Radial Nerve Injuries

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Radial nerve injuries continue to challenge hand surgeons. The course of the nerve and its intimate relationship to the humerus place it at high risk for injury with humerus fractures. We present a review of radial nerve injuries with emphasis on their etiology, workup, diagnosis, management, and outcomes. *(J Hand Surg Am. 2015;40(1):166–172. Copyright © 2015 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Radial nerve, nerve injury, nerve repair, humeral shaft fractures.

Appropriate management of radial nerve injuries, particularly in the setting of a closed humeral shaft fracture, continues to fuel controversy and challenge upper extremity surgeons. The course of the nerve and its intimate relationship to the humerus results in neurological injury complicating up to 22% of humeral shaft fractures. The nerve is also susceptible to both compressive and blast types of injury. Our current understanding of the etiology, workup, diagnosis, management, and outcomes of radial nerve injuries is reviewed and consolidated in the following pages. The authors' preferred management algorithm is also presented.

REGIONAL ANATOMY

The radial nerve is 1 of 2 terminal branches of the posterior cord of the brachial plexus. It is posterior to the axillary artery at the shoulder, and branches away from the axillary nerve proximal to the quadrangular space before passing through the triangular space. The nerve travels laterally deep to the long head of the triceps muscle and lies between the lateral and the medial heads of the triceps at the spiral groove, The radial nerve innervates the triceps before piercing the lateral intermuscular septum and entering the anterior compartment.

Multiple anatomical studies have attempted to define the precise location of the radial nerve as it descends in the arm. Gerwin et al[1] located the nerve at 20.7 cm proximal to the medial epicondyle and 14.2 cm proximal to the lateral epicondyle. Guse and Ostrum[2] found that the nerve crossed the humeral shaft posteriorly at an average distance of 12.4 cm distal to the posterior edge of the acromion and was never closer than 9.7 cm. The nerve emerged laterally at an average distance of 12.6 cm superior to the lateral epicondyle and was never closer than 10 cm. Zlotolow et al[3] found the radial nerve exiting the spiral groove 10.1 to 14.8 cm proximal to the lateral epicondyle and noted that it was an average of 10 cm, but never less than 7.5 cm, proximal to the distal articular surface when passing into the anterior arm through the lateral intermuscular septum. Fleming et al[4] found the radial nerve entered the anterior compartment within 5 mm of the junction of the middle and distal thirds of a line drawn from the lateral epicondyle to the lateral edge of the acromion in 95% of specimens. However, Bono et al[5] found that the radial nerve pierces the lateral intermuscular septum more proximally than previously described. They found the radial nerve pierces the septum 17.0 cm from the proximal humerus, representing 53% of humeral length, and 16.0 cm from the distal humerus, representing 47% of humeral length. Thus, the nerve may penetrate the septum closer to the midpoint of the humerus than previously thought.

After traversing the lateral intermuscular septum, the radial nerve gives off 1 to 3 accessory branches to the radial half of the brachialis muscle and a larger branch to the brachioradialis proximal to the lateral epicondyle,

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as well as branches to the anconeus and extensor carpi radialis longus (ECRL) muscles. Upon entering the forearm, the nerve divides into the superficial sensory radial nerve (SRN) and the posterior interosseous nerve (PIN). The PIN innervates the extensor carpi radialis brevis before passing beneath the arcade of Frohse, a fibrous arch of the proximal aspect of the supinator muscle[6] and then descending between the 2 heads of the supinator muscle. The PIN finally exits beneath the distal margin of the supinator muscle and divides into 6 subbranches, providing motor innervation to the wrist and digit extensors as well as a terminal sensory branch to the wrist capsule.

