Radial Nerve Palsy in the Setting of Humeral Shaft Fracture

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Learning Objectives

Upon completion of this CME activity, the learner will understand:

- The epidemiology and diagnosis of radial nerve injury associated with humeral shaft fractures.
- The treatment options and outcomes for humeral shaft fractures.
- The indications and approaches for radial nerve exploration in the setting of radial nerve palsy associated with humeral shaft fracture.

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The upper limb has a complex anatomy comprised of many nerve and vascular structures, making humeral shaft fractures extremely important. Injury to the humeral shaft commonly occurs due to trauma and affects younger male or older female patients. The radial nerve travels along the spiral groove of the humerus, placing it at an increased risk of damage in humeral shaft fractures. If injured, there are a variety of classifications of radial nerve injury, different indications for exploration, and treatment methods that orthopedic surgeons have

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available in treating these injuries. This review aims to discuss the etiology of humeral shaft fracture—associated radial nerve palsy, tools for diagnosis, and treatment. *(J Hand Surg Am. 2024;49(7):690—697. *Copyright © 2024 by the American Society for Surgery of the Hand. All rights reserved.)*

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THE HUMERUS IS THE LARGEST bone of the upper extremity, articulating proximally with the glenoid and distally with the radius and ulna at the elbow joint.[1] Humeral fractures are generally due to direct trauma to the upper limb, including blunt trauma due to collisions or falls, as well as penetrating injuries such as gunshot wounds. The most common site of fracture is the middle-third of the humerus, with 63.3% of all humeral shaft fractures located at this site (Figs. 1 and 2). Fractures are classified based on their location, open or closed status, and type of fracture.[2] The Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification of humeral diaphyseal fractures is divided into three categories based on the amount of contact between fracture fragments. Type A fractures, or simple fractures with more than 90% contact between fragments, are among the most common fractures, with an incidence of 64.2% among all humeral shaft fractures.[1]

Humeral shaft fractures pose a serious risk to the closely adjacent radial nerve. Given the location and course along the spiral groove of the humerus, the radial nerve is the most frequently injured nerve in the upper limb.[3] The radial nerve is a continuation of the posterior cord of the brachial plexus and contains nerve fibers from C5, C6, C7, C8, and T1 ventral roots. The motor function of the radial nerve includes extension of the elbow, wrist, and fingers. In addition to motor innervation, the radial nerve provides sensation to a portion of the anterolateral arm, dorsal forearm and dorsal thumb, index and middle fingers, and lateral half of the ring finger.[4]

Radial nerve injuries are usually diagnosed through physical examination, although electrodiagnostic and radiological studies can help identify the approximate location of injury or compression.[3]

EPIDEMIOLOGY

Humeral shaft fractures represent 3% of all fractures in the United States, most commonly caused by direct impact trauma.[1] The peak incidence of these fractures occurs in younger men under the age of 35 years, due to high energy trauma.[1,5] A second peak occurs in women between the ages of 60 and 80 years, usually due to low-energy mechanisms, such as a fall from a standing position on an outstretched arm.[1]

MECHANISM OF INJURY

Humeral shaft fractures generally occur secondary to blunt or penetrating trauma. Blunt injuries are most commonly due to high energy falls, motor vehicle/motorcycle accidents, or other direct impact loading to the arm.[5] Penetrating trauma, either by gunshot wounds, open lacerations, or incendiary device injury, is another mechanism causing humeral shaft fractures.[6] The most common cause of bone injury in gunshot wound patients is direct contact of the missile with the bone, with the degree of injury directly related to the amount of energy transferred. Humeral fracture fragments can cause damage to the closely apposed soft tissues, nerves, and arteries, either by stretch or laceration of these structures.

