Evaluation and Treatment of Acromioclavicular Joint Injuries

Augustus D. Mazzocca,* MD, Robert A. Arciero,*† MD, and James Bicos,‡ MD
*From the *Department of Orthopaedics, University of Connecticut Health Center, Farmington, Connecticut, and ‡JRSI Sports Medicine, Indianapolis, Indiana*

Acromioclavicular joint injuries and, more specifically, separations are commonplace both in general practice and during athletic participation. This article reviews the traditional classification as well as the clinical evaluation of patients with acute and chronic acromioclavicular joint separations. It also highlights many recent advances, principally in the anatomy and biomechanics of the acromioclavicular joint ligamentous complex. The concept of increases in superior translation as well as disturbances in horizontal translation with injuries to this joint and ligaments are discussed. This information, coupled with the unpredictable long-term results with the Weaver-Dunn procedure and its modifications, have prompted many recent biomechanical studies evaluating potential improvements in the surgical management of acute and chronic injuries. The authors present these recent works investigating cyclic loading and ultimate failure of traditional reconstructions, augmentations, use of free graft, and the more recent anatomic reconstruction of the conoid and trapezoid ligaments. The clinical results (largely retrospective), including acromioclavicular joint repair, reconstruction and augmentation with the coracoclavicular ligament, supplemental sutures, and the use of free autogenous grafts, are summarized. Finally, complications and the concept of the failed distal clavicle resection and reconstruction are addressed. The intent is to provide a current, in-depth treatise on all aspects of acromioclavicular joint complex injuries to include anatomy, biomechanics, benchmark studies on instability and reconstruction, clinical and radiographic evaluation, and to present the most recent clinical research on surgical outcomes.

Keywords: acromioclavicular joint separation; acromioclavicular joint reconstruction; acromioclavicular joint injury

The acromioclavicular (AC) joint is a robust articulation that anchors the clavicle to the scapula. It is the pivot point between the clavicle, which is anchored as a strut to the sternoclavicular joint, and the scapula, which moves in a complex pattern that is still not completely understood. This interface is what makes the AC joint simple yet oftentimes humbling to treat. Approximately 9% of shoulder girdle injuries involve damage to the AC joint, and similar studies have shown that most AC joint injuries (43.5%) occur in adults in their 20s. Acromioclavicular dislocations are overwhelmingly more common in men than in women (ratio 5:1), and these dislocations are more often incomplete than complete (2:1).[124] A recent study examining injuries of Division I college hockey teams showed AC joint separations to be the third most common injury.[49]

The anatomy and design of the AC joint make it a resilient joint that can resist a significant amount of force before disruption. Numerous procedures and protocols devised to treat the AC joint can make the choice of an appropriate treatment confusing. For this reason, it is important to understand the anatomy and biomechanics of the joint so that basic principles can be applied. An understanding of these basic principles allows the physician, therapist, or health care provider to evaluate certain clinical situations and apply treatments to specific patient disorders and needs. This article will define and explain the anatomy and biomechanics of the AC joint as well as describe the evaluation, diagnosis, and nonoperative and operative treatment for various disorders of the AC joint.

ANATOMY AND BIOMECHANICS

The AC joint is a diarthrodial joint that primarily rotates as well as translates in the anterior-posterior and the superior-inferior planes. The scapula (acromion) can protract and retract using the AC joint as a pivot point. It is surrounded by a joint capsule with synovium and an articular surface that is made up of hyaline cartilage containing an intra-articular meniscus-type structure. This intra-articular disk has tremendous variation in size and shape. DePalma et al,[39] Petersson,[119] and Salter et al[126] have demonstrated that with age this meniscal homologue undergoes rapid degeneration until it is no longer functional beyond the 4th decade. Its actual function in the joint is negligible.

The AC joint is stabilized both by static and dynamic stabilizers. The static stabilizers include the AC ligaments (superior, inferior, anterior, and posterior), the coracoclavicular ligaments (trapezoid and conoid), and the coracoacromial ligament. The dynamic stabilizers include the deltoid and trapezius muscles. The trapezius and serratus anterior muscles form a force-couple that dynamically stabilizes the joint. Fibers from the superior AC ligament blend with the fascia of the trapezius and deltoid muscles, adding stability to the joint when they contract or stretch.

The AC joint capsule and the capsular ligaments are the primary restraints of the distal clavicle to anterior-to-posterior translation.[50] Posterior horizontal instability of the distal clavicle can cause abutment of the posterolateral portion of the clavicle into the spine of the scapula. Clinically, horizontal instability of the AC joint can result in significant shoulder pain and disability.[78] Serial sectioning of the AC joint ligaments reveals that the superior ligament contributes 56% and the posterior ligament contributes 25% of the resistance to posterior displacement of the clavicle. Consequently, surgical treatment of the AC joint should be designed to avoid rendering the superior and posterior ligaments incompetent.

The coracoclavicular ligaments' main contribution is to vertical stability, preventing superior and inferior translation of the clavicle. This complex is made up of 2 structures—trapezoid ligament and conoid ligament. These 2 ligaments span the space (1.3 cm) between the coracoid and clavicle.[18] The trapezoid ligament is anterior and lateral to the conoid ligament, and both are posterior to the pectoralis minor attachment on the coracoid ligament. Bearden et al[13] reported a range of values for the coracoclavicular space of 1.1 to 1.3 cm. This distance becomes clinically important when differentiating incomplete versus complete AC joint separations. The larger the distance between the coracoid ligament and the clavicle, the more likely a complete dislocation has occurred.[13] The coracoclavicular ligaments perform 2 major functions: (1) They guide synchronous scapulohumeral motion by attaching the clavicle to the scapula, and (2) they strengthen the AC articulation.

Fukuda et al[50] have reported that with small displacements the AC ligaments are the primary restraints to posterior (89%) and superior (68%) translation of the clavicle. With larger displacements, the conoid ligament was found to be the primary restraint (62%) to superior translation, while the AC ligaments were still the primary restraint to posterior translation. The trapezoid ligament was found to be the primary restraint to compression of the AC joint at both small and large AC joint displacements.

Fukuda et al[50] stated that "if maximum strength of healing after an injury to the AC joint is the goal, all ligaments should be allowed to participate in the healing process." This statement is the basis for our technique of reconstruction. Urist[139] determined that the AC ligament was the primary restraint to anterior and posterior displacement and the coracoclavicular ligament, specifically the conoid, resulted in an overall superior displacement or an inferior displacement of the entire scapulohumeral complex. Fukuda et al

determined that the AC ligament contributed about 50% of the total restraining torque for small amounts of posterior axial rotation by superior displacement (65%). The force contribution of the conoid ligament to resist superior displacement increased significantly, to 60% of the total, with further displacement.

Lee et al[84] reported that the trapezoid and conoid ligaments play a major role in limiting excessive AC joint displacements both in the superior and posterior directions, while the inferior AC capsule ligament is the major restraint to anterior translation. They agreed with the recommendation of Fukuda et al that both the coracoclavicular and AC joint capsule ligaments should be considered for reconstruction. Klimkiewicz et al[78] confirmed these findings and reported that the superior and posterior AC capsule ligaments are the most important in preventing posterior translation of the clavicle to the scapula.

