44] Moreover, new clinical evidence reveals equivalent clinical outcome, complication, and failure rates between the modified Weaver-Dunn procedure and other ACCR techniques.[4,21,22] Thus, modifications of this technique and distal clavicle excision may still be relevant in our time.

This study does not contemplate conservative treatment. Chang et al. evaluated the functional outcome of conservative and surgical treatment of high-grade AC joint dislocations (including grade III injuries), finding no differences. A faster return to work was observed in

Table 3. Stability/Cost Index of Surgical Techniques Evaluated Under 70-N Protocols

Study	No. Specimens (per Group)	Surgical Techniques	Translational Biomechanical Protocol	Postloading Translational Testing Results (mm) and RSV	Implants and Estimated Costs	SCI
Hislop et al.,[43] 2019	24 (8)	(1) SCT* (2) DCT* (3) DCT + AC suture*	Cyclic loading included anterior, posterior, and superior translation of the clavicle relative to the acromion, a 70-N load was used on all samples over 500 cycles at 1 Hz.	(1) A: 5.01 ± 1.98 P: 7.97 ± 2.71 S: 13.51 ± 7.85. RSV: 228.09%. (2) A: 3.36 ± 1.99 P: 6.49 ± 3.86 S: 11.80 ± 4.57 RSV: 279.08%. (3) A: 5.65 ± 8.42 P: 9.52 ± 6.18 S: 13.36 ± 4.20 RSV: 211.78%. Control: A: 14.17 ± 8.56 P: 13.72 ± 4.18 S: 12.99 ± 6.80	(1) Two cortical buttons (Dog Bone; Arthrex), and two 2-mm suture tapes (FiberTape; Arthrex). (2) Three cortical buttons (Dog Bone; Arthrex), and two 2-mm suture tapes (FiberTape; Arthrex). (3) Three cortical buttons (Dog Bone; Arthrex), and two 2-mm suture tapes (FiberTape; Arthrex).	(1) 0.671 (2) 0.657 (3) 0.498
Le Hanneur et al.,[44] 2018	12 (6)	(1) Triple-bundle reconstruction* (2) Zooker's mWD*	Preconditioning was performed by cycling the AC joint between 0 and 25 N over 10 cycles; the specimens were then loaded to an amplitude of 70 N over 1000 cycles at a frequency of 1 Hz. Displacement at peak force was documented at 1 and 1000 cycles.	(1) A: 2.80 ± 0.87 P: 3.84 ± 2.50 S: 2.65 ± 2.34 RSV: 278.15%. (2) A: 5.39 ± 0.94 P: 14.01 ± 7.49 S: 1.33 ± 0.60 RSV: 105.09%. Control: (1) A: 4.71 ± 2.08 P: 9.14 ± 4.65 S: 3.84 ± 1.42 (2) A: 3.65 ± 0.77 P: 7.99 ± 4.85 S: 3.25 ± 1.40	(1) Three no. 2 sutures (FiberWire; Arthrex), and three 4 × 10-mm interference screws (Bio-Tenodesis screw; Arthrex). (2) A no. 2 suture (FiberWire; Arthrex), and a 2-cortical button system (TightRope; Arthrex).	(1) 0.364 (2) 0.271
Banffy et al.,[41] 2018	18 (9) No a priori power analysis was performed	(1) SCT* (2) DCT*	All specimens were conditioned for 10 cycles to 25 N for anterior–posterior and superior testing to eliminate creep phenomenon. The specimens were then randomly loaded to 70 N in either the anterior–posterior or superior direction, with the AC joint, CC ligaments, and CA ligament intact to establish baseline displacements for each specimen. Net displacement values in the superior, anterior, and posterior directions were recorded. Next, the AC and CC ligaments were completely sectioned. Reconstructions	(1) A: 4.6 ± 1.2 P: 5.1 ± 1.9 S: 4.5 ± 1.9 RSV: 150.70%. (2) A: 6.4 ± 3.8 P: 6.5 ± 3.2 S: 5.0 ± 2.0 RSV: 117.88%. Control (1) A: 4.9 ± 2.0 P: 5.8 ± 3.1 S: 3.9 ± 1.7 (2) A: 5.0 ± 1.1 P: 5.7 ±2.2 S: 4.8 ± 2.3	(1) A 1.3-mm suture tape (SutureTape; Arthrex), a 5.5 × 8-mm interference screw (PEEK Tenodesis Screw; Arthrex), a cortical button (Dog Bone; Arthrex), and a 3.0 × 14.5-mm suture anchor (SutureTak; Arthrex). (2) Two no. 2 sutures (FiberWire; Arthrex), a 1.3-mm suture tape (SutureTape; Arthrex), two 5.5 × 15-mm interference screws (Bio-Tenodesis screws; Arthrex), a	(1) 0.225 (2) 0.148