RADIAL NERVE INJURY AND HUMERAL SHAFT FRACTURE

This anatomical relationship explains the association between humeral fracture patterns and radial nerve injuries. The Holstein-Lewis fracture was assumed to be associated with radial nerve injury because of the proximity of the nerve to the bone in the distal third of the humerus.[7] This fracture has been found to be associated with a high incidence of neurovascular injuries—up to 22% in some studies.[8,9] However, in this location, the nerve is actually separated from bone by 1 to 5 cm of muscle. Therefore, radial nerve injuries in the distal third of the arm may have more to do with the fracture pattern than the proximity of the nerve to bone.[10,11] The nerve may be endangered by the proximal displacement of the distal fragment and radial displacement of the proximal fragment, and the resultant displacement of the intermuscular septum.[12] Other studies have found a higher incidence of radial nerve injury with middle third humeral fractures, suggesting that here proximity of nerve to bone is a greater risk factor.[11] Carlan et al[13] found the nerve to be at risk along the shaft of the humerus at 2 locations. The first was a 6.3-cm region where the nerve laid directly on the periosteum of the posterior humerus, at a level 17.1 to 10.9 cm proximal to the lateral epicondyle. The second location was a region of the lateral aspect of the distal third of the humerus, between 10.9 cm proximal to the lateral epicondyle and the proximal aspect of the metaphyseal flare. A meta-analysis by Shao et al[14] concluded that there was insufficient evidence to support Holstein and Lewiss original hypothesis[7] and that transverse or spiral fractures, located in the middle or middle-to-distal third of the bone, were actually the most likely to be associated with radial nerve palsy.

Clinical presentation

The hallmark of a radial nerve injury is wrist drop. Flexor tone overpowers the nonfunctional wrist extensors, and the hand is pulled into a flexed position. The wrist may be passively placed into extension, but the patient is unable to hold this posture, and the hand cannot be maintained in a functional position. In addition, extension of the fingers and thumb is lost, robbing the patient of the ability to open the hand prior to initiating grasp, and thereby rendering tasks requiring coordinated manual dexterity extremely difficult. If the lesion is distal to the origin of the PIN, ECRL function will be intact and the wrist will be pulled into radial deviation with attempts at extension.

Surgical approach

Multiple approaches have been described for exploration of the radial nerve, each varying in the amount of exposure provided. Gerwin et al[1] studied alternative exposures to the posterior humerus with respect to the radial nerve. These authors found that the posterior triceps splitting approach exposed 55% of the posterior humeral shaft, up to the radial nerve in the spiral groove. An additional 21% of humeral shaft could be exposed with mobilization of the radial nerve. They described a modified posterior approach, which exposed 94% of the humerus. In this approach, the triceps muscle is retracted medially to expose the lateral brachial cutaneous branch on the posterior aspect of the lateral intermuscular septum. This nerve is traced superiorly to the radial nerve, proximal to its piercing of the intermuscular septum. The septum is divided and the radial nerve can then be mobilized. The medial and lateral heads of the triceps are next elevated in a subperiosteal fashion and the radial nerve can be exposed with this approach from the distal humerus to the level of the axillary nerve (Fig. 1).

The posterior incision can be continued past the olecranon if more distal exposure is required. Skin flaps are elevated and the radial nerve can be localized in the interval between the brachialis and the brachioradialis muscles. The radial nerve divides into SRN and PIN upon entering the forearm. More distally, the nerve lies in the interval between the extensor carpi radialis brevis and the pronator teres muscles. The SRN can be traced distally on the undersurface of the brachioradialis, whereas the PIN dives beneath the supinator muscle. In order to follow the PIN distally, intramuscular dissection of the supinator muscle belly is necessary.

The lateral antebrachial cutaneous nerve can be identified exiting the interval between the biceps and the brachialis. It must not be mistaken for the radial nerve and should be protected. It may be used as a donor for nerve grafting.

