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Failed Fixation of Clavicle Fracture

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Anatomical Site

Clavicle fractures are very common injuries with a high incidence. They represent 2.6–4% of all fractures [1–5]. Historically, in the 1960s, many clavicle fractures were treated non-operatively with reported non-union rates hovering around 1% [6–8]. At that time, the non-union rate was considered higher in clavicle fractures treated with surgery than in clavicle fractures treated non-operatively [6, 7]. Currently, the reported non-union rate after conservatively treated clavicle fractures is considerably higher than early reports and many surgeons report improved functional outcomes after surgical treatment [2, 9–12]. However, it remains that most non-displaced clavicle fractures, regardless of location, are typically managed non-operatively [2, 6, 7, 13–15].

The clavicle is unique in many facets compared to other long bones. It is the only long bone to ossify via intramembranous ossification. It is the first bone in the body to ossify gestationally, in the fifth week of fetal life, and the last bone to complete ossification. However, like other long bones, its primary ossification is located centrally and there are two secondary ossification centers—one at each end of the clavicle. The medial ossification center is responsible for approximately 80% of the longitudinal growth and the lateral ossification center is responsible for approximately 20% [16].

The clavicle has several functional purposes. First, it serves as a base for muscular attachments. It also struts the glenohumeral joint in the parasagittal plane stabilizing the shoulder joint and the range of grasp in the three-dimensional space for the hand. It provides for arm-trunk power above the shoulder level. It protects the brachial plexus and vascular structures of the neck and extremities. Lastly, it provides a cosmetic function providing a gentle curve to the base of the neck [16].

Clavicle fractures have historically been classified by location according to three segments of equal length—lateral, midshaft, and medial thirds. This has classically been without any three-dimensional criteria or reference to anatomic structures [17]. However, newer data suggest the segments are unequal in length with the middle clavicle comprising the greatest length of the segments (Fig. 5.1) [17]. The clavicle is better represented by two inverse curves creating an "s" shape that enables the clavicle to absorb stress [18]. The first curve (medial) is more than half of

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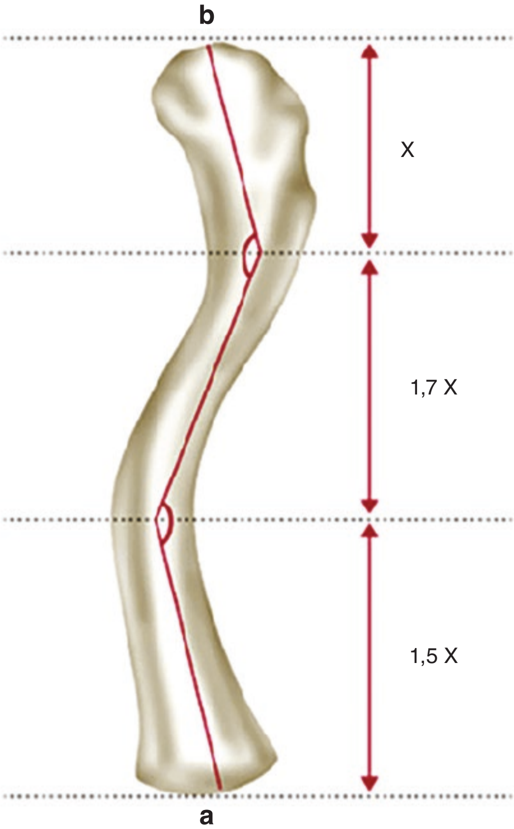

Fig. 5.1 Clavicle segments (lateral, midshaft, and medial) are unequal in length. The middle clavicle is the largest segment

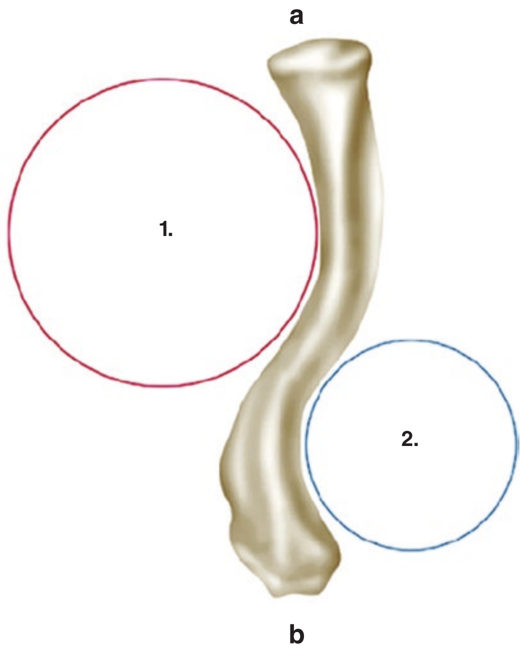

Fig. 5.2 The clavicle is represented by two inverse curves creating an "s" shape. The first curve (medial) is more than half of the length of the clavicle and is convex anteromedially; the second curve (lateral) has a radius that is half the size of the first curve and is convex posterolaterally