(continued)

Table 3. Continued

Study	No. Specimens (per Group)	Surgical Techniques	Translational Biomechanical Protocol	Postloading Translational Testing Results (mm) and RSV	Implants and Estimated Costs	SCI
			were performed with the ST CC ligament reconstruction and DT CC ligament reconstruction. After the surgical reconstructions were completed, the previously described testing procedure for the intact state was repeated.		3.0 × 14.5-mm suture anchor (SutureTak; Arthrex).	
Li et al.[45] 2014	12 (6) No a priori power analysis	(1) mWD (2) Triple ENDOBUTTON technique*	All specimens were conditioned for 10 cycles to 20 N for anterior–posterior and superior testing to eliminate creep phenomenon. The specimens were then loaded to 70 N in anterior, posterior, and superior directions. Random reconstructions were performed with either the triple endobutton technique or the modified Weaver–Dunn procedure. Specimens exhibiting bony failure were not used for reconstruction. When the specimen was reconstructed, the same test protocol for the intact specimens was repeated, and the displacement values were recorded.	(1) A: 37.03 ± 5.05 P: 14.85 ± 1.89 S: 5.59 ± 1.38 RSV: 40.79% (2) A: 8.72 ± 1.41 P: 8.03 ± 3.68 S: 5.19 ± 1.27 RSV: 116.68%. Control: (1) A: 5.70 ± 1.18 P: 10.11 ± 0.94 S: 4.79 ± 0.72 (2) A: 7.81 ± 2.22 P: 7.16 ± 1.95 S: 5.41 ± 1.05	(1) Two no. 2 sutures (ETHIBOND; Ethicon). (2) Five no. 2 sutures (ETHIBOND; Ethicon), and 3 cortical buttons (ENDOBUTTON).	(1) 0.510 (2) 0.256
Beitzel et al.,[42] 2011	40 (G B = 8, G C = 8, G D = 6) No a priori power analysis was performed	(1) Native (2) SCT* (3) DCT* (4) mWD	Cadaveric shoulders were tested for anterior, posterior, and superior translation (70-N load).	(2) A: 5.81 ± 1.16 P: 8.30 ± 1.94 S: 2.28 ±0.52 RSV: 156.38%. (3) A: 4.68 ± 0.6 P: 6.85 ± 0.83 S: 2.09 ± 0.86 RSV: 188.18%. (4) A: 11.36 ± 3.17 P: 13.51 ± 2.21 S: 3.31 ± 0.47 RSV: 90.95%. Control: (1) A: 7.92 ± 1.69 P: 7.84 ± 2.09 S: 4.28 ± 1.81	(1) None. (2) A 2-cortical button system (TightRope; Arthrex). (3) A 3-cortical button system (Twin Tail TightRope; Arthrex). (4) Two no. 2 sutures (FiberWire; Arthrex).	(2) 0.447 (3) 0.221 (4) 1.137
Zooker et al.,[28] 2010	12 (6)	(1) mWD augmented with fiber mesh cerclage (2) mWD augmented with a 2-cortical button system	For testing of the intact specimen, specimens were loaded before sectioning for 10 cycles in the superoinferior direction to 10-N in the superior direction and 70-N in the inferior direction at a rate of 3.3 mm/s.	(1) AP: 28.3 ± 2.7 SI: 5.8 ± 1.2 RSV: 52.20%. (2) AP: 15.0 ± 1.4 SI: 2.1 ± 0.1 RSV: 89.47%.	(1) A no. 2 suture (ETHIBOND; (Ethicon), and a 5-mm fiber mesh (MERSILENE; Ethicon) cerclage. (2) A no. 2 suture (ETHIBOND;	(1) 0.418 (2) 0.229

