Neuroma in Continuity

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Introduction

Carpal tunnel syndrome is the most common peripheral compressive neuropathy in the upper extremity, and surgical release is usually successful with recurrence rates ranging from 3 to 20% [1–4]. Symptoms after carpal tunnel release (CTR) have been classified into three different types – persistent, recurrent, and new [1]. Persistent symptoms are those that do not show any improvement after CTR, often due to inadequate release of the transverse carpal ligament, proximal compression, or incorrect diagnosis. Recurrent symptoms are those that initially improve after CTR only to recur at a later date and may be due to scar formation around the median nerve with subsequent traction neuritis, or proximal median nerve compression. Finally, new symptoms are symptoms that occur after CTR that are different than those that the patient initially presented with. These new symptoms are typically due to iatrogenic injury and will be the focus of this chapter.

Iatrogenic injuries that occur during carpal tunnel release may involve injuries to the vasculature, median or ulnar nerves or their branches, or to the surrounding flexor tendons [1, 5–7]. Injury to the median nerve during CTR commonly involves the nerve to the third webspace, the recurrent motor branch, or the palmar cutaneous branch (seen with more radially placed incisions) [5, 7, 8]. Complete transection of the median nerve has also been reported [6].

It is useful to review the classification of nerve injury when discussing iatrogenic median nerve injury following CTR (Fig. 17.1). Sunderland described I–V degree injuries with IV and V degree injuries being neurotmetic injury with no opportunity for recovery [9]. A IV degree injury is an in-continuity nonrecoverable injury. A V degree injury implies a physical separation between the proximal and distal physical components of the injured nerve with a neuroma proximally and a glioma distally. Typically, true IV degree injuries following carpal tunnel release would imply a complete or near-complete transection that had "healed" with dense scar tissue.

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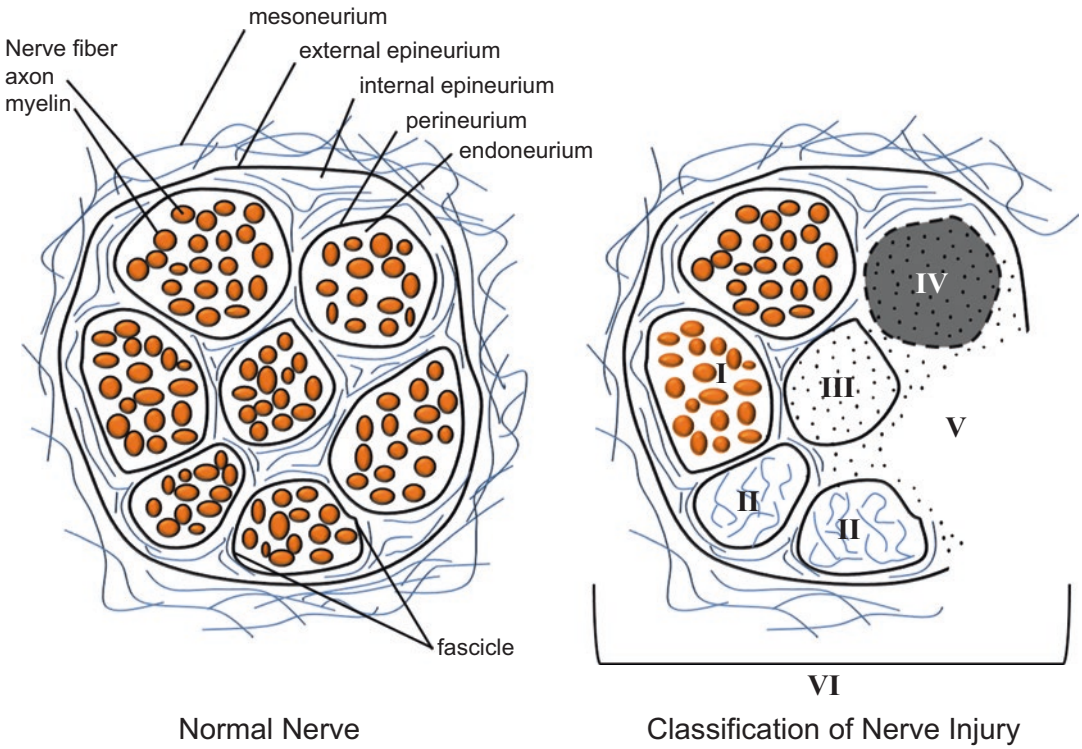

