Shoulder acromioclavicular joint reconstruction options and outcomes

Simon Lee¹ · Asheesh Bedi²

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Abstract Acromioclavicular joint separations are a common cause of shoulder pain in the young athletic population. In high-grade injuries, acromioclavicular joint reconstruction procedures may be indicated for functional improvement. There is currently no gold standard for the surgical management of these injuries. Multiple reconstructive options exist, including coracoclavicular screws, hook plates, endobutton coracoclavicular fixations, and anatomic ligament reconstructions with tendon grafts. This article aims to review pertinent acromioclavicular joint anatomy and biomechanics, radiographic evaluation, classification system, as well as reconstruction options, outcomes, and complications.

Keywords Acromioclavicular joint injury · Ligament reconstruction · Outcomes · Complications

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✉ Asheesh Bedi
abedi@med.umich.edu

Simon Lee
simlee@med.umich.edu

¹ Orthopaedic Surgery House Officer, University of Michigan Health System, 1500 E. Medical Center Dr., TC2912, Ann Arbor, MI 48109-5328, USA

² Harold and Helen W. Gehring Professor of Orthopaedic Surgery, Chief, Sports Medicine and Shoulder Surgery, University of Michigan Health System, Domino's Farms – MedSport, 24 Frank Lloyd Wright Drive, Lobby A, P.O. Box 391, Ann Arbor, MI 48106, USA

Introduction

Acromioclavicular (AC) joint separations are one of the most common causes of shoulder pain, particularly in the young and in athletes. This injury accounts for 8 % joint dislocations, and the overall incidence of this injury has been reported as up to 9.2 injuries per 1000 person-years in younger athletes [1]. However, the true incidence of AC joint injury is still likely to be underestimated as many of these cases go undiagnosed and untreated. While AC joint injuries can result from a multitude of causes, most injuries occur during activities with high-impact risks such as contact sports, football, ice hockey, and wrestling, with male athletes at greater risk than female athletes [1, 2]. The mechanism of injury is typically a direct impact at the acromion in the setting of an adducted shoulder. The initial traumatic force drives the acromion inferiorly, while the clavicle remains in its anatomic position and initiates a cascade of injury which begins with acromioclavicular ligament failure, followed by failure of the coracoclavicular ligaments. Severe injuries may disrupt the muscular attachments of the deltoid and trapezius from the clavicle as well.

Treatment of AC joint injuries continues to be controversial among clinicians, with much disagreement on the optimal intervention for variable severity of injury. The current literature contains a multitude of conservative and operative management options, each of which has been extensively modified. The abundant number of surgical techniques create difficulty in the determination of which procedure best suits a particular injury. The goal of this article is to review AC joint anatomy and biomechanics, radiographic evaluation, classification system, as well as joint reconstruction options, outcomes, and complications.

Anatomy

The distal clavicle articulates with the medial facet of the acromion and forms the diarthrodial synovial AC joint. While relatively small, this joint is crucial in maintaining proper scapulothoracic function as it serves as a vital link between the upper extremity and axial skeleton. The distal clavicle is oriented posteriorly and laterally, while the articular surface of the acromion is directed medially and anteriorly [3]. Components which primarily contribute to AC joint stability include the joint capsule, the acromioclavicular (AC) and coracoclavicular (CC) ligaments, and the intraarticular fibrocartilaginous disc. The fibrocartilaginous disc may significantly vary in geometry between patients and typically becomes incompetent after the age of 40 due to rapid degeneration following the second decade of life [4]. DePalma and Salter described two fibrocartilaginous disc variants: a common meniscoid-like disc and a rare complete disc [5, 6].