CLINICAL PRESENTATION AND PHYSICAL EXAMINATION

After traumatic injury to the upper arm, patients will present with pain and often visible deformity of the upper arm, with associated swelling and ecchymosis.[5] On examination, motor, sensory, and vascular function distal to the injury should all be documented. If skin tenting is noted, gentle realignment using gravity should be immediately performed.[5] When radial nerve injury is suspected in relation to a humeral shaft injury, it is critical to evaluate strength and function of all muscles innervated by the radial nerve, including triceps, forearm supinator, wrist, and finger extensors.[3,6] Sensory function of the radial nerve can be tested on the dorsum of the hand, particularly at the thumb-index web space and dorsal radial three and a half fingers as well as the dorsal radial arm and forearm.[3] Radiographic imaging of the affected upper arm is the next step in the process of evaluation of

FIGURE 1: Anteroposterior radiograph of displaced fracture at junction of middle and distal thirds of left humeral shaft.

FIGURE 2: Lateral radiograph of left humeral shaft fracture.

humeral shaft fracture in order to identify the exact location of the fracture and type of the fracture.[5] The standard for imaging includes at least two views of the affected arm with an evaluation of the joints above and below the arm to ensure no associated fractures.[5]

If nerve function is compromised following a humeral shaft fracture, options for evaluation include electromyography and nerve conduction studies (EMG) to measure nerve conductivity and muscle response, recommended no earlier than 3 weeks after injury.[3] Measurement of nerve function by EMG is typically delayed to allow time for Wallerian degeneration of axon and myelin substance to occur in order to accurately measure the degree of muscle denervation following an injury.[7] Although these methods are effective in identifying a nerve injury, early EMG cannot accurately distinguish between neuropractic, axonotmetic, or neurotmetic injuries in the early postinjury period; thus, many surgeons follow clinical recovery and defer EMG.

Semmes-Weinstein monofilaments can quantitively measure sensory loss and are particularly useful in evaluating peripheral nerve injuries to measure the response to touch using a numerical quantity.[8] In addition, ultrasound for neuromuscular evaluation has become increasingly popular as a noninvasive imaging modality. Ultrasound can show lesions and measure nerve area and traumatic swelling or injury,[9] making it another useful technique for identifying radial nerve injury in the setting of humeral shaft fracture.

INCIDENCE OF ASSOCIATED NERVE INJURY

Given its anatomic proximity to the shaft of the humerus, the radial nerve is the most likely nerve to be injured in cases of humeral shaft fracture; however, radial nerve palsy occurs in a minority of humeral shaft fractures overall. The overall incidence of radial nerve injury in cases of humeral shaft fractures is between 2% and 17%.[1]

Originally described in 1963,[10] the classic Holstein-Lewis humeral shaft injury consists of a spiral oblique humeral shaft fracture in the distal third of the shaft with the distal fragment displaced and the proximal end deviated toward the lateral side, with associated radial nerve palsy.[8] This fracture type and its association with radial nerve palsy is related to the fracture occurring at the point where the radial nerve passes through the lateral intermuscular septum and lies in direct contact with the bone with limited mobility. Due to the force of the injury, the distal fragment moves proximally and laterally, potentially lacerating, stretching, or entrapping the radial nerve. An epidemiologic study of 361 humeral shaft fractures by Ekholm et al[8] reported that Holstein-Lewis fracture patterns account for 7.5% of all humeral shaft fractures, with associated radial nerve palsy occurring in 22% compared with 7% of all other types of humeral shaft fractures.

TREATMENT OF HUMERAL SHAFT FRACTURES

Nonsurgical treatment

Options for nonsurgical treatment include a coaptation splint, cuff and collar, hanging arm cast, and functional/Sarmiento brace. Bohler first described the coaptation splint in 1935, as a method of dependency traction treatment for humeral shaft fractures.[11] Coaptation splinting involves placing a well-molded plaster slab from the axilla, around the elbow and over the deltoid with the elbow flexed. It is commonly placed in emergency care as the standard immobilization for initial presentation of humeral shaft injuries (Fig. 3). Chambers et al[12] compared outcomes in 55 patients who underwent coaptation splinting versus functional splinting for closed humeral shaft fractures, reporting that the coaptation splinting group had better correction of fracture coronal translation by 0.4 mm compared with the functional splinting group. The authors found no difference in coronal and sagittal translation but noted that they subjectively preferred the functional splinting method, reporting limitations of coaptation splinting, which was burdensome to apply and often poorly tolerated by patients.

