Clavicular Nonunion and Malunion: Evaluation and Surgical Management

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Abstract

Nonunions and malunions of the clavicle are uncommon but can be disabling. Pain, limitation of shoulder mobility, or local compression of the brachial plexus can produce profound functional impairment. Nonunions usually are associated with more severe fractures, open injuries, or failures of operative treatment. Reconstructive procedures are focused on gaining union and restoring clavicular anatomy—most often achieved with plates and screws and autogenous bone graft. Salvage procedures include excision of a bony prominence, partial or total clavicular resection, and resection of the first rib. While most patients with a malunited clavicular fracture are asymptomatic, osteotomy and correction of the deformity should be considered when there is associated functional or neurovascular impairment.

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Fractures of the clavicle are common injuries, accounting for 5% to 10% of all instances of adult skeletal trauma.[1,2] Despite this, nonunions and symptomatic malunions after clavicular fracture are uncommon. When these complications occur, however, they may be associated with a pattern of disability that includes not only pain but also impairment of upper extremity function.[3-7] In addition, deformity at the fracture site can result in local compression of the brachial plexus or subclavian vessels.[3,5,6] Successful treatment of posttraumatic clavicular nonunion or deformity represents a major challenge for orthopaedic surgeons, in part because of the technical difficulty of securing adequate skeletal stabilization and also because of the unique anatomic features of the clavicle.

Anatomy and Function of the Clavicle

The clavicle is the only long bone to develop by intramembranous ossification, which commences during the fifth week of intrauterine life from a single centrally situated ossification center. Secondary centers of ossification develop at both ends of the growing bone. The most medial of these growth centers ultimately accounts for up to 80% of the longitudinal growth.

The clavicle has a unique S-shaped configuration, with a convex anterior curve medially and a convex posterior curve laterally. This curvature is reportedly more pronounced in males, due to the stronger muscle pull. The clavicle is held securely at both ends by a combination of stout ligaments and joint capsules, with a number of muscular insertions and origins along the length of the bone. In cross section one can see a gradual transition from a flattened lateral end through a tubular middle zone to an expanded medial end. The central third, which has sparse medullary bone and lacks the muscular coverage of the lateral and medial thirds, is the site of the vast majority of clavicular nonunions.

Functionally, the clavicle acts as a bony strut that links the chest with the upper limb and contributes to the power and stability of the extremity, especially in overhead activities. It also transmits the supporting forces of the trapezius muscle to the scapula via the intact coracoclavicular ligaments.[8] During elevation of the arm, trapezius action is responsible for raising the clavicle by approximately 30 degrees about the sternoclavicular axis. When the coracoclavicular ligament is intact, this force is transmitted to the scapula; therefore, early scapular rotation during elevation of

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the limb is initiated by motion of the clavicle. Of lesser importance are the functions of the bone in providing a framework for muscle attachments and in offering protection to the subclavian vessels and brachial plexus.

Complex forces act on the clavicle during upper limb mobilization.[8] During protraction / retraction of the shoulder, the scapula subtends an angle of 50 degrees with the sternoclavicular joint. Two thirds of this movement is due to clavicular motion.[8] In elevation of the arm to the fully abducted position, the clavicle angles upward by 30 degrees and backward by 35 degrees, with the motion occurring at the sternoclavicular joint. During this movement, the clavicle also rotates about its longitudinal axis as much as 50 degrees. These motions combine to produce bending moments in the coronal and sagittal planes, with torsional forces along the long axis of the bone but largely concentrated at the middle section of the clavicle. It is not surprising, therefore, that those fractures that fail to unite are located more often in the middle third of the clavicle.

Fracture Classification

The classification of Allman[9] has been well accepted in delineating basic fracture patterns in the clavicle. Three basic groups are identified. Group I fractures involve the middle third and account for 80% of all fractures; group II fractures involve the outer third and account for 10% to 15% of all fractures; and group III fractures involve the medial third and represent 5% of the total. Group II fractures have been further divided by Neer into five subtypes on the basis of the relationship of the fracture to the coracoclavicular ligaments[1] (Table 1).

