Clavicle Nonunion and Malunion

Surgical Interventions for Functional Improvement

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KEYWORDS

• Clavicle • Clavicle nonunion • Clavicle malunion • Bone grafting
• Clavicle shortening • Revision surgery

KEY POINTS

- Clavicle nonunion or malunion occurs in 5% to 15% of clavicle fractures treated nonoperatively and can cause significant shoulder pain and dysfunction.
- At our institution, nonunions and malunions are typically addressed with superiorly positioned, precontoured compression plating.
- The need for biological augmentation, whether autograft or allograft, is debated. The authors prefer to use allograft augmentation particularly in the setting of atrophic nonunion.
- With careful preoperative planning and meticulous surgical technique, radiographic union and good to excellent clinical outcomes are reliably achieved after operative management of these complex injuries.

INTRODUCTION

Clavicle fractures are common injuries, comprising 2% to 10% of all fractures in adults, with roughly 75% occurring at the middle third of the bone, 20% at the distal third, and the remaining occurring medially.[1,2] Owing to excellent early outcomes studies, most of these fractures were treated nonoperatively.[3,4] Nonunions of the clavicle have been historically considered as rare, with Neer referring to the clavicle as the "invincible bone."[3] However, more recent evidence demonstrates variability in healing by subtype and suggests there are specific subsets of patient and fracture characteristics associated with higher risk of poor outcome, including nonunion or malunion. Modern studies have shown that nonunion after nonoperative treatment occurs in

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5.9% to 15% of patients depending on fracture subtype.[1,5] As more detailed patient-reported outcome measures become the standard, there seems to be a greater recognition of functional deficits in this patient population than previously considered.[6] Thus, it is important for surgeons to understand the treatment principles of these challenging pathologic conditions. To that end, the purpose of this article is to provide a brief overview of the diagnosis and workup of clavicle nonunion and malunion, followed by a comprehensive review of the surgical techniques used to address this condition.

BACKGROUND

Malunion and nonunion of the clavicle can severely affect its function.[7] Although most clavicle fractures treated nonoperatively go on to some degree of malunion, most of these are mild and asymptomatic.[6] However, particularly with large initial displacement, significant malunion and subsequent deformity can occur. In this setting, the native kinematics of the clavicle are altered, and patients may experience pain, decreased strength and endurance, and dissatisfaction with cosmesis.[8] Further, computational studies have demonstrated that with progressive shortening of the clavicle, there is a resultant decrease in the moment-generating capacity of the shoulder, leading to impaired shoulder abduction, flexion, and internal rotation.[9]

Similar to symptomatic malunion, nonunion can cause a significant deleterious effect on patient outcomes. Subsequently, many studies have attempted to highlight patient-specific and fracture-specific risk factors that predispose to nonunion. Patient-specific risk factors are potentially modifiable variables and are imperative to optimize. Advanced age, female gender, obesity, poor functional status, malnutrition, vitamin deficiencies, smoking, infection, and certain medications or treatment modalities such as radiation and chemotherapy increase the odds of a poor outcome.[10,11] Fracture-specific factors include shortening greater than 2 cm, high degree of fracture comminution, and Neer type II fractures.[6,12,13] Although neither the aforementioned patient nor fracture characteristics represent an absolute indication for surgery, they should be discussed with the patient during the shared decision-making process and can help guide initial operative versus nonoperative management decisions.

CLINICAL SYMPTOMS, DIAGNOSIS, AND WORKUP

Patients with clavicle malunion will often present with weakness, easy fatiguability, and cosmetic complaints. More rarely, they may present with scapular winging or symptoms of thoracic outlet syndrome. Similarly, symptomatic nonunion patients commonly complain of pain, impaired shoulder function, easy fatigability with overhead activity, and suboptimal mobility.[14,15]

A comprehensive history and physical examination are essential when evaluating patients with clavicle malunions and nonunions. A thorough interview should clarify the details surrounding the injury itself, medical comorbidities, surgical history, current and recent medications, and the patient's social situation. Understanding patient-specific risk factors allows the surgeon to both identify the root cause(s) of nonunion and to optimize the chance of successful treatment. The physical examination includes the evaluation of the injured and contralateral clavicle, ipsilateral upper extremity, and cervical spine.