Fig. 17.1 (**a**) Schematic representation of the cross-section of a normal peripheral nerve showing the connective tissue and nerve tissue components. (**b**) The cross-section of the peripheral nerve demonstrates a mixed, or sixth degree, injury pattern. This fascicle at the top left is normal. Moving in the counter clockwise direction, fascicle I is a first degree injury (neurapraxia) with segmental demyelination. Fascicle II is a second degree injury (axonotmesis). The second degree involves both the axon and the myelin. The endoneurial tissue is not damaged. Fascicle III demonstrates a third degree injury, with injury to the axon, myelin, and endoneurium. The perineurium is intact and normal. Fascicle IV demonstrates a fourth degree injury, with injury to the axon, myelin, endoneurium, and perineurium. The fascicle is marked by scarring across the nerve, with only the epineurium being intact. Fascicle V is a fifth degree injury in which the nerve is not in continuity and is transected. The surgeon will separate the fourth and fifth degree injury patterns, which will require reconstruction from the normal fascicles and the fascicles demonstrating first, second, and third degree injury patterns. These latter patterns of injury require, at most, neurolysis. (Permission to reprint from Thieme in Nerve Surgery by Mackinnon)

Those would be treated with nerve grafting. The management of the IV degree, or true neuroma in continuity, is therefore fairly straightforward. By contrast, it is the combination injury or, as Mackinnon has emphasized, a VI degree injury that is the major challenge for reconstructive nerve surgeons [10]. In these injuries, some of the fascicles may be normal or have the potential for complete recovery. Other fascicles with neurotmetic injuries will need reconstruction. It is these more challenging VI degree injuries that we emphasize in this chapter.

Diagnosis

The evaluation of these patients starts with a detailed history and physical exam. Focus is placed upon the pre- and postoperative symptoms. Patients with an iatrogenic injury to the median nerve resulting in a neuroma in continuity will complain of new neurological symptoms after their CTR, in the form of numbness, weakness, or pain, and these symptoms are often severe (Fig. 17.2). Physical examination can help to identify the area of injury. Careful sen-