Table 1
Neer Subclassification of Group II (Lateral Third) Clavicular Fractures

Fracture Subtype	Description
1	Minimally displaced (interligamentous)
2	Displaced - fracture line is medial to the coracoclavicular ligament insertion
3	Fracture involves the acromioclavicular articular surface
4	Displaced - coracoclavicular ligaments remain attached to periosteal sleeve (childhood injury)
5	Displaced - ligaments are attached to an inferior butterfly fragment separate from the main fracture fragments

As with all skeletal disruptions, other attributes, such as the extent of displacement, the number of fracture fragments, the integrity of the overlying skin, and associated injuries, will influence the outcome. Displaced fractures, especially those of the middle third, are subjected to the deforming forces of the weight of the arm, which further displace the lateral fragment inferiorly while the sternocleidomastoid muscle attachment elevates the medial fragment. In displaced group II fractures, stability is determined to a large degree by the integrity of the coracoclavicular ligaments.

Nonunion

Predisposing Factors

Although nonunion following clavicular fracture is uncommon, its potential impact on upper limb function has led to an attempt to better understand both the etiology and the operative management.[4,6,7,10-12] Nonunion is considered to be present when there has been little or no progression of clinical or radiographic healing at a minimum of 16 weeks after injury. Malunion is common, but its impact on shoulder mechanics is also poorly understood and has only recently been investigated in the literature.[4]

The reasons for the development of a clavicular nonunion have yet to be clearly defined. Wilkins and Johnston,[7] in an analysis of clavicular nonunions, suggested that the severity of initial trauma and the extent of displacement of the fracture fragments are the most significant factors predisposing to nonunion. Some of the nonunions in their study developed in the presence of a comminuted fracture, a fracture that was widely displaced, or associated trauma to the thorax, spine, or ipsilateral extremity. They were unable to define a relationship between the duration of immobilization and the development of a nonunion. They also observed that several nonunions occurred after refracture of a previously healed clavicular fracture. It is important to note that this study, as well as most published analyses of clavicular nonunion, did not follow the fractures longitudinally from inception to healing, but rather represented a retrospective review of a selected group of patients with a nonunion.

Other studies have supported the severity of the initial trauma and the extent of fracture-fragment displacement as the most important factors that might lead to failure of union.[6,7,11] None of these studies has implicated such elements as soft-tissue interposition and inadequate immobilization as important risk factors.

Others have cited operative manipulation of a closed clavicular fracture as a source of nonunion. Neer[2] retrospectively evaluated the data on a large series of patients with fractures of the clavicle and found the incidence of nonunion to be 0.1% in those treated nonoperatively, in contrast to 4.6% in those treated operatively. His observations were confirmed in a more recent study by Poigenfürst et al,[13] who also found a nonunion rate of 4% in 122 fractures treated by open reduction and plate fixation. However, neither study adequately stratified the fractures for severity of injury. Thus, it is possible that the operatively treated group may have included patients with fractures at greater inherent risk of nonunion. Some of the operative failures also may have been the result of technical inadequacies.

Preoperative Evaluation

Disability associated with a nonunited fracture of the clavicle may be due to pain at the site of nonunion; altered shoulder mechanics, either in response to pain or due to malposition of the fracture fragments; "ptosis" of the shoulder and upper limb due to one or more of the above problems; or local compression of the underlying brachial plexus or vascular structures. In a retrospective review of 23 nonunions treated at the Massachusetts General Hospital reported by Jupiter and Leffert,[6] 5 patients were found to have signs and symptoms consistent with local compression of the lower trunk of the brachial plexus. Another 4 patients had signs and symptoms of thoracic outlet compression due to the ongoing ptosis of the shoulder girdle. In addition, several patients were observed to have lost glenohumeral motion due in large part to prolonged immobilization.

In a group of 21 symptomatic nonunions reported by Boehme et al,[10] pain was a prominent symptom in 18 patients. Although the precise nature of the neurologic deficit was not specified in their analysis, at least 5 patients had subjective numbness or paresthesia.

