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Review Article

Management of Failed Carpal and Cubital Tunnel Release: An Evidence-Based Guide to Success

Andrew K. Ence, MD, [*] Brent R. DeGeorge Jr., MD, PhD [*,†]

[*] Department of Orthopaedic Surgery, University of Virginia, Charlottesville, VA
[†] Department of Plastic Surgery, University of Virginia, Charlottesville, VA

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Carpal tunnel and cubital tunnel syndromes are the most common compressive neuropathies of the upper extremity with surgical treatment having high success rates for both conditions. Although uncommon, persistent or recurrent carpal and cubital tunnel syndrome presents a challenge for patients and providers. Diagnosis of persistence versus recurrence of the pathology is key in establishing an appropriate treatment plan to provide the best possible patient outcomes. After an established diagnosis, a wide array of treatment options exist which varies based on previous procedures performed. This review discusses relevant anatomy, etiology, and clinical presentations of persistent and recurrent carpal and cubital tunnel syndromes. The range of treatment options is presented based on history and diagnostic findings. Treatment options span from revision of nerve decompression to the use of soft tissue rearrangement procedures. Some specific treatment options discussed include simple revision nerve decompression, external neurolysis, soft tissue rearrangement, such as the hypothenar fat flap or various transposition techniques, and the use of nerve wraps. Included is an evidence-based management guide for diagnosis and treatment of persistent versus recurrent carpal and cubital tunnel syndromes.

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Carpal tunnel syndrome (CTS) and cubital tunnel syndrome (CuTS) are the first and second most common compressive neuropathies of the upper extremity. In the United States, the incidence of CTS has been estimated to be approximately 424 cases per 100,000 patients and between 1997 and 2010 was the second most common cause of days lost from the workplace.[1] There are approximately 75,000 new cases of CuTS reported annually[2] with an incidence of approximately 20.9 cases per 100,000 patients.[3]

Carpal tunnel release (CTR) for addressing CTS is one of the most common procedures performed on the hand with a success rate between 80%–95%[4–6] and the success rate of decompression of the ulnar nerve at the elbow for CuTS is estimated to be between 65%–95%.[2,7] Despite a relatively high success rate and generally overall improved outcomes in both conditions when treated surgically, recurrence rates following surgery for CTS are estimated to be approximately 7%–20% with between 3%–5% requiring revision surgery within a median time of 1.23 years.[8–12] Recurrence following cubital tunnel release (CuTR) is estimated at approximately 19%–25%,[13,14] with a revision surgery rate between 3%–19% occurring at a median time of 10 months.[13,15] Recurrence of both conditions following primary decompression has produced diagnostic and therapeutic challenges for patients and surgeons and has been shown to lead to poorer outcomes including but not limited to persistent pain, numbness/tingling, and loss of function with a lower chance of full symptom resolution.[16]

The purpose of this article is to review pertinent anatomy, etiology, clinical presentations and treatments associated with persistent or recurrent CTS and CuTS. Furthermore, the article will discuss evidence supporting various treatment options for persistent and recurrent disease while providing an evidence-based guide to assist with clinical decision making when treating these challenging conditions.

Anatomy

The median nerve (MN) originates from the C5 to T1 nerve roots and receives contributions from the medial and lateral cords of the

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Corresponding author: Brent R. DeGeorge, Jr., MD, Department of Plastic and Orthopaedic Surgery, University of Virginia, Box 800376, Charlottesville, VA 22903.
E-mail address: brent.degeorge@virginia.edu (B.R. DeGeorge).

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brachial plexus. In the arm, the nerve courses lateral to the brachial artery in the upper arm and medial to the artery at the elbow. The MN enters the forearm between the pronator teres and biceps tendon before traveling between the flexor digitorum superficialis (FDS) and flexor digitorum profundus, emerging between the FDS and flexor pollicis longus. The MN enters the hand via the carpal tunnel along with the FDS, flexor digitorum profundus, and flexor pollicis longus tendons. It is at this point where the nerve is most susceptible to compressive forces as the transverse carpal ligament (TCL) forms the roof of the carpal tunnel, effectively limiting the space available for these structures to occupy. After exiting the carpal tunnel, the MN branches into the recurrent branch to the thenar compartment as well as digital cutaneous branches supplying the radial 3½ digits.[17,18]