(continued)

Table 3. Continued

Study	No. Specimens (per Group)	Surgical Techniques	Translational Biomechanical Protocol	Postloading Translational Testing Results (mm) and RSV	Implants and Estimated Costs	SCI
			Because the coracoid was loaded for superoinferior loading in this model, superior loading represented inferior movement of the clavicle and inferior loading represented superior movement of the clavicle. Measurements for the intact specimen under load were obtained from the tenth load cycle. A consistent manual load was applied in both anterior and posterior directions to achieve maximum displacement in the anteroposterior direction. After repair, the coracoid of all specimens was loaded to 10-N in the superior direction (inferior movement of the clavicle) and 70 N in the inferior direction (superior movement of the clavicle) for 2000 cycles to simulate early post-operative loading. Repaired superoinferior data were obtained from the first loading cycle after repair and after 2000 cycles.	Control: (1) AP: 10.5 ± 2.1 SI: 4.3 ± 0.9 (2) AP: 8.0 ± 1.1 SI: 5.4 ± 0.8	Ethicon), and a 2-cortical button system (TightRope; Arthrex).	

AC, acromioclavicular; CA, coracoacromial; CC, coracoclavicular; DCT, double clavicular tunnel; DT, double tunnel; mWD, modified Weaver-Dunn; P, posterior; RSV, relative stability value; S, superior; SCI, stability/cost index; SCT, single clavicular tunnel; ST, single tunnel.

Techniques denoted with an asterisk (*) exceeded the minimum acceptable threshold of stability.

Table 4. Load-to-Failure/Cost Index of Surgical Techniques Evaluated Under Superior Direction Load-To-Failure Protocols

Study	No. Specimens	Surgical Techniques	Superior Direction Load-To-Failure Protocol	LtF Results (N)	Implants and Estimated Costs	LtF/Cost Index
Lobao et al.,[46] 2020	14 (7)	(1) Synthetic ligament technique* (2) CC suspensory construct*	LtF superior tensile test at 120 mm/min. To assess LtF, the servohydraulic system was set to monotonically load each specimen and stop when a drop in force of 50% from the maximum applied force was reached.	(1) 580.5 (2) 750.2	(1) A synthetic ligament (LockDown), a 3.5-mm cortical screw and a washer. (2) Two 2-mm suture tapes (FiberTape; Arthrex).	(1) 0.726 (2) 0.413
Banffy et al.[41] 2018	18 (9) No a priori power analysis was performed	(1) SCT (2) DCT	After the surgical reconstructions were completed, the previously described testing procedure for the intact state was repeated, followed by testing to failure in the superior direction. No rate for LtF testing shown in the text. Load-displacement curves were used to determine the load at failure as the overall maximum load.	(1) 398 (2) 356	(1) A 1.3-mm suture tape (SutureTape; Arthrex), a 5.5 − 8-mm interference screw (PEEK Tenodesis Screw; Arthrex), a cortical button (Dog Bone; Arthrex), and a 3.0 × 14.5-mm suture anchor (SutureTak; Arthrex). (2) Two no. 2 sutures (FiberWire; Arthrex), a 1.3-mm suture tape (SutureTape; Arthrex), two 5.5 × 15-mm interference screws (Bio-Tenodesis screws; Arthrex), a 3.0 × 14.5-mm suture anchor (SutureTak; Arthrex).	(1) 0.594 (2) 0.448
Le Hanneur et al.,[44] 2018	12 (6)	(1) Triple-bundle reconstruction* (2) Zooker's mWD*	Reconstructed joints were LtF in the superior direction at a constant distraction rate of 1 mm/s to assess the maximal tensile loading capacity and the displacement to failure of each technique; the corresponding stiffness was calculated from the slope of the linear region of the force−displacement curve. Failure was defined as construct breakage with interruption of the linear progression of the slope of the force −displacement curve.	(1) 472 (2) 516	(1) Three no. 2 sutures (FiberWire; Arthrex), and three 4 × 10-mm interference screws (Bio-Tenodesis screw, Arthrex). (2) A no. 2 suture (FiberWire; Arthrex), and a 2-cortical button system (TightRope; Arthrex).	(1) 0.617 (2) 1.323
Naziri et al.[48] 2016	18 (9) No a priori power analysis was performed	(1) Reconstruction using grafts with UHMWPE suture ran throughout the entire length* (2) Reconstruction with only native allografts	Tensile tests were performed using a mechanical testing machine at a rate of 50 mm/min. A maximum load and displacement to failure were collected. Failure was defined at the breaking point of the failure test curve.	(1) 437.5 (2) 94.4	(1) A no. 5 suture (FiberWire; Arthrex), and two 5.5 × 8-mm interference screws (PEEK Bio-Tenodesis Screws; Arthrex). (2) Two 5.5 × 8-mm interference screws (PEEK Bio-Tenodesis Screws; Arthrex).	(1) 0.931 (2) 0.220