Finally, Debski et al,[38] advancing earlier research, recommended that the conoid and trapezoid ligaments should not be considered as 1 structure when surgical treatment is considered, and that capsular damage resulted in a shift of load to the coracoclavicular ligaments. They also reported that the intact coracoclavicular ligaments cannot compensate for the loss of capsular function during anterior-posterior loading as occurs in type-II AC joint injuries.

Motion of the Acromioclavicular Joint

Rockwood et al[124] have reported that there is approximately 5° to 8° of rotation (in line with the scapula) detected at the AC joint with forward elevation and abduction to 180°. Ludewig et al[92] reported that during elevation of the arm, the clavicle, with respect to the thorax, undergoes elevation (11° to 15°) and retraction (15° to 29°). Codman[30] described that with an intact AC joint, scapular motion (3 planes, 2 translations) is synchronously coupled with arm motion by the clavicle. This motion is guided by the coracoclavicular ligaments. Because of the obligatory coupling of clavicle rotation with scapular motion and arm elevation, the AC joint should not be fixed, either by fusion, joint-spanning hardware (screws, plates, pins) or by coracoclavicular screws. Motion will be lost, limiting shoulder function, or the hardware may fail. Normal scapular motion consists of substantial rotations around 3 axes and not simply upward rotation.[99] Motion of the scapula (protraction-retraction) plays a major role in the motion at the AC joint.

CLASSIFICATION OF ACROMIOCLAVICULAR DISLOCATION

The pathologic characteristics of AC joint dislocation were originally described by Cadenat[27] as a sequential injury beginning with the AC ligaments, progressing to the coracoclavicular ligaments, and finally involving the deltoid and trapezial muscles and fascia. Tossy et al[136] later classified the injury into types I, II, and III. Rockwood et al[124] expanded the classification in 1984 to include types IV, V, and VI. The expanded classification recognized a variety of

complete AC joint dislocations. These classifications, which correlate with increasing soft tissue injury are: type I, AC ligament sprain with the AC joint intact; type II, AC ligament tear, coracoclavicular ligaments intact, and AC joint subluxated; type III, AC and coracoclavicular ligaments torn with 100% AC joint dislocation; type IV, complete dislocation with posterior displacement of the distal clavicle into or through the trapezius muscle; type V, exaggerated superior dislocation of the AC joint between 100% and 300%, increasing the coracoclavicular ligament distance 2 to 3 times, and including disruption of the deltotrapezial fascia; and type VI, complete dislocation with inferior displacement of the distal clavicle into a subacromial or subcoracoid position.

MECHANISM OF INJURY

The mechanism of most AC joint injuries and distal clavicle fractures is direct trauma, caused by a fall or blow with the arm in the adducted position. The subcutaneous position of the joint, without a large amount of muscle protection, theoretically increases the incidence of injury. The stability of the sternoclavicular joint transfers the energy of the injury to the AC and coracoclavicular ligaments. Indirect injury to the AC joint may occur by falling on an adducted outstretched hand or elbow, causing the humerus to translocate superiorly, driving the humeral head into the acromion.

DIAGNOSIS/PHYSICAL EXAMINATION

Pain originating from the superior anterior aspect of the shoulder may be challenging to localize to 1 specific structure. A likely explanation of this phenomenon is the innervation of the AC joint and superior aspect of the glenohumeral joint (Figure 1). The lateral pectoral nerve provides sensation to the anterior aspect of the shoulder. Gerber et al[52] evaluated patterns of pain and found that irritation to the AC joint produced pain over the AC joint, in the anterolateral neck and in the region in the anterolateral deltoid. Irritation of the subacromial space produced pain in the region of the lateral acromion and the lateral deltoid muscle but did not produce pain in the neck or trapezius region.

The history and the mechanism of injury are important in making an accurate diagnosis. A direct blow to the AC joint or a fall on the elbow forcing the head of the humerus into the AC joint is the mechanism associated with an AC separation. Injury to the AC joint is identified by a triad of point tenderness, pain at the AC joint with cross-arm adduction, and relief of symptoms by injection of a local anesthetic agent. The cross-arm adduction test is performed with the arm elevated to 90° and then adducted across the chest with the elbow bent at approximately 90°. This cross-arm adduction will produce pain specifically at the AC joint. It may sometimes produce pain in the posterior aspect of the shoulder associated with a tight posterior capsule or produce pain at the lateral aspect of the shoulder, which is also associated with rotator cuff injury. The reason that the cross-arm adduction test causes pain at the AC joint specifically is due to the compression across the AC joint with that motion.
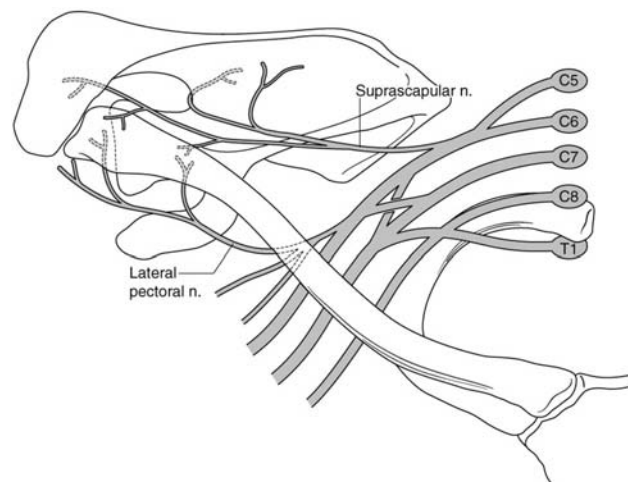

Figure 1. The acromioclavicular joint has dual innervation from both the suprascapular nerve and the lateral pectoral nerve. Reprinted from the article "Injuries to the Acromioclavicular Joint" by DeLee, Drez, and Miller in the book *Delee & Drez's Orthopaedic Sports Medicine: Principles and Practice*, p. 916, Copyright 2003, with permission from Elsevier.

Walton et al[142] recently documented the accuracy of clinical tests for determining whether pain is caused by AC joint injury. They describe using the Paxinos test (thumb pressure at the posterior AC joint) and a bone scan to accurately assess pain secondary to the AC joint pathology. O'Brien et al[115] recommended the active compression test for diagnosis of AC joint abnormalities.

The O'Brien test may be particularly helpful when attempting to differentiate symptoms of AC joint arthrosis from intra-articular lesions, especially with lesions of the superior glenoid labrum. The test is performed with the arm elevated to 90°, elbow in extension, adduction of 10° to 15°, and a maximum pronation of the forearm with obligate internal rotation of the arm. The examiner applies a downward force resisted by the patient. Symptoms referred to the top of the shoulder and confirmed by examiner palpation of the AC joint indicate damage to this structure. Symptoms referred to the anterior glenohumeral joint suggest labral or biceps injury. The sensitivity and specificity of this test has been called into question.[61] One study reported the sensitivity of this test for AC lesions was only 41% but the specificity was 94%.[28] This test is often used to assist in the diagnosis of superior labral tears; lesions of the superior labrum and AC joint can be difficult to distinguish. The sensitivity (63%) and specificity (73%) has been determined for superior labral pathology.[52]

Described next are the basic mechanisms, radiographic findings, and clinical examination findings for the 6 types of AC joint injuries.

