



Median and Ulnar Nerve Injury at the Elbow and Wrist

8

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8.1 Ulnar Nerve Injury at the Elbow

8.1.1 Risks/Incidence/Mechanism of Injury

Entrapment of the ulnar nerve is the second most common compressive neuropathy behind carpal tunnel and can happen along any length of the nerve but is most common in the cubital tunnel [27]. Subsequently, cubital tunnel release is a common orthopedic procedure. The goal of the procedure is to relieve compression on the ulnar nerve, thus relieving patients' ulnar neuropathy; however, there is a risk of recurrent compression or iatrogenic injury to the ulnar nerve. Seventeen percent of traumatic nerve injuries occur secondary to iatrogenic damage [34]. Injury is due to direct or indirect mechanisms and can occur due from both intrinsic and extrinsic etiologies. Intraoperatively, the ulnar nerve may be injured from complete or partial dissection. Intrinsic

pathology due to fracture fragments, fracture malunion, or excess callus formation can cause ulnar compression within the cubital tunnel [27]. Extrinsic injury may occur from iatrogenic compression from placement of surgical retractors, implants, positioning or even prolonged upper arm tourniquet use [49, 69].

In addition to injury during cubital tunnel release, the ulnar nerve is at risk from trauma. Approximately 2% of all adult fractures involve the elbow [3] in a bimodal distribution with peak incidences between 12 and 19 years and in those over 80 years of age [51]. As the humeral shaft approaches the distal humerus, it bifurcates into the medial and lateral columns. Mouchet first described ulnar nerve palsies from distal humerus fractures in 1914 [48]. When evaluating patients with periarticular fractures, it is important to perform a thorough neurovascular exam and document any preexisting nerve injuries. Traumatic ulnar nerve injuries occur equally at the arm and elbow, less commonly in the forearm and wrist [42]. Iatrogenic ulnar nerve injury following surgical fixation of periarticular elbow fractures results from surgical manipulation of the ulnar nerve, inadequate release, and postoperative immobilization resulting in fibrosis. For all medial and posterior approaches to the elbow, the ulnar nerve should be identified and tagged to prevent iatrogenic injury.

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8.1.1.1 Pertinent Anatomy

The ulnar nerve arises from the C8 and T1 nerve roots and the medial cord of the brachial plexus. It travels with the brachial artery at the level of the upper arm until the insertion of coracobrachialis where it separates and travels posteriorly with the ulnar collateral artery within the anterior compartment. It then pierces the medial intermuscular septum, traveling from the anterior compartment to the posterior compartment. It travels under the arcade of Struthers, lying on top of the medial head of the triceps. At the level of the elbow, the ulnar nerve lies posterior to the medial epicondyle between the olecranon and the medial epicondyle within the cubital tunnel. The floor of the cubital tunnel is formed by the medial collateral ligament and elbow joint capsule and the roof is formed by the arcuate ligament. Distal to the cubital tunnel, the ulnar nerve then travels between the two heads of FCU and lies between FCU and FDS as it moves distally into the anterior compartment of the forearm.

There are several sites of compression of the ulnar nerve at the elbow including the medial intramuscular septum, the arcuate ligament at the cubital tunnel, and the two heads of FCU. Less commonly nerve compression can happen due to rare anatomic variants: proximally at the arcade of Struthers or distally due to an anomalous anconeus epitrochlearis [38, 58].

8.1.2 Prevention Strategies

In a systematic review, 75% of patient who underwent cubital tunnel release reported some residual symptoms [26]. Persistent symptoms after cubital tunnel release are typically due to scarring, incomplete decompression, missed diagnosis, iatrogenic injury, or ulnar nerve instability at the elbow [52, 54]. Adequate proximal and distal dissection can help surgeons ensure sufficient release. The nerve should be followed proximally, and the point where the nerve crosses from the anterior to the posterior compartment should be identified. Typically, there is a band of fascia at the septum that needs to be released and less commonly found, the arcade of Struthers

[58]. To ensure adequate exposure, place the tourniquet high when positioning and prepping the patient so this proximal dissection can be performed. Distally, the nerve should be followed into the muscle of FCU to ensure complete release of the FCU fascia encasing the nerve. Additionally, if the patient has an anconeus epitrochlearis, a myotomy is necessary to ensure complete decompression of the nerve [47].

There is not a consensus on whether a transposition should be performed at the time of primary cubital tunnel release. The authors prefer to transpose when there is documented instability of the ulnar nerve preoperatively or intraoperatively. If there is documented electrodiagnostic denervation of the intrinsic muscles, then we would also recommend transposition.

During primary cubital tunnel release, the surgeon must take care as the median antebrachial cutaneous nerve often crosses the surgical field [36]. The medial antebrachial cutaneous nerve originates from the medial cord of the brachial plexus. Transection of the MABCN during cubital tunnel release can result in a painful neuroma that can be misdiagnosed as recurrent disease and may ultimately require neuroma excision [55]. Typically, the MABCN is deeper than expected and lies along the triceps fascia and crosses the surgical field at or below the medial epicondyle [24, 36].

Several techniques can be employed to help prevent iatrogenic ulnar nerve injury during the approach to and fixation of distal humerus fractures. When identifying the nerve, it is important to adequately liberate the nerve proximally and distally. This will prevent unnecessary traction and compression on the nerve during retraction. Additionally, this will help prevent postoperative compression within the cubital tunnel from local tissue swelling related to the trauma and surgery. We have found that securing a penrose drain with a suture as opposed to a hemostat around the nerve to be a superior method of retraction to avoid unnecessary traction on the ulnar nerve from surgeons, first assists and scrub techs.

There is not a clear consensus on whether or not the ulnar nerve should be transposed at the conclusion of the procedure. The soft tissue

damage associated with distal humerus fractures is severe and postoperative scar formation around the ulnar nerve can be expected. Some argue that the soft tissue dissection required for a transposition at the end of the procedure is substantially more than that required for the primary procedure [19]. Wiggers has demonstrated that the incidence of ulnar neuropathy after surgical treatment of the distal humerus is independent of transposition [70], whereas Wang transposed 20 patients at the time of open reduction and internal fixation and had no incidence of postoperative neurapraxia [68]. Conversely, Chen demonstrated in a retrospective study that patients who underwent anterior transposition were four times more likely to have ulnar nerve symptoms postoperatively [20]. Unfortunately, there is no level 1 evidence for or against transposition. We prefer anterior transposition of the ulnar nerve into the subcutaneous tissues at the conclusion of the procedure.