The ulnar nerve (UN) originates from the C8-T1 nerve roots and receives contributions from the medial cord of the brachial plexus. The nerve courses posteromedial to the brachial artery in the anterior compartment of the upper arm. Approximately 8 cm above the medial epicondyle, the nerve pierces the medial intermuscular septum at the arcade of Struthers and travels posterior to the medial epicondyle through the cubital tunnel, of which Osborne's ligament, a common constrictive structure, forms the roof. The nerve then courses distally, below the leading edge of the flexor-pronator aponeurosis called the arcuate ligament, then between the 2 heads of the flexor carpi ulnaris (FCU). The nerve then travels down the forearm between the FCU and the FDS before entering Guyon canal at the wrist where it bifurcates into sensory and deep motor branches, innervating the intrinsic muscles of the hand as well as the small and ulnar half of the ring finger. Common sites of compression of the UN at the elbow include the medial intermuscular septum, arcade of Struthers, medial epicondyle, Osborne's ligament, arcuate ligament, and the fascia between the 2 heads of the FCU.[19,20]

Etiology

The American Academy of Orthopaedic Surgeons clinical practice guidelines define CTS as "symptomatic compression neuropathy of the MN at the level of the wrist, characterized physiologically by evidence of increased pressure within the carpal tunnel and decreased function of the nerve at that level."[1] This statement is accepted widely among the hand surgery community and has been endorsed by the American Society for Surgery of the Hand. Despite this clear definition, the exact etiology of increased pressure leading to CTS is not fully understood. Most cases of CTS are idiopathic but risk factors for the development of carpal tunnel include pregnancy, wrist trauma, obesity, hypothyroidism, renal disease, diabetes, and inflammatory arthropathies.[21] Evidence supporting occupational factors, such as repetitive hand use, vibration, and manual labor, as major risks for CTS is inconsistent with a meta-analysis by Lozano-Calderón et al[22] showing correlation in 46%–70% of studies.

Cubital tunnel syndrome can be attributed to multiple factors. Increased pressure on the UN at the elbow, decreased excursion of the nerve during elbow motion, instability, and subluxation of the UN and pathologic changes that occur to the nerve and its microvascular blood supply all can be considered important factors.[23] With elbow flexion, the volume of the cubital tunnel decreases by up to 55% with intraneural and extraneural pressures exceeding 200 mmHg while also allowing for an average of 4.7 mm of elongation of the UN.[24] Ulnar nerve hypermobility and instability also can lead to increased nerve irritability, contributing to the development of CuTS.[25] Factors that alter the normal physiologic characteristic of the nerve or its gliding can lead to edema and ischemic changes to the nerve, promoting a cycle of continued irritation, edema, ischemia, and irritability which contribute to the development of structural alteration, such as perineural fibrosis and focal demyelination, contributing to nerve conduction problems.[26]

While there are many studies regarding risk factors for primary disease, studies identifying occupational or physiologic risk factors for recurrence of disease are limited and inconsistent in their results. For example, Camp et al[27] found obesity, tobacco use, younger age, hypercoagulable disorder, liver disease, and anemia to be risk factors for recurrent CuTS, while Smit et al[28] showed that body mass index and smoking were not independent risk factors. Despite the lack of clear evidence, it would be wise for providers to address any modifiable risk factors of primary disease as some of these may be unrecognized factors that contribute to the development of recurrent disease.

Clinical Presentation

Thorough history and physical examination are of utmost importance in the evaluation of a patient for possible recurrent CTS or CuTS. Determining the timing of symptoms may be helpful in distinguishing between a true recurrence (return of symptoms following a symptom-free or symptom-improved interval) versus persistent symptoms (without a symptom-free or symptom-improved period) following the procedure. In some cases, symptoms may be completely different from previous patient complaints and could be attributable to a separate etiology completely. Patients with symptoms that have persisted with little to no relief since the time of primary procedure may have had an incomplete release, an inaccurate diagnosis, or pathology involving the nerve that is irreversible. A patient with true recurrence of symptoms may have had increased scar tissue or perineural fibrosis leading to secondary compression of the nerve. In the setting of new symptoms, a patient may have sustained an iatrogenic nerve injury, or a new compression point may have been created as a result of the surgery.

Review of any prior electrodiagnostic studies or operative reports should be performed carefully. This is important to provide an understanding of the preoperative severity of disease and details of prior surgical intervention.

