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Humeral shaft fractures: a review

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Fractures of the humeral shaft are common, account for approximately 3% of all orthopaedic injuries, and result in a significant burden to society from lost productivity and wages.^{19,47,64} Treatment modalities have greatly evolved since their first description in ancient Egypt (circa 1600 BC); however, fundamental management principles have remained consistent throughout time.¹⁰ Nonoperative management continues as the mainstay for treatment of the majority of these injuries, with acceptable healing in more than 90% of patients. Surgical treatment is generally reserved for open fractures, polytrauma patients, ipsilateral humeral shaft and forearm fractures, and cases in which there is a failure to tolerate or maintain alignment in a functional brace.^{11,19,56} Advances in internal fixation modalities have improved surgical outcomes.^{6,14,38,62} Operative treatment can be performed via external fixation, intramedullary nails, or plate-and-screw constructs, with each method resulting in predictably high union rates.^{21,56} Despite the numerous surgical techniques, plate fixation remains the gold standard for fixation of humeral shaft fractures.

Relevant anatomy and biomechanical considerations

The humeral shaft is defined as the expanse between the proximal insertion of the pectoralis major and the distal metaphyseal flare of the humerus. Cylindrical in shape, the shaft inherently provides strength and resistance to both torsional and bending forces. Distally the bone transitions into a triangular geometry with the base posterior; the supracondylar region maintains a narrow anterior-posterior dimension. Important osseous landmarks of the humeral shaft include the deltoid tuberosity at the mid-anterolateral aspect, which serves as the insertion for the deltoid muscle, and the spiral groove posteriorly, which houses the profunda brachii artery and radial nerve as they traverse proximally to distally in a posterolateral direction.

The humeral shaft serves as the insertion and origin site for several major muscles of the upper extremity. These play an important role in the biomechanical consequences of different fracture patterns. Muscles inserting on the shaft include the deltoid, pectoralis major, teres major, latissimus dorsi, and coracobrachialis; those originating on the shaft include the brachialis, brachioradialis, and the medial and lateral heads of the triceps brachii. In fractures occurring between the more proximal pectoralis insertion and the more distal deltoid insertion, the proximal fragment is adducted by the pull of the pectoralis and the force of the deltoid pulls the distal fragment upward and laterally. In comparison, fractures occurring distal to both insertions

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cause abduction of the proximal fragment due to the deltoid, whereas the distal fragment is drawn proximally due to the pull of the biceps brachii, coracobrachialis, and triceps muscles.^{11,30}

The blood supply to the humeral shaft is provided predominantly by the nutrient artery, a branch off of the brachial artery that penetrates at the proximal third of the humerus on the medial side of the bone. The periosteum and the surrounding muscle bed also provide vascularity, to a lesser degree. Given the major role the nutrient artery plays in nourishing the humeral shaft, its disruption either through traumatic or iatrogenic means can be detrimental to fracture healing. It should be protected and preserved during surgical dissection.^{11,13,19,41}

Regarding important neurologic structures, the median, ulnar, and radial nerves all lie in close proximity to the humeral shaft. The median nerve travels adjacent to the coracobrachialis muscle belly, directly medial to the humerus and brachial artery, and provides no innervation to the muscles proximal to the elbow.^{11,19,30} It is easily localized in the distal arm, where it lies on the anterior aspect of the brachialis muscle. In the proximal arm, the ulnar nerve runs in a similar fashion to the median nerve but lies posterior to the brachial artery. As the ulnar nerve travels distally, it pierces the medial intermuscular septum two-thirds the distance down, thus moving from the anterior to the posterior compartment of the arm. It continues in the posterior compartment on its way toward the medial elbow. Like the median nerve, the ulnar nerve provides no innervation to muscles proximal to the elbow.^{11,30} Finally, the radial nerve, with its intimate and circuitous relationship to the humerus, is of special interest when treating humeral shaft fractures. The nerve begins its descent down the arm as a terminal branch off of the posterior cord of the brachial plexus and then enters the spiral groove just posterior to the deltoid tuberosity. It then courses posterolaterally adjacent to the bone, providing motor innervation to the triceps musculature. It finally exits the spiral groove on the lateral aspect of the humerus approximately 10 to 15 cm distal to the lateral acromion; it is there that the nerve is tightly bound by the lateral intermuscular septum and, therefore, highly susceptible to traction injury.^{11,19,24,29}

History of humeral shaft treatment

Methods and materials used for immobilization of humeral shaft fractures have remained relatively unchanged over the past several millennia. In the Edwin Smith Papyrus, circa 1600 BC, Egyptians first described treatment of 3 humeral shaft fractures with splints made of cloth, alum, and honey. Thirteen hundred years later, the Greeks, in *De Fracturis* (415 BC), described the use of weights for traction during closed reductions and elaborated on specific methods of splinting with bandages soaked in cerate (an ointment composed of lard mixed with wax) after reduction was

performed. The Roman author Celsus (25 BC to AD 50) then penned the medical text *De Medicina*, in which he described different humeral shaft fracture patterns, as well as benefits of fracture reduction including length restoration and reduction of pain. He also expanded on the Hippocratic methods of splinting and described how tight bandaging could cause gangrene of the extremity.¹⁰