Type I

Direct force to the shoulder produces a sprain of the AC ligaments. The coracoclavicular and AC ligaments are all intact, and the radiographic examination is normal.
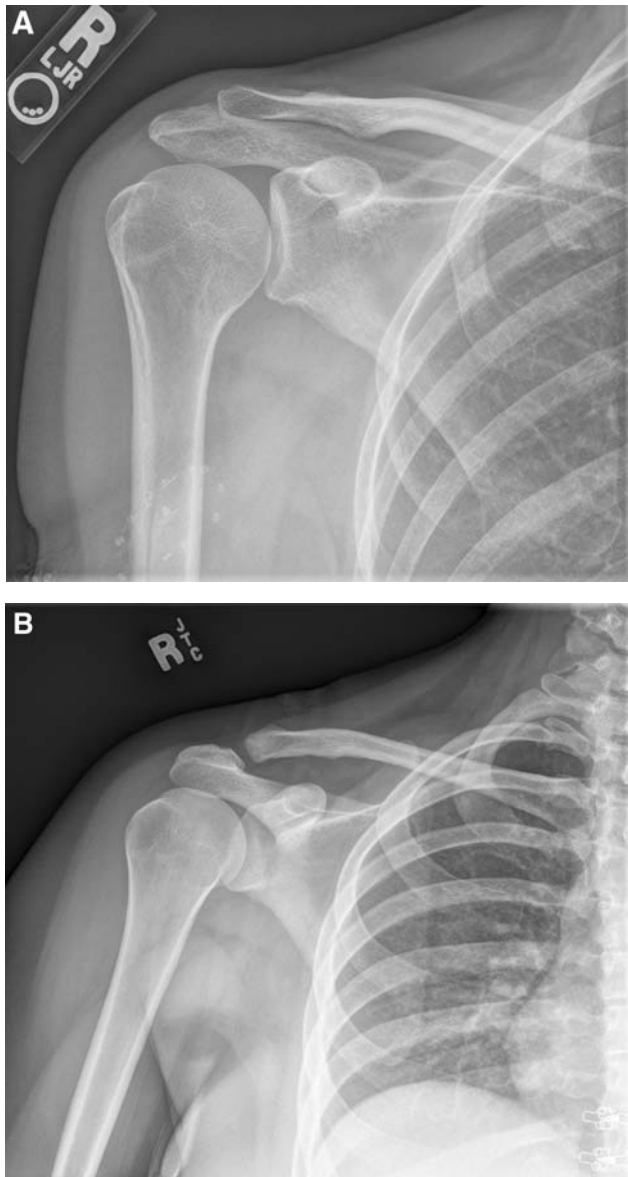
Figure 2. A, true anteroposterior radiograph of shoulder showing overlap of the acromioclavicular joint with the scapular spine. B, tilting the x-ray beam 10° cephalad provides an unobstructed view of the acromioclavicular joint.

Type II

In type II injuries, an increased force to the point of the shoulder is severe enough to rupture the AC ligaments yet not severe enough to rupture or affect the coracoclavicular ligaments. The clavicle is unstable to direct stress examination. On radiographs, the lateral end of the clavicle may be slightly elevated; however, stress views fail to demonstrate a 100% separation of the clavicle and the acromion.

Type III

This injury is a complete disruption of both AC and coracoclavicular ligaments without significant disruption of the deltoid or trapezial fascia. The upper extremity is usually held in an adducted position with the acromion depressed, while the clavicle appears "high riding." The clavicle is unstable in both the horizontal plane and the vertical plane, and stress views on radiographic examination are abnormal. Although the clavicle appears high on the radiographs, in reality the acromion and remainder of the upper extremity is displaced inferior to the horizontal plane of the lateral clavicle. Pain with motion is severe, typically for the first 1 to 3 weeks.

Type IV

The distal clavicle is posteriorly displaced into the trapezius muscle and may tent the posterior skin. The posteriorly displaced clavicle is easily seen on an axillary radiograph. It is important to evaluate the sternoclavicular joint because there can be an anterior dislocation of the sternoclavicular joint and posterior dislocation of the AC joint.

Type V

This is a more severe form of a type III injury, with the trapezial and deltoid fascia stripped off of the acromion as well as the clavicle. It is manifested by a 2- to 3-fold increase in the coracoclavicular distance, or a 100% to 300% increase in the clavicle-to-acromion radiographic distance. The shoulder manifests as a severe droop, secondary to downward displacement of the scapula and humerus due to loss of the clavicular strut. The weight of the arm and the geometry of the chest wall cause an anterior-inferior translation of the scapula around the thorax, referred to as the third translation of the scapula.

Type VI

A type VI injury is an inferior dislocation of distal clavicle. Gerber and Rockwood[53] have reported 3 cases. This injury is associated with severe trauma and frequently accompanied by multiple other injuries. The mechanism is thought to be severe hyperabduction and external rotation of the arm, combined with retraction of the scapula. The distal clavicle is found in 2 orientations, either subacromial or subcoracoid. With the subcoracoid dislocation, the clavicle becomes lodged behind the intact conjoined tendon. The posterior superior AC ligaments, which often remain attached to the acromion, get displaced into the AC interval, making anatomic reduction difficult. The tissue needs to be surgically cleared and then reattached after reduction. Most patients with type VI injuries have paresthesia that resolves after relocation of the clavicle.

RADIOGRAPHIC EVALUATION

Proper radiographic evaluation of the AC joint requires 1/3 to 1/2 of the x-ray penetration needed for glenohumeral joint exposure. This explains why, in a standard anteroposterior view of the shoulder, the AC joint will be over-penetrated (dark) and small or subtle lesions may be

overlooked. When the history and physical examination indicate possible AC joint injury, specific directions must be given to the radiology technician in obtaining the appropriate view. Anteroposterior, lateral, and axial views are standard views taken for the shoulder; however, a Zanca view is the most accurate view to look at the AC joint. This view is performed by tilting the x-ray beam 10° to 15° toward the cephalic direction and using only 50% of the standard shoulder anteroposterior penetration strength (Figure 2).

The axial view of the shoulder is important in differentiating a type III AC joint injury from a type IV injury. Visualization of the scapula anterior to the clavicle will indicate a type IV lesion. When there is a normal coracoclavicular interspace but a complete dislocation of the AC joint, a coracoid fracture should be suspected. A Stryker notch view is helpful in diagnosing this condition.

Normal Radiographic Findings

The configuration of the AC joint on anteroposterior radiographs varies significantly. Zanca[147] reported that the AC joint width is normally between 1 and 3 mm. Petersson[119] reported that the AC joint space diminishes with increasing age, thus a joint space of 0.5 mm is normal in 60-year-old patients.