Functional bracing of the humerus following fracture immobilizes the fracture between the shoulder and the elbow while still allowing for free motion at both these joints.[13] Sarmiento described the functional brace to immobilize the fracture site with a compressive effect of the brace on the surrounding soft tissue. Realignment of the fracture fragments is achieved via the effect of gravity while allowing mobility to minimize joint stiffness. Sarmiento et al[14] reported on 620 patients treated with functional brace from 1978 to 1990, demonstrating a high rate of union 602/620 (97%) and good outcomes, especially in closed fractures. A total of 7/620 (0.01%) went on to nonunion in brace. Denard et al[15] compared outcomes of surgical treatment versus nonsurgical treatment of humeral shaft fractures treated with functional bracing and reported nonunion in 44/213 (20.6%) of patients, and malunion in 27/213 (12.7%) of the cohort treated nonsurgically with brace. Rämö et al performed a randomized controlled trial to compare surgical fixation versus functional bracing in

FIGURE 3: Radiograph of humeral shaft position after coaptation splint application to fracture.

82 patients with humeral shaft fractures and reported a mean Disabilities of the Arm, Shoulder, and Hand score of 12.0 (95% CI: 7.7−16.4) in the functional bracing group at 12 months compared with DASH of 8.9 in the surgical group.[16] Toivanen et al followed 93 patients who received functional brace treatment for humeral shaft fracture, reporting 72 fractures (77%) had healed fully at six weeks follow-up.[17] Koch et al[18] reported a long-term follow-up of 67 patients with humeral shaft fractures who were treated by Sarmiento functional brace. The authors noted that 58/67 patients (87%) had healed clinically at a mean of 10 weeks, concluding that nonsurgical treatment led to excellent results.

The collar and cuff is an additional nonsurgical immobilization technique, in which patients are positioned with their arm internally rotated and the humeral shaft in line with the humeral head.

In this position, while holding the body upright, traction is generated by gravity, allowing the humeral shaft to realign with the proximal humerus.[19]

Surgical treatment

There are three main surgical techniques to treat humeral shaft fractures: open reduction and internal

FIGURE 4: Radiograph demonstrating plate and screw fixation of left humeral shaft fracture.

fixation (ORIF) using plate fixation, intramedullary nail fixation, and minimally invasive plate osteosynthesis.[20] Open reduction and plate fixation allows for direct visualization and anatomic reduction of the humerus (Fig. 4) but has higher risks to nerve and soft tissue due to operative dissection.[21] Looking specifically at ORIF in the setting of humeral shaft fractures, the anterior approach allows fixation with the patient positioned supine. Zhao et al[22] evaluated various approaches to ORIF of humeral shaft fractures and concluded that anterolateral or posterior approaches lead to concerning soft tissue and local vascularity disruption, which can decrease healing potential and allow for an increased risk of deep infection.

Intramedullary nail fixation involves the insertion of a load-sharing device that has less stress shielding, minimizes tissue disruption, and allows for the preservation of the periosteum.[22] However, the risk of shoulder impingement and rotator cuff complications that accompany this technique must be considered.[23]

Minimally invasive plate osteosynthesis is an alternative surgical technique, as Shetty et al[24] described, with decreased surgical trauma to the soft tissue and maintenance of periosteal circulation to the humerus while using the minimally invasive plate osteosynthesis approach. Heckler et al[25] surveyed three groups of physicians: American Society of Surgery of the Hand, Orthopaedic Trauma Association, and a group of orthopedic surgery residents. When asked about implant of choice for surgical fixation of a closed neurovascularly intact midshaft humeral diaphysis fracture in an adult, plates and screws were the most common choice among all groups, with 373 of 558 total physicians selecting plates and screws. Intramedullary nail was the second choice among all groups, with 144 physicians preferring intramedullary nailing.