Since the first narrative description, other various splinting techniques have come into vogue, including hanging-arm casts, Thomas arm splints, modified Velpeau dressings, coaptation splints, shoulder spica casts, and abduction-type splints. Despite the various modifications in theme, the basic principle of fracture stabilization has remained unchanged throughout time. The main limitation of many of these earlier splinting techniques was the impairment imparted to the patient with regard to activities of daily living. These apparatuses extended from the shoulder to past the elbow, and the prolonged use required for healing of humeral shaft fractures often resulted in stiffness in both the shoulder and elbow. It was not until 1977, when Sarmiento et al⁵⁵ first described functional bracing, that a major advancement was made and the modern era of splinting was introduced.

Since its first inception, functional bracing has become the gold standard for definitive management of the majority of midshaft humeral fractures. A functional brace is an orthosis with an anterior and posterior prefabricated shell that is contoured to accommodate the arm musculature (Fig. 1). Fracture stabilization is accomplished via the hydrostatic compressive forces of the surrounding soft tissues and is not dependent on the rigidity of the splinting material.⁷² As demonstrated by Sarmiento et al⁵⁵ through laboratory analysis, the fracture callous created through functional activity during the reparative process is more robust and is mechanically stronger than that gained through rigid immobilization. The advantage of this type of bracing is that it avoids unnecessary immobilization of other joints and allows for earlier restoration of motion and function to the injured extremity.

Current nonoperative management

It is important to stress that most transverse to short oblique humeral shaft fractures are amenable to nonoperative management and recommendations by some authors for immediate surgical intervention are not supported by level II studies.^{54,55,57} In a level III comparative study of extra-articular distal-third diaphyseal humeral fractures, the authors concluded that although operative treatment resulted in more predictable alignment and a potentially quicker functional return, the operative risks were not insignificant and included loss of fixation (1), infection (1), and post-operative radial nerve palsy (3). Among the 19 patients treated surgically, a 26% complication rate was reported. Comparatively, in the group that underwent brace treatment



Figure 1 A Sarmiento (functional) brace. The material is a thermoplast moldable splint with Velcro straps that can be tightened as swelling subsides to allow continued compression on the fracture. The brace is applied in a manner that allows shoulder and elbow motion.

the end result in each case was a healed fracture with excellent functional outcome, with only minor skin complications due to local brace irritation noted. Advocates for surgical treatment should acknowledge that even in cases in which brace treatment is a challenge, the literature does not support the superiority of operative treatment.³³

The current strategy for nonoperative management involves the immediate immobilization of the injured extremity via a coaptation splint, sling, and/or swath to provide initial fracture stability, pain control, and resolution of the edema. Once the majority of the soft-tissue swelling subsides, typically after 10 to 14 days, the initial splint is exchanged for a functional brace that provides circumferential soft-tissue compression.^{5,11,19,37,55,57} This type of bracing is suitable for the majority of humeral shaft fractures and has the benefit of avoiding immobilization of the shoulder and elbow, which can lead to further morbidity including shoulder capsulitis and elbow stiffness.

When fitted properly, the brace should extend medially from 2.5 cm beneath the axilla to 1 cm proximal to the medial epicondyle. On the lateral aspect of the arm, the brace should be placed so that it spans from just below the lateral acromion to a point just above the lateral epicondyle.⁵⁵ Velcro straps that are fashioned around the brace are tightened periodically as the swelling subsides to maintain the constant compressive environment during the reparative process. Adequate placement of the orthosis will provide unhindered range of motion of the shoulder and elbow. Active motion of these joints should begin as soon as tolerated. Use of the brace is typically continued for a period of approximately 8 weeks, at which time it is discontinued with the assumption that, based on clinical and radiographic

examination, adequate fracture healing is confirmed. Bracing may be continued for a longer or shorter duration based on each individual circumstance and the amount of healing evident both clinically and radiographically.

Nonoperative management of humeral shaft fractures results in predictably good outcomes, with acceptable alignment and healing occurring in more than 90% of cases. In the largest clinical analysis to date, Sarmiento et al⁵⁷ reported on 922 patients treated with a functional brace for both closed and open humeral shaft fractures. In total, 67% of patients were available for follow-up, and among these patients, 98% of all closed injuries and 94% of all open fractures healed. Malunion, described as angular deformity greater than 16° in any plane, occurred in a varus position and apex-anterior angulation 13% and 19% of the time, respectively. Only 2% of patients reported loss of shoulder motion exceeding 25° as compared with the uninjured side. Subsequent studies by Zagorski et al,⁷² Sharma et al,⁶¹ and most recently, Rutgers and Ring⁵⁴ have corroborated these findings, with good clinical outcomes reported through functional bracing.