The trapezoid ligament laterally and conoid ligament medially collectively comprise of the CC ligaments. These structures function as a static anterior-inferior stabilizer of the AC joint. The ligaments originate from the superior surface of the coracoid and diverge as they course superiorly, with the conoid ligament broadly inserting posteromedially onto the conoid tuberosity medially and trapezoid ligament narrowly inserting anterolaterally at the trapezoid ridge at the inferior distal clavicle [7]. These distinctive trajectories and insertion sites suggest individual function of each ligament and form some of the basis for anatomic reconstruction techniques for restoration of native biomechanical function. Gender differences exist in the distance between the distal end of the clavicle and medial edge of the conoid tuberosity (males 47.2 ± 4.6 mm; females 42.8 ± 5.6 mm; $P = 0.006$) as well as the distance to the center of the trapezoid tuberosity (males 25.4 ± 3.7 mm; females 22.9 ± 3.7 mm, $P = 0.04$) [8]. However, the ratio between the clavicle length to the medial edge of the conoid tuberosity distance (0.31) and the trapezoid distance (0.17) was equal between genders [8]. The mean distance from the coracoid precipice to the conoidal center and trapezoidal center is 16.4 ± 2.4 and 10.9 ± 2.4 mm, respectively [9]. Mazzoca et al. has demonstrated that the cascade of injury in AC joint separations consistently started with initial conoid ligament failure followed by trapezoid ligament with superior loading [10].

The AC capsule is relatively thin, but maintains significant ligamentous support in the form of the AC ligaments. These four AC ligaments (anterior, posterior, superior, and inferior) primarily function as a static anterior-posterior joint stabilizer [11]. Klimkiewicz et al. showed that sectioning of the superior and posterior AC ligaments contributed to significant subsequent posterior translation, contributing 56 and 25 %, respectively, of the force required resist to posterior displacement of the distal clavicle a specified distance [12]. The AC joint

capsule inserts approximately 2.8 mm lateral of the medial acromion and approximately 3.5 mm medial to the distal clavicle [13]. Consequently, the authors recommended no more than a 2–3-mm medial acromial or 3–4-mm distal clavicle resection to minimize violation of the AC capsular insertion sites [13]. Micro-sectioned histologic samples utilized by Renfree and Wright demonstrated that resection of as little as 2.6 mm of the distal clavicle in males and 2.3 mm in females may disrupt the superior AC ligament [3]. Corteen et al. also showed that a 1-cm resection of the distal clavicle resulted in a 32 % increase in posterior translation as compared to an intact cadaveric specimen [14].

Radiographic evaluation

Plain anteroposterior (AP) and axillary radiographs are the initial imaging modality of choice for the evaluation of suspected AC joint injuries [15]. Vertical displacement of the distal clavicle may be observed on the AP view, while anteroposterior displacement may be evident on the axillary view (Fig. 1). AP-weighted stress views may be performed and are compared with non-stressed views to evaluate whether the additional downward force reveals ligamentous incompetency. However, it is unclear if this modality provides any additional diagnostic value and has fallen out of favor among some clinicians [16]. The addition of the Zanca view (AP with 10–15° cephalic beam inclination) allows for optimized evaluation by opening the AC joint and avoiding the superimposition of the acromion on the distal clavicle [17]. A wide plate should be utilized with the AP and Zanca views to incorporate the contralateral shoulder for direct comparison views on a single cassette [18]. The distal clavicle has been shown to subluxate by up to 50 % in normal shoulders [19]. Posterior dislocations may be evaluated with a lateral view of the acromion, commonly be overlooked on AP and stress views [19].

There is growing popularity in the utilization of other imaging modalities such as magnetic resonance imaging (MRI) and ultrasound for the diagnosis of AC joint injuries. MRI allows for the visualization of ligamentous and soft tissue structures, allowing for extent of injury evaluation and potentially providing valuable information for operative decision making [20]. Nemas et al. showed that MRI evaluation was concordant with radiographic AC joint injury classification in 52.2 %, but reclassified injuries as less severe in 36.4 %, more severe in 11.4 % [21]. MRI may also be helpful in identifying other associated shoulder pathology as Pauly et al. reported a 15 % incidence of concomitant injuries following high-grade type IV AC injuries, requiring additional surgical interventions [22]. Ultrasonography allows for dynamic evaluation of the AC joint when radiographs are equivocal. Peetrons and Bédard described an ultrasound analysis technique on patients

Fig. 1 Anteroposterior (a) and axillary (b) radiographs of a Rockwell type IV acromioclavicular joint dislocation

with Rockwell I injuries incorporating a dynamic cross-arm maneuver and were able to detect abnormal micromotion of the clavicle suggestive of AC joint injury not evident on plain radiographs [23]. Bilfeld et al. showed that ultrasound detected CC ligament injuries with 88.9 % sensitivity, 90.0 % specificity, a 92.3 % positive predictive value, and an 85.7 % negative predictive value, correlating well with MRI findings [24]. These methods may be valuable supplemental tools when radiographs provide insufficient data for accurate diagnosis or classification; however, costs and false positive findings may limit their routine use.