the length of the clavicle and is convex anteromedially; the second curve (lateral) has a radius that is half the size of the first curve and is convex posterolaterally (Fig. 5.2) [18].

Clavicle fractures most commonly involve the midshaft region, approximately 69% of the time [1, 8]. Lateral clavicle fractures and medial clavicle fractures have a considerably lower incidence accounting for 28 and 3% of clavicle fractures, respectively [1]. Risk factors for non-union of clavicle fractures include fracture shortening of 1.5–2 cm, female sex, smoking, fracture comminution, fracture displacement, older age patients, severe initial trauma, soft tissues interposition, open fractures, polytrauma, inadequate initial immobilization, and unstable lateral fractures [8, 16, 19]. However, in general, non-union rates vary based on fracture location, fracture energy, and fracture morphology. An example of this is seen in medial clavicle fractures, which are typically high-energy injuries with a relatively high risk for non-union compared to lower energy injuries. The non-union rates of medial clavicle fractures also vary if they are non-displaced or displaced. Non-displaced medial clavicle fractures have a non-union rate of 7% and displaced medial clavicle fractures have a non-union rate of 14–20% [1, 10, 20–22].

Avoiding failure of fixation of clavicle fractures is particularly challenging due to the deforming forces on the fracture fragments that implants are required to withstand until fracture union. The weight of the arm and the pull of the pectoralis major muscle produce an inferior and medial force to the lateral clavicle, respectively. The sternocleidomastoid muscle creates a superior force vector medially on the clavicle (Fig. 5.3) [16]. Fixation methods chosen must be able to withstand these forces until fracture union.

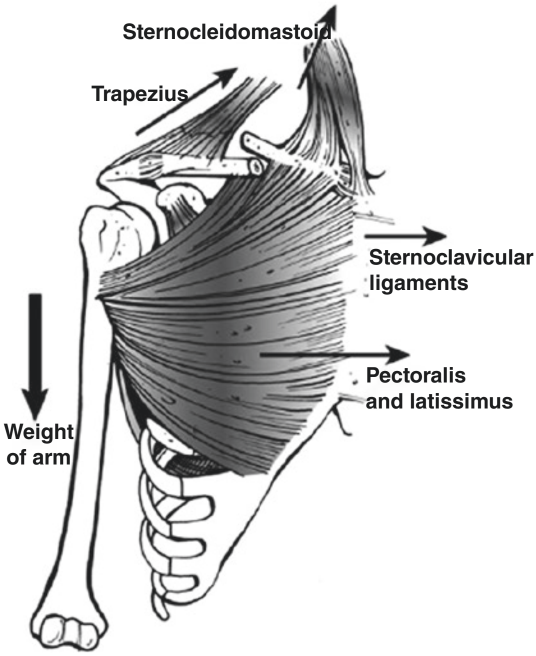

Fig. 5.3 Deforming forces on clavicle fractures

Elevation of the arm imparts forces on the clavicle that fracture fixation methods must also be able to withstand until fracture union. During elevation of the arm, the clavicle angles upward by approximately 30 degrees, posteriorly by approximately 35 degrees, and rotates about its longitudinal axis as much as 50 degrees [23]. These motions subject the clavicle to bending moments in the coronal and sagittal planes that stress the implants until fracture union.

Other challenges in avoiding fixation failure are due to the compositional characteristics of the bone that are innate to the clavicle. The anatomic middle third of the clavicle is largely cortical bone, with sparce cancellous bone, and few soft tissue attachments [24]. Cortical bone heals slower than cancellous bone prolonging the duration the implants must withstand the deforming forces until fracture union compared with metaphyseal fractures [25].