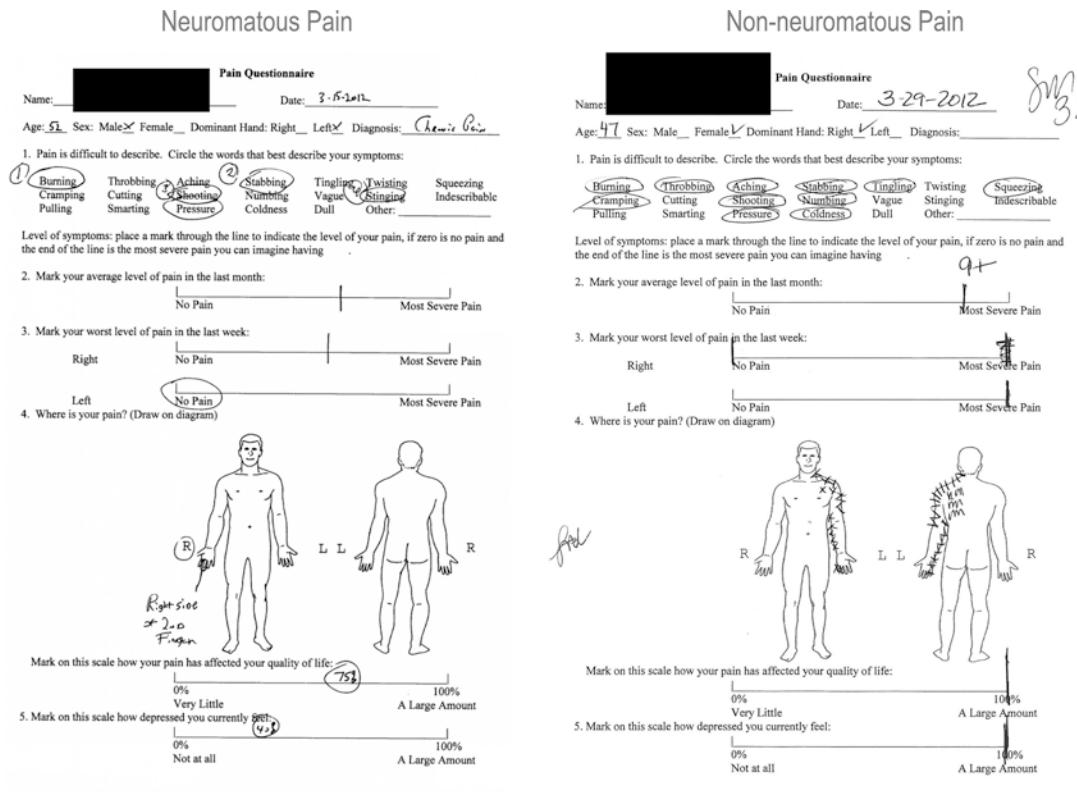

Fig. 17.2 Pain descriptions for neuromatous pain and non-neuromatous pain. The pain evaluation is an important tool for distinguishing types of pain and helping with the diagnosis. Neuromatous pain includes description of focal, brief, intermittent, sharp, often intense, and localizes to a specific nerve territory. Non-neuromatous pain includes description of diffuse and of varying quality and duration. (Permission to reprint from Thieme in Nerve Surgery by Mackinnon)

sory testing including two-point discrimination, Semmes-Weinstein monofilament testing, and the ten test of both the median innervated digital nerves and the palmar cutaneous branch can determine if all or a portion of the nerve has been injured which will help guide surgical management. Each digital nerve should be separately evaluated in the autonomous area (the volar lateral side of the middle phalanx). We have found the ten test to be very useful in the evaluation of these patients. Patients are given a scale of 1–10 with 10, normal; 5, half; and 0, no sensation. The normal hand is used as the control for 10, and then the injured finger(s) is touched in the same autonomous zone simultaneously with the contralateral side, and the patient reports a number between 0 and 10 [11]. We also use the scratch collapse test ethylene chloride hierarchy to evaluate for persistent and recurrent secondary carpal tunnel, evaluation of the median nerve in the forearm as well as iatrogenic median nerve injury [12]. A Tinel sign can help to localize the area of injury and should be performed proximal to the carpal tunnel as percussion over the carpal tunnel at the level of the injury will often result in severe and intolerable pain for the patient. We call this a "proximal" Tinel and specifically ask the patient to describe the precise distribution of the Tinel. Weakness or atrophy of the abductor pollicis brevis indicates an injury to the recurrent motor branch of the median nerve.

Nerve conduction studies should be performed during the evaluation of any patient presenting with symptoms of a failed carpal tunnel release, and the results should be compared to preoperative studies. Evidence of worsening median nerve function when compared to previous studies often

implies injury to the median nerve or one of its branches and helps guide the decision for surgery. Recording to each median nerve, innervated digital nerve may be necessary to evaluate the VI degree injury pattern. For example, an injury to the third webspace fascicular group may not be noted if the electrodiagnostic reading is from the index finger.

Treatment

General Principles

Surgical treatment of a neuroma in continuity after carpal tunnel release requires careful attention to technique. The original incision site should be ignored in favor of a larger ulnarly placed incision that crosses the proximal wrist crease and carries on distal to the original incision to allow adequate exposure. The median nerve is first identified both proximal to the zone of injury in order to minimize the risk of further iatrogenic injury. Guyon's canal is then released and the flexor retinaculum divided on the ulnar border. The flexor retinaculum is then retracted, and the injured median nerve will be visualized adherent to the overlying scar from original incision.

Identification and Resection of the Zone of Injury

Internal neurolysis of the internal and external epineurium is performed using microsurgical instrumentation until normal fascicles and bands of Fontana are encountered (Fig. 17.3). The extent of