In some cases, patients may have a completely new problem masquerading as peripheral nerve compression. Mechanical compression of the nerve as in cases of cervical radiculopathy and thoracic outlet syndrome, peripheral neuropathies, such as diabetic neuropathy or drug/radiation induced neuropathies, autoimmune neuronal damage, and vascular disease also can present with symptoms similar to CTS and CuTS, such as pain, and sensorimotor dysfunction.[29–33] In 1973, Upton and McComas[34] developed a hypothesis stating that a proximal lesion of a peripheral nerve predisposed that nerve to a second lesion distally leading to a "double crush" phenomenon. More recently, the term "multifocal neuropathy" has been used to describe the presence of compressive or other neuropathic lesions that contribute synergistically to nerve dysfunction and symptoms present in CTS and CuTS.[35,36]

For patients with prior CTR, information regarding whether open or endoscopic release was performed may be helpful in determining persistent versus recurrent disease. In a study by Forman et al[37] 27% of patients with prior endoscopic CTR never had relief of symptoms while 73% had initial relief followed by recurrence within a 12 month period. Historically, some studies have shown a slight increased incidence of revision CTR following primary endoscopic release as well as a higher incidence of incomplete release with endoscopic techniques suggesting more likely that these patients have persistent, rather than recurrent disease.[12,38,39] More recent data have refuted this, suggesting no true difference between the 2 techniques. In a systematic review and meta-analysis of randomized control trials Li et al[40] found that the rates of recurrence using endoscopic techniques were equivalent to that of open release with no significant difference in permanent nerve injury. Studies also support that patients who undergo endoscopic release have higher satisfaction rates, improved key pinch strengths, earlier return to work, and fewer scar related complications.[40−42]

Diagnostic criteria, such as the CTS-6 (numbness in the MN distribution, nocturnal numbness, weakness/atrophy of the thenar musculature, Tinel's sign, Phalen's test, loss of 2-point discrimination) is a useful tool in determining primary CTS and can be used in lieu of electrodiagnostic testing.[43,44] As some providers do not rely on electrodiagnostic testing and instead use the CTS-6, it is important to evaluate each patient using these criteria to allow for comparison to preoperative and postoperative scores.

Examination for CTS should begin with the cervical spine to evaluate for possible cervical radiculopathy or thoracic outlet syndrome, as persistent upper-extremity neuropathic symptoms may be a representation of double crush phenomenon. Inspection of prior surgical incisions should be performed with care taken to note any tenderness or excessive scar tissue formation. Provocative maneuvers, such as Tinel'is sign, Phalen test, and the carpal tunnel compression test, should be compared to the contralateral side as well as with documentation from preoperative evaluation. Grip strength and sensory testing are objective measures that should be used to quantify dysfunction in the affected extremity. Evaluation of thenar muscle atrophy in CTS is important as patients with muscle atrophy are more likely to have advanced nerve damage and are less likely to respond to surgery.[45]

In cases of previous in situ CuTR, it is important to know the technique used. Toirac et al suggest that patients had higher satisfaction and lower complication rates following in situ endoscopic CuTR when compared to open techniques and attributes this in part to a lower incidence of injury to the medial antebrachial cutaneous nerve, which is a known risk for the need for revision surgery.[46] Additional studies suggest that there are no significant long-term differences in outcome or recurrence rates between endoscopic and open techniques.[47−52]

As with evaluation of CTS, examination for CuTS should begin with the cervical spine to evaluate for alternative causes of symptoms or evidence of double crush phenomenon. Prior surgical incisions should be inspected with care taken to note any tenderness or excessive scar tissue formation. Some patients may present with Tinel's sign within the area of operative dissection suggestive of a symptomatic neuroma. Evaluation for possible medial antebrachial cutaneous nerve neuroma also should be performed by looking for skin hyperalgesia and possible Tinel sign over the course of the nerve as this is a known complication following CuTR.[16,53,54] Grip strength and sensory testing should be used to quantify dysfunction in the affected extremity. In the case of recurrent CuTS, assessment of elbow deformity and motion should be evaluated. Sensory testing of the UN distribution in the hand can be useful to distinguish between CuTS and UN compression at the wrist as sensation in the dorsum of the hand will be preserved in ulnar tunnel syndrome. Intrinsic atrophy and weakness with CuTS are important indicators of the severity of nerve damage and again may indicated more advanced nerve injury and a decreased response to surgery.[45] Clawing, a positive Froment sign, or positive Wartenberg sign are all important findings to note. The medial epicondyle and UN should be palpated to assess for the stability of the UN within the cubital tunnel. A brief summary of history and examination findings can be found in Table 1.

Diagnostic Studies

Diagnosing primary CTS and CuTS remains a clinical diagnosis. The use of the CTS-6 or other validated criteria may be helpful in establishing the appropriate diagnosis without the use of electrodiagnostic testing.[43,44] The indications and use of preoperative electrodiagnostic testing in primary CTS and CuTS is somewhat controversial and despite being a clinical diagnosis, up to 56% of hand surgeons continue to order electrodiagnostic testing routinely with the top reasons being unclear diagnosis, worker's compensation patients, grading severity, and providing baseline evaluation in the event of persistent symptoms.[55]

For patients presenting with CTS or CuTS symptoms after a previously performed decompression, the investigators prefer to obtain electrodiagnostic testing. This is most helpful when patients have results from testing performed before their index surgery, allowing for comparison and evaluation for any improvement in nerve or muscle functional parameters. Repeat electrodiagnostics are less useful when there are no preoperative studies for comparison but may provide a baseline measure of current nerve function and severity of disease, allowing for comparison to later studies if ever obtained. These studies also can provide evidence of possible radiculopathy, peripheral neuropathy, or other multifocal neuropathies resulting in double crush phenomenon as discussed above.