In practice, operative indications for clavicle fractures vary between providers. However, the literature reports indications for operative treatment that include (1) >2 cm displacement; (2) open fracture; (3) extensive soft tissue damage; (4) neurovascular compromise; (5) high-energy mechanisms with high-energy injury patterns (floating shoulder, shoulder impaction, polytrauma); (6) symptomatic malunions and nonunions; (7) improve cosmesis [4, 17]. This list of operative indications is highly specific; however, it can be generalized to clavicle fractures that are at modest risk for non-union, to restore anatomy, to maximize function and to improve cosmesis relative to non-operative management.

Non-operatively managed clavicle fractures have traditionally been treated in the figure-of-eight brace, but newer literature suggests elbow-to-body sling had similar results with improved tolerance and ease of use [26, 27]. Non-operatively managed clavicle fractures almost universally heal with some degree of malunion; however, symptomatic malunion is uncommon [8, 28].

Operatively managed fractures have been treated primarily via plate osteosynthesis and occasionally with intramedullary fixation. Plate osteosynthesis and intramedullary fixation both encompass a large variety of implants. Plate osteosynthesis has been considered the gold standard fixation option for midshaft clavicle fractures [17]. In modern practice, there are a large variety of plate types used for midshaft clavicular fracture fixation including reconstruction plates, dynamic compression plates (DCPs), mini-fragment plates and pre-contoured plates. Each of these types may or may not have locking capability.

Reconstruction plates were historically the primary plating option. They would be contoured intra-operatively by the surgeon to fit the highly curved bony anatomy. These plates are much less commonly used today in favor of modern pre-contoured plating options. Complications have developed secondary to the strength of the plate, which has a high incidence of failed fixation. These plates are too thin and malleable (notched edges) resulting in a less rigid plate that can be unable to withstand the deforming forces on the fracture (Fig. 5.4). Failure rates with single-plating reconstruction plates have been reported to be as high as 53%. Dynamic compression

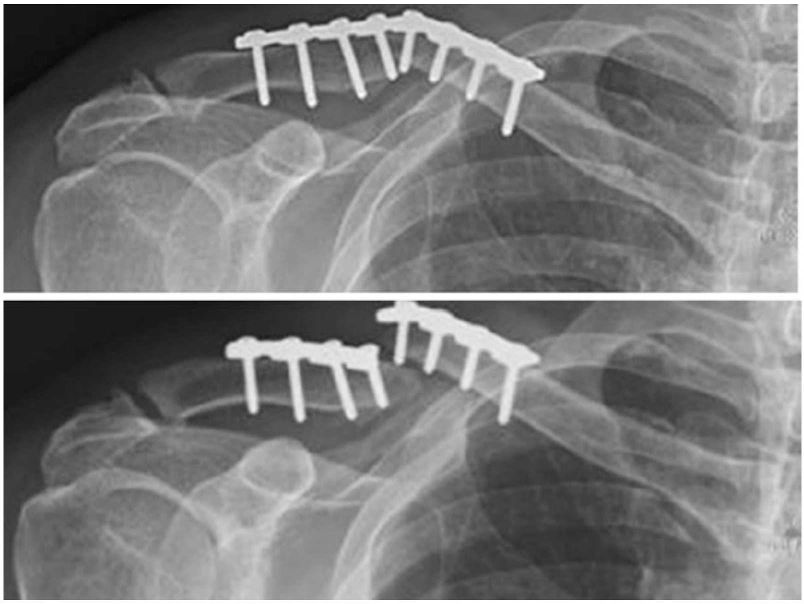

Fig. 5.4 Progression of plate failure from bending those ultimate leads to breakage of the plate

plates (DCPs) and other similar plates have offered increased plate strength but multiplane contouring of the plate to the clavicle is extremely difficult. Many surgeons, therefore, began to dual-plate clavicle fractures to increase multiplanar strength and in-turn reduce the failure risk [29–32]. Modern dual-plating techniques have a much lower failure rate than reconstruction plates alone with reports of failure rates in the range of 2–3% [29].

Newer anatomic plates have offered significantly easier plate application and significantly less contouring. However, there is still a wide variation in mismatch, and they often still require contouring for proper application to the clavicle. Compared with reconstruction plates, these plates are typically more robust and can withstand greater deforming forces [17]. Like reconstruction plates, anatomic plates have the option to be locked or nonlocked. Plates with locked screws have been shown to have lower failure rates in clavicle fractures [33]. Studies have also shown that bicortical locked screws have lower failure rates than unicortical locked screws in clavicle fractures [34].