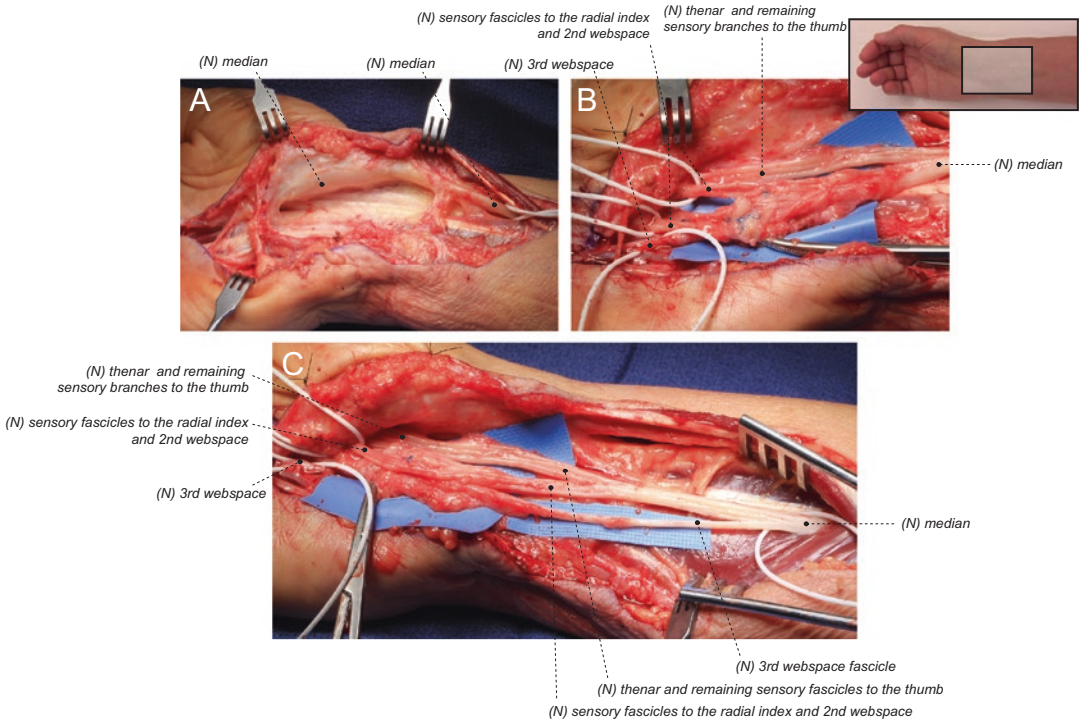

Fig. 17.3 Exposure of median nerve and intraneurolysis. (**a**) The median nerve was identified proximal and distal to the zone of injury. It was found to have a course within dense scar tissue. (**b**) The median nerve was isolated from the scar tissue, and distal neurolysis revealed the sensory branches of the median nerve. The intact thenar motor branch and sensory fascicles to the thumb were protected. Suture material was found within the remainder of the injured median nerve. (**c**) Proximal neurolysis revealed the fascicular anatomy of the median nerve. The third webspace is neurolyzed proximally so that it can be used as graft material. (Permission to reprint from Thieme in Nerve Surgery by Mackinnon)

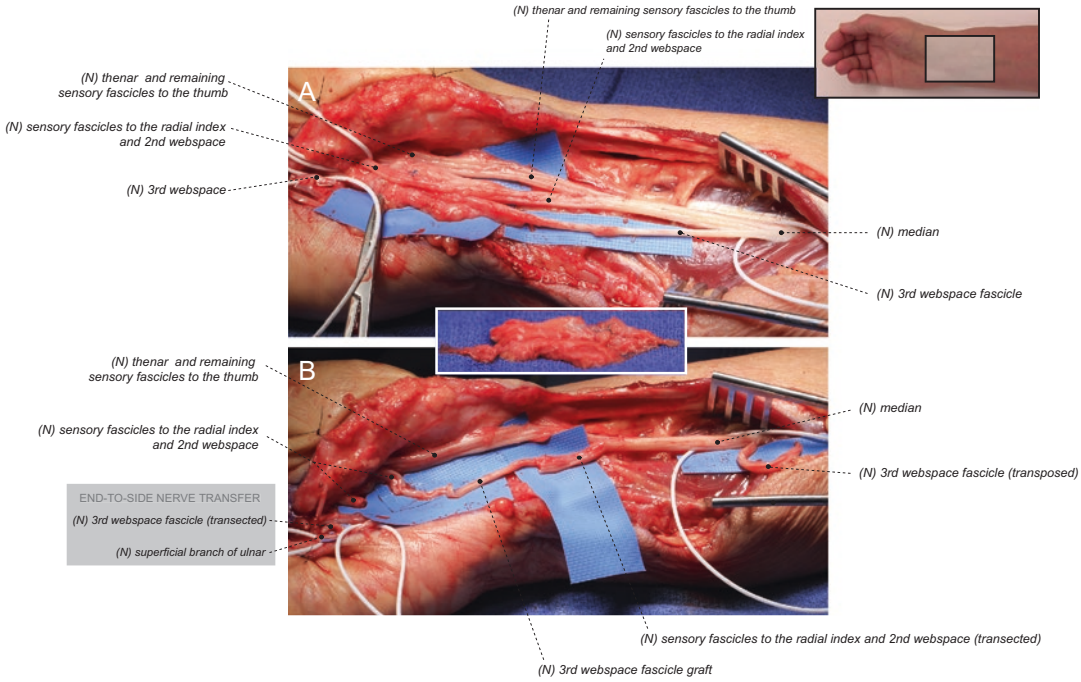

Fig. 17.4 Neuroma resection and first webspace grafted with a third webspace graft. (**a**) The zone of injury was identified, and the neuroma was resected with proximal and distal median nerve components identified. The third webspace was further neurolyzed proximally to mobilize graft material. (**b**) The proximal end of the third webspace fascicle was transected and used as a nerve graft to repair a portion of the median nerve. The proximal remainder of the third webspace was transposed proximally to prevent a painful neuroma. The distal third webspace was end-to-side transferred to the sensory component of the ulnar nerve to provide rudimentary sensation for donor deficit. (Permission to reprint from Thieme in Nerve Surgery by Mackinnon)