Frequently debated concerns regarding closed management of humeral shaft fractures pertain to the amount of angulation that is acceptable for a good outcome and the proper management of an associated radial nerve injury. With regard to angular deformities, given the mobility afforded by the shoulder and elbow, malunions of the humeral shaft are well tolerated with minimal functional impairment.^{4,5,22,37,40,55,57,61,65} Parameters deemed acceptable for fracture reduction have included up to 30° of varus angulation, 20° of anterior bowing, and up to 15° of internal rotation; beyond these limits, cosmetic deformity and functional impairment may be shown clinically.³⁵ In terms of neurologic sequelae, injury to the radial nerve with neurapraxia is the most frequently encountered nerve deficit associated with humeral fractures and is found in up to 18% of all patients.⁴⁶ Spontaneous recovery over a period of 4 months occurs in 70% to 92% of patients managed with observation; therefore, its presence is not an indication for open management and nerve exploration.^{51,60} Conversely, nerve loss after application of a brace or closed reduction of the fracture is sometimes considered a relative indication for nerve exploration; however, no studies document improvement with such management, and most authors continue to recommend against operative intervention.^{2,8}

Limitations to functional bracing do exist and need to be taken into consideration when determining the appropriate treatment strategy for each patient. Open fractures, specifically Gustilo type III injuries with extensive soft-tissue stripping, are not amenable to bracing because of the wound contamination, soft-tissue deficits, and inherent difficulties with dressing care. These fractures are best managed with immediate stabilization through internal or external fixation means.⁵⁶ The decision to choose an external fixator is based on the severity of the soft-tissue injury and the overall

medical status of the patient.⁵⁸ In the setting of gross contamination with severe soft-tissue loss, external fixation can provide an effective means to stabilize the fracture to prevent further soft-tissue injury and provide a stable environment conducive to soft-tissue healing. Conversely, in situations where the patient is not hemodynamically stable because of severe head or chest trauma, external fixation of the humeral fracture can aid in nursing care when access to the chest or positioning of the arm is vital to proper ventilation and oxygenation of the patient.

Fracture patterns with a high propensity for nonunion are also believed to be best managed by immediate fixation to potentially improve the healing rate. Fractures at particular risk include humeral fractures associated with ipsilateral brachial plexopathies and long oblique fractures with proximal extension. Brien et al,⁹ in an analysis of 21 patients with humeral shaft fractures and ipsilateral brachial plexus injuries, found that nonunion developed in 45% of patients treated nonoperatively. They hypothesized that muscle contractility is an essential component of successful brace treatment and believed that severe neurologic injury is a relative contraindication to conservative management. A high risk of nonunion has also been observed in patients with long oblique fractures with proximal extension. Soft-tissue interposition between the fracture fragments occurs due to buttonholing of the sharp distal fragment through the deltoid muscle belly. Toivanen et al⁶³ and Rutgers and Ring⁵⁴ reported 54% and 29% incidences of nonunion, respectively, for this type of injury and supported close observation and possible early intervention if healing is not observed by 2 months.

Relative indications for surgery also include the cases of “floating elbow” with concomitant fractures of the humerus and both forearm bones, morbidly obese patients whose bracing is uncomfortable or not feasible because of the impediments of the surrounding soft tissues, and cases in which closed management has failed.^{51,56}

Surgical treatment of humeral shaft fractures

Operative management is a viable treatment method in the appropriate setting with the indications previously discussed. The 2 primary methods of definitive operative fixation are intramedullary nailing (IMN) and compression plating. External fixation, as previously noted, does play a role and is increasingly used in the polytrauma patient or combat setting for temporary stabilization; however, its use for definitive management of humeral shaft fractures is limited and not generally advised because of the concern for deep injection.¹⁷

Intramedullary nailing

Implants used for intramedullary fixation of the humerus range from both flexible nails and Kirschner wires to the

current trend of more rigid locking humeral nails. Smaller-diameter implants (Rush pins or Ender nails) are limited in efficacy because of an inability to obtain rotational or axial control leading to numerous complications and the need for additional supplementary fixation.^{12,59,68} Locking nails were then introduced in hopes of better addressing the pitfalls associated with the preliminary devices and remain the standard intramedullary implant used today. IMN is theoretically advantageous to plating from both a biomechanical and surgical perspective. From a biomechanical standpoint, the intramedullary positioning of these devices places them in line with the mechanical axis of the humeral diaphysis, thereby subjecting the implant to lower bending loads. In turn, by being centrally positioned, the nail functions in a “load-sharing” capacity and mitigates the potential effects that stress shielding may play as compared with compression plating.^{18,31} With regard to surgical benefits, the nail is able to be introduced through a smaller incision, which allows a smaller surgical approach and less soft-tissue stripping as compared with plating techniques. Conditions better suited for intramedullary fixation include pathologic and impending pathologic fractures, segmental injuries, and fractures in osteopenic bone. Contraindications to IMN include concomitant neurologic deficit, as well as Gustilo and Anderson grade III open injuries because of the concern for intramedullary contamination.