Den Hartog et al[21] compared outcomes of treatment in a cohort of 390 patients, with 245 patients treated surgically, and 145 patients placed in functional braces. The majority of surgically treated patients were stabilized with intramedullary nail fixation. Shoulder range of motion values were 33°−56° higher in the surgical group than in the nonsurgical group. The study also reported that the surgical group had a better ability to participate in sports and hobbies at six weeks (4.9 vs 4.0 in the nonsurgical group) and at three months (6.7−5.7 in the nonsurgical group), with both groups reporting similar outcomes at 12 months.[21] The authors concluded that surgical treatment of humeral shaft fractures in adults was safe and was the superior treatment method compared with nonsurgical treatment, due to the 2-fold reduced risk of nonunion and increased range of motion at the shoulder and elbow joints.

Cannada et al[26] compared plate and screw fixation and functional bracing in isolated humeral shaft fractures, using patient-rated outcomes including pain and DASH. This study reported no differences in the DASH score, visual analog score, or elbow range of motion at six months. There was an 11% rate of nonunion in the functional bracing group, and a 2% nonunion and infection rate in the ORIF group.

Treatment of associated radial nerve palsy

Observation: In humeral shaft fractures with radial nerve palsy on presentation, expectant management is generally indicated in cases of closed fracture and low-energy trauma, with the hypothesis that the nerve injury is neuropractic due to a stretch of the radial nerve. The literature supports nonsurgical management of radial nerve palsy because spontaneous recovery in these injuries is reported to occur in over 70% of patients.[1] Ostermann et al[27] theorized that in patients with low-energy trauma, radial nerve palsy is often caused by simple nerve contusion or stretch neurapraxia, with the nerve commonly structurally intact. The authors concluded that for patients with low-energy trauma and advanced age with associated comorbidities, watchful waiting is the more appropriate plan as opposed to surgical exploration.

Studies of outcomes also support initial observation of radial nerve deficits after humeral shaft fractures.[1,28] Heim et al[29] retrospectively reviewed a cohort of 127 patients with radial nerve palsy following humeral shaft fracture and noted functional radial nerve recovery in 111 patients (87.3%). Bumbasirević et al[30] presented 117 cases of patients with humeral shaft fracture and radial nerve palsy, with 101 fractures being managed non-operatively and 16 fractures that underwent external fixation due to poor bony alignment, but no patients underwent initial radial nerve exploration at the fracture site. A total of 111 cases (95%) had initial signs of spontaneous radial nerve recovery at six weeks postinjury, with full radial nerve recovery at a mean of 17 weeks postinjury.

Indications for nerve exploration

Early exploration of the radial nerve in the setting of humeral shaft fracture is indicated in cases of open fracture, vascular injury, high energy trauma, high velocity gunshot wounds or penetrating injury, and radial nerve deficit after attempted closed reduction (secondary radial nerve palsy).[1] Although certain fracture locations/patterns are correlated with a higher risk of radial nerve injury (middle shaft, spiral, and transverse), there are no data to support intervention based on bony characteristics.[31] In the Heckler et al[25] survey, open humeral shaft fracture with radial nerve palsy was recommended for exploration by the majority of respondents.

One of the main advantages of early radial nerve exploration within 7–14 days of trauma is the ability to accurately assess the structural integrity and damage to the nerve, from contusion to full laceration.[32] Surgeons favoring early nerve exploration cite the risk of persistent palsy if not explored early, with accompanying atrophy and motor endplate loss that could compromise full recovery.[33] The disadvantage to early exploration is potential overtreatment with an unnecessary procedure because the nerve spontaneously recovers in 73% to 92% of cases.[34]

Yorukoglu et al[35] supported early exploration of the radial nerve, citing results of 24 patients (17 men and 7 women) with an age range of 18–72 years with primary radial nerve palsy following closed humeral shaft fracture. These patients underwent early radial nerve exploration within an average of 4.8 days after fracture. They observed radial nerve compression in seven patients (29.1%) and one patient with a radial nerve transection. Following early intervention, they reported radial nerve function recovery in 95.8% of patients. Li et al[28] performed a systematic review of 30 studies with non-operative management, early exploration, or late exploration of radial nerve palsy and reported no difference between the expectant observation and early exploration groups in cases of closed humeral shaft fractures.