8.1.2.1 Typical Course/Natural History

Without intervention, about half of ulnar neuropathies due to compressive pathology resolve without intervention [45]. There has not been much clinical research on the long-term outcomes of severe ulnar nerve injuries. Most patients with early compressive disease have intermittent numbness and paresthesias in the ring and small fingers that is worse at night; however, as the disease progresses this becomes more constant. Patients with closed untreated ulnar nerve injuries risk losing hand intrinsic function [71]. Patients will often complain of clumsiness and loss of dexterity. It is important for the clinician to obtain a complete history as to not miss concurrent cervical myelopathy.

8.1.2.2 Initial Evaluation/Exam

Many patients with cubital tunnel syndrome will have tenderness to palpation over the ulnar nerve at the medial elbow. This point of tenderness may be at the level of the cubital tunnel or distally as the nerve travels underneath the FCU fascia. Additionally, special attention should be paid to whether the nerve is hypermobile or subluxating over the medial epicondyle.

Patients with ulnar nerve injuries will have numbness and/or paresthesias within the ulnar half of the ring and the entire small finger. The distribution of numbness and paresthesias can differentiate between high and low ulnar nerve injuries. The dorsal cutaneous branch of the ulnar nerve, which branches from the common ulnar nerve proximal to Guyon's canal, supplies the sensation to the dorsal ulnar half of the hand. Patients with high ulnar nerve pathology will have numbness over the dorsum of their hand as well as in their ring and small fingers; as opposed to patients with low ulnar nerve pathology who will retain the sensation to the dorsum of their hand.

Hand weakness is also a typical presentation as the ulnar nerve innervates the hand intrinsics. Patients with high ulnar nerve injuries are unable to fire flexor carpi ulnaris and flexor digitorum profundus of the ring and small finger in addition to intrinsic muscle paralysis. This results in a claw deformity as well as weakness with pinch and grip. The motor exam in patients with ulnar nerve injuries should test the function of FDP to the ring and small fingers as well as to the palmar and dorsal interossei and the two most ulnar lumbricals.

Below are some specific exam techniques that can be used to isolate ulnar nerve function.

- Froment's sign – thumb IP hyperflexion with pinch
- Jeanne's sign – thumb MCP hyperextension and abduction with pinch
- Wartenberg's sign – small finger abduction with finger extension

When testing intrinsic muscle function, the examiner must be aware of potential anatomic variations in which the interossei or lumbricals are innervated by the median nerve. For example, 7% of the population have an anomaly known as the Martin–Gruber communication, in which the anterior interosseus nerve communicates with the ulnar nerve in the proximal forearm, thus providing a dual innervation to flexor digitorum profundus and the intrinsics [28, 43]. There is also an

analogous connection in the hand known as the Riche–Cannieu interconnection, which is a connection between the recurrent branch of the median nerve and the ulnar nerve that allows the median nerve to innervate all the lumbricals [27].

One must differentiate ulnar nerve palsies from brachial plexus and cervical spine pathology. Spurling’s test for cervical nerve compression and Allen’s test for thoracic outlet syndrome can help in differentiating between these pathologies. Sensory assessment in the distributions of the medial antebrachial cutaneous nerve and medial brachial cutaneous nerve are also useful in localizing the lesion.

8.1.3 Diagnostic Tests/Imaging

Several diagnostic tests can be useful when diagnosing ulnar nerve injury. We recommend obtaining plain radiographs of the elbow to identify any posttraumatic deformity or soft tissue calcifications that may be causing compression and symptoms.

EMG can be helpful in diagnosis as it can help delineate the location of nerve pathology [71]. EMG is limited with severe axonal injury and in acute injury. It also does not take into account anatomic variants [71]. It is also important to note that EMG is highly operator-dependent, and results vary from patient to patient due to comorbidities or age [62]. They can be very helpful if the surgeon is trending an exam as they can document nerve recovery or worsening neuropathy [62].

Ultrasound may provide a benefit over MRI or CT. In addition to being relatively easy to perform and cheap, it can show the topography of the nerve as well as changes in the muscles due to denervation [12]. CT or MRI may be helpful to identify soft tissue or bony variants as possible areas of compression.

8.1.4 Surgical Techniques

8.1.4.1 Revision Cubital Tunnel

In patients who have failed cubital tunnel release, a revision cubital tunnel release may be required. Several options are available for revision surgery

including neurolysis, transposition, and nerve wrapping with biologic materials such as fat, vein, or implants like collagen or porcine submucosal nerve wraps. Please refer to Example 8.1 for intraoperative photographs of a revision carpal tunnel with external neurolysis.

Historically, the most popular revision technique is submuscular transposition in which the nerve is fully released and placed in the plane below the flexor pronator mass [67]. Unfortunately, this technique requires the release of the flexor pronator mass from the medial epicondyle and requires 2–3 weeks of postop immobilization. As expected, the success rate of revision cubital tunnel release and submuscular transposition is less than that of patients undergoing primary cubital tunnel release [67]. It remains a useful surgical technique; however, it has not been shown to be superior to simpler techniques such as a subcutaneous transposition. In a systematic review, a combined analysis of all revision cubital tunnel release techniques had a 78% success rate, with a 71% success rate with submuscular transposition [60].

More recently, many surgeons opt to use nerve wraps in revision cubital tunnel surgery. Unfortunately, there is not an abundance of literature on the use of nerve wrapping in the treatment of nerve compression; however, the safety of nerve wraps in patients with neuropathy secondary to scarring has been shown [30]. Several biomaterials are available for nerve wraps: collagen, porcine extracellular matrix, and amniotic membranes. The authors prefer semi-transparent products because this allows visualization of the underlying nerve. In a review of 15 patients who underwent revision cubital tunnel surgery with collagen wrapping of the ulnar nerve, 83% reported improvement of symptoms [60]. In another review of 12 patients treated with porcine extracellular nerve wrapping at the time of revision cubital tunnel release, patients had significant decrease in preoperative pain levels as well as improved grip and pinch strength [46]. We have found several techniques that are useful when using nerve wraps to minimize complications. It is important to not “overwrap” the nerve thus causing a potential site of compression. Furthermore, it is helpful to release the tourni-

quet and obtain hemostasis before applying and securing the nerve wrap. Lastly, the surgeon should be cautious of placing the wrap directly subcutaneously, as it can cause a foreign body reaction; we prefer to avoid the use of wraps where this may occur.

Example 8.1 Revision cubital tunnel with external neurolysis (Figs. 8.1, 8.2, and 8.3).