Modern intramedullary devices can be implanted in either an antegrade or retrograde fashion with the decision based on the location of the fracture and the surgeon’s bias. Antegrade IMN is best suited for proximal- and middle-third fractures; however, its use for distal-third injuries has also been reported. When one is performing an antegrade technique, the anterolateral approach is the most commonly used. An incision is made longitudinally just inferior to the anterolateral corner of the acromion. The deltoid is split with care in line with its fibers to avoid injury to the axillary nerve, which lies 4 to 5 cm distal to the anterolateral acromion. The subdeltoid bursa is excised to visualize the supraspinatus tendon, which is then split atraumatically at its central portion. The nail is then introduced through the medial sulcus of the greater tuberosity to gain intramedullary access (Fig. 2). In contrast, a retrograde technique is useful for management of fractures involving the middle portion of the diaphysis or distal-third of the humeral shaft. This approach is made via a 4- to 5-cm incision overlying the posterior aspect of the distal humerus in line with the olecranon tip. The triceps tendon is split and elevated in a subperiosteal fashion just proximal to the olecranon. The entry portal into the canal is then located 1.5 to 2 cm proximal to the olecranon fossa.

The literature regarding management of humeral shaft fractures with locked humeral nailing has been inconsistent at best and has raised concerns based on the various complications noted. One of the chief issues after both antegrade and retrograde techniques has been the insertion-site morbidity created at the nail entry site. In the previous



Figure 2 Intramedullary nail of a humeral shaft fracture. The starting point for antegrade IMNs is the medial aspect of the greater tuberosity.

literature, the incidence of shoulder dysfunction has been reported to range from 6% to as high as a 100%.^{32,49,50} Much of the problem is believed to be due to either subacromial impingement caused by a prominent nail or scar tissue and/or damage to the rotator cuff in its critical zone of hypovascularity creating chronic tendon tearing. Several authors have described different approaches with improved outcomes with the main lesson learned from these techniques being that avoidance of the avascular zone of the rotator cuff and careful repair of the tendon after nail insertion may attribute better outcomes and less morbidity.^{16,45} In fact, in a recent study by Rommens et al⁵² reported on 92 patients who underwent rigid unreamed humeral nailing, only 2 patients (2.2%) reported shoulder dysfunction. Proponents of the retrograde technique would safely counter that shoulder dysfunction is avoided with this approach but it is not without its own share of complications, including iatrogenic supracondylar fracture, extension loss of the elbow, and heterotopic ossification.^{20,53}

Another commonly reported concern pertains to the rate of nonunion after intramedullary humeral fixation. Nonunion rates have ranged between 0% and 29% in the literature, with many of the higher incidences having been noted in several older studies using first-generation implants such as the Seidel nail. In its early form, the Seidel nail had poor rotational stability,⁷⁰ which likely allowed for fracture motion

and contributed to the relatively high incidence of nonunion, as noted in the study by Reimer, where a 25% nonunion rate was reported.⁴⁹ A recent level II prospective study by Putti et al,⁴⁸ however, comparing modern locked humeral nails with direct compression plating, found no significant difference in union rates or functional outcomes but did note a statistically significantly higher complication rate in the nail group. Interestingly, a meta-analysis originally done in 2006 and updated in April 2010 found no statistical difference between plates and nails in the treatment of humeral shaft fractures; however, with the inclusion of the data of Putti et al, the authors of the meta-analysis offered a reupdate that confirmed a higher risk of complication with nailing based on the current body of literature.^{27,28} The ideal surgical treatment for these fractures continues to be a topic for debate. Although, historically, compression plating has been considered the gold standard for surgical management, further large prospective studies must be performed before a definitive conclusion can be drawn.^{6,27,28,42} Several recent prospective randomized studies have shown that although specific complications may differ, both union rates and functional results are comparable between nailing and plating of humeral shaft fractures (Table I).

Open reduction/internal fixation

Open reduction—internal fixation continues to be the mainstay of operative management for humeral shaft fractures and is the treatment of choice of the senior authors (B.B. and M.M.). Fixation techniques described include standard direct compression plating with or without lag screw fixation (Figs 3 and 4), bridge plating strategies for spanning of comminuted segments, and locking and hybrid locking techniques, which have been increasingly used in the setting of comminution or osteopenic bone. Basic AO/Orthopaedic Trauma Association principles are recommended when pursuing any of these techniques and are paramount to successful fracture healing.