The coracoclavicular interspace can also exhibit variability. Bosworth[18] stated that the average distance between the clavicle and coracoid process is usually between 1.1 to 1.3 cm. Bearden et al[13] reported that an increase in the coracoclavicular distance of 25% to 50% over the normal side indicated complete coracoclavicular ligament disruption.

TREATMENT

A plethora of literature and opinions exist regarding the optimal treatment of AC joint injuries. In analyzing various management schemes, it is important to keep the overall goals of treatment in mind. Is the treatment directed at correcting the anatomic deformity, functional impairment, or pain? In most AC joint separations, incomplete injuries (types I and II) are treated nonoperatively with a sling, ice, and a brief period of immobilization, typically lasting 3 to 7 days. Complete AC joint injuries (types IV, V, and VI) are usually treated surgically because of the significant morbidity associated with persistently dislocated joints and severe soft tissue disruption.

Treatment of type III injuries remains controversial, with a trend toward initial nonoperative treatment in most cases. This controversy results from the low level of evidence of the early literature and the evaluation of all AC joint injuries with a type I through III classification system. Type III AC injuries in the older studies included Rockwood's classification of type IV, V, and VI injuries.[124] Rockwood reported that type III injuries are usually treated nonoperatively, particularly in patients who participate in contact sports (football, hockey, soccer, and lacrosse), where the risk of reinjury is high.[124] A subset of patients, of course, will have persistent

pain and an inability to return to their sport or job with nonoperative treatment. In these cases, successful surgical stabilization has allowed return to sport or work. Evidence supporting nonoperative treatment of type III AC dislocations has been provided by a meta-analysis.[121] In a review of 1172 patients, 88% who were operatively treated and 87% who were nonoperatively treated had satisfactory outcomes. Complications included the need for further surgery (59% operative versus 6% nonoperative), infection (6% vs 1%), and deformity (3% vs 37%). Pain and range of motion were not significantly affected. The authors did not recommend surgery for type III AC joint injuries in young patients.

In 1997, McFarland et al[100] published the results of a survey of Major League Baseball team physicians evaluating treatment modalities for type III AC joint injuries in pitchers. They found that 69% of physicians would manage their players with a course of nonoperative treatment. Of the 32 patients with type III injuries, 20 were treated nonoperatively and 12 operatively. There was complete pain relief and normal function in 80% of the nonoperatively treated pitchers and 91% in the operatively treated. Larson and Hede[83] prospectively compared nonoperative and operative treatment with similar rates of persistent symptoms (8% in the operative group vs 10% in the nonoperative group).

Nonoperative Treatment

Most types I and II AC joint separations are treated nonsurgically, and type III injuries are usually evaluated on a case-by-case basis, taking into account hand dominance, occupation, heavy labor, position/sport requirements (quarterbacks, pitchers), scapulothoracic dysfunction, and the risk for reinjury. Schlegel et al[127] in a prospective study on nonoperative treatment of type III AC injuries, showed that at 1 year there was a 17% decrease in bench press strength, but 80% of subjects did not feel that it affected them. This study noted a 20% (4 of 20) rate of suboptimal outcome with conservative treatment. Types IV, V, and VI injuries are generally treated operatively.[19] There is some literature to support reduction of the clavicle in types IV, V, and VI injuries, turning them into a type III injury and then treating them conservatively.[113] Mouhsine et al[106] found that 27% of conservatively treated types I and II AC joint separations required further surgery at 26 months after injury. Nuber and Bowen[113] reported on the successful treatment of failed types I and II AC joint separations with arthroscopic management.

At the time of complete AC dislocation, the coracoclavicular ligaments may avulse the coracoid instead of tearing. Hak and Johnson[65] reported 1 case of coracoid avulsion in association with AC dislocation, which they treated nonoperatively with a favorable outcome. They recommended treating an AC dislocation with a coracoid avulsion like an isolated type III injury. Eyres et al[44] reported treating 12 coracoid fractures that were not associated with AC dislocation. The 10 patients without extension into the glenoid were treated nonoperatively with good results.

Athletes involved in throwing or contact sports are sometimes considered as special cases. Some argue that

throwing requires an anatomic reduction of the AC joint. Recent reports of successful nonoperative treatment of Major League Baseball pitchers suggest this is not the case. Therefore, the preferred treatment of type III injuries remains nonoperative, with surgical treatment reserved for those patients who present with persistent symptoms after 3 to 6 months, even in high-level athletes.

The main goals of treatment, whether surgical or nonsurgical, are to achieve a pain-free shoulder with full range of motion, normal strength, and no limitations in activities. The demands on the shoulder will differ from patient to patient, and these demands should be taken into account during the initial evaluation.

Gladstone et al[54] described a 4-phase rehabilitation program for athletes. These phases are (1) pain control, immediate protective range of motion, and isometric exercises; (2) strengthening exercises using isotonic contractions; (3) unrestricted functional participation with the goal of increasing strength, power, endurance, and neuromuscular control; and (4) return to activity with sport-specific functional drills.

It must be emphasized that patients with type III injuries treated nonoperatively versus operatively demonstrate no difference in strength at 2-year follow-up.[134] Schlegel et al,[127] in a prospective study, found that isometric testing revealed no significant difference in strength between nonoperatively and operatively treated patients. They did find, however, a reduction of 17% in bench press strength with nonoperatively treated patients. If symptoms persist—including increased instability, impingement due to scapular dyskinesia, decreased strength, inability to get the arm into a cocking position in throwing, and pain, especially posterior instability with the clavicle abutting the anterior portion of the spine of the scapula—then surgery may be indicated.

Surgical Techniques

The literature is replete with surgical techniques used to treat complete AC dislocations, including primary repair of the coracoclavicular ligaments, augmentation with autogenous tissue (coracoacromial ligament), augmentation with absorbable and nonabsorbable suture as well as prosthetic material, and has included coracoclavicular stabilization with metallic screws.[1,2,10,17,26,73,77,85,101,105,109,117,124,130,133,135,137,139,143,144,148] The Weaver-Dunn technique, using transfer of the coracoacromial ligament, has been the most popular procedure used to treat acute and chronic AC joint injuries.[143] Several more recent reports have described good results with modifications of the Weaver-Dunn technique.[82,143,144] However, in 2 independent studies by Tienen et al[135] and Weinstein et al,[144] compromised results were observed in patients who had residual subluxation or dislocation after surgery with this technique. We believe residual symptoms and subluxation has led to the recent interest in evaluating this technique, its modifications, and the development of newer concepts in reconstruction of the coracoclavicular ligaments. The following section reviews and summarizes recent basic science investigations evaluating AC joint reconstructions.

Biomechanical Studies of Acromioclavicular Joint Reconstruction

Coracoacromial Ligament Transfer and Transfer With Augmentation. From a biomechanical perspective, the importance of the coracoclavicular ligaments and AC ligaments in controlling superior and horizontal translations has been elucidated.[38,50,70,78] Despite the common occurrence of AC joint separation and the extensive experience with surgery in the treatment of these injuries, only recently have investigators evaluated the biomechanical properties and performance of various augmentation and reconstructive procedures.[33,40,60,66,70,83,97,105]

First, the coracoacromial ligament as a graft source transferred to the distal clavicle represents only 20% of the ultimate load of the intact coracoclavicular ligament complex.[85,105] Motamedi et al[105] evaluated the biomechanics of the coracoclavicular ligament complex and augmentations used in repair and reconstruction. Augmentations around or through the clavicle improved load to failure and stiffness of the reconstructions.