When performing revision cubital tunnel surgery, the authors prefer to perform a neurolysis, anterior transposition, and the use of a pedicled adipose flap, as seen in Example 8.2. Rosenwasser initially described this technique in 2014. In this procedure, a well-vascularized adipose flap is created and the nerve is subsequently wrapped creating a similar environment to that of periph-

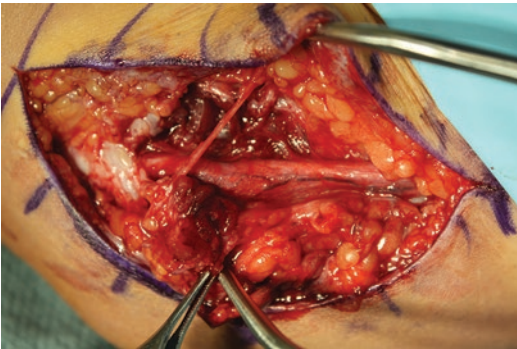


Fig. 8.1 Intraoperative photograph of scar around an ulnar nerve following cubital tunnel release with subcutaneous transposition

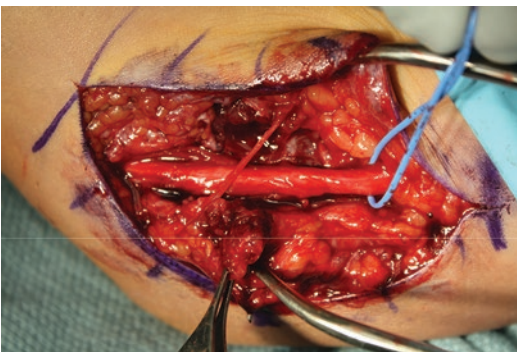


Fig. 8.2 External neurolysis is performed so that the ulnar nerve can be mobilized

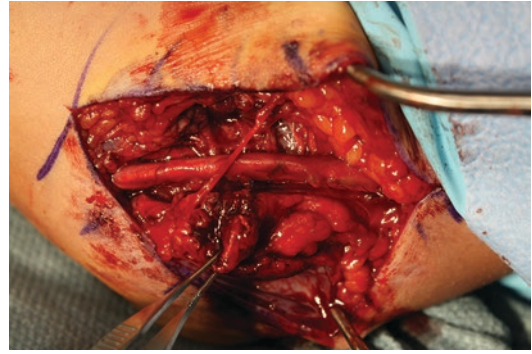


Fig. 8.3 The nerve is transposed anteriorly with a fascial sling to prevent future subluxation

eral nerves. This technique reduces postoperative perineural scarring [25].

Technique

- The ulnar nerve is exposed and decompressed using a classic cubital tunnel approach.
- In revisions, neurolysis is performed; the ulnar nerve is freed from any scar tissue and mobilized.
- A vascularized adipose flap is then created from the anterior subcutaneous tissue overlying the nerve.
- A central cutaneous artery from the brachial artery is identified supplying the flap. Care must be taken to maintain this vascular supply to the flap.
- The fat is then elevated using sharp dissection from the subcutaneous tissue while visualizing the vascular pedicle.
- The ulnar nerve is transposed anteriorly and completely wrapped by the pedicle in a posterior to superior fashion.
- The pedicle is sutured to the subcutaneous tissue, thus completely encompassing the ulnar nerve.
- Once wrapping is complete, the elbow is taken through normal range of motion to ensure nerve gliding through the adipose tissue.

Example 8.2 Vascularized adipose flap (Figs. 8.4, 8.5, 8.6, 8.7, 8.8, and 8.9).

The surgical approach to ulnar nerve neuropathy following surgical fixation of the distal

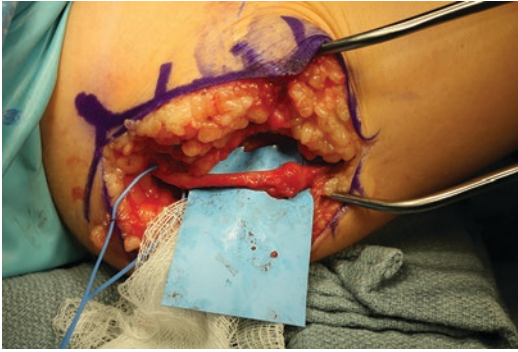


Fig. 8.4 Intraoperative photo of an ulnar nerve neuroma following a missed ulnar nerve injury



Fig. 8.7 A central cutaneous artery from the brachial artery is identified supplying the flap. The fat is then elevated using sharp dissection from the subcutaneous tissue while visualizing the vascular pedicle

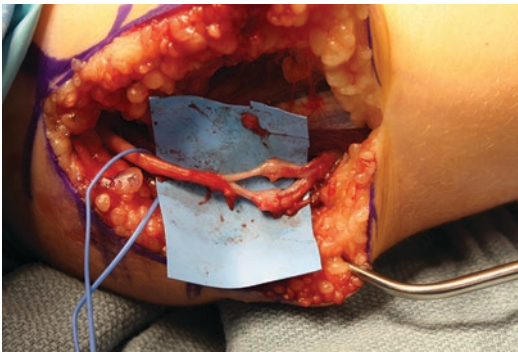


Fig. 8.5 Internal neurolysis is performed after the completion of external neurolysis



Fig. 8.8 The ulnar nerve is transposed anteriorly and completely wrapped by the pedicle in a posterior to superior fashion



Fig. 8.6 A vascularized adipose flap is then created from the anterior subcutaneous tissue overlying the nerve



Fig. 8.9 The pedicle is sutured to the subcutaneous tissue, thus completely encompassing the ulnar nerve

humerus is similar to that of revision cubital tunnel. If patients present with postoperative ulnar neuropathy, ulnar nerve neurolysis has good reported outcomes. In 20 patients with ulnar neuropathy following the surgical treatment of elbow fractures treated with ulnar neurolysis and transposition, 17 patients reported good-to-excellent improvement in function and symptoms [39].

8.1.4.2 Nerve Transfer Techniques

The anterior interosseous nerve can be transferred to the ulnar nerve transfer to preserve the motor endplates to the distal muscles innervated by the ulnar nerve. In this procedure, detailed in Example 8.3, the terminal branch of AIN to pronator quadratus is transferred in a reverse end-to-side manner to an ulnar nerve motor branch in the forearm [8]. In a retrospective study, 85% of patients who underwent the reverse end-to-side AIN to ulnar nerve transfer had improvement of hand intrinsic function [7].