neurolysis required will vary by case and should continue until normal fascicles are encountered. We start the neurolysis proximally above the area of suspected injury and carefully proceed distally. Normal fascicles are first neurolysed to protect their function. All injured fascicles are identified and resected taking care to protect the uninjured, healthy portions of the nerve (Fig. 17. 4).

Selection of Nerve Graft

We recommend the use of autogenous nerve grafts to reconstruct injuries involving critical portions of the median nerve and the use of allografts to reconstruct noncritical sensory injuries. Typically an allograft will not be necessary.

It is our preference to obtain a nerve graft from the operative extremity. The anterior branch of medial antebrachial cutaneous (MABC) nerve is our graft of choice when a long graft is needed (Figs. 17.5 and 17.6). It is located in the medial upper arm next to the basilic vein along the medial border of the biceps and supplies sensation to the ulnar volar forearm. If a shorter segment of graft is needed, the anterior interosseous nerve to the pronator quadratus muscle in the distal forearm is an excellent donor which is in the operative field and results in no sensory deficit. Alternatively, the lateral antebrachial cutaneous nerve may be used.

The branch of the median nerve to the third webspace may also be used as a donor (Fig. 17. 7). Proximal mobilization of the third webspace branch results in an appropriately sized graft which may be used to reconstruct more critical median nerve function. We will then transfer the distal aspect of the third webspace branch end-to-side to the sensory component of the ulnar nerve to provide restoration of rudimentary sensation to the third webspace. The proximal end of the third