There are many different intramedullary fixation options. These are much less commonly used than they were in the past due to a relatively high failure rate compared to plate fixation devices. Like other mechanical devices, intramedullary devices vary in their strength due to design differences. Solid fixation devices have been shown to be stronger than cannulated fixation devices. Studies have shown that fixation of midshaft clavicle fractures with cannulated screws may lead to early failure because the device may have inadequate mechanical strength [35]. Additionally, in comparison to plate osteosynthesis, intramedullary devices have been shown to be inferior when rotational stiffness is required [29].

Etiology of Failure of Fixation

Failure of fracture fixation is typically secondary to one of two causes, excluding infectious etiology, fracture non-union and/or inappropriate implant selection (Fig. 5.5). An infectious etiology must always be considered and ruled out, but this is outside the scope of this text.

Clavicle non-union is a common cause of failed fixation in clavicle fractures. Risk factors for non-union include intrinsic and extrinsic factors. Intrinsic factors include age, smoking and female gender [19]. Extrinsic factors include dis-

Fig. 5.5 Example of implant failure. The plate is bent and the screws are beginning to pull out

placement, shortening, soft tissue interposition, open fractures, polytrauma and inadequate initial immobilization [16, 19]. Clinicians use a variety of criteria to define a non-union. Typically, a non-union is defined as a fracture that is not healed by 6–9 months and a delayed union is defined as a fracture that is not healed between 3–6 months [16]. However, in practice, many clinicians treat unhealed fractures as non-unions at earlier time-frames. Non-union inevitably leads to failure of fixation because the implant(s) fatigue due to the mechanical load via stress transfer. This stress transfer to the plate and screws will ultimately end in breakage and/or loosening of the implant(s).

Blood supply to the clavicle may also be a factor in development of non-union. In the anterior part of the middle segment of the clavicle the blood supply is purely periosteal, from the thoracoacromial artery via the pectoralis major and deltoid muscles. Therefore, care to preserve midshaft periosteum during dissection may mitigate non-union risk for fractures in this area [36]. The posterior clavicle vascularization is received from the suprascapular artery via periosteal branches and a nutrient branch lending to greater healing potential and lower non-union rates [36].

Another common cause for implant failure is selection of the incorrect implant for the fracture being treated. Plates that are too thin and malleable may lead to early breakage, bending and/or the backing out of screws. A plate that may be appropriate in a younger patient with anatomical cortical reduction may not be appropriate for a geriatric patient with a comminuted fracture pattern. Understanding the fracture personality and quality of bone of the patient is essential.

Clinical Examination

Failed hardware in clavicle fracture fixation rarely presents asymptomatically in patients. Patient's often experience disability due to pain at the fracture/non-union site, altered shoulder mechanics and/or compressive lesions on the brachial plexus or vascular structures (Fig. 5.6) [16]. Symptoms most often result from prominent loose screws, broken or bent plates and/or deformity of the shoulder. Symptoms present as tenderness to palpation, gross motion, crepitus, pain, and/or paresthesias [8].

When evaluating patients with pain after clavicle fracture surgery, it is important to take a careful history and perform a thorough physical exam. Asking questions regarding the onset of pain, change in function, change in shoulder contour, recent trauma, and recent illnesses can aid in making a diagnosis. A thorough physical exam can aid the clinician in making the correct diagnosis by examining the patient for shoulder asymmetry, prominent screws/plates, gross motion at the fracture/non-union site, and any evidence of infection.