Technique

- An incision is made that extends from ulnar to the thenar crease to about 8–12 cm proximal above the ulnocarpal joint.
- Distally, the palmar carpal ligament is identified and Guyon's canal is released.
 - This allows for better visualization of the deep motor branches of the ulnar nerve, which is ulnar to the hook of the hamate and deep to the hypothenar muscles.
- Proximally, the dorsal sensory branch of the ulnar nerve arises from the ulnar nerve proper approximately 8 cm above the ulnocarpal joint and is identified.
 - The topography of the nerve fascicles is consistent at this level such that from ulnar to radial, the fascicles are arranged as sensory–motor–sensory.
 - The most ulnar sensory fascicles make up the dorsal sensory branch, which have divided from the ulnar nerve proper.

- The most ulnar fascicles within the ulnar nerve proper are the motor fascicles to the intrinsic muscles.
- At the most proximal aspect of the incision, the flexor muscles are retracted radially and the pronator quadratus (PQ) is identified.
- AIN is found entering the PQ. The muscle is divided to trace the AIN distally to divide the nerve with as much length as possible.
- AIN is then divided distally and then transposed toward the ulnar nerve.
- Flexor digitorum profundus can be released proximally to prevent tension on AIN.
- Under the microscope, the motor fascicular bundle of the ulnar nerve is identified through an epineural window and separated from its neighboring sensory bundles.
- Once the motor fascicle has been identified, a tension-free coaptation is performed in an end-to-side fashion with 9.0 nylon epineural suture. We have found that a large (~5 mm) epineural window is necessary to properly perform the end-to-side transfer.
- The wrist should be taken through full pass ROM to ensure that the repair is tension free.

Example 8.3 AIN to ulnar nerve transfer (Figs. 8.10, 8.11, 8.12, 8.13, 8.14, 8.15, 8.16, 8.17, and 8.18).

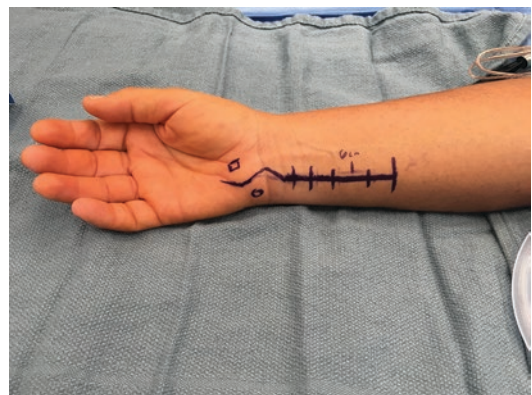


Fig. 8.10 A Brunner-type incision across the wrist just ulnar to the thenar crease that extends 8–10 cm above the ulnocarpal joint

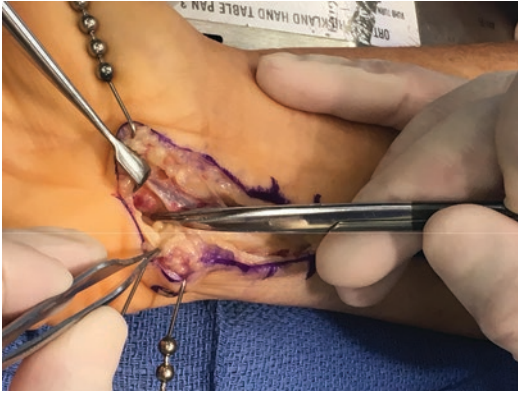


Fig. 8.11 The palmar carpal ligament is identified and Guyon's canal is released

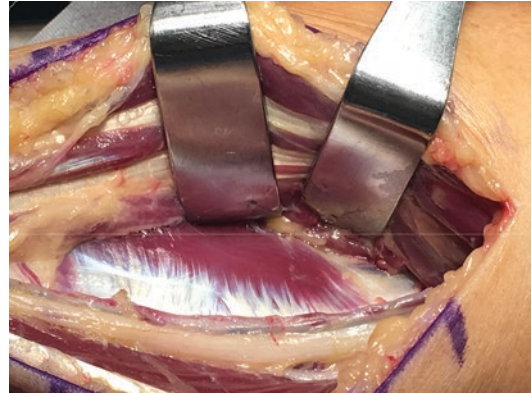


Fig. 8.14 At the most proximal aspect of the incision, the flexor muscles are retracted radially and the pronator quadratus (PQ) is identified

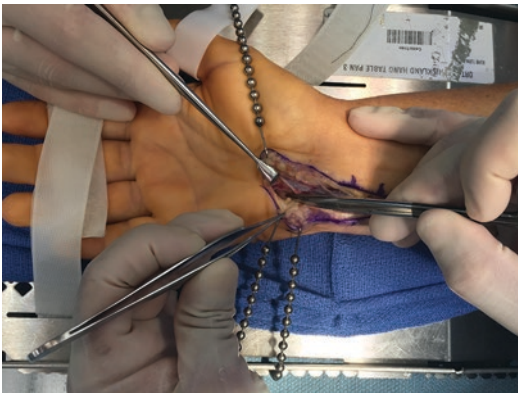


Fig. 8.12 The deep motor branches of the ulnar nerve is identified ulnar to the hook of the hamate and deep to the hypothenar muscles. These fascicles can be followed proximally to better visualize the branch of the dorsal sensory nerve fascicles from ulnar nerve proper

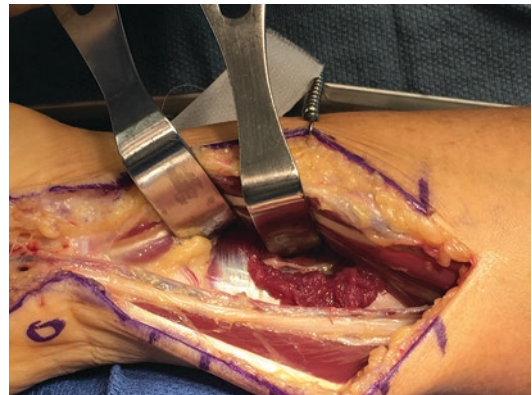


Fig. 8.15 AIN is found entering the PQ. The muscle is divided to trace the AIN distally to divide the nerve with as much length as possible



Fig. 8.13 The dorsal sensory branch of the ulnar nerve branches at about 6–10 cm proximal to the ulnocarpal joint