There is growing interest in the use of advanced imaging such as ultrasound (US) and magnetic resonance imaging (MR) to provide additional information regarding peripheral nerve morphology and surrounding soft tissues.[56] The use of these modalities demonstrated findings such as nerve swelling, flattening of nerves at compression sites, and abnormal nerve structure that may support a diagnosis of CTS or CuTS.[57−61] Advanced imaging also may be useful in the diagnosis of extrinsic causes of compression, such as masses or aberrant musculature.[56] Unless there is suspicion for possible mass or abnormal anatomy leading to recurrent CTS or CuTS, the investigators do not obtain advanced imaging and rely on clinical examination and electrodiagnostic testing as described above.

In the setting of primary CTS, corticosteroid injections can have a diagnostic and therapeutic role, but do not provide significant long-term relief.[62−64] Studies regarding injections in the setting of recurrent disease are lacking. In one study, Beck et al[8] found that relief from injections as a diagnostic test for predicting successful revision CTR had a high sensitivity and positive predictive value of 87% each. In the setting of recurrent disease, the investigator will use injections as a diagnostic tool unless otherwise contraindicated. A summary of examination and diagnostic findings helpful in determining the need for surgical intervention is included in Table 2.

Treatment Options

Carpal tunnel

In the setting of failed CTR, a variety of treatment options are available and further treatment should be discussed thoroughly with the patient. Scar massage, splinting, and exercises, such as nerve and tendon glides, have limited use but may provide the patient with some mild symptom relief while maintaining some level of function in the extremity. Corticosteroid injections may provide diagnostic and therapeutic benefits in this setting as they have been shown to be beneficial in the treatment of primary disease and can be a useful tool in diagnosis of recurrent disease as discussed previously.

After failure of conservative treatments to provide any meaningful relief of symptoms in the setting of persistent or recurrent CTS, it is reasonable to consider revision surgery. The investigator is willing to offer a revision procedure if the patient continues to experience persistent symptoms that interfere with quality of life

Table 1
History and Examination Components of Carpal (CTS) and Cubital Tunnel (CuTS) Syndromes

CTS	CuTS
History	History
Numbness predominately or exclusively in median distribution	Numbness predominately or exclusively in ulnar distribution
Nocturnal numbness	Nocturnal numbness
Physical examination	Physical examination
Thenar atrophy and/or weakness	Intrinsic atrophy and/or weakness
Positive Phalen's test	Positive Froment sign
Loss of 2–point discrimination	Positive Wartenberg sign
Positive Tinel sign	Positive flexion-compression test
	Positive Tinel sign

or daily function after the completion of 6-12 weeks of supervised therapy and failure of other conservative treatments.

Revision CTR only

When incomplete release is thought to be the primary reason for persistent or recurrent CTS, a revision CTR using an open technique to ensure a complete release of any remaining TCL fibers may be enough to provide resolution of symptoms. As discussed previously, no resolution of symptoms following primary CTR may indicate persistent disease due to incomplete release. In some cases, a significant amount of scarring in the place of the TCL may be present and could be a source of compression to the MN. Scar tissue formation can make it difficult to determine if there are any remaining intact fibers of the TCL. At the time of revision surgery, care is taken to identify the nerve outside the prior surgical field to ensure it is protected during the release of overlying and surrounding tissue. During revision surgery it is important to release any constrictive tissue thoroughly, whether it is scar or remaining intact TCL, ensuring the carpal tunnel is open and completely released. Revision CTR alone, with extension of the incision proximal to the wrist crease has been successful in up to 60% of cases.[65] In this study, unsuccessful outcomes were attributed to additional factors, such as cervical radiculopathy, demyelinating disease, pronator syndrome, and cerebrovascular accident. The remaining patients with unsatisfactory outcomes did not have any identifiable factors as to the reason for unsuccessful surgery.

External neurolysis

Following revision release of the TCL and any overlying scar tissue, the nerve also may be involved intimately with scarring and perineural fibrosis. The nerve also may have become adherent to the underside of the previously released TCL, preventing adequate nerve gliding and causing compression of the nerve.[39,66] Release of this scarring and fibrosis through external neurolysis can allow for decompression of the nerve from these causes of secondary compression (Fig. 1). Spielman et al[67] and Pattankar et al[68] found the addition of external neurolysis to MN decompression led to improved outcomes over decompression alone.