Manske and Szabo[11] described pain as the prominent symptom in all 10 of their nonunion patients. In 3 of the 10 patients paresthesia could be induced by extreme abduction or flexion of the affected shoulder. The experience of Wilkins and Johnston[7] was similar, with moderate to severe pain occurring in 17 of 19 of their surgically treated patients. Two of these patients had clinical evidence of thoracic outlet compression.

Given the relatively subcutaneous nature of the clavicle, the morphology of the nonunion usually will be well visualized by standard radiographic evaluation. The abduction-lordotic view described by Riemer et al[14] is extremely helpful in following up the operative treatment (Fig. 1). In patients in whom the diagnosis is in question, conventional or computed tomography may be necessary to confirm the diagnosis. If neurovascular compression is suggested by the history and/or physical examination, electromyographic studies will be useful preoperatively in documenting the site, nature, and degree of compression. In rare instances, angiography may be required to delineate the subclavian vessels.

When planning an operative approach, particularly when there is a malpositioned clavicle, an anteroposterior projection of both clavicles will help to define the length that must be regained. This often will

A

B

Fig. 1 **A,** Standard anteroposterior radiograph of clavicular nonunion following plate stabilization. **B,** The abduction-lordotic view offers enhanced visualization of the radiographic anatomy of the clavicle.

require an intercalary iliac-crest bone graft.[12]

Surgical Treatment

Indications

Pain at the nonunion is the most frequent impetus for operative intervention. Other indications include extremity dysfunction in the form of shoulder stiffness, ptosis, and the coexistence of neurovascular signs and symptoms.

Options

A variety of surgical maneuvers have been espoused in the treatment of nonunions of the clavicular shaft. They can be divided into two categories: reconstructive procedures and salvage procedures. The essential difference between these treatments is that reconstructive operations are designed with the primary aim of achieving bone union in an anatomic position, while salvage procedures are designed to alleviate symptoms or deformity without addressing bone healing.

Salvage Procedures

Salvage procedures that have been utilized include excision of bony prominences, clavicular resection (partial or total), and resection of the first rib.

The practice of resection of part or all of the clavicle as a space-making procedure was formerly used in the treatment of "shoulder girdle syndrome,"[5,8] which is now recognized as thoracic outlet or subclavian vascular compression. This operation was designed to increase the space available at the costoclavicular outlet. Particular importance was placed on complete extraperiosteal excision of the bone (to prevent new bone formation in the periosteal remnant) and on resuture of the attachments of the clavicular musculature.

Resection procedures were popular in an era when implant technology for reconstructive procedures was not yet available and are now largely of historical interest only. Only in rare circumstances should such operations be contemplated, since recent investigations have emphasized the pivotal role of the clavicle in normal upper extremity function. Thus, reconstructive surgery is favored in the management of most symptomatic nonunions.[4]

There remains one situation in which resection may occasionally be the treatment of choice. In nonunion of displaced group II fractures in which the lateral fragment is small, excision of the fragment followed by reattachment of the coracoclavicular ligament to the outer end of the medial clavicular remnant offers a predictable alternative to reconstructive efforts.

Reconstruction

It would appear from the contemporary literature that most investigators advise an attempt at gaining union when faced with a symptomatic nonunited fracture of the clavicle.[2-4,6,7,10-12,15-19] The specific tactics have varied from the use of threaded intramedullary pins[10,15,20] to external skeletal fixation[19] to internally applied plates and screws.[4,6,7,11,12,16-18] Our preferred technique is as follows:

A straight incision is made parallel to the long axis of the clavicle. We advise careful identification and preservation of the cutaneous supraclavicular nerves as they cross the anterior border of the clavicle, since damage to these may result in dysesthesia in the postoperative period. This can be facilitated by using loupe magnification (Fig. 2). The nonunion is exposed by careful subperiosteal dissection, with caution taken to avoid damage to adjacent neurovascular structures on the inferior aspect of the bone.

In unstable nonunions and those associated with deformity, the application of a small distractor will help control the fragments and will aid in obtaining the desired length and alignment. In the case of a hypertrophic well-aligned nonunion, the bony prominences at the site of the nonunion are trimmed, and the exuberant bone is used as an autogenous bone graft. The nonunion itself does not require debridement, as the fibrocartilage will progress to union as a result of the mechanical stimulus provided by the presence of a plate and screws.