Classification

Developed in 1984 and based on the original work of Tossy, the Rockwood classification is the most commonly utilized tool for evaluating and guiding the management of AC joint injuries. This system is based on radiographs and represents the continuum of AC and CC ligament injuries, increasing in severity based on the extent of soft tissue damage (Table 1) [25, 26]. Type I injuries are sprains or partial tears of the AC ligaments without evidence of radiographic or clinical instability. Tenderness to palpation may be present over the AC joint, but absent over the CC ligaments. Type II injuries result from complete tears of the AC ligaments without disruption of the CC ligaments, resulting in distal clavicle instability in the anterior-posterior plane and radiographic widening of the AC joint space. This type has been reported to be the most common AC joint injury diagnosed in a cohort of young athletes [1]. Stretching of the CC ligaments may also result in mild superior translation of the distal clavicle and tenderness with palpation of the clavicle. Type I and II AC joint injuries typically respond well to non-operative management utilizing pain control, sling immobilization, early shoulder range of

motion, and rehabilitation [27]. Initial sling immobilization alleviates stress at the injured ligaments, allowing for rest and healing. Early shoulder rehabilitation with passive and active motion is recommended. Heavy lifting and contact activities should not commence until the extremity is relatively pain free and symmetric range of motion is achieved. However, while the initial literature demonstrated positive results, intermediate and long-term follow-up demonstrate that this population is still at risk for long-term symptoms, and patients should be advised of this potential outcome [28, 29].

Type III injuries involve disruption to both the AC and CC ligaments, resulting in combined superior-inferior and anterior-posterior instability. The distal clavicle is displaced superiorly but is usually reducible and the CC space in the affected extremity may be increased 25 to 100 % as compared to the contralateral side. The management of type III injuries continues to be controversial among orthopedic surgeons. Many clinicians advocate initial non-operative management and report good-to-excellent results in most cases [27, 30–34]. However, some case series have demonstrated persistent decreased function and increased pain at final follow-up. In a series of 24 non-operatively managed type III injuries, Gumina et al. found that 70.6 % developed scapular dyskinesia and 58.3 % developed SICK scapula syndrome, likely due to persistently dysfunctional shoulder biomechanics [35]. In a follow-up study, a majority of these patients experienced clinical improvement with rehabilitation, but a subset continued to experience long-term shoulder dysfunction [36]. Additionally, while Schlegel et al. found no significant difference in range of motion and rotational strength in a series of 25 non-operatively managed type III injuries, 20 % of patients found their persistent deformity unacceptable and a mean 17 % decrease in bench-press strength was noted [37].

Thus, individual patient characteristics such as sport, level of competition, and functional demand should be considered.

Table 1 Rockwell classification for acromioclavicular joint injury

Type	AC joint	AC ligament	CC ligament	Deltoid and trapezius muscles
I	Intact	Sprain	Intact	Intact
II	Vertically displaced (<25 %)	Torn	Sprain/intact	Intact
III	Vertically dislocated (25–100 %)	Torn	Torn	Typically intact
IV	Posteriorly dislocated through trapezius	Torn	Torn	Detached
V	Dislocated with rupture of deltotrapezial fascia (100–300 %)	Torn	Torn	Detached
VI	Subacromial or subcoracoid position clavicular dislocation	Torn	Torn	Detached

AC acromioclavicular, CC coracoclavicular

The current available literature suggests that management of type III injuries and made on an individualized basis, generally advocating for initial non-operative management, but with consideration for early surgical intervention in patients with high functional demand such as overhead athletes and manual laborers [27, 38]. Regardless, operative management of type III injuries is recommended for patients who fail conservative treatment and present with persistent pain, scapular dysfunction, and weakness.

Type IV injuries are characterized by complete posterior displacement of the distal clavicle with a concomitant injury to the trapezial fascia. Tenting may be seen on the posterior aspect of the shoulder. Type V injuries also involve complete tears of the AC and CC ligaments, but with a severe CC space widening of greater than 100 %. The clavicle often pierces the deltotrapezial fascia and becomes non-reducible, presenting with significant drooping deformity of the shoulder. Type VI injuries result from detachment of the trapezius and deltoid from the distal clavicle resulting in severe inferior dislocation due to hyperabduction and external rotation. The distal clavicle is positioned in either subacromial or subcoracoid space. There is consensus in the literature that type IV, V, and VI injuries are indications for surgical intervention.