Routine laboratory work is not considered mandatory for cases of malunion. In cases of nonunion, surgeons should consider obtaining a complete blood count, erythrocyte sedimentation rate, c-reactive protein, vitamin D level, and calcium levels

because these may provide important information regarding infection and bone health. Malnutrition laboratories, including serum albumin, total lymphocyte count, and ferritin can be considered, although we do not send these routinely for all patients. Cotinine testing has been shown in the arthroplasty literature to both aid in smoking cessation programs as well as to verify patient compliance with smoking cessation.[16]

Plain radiographs are often sufficient to diagnose nonunion or malunion. A standard radiographic series involves anteroposterior view of the bilateral clavicles and a 45° cephalic tilt radiograph of the injured clavicle. If available, serial plain radiographs from the time of initial injury should be evaluated to understand the evolution of the fracture.

Computed tomography (CT) scans are not routinely used to evaluate clavicle nonunions and malunions, although they can provide details in multiple planes that may be beneficial in surgical decision-making and planning in the setting of complex deformities. CT scans also allow for a more precise understanding of the degree of fracture healing, if any. In our practice, we obtain a CT scan for patients who have undergone previous open reduction and internal fixation of a clavicle where nonunion is suspected on plain radiographs. In addition, for any patient who wishes to proceed with hardware removal (minimum 2 years postoperatively), we obtain a CT to ensure that their "pain" is truly from the hardware, and not an unrecognized nonunion.

TREATMENT

Overview

The goal of treatment is to ensure a stable clavicle that is painless through full active range of motion. To achieve this, it is helpful to determine why the fracture did not heal and subsequently, how it can be treated based on the possible causes of nonunion.

Clavicle malunions or nonunions that are asymptomatic often do not require surgical intervention.[13,17] Patients with painful malunion, painful nonunion, those with decreased function, associated thoracic outlet syndrome, brachial plexus neuropathy, or associated vascular injury should be considered for surgery.[18]

Resection Procedure

Partial or entire clavicle resection has largely fallen out of favor because it negatively affects shoulder stability and function. Historically, it was used in the treatment of concomitant thoracic outlet syndrome or subclavian vascular compression, with the intent of removing the clavicle to increase costoclavicular space.[19] However, with the improvement of implants and a large body of literature supporting excellent outcomes for modern plating systems, resection is now uncommon.[20–24]

However, in the setting of distal clavicle nonunion or malunion, excision of the distal fragment can be considered if the fragment is too small for fixation, if there is poor bone stock, and if acromioclavicular arthrosis is present.[25,26] There is no general consensus regarding the size of the lateral fragment that dictates whether excision or reconstruction is the appropriate route.

Reconstruction Procedures

Reconstruction techniques for clavicle nonunions include reconstruction plates, locking compression plates, hook plates, coracoclavicular screws, intramedullary fixation, bone grafting, and several combinations of the above.[27–29]

Plating—midshaft clavicle

Biomechanical studies have demonstrated that superior plating provides significantly greater stiffness and fracture rigidity as compared with anterior plating; this has been

attributed to its tension-bearing face and greater moment of resistance because it sits farther away from the inferior cortex compared with the anterior plate.[5,30,31] However, the superior plate has been associated with hardware prominence due to the subcutaneous position of the plate, and consequently has been linked to higher rates of reoperation and hardware removal.[32] Although there are potential downstream disadvantages, superior plating has been shown to result in high levels of bony union following clavicle nonunion. A recent prospective randomized control trial demonstrated that there was no difference in union rates between locking and nonlocking superior plate fixation for displaced midshaft clavicle nonunions; however, there was a statistically significant decreased time to union observed in the locking plate cohort (13 weeks vs 17 weeks, respectively, $P = .009$).[33]

Anterior plates have classically been associated with decreased hardware prominence and improved soft tissue coverage compared with superior plates.[34,35] Recent studies have demonstrated anterior plating to have similar functional outcomes and union rates to superior plating.[32,32,35] Further, both plate locations have similar risks of iatrogenic neurovascular injury, and one has not been proven to be greater than the other at decreasing risks to the brachial plexus and its branches or the subclavian vein and artery.[36,37]