Nerve wrap with collagen or vein

Adjuvant treatments, such as autologous vein or collagen wraps, may allow for decreased scarring and perineural fibrosis following revision decompression while also allowing for improved nerve gliding (Fig. 2). It has been theorized that the intima of vein grafts provide a smooth gliding surface for nerves while allowing for nutrient diffusion and has been shown to decrease scarring in rat models.[69] The use of autologous vein wrapping has been shown to result in improvement of symptoms and a decrease in postsurgical scar formation.[70,71] In addition to autologous grafts, commercially available nerve wraps are an option. These wraps are composed primarily of collagen derived from bovine, porcine, or human sources and have been shown to lead to less intraneural collagen deposition following nerve injury in a rat model.[72] Although studies regarding the efficacy and outcomes of the use of commercially available nerve wraps is limited, studies have shown some promise in the treatment of recurrent CTS with improvement in pain, grip strength, pinch strength, and 2-point discrimination in the setting of revision surgery.[73–76]

Table 2
Findings Suggesting Surgical Intervention in Recurrent/Persistent Disease

Physical Examination Consistent with CTS or CuTS
- Persistent numbness, muscle atrophy/weakness, positive provocative tests
Updated electrodiagnostic evidence showing CTS or CuTS
MRI or US findings suggestive of disease
- Nerve swelling, nerve flattening at compression sites, abnormal nerve structure
Positive response to steroid injection

Hypothenar fat flap

Additional techniques using local tissue rearrangement such as hypothenar fat flaps also are acceptable treatments following revision CTR. The use of a hypothenar fat flap can allow for improved coverage of the exposed MN while providing a barrier between the nerve and the divided TCL, protecting it from further fibrous ingrowth and scarring (Figs 3, 4). This technique is less technically demanding than other soft tissue rearrangement flaps with symptomatic improvement in 90% of patients.[77,78] A recent meta-analysis of surgical options for recurrent CTS found that results were similar for all treatment techniques used, but had a trend toward more positive outcomes on the Boston Carpal Tunnel Questionnaire symptom severity scale with the use of the hypothenar fat flap.[4] The procedure uses a transposition of a vascularized fat pad from the hypothenar eminence. The tissue then is placed between the MN and the radial side of the carpal tunnel. The technique has been modified over the years by Strickland et al,[77] Mathoulin et al,[79] then later Chrysopulo et al[80] The technique is accomplished by elevating a hypothenar skin flap with a thin layer of adipose left on the flap. The superficial flap is raised to the ulnar side exposing the fat pad overlying the hypothenar muscles and the TCL. The fat pad then is elevated off the musculature along with the ulnar neurovascular bundle. The ulnar leaf of the TCL then is excised off the hook of the hamate allowing greater mobilization of the fat flap. The flap then is transposed across the contents of the carpal tunnel and into the interval between the contents and radial wall of the carpal tunnel.[80]

Cubital tunnel

For patients who have failed conservative treatment for persistent or recurrent CuTS, revision surgery may be indicated. Surgical options for revision surgery vary and options should be considered while factoring in patient comorbidities including psychiatric illness and secondary gain as well as the technique used for the previous surgery. Perineural scarring, retained intermuscular septum or common flexor aponeurosis, and nerve instability all are potential problems contributing to failed surgery.[81,82] Once the decision to proceed with surgery has been made, options for treatment include external neurolysis, nerve transposition, medial epicondylectomy, and nerve wrapping. Regardless

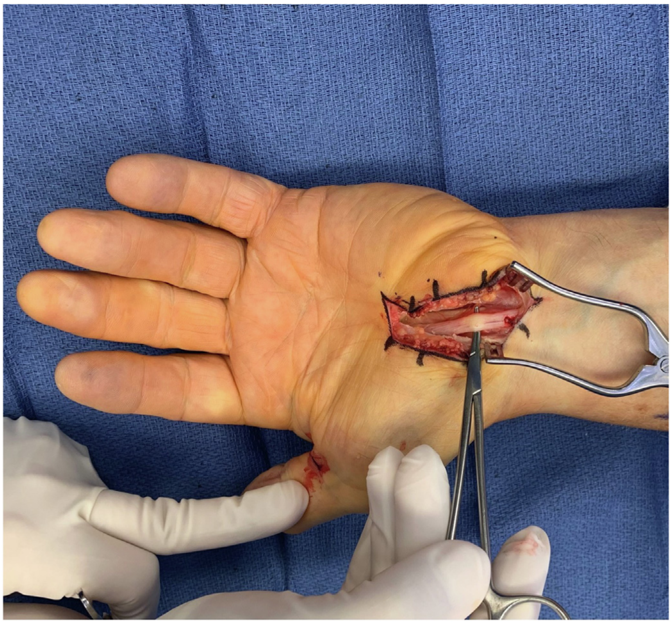

Figure 1. Intraoperative image of MN following revision decompression and external neurolysis.