Surgical treatment options and outcomes

Coracoclavicular screw

Bosworth classically described his non-cannulated coracoclavicular lag-screw fixation technique to manage acute complete acromioclavicular dislocations in 1941 [39]. Open reduction is performed on the AC joint dislocation followed by insertion of the screw between the distal clavicle and the coracoid process, lagging the clavicle inferiorly to an anatomical position. In a study of 56 patients undergoing intra- and extraarticular ligament repair for types III–V injuries with rigid 4.5-mm cortical lag-screw CC fixation, Assaghir et al. reported good-to-excellent long-term outcomes in 94.6 % of patients with an average follow-up of 76.6 months [40]. The

screw may also be inserted percutaneously under fluoroscopic image guidance, but Tsou et al. reported a 32 % failure rate in 53 patients undergoing this technique. Even with adequate screw positioning, hardware failure and obligatory screw removal has decreased the popularity of this technique.

Hook plate

Balser first described the hook plate technique for anatomic reduction and fixation of AC joint dislocations in 1976 [41]. The plate is fixed superiorly to the distal clavicle and reduces the joint by utilizing a transarticular hook which engages the inferior surface of the acromion. Wolter and Eggers introduced a modified plate with the addition of a vertical hook in 1984 [42]. Kienast et al. reported 89 % good-to-excellent Constant score (mean 92.4) and 84 % good and excellent Taft scores in 225 cases with an average follow-up of 36 months [43]. However, the authors described a 10.6 % complication rate, and all patients had some degree of hardware pain or discomfort until the plate was removed [43]. Salem and Schmelz reported an excellent mean Constant score of 97 and a mean Taft score of 10.6 in a cohort of 23 cases with an average follow-up of 30 months; however, eight cases demonstrated radiographic loss of reduction following plate removal 10 weeks post-operatively [44]. Di Francesco et al. reported a mean Constant score of 91 on 42 cases with an average follow-up of 18 months [45]. Acceptable AC joint alignment was achieved post-operatively, but 12 % of cases demonstrated loss of reduction at 1 year following the primary operation.

Lin et al. performed a study utilizing dynamic ultrasound evaluation of 40 cases and found that while 97.5 % achieved clinical and radiological union and/or ligamentous healing, 37.5 % developed subacromial impingement syndrome, six cases of which additionally were noted to have concomitant rotator cuff lesions [46]. These patients demonstrated significantly worse outcome scores compared to those who did not demonstrate impingement. Additionally, 50 % of cases had evidence of acromial erosion due to the subacromial hook, a more serious complication which can lead to acromial osteolysis or fractures [46, 47]. The Canadian Orthopaedic

Trauma Society recently completed a multicenter-randomized clinical trial involving hook plate fixation versus non-operative treatment of 83 AC dislocations, finding not significantly different long-term outcomes scores between the two groups [48]. In fact, the non-operative arm demonstrated significantly superior DASH scores through 3 months and superior Constant scores up through 6 months. While the operative group demonstrated better radiographic results, they had 14 complications (7 major, 7 minor), including two reoperations, as compared to only three complications in the non-operative group (2 major, 1 minor) without reoperation. While this technique is gaining popularity, the necessity of implant removal at 3 months, uncertain superiority over non-operative management, and the higher incidence of complications are important considerations when considering its use.

Endobutton coracoclavicular fixation

The advent of anatomic reconstruction techniques in an attempt to achieve improved AC joint strength and stiffness more comparable to the normal has gained rapid popularity. The TightRope System (Arthrex, Naples, FL) is the most widely used synthetic technique and has been modified for use as a prosthetic replacement for CC ligament reconstruction. The device consists of titanium endobuttons (titanium device utilized in conjunction with suture to secure cortical fixation) placed through drill holes at the distal clavicle and coracoid, which connected with a #5 FiberWire suture (Arthrex, Naples, FL). With the first generation TightRope, single drill holes in the clavicle and coracoid were placed to recreate the anatomic course of the CC ligament complex as one unit and used a single TightRope system. The second generation utilizes two TightRope systems in an attempt to more closely recreate the individual vectors of both the coronoid and trapezoid ligaments from the coracoid in an attempt to improve AC joint biomechanics. Biomechanical studies have shown that #5 FiberWire has a biomechanical limitation of 485 N as compared to the native CC ligament complex of 589 N [49]. The two TightRope has therefore been shown to provide comparable biomechanical strength as compared to the native ligament [50, 51].