Dual plating is less commonly used to treat clavicle nonunion. The literature is mixed regarding the biomechanical properties of dual plating compared with traditional single plating. Ziegler and colleagues demonstrated that no significant difference in bending stiffness or load to failure was observed among dual mini-plating, superior plating, and anteroinferior plating of midshaft clavicle fractures in 18 cadavers.[38] Prasarn and colleagues also found dual mini-plating to be relatively similar to anterior and superior plating in terms of axial and torsional stiffness, although significantly superior to both in terms of bending stiffness.[20] Recently, Boyce and colleagues investigated the stiffness and survivorship of a combination plate construct (traditional superior plate with additional mini anterior plate) compared with single superior plating and dual mini-plating. This biomechanical study demonstrated that in a comminuted clavicle fracture sawbones model, dual mini-plating demonstrated the lowest stiffness and survivorship of the 3 cohorts, whereas the combination of an anterior mini plate and the conventional superior plate was significantly stiffer and had higher load to failure than the other 2 cohorts.[39] Clinically, dual plating has shown excellent outcomes in terms of achieving bony union after clavicle fracture.[20] However, the literature is lacking on long-term outcomes of dual plating in clavicle nonunions specifically.[40]

Plating—distal clavicle

It has been well established that nonoperative treatment of distal clavicle fractures has a higher relative risk of nonunion, particularly the unstable Neer type II.[41] Fixation is often challenging due to the small size of the lateral fracture fragment, the often-poor bone stock, concurrent coracoclavicular ligament disruption, and potential for iatrogenic trauma to the acromioclavicular joint. Common techniques include hook plating, plate and screw osteosynthesis alone, plating with coracoclavicular reconstruction, and suture fixation.

Hook plates are commonly used for distal clavicle fractures and have been shown to have excellent union rates although with a high rate of postoperative hardware pain and subsequent plate removal.[42,43] More specifically, several studies have shown that after fracture, hook plates result in high union rates ranging from 94% to 100%, similar to that of anterior/superior plates, suture, or pin fixation.[42–46] However, some studies have shown that higher complication and revision rates are associated with hook plates compared with locking plates and coracoclavicular fixation.[42,44] Common

complications include rotator cuff impingement, subacromial inflammation, and acromial fractures. Hook plates are removed after a minimum of 3 months from date of implantation to prevent the development of subacromial impingement or iatrogenic rotator cuff pathologic condition. This should be considered and counseled on during the preoperative visit.

As with midshaft clavicle fractures, superior, anterior, and dual plating can be used to treat distal clavicle nonunions as well. Ideally, 3 bicortical screws are needed to achieve adequate plate fixation, which can be challenging if the fracture fragment is small.[47] When there is sufficient bone stock, the fragment is large, and the coracoclavicular ligaments are disrupted, plate fixation is appropriate. In a cadaveric study, Worhacz and colleagues demonstrated that superior precontoured locking plates have significantly greater stiffness and load to failure compared with superior nonlocking and anterior locking constructs in distal Neer type IIA fractures.[48] Conversely, Wilkerson and colleagues showed in 6 cadavers with type IIB fractures that anterior dynamic compression plates had a statistically significant higher load to failure than superior dynamic compression plates. In a clinical case series on unstable distal clavicle fractures, Shin and colleagues found that precontoured anatomic plate fixation has high union rates and satisfactory clinical outcomes, thus demonstrating the utility of precontoured plates in maintaining fixation of unstable distal fractures.[45]

In fracture patterns that involve disruption of the coracoclavicular ligaments, reconstruction of the ligament reconstruction can yield positive outcomes. Yagnik and colleagues demonstrated that all 21 patients with unstable distal clavicle fractures who were treated with a combination of cortical button fixation and coracoclavicular (CC) ligament reconstruction achieved union within 4 months.[49] Further, all patients were reported to have achieved good functional outcomes and satisfaction with their surgery, based on mean improvements in American Shoulder and Elbow Surgeons (ASES) scores and University of California Los Angeles (UCLA) scores.[49] Still, further investigation is warranted before this technique can be recommended over plate fixation. Similarly, though CC ligament reconstruction in combination with plating is an option, it has not been well studied in the setting of distal clavicle nonunion. Rieser and colleagues demonstrated in 21 cadavers that biomechanically, a distal-third locking plate combined with CC ligament reconstruction had increased stiffness, decreased displacement, and maximal resistance to compression compared with either construct alone.[50] A construct that provides greater stiffness and stability may be better suited to prevent hypertrophic nonunion. Clinically, Schliemann and colleagues demonstrated that a combination of locking plate fixation and CC ligament reconstruction led to bony union within 6 to 10 weeks in 14 patients with unstable distal clavicle fractures.[51] Finally, in a case series of 38 patients with distal clavicle nonunion, Robinson and colleagues found that locking plate fixation combined with a tunnel suspensory device led to the achievement of bony union for all patients and low complication rates across the cohort.[52]

It should be noted that there are few studies in the literature directly comparing these fixation techniques and their outcomes in the setting of distal clavicle nonunion. Most of the literature focuses on outcomes following distal clavicle fracture.