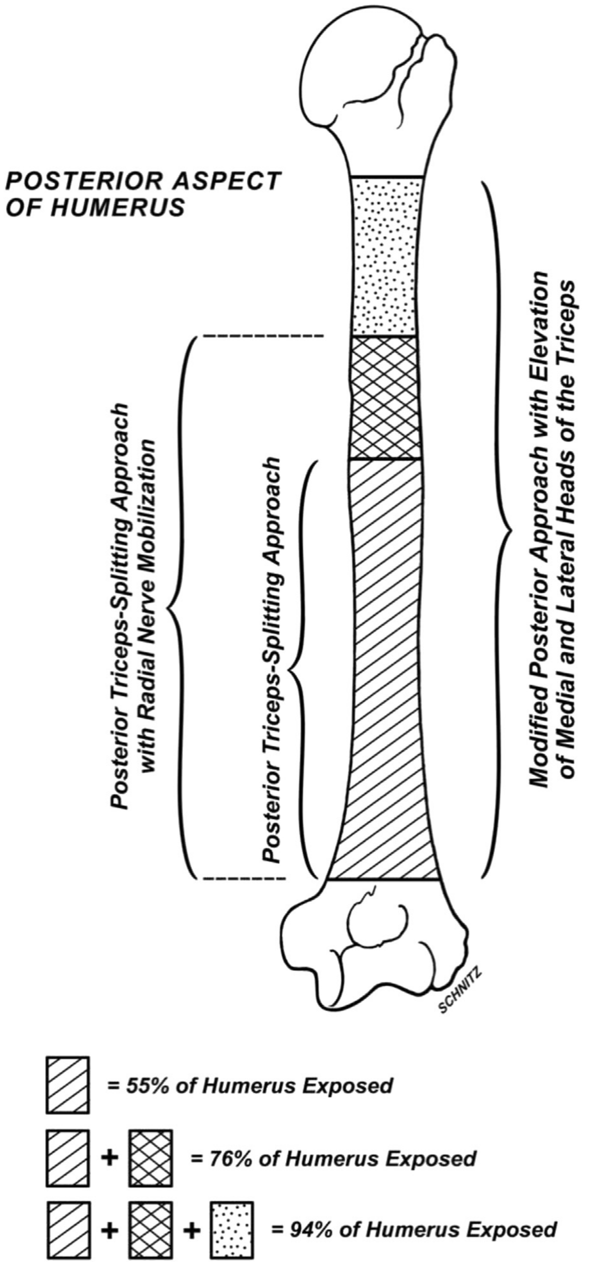

FIGURE 1: A comparison of the extents of exposure provided by variations of the posterior approach to the humerus. (Reprinted with permission from DeFranco MJ, Lawton JN. Radial nerve injuries associated with humerus fractures. *J Hand Surg Am.* 2006;31[4]:655−663. Copyright © 2006 Elsevier, Inc.)

Management

Controversy continues regarding the appropriate timing of surgical exploration of radial nerve injury associated with a closed humerus fracture. These injuries, which usually represent neurapraxia or axonotmesis, have a high rate of spontaneous resolution, reportedly between 60% and 92%.[11,15−17] Many researchers have concluded that observation of these injuries is appropriate.[10,11,15] However, some advocate early operative exploration, citing as benefits the technically easier repair and superior outcomes compared with delayed nerve repair. Reports on late exploration after closed humeral shaft injuries have found the nerve to be entrapped in bone in 6% to 25% of cases or lacerated in up to 20% to 42%.[9,15,18−21] Some view this as an unacceptably high risk of expectant management and endorse early surgical exploration.[22]

Radial nerve exploration after a humerus fracture is indicated for open fractures, high-velocity gunshot wounds or penetrating injury, and vascular injuries. Some advocate exploration for a nerve deficit that develops after closed reduction (secondary radial neuropathy) and in Holstein-Lewis fractures, although the latter is somewhat controversial.[23,24] Shao et al[14] found in a review of published series that the rate of spontaneous nerve recovery after secondary radial neuropathy was similar to that of primary radial neuropathy. Shah and Jebson[25] concluded that, although the literature is limited, it supports expectant management of secondary radial neuropathy. Bishop and Ring[26] added ipsilateral forearm fracture, or “floating elbow,” to this list, stating that radial nerve exploration would be favored here and advantage should be taken of the surgical opportunity presented by the fracture management. Radial nerve injury associated with an open humeral shaft fracture is a high-energy injury and the zone of injury is extensive, with crush and stretching components.[27] Given these factors, primary neurorrhaphy is not recommended. Such injuries should be managed with resection of the damaged portion of the nerve and nerve grafting of the resultant deficit, performed as a secondary procedure, after fracture fixation and thorough wound debridement.[25]