Fig. 2 Subcutaneous dissection is performed under loupe magnification to preserve the integrity of the crossing supraclavicular nerves.

More commonly, one is faced with sclerotic rounded ends at the nonunion site, with interposed fibrous tissue that requires excision. In these instances, a gap will be present, which can be reconstituted with an intercalary iliac-crest graft. The recipient ends of the clavicle are trimmed of marginal callus, and the canals are opened with a 3.2-mm drill bit.

Through an oblique incision along the midpoint of the ilium, the crest is exposed subperiosteally. A tricortical section, measuring one and one-half times the anticipated size of the final graft, is removed with either osteotomes or a small oscillating saw. The graft is sculptured to create large cancellous pegs at each end, which plug into the prepared medullary canals of the clavicle, maximizing stability of the graft during plate fixation (Fig. 3). The graft is positioned so that the dorsal cortical margin of the iliac crest lies on the inferior surface of the clavicle, affording the advantages of better purchase of a screw as well as more resistance to bending forces at the nonunion site. Additional cancellous graft from the iliac crest is compacted into the medullary canals of each fragment before the final impaction of the corticocancellous segmental graft. The apical deformity of a clavicular nonunion tends to be directed superiorly, creating a preexisting tension and compression surface of the clavicle. For this reason, we favor application of a plate to the superior, or tension, surface when possible; by doing so, the forces of distraction acting on the bone will be converted into compressive forces (the tension band principle), optimizing skeletal stability and promoting healing.

Fig. 3 Sculptured tricortical iliac-crest bone graft.

Satisfactory clavicular fixation has also been reported with semitubular, reconstruction, and standard dynamic-compression plates. Our preference has been to use the limited-contact dynamic-compression plate (LCDC Plate, Synthes, Paoli, Pa), which offers several advantages in this situation.[12,18] The uniform stiffness of the implant facilitates precise contouring in all planes to accurately match the unique anatomy of the clavicle. Furthermore, since there is no solid central section, screw placement into the intercalated bone graft is easier. In addition, the screw holes permit compression in either direction to enhance graft incorporation on both its surfaces. Ideally, a minimum of three screws should be placed in each major fragment, with an additional screw securing the central graft; therefore, at least a six-hole plate (but preferably an eight-hole plate) is preferred. After completion of the plating procedure, the cortical bone adjacent to the nonunion site is “shingled,” and additional cancellous bone chips are placed on the inferior aspect of the nonunion (Fig. 4). In cases in which shortening of the clavicle is not a concern, stability of fixation may be enhanced by ensuring that the reduced contacting surfaces are sufficiently oblique to permit the passage of a single interfragmentary lag screw through the plate (Fig. 5).

We prefer to close the wound over a suction drain, ensuring meticulous hemostasis. The skin is closed in an atraumatic fashion with use of a subcuticular suture. These measures will reduce the incidence of wound hematoma and promote cosmetic wound healing.