Bone Grafting

The need for supplemental bone grafting is the subject of debate in the literature.[53] This is typically recommended with atrophic clavicle nonunions or to achieve appropriate length when segmental defects are present. Autogenous bone grafting (commonly from the iliac crest bone graft [ICBG]) is the gold standard, given its trifecta of osteoinductive, osteoconductive, and osteogenic healing.[22,54–57] In a retrospective

review of 34 clavicle nonunions treated with plate fixation and ICBG, all 34 patients achieved bony union.[56] Known disadvantages to this technique include increased operative time, neurogenic injury, donor site pain, hematoma formation, and iliac fracture.[24,58] In a retrospective study, Beirer and colleagues demonstrated that radiographic bony union was achieved in all 14 patients with clavicle nonunion or malunion who were treated with precontoured locking plates and ICBG, with one patient refracturing 3 years after surgery.[59] However, 14% of patients sustained secondary fracture of their anterior superior iliac spine following grafting. Although rare, iliac crest fractures following harvest can be avoided through minimally invasive, percutaneous methods.[60] Bone grafting can be used to treat distal clavicle nonunions as well. In a case series of 10 patients with distal clavicle nonunion, Villa and colleagues found all nonunions healed within 4 months of surgery, after either dual mini-plating with bone graft and single plating with bone graft.[61]

Demineralized bone matrix (DBM) and bone morphogenic protein (BMP) can be used as alternatives to ICBG. Although these methods eliminate donor-site and harvest complications, neither is osteogenic and BMP is solely osteoinductive. Yet, studies thus far have largely demonstrated excellent outcomes whether autograft or allograft is used. Wiss and colleagues reported a series of 78 clavicle nonunions treated with superior plating or dual plating, with or without bone graft via either autogenous ICBG, BMP-2, or BMP-7. The study found that there were no statistically significant differences in healing rates between the type of plate or bone graft used to treat the nonunion. Further, 87.5% of patients healed after their primary nonunion surgery.[24]

Vascularized Bone Grafting

Rarely, vascularized bone graft may be used in settings of chronic or persistent nonunion that have failed to respond to operative reconstruction or atrophic nonunions with significant bone loss. Vascularized bone graft bypasses the process of creeping substitution observed in nonvascularized bone grafting, thus allowing for potentially improved healing processes and revascularization of necrotic bone.[62] Commonly, the vascularized periosteal graft is taken from the medial femoral condyle, iliac crest, fibula, or radius and then anastomosed with the thoracoacromial trunk.[63] There is limited information in the literature regarding the use of vascularized bone reconstruction in clavicle nonunion. In a retrospective series of 7 patients with symptomatic recalcitrant clavicular nonunion who were treated with medial femoral condyle graft, all patients achieved clinical and radiographic union by an average of 15 months; shoulder motion and pain scores improved, and minimal donor site morbidity was observed.[64] Fuchs and colleagues described vascularized medial femoral condyle transfer in 3 patients with atrophic nonunion of the clavicle.[65] In each case, patients achieved bony union by a minimum of 5 months and sustained improvements in their shoulder function, range of motion, and pain levels. Similarly, Momberger and colleagues also demonstrated that vascularized fibular grafting for segmental clavicular nonunion in 3 patients was a successful salvage procedure, which led to radiographic healing and improvements in pain and shoulder function.[63] Ultimately, the results of these studies indicate that vascularized bone grafting is a useful tool for addressing recalcitrant bony nonunion in the clavicle, although we recommend its use as a salvage method.