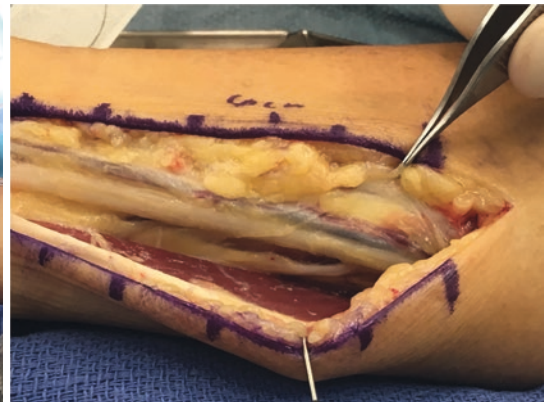




Fig. 8.16 AIN is then divided distally and then transposed toward the ulnar nerve

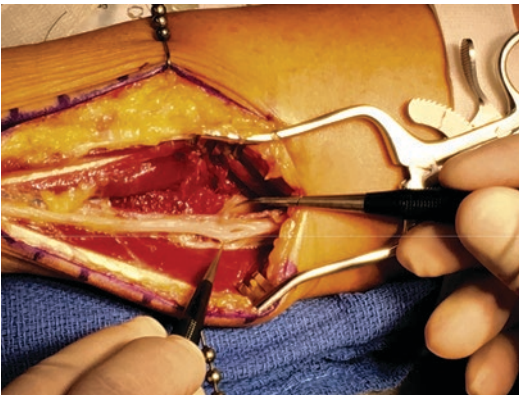


Fig. 8.17 Under the microscope, the motor fascicular bundle of the ulnar nerve is identified through an epineurial window and separated from its neighboring sensory bundles



Fig. 8.18 A tension-free coaptation is performed in an end-to-side fashion with 9.0 nylon epineurial suture

8.1.5 Salvage Techniques

8.1.5.1 Tendon Transfer Techniques

Clawing deformity in ulnar nerve injury is due to loss of intrinsic muscle function. Without the intrinsic function, unopposed extensor digitorum communis function causes hyperextension at the MCP joint. The claw deformity in the ring and small finger results from reciprocal flexion at the PIP and DIP. Thus, to correct the claw deformity, several tendon transfers can be performed to prevent MCP hyperextension.

The most common tendon transfers used to correct the clawing deformity are the Zancolli lasso or the modified Stiles–Bunnell transfer. When deciding between these two procedures, one must evaluate the integrity of the PIP central slip. This can be determined by the Bouvier maneuver. With claw deformity, patients are unable to actively extend the PIP joint when the MCP is hyperextended. Patients with a positive Bouvier's maneuver are able to actively extend PIP with MCP extension blocked, indicating that the central slip remains competent [10].

The Zancolli lasso uses flexor digitorum superficialis (FDS) of the affected finger to restore MCP flexion. It is indicated when patients have a positive Bouvier maneuver or central slip compensation [10]. In a retrospective study by Hastings and McCollum, 19 out of 23 digits treated with the Zancolli lasso reported successful correction of the claw deformity at their 5-year follow-up [29]. The procedure originally described by Zancolli recommends using FDS to each individual finger [72]. Alternatively, Anderson suggests using the middle finger FDS tendon and splitting it into four to symmetrically control MCP flexion of all fingers [2]. The procedure corrects clawing by setting the hand in an intrinsic plus position. Unfortunately, this technique can create an iatrogenic swan neck deformity from PIP hyperextension from the loss of FDS influence on PIP flexion. Transecting the FDS tendon proximal to the bifurcation helps to prevent this [10].

Technique

- A zigzag Bruner's incision is made midpalm and the tendon sheath between the A1 and A2 pulleys is identified and incised.
- The FDS tendon is then transected about 2 cm proximal to its bifurcation, pulled from the tendon sheath and out of the A1 pulley.
- Using 3-0 suture, the tendon is then repaired to itself superficial to the A1 pulley.
- The tendon repair should be performed with the wrist in neutral and the MCP in about 50° of flexion.

The Stiles–Bunnell transfer technique is used when the patient does not have a compensatory central slip, that is, they are unable to actively extend PIP during both MCP hyperextension and when the MCP joints are blocked [10]. In this procedure, the FDS tendon of the long finger is used to create MCP flexion and IP extension [16]. Excessive tension during insertion can result in PIP hyperextension and a swan neck deformity [57].

Technique

- Similar to the Zancolli procedure, a midpalm incision is made to retrieve the FDS tendon and the FDS tendon is transected just proximal to its bifurcation between the A1 and A2 pulleys.
- The tendon is then split longitudinally and retracted from the tendon sheath proximally.
- Two radial incisions are made over the proximal phalanx of the ring and small fingers to expose the radial lateral bands of each finger.
- The ends of the tendon are then tunneled through the lumbrical canal which places the tendon graft palmar to the MCP axis of rotation.
- The tendon grafts are inserted into the lateral bands of the small and ring fingers with the wrist in neutral, the MCP joints in about 60° of flexion, and the PIP joints in full extension.

To restore thumb adduction and power pinch the extensor carpi radialis brevis (ECRB) is commonly used [57]. Patients with impaired power

pinch who underwent an ECRB adductorplasty had a two-fold increase in pinch force postoperatively [59].

Technique

- A dorsal incision is made in the fourth web space and the ECRB tendon is detached from its insertion at the fourth metacarpal base.
- The tendon is retracted proximally beneath the extensor retinaculum. It is routed dorsal to palmar between the second and third metacarpals to allow the third metacarpal to act as a pulley.
- A small incision is made over the thumb MCP joint to expose the adductor pollicis insertion and the graft is secured to the insertion. A free tendon graft can be used to obtain the appropriate length and tension.

The use of brachioradialis tendon extended with a tendon graft has also been described to restore thumb adduction and power pinch. After the transfer is complete, there should be strong thumb adduction with the wrist in neutral and moderate tension on the brachioradialis tendon.

Technique

- An incision is made between FCR and the radial artery and the brachioradialis tendon is freed from overlying fascia. The tendon can be extended with a tendon graft, typically a palmaris longus graft.
- Three additional incisions are made over the radial thumb MCP joint, the palmar third web space, and dorsal third web space.
- A tendon graft from a slip of abductor pollicis longus is then sewn into abductor pollicis brevis.
- This graft is passed palmar to adductor pollicis. This can be visualized using the palmar incision. It is then passed dorsally through the third web space.
- The brachioradialis tendon graft is then passed into the dorsal incision.
- The two grafts are sewn together with the wrist in neutral and the thumb fully extended. There should be no tension on the graft.