Venjakob et al. has published the longest term follow-up of 58-month results in a series of 23 patients undergoing two suture-button fixations for acute AC joint dislocation [52]. Ninety-six percent of cases were very satisfied or satisfied, and patients reported a significant improvements of VAS score to 0.3 ± 0.6 and Constant score to 91.5 ± 4.7 as compared to baseline levels ($P < 0.05$) [52]. Overall, this cohort reported eight radiographic failures which comprised of undercorrection and/or posterior displacement, and four additional CC distance overcorrections [52]. Scheibel et al. also reported on 37 cases with a mean follow-up of 26.5 months and found that the subjective shoulder value reached 95.1 %, the mean Constant score reached 91.5 points, the mean

Taft score reached 10.5 points, and the acromioclavicular joint instability score reached 79.9 points [53]. However, significant lengthening of the operative side CC distance were present (13.6 mm) as compared to the asymptomatic contralateral side (9.4 mm) and radiographic signs of posterior instability were present in 42.9 % of cases [53].

In relation to return to play, Saier et al. surveyed 42 patients who underwent anatomic reconstruction of Rockwood type V AC joint injuries and demonstrated that all cases were able to return to some sporting activity at 31 months follow-up [54]. Constant scores in this cohort significantly improved to a mean of 94 compared to pre-injury levels ($P < 0.02$) and QuickDASH (mean 6, range 0–54) and DASH-Sport-Module (mean 6, range 0–56) revealed only minor disabilities. Sixty-two percent of patients noted that subjective sports specific AC joint integrity to be at least similar to their baseline level prior to injury. The authors did find that patients had significantly lower levels of sporting intensity (7.3 to 5.4 h/week, $P = 0.004$) and a decreased level of competition ($P = 0.02$), though 50 % of these cases noted reasons other than their shoulder injury as a cause.

However, this technique is not without significant risk as Clavert et al. reported on the complications of 116 primary anatomic button fixation in a prospective multicenter study [55]. The authors described an overall complication rate of 27.1 % with 11 complications due to hardware failure resulting in a loss of reduction, one coracoid fracture, seven cases of adhesive capsulitis, two local infections, and five cases of symptomatic hardware. Forty-eight patients also had persistent dislocation of >150 % on an AP radiographs. No intraoperative complications were reported. Patients experiencing a complication had significantly lower Constant scores as compared to those without complications (71 vs. 93, $P < 0.0001$) and could not return to the same level of sports activities due to persistent pain [55]. The TightRope has several advantages, particularly the ability for minimal soft tissue disruption through an arthroscopic approach and generally satisfactory outcomes. However, caution should be used as these constructs have been shown to be prone to posterior instability and a significant risk of hardware issues.

Ligament reconstruction

The Weaver-Dunn procedure was first described in 1972 and utilizes the native coracoacromial (CA) ligament in AC joint reconstructions [56]. This technique involves the distal clavicle excision in combination with transfer of the CA ligament from the acromion to the distal clavicle remnant in an attempt to restore AC stability. However, the clinical outcomes for this procedure have been lacking as Weaver and Dunn initially reported only a 75 % good-to-excellent outcomes with their original technique. Additionally, a recent systematic review by Sood et al. demonstrated that there was only a low level of

evidence to support the use of CA ligament transfers for AC joint dislocations [57]. The authors also noted that this fixation construct is associated with a high rate of deformity recurrence even in combination with adjunct fixation due to the high incidence of fixation related complications [57]. Harris et al. performed a cadaveric biomechanical study comparing the structural properties of various AC joint reconstruction techniques and found that CA ligament transfers proved to be the weakest and least stiff construct [58]. While superior-inferior stability is improved, stability in the anterior-posterior plane is not restored and the initial strength of the CA ligament transfer is only approximately 25 % of the native CC ligament strength [58, 59]. Consequently, the recurrent subluxation rate for this construct has been reported in up to 30 % of patients in the procedure has subsequently undergone several modifications and has generally fallen out of favor for high-grade AC joint dislocation injuries.