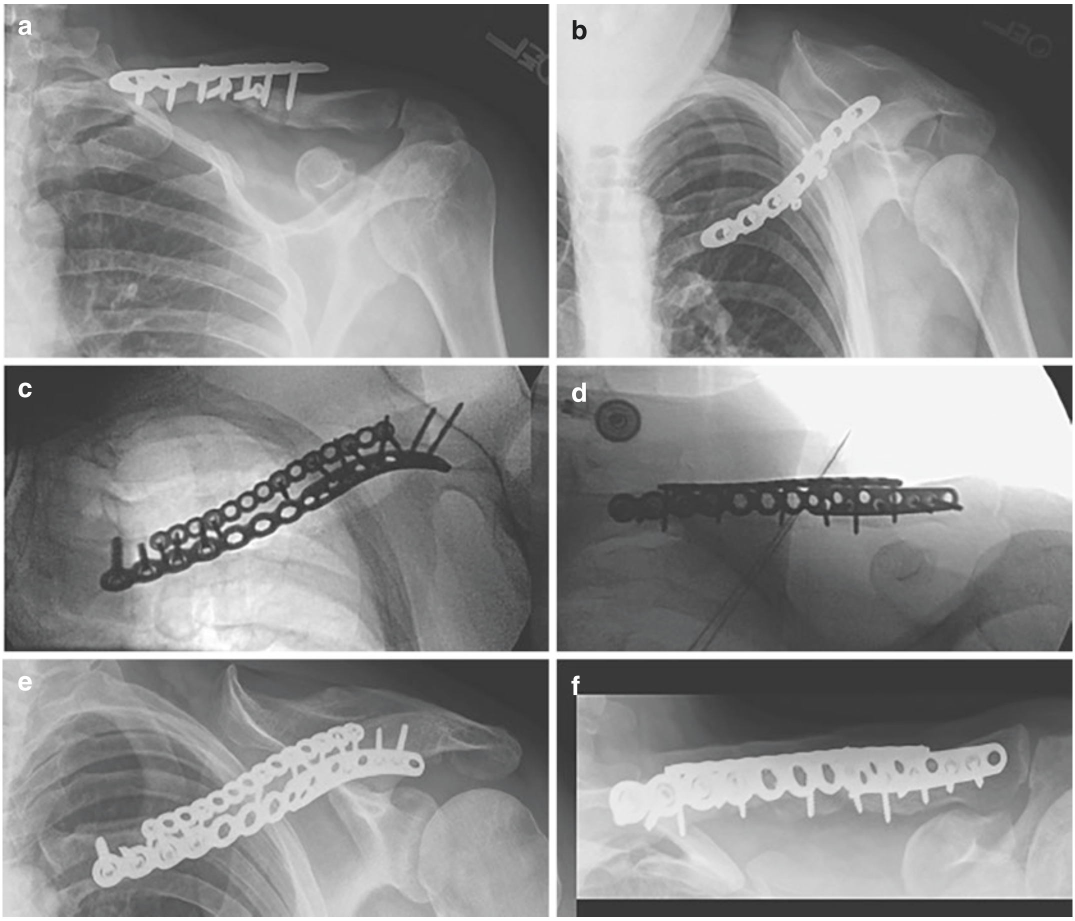

Fig. 5.6 This is a 37-year-old male patient who presents with pain and clicking 1 year status post-open reduction internal fixation of a clavicle fracture. (**a**, **b**) clinical film; (**c**, **d**) intra-operative films; (**e**, **f**) 5 months follow-up

Diagnostic

When a patient presents with pain and a history of a previously treated clavicle fracture, failed fixation should be ruled out. All patients being worked up for failed fixation require plane radiographs of the clavicle. There are multiple images that can be obtained, but most commonly a plane anteroposterior X-ray is obtained. Additional images that may be helpful are clavicle inlet and outlet films (aka serendipitous views), which are performed by obtaining images with craniocaudal tilt and caudocranial tilt, respectfully. Shortening is difficult to accurately assess on unilateral plain X-rays. Therefore, a bilateral clavicle X-ray and/or CT is more useful to evaluate shortening. Additionally, inferior displacement is commonly underestimated on supine films; therefore, obtaining films in the upright position may be beneficial [37].

Plain X-ray images typically can confirm the diagnosis and aid in understanding fragment locations and failed implant locations. However, sometimes the implant failure is subtle (i.e., screw loosening) and degree of healing difficult to evaluate using plain X-rays alone. This may be secondary to the location of the prior implants obstructing the visualization of fracture union or it may be secondary to the severity of fracture comminution. Therefore, in cases where failed fixation is not obvious, but the clinical concern remains elevated, a CT scan may add valuable information. It may also be helpful given the curved shape and small diameter of the bone, but sometimes it may be obscured by metal artifact. Other advanced imaging modalities such as MRIs are not typically useful.

All patients that are being worked up for failed fixation require a general lab workup to rule out infection as the etiology. This varies slightly by institution, but in general a complete blood count (CBC), erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) are sufficient. Additionally, most surgeons will obtain deep cultures at time of revision surgery. Other biochemical tests are not generally warranted.