Coracoclavicular Suture, Cerclage, Slings, and Screw Fixation. A single 6.5-mm cancellous screw placed from the clavicle to the coracoid had a significantly lower failure load and was a stiffer construct than polydioxanone augmentations triple-stranded and braided and placed via a coracoclavicular cerclage method through drill holes. Harris et al[66] reported that bicortical screw augmentation through the coracoid ligament provided superior strength and comparable stiffness to that of the coracoclavicular ligaments. This study did not involve cyclic loading and did not evaluate anterior-posterior translation.

Jari et al[70] evaluated the biomechanical function of a suture-type coracoclavicular sling procedure with a coracoacromial ligament transfer construct and a Rockwood screw (DePuy Orthopaedics, Warsaw, Ind). This study was unique in the assessment of not only superior translation, but also anterior and posterior translation after these surgical procedures. Furthermore, in situ graft forces were measured. Importantly, the in situ forces for all 3 surgical constructs were significantly increased compared with the intact coracoclavicular ligaments. The authors concluded that current surgical procedures do not have the appropriate stiffness to restore the stability of the intact joint before healing. This may be a biomechanical explanation for the recurrence of subluxation and dislocation after coracoclavicular ligament reconstruction using the well-accepted Weaver-Dunn procedure. Other types of fixation have been biomechanically evaluated, including suture cerclage and suture anchors.[40] Although none of these techniques fully restored native AC joint stability, they were still found to be superior to the Weaver-Dunn procedure.

Free Graft Augmentation/Reconstruction of the Coracoclavicular Ligament Complex. Several authors have advocated using a separate and potentially more robust graft source to improve surgical results.[24,26,34,57,58,63,72,81,83,86,103] As cited previously, Lee et al[85] performed a biomechanical study comparing reconstruction of the coracoclavicular ligaments with free tendon grafts to the intact coracoclavicular ligament complex and
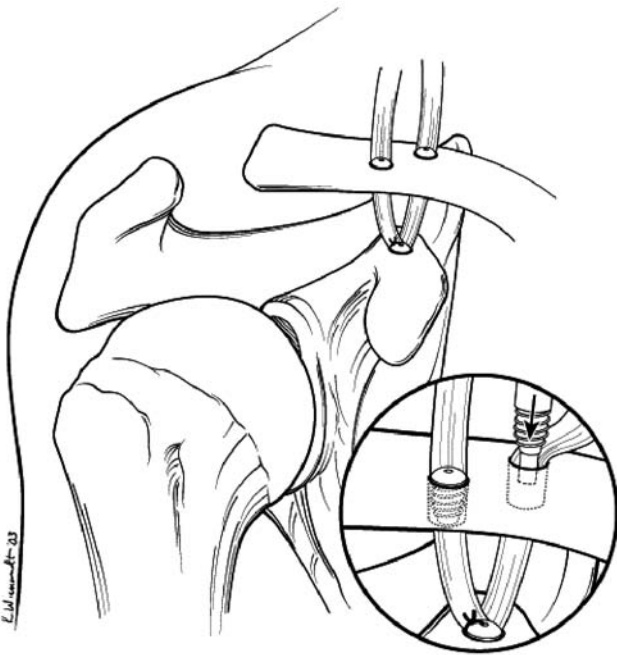
Figure 3. Final view of the anatomic coracoclavicular ligament reconstruction. Note the position of the clavicular bone tunnels in relation to the center line of the clavicle and the interference screw fixation backed up with a nonbiologic No. 5 FiberWire suture (Arthrex, Naples, Fla) through the cannulated holes of the interference screws.

a coracoacromial ligament transfer. The coracoacromial ligament transfer was the weakest construct. Importantly, in this study, a free gracilis, toe extensor, or semitendinosus graft had an ultimate failure load that was equivalent to the native coracoclavicular ligaments.

Anatomic Reconstruction With Free Graft. The use of a free tendon graft placed in a more anatomic position attempting to reproduce the trapezoid and conoid ligaments has been shown to perform as the intact coracoclavicular ligament complex in our laboratory[97] (Figure 3). Costic et al[33] found that the anatomic coracoclavicular reconstruction more closely approximates the stiffness of the native coracoclavicular ligaments than a standard Weaver-Dunn repair. Grutter and Petersen[60] have also shown a successful variation in reconstructing the AC and coracoclavicular ligaments. All these techniques have been validated biomechanically as being superior to the existing procedures.

Conclusions. Several conclusions can be drawn from a review of these more recent biomechanical studies: (1) The well-accepted coracoacromial ligament transfer is only 1/4 as strong as the intact coracoclavicular ligaments; (2) this can be improved by augmenting the coracoacromial ligament transfer with a suture or tape material in a sling fashion around the base of the coracoid process; (3) the coracoacromial ligament transfer with augmentation has

been shown to have no effect on anterior-posterior translation of the distal clavicle; (4) surgical reconstructions have much higher in situ graft forces when the AC joint capsule is either injured or incompetent; and (5) a free tendon graft appears to provide a substantial improvement in initial stability or load-to-failure equivalent to the intact coracoclavicular ligaments and represents a biomechanical improvement compared with coracoacromial ligament transfer. As mentioned previously, these findings may explain the observed residual instability and pain that can occur after reconstruction of the chronic complete AC joint dislocation.[135,144]

Surgical Reconstruction of Acromioclavicular Joint Dislocations

Six basic operative techniques used to treat AC dislocations are reviewed: (1) AC ligament repair, (2) dynamic muscle transfer, (3) coracoacromial ligament transfer, (4) coracoclavicular ligament repair, (5) distal clavicle resection with coracoclavicular reconstruction, and (6) anatomic reconstruction of the coracoclavicular ligaments. In addition, some authors have advocated combinations of these procedures.

Acromioclavicular Ligament Repair (Level IV Evidence). Sage and Salvatore[125] advocated AC ligament repair and reinforcement of the superior AC ligament with the joint meniscus. Many authors have recommended transarticular smooth or threaded pins to supplement the repair.[2,6,11,12,13,25,36,45,69,93,96,102,107,116,139] In a comparison of smooth pins, threaded pins, and a cortical screw by Eskola et al,[43] 13 of 86 patients available for follow-up had symptomatic osteolysis, and 8 of these 13 patients were among the 25 patients who had been treated with a Bosworth screw. Other authors have reported on the use of an AC joint plate for complete separations.[22,64,67,141] Good or excellent results have ranged between 60% and 94%. Broos et al[22] compared the Wolter plate and the Bosworth screw and found no significant difference in outcomes.

Dynamic Muscle Transfer (Level IV Evidence). Transfer of the short head of the biceps tendon with or without the coracobrachialis has been described, usually with acceptable results.[7,8,24,27,41,56,129] However, Skjeldal et al[129] reported 10 complications in 17 patients, including coracoid fragmentation, infection, and pain.