Open reduction—internal fixation of humeral shaft fractures can be performed through a variety of approaches. The selection of a surgical approach by the operating physician is dictated by the his or her experience, the location of the fracture, and the presence of a concomitant radial nerve injury. A detailed description of each approach to the humerus is beyond the scope of this review; however, one may refer to the recent publication by Zlotolow et al⁷⁴ for a better understanding of the relevant anatomy.³¹ Each exposure possesses its own pearls and pitfalls, and a thorough appreciation of these and a general knowledge of the anatomy can aid the surgeon in efficiently achieving optimal fracture management. The anterolateral approach is useful for exposure of fractures involving the proximal and middle thirds of the humeral shaft. The benefits of this approach include its extensile nature and its avoidance of the radial nerve. A posterior approach may be better suited

Table I Prospective comparative studies of IMN versus plate fixation of humeral shaft fractures

| Author | Study design | No. of cases | Fixation method | Union (%) | Mean time to union (wk) | Good to excellent results | Reoperation (%) | Complications (%) | Notes |
|---|--------------|--------------|---------------------------|-----------|---------------------------|---------------------------|-----------------|-------------------|---|
| Chapman et al ¹⁴ (2000) | Prospective | 38 | IMN | 95 | 9.8 | NR | 3 | 13 | 6 patients had shoulder pain and stiffness |
| McCormack et al ³⁹ (2000) | Prospective | 46 | Plate | 93 | 10.4 | NR | 7 | 15 | 6 patients had elbow pain and stiffness |
| Putti et al ⁴⁸ (2009) | Prospective | 13 | IMN | 85 | NR | NR | 46 | 77 | |
| | Prospective | 22 | Plate | 95 | NR | NR | 5 | 13 | |
| | Prospective | 16 | IMN, unreamed, rigid | 100 | NR | NR | 6 | 50 | 3 device related ³ capsulitis ² radial nerve palsy |
| | | 18 | Dynamic compression plate | 94 | NR | NR | 6 | 17 | Implant failureinfectioncapsulitis |
| Singsetti and Ambedkar ⁶² (2010) | Prospective | 25 | IMN | 95 | 50% of cases before 16 wk | 65 | 8 | 8 | 1 infection tx with I+D, 1 nonunion treated exchange nailing |
| | | 20 | Plate | 93.75 | 75% of cases before 16 wk | 94 | 10 | 15 | 1 radial nerve palsy, 1 infection treated with I+D, 1 nonunion treated with bone grafting and plating |

IMN, antegrade intramedullary nailing; NR, not reported.

for fractures extending between the olecranon fossa and distal middle-third of the humerus. This approach also accommodates very distal plating of the humerus along the posterolateral column, where additional fixation into the posterior capitellum is critical for stability of the distal segment (Figs. 5 and 6). The triceps tendon can be either split midline (triceps splitting) or released medially and laterally and mobilized (triceps sparing) to allow visualization of the bone. In both techniques, the radial nerve must be dissected and identified to avoid iatrogenic injury from either cutting it during exposure or plating over it during fracture fixation. Finally, should a vascular injury be present, the anteromedial approach may be of benefit because of the direct access it affords to the neurovascular bundle.

We believe that a triceps-sparing technique provides superior exposure to the posterior humerus, and it is our standard approach for most distal-third shaft fractures (Figs. 6 and 7). The benefits of this approach include its extensile nature should proximal exposure be necessary and its direct access to the radial nerve should a laceration exist at the time of fracture necessitating concomitant nerve repair. The skin incision is made midline. The posterior antebrachial cutaneous nerve is then visualized traversing into the lateral skin flap. It is then traced back proximally to assist in identification of the radial nerve. Once the nerve has been identified, a Penrose drain is placed around it to assist in subsequent mobilization. The triceps musculature is then reflected medially to expose the humeral shaft. In cases that require more cephalad exposure, the triceps is split between the long and lateral heads. It is here that the radial nerve is identified and protected.

Basic AO/Orthopaedic Trauma Association principles should be applied when performing plate fixation of humeral shaft fractures including restoration of anatomic alignment, avoidance of soft-tissue stripping to preserve vascularity to the fracture fragments, and provision of stable rigid fixation to allow for early range of motion and optimal functional recovery. In situations of comminution or in the presence of oblique or spiral patterned fractures, lag screw fixation should be used to both simplify the fracture and maximize inter-fragmentary compression. Plates applied in this setting function as a neutralization device protecting the lag screw from torsional or axial forces. When possible, lag fixation through the plate can provide further added construct stability. We currently use a bone tenaculum for fracture reduction and then perform lag screw fixation, and we have found this to be more effective than provisional K-wire fixation. To minimize damage and splintering of smaller fragments, use of small-fragment or mini-fragment screws may be of additional benefit. In the setting of high-energy trauma and severely comminuted fracture patterns, anatomic reduction may not be feasible, and bridge plating techniques to maintain alignment and provide fracture stability may be more appropriate in these circumstances. Using a longer plate to



Figure 3 Humeral shaft fracture treated with 2 lag screws and compression plate.

obtain a greater working length is recommended when bridging a comminuted segment. Excision of comminuted fracture fragments and subsequent shortening of the humerus through direct compression plating of the proximal and distal segments also comprise a potential treatment option in the face of severe comminution. Concerns regarding the effects of humeral shortening on the biomechanical forces of arm musculature have been studied and should be considered when one uses this technique, understanding that shortening greater than 2 cm may result in significant muscular weakness.³¹