(continued)

Table 4. Continued

Study	No. Specimens	Surgical Techniques	Superior Direction Load-To-Failure Protocol	LtF Results (N)	Implants and Estimated Costs	LtF/Cost Index
Struhl et al.[47] 2016	12 (6)	(1) Double ENDOBUTTON construct* (2) Dog Bone button construct*	LtF testing was performed at a rate of 1 mm/s in the superior direction, and load-displacement curves were obtained. Failure was defined as a 10-mm superior displacement or any fracture, insufficiency, or material incompetence.	(1) 558 (2) 552	(1) A 2-cortical button system (ENDOBUTTON CL system; Smith & Nephew), and a no. 5 suture (ETHIBOND; Ethicon). (2) A 2-cortical button system (Dog Bone; Arthrex).	(1) 1.431 (2) 1.577
Abat et al.,[49] 2015	18 (9) No a priori power analysis was performed	(1) Control (2) DCT* (3) Repair in a "V" configuration with 2tunnels in the clavicle and one in the coracoid	The traction test was performed at a speed of 15 mm/min. Pretensioning was performed at 15 N before the displacement of the bar of the testing machine was initiated. The test was stopped when the tensile force dropped by 60% of the maximum applied force (Fmax 60%) or when the mobility of the part or implant failure was observed. In each test, the maximum breaking force (in N) was obtained.	(1) 444.0 (2) 495.6 (3) 343.9	(1) Native. (2) Two 2-cortical button system (ZipTight; Biomet). (3) A 2-cortical button system (ZipTight; Biomet).	(2) 0.708 (3) 0.983
Weiser et al.,[50] 2015	24 (6)	(1) Double TR* (2) Double TR with AC repair* (3) Single TR with AC repair* (4) PDS sling with AC repair*	Vertical LtF 25 mm/min determined after cyclic testing. Failure was defined as a vertical dislocation of more than 20 mm, or any fracture, insufficiency, or material failure.	(1) 884.4 (2) 846.8 (3) 708.0 (4) 767.0	(1) Two 2-cortical button systems (TightRope; Arthrex). (2) Two 2-cortical button systems (TightRope; Arthrex) and a 3-mm suture tape (PDS; Ethicon). (3) A 2-cortical button system (TightRope; Arthrex) and a 3-mm suture tape (PDS; Ethicon). (4) A 5-mm suture tape (PDS; Ethicon) and a 3-mm suture tape (PDS; Ethicon).	(1) 1.263 (2) 1.079 (3) 1.628 (4) 4.512
Grantham et al.,[23] 2016	16 (8) No a priori power analysis was performed	(1) Double endobutton technique using a 2-cortical button system* (2) Coracoid cerclage sling	LtF characteristics of the reconstruction were measured by mounting the shoulder onto a material testing machine. The clavicle was fixed to the Instron crosshead with a fixed load cell, and the specimen was pulled in a superior direction at a rate of 50 mm/min.	(1) 448.4 (2) 226.9	(1) A 2-cortical button system (ENDOBUTTON CL system; Smith & Nephew), and a no. 5 suture (ETHIBOND; Ethicon). (2) Three no. 2 sutures (FiberWire; Arthrex).	(1) 1.150 (2) 1.891
Li et al.[45] 2014	12 (6) No a priori power analysis was performed	(1) mWD (2) Triple Endobutton technique*	LtF test followed at 25 mm/min in the superior direction to simulate AC joint dislocation. No failure definition.	(1) (1) 171.64 (2) 686.88	(1) Two no. 2 sutures (ETHIBOND; Ethicon) (2) Five no. 2 sutures (ETHIBOND; Ethicon), and 3 cortical buttons (ENDOBUTTON).	(1) 2.146 (2) 1.510