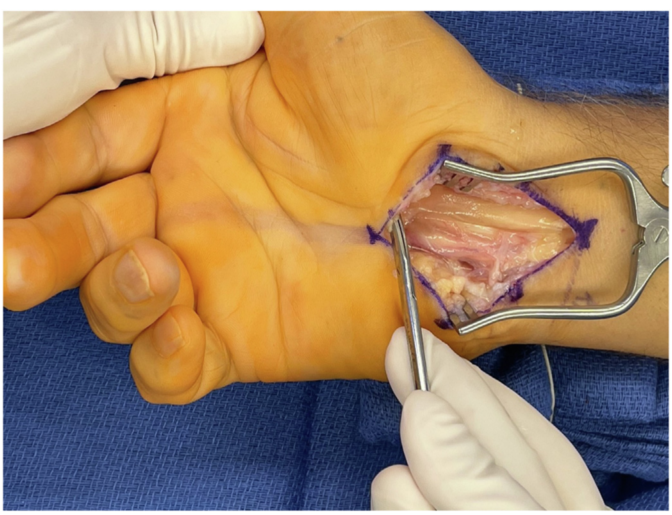

Figure 2. Intraoperative image of revision MN decompression with collagen nerve wrapping.

of the technique used, care should be taken to address potential causes of the failed index procedure.

External neurolysis

Performance of external neurolysis is standard in any revision surgery setting. In the setting of revision surgery, scar formation and fibrosis about the UN are found commonly and can be a potential source of nerve compression. In some cases, external neurolysis may be sufficient treatment for this. Dagregorio and Saint-Cas[83] found that external neurolysis without additional mobilization of the nerve had satisfactory or complete relief of symptoms, including pain, paresthesias, and grip weakness, in a majority of patients with failed primary CuTR. A single patient had a “poor result” with no resolution of symptoms, continued tenderness over the nerve, and absent 2-point discrimination at 10 mm.

Figure 3. Intraoperative image of revision MN decompression showing dissection of hypothenar fat flap.

Figure 4. Intraoperative image of revision MN decompression with transposition of hypothenar fat flap.

Anterior subcutaneous transposition

Anterior subcutaneous transposition is an option if the patient underwent in situ release at the time of the index procedure. During revision surgery, care must be taken to release residual areas of compression fully, particularly the medial intermuscular septum proximally, the flexor-pronator aponeurosis distally, and any overlying scar tissue. This release allows the nerve to be transposed anteriorly without creating any additional compression points proximal or distal. Good or excellent results have been achieved following anterior subcutaneous transposition with improvements in sensory and motor function.[81,84]

Anterior submuscular/transmuscular transposition

If a patient has failed previous surgery with in situ decompression or the use of a subcutaneous transposition, an alternative option is submuscular or transmuscular transposition involving the use of a fascial sling. Again, any areas of residual scarring or compression must be addressed, taking

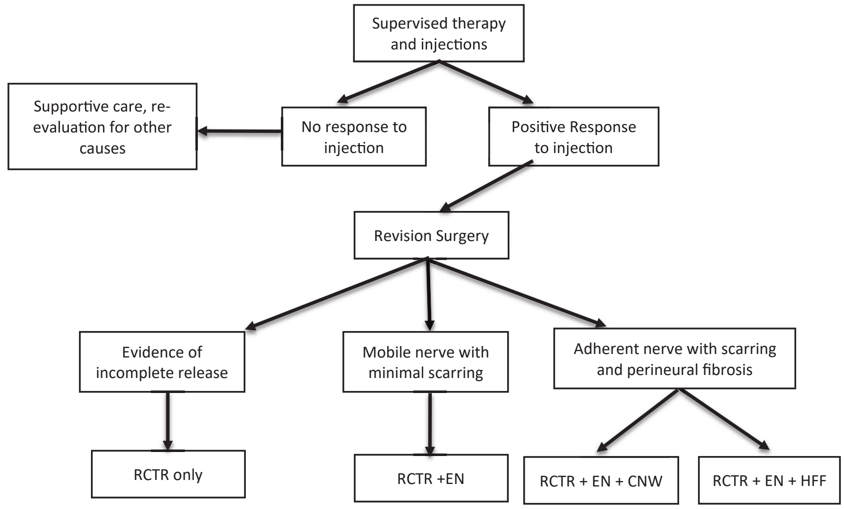

Figure 5. Algorithm for management of failed primary CTS procedures. RCTR, revision carpal tunnel release; CNW, collagen nerve wrap; EN, external neurolysis; HFF, hypothenar fat flap.