If observation is chosen, many consider 4 to 6 months to be an appropriate length of time for expectant management, based on the accepted nerve regeneration rate of 1 mm/day. An electrodiagnostic study may be performed at 2 to 3 months if no recovery has been observed, although some authors consider it as early as 7 weeks.[12,28] Ultrasound can be used to trace the radial nerve through the zone of injury and may show nerve entrapment.[29,30] A migrating Tinel sign may also be helpful for monitoring progress. The brachioradialis and radial wrist extensors are the first muscles to be reinnervated, typically within 3 to 4 months after a radial nerve injury. Spontaneous recovery is unlikely if there is no evidence of improvement by 7 months.

Failure to demonstrate signs of nerve recovery by clinical or electrodiagnostic assessments by 6 months warrants surgical exploration of the radial nerve. Intraoperative measurement of action potentials can be

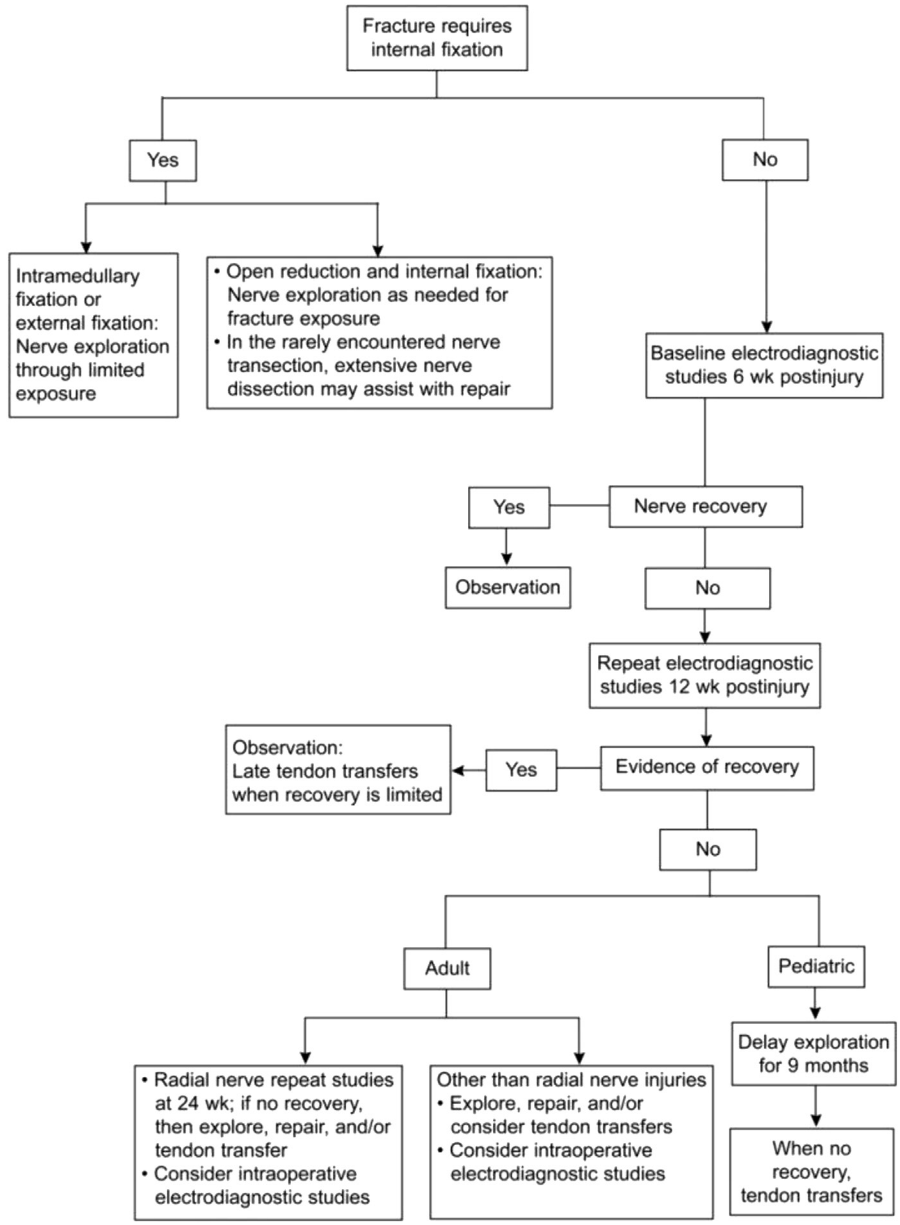

FIGURE 2: Algorithm for management of radial nerve palsy in humerus fracture. (Reprinted with permission from Mohler LR, Hanel DP. Closed fractures complicated by peripheral nerve injury. *J Am Acad Orthop Surg*. 2006;14[1]:32–37. Copyright © Wolters Kluwer Health.)

performed if the nerve is found to be in continuity. This information can aid the surgeon in choosing among leaving the neuroma in situ, resecting the lesion and grafting the resultant defect, and/or proceeding with tendon transfers.[31] Tendon transfers for restoration of hand and wrist extension is beyond the scope of this review. Nerve transfers are advocated by some as a reconstructive technique that avoids some of the disadvantages associated with tendon transfers, and satisfactory results have been reported for restoration of radial nerve function with this approach.[32–34] A summarized algorithm of our preferred treatment for both adult and pediatric patients is presented in Figure 2:

Surgical technique: The patient is positioned supine with the arm on a standard radiolucent hand table. General anesthesia with complete paralysis is used to obtain maximal muscle relaxation.