The role of locking or hybrid locking plating techniques for humeral shaft fractures remains a topic of debate. In the setting of normal-quality bone and simple fracture patterns, standard compression plating remains an effective technique for humeral shaft fracture fixation from both a biomechanical and cost perspective. In a recent study comparing locking plates with non-locking plates for a comminuted midshaft fracture model, no biomechanical advantage was noted with regard to torsion, bending, or axial stiffness between the 2 constructs.⁴⁴ Locking screws are also costly, averaging 5 times greater than their non-locking 3.5-mm counterpart (\$134 vs \$27; 2010 Synthes, Inc. [West Chester, PA, USA] pricing). In the face of rising health care costs and with the lack of biomechanical superiority, their use should



Figure 4 Lag screws and compression plating of comminuted humeral shaft fracture.

be minimized or avoided in the setting of good bone stock. In comparison, when faced with poor bone quality, the use of locking plates may be advantageous. In a biomechanical study by Gardner et al²³ in an osteoporotic fracture model, the unlocked screw constructs had significantly lowered stability compared with the locked constructs, as shown by a loss of stiffness under cyclic loading. In the setting of osteoporosis, therefore, locking plates may provide better stability and avoid the inherent risks of fixation failure and nonunion that could occur with standard plates. Interestingly, Gardner et al also found no difference in hybrid constructs (combining locking screws and non-locking screws in the same plate) as compared with all-locked constructs. This finding may help mitigate costs because standard screws that may be used for initial compression of the plate to the bone may be left in place without undue biomechanical consequences and do not have to be replaced by more expensive locking screws in circumstances where locking fixation is deemed necessary.

For most transverse fractures, compression with a broad 4.5-mm dynamic compression plate is recommended to achieve primary bone healing. The broad 4.5-mm plate incorporates staggered screw holes in its design, a feature that helps to prevent splintering of the humerus and propagation of existing fracture lines. The 4.5-mm plate can be used for most humeri of adequate size. However, for smaller patients, a narrow 4.5-mm dynamic compression plate is recommended. Pre-bending of the plate prevents

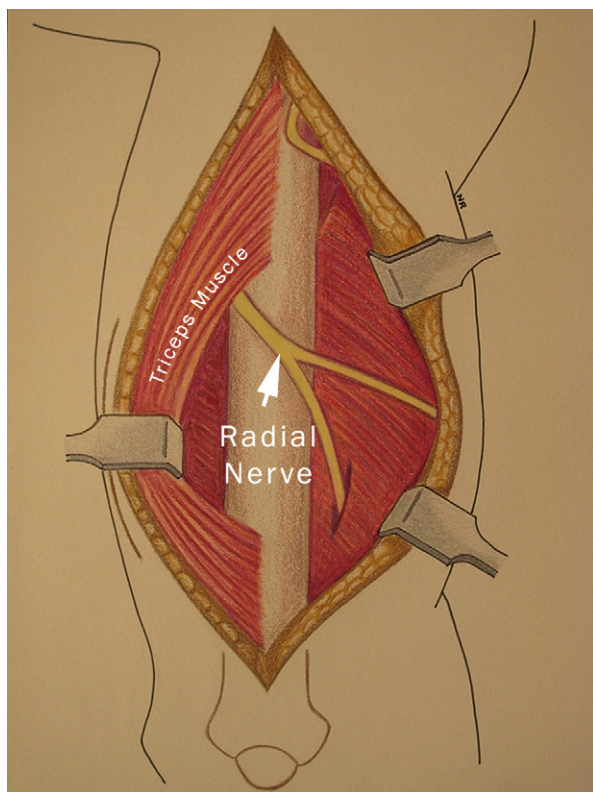


Figure 5 Posterior “triceps-slide approach.” This posterior approach keeps the triceps intact and slides the muscle belly from lateral to medial for plate application. The radial nerve, posterior brachial cutaneous nerve, and axillary nerve are well illustrated.

gapping of the fracture at the opposite cortex. Ideal plate osteosynthesis should include a minimum of 6 cortices’ fixation above and below the fracture, although 8 cortices are preferable. An articulated tensioner or a Verbrugge clamp with a push-pull screw can be used to maximize compression at the fracture site (Fig. 8).

Minimally invasive techniques have been described and used effectively. Zhiquan et al⁷³ prospectively evaluated 13 patients treated with a minimally invasive anterior plating technique with a 4.5-mm dynamic compression plate. Union occurred in all patients, with a mean healing time of 16.2 weeks (range 12-32 weeks), with no incidences of nonunion, implant failure, or radial nerve palsies and excellent results regarding elbow function. Apivatthakakul et al³ anatomically evaluated the feasibility of minimally invasive anterior plating and confirmed that it was clinically safe as long as plating occurred with the arm maximally supinated to avoid injury to the radial nerve. Advantages of this technique include less soft-tissue dissection as compared with open plating and the possibility of earlier return of shoulder and elbow range of motion.³⁶

Open fractures of the humeral shaft should be treated in accordance with general principles of open fracture management including adequate debridement, appropriate preoperative and perioperative antibiotic prophylaxis, and tetanus toxoid and antibody as indicated. Rigid fracture