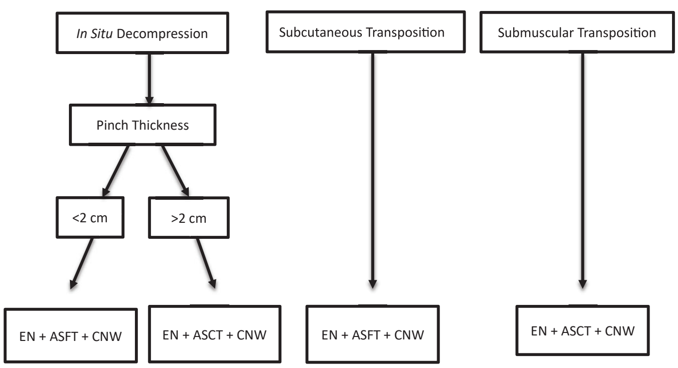

Figure 6. Algorithm for operative management of failed primary CuTS procedures. ASCT, anterior subcutaneous transposition; ASFT, anterior subfascial transposition; CNW, collagen nerve wrap; EN, external neurolysis.

care to avoid creating new areas of compression. Vogel et al[82] found submuscular transposition and flexor-pronator lengthening achieved 78% patient satisfaction, while Aleem et al[2] found 79% of patients had clinical improvement with submuscular transposition alone.

Medial epicondylectomy

An alternative to isolated nerve transposition is that of medial epicondylectomy. This involves elevating the flexor-pronator origin subperiosteally off the epicondyle while taking care to protect the anterior bundle of the medial collateral ligament. The goal is to remove the minimal amount of bone to allow for smooth tracking of the nerve during flexion and extension of the elbow to eliminate the risk of nerve subluxation or the creation of secondary compression points. A systematic review by O'Grady et al[85] found that when compared to transposition alone, medial epicondylectomy had no significant difference in outcomes in 2 studies, had improved outcomes in 3 studies, and had similar outcomes in another study.

Vein or collagen nerve wrap

As discussed previously, perineural scarring can contribute to failure of CuTR. Revision surgery in a wound bed with prior scarring can lead to additional scarring and adhesions that could contribute to further compression and decreased nerve gliding. The use of adjuvant treatments, such as vein or collagen nerve wraps, has gained popularity with the thought that the wraps may provide improved nerve gliding and a decrease in fibrous ingrowth about the nerve. Papatheodorou et al[76] suggest that the use of collagen nerve wraps is a safe and effective method of protecting the nerve following revision CuTR and had improvement in 11 of 12 patients with no complications. Soltani et al[73] found the use of Type 1 collagen nerve wraps for compressive neuropathies led to clinical improvement with no intolerance. Studies suggest that the use of autogenous vein wrapping also can provide an effective barrier around the nerve to prevent scarring, but this technique comes with the additional morbidity of vein graft harvesting.[71,86]

Investigator's preferred technique

In the setting of persistent or recurrent CTS, all patients participate in a supervised therapy program for at least 6–12 weeks (Fig. 5). Patients are offered a carpal tunnel injection with corticosteroid unless contraindicated due to other medical comorbidities, such as diabetes. The patient's response to injection helps to counsel the patient on expected outcomes of revision surgery and the investigator is willing to offer surgery if the response to injection is positive. Electrodiagnostic studies also are repeated, allowing for comparison of preoperative and postoperative testing. If the newly obtained studies demonstrate evidence of peripheral neuropathy, radiculopathy, or other multifocal neuropathy, the patient is referred to a spine specialist, endocrinologist, or other specialist for appropriate evaluation and treatment. Revision surgery may be considered if they continue to have persistent symptoms that interfere with quality of life or daily function and have failed the prescribed course of supervised therapy. The same rationale is used in the approach to patients with persistent or recurrent CuTS with the exemption of the use of injections.

For revision carpal tunnel surgery, a standard incision is made in the palm of the hand, using the previous carpal tunnel incision if an open procedure was performed initially. This incision then is extended 2 cm proximal to the proximal wrist crease. Proximal extension of the incision allows for complete visualization of the MN as well as any significant scarring or fibrosis associated with the nerve. The MN is identified proximal to the wrist crease and

Figure 7. Intraoperative image of revision UN decompression with significant edema of the UN.