Coracoclavicular Ligament Repair (Levels IV and V Evidence). Coracoclavicular ligament repair was introduced by Bosworth[17] in 1941; he referred to it as a screw suspension procedure, which he performed percutaneously. Tsou[137] reported on 53 patients in 1989 who underwent percutaneous cannulated screw coracoclavicular fixation and found a 32% technical failure rate. In 1968, Kennedy[76] reported on coracoclavicular screws with AC débridement and trapeziodeltoid repair. Jay and Monnet[71] reported on 31 patients who underwent coracoclavicular ligament repair and Bosworth screw fixation with deltotrapezial repair. Lowe and Fogarty[91] used a similar technique in 21 patients.

Bearden et al[13] and Albrecht[3] recommended using wire loops around the clavicle and coracoid. Many others have used loops of other material.[47,55,69,103,110,126] Bunnell[26] in 1928 and Lom[90] in 1988 used fascia lata to reconstruct the coracoclavicular ligaments.

There have been numerous recent reports of coracoclavicular ligament repair using a polydioxanone (PDS) suture or cerclage.[56,58,68,95,103,120] Clayer et al[29] found that a PDS coracoclavicular sling did not maintain reduction, but good results were obtained in 6 patients. Gohring et al[56] and Pfahler et al[120] separately compared PDS cerclage with other techniques. Gohring et al compared the surgical treatment of 64 complete AC joint dislocations with 3 techniques: tension band, Wolter hook-plate, or PDS cord (braided). Early postoperative complications occurred in 43% of patients treated by tension band, 58% of those treated by hook-plate, and 17% of those treated by PDS cord. Acromioclavicular joint instability at an average 35-month follow-up was seen in 32% of patients with a tension band, 50% with the plate, and 24% with the PDS cord. The authors recommended limiting surgery to younger, athletic patients.

Coracoacromial Ligament Transfer (Level IV Evidence). Neviaser[110] introduced coracoacromial ligament transfer without coracoclavicular ligament repair. Variations on this principle have also been reported.[2,5,12,27,69,104,116,131] Several authors have emphasized imbrication of the deltotrapezial fascia as part of any surgical treatment.[11,25,89] de la Caffiniere et al[37] felt that transfer of the coracoacromial ligament, which they attributed to Cadenat, is usually too weak and too short for the treatment of AC dislocation. They used a reinforcement flap made by a lateral supraclavicular detachment of the superior fibrous capsular sheath. Of 26 patients, all 19 who underwent reinforced repair had no recurrence of dislocation, while all 7 without reinforcement experienced recurrence. Kumar et al[79] treated 14 AC dislocations with coracoacromial ligament transfer and coracoclavicular fixation with a screw. All 14 patients had excellent or good results. Guy et al[63] treated 23 chronic separations with coracoacromial ligament transfer and a Bosworth screw. Nineteen of 23 showed good to excellent results, and the 4 patients with fair or poor results had a previous distal clavicle resection.

Results after more severe injuries may not be as good. Verhaven et al[140] achieved a 71% good or excellent outcome in 28 patients treated surgically for acute type V injuries. A double velour Dacron graft was placed in a cerclage fashion with repair of the coracoclavicular ligaments. Loss of reduction was observed in 44% of patients. Outcome was unrelated to reduction of the joint, osteolysis, or calcifications.

Distal Clavicle Resection and Coracoclavicular Ligament Reconstruction (Level IV Evidence). Distal clavicle resection may be performed as a salvage procedure for persistent pain after AC separation, especially type I or type II injuries, or as treatment of degenerative or osteolytic AC joint arthrosis. In either case, reports indicate that a high rate of success can be expected, although patients with fractures or instability do not demonstrate the same outcome.[80] Distal clavicle resection was reported separately in 1941 by Mumford[107] and Gurd.[62] Mumford excised the distal clavicle in patients with

persistent subluxation and degenerative changes and emphasized the need for coracoclavicular ligament reconstruction when the distal clavicle was noted to be tender. In general, when the distal clavicle is unstable, distal clavicle resection is accompanied by coracoclavicular ligament reconstruction with or without augmentation.

In the classic article by Weaver and Dunn[143] published in 1972, 15 patients with type III injuries were treated with distal clavicle resection and coracoclavicular ligament reconstruction using the coracoacromial ligament. Rauschning et al[123] reported that 18 patients had stable, painless shoulders after this procedure. Kawabe et al[74] and Shoji et al[128] transferred the coracoacromial ligament with an acromial bone block to the distal clavicle and fixed it with a screw.

Modified Weaver-Dunn Operative Technique With Augmentation. Operative treatment begins with a diagnostic glenohumeral and subacromial arthroscopy.[122] Berg and Ciullo[14] have shown that some patients with AC joint injury have concurrent superior labral tears. These tears can be definitively diagnosed and treated with arthroscopy. The coracoacromial ligament is released, preserving its overall length. A suture is placed in the end of the ligament and brought out through the anterior portal. An arthroscopic distal clavicle excision is completed. Typically, this involves removing 2 to 3 mm from the medial edge of the acromion and 7 to 8 mm from the lateral edge of the clavicle for a space of greater than 1 cm. A small saber-type incision is made, starting slightly medial and posterior to the AC joint and extending to just above the coracoid. A horizontal incision is made in the deltotrapezial fascia across the AC joint. The joint is completely exposed with an anterior and posterior subperiosteal dissection using a needle-tip bovie. Care is taken to maintain the strength of the periosteum and deltotrapezial fascia to allow a secure anatomic closure.

Two drill holes are made with a 1.6-mm drill 5 mm medial to the distal end of the clavicle. The coracoacromial ligament is dissected out and a No. 2 Ethibond suture (Ethicon Inc, Somerville, NJ) is placed into the end of a ligament with a whip stitch. The sutures are placed through the end of the clavicle and tied over the holes. Reduction of the AC joint is maintained during this procedure by pushing down on the clavicle and up on the humerus. As mentioned in the the discussion of the biomechanics of coracoclavicular ligament reconstruction, augmentation of the transfer of the coracoacromial ligament with cerclage suture, wire, or metal fixation between the distal clavicle and coracoid improves the biomechanical performance of the Weaver-Dunn procedure.

Two recent reports involving small case series after previous failed surgery for AC joint dislocation recommended augmentation of the Weaver-Dunn procedure with a free gracilis or semitendinosis autograft.[72,81] Other suitable alternatives used to augment the Weaver-Dunn procedure include a section of fascia lata or palmaris longus autograft, or hamstring allograft. A drill hole is placed in the clavicle and, with a loop of suture or a Hewson suture passer, the autograft is passed though the hole, twisted in a figure-of-8 fashion and tied to itself with permanent suture (Figure 4).

Breslow et al[21] have shown biomechanically that similar stability can be provided by placing a suture around the base of the coracoid or placing suture anchors in the coracoid itself for augmentation.