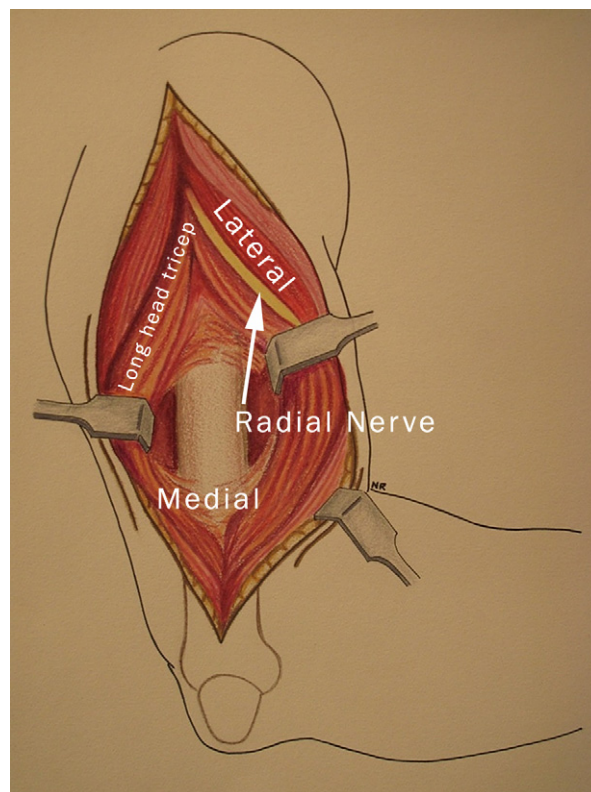


Figure 6 Posterior “triceps-split approach.” This approach splits the triceps muscle belly between the medial and lateral heads, moving the radial nerve laterally and allowing for plate application beneath the nerve.

fixation should be performed as soon as the wound is adequately debrided and the patient is medically stable.^{7,34} Use of temporary external fixation as discussed previously may be advantageous in the setting of severe wound contamination to aid with subsequent surgical debridements and immediate stabilization of the extremity.

Outcomes of plate fixation of humeral shaft fractures are generally very good, with union rates in the 92% to 96% range, time to union averaging around 12 weeks, and complication rates ranging from 5% to 25%.^{15,25,26,42,43,67,69} Complications of the surgical treatment of these fractures are similar to those related to the surgical management of other fractures including infection, nonunion, malunion, neurovascular injury, and the need for additional surgery. Iatrogenic injury to the radial nerve is possible with most approaches to the humeral shaft, so its location should be recognized with all open dissections.

Complications

Nonunion

Even with adequate operative or nonoperative techniques, nonunion develops in a significant percentage of humeral shaft fractures. Nonoperative management can be associated

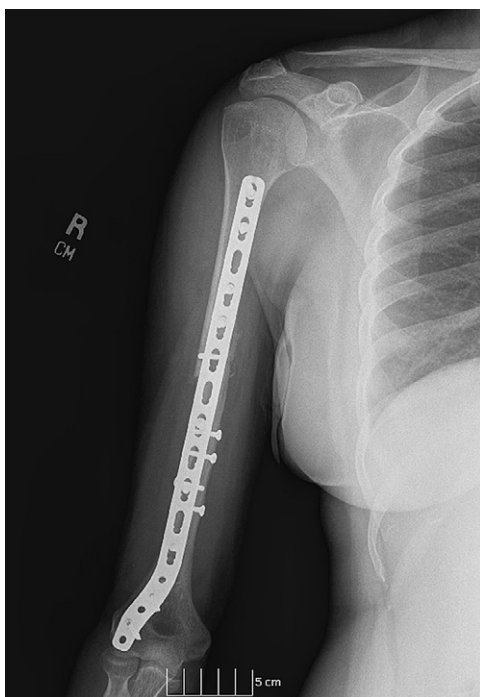


Figure 7 The posterior approach can be extended proximally and distally for long plate application.

with nonunion rates as high as 10% of cases,⁵⁴ whereas operative techniques can result in even higher rates of nonunion, up to 30%.⁶⁶ Thus, it is important to understand the biology and treatment options for humeral shaft nonunions. Nonunions can be problematic, but excellent results can be achieved by appropriate identification of the type of nonunion and adhering to sound treatment principles at the time of operation.

In general, nonunions of fractures fall into 3 distinct categories, and their treatment can be generalized according to the type of nonunion. The most common type of nonunion is the atrophic nonunion, which is essentially a failure of biology at the fracture site. Treatment for this type of nonunion is aimed at enhancing the biologic milieu of the fracture site to make it more hospitable for fracture healing. Strategies include bone grafting and the use of bone morphogenetic protein compounds to enhance healing. In contrast, a hypertrophic nonunion is a problem of mechanical stability, where the bone is trying to heal but the mechanical instability at the fracture site prevents complete osseous union. Treatment goals, therefore, involve enhancing the stability of the fixation construct. The final type of nonunion is the infected nonunion. Treatment of this problem requires debridement of necrotic tissue, treatment of the infection, and establishment of a stable mechanical construct to aid in fracture healing.