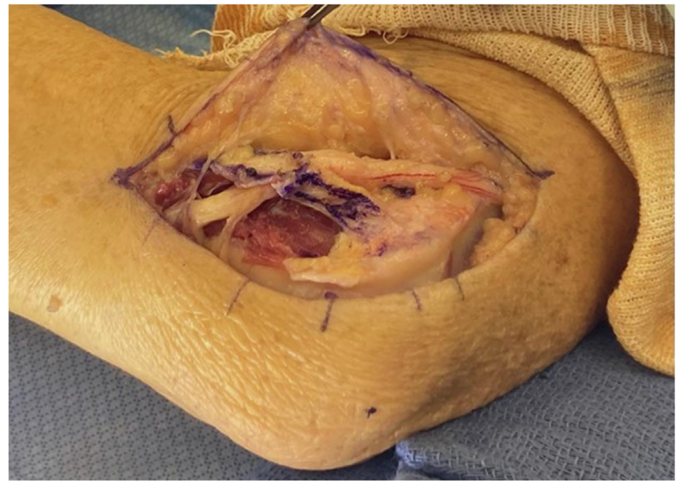

Figure 8. Intraoperative image of revision UN decompression following anterior subfascial transposition.

followed distally where the carpal tunnel is released. Attention is made to note the level of scarring above and around the area of the TCL. In the setting of revision surgery, it can be difficult to note any remaining bands of the TCL from the prior surgery, but care is made to ensure that the carpal tunnel is inspected thoroughly and that the MN is decompressed completely. If the nerve is adherent or there is scarring that is causing compression of the nerve, an external neurolysis is performed. In most cases where an external neurolysis is performed, the nerve is wrapped with a commercially available collagen nerve wrap. The wounds then are closed, and the patient is placed in a volar resting splint for 2 weeks.

Determination of revision CuTS technique is influenced by prior technique used (Fig. 6). During revision CuTS surgery, the prior incision is used. Extension of the incision proximally and distally is important, allowing for the identification of correct surgical planes within untouched tissue. Dissection though subcutaneous tissues is performed carefully to identify any branches of the medial antebrachial cutaneous nerve. In most cases, the UN is found and dissected out in the proximal aspect of the incision. The nerve then is traced distally, past the medial epicondyle, between the 2 heads of the FCU with any points of constriction being released completely. An external neurolysis is performed, dissecting away any significant scar or fibrosis. In some cases, scarring may be so significant, there is no discernible plane between scar and nerve. When this is found, a small amount of scar is left with the nerve to avoid any chance of nerve injury. When an in situ release was performed previously an anterior transposition then is completed. To determine the type of transposition, the tissues over the medial elbow are pinched. If the pinch thickness of skin and subcutaneous tissues is >2 mm then a subcutaneous transposition is performed. If the tissues are <2 mm a subfascial transposition is performed. To do this, a vessel loop is placed around the nerve and gentle traction is used to identify adherent tissues that can be released, allowing for greater anterior mobility of the nerve. Care is taken to release any fascial bands that may cause secondary points of constriction or sharp edges, particularly around the edge of the flexor-pronator origin and the medial intermuscular septum (Fig. 7). In most revision cases, a collagen nerve wrap then is used to decrease fibrous ingrowth and allow for improved nerve gliding. Either a subcutaneous transposition using a sling made of subcutaneous fat secured to the medial epicondyle, or a subfascial transposition with a step-cut fascial sling is used to prevent any posterior subluxation of the nerve. To create the fascial sling, a step-cut is made in the flexor-pronator fascia, creating anterior and posterior flaps. The nerve then is mobilized anteriorly, the flaps are transposed over the nerve, and the ends of each flap are sutured together, creating a loose sling above the nerve (Fig. 8). Regardless of the method used, the nerve is inspected during flexion and extension to ensure there are no remaining points of constriction and that the nerve glides without difficulty. In instances where the patient had a previous subcutaneous transposition, a subfascial transposition would be performed with nerve wrapping. If the index procedure was subfascial or submuscular transposition, a subcutaneous method with nerve wrap would be used. The wound then is closed, and the patient is placed in a long arm splint for 2 weeks.

In conclusion, the diagnosis and treatment of recurrent or persistent CTS and CuTS presents a significant challenge to the patient and surgeon. Through thoughtful and thorough preoperative evaluation and sound surgical technique, using multiple available options, surgeons can provide appropriate treatment that can lead to successful outcomes.

Despite multiple treatment options available for the treatment of these challenging conditions, long-term evidence is lacking regarding the most effective technique. Multicenter, prospective randomized trials with adequate powering for level I evidence would be most helpful in providing recommendations for clinical decision making. Even without this level of evidence, results of many of the treatment options discussed here are encouraging and should be considered when faced with the difficult scenario of recurrent or persistent CTS and/or CuTS.

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