Radial nerve exploration at 3 months or more after initial radial nerve injury is characterized as late exploration. Proponents of late exploration believe it to be beneficial because it allows adequate time for potential spontaneous nerve recovery. If no recovery is seen, exploration is recommended with suspicion of nerve injury. Late exploration is recommended for patients who have no nerve recovery within 3–5 months of injury. Pollock et al[34] theorized that late exploration allows for the neurilemmal sheath to thicken, which facilitates repair if a neurorrhaphy is needed. DeFranco et al[1] believe that the main disadvantage of delayed surgical intervention is scarring and fibrosis, which makes exploring the nerve more difficult and can lead to worse outcomes. This group reported neurologic recovery varying from 0% to 31% in patients who underwent treatment following late radial nerve exploration.

Ilyas et al[36] conducted a systematic review of 1,423 patients with radial nerve palsy following humeral shaft fracture, reporting that of 836 patients managed with non-operative treatment with radial nerve observation and 645 had spontaneous nerve recovery (77.2%). Of 488 patients who underwent early radial nerve exploration within three weeks of injury, 438 (89.8%) had radial nerve recovery, whereas in 166 patients who underwent late radial nerve exploration at eight or more weeks after injury, 113 (68.1%) had documented radial nerve recovery.

Surgical approaches to humeral shaft in setting of radial nerve palsy

Although evidence is mixed with regard to surgical approach (open vs intramedullary) and risk of secondary radial nerve injury,[37] most authors recommend open reduction and plate fixation of the humeral shaft when concomitant exploration of the radial nerve is performed.[38,39] In a multicenter retrospective study, Claessen et al[39] noted that iatrogenic injury to the radial nerve was highest using the lateral approach, in 20% of patients, and lowest with the anterolateral approach at 1/25 patients. A study of 28 patients with primary radial nerve palsy in association with diaphyseal humeral fractures described the use of the anterolateral technique to expose the radial nerve between the biceps and brachioradialis, and fixation using 4.5 plates.[38] In contrast, Schwab et al[40] described primary radial nerve palsy in 20/151 humeral shaft fractures and explored the radial nerve in nine cases using a posterior approach to the humerus.

CONCLUSIONS

Humeral shaft fracture with concomitant radial nerve palsy is an important injury of which all hand surgeons should be aware. A thorough understanding of radial nerve anatomy in relation to the humeral shaft is necessary for the diagnosis and treatment of these injuries in patients. Humeral shaft fractures with and without accompanying radial nerve palsy can be treated nonsurgically or with surgery. For closed fracture with associated radial nerve palsy at presentation, observation is a reasonable approach, with spontaneous recovery the likely result. Relative indications for radial nerve exploration include delayed recovery following initial non-operative treatment, whereas the absolute indications for radial nerve exploration include open fracture, vascular injury, high energy mechanism of injury, loss of nerve function after fracture manipulation, or iatrogenic (secondary) radial nerve palsy following ORIF of a primary humeral shaft fracture.

CONFLICTS OF INTEREST

No benefits in any form have been received or will be received related directly to this article.

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JOURNAL CME QUESTIONS

Radial Nerve Palsy in the Setting of Humeral Shaft Fracture

1. The Holstein-Lewis fracture occurs in what location?
   a. Proximal third of the humerus
   b. Surgical neck of the humerus
   c. Distal third of the humerus
   d. Supracondylar region
   e. Segmental fracture involving 2/3 of the humerus

2. Which of the following concepts contributes to the working of functional bracing?
   a. Immobilizing the joint below the fracture
   b. Compressive effect on the soft tissues
   c. Three-point mold
   d. Decreasing edema

3. A patient presents with radial nerve palsy and closed humeral shaft fracture. Based on evidence, the radial nerve injury should be treated with which of the following?
   a. Observation
   b. Exploration
   c. EMG at 2 weeks
   d. E-stim for healing

4. Which of the following surgical approaches used to treat the humeral shaft has the lowest risk of injury to the radial nerve?
   a. Posterior
   b. Lateral
   c. Anterolateral
   d. Triceps-on

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