Primary epineurial neurorrhaphy can be performed with loupe or microscopic magnification using 8-0 nylon suture and standard microsurgical technique for end-to-end repair. Group fascicular repair is not performed. Use of a surgical microscope is preferred and has been shown to result in more precise repairs than

Current Concepts

neurorrhaphy in a cadaveric model.[35] If the lesion is distal enough, a sterile tourniquet may be used. For radial nerve injuries associated with humeral shaft fractures, fracture stabilization should be done first, followed by vascular repair if necessary, with nerve repair done last.[12]

Proper joint positioning is important because the nerve repair must be tension free. The injured nerve must be trimmed back to healthy fascicles. Nerve grafting is necessary if the resultant gap is too large to allow for a tension-free repair. It is important to consider this possibility before surgery to allow for discussion with the patient, informed consent, and appropriate preparation of donor sites.

If direct end-to-end repair is only possible with the elbow flexed, consideration should be given to primary nerve grafting. Alternatively, primary repair can be done with the elbow in flexion and this position maintained for 3 weeks after surgery, at which time the elbow is extended 30°/week until full extension is obtained.

POSTOPERATIVE REHABILITATION

A cock-up wrist splint is used as long as a wrist drop persists to prevent development of a wrist flexion contracture. The splint may be removed during therapy to allow for wrist range of motion exercises. Dynamic splinting is another option, especially for highly motivated and engaged patients. Use of the wrist splint is discontinued only after active wrist extension has been regained. The development of a permanent 15° elbow flexion contracture is not uncommon, but this risk can be minimized by avoiding excessive flexion of the elbow during nerve repair and postoperative immobilization.