Anatomic Coracoclavicular Ligament Reconstruction (Level V Evidence). As mentioned previously, there has been significant interest in a more anatomic reconstruction of the coracoclavicular ligaments in response to the recent clinical reports of persistent pain and recurrent subluxation after the modified Weaver-Dunn procedure. Several authors have evaluated techniques attempting to reproduce both the conoid and trapezoid ligaments, but these have been in vitro cadaveric biomechanical studies.[33,60,97] At the University of Connecticut, a prospective outcomes study is under way to evaluate the results of this procedure and its place within the armamentarium of procedures to address AC joint instability. No conclusions can be drawn at this time.

Distal Clavicle Resection Without Coracoclavicular Ligament Reconstruction (Level IV Evidence): For Persistent Pain After Types I and II Injuries, Arthritis, Traumatic Osteolysis. Much of the recent literature involves the development of the technique for arthroscopic distal clavicle resection and the comparison of classic open with new arthroscopic methods.[114] A summary of recent literature regarding resection of the distal clavicle is presented in Table 1.[98] Snyder et al[132] and Levine et al[87] reported results of arthroscopic resection with combined results of 92% good or excellent. Many authors have contributed to the development of techniques for arthroscopic distal clavicle resection.[15,51,75,132] Eskola et al,[43] Flatow et al,[47] and Levine et al[87] have all reported worse outcomes of resection in patients with instability of the AC joint. A stabilization procedure in addition to resection is indicated for patients with AC joint arthrosis and instability. Eskola et al also reported worse results in patients with a history of a distal clavicle fracture.

Excessive posterior translation after distal clavicle resection can be associated with pain, and the AC joint capsule helps restrain this motion. Clinically, the most likely scenario is that the scapula translates anteriorly, causing a perceived posterior translation of the clavicle. Blazar et al[16] looked at translation of the clavicle after distal clavicle resection. Motion in the anteroposterior direction was 8.7 mm, compared with 3.2 mm on the contralateral side. Visual analog pain scores correlated to the amount of translation. Translation and pain did not correlate with the amount of apparent joint space after surgery. As noted previously, Klimkiewicz et al[78] used a cadaver model to evaluate the contributions of the superior, inferior, anterior, and posterior ligaments of the AC joint. To avoid posterior translation, techniques that spare the posterior and superior capsular ligaments should be used. Branch et al[20] demonstrated in a cadaver model that only a 5-mm resection of the distal clavicle is required to ensure that no bone contact between the distal clavicle and acromion occurs with elevation. They found no difference between removal of the superior or inferior ligament for joint access. In another cadaver model, Matthews et al[94] compared arthroscopic and open distal clavicle resection.
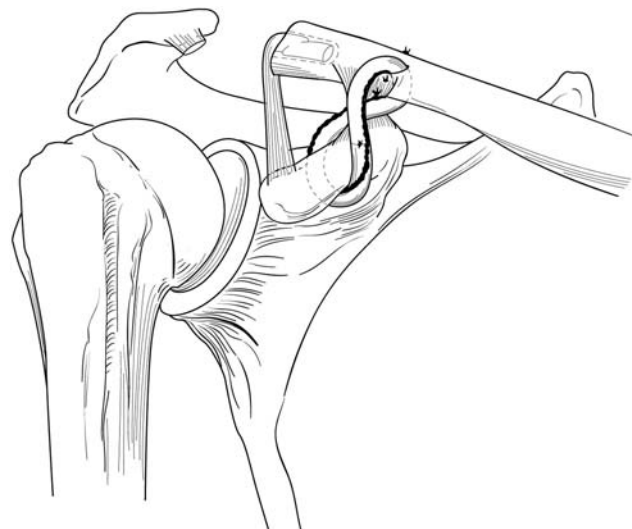

Figure 4. The modified Weaver-Dunn procedure with tendon graft augmentation.

No significant differences were found between the 2 methods in terms of displacement.

There is conflicting evidence regarding the effect of resection on strength and range of motion. Auge[5] reported that all 10 of his patients who underwent resection of the distal clavicle were able to return to their previous sports. Novak et al[112] reported no clinically perceptible loss of motion or strength in 18 of 23 patients, although objective strength testing was not performed using a calibrated measuring device. Petchell et al[118] found that motion and strength were not restored in their patients who underwent resection for arthrosis without instability. Although all of their patients reported that they were satisfied, over 50% had ongoing difficulties with activities of daily living, sleeping, or working. In addition, 29% of patients were unable to participate in their previous sports activities. Cook and Tibone[32] reported on open resection in 17 athletes with type II AC joint separations and chronic pain. Sixteen of the athletes returned to their previous level of activity, but some complained of decreased strength, which was seen on Cybex dynamometer testing at low speed but not at high speed.

Failed Distal Clavicle Resection (Level V Evidence). The reasons for failure of distal clavicle resection are often subtle and difficult to evaluate clinically. In an evaluation of 28 patients with unstable AC joints secondary to an aggressive distal clavicle excision, Nicholson found a painful click or pinch at the posterior aspect of the AC joint with forward elevation at and above 90° (unpublished data presented at AAOS Annual Meeting, 1999). He also found that the pain was reproduced with forced posterior clavicle translation, trapezius spasm, and a manual anteroposterior translation of the distal clavicle of more than 1 cm. The reason for failure is thought to be secondary to instability of the distal clavicle in the anteroposterior direction or increased horizontal translation due to compromise of the

TABLE 1
Summary of Recent Literature Regarding Resection of the Distal Clavicle

Author(s)	Patients	Injury	Treatment	Outcome
Auge[5]	10	Osteolysis	Resection	Returned to sport in mean of 3.2 mo
Cook and Tibone[32]	17	Type II in athletes	Resection	16/17 returned to sport
Eskola et al[43]	73	Mixed	Resection	21 good, 29 satisfactory, 23 poor, poor result more common in fractures
Flatow et al[47]	41	Arthrosis vs instability	Resection	27/29 good or excellent for arthrosis, 7/12 for instability
Levine et al[87]	24	Arthrosis	Arthroscopic	71% excellent, 16.5% good, 12.5% failures
Novak et al[112]	23	Arthrosis	Resection	18/23 good or excellent with normal motion and strength, failures in instability
Petchell et al[118]	18/39 available for follow-up	No instability	Resection	All satisfied
Snyder et al[132]	50	Arthrosis	Arthroscopic	47 good or excellent

AC ligaments. For this same reason, one should be cautious about distal clavicle resection alone for treatment of persistent pain after a type II separation.

There remains some controversy regarding the development of AC joint symptoms after arthroscopic partial distal clavicle resections. Neer[108] recommended the removal of any osteophytes from the inferior aspect of the distal clavicle when performing open subacromial decompressions. He opined that these osteophytes could contribute to narrowing of the space available for the rotator cuff. With the development of arthroscopic techniques for subacromial decompression, some surgeons have suggested removing "osteophytes" from the inferior clavicle. However, after arthroscopic acromioplasty, part of the native distal clavicle is exposed and certainly some techniques have included removal of this inferior aspect of the clavicle in the "coplaning" procedure.