(continued)

Table 4. Continued

Study	No. Specimens	Surgical Techniques	Superior Direction Load-To-Failure Protocol	LtF Results (N)	Implants and Estimated Costs	LtF/Cost Index
Martetschläger et al.,[51] 2013	24 (12) No a priori power analysis was performed	(1) Native (2) PDS cerclage reconstruction*	LtF, stiffness and elongation at LtF and failure mode were evaluated. LtF was considered when the testing machine stopped at a drop in force of 50% from the applied maximum force (Fmax 50%). The recorded Fmax was equated with the LtF. Clinical failure was defined as elongation of 12 mm (ca. 1 mm less than elongation at failure of the native ligaments).	(1) 590.1 (2) 569.9	(1) Native. (2) Two 1.5-mm braided cord cerclages (PDS; Ethicon), and a 1.0-mm braided cord (PDS; Ethicon).	(2) 2.235
Nüchtern et al.[52] 2013	18 (6) No a priori power analysis was performed	(1) Locking hook plate (2) TR* c) Bone anchor systems*	LtF testing was performed using a static increasing axial load at a rate of 25 mm/min. Failure was defined as a 20-mm superior dislocation or any fracture, insufficiency, or material failure occurrence. Photographic and radiographic documentation was obtained in every case.	(1) 248.9 (2) 832.0 (3) 538.0	(1) Locking hook plate (LCP Hook Plate; Synthes). (2) Two 2-cortical button systems (TightRope; Arthrex). c) Two 6.5-mm suture anchors (Corkscrew anchors; Arthrex), and 2 cortical buttons (small plates).	(1) 0.332 (2) 1.189 (3) 0.727
Shin et al.[30] 2014	12 (6)	(1) Single tendon anatomic AC—CC reconstruction* (2) Coracoid cerclage reconstruction	LtF at 50 mm/min. The direction of load corresponded to superior clavicle translation. No failure definition.	(1) 443.2 (2) 295.4	(1) Three no. 2 FiberWire (Arthrex), 14 × 3.5-mm 2-cortical button system (GraftRope; Arthrex), and 4.75-mm and 5.5-mm interference screws (Bio-Tenodesis screw; Arthrex). (2) Two no. 2 sutures (FiberWire; Arthrex), Two 4.5-mm interference screw (Bio-Tenodesis screw; Arthrex).	(1) 0.492 (2) 0.579
Staron et al.[54] 2013	16 (8)	(1) Lee's modified knot fixation technique (2) Mazzocca's modified anatomical double-bundle technique with interference screws	The intact CC ligaments were tested to failure with superior displacement at a rate of 2 mm/s. Reconstruction was performed using a semitendinosus tendon allograft, and LtF was repeated for each construct. Failure was defined as 2 cm of displacement, which is approximately the amount of displacement of a grade 3 acromioclavicular separation.	(1) 347.5 (2) 326.9	(1) Three no. 2 sutures (FiberWire; Arthrex). (2) Two no. 2 sutures (FiberWire; Arthrex), and two 5.5 × 15-mm interference screws (Bio-Tenodesis screw; Arthrex).	(1) 2.896 (2) 0.641

(continued)