8.1.6 Outcomes

Postoperative outcomes of primary cubital tunnel release are related to pre-operative disease severity. Overall, the primary cubital tunnel release has about a 90% success rate for mild cases. However, the total relief rate decreases for more severe cases [24]. The success following revision cubital tunnel is less reliable. Nonetheless, revision cubital tunnel with neurolysis and nerve wrapping has been shown to be effective in reducing pre-operative pain and improvement in grip strength [46]. Outcomes following nerve transfer for ulnar nerve injuries are variable. Following supercharge end-to-end procedures, intrinsic function is more likely to return following nerve transection and less reliably returns following compression injuries [7]. In the setting of ulnar nerve injuries, tendon transfers that restore thumb adduction typically restore pinch strength to about 50% of normal [10]. Tendon transfers that improve intrinsic function like the Zancolli lasso and Stiles-Bunnell transfer tend to maintain excellent correction of claw deformities [72]. Additionally, ERCB transfer offers improved grip strength [59].

8.2 Wrist

8.2.1 Carpal Tunnel Release

8.2.1.1 Risks/Incidence/Mechanism of Injury

Carpal tunnel is one of the most frequently performed orthopedic procedures likely due to the increase in ambulatory surgery centers and the use of local anesthesia. Iatrogenic median nerve injury secondary to carpal tunnel release occurs in about 0.06% of cases. A large retrospective review from 2014 on iatrogenic nerve injuries found that the median nerve was the most commonly iatrogenically damaged nerve, and the majority of iatrogenic median nerve injuries occur during carpal tunnel surgery [4, 49]. Whether or not the operative surgeon is trained in hand surgery is one of the most significant factors contributing to median nerve injury during carpal tunnel release [6].

In primary carpal tunnel surgery, there remains a choice between open versus endoscopic carpal tunnel release. Open carpal tunnel release remains the gold standard for carpal tunnel surgery; however, as minimally invasive surgery gains popularity, endoscopic release is gaining popularity. In open release, the transverse carpal tunnel ligament is visualized and transected to release compression within the carpal tunnel. In endoscopic release, a single incision and portal is made to transect the retinaculum. The outcomes of endoscopic release are encouraging with some authors reporting a 93% success rate [41]. In a randomized control trial, Kang et al. found that patients prefer endoscopic over mini-open carpal tunnel release, mainly because of scar formation and pain with the open technique [31]. However, the risk of nerve injury is higher in patients undergoing endoscopic CTR when compared to open CTR [13]. With lack of complete visualization, patients may experience a devastating transection of the median nerve during ECTR [40]. As seen in Example 8.4, median nerve repair after injury following ECTR can involve an extensive incision, a large nerve gap, and subsequent nerve grafting. Early reports of the outcome of ECTR reported frequent major neurovascular injury; however, more recent studies suggest that these findings may have been due to surgeon inexperience with endoscopic surgery, rather than the endoscopic technique itself [65]. Although more recent studies have suggested similar patient outcomes and relief of symptoms with open and endoscopic techniques, the authors prefer open carpal release as we believe good visualization reduces the possibility of median nerve injury.

Example 8.4 Median nerve injury after endoscopic CTR (Figs. 8.19, 8.20, and 8.21).

The median nerve is also at risk during the treatment of distal radius fractures or as a result of the initial trauma. In a survey conducted in 2001, radius fractures accounted for 44% of all emergency room visits for hand and wrist fractures [21]. In a prospective study, traumatic median nerve injury occurred primarily in the

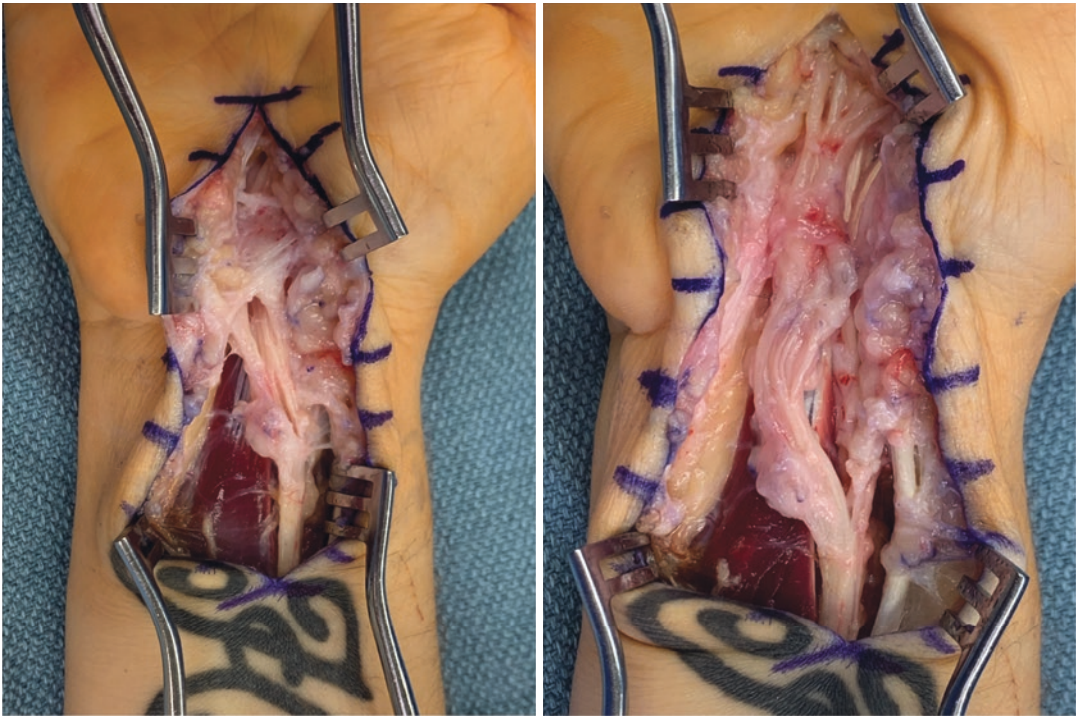


Fig. 8.19 Intraoperative photograph of an exploration of median nerve injury following endoscopic carpal tunnel release



Fig. 8.20 A 5.5-cm nerve gap (left) following the resection of an injured median nerve (right) following endoscopic carpal tunnel release



Fig. 8.21 Successful median nerve repair following grafting with nerve allograft

forearm and in the wrist [42]. Complication rates from volar locking plating of a distal radius fracture have been reported from 3% to 36% [64]. Carpal tunnel syndrome is the most common nerve-related complication from operative fixation of distal radius fractures. The rate of carpal tunnel syndrome from use of volar locking plate fixation of distal radius fractures has been reported from 2% to 8% [1, 64], although similar rates have been described for nonoperative treatment of distal radius fractures [1]. Carpal tunnel syndrome following distal radius fractures is thought to be a product of the nerve damage from the fracture, surrounding soft tissue fibrosis or scarring following healing from the trauma, or from prominent callus from fracture healing. The approach to carpal tunnel syndrome after distal radius fracture is similar to that of revision carpal tunnel release.