The utilization of autograft or allograft for the anatomic reconstruction of the CC and AC ligaments in acute AC joint dislocation has rapidly gained popularity in the past few decades [60]. Initially described by Jones et al. in 2001, this open technique involves creating two tunnels through the distal clavicle at the coronoid and trapezoid footprints, reducing the AC joint into anatomic position, passing a tendon graft through each tunnel and around or through the inferior aspect of the coracoid with the longer remaining tail of the graft exiting the lateral tunnel [61]. This construct is then secured with two interference screws or cortical buttons at the clavicle and completes the double-bundle reconstruction. The remaining longer limb of the graft may then be used to reconstruct the superior and posterior AC ligaments and subsequently complete a triple-bundled reconstruction. This technique aims to anatomically reconstruct both the AC and CC ligaments of the joint (Figs. 2 and 3). Table 2 demonstrates some pearls and

pitfalls to consider when performing tendon reconstruction for AC joint injuries.

Biomechanical studies have demonstrated that free graft AC joint reconstruction more closely re-creates initial anterior-posterior and superior-inferior translational stability of the native joint as compared to the Weaver Dunn procedure [62]. Mazzocca et al. compared 42 cadaveric specimens randomly assigned to either arthroscopic suture fixation, open-modified Weaver-Dunn repair, or anatomic CC ligament reconstruction with allograft and found that the anatomic ligament reconstruction was the most stable construct [63]. Tauber et al. showed significantly superior clinical and radiographic outcomes of anatomic semitendinosus CC ligament reconstruction when compared to a modified Weaver-Dunn procedure in a prospective comparative study of 24 cases with 37-month mean follow-up. The semitendinosus CC ligament reconstruction group had significantly higher ASES scores (96 vs. 86, $P < 0.001$), higher Constant score (93 vs. 81, $P < 0.001$), and decreased CC space widening under stress ($P = 0.027$). Additionally, horizontal instability could be treated with anatomic CC ligament reconstruction, unlike the Weaver-Dunn procedure.

Numerous studies in the literature have reported generally good-to-excellent outcomes after anatomic CC ligament reconstruction with biologic grafts [35, 64–74]. These include several modifications to this technique have been reported in the literature including the use of a coracoid bone tunnel for inferior graft fixation as well as augmentation of the graft loop with the addition of a synthetic cortical button fixation. Carofino et al. reported on a series of 17 cases and demonstrated significant improvements in the mean ASES scores (52 to 92), mean SST scores (7.1 to 11.8), and mean Constant Murley scores (66.6 to 94.7) [60]. Patients also reported significant improvement in pain with a posterior-directed force,

Table 2 Pearls and pitfalls when considering anatomic acromioclavicular reconstruction with tendon grafts

Pearls	Pitfalls
<ul style="list-style-type: none"> • Assure adequate clearance of soft tissue, including residual capsule and scar tissue, to allow for complete joint reduction • The use of anatomic clavicular tunnels restores CC ligament footprints and more closely restores native biomechanics • Consider one tunnel if AP clavicular width is <18 mm to reduce clavicular fracture risk • Avoid coracoid tunnels, particularly >6 mm to reduce coracoid fracture risk • Maximize the use of provisional reduction techniques to facilitate graft fixation • Augmentation or reconstruction of the AC ligaments and capsule improves post-operative joint mechanics 	<ul style="list-style-type: none"> • Incomplete distal clavicle resection <ul style="list-style-type: none"> - Incomplete resection posteriorly and superiorly is most common - Resect minimum of 10 mm to assure clearance with crossed adduction maneuvers - Must view from multiple portals to ensure adequate clearance, including the direct anterior position - Consider open resection in cases of significant deformity or large chest wall • Excessive resection and instability <ul style="list-style-type: none"> - Excessive CC ligament resection results in superior clavicular instability - Excessive AC ligament resection results in anterior-posterior instability

Fig. 2 Arthroscopic view of an acromioclavicular joint reconstruction with allograft tendon. **a** Creation of bone tunnels through the distal clavicle. **b** Placement of a passing suture around the base of the

coracoid for graft placement. **c** Final position of the tendon graft looped around the base of the coracoid

forward elevation, and horizontal abduction; however, three failures were reported due to persistent pain even after revision, infection, and loss of reduction. Millett et al. recent reported 2-year follow-up results on 31 shoulders that underwent anatomic CC ligament reconstruction and found significant improvements in mean post-operative ASES scores (58.9 vs. 93.8, $P < 0.001$) and SF-12 PCS scores (45.3 vs. 54.4, $P = 0.007$) compared to baseline [75]. The SANE score was 89.1 and the QuickDASH score was 5.6. But the authors also reported a 22.6 % complication rate which included two graft rupture or attenuation, two clavicle fractures, two distal clavicle hypertrophy, and one adhesive capsulitis.