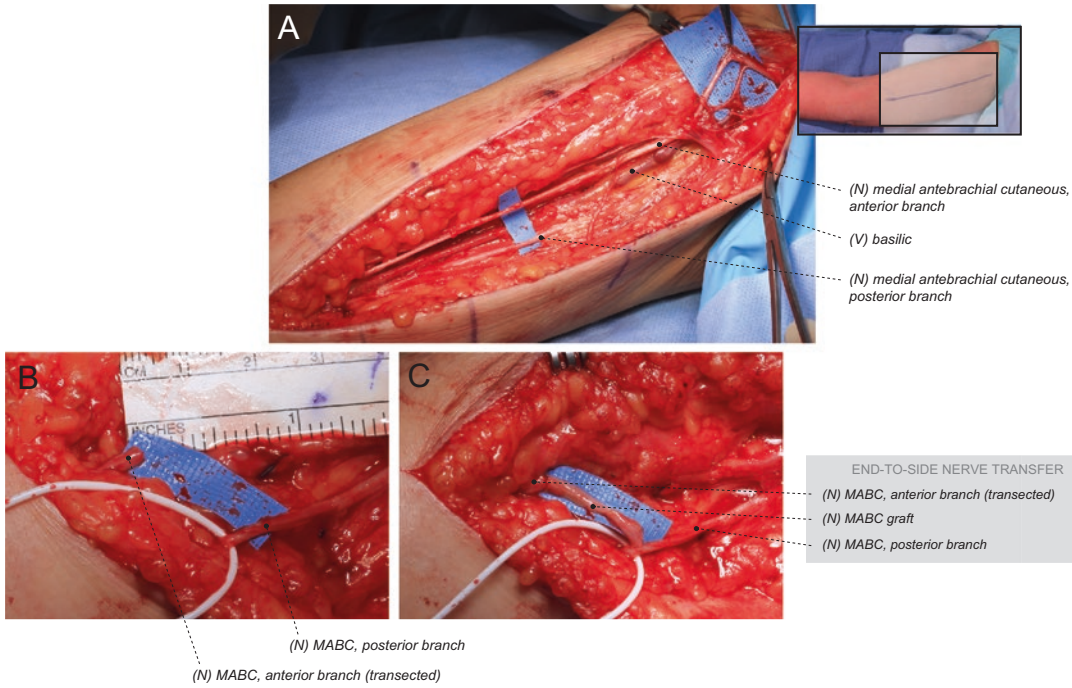

Fig. 17.5 Anterior branch of medial antebrachial cutaneous nerve graft harvest. (**a**) The anterior branch of the medial antebrachial cutaneous nerve (MABC) was exposed superior to the basilic vein and isolated in the medial aspect of the arm. The posterior branch of the MABC nerve was also identified inferior to the basilic vein. (**b**) The anterior branch of the MABC nerve was harvested. (**c**) To restore rudimentary sensation in the MABC anterior branch distribution, the distal end of the MABC anterior branch was transferred to the MABC posterior branch in an end-to-side fashion. Following the prioritized ulnar nerve reconstruction with the harvested MABC graft, the unused MABC graft material was used to bridge the end-to-side nerve transfer for a tension-free repair. (Permission to reprint from Thieme in Nerve Surgery by Mackinnon)

webspace branch should be transposed proximally and buried between the superficial and deep flexor muscles to prevent a painful neuroma. We do a proximal "crush" of the third webspace fascicle to make a II degree injury and move the axonal regeneration front proximally. We also use a long (5 cm) nerve allograft to repair to the distal end of the third webspace nerve to "dwindle" nerve regeneration and prevent neuroma formation.

Outcomes

There have been a number of studies looking at the outcomes of patients requiring revision carpal tunnel surgery, though most of these cases involve patients presenting with recurrent or persistent symptoms with little data available on the long-term outcomes of those patients treated for a neuroma in continuity. Zieske et al. reviewed the results of revision carpal tunnel surgery in 97 extremities [7]. Revision surgery was performed for new symptoms in 36 of these 97 extremities, and of these 36 patients with new symptoms, 19 were noted to have an iatrogenic nerve injury. At an average postoperative follow-up of 4.7 ± 3.3 months, these patients showed an improvement in pinch and grip strength and an improvement in pain scores (Fig. 17.8). Detailed outcomes regarding improvement in sensation and function were not possible given the duration of follow-up reported. Jones et al. reported on 55 revision

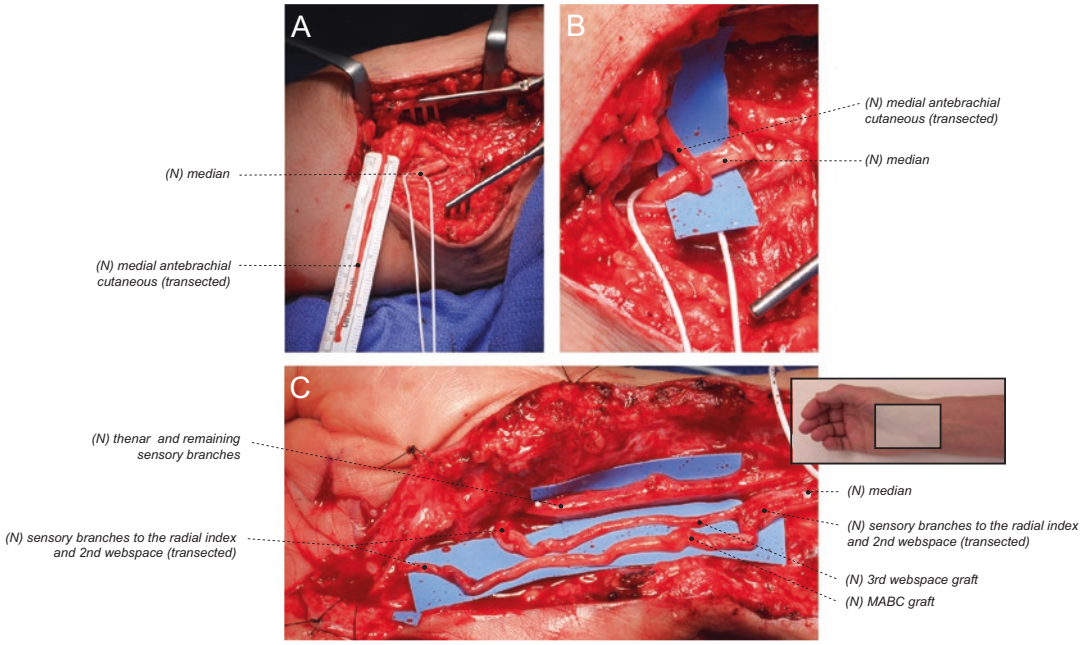

Fig 17.6 Second webspace grafted with a medial antebrachial cutaneous nerve graft. (**a**) The medial antebrachial cutaneous nerve (MABC) was isolated within the arm for donor material. (**b**) The MABC was than transected with the distal end transferred to the sensory component of the median nerve through and end-to-side epineural window fashion. The sensory component of the median nerve is located on the superior aspect of the median nerve. Note that in this image, the median nerve has been rotated so that it appears to be on the inferior portion. (**c**) The MABC graft was used to repair the remaining portion of the median nerve. The thenar branch and remaining sensory branches to the thumb were protected and were found to be not injured. (Permission to reprint from Thieme in Nerve Surgery by Mackinnon)