For atrophic nonunions, we prefer a technique that was originally described by Wright et al.⁷¹ This procedure uses an intramedullary allograft fibular strut and a compression plate and allows for restoration of medullary blood flow and

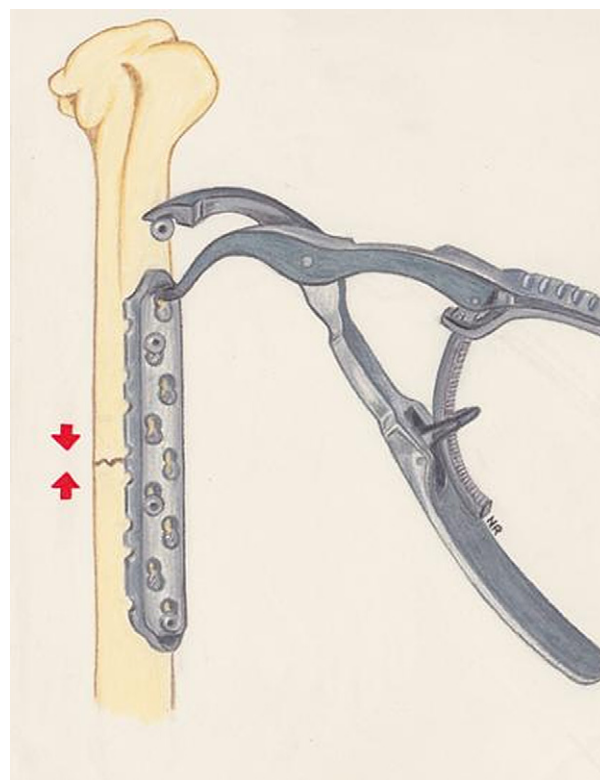


Figure 8 Push-pull screw compression. One technique to increase compression across a fracture is to place a push-pull screw a short distance from the end of the plate; a Verbrugge clamp can be used to pull the plate toward the screw after fixation of the plate to the distal fragment.

reconstruction of the humeral shaft. By use of this technique, Wright et al achieved a 89% union rate at 3.5 months postoperatively. We have used this technique in a consecutive series of 20 patients presenting with an atrophic nonunion of the humeral diaphysis; each patient was treated by compression plating and an intramedullary allograft strut. A union rate of 95% was observed in our series. This treatment failed in 1 patient who had a gunshot wound and multiple previous surgical attempts at fixation and, ultimately, refused further surgical intervention.

Radial nerve injury

Radial nerve injury is a common complication of humeral shaft fractures, occurring in up to 18% of closed injuries.⁴⁶ Most commonly, radial nerve injuries are associated with middle one-third spiral humeral shaft fractures.⁶⁰ Fortunately, recovery can be expected with observation alone in 90% at 4 months after injury.⁴⁶ In the scenario of closed humeral shaft fractures with concomitant radial nerve palsies, surgical exploration is not required. Indications for surgical exploration of the radial nerve include neurologic compromise after closed reduction of a humeral shaft fracture, open fractures with associated radial nerve palsies, radial nerve palsy after a penetrating injury, and spiral or



Figure 9 Holstein-Lewis fracture. This fracture is known for a high incidence of radial nerve palsies.

oblique fracture patterns in the middle to distal one-third of the humeral shaft (ie, Holstein-Lewis fracture) (Fig. 9) with associated radial nerve palsy.⁴⁶ Radial nerve dysfunction after attempts at closed reduction of the associated fracture may represent nerve laceration due to reduction maneuver or nerve interposition between fracture fragments.⁴⁶

Without objective clinical signs of radial nerve recovery 6 weeks after the injury (ie, return of brachioradialis, extensor carpi radialis longus, and brevis muscle function), electromyography (EMG) and nerve conduction studies should be performed to evaluate nerve function. In the presence of muscle action potentials on EMG testing, observation of the radial nerve for recovery should be continued. However, in the presence of denervation where fibrillation potentials will be observed, EMG and nerve conduction studies should be repeated at 12 weeks after the injury. In the absence of recovery at 12 weeks, as indicated by clinical examination and neurophysiologic testing, surgical exploration of the radial nerve is recommended. Should the radial nerve not recover, tendon transfer procedures have shown success for the treatment of radial nerve palsy.¹

Summary

Humeral shaft fractures are common orthopaedic injuries that can often be managed nonoperatively with

high union rates and excellent results as the general outcome. Specific indications exist for operative management and include polytrauma patients, open fractures, certain fracture patterns, and failure to maintain an acceptable closed reduction. Plate fixation of humeral shaft fractures has historically been considered the gold standard of operative management based on a lower complication rate; however, newer intramedullary devices may prove as effective in fracture management pending future prospective analysis. Although radial nerve palsy remains a vexing and common comorbidity of humeral shaft fracture management, recovery can be expected in most circumstances.

Disclaimer

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