Intramedullary Procedures

Intramedullary fixation of clavicle nonunion and malunion can be achieved through a variety of methods, such as Kirschner wires, elastic titanium nails, Steinmann pins,

or external fixation. Current available literature indicates that intramedullary fixation can achieve similar union rates and clinical outcomes to plating. However, many of these studies have a small sample size or are retrospective in nature. In patients with clavicle malunion, Smekal and colleagues demonstrated that elastic stable intramedullary nailing with corrective osteotomy resulted in 100% bony union and improved disabilities of the arm, shoulder, and hand (DASH) outcomes compared with preoperative levels; however, this case series only consisted of 5 patients.[66] Kleweno and colleagues demonstrated in a retrospective study comparing patients with midshaft clavicle fracture treated with intramedullary pinning versus plating, that patients in the pin group all achieved bony union, with 28% of patients experiencing associated complications. However, the study only included simple and wedge clavicle fractures, raising the point that pinning may not be amenable to fixation of every type of clavicle fracture or nonunion.[67] Ultimately, from a biomechanical perspective, intramedullary fixation results in decreased rigidity compared with plating, and in the setting of nonunion, stable and rigid fixation is the goal. With the paucity of evidence in the current available literature regarding intramedullary fixation in the setting of clavicle nonunion or malunion and the decreased rigidity that intramedullary fixation affords, we recommend plating and its adjuvants for the treatment of clavicle nonunion or malunion.

MALUNION

Similar to nonunions, surgical indications for malunion include pain, functional limitations, and neurologic problems such as brachial plexus compression and thoracic outlet syndrome. Patient dissatisfaction with cosmesis and appearance is also an important consideration not to be overlooked. The standard approach to clavicle malunions is osteotomy through the original fracture plane followed by subsequent plate osteosynthesis. Osteotomy is critical to restore anatomic length, alignment, and rotation. This can be technically challenging because it requires realignment of the bony segments in 3 orthogonal planes and, if not correctly performed, may lead to persistent malunion. The contralateral, uninjured side can be used to gauge the proper length, alignment, and rotation.[68] Both anterior and superior plating can be used. Compression plating, with or without bone grafting, is commonly used. In a case series on 15 patients with midshaft clavicle malunion, McKee and colleagues performed corrective osteotomy and subsequent compression plating; 14 of the patients achieved bony union, clavicle length, and alignment.[7] Further, patient-reported outcomes as measured by DASH were found to improve for all patients ($P = .0001$).[7] Similarly, Hillen and colleagues found that corrective osteotomy followed by posterior-superior plate and screw fixation resulted in 9 out of 10 patients achieving union and significant improvements in patient-reported outcomes as measured by DASH.[69] However, in that study, 7 of the 10 patients did require plate and screw removal due to pain and irritation from the hardware.

COMPLICATIONS

Many of the complications seen with operative management of clavicle nonunion or malunion are the same or similar to the complications of clavicle fractures. Persistent hardware irritation or pain, hardware breakage, or infection can occur.[70] Much of the available literature has shown that union can be reasonably expected after operative management of clavicle nonunion or malunion.[7,20,33,35,51,58,61,69,70] Although infrequent, vascular compromise, thoracic outlet syndrome, or brachial plexopathy following nonunion or malunion have been reported in the literature, largely through

case reports.[71] Although there are no standard guidelines for the optimal management of these complications, resection of the callus, neurolysis of brachial plexus, if involved, and the removal of any hardware that may be contributing to symptoms are advised.[72,73]

Overall, complication rates are generally reported to be low after clavicle nonunion intervention. In a systematic review and meta-analysis, Sidler-Maier and colleagues found that the complication rate across 103 patients treated surgically for clavicle