Coracoid or clavicular fractures are some of the more serious complications associated with anatomic reconstruction of

the AC joint. Millett et al. presented a review of 12 studies in the literature which reported complications following anatomic CC ligament reconstruction with biologic grafts and described an overall complication rate of 39.8 % [75]. The most serious complications being graft failure, hardware complications, and distal clavicle and/or coracoid fractures as a result of the bone tunnels. Martetschläger et al. calculated the survivorship of anatomic CC ligament reconstruction in a series of 59 cases to be 86.2 % at 1 year and 83.2 % at 2 years, with an overall complication rate of 27.1% [67]. Similarly, the authors described two clavicle fractures and one coracoid fracture which were associated with 6-mm bone tunnels.

Coale et al. utilized a prospective computed tomography shoulder registry to generate 23 virtual 3D shoulder specimens to simulate various cortical drilling positions at the clavicle and coracoid [76]. The authors found that transclavicular-transcoracoid techniques cannot restore the footprints of the conoid and trapezoid ligaments without significant risk of cortical breach and fracture. However, if a coracoid bone tunnel is to be created, Ferreira et al. demonstrated in a load-to-failure biomechanical cadaveric study that the center-center or medial-center coracoid trajectory had the higher peak load to failure, which may minimize coracoid fracture. Izadpanah et al. used MRI virtual 3D shoulders to perform a kinematic evaluation comparing horizontal transcoracoid drilling, transclavicular-transcoracoid drilling, and underneath tendon passage techniques. [77] While none of the techniques fully restored the kinematic function of the native CC ligaments, the authors concluded that transclavicular-transcoracoid techniques restored conoid length and may be suited for isolated vertical instability, while horizontal transcoracoid techniques created the most shortened trapezoid length in abduction and could better benefit horizontal AC instability.

In an effort to reduce coracoid fractures, the coracoid base looping technique was developed to avoid coracoid bone tunnels. Milewski et al. reviewed complications associated with 27 patients undergoing AC joint reconstruction, 10 cases of which utilized a coracoid bone tunnel and 17 utilized a

Fig. 3 Post-operative anteroposterior radiograph of an anatomically reconstructed acromioclavicular joint with tendon graft showing successful reduction of the joint to an anatomic position. Arrows indicated position of clavicular bone tunnels

coracoid base loop [70]. The tunnel group demonstrated an 80 % complication rate as compared to a 35 % complication rate among the loop group. While coracoid fractures and loss of reduction were described in the tunnel group, clavicle fractures were unique to the loop group. Recent biomechanical studies support the notion of significant decreased load to failure of the clavicle with large bone tunnels [78•, 79, 80•]. Millet et al. advocated for an anatomic CC ligament reconstruction utilizing for an allograft loop around both the coracoid base and distal clavicle with the use of 3-mm bone tunnels, avoiding the use of bone large tunnels with the goal of reducing either clavicle or coracoid fractures [75, 81, 82].

Conclusion

While there is ongoing debate as to which technique should be the gold standard of the surgical management of high-grade acromioclavicular joint injuries, operative techniques continue to advance with technology and an improved characterization of the anatomy. These injuries continue to represent a diagnostic and management challenge to clinicians. The anatomic reconstruction of the coracoclavicular and acromioclavicular ligaments with grafts demonstrates encouraging clinical and biomechanical outcomes; however, significant complications remain with these procedures. Additionally, improved delineation on the appropriate management for type III injuries need to be better defined. Higher level comparative evidence with long-term follow-up is required moving forward to further calibrate and evolve management of acromioclavicular joint injuries in the future.

Compliance with Ethical Standards

Conflict of Interest Simon Lee and Asheesh Bedi declare that they have no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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