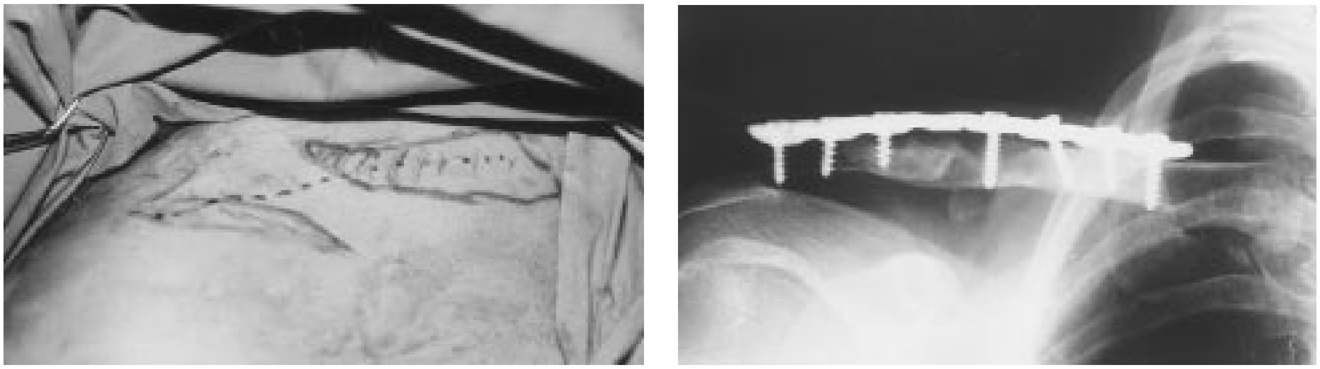
Rehabilitation

One of the advantages of secure skeletal fixation utilizing plates and screws is that immediate postoperative motion can be instituted. Our current practice, provided we are confident with the security of fixation, is to use a sling for patient comfort during the initial 2 postoperative weeks. The sling may be removed for short periods of passive shoulder pendulum and overhead elbow-flexion (without resistance) range-of-motion exercises, which are continued until fracture union has been demonstrated. Thereafter, progressive strengthening exercises are permitted, although full overhead activities may not be resumed until sound healing has been demonstrated clinically and radiologically, which usually occurs 6 to 8 weeks postoperatively. A return to all occupational duties and recreational pursuits is usually possible by 3 months after reconstruction.

In most cases, plate removal is unnecessary; on occasion, however, hardware may cause skin problems due to its prominence. In those instances, we remove the plate, provided a minimum of 12 months has elapsed since the time of reconstruction.

Results of Treatment

Surgical treatment of established nonunion can produce satisfactory results as measured by symptomatic improvement and restoration of function. Treatment by compression plating in combination with bone grafting has produced consistently good outcomes in all series.



A B

Fig. 4 The technique of intercalary graft restoration of clavicular length. **A,** A nonunion in a 60-year-old woman is traced on the skin. **B,** Radiograph obtained 3 months after surgery shows healed nonunion.

In the series reported by Jupiter and Leffert,[6] 19 of the 21 cases were treated to gain union. Success was achieved in 92% after treatment by plating and autogenous cancellous grafting. A recent (unpublished) audit of 14 additional cases treated by plating with the addition of an intercalated corticocancellous graft revealed successful incorporation of the graft, with rapid healing and excellent function in each case. Local pain, brachial plexus neuropathy, and thoracic outlet compression were reliably abolished.

In the series reported by Karaharju et al,[17] 12 cases treated by plating with autogenous cancellous grafting went on to prompt healing. Similar results with this treatment protocol in 10 patients have been reported by Manske and Szabo.[11] Edvardsen and Ødegård[16] also had a 100% rate of union in 6 patients treated by compression plate with the addition of an onlay corticocancellous tibial graft. No information regarding long-term extremity function is available in these studies, since most are concerned with bone healing as the defined end point of treatment.

Union rates after intramedullary pin fixation are more variable, although definitive conclusions cannot be based on the small numbers treated in each series. Wilkins and Johnston[7] described pin breakage in 2 of their 4 patients; both had continued nonunion. These figures contrast with those of Neviaser et al[20] and Connolly and Dehne,[3] who described union in all 4 and 6 of their cases, respectively. Boehme et al[10] reported a union rate of 95% in a group of 21 midshaft nonunions treated with a threaded intramedullary pin with a compression facility. More recently, Capicotto et al[15] reported on the successful treatment of 14 patients, although there were two cases of late refracture after removal of the hardware.

Incidents of technical problems due to pin breakage or distal migration have been reported in the literature, but these cases are uncommon in the larger series, suggesting that experience and careful technique are important in minimizing these complications. External fixation of clavicular fractures and nonunions using a standard Hoffman apparatus has been reported by Schuind et al[19]; in all five cases of nonunion, healing was uneventful. Although the clavicle offers good pin purchase, particu-

Fig. 5 An interfragmentary lag screw provides optimal stability of oblique nonunion.

lar care is needed to avoid neurovascular complications during pin insertion.

We believe plate fixation offers the most predictable solution to the difficult problem of symptomatic nonunion, although alternative methods have acceptable results provided careful attention is paid to detail during surgery and rehabilitation. Longer-term outcome studies are required to evaluate upper extremity function after reconstruction.