carpal tunnel surgeries, only 2 of which involved patients presenting with new symptoms related to iatrogenic nerve injury [8]. Improvement in thenar strength was seen in 48% of patients, and pain, numbness, and paresthesias improved or resolved in 80% of patients. They did not report specifically on the outcomes of those patients with iatrogenic nerve injuries.

Iatatrogenic nerve injury after carpal tunnel release resulting in neuroma in continuity is a devastating complication. Careful diagnosis and meticulous surgical reconstruction will often improve patient's symptoms, but further study is needed to better define the long-term outcomes of this challenging patient population.

Conclusion

There is universal agreement that *prevention* of median nerve injuries during carpal tunnel surgery is imperative. Points we emphasize with primary carpal tunnel release include the following:

- Our incision is made 6 mm ulnar to the thenar crease to avoid direct healing over the median nerve which can result in scar traction neuritis and recurrent carpal tunnel syndrome and to place it in the watershed between the palmar cutaneous median and ulnar nerves.
- The incision is "as long as needed." If necessary, a Bruner incision is used to cross the

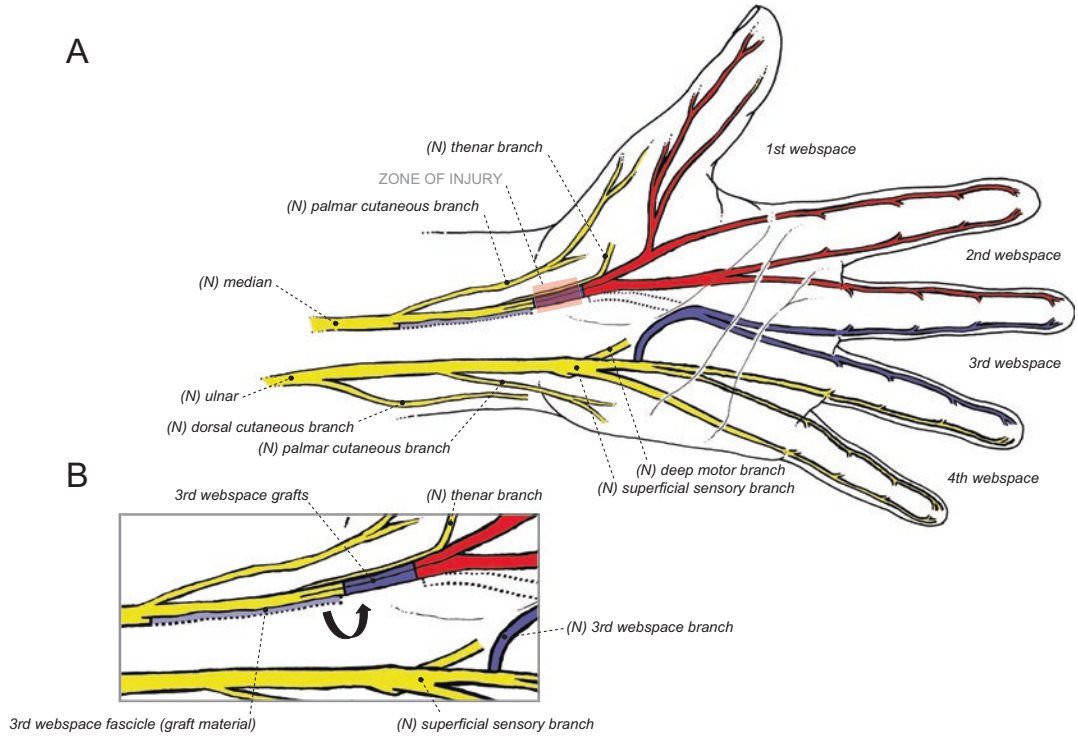

Fig. 17.7 Noncritical nerve graft material from proximal to nerve injury. Noncritical nerve material proximal to a nerve injury is an available option for grafting. (**a**) The third webspace is an excellent donor nerve for grafting in a case of distal median injuries. Injury to the median nerve at the wrist allows for the harvest of the proximal noncritical third webspace nerve fascicle. The harvest of the third webspace fascicle occurs on the medial aspect of the median nerve. (**b**) The third webspace fascicle can be used as graft material for reconstructing critical components of a distal median nerve injury. (Permission to reprint from Thieme in Nerve Surgery by Mackinnon)

wrist to get safe and complete release of the distal antebrachial fascia.