Table 4. Continued

Study	No. Specimens	Surgical Techniques	Superior Direction Load-To-Failure Protocol	LtF Results (N)	Implants and Estimated Costs	LtF/Cost Index
Tashjian et al.,[31] 2012	8	(1) Interference screw fixation method* (2) Side-to-side suturing (3) Square knot*	LtF testing was performed on each construct. Using position control, mechanical testing of each specimen was performed by moving the clavicle in a superior direction at a constant displacement rate of 25 mm/min while continuously recording displacement and load. Ultimate failure was defined as the first significant decrease in load seen on the load-displacement graph.	(1) 469.7 (2) 510.7 (3) 614.8	(1) Two 5.5 × 25-mm interference screws (PEEK Bio-Tenodesis screws; Arthrex). (2) A no. 2 suture (FiberWire; Arthrex). (3) A no. 2 suture (FiberWire; Arthrex).	(1) 1.092 (2) 12.768 (3) 15.370
Beitzel et al.,[42] 2011	40 (G B = 8, G C = 8, G D = 6) No a priori power analysis was performed	(1) Native (2) SCT* (3) DCT* d) mWD	LtF testing (120 mm/min) was then performed in a superior direction to evaluate the maximal loading capacity of the reconstruction. No failure definition.	(2) 591.35 (3) 651.16 (4) 311.13 Control: (1) 579.44	(1) None. (2) A 2-cortical button system (TightRope; Arthrex). (3) A 3-cortical button system (Twin Tail TightRope; Arthrex). d) Two no. 2 sutures (FiberWire; Arthrex).	(1) 1.690 (2) 0.766 (3) 3.889
Clevenger et al.,[53] 2011	14 (7)	(1) Hamstring allograft CC reconstruction* (2) Hamstring allograft CC reconstruction plus a CA ligament transfer*	LtF testing was added to the protocol after the initial 4 specimens had been tested and were, therefore, performed on 10 of the specimens, independent of the reconstruction technique used. Using position control, we performed mechanical testing of each specimen by moving the clavicle in a superior direction at a constant displacement rate of 25 mm/min while continuously recording displacement and load. Ultimate failure was defined as the first significant decrease in load seen on the load-displacement graph.	(1) 970.3 (2) 952.7	(1) Two no. 5 sutures, and a no. 2 suture (FiberWire; Arthrex). (2) Two N° 5 sutures, and two N° 2 sutures (FiberWire; Arthrex).	(1) 8.086 (2) 5.954

AC, acromioclavicular; CA, coracoacromial; CC, coracoclavicular; DCT, double clavicular tunnel; Fmax, maximum force; LtF, load-to-failure; mWD, modified Weaver-Dunn; PDS, polydioxanone; SCT, single clavicular tunnel; TR, TightRope; UHMWPE, ultra-high molecular-weight polyethylene.

Techniques denoted with an asterisk (*) exceeded the minimum acceptable threshold of load to-failure.

Table 5. STROBE Statement Checklist Score of Included Studies

Study	Year	Score (max. 32)
Zooker et al.[28]	2010	29
Beitzel et al.[42]	2011	28
Clevenger et al.[53]	2011	29
Tashjian et al.[31]	2012	29
Staron et al.[54]	2013	30
Shin et al.[30]	2014	30
Nüchtern et al.[54]	2013	28
Martetschläger et al.[51]	2013	28
Li et al.[45]	2014	28
Grantham et al.[23]	2016	28
Weiser et al.[50]	2015	29
Abat et al.[49]	2015	29
Naziri et al.[48]	2016	29
Struhl et al.[47]	2016	31
Banffy et al.[41]	2018	28
Le Hanneur et al.[44]	2018	31
Hislop et al.[43]	2019	29
Lobao et al.[46]	2020	31

the conservative group in exchange for cosmesis.[14,15] It is important to highlight that choosing conservative treatment as the initial option will not jeopardize clinical outcome if surgical treatment is subsequently needed.[4] To date, the percentage of conservative treatment failures related to associated injuries in AC joint dislocations is unknown, but Ruiz Ibán et al.[60] have reported 1 in every 5 patients undergoing surgical treatment to fail based on a meta-analysis of 21 studies.

Meta-analysis of biomechanical studies in the last decade and available evidence shows greater SCI in non-ACCR surgical techniques of AC joint dislocations. Non-ACCR techniques, or techniques combining 2 clavicular tunnels separated by at least 10 mm, a mean of 2 sutures, and/or suture tapes provide supraphysiologic stability and load-to-failure in controlled biomechanical testing. In addition, they show the greatest SCI and LtFCI when considering implant costs.