Median nerve injury following distal radius fracture can also result from the surgical approach itself. Common approaches for volar locking

plating of a distal radius fracture include the classic volar Henry approach through the interval between the flexor carpi radialis and radial artery or modified Henry approach through the FCR tendon sheath. The median nerve is located deep and ulnar to the FCR tendon. Surgeons must be cautious of identifying and protecting the nerve during this approach to avoid iatrogenic compression or transection.

8.2.1.2 Pertinent Anatomy

The carpal tunnel is a canal that is enclosed by the carpal bones and the transverse carpal ligament through which the median nerve, the eight tendons from the flexor digitorum superficialis and flexor digitorum profundus, and the tendon of flexor pollicis longus traverse. The median nerve typically is found just deep to the transverse carpal ligament and slightly radially from the center. The median nerve is the most superficial structure within the carpal tunnel. As such, injury to the median nerve may occur during incision of the transverse carpal ligament resulting in a mixed sensory and motor median nerve palsy.

The recurrent branch of the median nerve is a motor branch of the median nerve that innervates abductor pollicis brevis, opponens pollicis, and the superficial head of the flexor pollicis brevis. Its branch point varies, putting it at risk during CTR. The most common take off described is a radial-volar subligamentous take off; however, Lanz has described ulnar, transligamentous and extraligamentous take offs [56]. The thenar branch may be injured by surgical dissection distal to the carpal tunnel or if it is encountered beneath the transverse carpal ligament. This results in a purely motor nerve palsy and paralysis of the thenar muscles.

8.2.1.3 Prevention Strategies

Careful attention to anatomy and methodical surgical technique is of utmost importance during primary carpal tunnel release to prevent injury to the median nerve. The incision should be made in line with the radial border of the index finger. To avoid damage to the palmar cutaneous branch of the median nerve, the incision should not extend

proximally past the proximal border of the transverse carpal ligament. Similarly, the distal incision should not pass the Kaplan's cardinal line to protect the third digital nerve as well as the superficial palmar arch.

8.2.1.4 Typical Course/Natural History

The early stages of compressive damage to the median nerve may be reversible with proper treatment, however the late stages may not be [50]. Patients with long-standing median nerve injuries or severe median nerve compression will have thenar weakness and visible atrophy of the thenar muscles. Additionally, patients have constant, as opposed to intermittent, numbness in the thumb, index, and radial half of the long finger. Interestingly, patients with long-standing low median nerve injury or compression will have more neuropathic pain than their counterparts with earlier staged disease [73].

8.2.1.5 Initial Evaluation/Exam

Injury to the median nerve at the level of the wrist will result in a low median nerve palsy. Patients will have both motor and sensory symptoms. If the nerve injury is secondary to a compressive etiology, patients will complain of pain and paresthesias over the palmar-radial aspect of the hand [62]. On motor exam, the examiner will find that the patient will be unable to abduct and oppose the thumb secondary to loss of innervation of the thenar muscles [35]. In low median nerve injuries, the ability to fire flexor pollicis longus and flexor digitorum profundus to the index finger may be preserved because the anterior interosseous branch of the median nerve branches proximal to the wrist.

8.2.1.6 Diagnostic Tests/Imaging

As with ulnar nerve pathology, a variety of testing can be used to diagnosis median nerve pathology and palsies. Plain radiographs should be taken to evaluate for any posttraumatic deformity causing compression, soft tissue calcifications, tumor, or Keinbock's disease [62]. Carpal tunnel view is rarely helpful. EMG can be helpful in determining the level of median nerve injury or compression. In low median nerve injuries,

patients will have denervation of their thenar muscles [62]. Whereas, in high median nerve injuries there will also be denervation of proximal forearm muscles such as flexor carpi radialis, flexor digitorum to the index finger, and flexor pollicis longus [62]. As mentioned previously in the discussion about ulnar nerve injuries, ultrasound, CT, and MRI can be performed to help delineate soft tissue abnormalities or variations that may be causing nerve compression or injury.

8.2.1.7 Surgical Techniques Revision Carpal Tunnel

Many patients feel immediate relief after carpal tunnel release. However, failure of primary CTR has been reported in 7–25%, with reports of 5–12% requiring revision surgery [32]. Persistent carpal tunnel syndrome refers to the recurrence of preoperative symptoms after carpal tunnel release [73]. Treatment failure may be due to incomplete release, recurrent compression, or incorrect diagnosis. Incomplete release is the most common need for revision surgery. As opposed to patients with primary CTS, patients with recurrent or persistent carpal tunnel syndrome following CTR tend to present with neurogenic pain as opposed to numbness [73]. Recurrent compression occurs more frequently in patients with comorbidities such as diabetes and hypertension [44].

Strickland described a technique in which the median nerve is protected in a vascularized hypothenar fat pad [61]. The fat pad receives its blood supply from a branch of the ulnar artery within Guyon's canal. The hypothenar fat pad is dissected from the subcutaneous tissue and the ulnar nerve and artery are identified proximally near Guyon's canal. The canal is released and the flap is mobilized radially while maintaining the ulnar arterial supply to cover the median nerve. This provides the nerve with a protected, enriched trophic environment. Patients who underwent revision carpal tunnel release with a hypothenar fat flap have been shown to have reported improvement in nighttime paresthesias, neuropathic pain, as well as grip strength [5, 61].

As with revision cubital tunnel release, nerve wrapping has been described with revision carpal tunnel. In a review of ten patients who underwent

revision carpal tunnel with nerve wrapping, at 3-year follow-up, all patients had improvement of clinical symptoms, improved two-point discrimination, and median nerve conduction tests [33].

Excision and nerve grafting is indicated in when there is clear median nerve injury, the nerve is injured in multiple areas or the nerve is damaged beyond repair. We recommend a combination of neurolysis and nerve grafting in clinical situations where there is partial injury and a demarcated zone of injury.

Example 8.5 Revision carpal tunnel (Figs. 8.22 and 8.23).