Formulation of Preoperative Planning

After a diagnosis of a clavicle aseptic non-union with failed fixation is made, a careful and detailed surgical plan should be formulated. Typically, this is initiated with clinical X-rays that were previously obtained and supplemented with bilateral CT scans of the clavicles. Three-dimensional reconstruction images may be formatted, which can be very helpful in understanding fracture morphology. These images allow direct measurements of both clavicles to determine the degree of shortening and the location of displaced fractured implants. Pre-operative plans can be created using tracing paper or more modern operative planning software if the surgeon desires.

At the time of revision surgery, it is helpful to know which implants where previously used to assure removal instruments are available. If the existing implants cannot be identified, universal removal sets should be available. Scrutiny of pre-operative studies will aid in assuring all screws are removed prior to attempting to remove plates. Intra-operative fluoroscopy is used to localize buried or otherwise not visible implants and used to confirm removal. If possible, if is helpful to know the metallurgy of the implants used to better prepare for implant removal. Titanium locking screws more commonly strip with removal or are found to be cold-welded to the plate than stainless steel locked screws. Carbide drill bits can also be useful to remove screws that are cold-welded into the plate.

New Implant Selection

In general, revision clavicle surgery for failed fixation requires an increase in implant rigidity compared to the previous surgery. This may be done with either 1 or 2 implants in various sizes and plate categories. If a single plate is to be used, this will typically be a 3.5 mm plate on either the superior or anteroinferior surface of the clavicle. If two plates are used, a 3.5 mm plate may be supplemented with an additional 2.7 or 2.4 mm plate placed orthogonal to the first plate. Occasionally, in a small statured person, dual 2.7 mm plates or a 2.7 mm plate and a 2.4 mm plate may be sufficient. Orthogonal plating may be useful in maintaining reduction and it increases torsional strength; good outcomes with dual-plating have been reported [38–40]. It may be helpful to have precontoured plates available to help recreate the “S”-shape of the normal clavicle using the plate contour as a template (Figs. 5.7 and 5.8).

Fig. 5.7 An example of a plating construct for a medial clavicle non-union

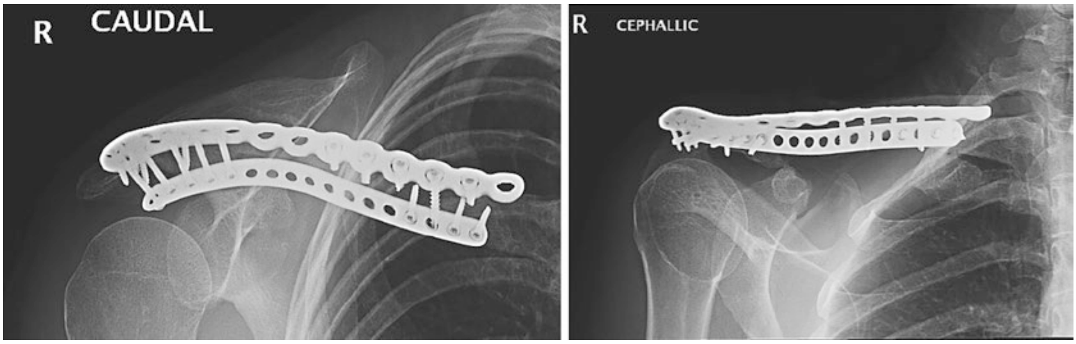

Fig. 5.8 An example of a plating construct for a lateral clavicle non-union

Need for Bone Grafting

Bone grafting in revision clavicle fracture surgery is not absolutely necessary [41]. If two healthy surfaces of bone are available for compression, length is satisfactory and the patient is a good host, then it may not be required. Multiple studies have reported excellent clinical results in treating clavicle non-unions without bone graft [42–45]. However, intercalary tricortical autograft is commonly needed when bone defects are present. This may be used to help obtain union and restore anatomic length [16]. Cancellous autograft can also be supplemented at the margins of the fragments. Autogenous iliac crest bone graft is still considered to be the gold standard because of its osteogenic, osteoconductive, and osteoinductive properties, but other anatomic donor sites and allograft options may be used if needed [24]. Disadvantages to autograft include limited volume of bone available, increased operative time, increased blood loss, and donor site morbidity [46–49]. Other graft options include vascularized fibular autograft, non-vascularized fibular autografts, allografts, and bone graft substitutes but these have limited roles in the treatment of clavicle non-union [50, 51].