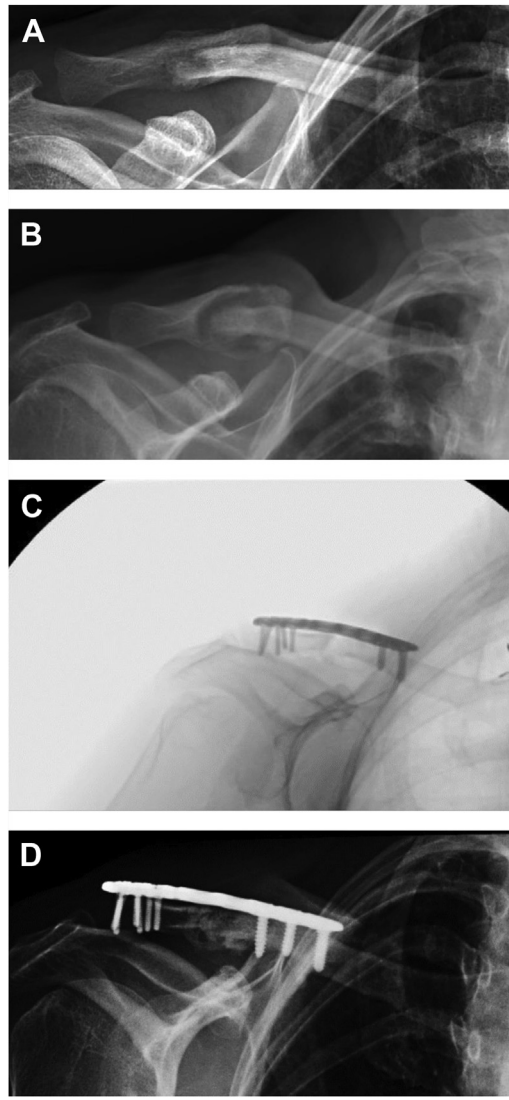

Fig. 1. Caption: Case of a 64-year-old right-hand-dominant woman, (*A*) initially sustained a minimally displaced right lateral clavicle fracture after falling onto the pavement; (*B*) 1 year after her injury, radiographs revealed hypertrophic nonunion of her lateral clavicle; (*C*) She was then treated with a precontoured locking plate (Acumed, Hillsboro, OR, USA) to obtain fixation and (*D*) went on to achieve healing of the distal clavicle nonunion at 5 months follow-up.

malunion was less than 6%.[70] Although infrequent, refracture following callus removal, loss of fixation, and infection were the reported complications.

SUMMARY

Clavicle nonunion and malunion are relatively uncommon but when symptomatic can result in pain and dysfunction that requires surgical intervention. Various reconstructive and grafting techniques are available to achieve stable fixation and union. In the setting of persistent nonunion, vascularized bone grafting may be necessary. A thorough understanding of the patient's type of nonunion and potential for healing is crucial for achieving satisfactory results, as is thoughtful preoperative planning and surgical fixation.

REPRESENTATIVE CASE—HYPERTROPHIC NONUNION

A 64-year-old right-hand-dominant woman initially sustained a minimally displaced right lateral clavicle fracture after falling onto the pavement (Fig. 1A). She was treated nonoperatively at an outside hospital. Five months later, she was seen by the senior author; at that time, she reported ongoing pain, and examination showed decreased strength of her right supraspinatus compared with her contralateral side. She was treated nonoperatively with trial of physical therapy for 8 months, during which she reported continued anterior pain. Twelve months after her injury, she presented to the office with pain and decreased shoulder range of motion; radiographs revealed hypertrophic nonunion of her lateral clavicle (Fig. 1B). Given her painful nonunion, she was indicated for surgery. She was taken to the operating room, placed in the beach chair position, and the nonunion was debrided to healthy viable bone. A precontoured locking plate (Acumed, Hillsboro, OR, USA) was used to obtain fixation (Fig. 1C). Autograft from the resected nonunion and DBM allograft putty (Arthrex, Naples, FL, USA) were placed around the nonunion to promote bony healing. At 5-month follow-up, the patient reported minimal pain as well as full active range of motion. Radiographs show healing of the distal clavicle nonunion (Fig. 1D).

CLINICS CARE POINTS

Pearls
- Use an evidence-based approach based on fracture subtype to guide recommendations and treatment with respect to nonoperative versus operative management
- In the case of nonunion, ensure preoperative optimization by counseling patients on modifiable risk factors and making appropriate referrals (ie, nutrition or smoking cessation)
- Minimize risk of hardware irritation by meticulously elevating the periosteal layer for later closure
- Counsel all operative patients on the potential need for future surgical removal of hardware

Pitfalls
- Do not treat all clavicle fractures as equal; prognosis varies widely based on subtype
- If using a hook plate for operative fixation, take care to not overreduce the clavicle with respect to the acromion. The patient should be counseled on the need for future removal of hardware with the use of this implant
- Poor drilling technique and/or excessively long screws can lead to neurovascular compromise; one can mitigate this risk by placing a retractor beneath the inferior aspect of the clavicle

DISCLOSURE

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