Limitations

There are some limitations to this study that should be noted. First, a high degree of heterogeneity exists in the included studies. Different preconditioning protocols, cycles, and frequency of loading, load-to-failure rates, and failure definitions were found. However, the direction and quantity of mechanical loading in each study were similar. Second, our study does not consider rotational stability that may play an essential role in the outcome.[9,32]

Third, the sample size in the included biomechanical studies comparing non-ACCR versus ACCR techniques was limited to 5 studies for 3-direction 70-N protocols and 7 studies for load-to-failure protocols, for a total of 16 techniques of 41 assessed in the SCI and LtFCI analysis (18 studies). However, the differences between the 2 groups were statistically significant. Lastly, the standardization of the cost of implants may modify the SCI and LtFCI of specific techniques. Special attention was taken to preserve the price ratio between the type of implants, which could potentially alter the indexes rather than values themselves. We recognize that the cost of ACCR techniques involving the use of grafts is underestimated in our calculations. Autograft tissue can be used; however, this adds surgical time and cost for graft harvest and preparation, and there is accompanying patient morbidity. Allograft tissue avoids harvest time and morbidity; however, there is a significant additional cost for allograft tissue (around $2775).[61] Accounting for the graft cost would result in an even lower SCI and LtFCI value for ACCR techniques. It is important to state that graft implementation's biological benefits cannot be evaluated in biomechanical studies, especially in chronic injuries where the native ligament' healing potential is impaired.[5,6,10,21] However, graft implementation has shown greater early elongation than suture constructs,[23,31,48,53,54] which show no relevant creep or stretching after 100-500 cycles and are potentially relevant in the acute setting.[43,53] In addition, all but 3 of the included studies used implants from the same manufacturing company.

Future research in cost-effectiveness will bring new perspectives in the treatment of AC joint dislocations. It is unknown how much stability is needed to provide clinical benefits, and when additional biomechanical stability fails to provide additional clinically relevant improvement, it results in higher costs. Nevertheless, excellent and comparable clinical subjective outcome

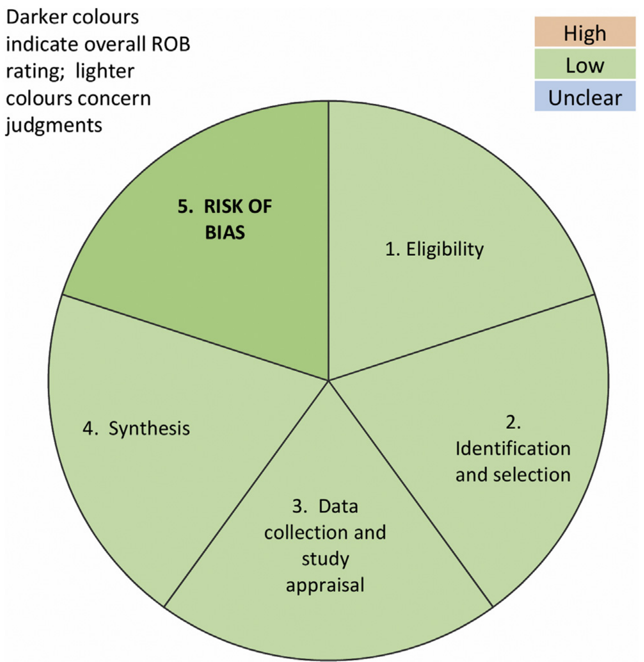

Fig 5. Risk of bias summary: review authors' judgments about each risk of bias using ROBIS tool. (ROB, risk of bias.)

scores suggest that any technique provides acceptable results for most patients.

Conclusions

Non-ACCR and ACCR techniques exceeded the minimum acceptable threshold of stability and failure loads in controlled biomechanical testing. However, non-ACCR and techniques combining two clavicular tunnels separated by at least 10 mm, a mean of 2 sutures and/or suture tapes provide supraphysiologic stability and failure loads at a lower cost of implants.

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