Tips and pearls

For proximal radial nerve injuries associated with humeral shaft fractures, anterior radial nerve transposition through the fracture site may be useful. In fractures at high risk for nonunion, this may protect the nerve from iatrogenic injury at the time of subsequent operations on the humerus.[36] This technique has been shown in preliminary studies to be safe and effective. The radial nerve is particularly difficult to mobilize adequately to allow for tension-free primary nerve repair. Anterior transposition can increase the functional length of the radial nerve by 11 mm, thereby increasing the potential of performing a tension-free primary neurorrhaphy.[37,38]

Management outcomes

Whereas the radial nerve is the most frequently injured nerve in combat injuries, among civilians it is much less commonly injured than the median or ulnar nerve.[39] McAllister et al[40] reported on 813 patients with 1,111 peripheral nerve injuries in the upper limb. Of these injuries, 62.5% involved common or proper digital nerves; 19.0% involved the median nerve, 15.9% involved the ulnar nerve, and 2.1% involved the radial nerve. Early reports of radial nerve repair were optimistic. Zachary[41] reported the results of 113 direct suture repairs of radial nerve injuries performed within 6 months of injury, with good to fair results obtained in over 60% of their cases. Seddon[42] reported on his series of 63 radial nerve sutures and similarly obtained over 75% good to fair results. Kline and Hudson,[43] in their series of 171 radial nerve repairs, reported better outcomes in lacerated nerves than for nerves injured in fractures or gunshot wounds. They also obtained better results with primary repair and had their worst results with nerve grafting.

Shergill et al[44] published the results of 260 radial nerve and PIN repairs. Overall, there were few PIN injuries in their series but results for PIN repairs were superior to those for radial nerve repairs. Radial nerve repairs were graded as good in 30% and fair in 28%, but 42% of repairs were considered failures. The main determinant of outcome was the severity of the initial injury. Open, tidy injuries resulted in 79% good results compared with 36% good results for cases with associated arterial injuries. Failures were the norm when nerve trunk defects exceeded 10 cm. Finally, early repairs performed within 14 days of injury achieved good results in 49% compared with only 28% in the later repairs. All repairs performed after 1 year failed. Ring et al,[27] in a study on radial nerve palsies associated with high-energy humeral shaft fractures, found that transection of the nerve was usually associated with open fractures. In this setting, the results of primary radial nerve repair were poor owing to the broad zone of injury and the frequent need for nerve grafting.

Roganovic and Pavlicevic[45] reported on the differential recovery potential of peripheral nerve graft repairs. A homogeneous group of 393 patients ranging between 21 and 30 years of age who had undergone repair by sural nerve grafting was presented. The grafts were less than 4 cm in length, time from injury to surgery ranged from 1 to 3.5 months, there were no associated complete nerve injuries, and conditions in the area of the repair were favorable. The distribution of injuries was as follows: 48 median, 84 ulnar, 74 radial, 69 tibial, 96 peroneal, 14 musculocutaneous, and 8 femoral. The mean postoperative follow-up period was 5.8 years, with a minimum of 4.2 years. Treatment outcome was determined by degree of sensorimotor recovery. For proximal repairs, motor recovery was significantly better for the radial nerve than for the ulnar nerve (66.7% vs 15.4%, respectively). For intermediate repairs, the musculocutaneous and radial nerves displayed significantly better motor recovery than the median and ulnar nerves (100% and 98.3% vs 52% and 43.6%). Finally, for distal repairs, motor recovery potential was similar for all (88.9%–100%) but the peroneal nerve, where recovery was poor (56.3%).

The senior author's (C.A.) personal experience with proximal radial nerve injuries reflects that of the literature. Radial nerve repair, in part owing to the primarily motor composition of the nerve and relatively proximal sites of innervation, has displayed better recovery potential than other proximal nerve lesions. Although primary repair is not always possible because of segmental injury due to crush or other mechanical disruptions of the nerve, the results of primary repair are superior to repairs requiring nerve grafting. We recommend primary nerve repair when possible, without tension, in a well-vascularized bed of soft tissue. Complex cases of radial nerve injury that do not meet these criteria should be treated by early secondary repair 2 to 3 weeks after injury. If secondary repair is elected, the 2 nerve ends can be loosely sutured together at the time of primary evaluation to prevent retraction. If a tension-free secondary repair cannot be easily achieved, nerve grafting should be performed.

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