8.2.1.8 Salvage Techniques

To restore thumb opposition, several tendon transfers can be performed. Most commonly used

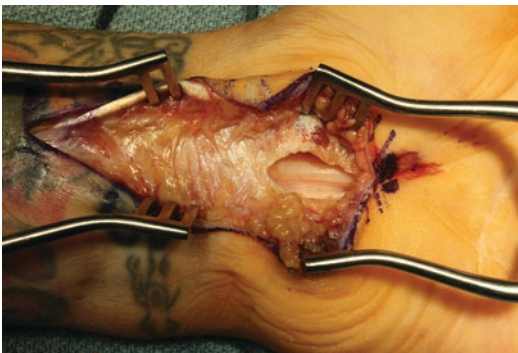


Fig. 8.22 Intraoperative photograph of an incompletely released carpal tunnel

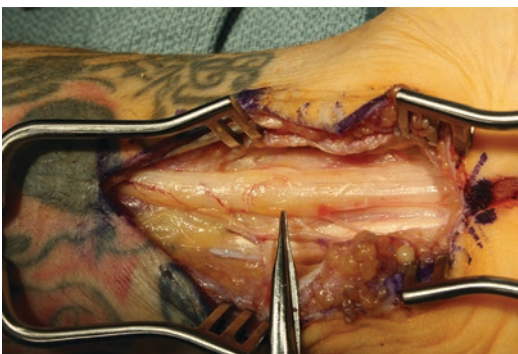


Fig. 8.23 After external neurolysis is performed, the median nerve is found to have the classic “hourglass” sign

techniques are the Burkhalter, Royle-Thompson, or Camitz.

Burkhalter first described the transfer of extensor indicis proprius to abductor pollicis brevis to restore thumb opposition [17]. The EIP tendon is passed along this same route and then attached to the APB insertion. Anderson et al. reported that 87% of patients treated with this technique had a good or excellent result [2].

Technique

- A longitudinal incision is made over the dorsal index finger MCP joint.
- EIP is identified palmar and ulnar to the extensor digitorum communis tendon and divided on the proximal edge of the extensor hood. If necessary, the tendon can be elongated by taking a slip of the extensor mechanism. The extensor hood should be repaired with braided suture.
- A second incision is made on the ulnar aspect of the dorsal wrist just proximal to the ulnar styloid. When making this incision it is important to keep in mind where the dorsal sensory branch of the ulnar nerve crosses the wrist.
- The EIP is identified in the 4th extensor compartment. The extensor retinaculum over the 4th compartment is released and the tendon is mobilized through the dorsal incision.
- Two additional incisions are made on the radial side of pisiform and on the radial border of the thumb MCP joint.
- Using blunt dissection, a subcutaneous tunnel is made from the dorsal wrist incision to the pisiform incision and then to the thumb MCP incision.
- The tendon graft is passed through this tunnel and repaired to the APB insertion.

Royle-Thompson refers to the transfer of FDS of the ring finger to APB insertion with the use of a Bunnell pulley to redirect the vector of pull [15]. Cooney et al. showed a 40% restoration of thenar strength following this transfer in a biomechanical study [22].

Technique

- A transverse palmar skin incision is made over the A1 pulley of the ring finger. The A1 pulley

is identified and incised longitudinally as in a trigger finger release.

- The FDS and FDP tendons to the ring finger are identified and separated. Traction is applied to the FDS tendon and then it is transected transversely proximal to the bifurcation. During this step, the surgeon must protect the FDP tendon.
- A second incision is made along the volar ulnar forearm over the flexor carpi ulnaris (FCU) insertion on the pisiform. Through this incision, FCU, FDS to the ring finger, and the ulnar neurovascular bundle are identified.
- While protecting the neurovascular bundle, the radial half of FCU is transversely divided just proximal to the insertion on the pisiform. The radial half of FCU is separated from the ulnar half of FCU.
- The radial tendon graft is looped through the ulnar half of FCU and secured near the pisiform to create a pulley.
- The ring finger FDS graft is then retracted through the volar incision and passed through the pulley.
- A third incision over the radial thumb MCP joint is made and the FDS graft is passed subcutaneously to this incision.
- One slip of the graft is secured to the distal radial aspect of the APB tendon and the other slip is attached to the extensor hood.

Camitz initially described the transfer of palmaris longis to APB in 1929 [18]. Today it is typically reserved for patients with long-standing carpal tunnel syndrome [57]. Terrono et al. showed that 94% of patients underwent the Camitz procedure with regard to improvement of thumb dexterity [63]. Patients must have a palmaris longus to properly perform the procedure.

Technique

- A longitudinal incision is made from the wrist crease and extended distally to the proximal palmar crease.
- The palmaris longus tendon is identified and harvested. The length can be extended by also harvesting the palmar fascia.

- A second incision is made over the dorsum of the thumb MCP joint and the harvested tendon is passed subcutaneously from the palmar incision to the thumb incision.
- The palmaris longus tendon is then attached to the insertion of APB. The restoration of thumb abduction results from the vector of pull of the PL [14].

8.2.1.9 Outcomes

Outcomes following secondary carpal tunnel syndrome are worse than primary carpal tunnel syndrome and patients typically experience less relief in their symptoms [9]. As with revision cubital tunnel, revision carpal tunnel involves neurolysis with a possible hypothenar flap or nerve wrapping. As detailed in Example 8.5, when performing revision carpal tunnel surgery, a longer more ulnar incision that extends to the wrist crease is made to allow for visualization of the median nerve proximal and distal to the prior scarring [73]. Approaching the prior scarring from the ulnar border allows for identification of normal anatomical landmarks and facilitates safe dissection [66, 73]. Surgeons may have to also release Guyon's canal to protect the ulnar neurovascular bundle during this approach [66]. The median nerve is followed proximally and distally into the carpal tunnel and external, and/or internal neurolysis is performed per the surgeon's discretion.

Complex regional pain syndrome includes a constellation of symptoms such as sensory and motor abnormalities as well as pain that results in dysfunction, disability, and chronic pain. The pathophysiology of CRPS is thought to be heterogeneous. Three major physiologic pathways have been identified that contribute to the development of CRPS: maladaptive neuroplasticity, vasomotor dysfunction, and aberrant inflammatory mechanisms [37]. Complex regional pain syndrome is common following upper extremity fracture; however, the incidence varies greatly on the diagnostic criterion that is used [11]. These patients experienced more pain after injury and were unlikely to be symptom free at 1 year [11]. The incidence of CRPS following surgical fixation of distal radius fractures is 8.8% [53]. Female gender, more com-

munit fracture patterns or open fractures, high-energy mechanisms, and comorbid fibromyalgia are predictive of the development of CRPS [23, 53]. It has been suggested that surgeons should assess patients for these potential risk factors before fixation of distal radius fractures and treat with prophylactic ascorbic acid preoperatively or with corticosteroids postoperatively to reduce inflammation and free radical formation [53]. There is little evidence supporting effective interventions for the prevention of CRPS.

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