- In obese patients, a forearm tourniquet is utilized to prevent the development of a venous tourniquet.
- The ligament is released on the ulnar side so as to not have healing of the median nerve to the cut edge of the ligament which can result in scar traction and recurrent carpal tunnel syndrome.
- At the proximal and distal ends of the release, the surgery is "slowed" to ensure no iatrogenic injury to the median nerve and that there is a complete release [13]. The third webspace component of the median nerve branches from the main median nerve in the distal aspect of the release, and this is an area where "slowing down" is critical.
- The proximal release is never "blind." We will move to the end of the operating table to be able to release the proximal portion of the carpal ligament and the distal antebrachial fascia under direct vision. If visualization of the median nerve is not complete, then the incision is extended.
- The wrist is immobilized in a neutral position for 2 days after which the dressing is removed and patients are encouraged to "move, but not use" their hand for 2 weeks.

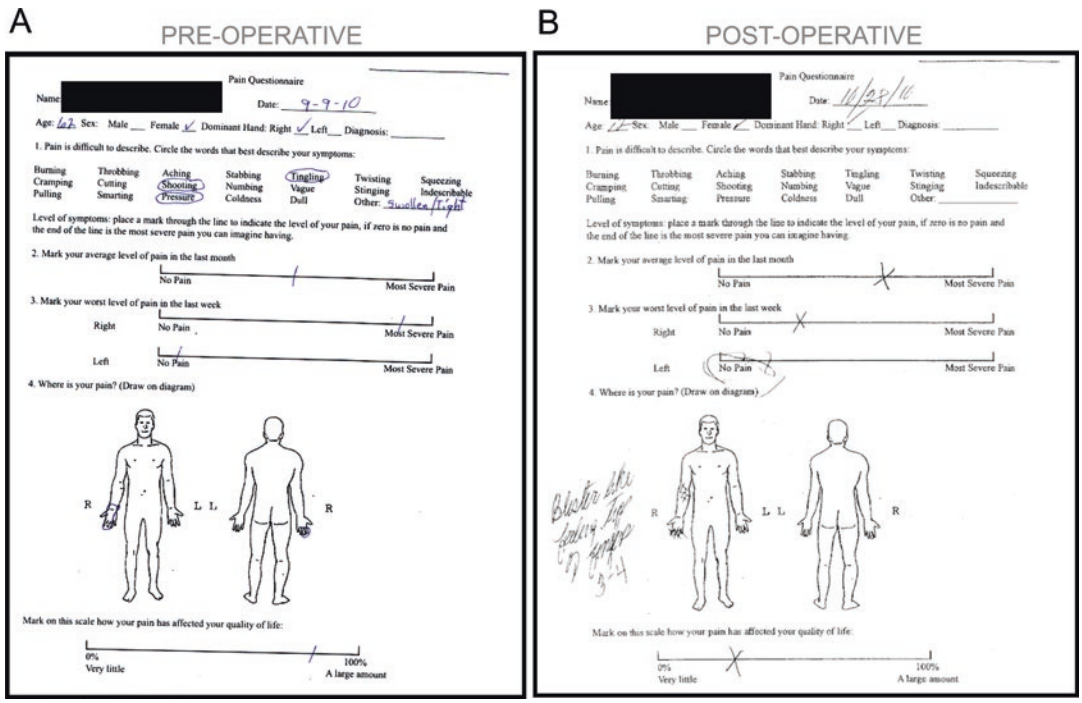

Fig. 17.8 Preoperative and postoperative pain diagram. (**a**) Preoperative pain diagram demonstrates pain upon presentation 2 years after a right-hand endoscopic carpal tunnel release, failed primary median nerve repair, and stem cell injection into the wrist. (**b**) Postoperatively following the revision reconstruction by our institution, pain was reduced significantly. (Permission to reprint from Thieme in Nerve Surgery by Mackinnon)

While CTR is a relatively easy and straightforward procedure, the potential for catastrophic nerve injury exists. We believe that attention to these critical points minimizes the risk of nerve injury during CTR.

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