Malunion

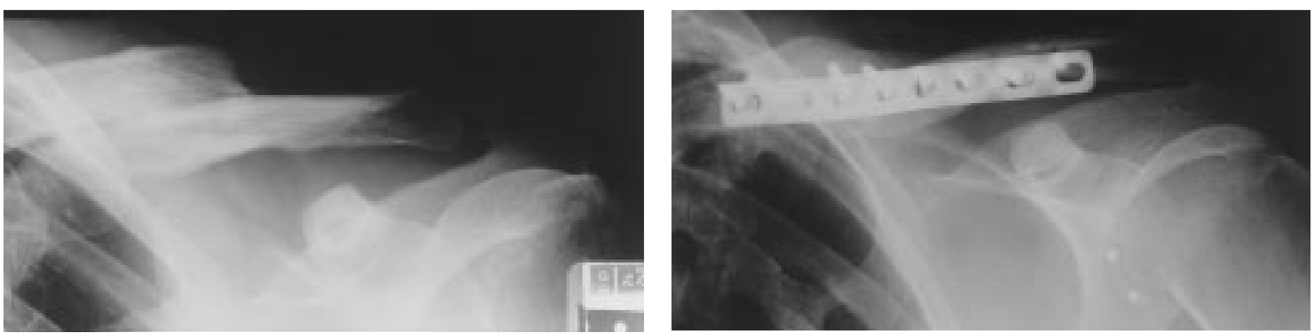
Although many clavicular fractures heal with deformity, there is a paucity of literature regarding associated dysfunction.[4] Unless there is a visible deformity, most patients with malunion function well. On rare occasions, exuberant callus can produce a local compression on the underlying brachial plexus, which may resolve as the callus matures. Should the signs and symptoms of neurologic compression persist after maturation of the callus, consideration should be given to resection of the callus, leaving the clavicle intact.

Given the mechanical role of the clavicle in normal shoulder girdle function, it should not come as a surprise that a clavicular fracture that has healed with shortening or angular deformity can result in dysfunction, especially in the individual involved in overhead manual labor or sporting activities. In the study by Eskola et al,[4] shortening by more than 15 mm was associated with shoulder discomfort.

In an unpublished series of four patients, we performed a clavicular osteotomy for deformity associated with ipsilateral glenohumeral dysfunction either alone or in combination with scapulothoracic dysfunction (Fig. 6). The malunion was osteotomized through the plane of the deformity, realigned with use of a small distractor, and secured with a plate and screws. In each case, the functional outcome was satisfactory.

Summary

Although fractures of the clavicle are relatively common injuries, accounting for 5% to 10% of all instances of adult skeletal trauma, nonunions and malunions after such injuries are uncommon. They can prove to



A B

C D

Fig. 6 Functional outcome after treatment of long-standing malunion associated with glenohumeral and scapulothoracic dysfunction. **A,** The foreshortened malunited clavicle. **B,** Radiographic appearance of the clavicle after lengthening and plate fixation. **C** and **D,** Final functional result.

be disabling, however; pain, limitation of shoulder mobility, and local compression of the brachial plexus or subclavian vessels can result in profound functional impairment.

Pain at the site of nonunion is the most frequent impetus for operative intervention. Other indications include altered shoulder mechanics, shoulder stiffness, and neurovascular signs and symptoms.

Surgical treatment of established nonunion has proved efficacious in terms of symptomatic improvement and restoration of function. Posttraumatic clavicular nonunion or deformity represents a major challenge for orthopaedic surgeons, however, because of the technical difficulty of securing adequate skeletal stabilization and also because of the unique anatomic features of the clavicle.

Two general approaches have been espoused: salvage procedures and reconstructive procedures. Salvage procedures include excision of a bony prominence, partial or total clavicular resection, and resection of the first rib. Reconstructive procedures are focused on gaining union and restoring clavicular anatomy—most often achieved with plates and screws and autogenous bone graft. One of the advantages of secure skeletal fixation with plates and screws is that immediate postoperative motion can be instituted.

Most patients with a malunited clavicular fracture are asymptomatic. If there is associated functional or neurovascular dysfunction, however, osteotomy and correction of the deformity should be considered.

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