Revision Surgery

A stepwise approach is used in addressing failed fracture fixation:

1. The revision surgery is typically performed through the previous surgical approach, which is typically through a previous transverse incision. Care must be taken to preserve native tissue for an adequate closure at the end of the case.
2. Anatomical landmarks are used to assist to accurately access and adjust length and rotation before prior implants are removed. Once length is either established or landmarks are marked based on your pre-operative plan, the previous implants can then be removed.
3. Five tissue samples are obtained and sent to microbiology to rule out indolent infection.
4. Debridement of non-union is performed in multiple rounds. This is typically initiated with a curette and pituitary rongeur. Once the edges are free of soft tissue a burr is used to freshen the bone edges until bleeding bone edges are visualized.
5. The canal is opened in both directions either with a curette if the canal is maintained or a drill bit if bone has grown over the fracture edges.
6. A provisional reduction is the obtained with reduction clamps and/or provisional plates. K-wire fixation in hard diaphyseal cortical clavicle bone has limited utility and can cause heat necrosis.
7. With a provisional reduction obtained, the final implant selection may be determined. Initial small/thin reduction plates are applied to whichever surface (anterior/inferior or

superior) is most amenable given the location of the reduction clamps. A more robust plate is then applied to the opposite surface from the reduction plate. When deciding on the relative location of thin and thick plates in a dual-plate construct, consideration should also be given to the fracture obliquity so that dynamic compression is through the thicker plate.

8. If bone graft is needed, it should be harvested after a provisional reduction is obtained. Timing of the bone graft harvest is such that it can be used and implanted soon after harvest so that it does not lose biologic activity by being at room temperature for a prolonged period.
9. The previously selected plates are then applied to the clavicle. If structural graft is used, it is compressed to the native bone with the plates and screws or a tensioning device. Additionally, at least one screws is placed through the graft to avoid migration. Cancellous graft can then be placed around the non-union margins.
10. A standard multi-layered closure is then performed.
11. Post-Operative Protocol:
    - (a) Immediately post-operative
        - (i) Coffee-cup weightbearing
        - (ii) Active range of motion of the shoulder, elbow, forearm, and hand
        - (iii) Overhead motion avoided for the first 4 weeks
    - (b) First follow-up appointment: ~2 weeks post-op
        - (i) Wound check and suture removal
        - (ii) No images are typically obtained at this visit
    - (c) Second follow-up appointment: ~6 weeks post-op
        - (i) X-rays are obtained
        - (ii) Overhead motion is initiated following clinical and radiographic evaluation typically at this point
    - (d) Further follow-up: Until union and clinical improvement

Summary: Lessons Learned

Clavicle fractures are common injuries with a relatively high incidence of non-union compared to other fractures. An appropriate understanding of clavicle fracture deforming forces (i.e., weight of the arm, pull of the pectoralis major muscle, and pull of the sternocleidomastoid muscle), degrees of motion about the clavicle (i.e., bending moments in the sagittal and coronal planes), and compositional characteristics of the bone (i.e., high quantity of cortical bone) may aid in mitigating the risk of non-union after the index surgery. Additionally, an understanding of the fracture morphology and the patient treated should guide early treatment in acute fractures. Historical plate designs were typically thin and malleable, whereas modern plating designs tend to be stronger and are often pre-contoured lending to more fatigue resistance and ease of plate application. Dual-plating options offer increased rigidity and fatigue resistance, which may further mitigate failure of fixation.

Failure of fracture fixation of clavicle fractures is typically secondary to one of two causes, fracture non-union, and/or inappropriate implant selection, excluding infectious etiology. Failed hardware in clavicle fracture fixation rarely presents asymptomatically in patients. Symptoms most often result from prominent loose screws, broken or bent plates, and/or deformity of the shoulder. Symptoms present as tenderness to palpation, gross motion, crepitus, pain, and/or paresthesias [8].

If failed fracture fixation is identified, appropriate workup should be started immediately. This should always include an infectious workup to rule out an infectious etiology. Radiographs and bilateral CT scans of the clavicle may aid in the diagnosis of failed fixation and may be used in surgical planning for revision surgery.

A thorough pre-operative plan and an inventory of the necessary equipment enable a successful revision surgery. Revision surgery can be performed with various options of plate types, plate locations, plate quantities, bone graft (structural or non-structural), and augmentation with suture and tendon allografts as needed depending on the fracture morphology, location and biological needs. A stepwise surgical approach is best to optimize the possibility of a successful revision clavicle surgery.

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