Fischer et al[46] reviewed 183 subacromial decompressions and divided them into 3 groups. The group in which the distal clavicle was not "copland" and the group that had a formal arthroscopic distal clavicle resection had no postoperative symptoms referable to the AC joint. However, the group that included a partial distal clavicle resection (coplaning) along with the subacromial decompression showed a high incidence of postoperative AC joint symptoms (14 of 36, or 39%). Because of these results, an "all or none" philosophy was advocated. In other words, the distal clavicle is left alone for routine subacromial decompression, or a formal distal clavicle resection is performed if the patient has significant AC injury. In contrast, Barber's recent report demonstrated no compromise with coplaning.[9] Eighty-one patients undergoing arthroscopic subacromial decompression were divided into 3 groups. Group 1 (24 patients) underwent removal of inferior clavicle osteophytes; group 2 (34 patients) had a distal clavicle hemiresection, with up to 50% of the articular cartilage removed; and group 3 (23 patients) had complete distal

clavicle resection. At follow-up, the average Constant, American Shoulder and Elbow Society (ASES), Rowe, and Single Assessment Numeric Evaluation (SANE) scores were as follows: for group 1, 97.1, 97.5, 96.9, and 95.8, respectively; for group 2, 95.1, 97.4, 96, and 92.8, respectively; and for group 3, 96.3, 98.3, 96.1, and 95.7, respectively. No patient required additional shoulder surgery. They concluded that coplaning did not increase AC joint symptoms, compromise clinical results, or lead to additional surgery at an average follow-up of 6 years. The differences in opinion between these 2 articles suggest that the "all or none" philosophy is controversial.

Postoperative Care

A variety of factors affect the postoperative management of AC joint surgery. If the procedure includes only a distal clavicle resection, then a short (1 to 3 days) period of immobilization is followed by a range of motion program. Strengthening begins at 4 to 6 weeks. Heavy weight training can begin at 3 months, but power athletes will often require 6 to 12 months to return to peak strength.

After a coracoclavicular ligament reconstruction, the arm is supported with an external device such as a sling and immobilizer. Gentle range of motion activities in the supine position can begin after 7 to 10 days. Range of motion with the arm unsupported in an upright position should be delayed until the reconstruction has had time to develop early biologic stability. For an acute repair, this takes 4 to 6 weeks. A chronic repair with severe soft tissue involvement (eg, a type V separation) may take up to 6 to 12 weeks before unsupported range of motion is allowed. Emphasis at this point should be placed on strengthening the scapular stabilizers. These muscles decrease the load on the joint by keeping the scapula in a relatively retracted position. Strengthening in an acute repair begins at 6 to 12

weeks, with weight training started at 3 to 4.5 months. Strengthening in a chronic repair is appropriately delayed. Power athletes and workers with heavy physical demands generally take 9 to 12 months to reach peak strength, especially with pressing activities or lifting from the floor, such as in a dead lift.

Historically, motion is limited until pins are removed at 6 to 8 weeks. After coracoclavicular screw fixation, range of motion begins when pain subsides. Bosworth[17,18] recommended no heavy activity for 8 weeks. Alldredge[4] recommended no immobilization; Bearden et al,[13] a sling for 10 to 14 days; Jay and Monnet,[71] a sling for 4 weeks; and Gollwitzer,[58] a Velpeau cast for 4 weeks. Recommendations regarding hardware removal have varied.[4,13,71,76,145] After coracoid transfer, Brunelli and Brunelli[24] recommended 90° of elbow flexion with gradual straightening starting on day 5 to reduce the AC joint and protected activities for 6 to 8 weeks.

Complications of Surgery

Hardware migration is the most serious complication of AC joint reconstructions. The frequency of pin migration has prompted most surgeons to abandon their use, particularly smooth pins. Those who still use pins check their position with frequent radiographs and remove them after some interval of healing. Pin migration into the lung and spinal canal has been reported.[96,111] Lindsey and Gutowski[88] reported migration of pins into a patient's neck, posterior to the carotid sheath. Eaton and Serletti[42] and Urban and Jaskiewicz[138] reported migration into the pleural cavity, and Kumar et al[79] reported laceration of the subclavian artery by a migrated pin. Grauthof and Kalmmer[59] reported 5 cases of pin migration into the aorta, subclavian artery, or lung.

Loss of reduction of the AC joint is not uncommon. The weight of the arm and scapula places tremendous static forces on the coracoclavicular reconstruction. Younger patients have a tendency to discontinue efforts to support the arm during the first 6 weeks of their postoperative rehabilitation, when it is necessary to protect the reconstruction. Efforts at augmentation of the repair and reconstruction have helped to reduce the incidence of complete failure, but partial loss of reduction remains common. In one report, Mayr et al[95] reported a loss of reduction rate of 28%, with a less satisfactory outcome in these patients.

Another complication is too much distal clavicle resection, creating the difficult triad of a shortened clavicle, no AC ligaments or attachment sites, and scapular rotatory instability. Other surgical complications include infection, aseptic reaction to the reconstruction, calcifications, erosion through the clavicle from nonabsorbable materials used to augment the repair and reconstruction, fracture of the coracoid, osteolysis, and persistent pain. Reported rates of infection range from 0% to 9%, with an average of 6%, taking into account numerous reports.[58,68,95,146] Colosimo et al[31] reported an aseptic foreign body reaction to Dacron graft used to reconstruct the coracoclavicular ligaments. Calcification in the reconstructed ligament has

been noted, but it does not appear to affect results.[68] In fact, if the reduction is maintained and calcification occurs, the stability of the reconstruction seems to be enhanced.

Erosion of cerclage material through the clavicle or coracoid is a well-documented complication.[34,35,57] A modification of the cerclage technique to place material through an osseous tunnel in the clavicle rather than completely around it decreases the severity of this complication because erosion does not create a complete discontinuity between the medial and lateral clavicle. Fracture of the coracoid may occur with placement of a coracoid screw.[102]

Distal clavicle osteolysis associated with AC fixation has been reported.[43] Smith and Stewart[131] recommended resection of the distal clavicle at the time of surgical reduction to avoid this complication. The complication of late AC joint arthrosis is avoided and therefore distal clavicle resection has become an integral part of any AC instability reconstruction.

Chronic pain after surgical treatment of AC instability can be another challenging complication. Many possible causes need to be considered, including horizontal instability (anterior to posterior) of the clavicle, subacromial injury, and neurologic injury. Neurologic injury can occur with the initial trauma or with the surgical procedure. For example, suprascapular neuropathy may occur after distal clavicle resection and has been associated with resections of greater than 1 cm.[93]

SUMMARY

The anatomy of the AC joint is extremely individualized, with tremendous variation in intra-articular angle, joint congruity, motion, and strength. There is an expanding body of knowledge, based on biomechanical data, that supports individual reconstruction of the coracoclavicular and AC ligaments. This article has attempted to review the anatomic, biomechanical, and clinical literature to arm the reader with basic principles to facilitate treatment of AC joint instability. An understanding of these basic principles allows the physician, therapist, or health care provider to evaluate certain clinical situations and apply treatments to specific patient disorders and needs.

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