Revision Carpal Tunnel Surgery Options

16

Yaron Sela, Loukia K. Papatheodorou, Lindsay Hess, Dean G. Sotereanos, and Mark E. Baratz

Key Points

- In evaluating a patient for revision carpal tunnel surgery, it is important to document whether the symptoms are persistent, recurrent, or acutely worse after the CTR.
- If numbness is worse, two-point discrimination and Semmes-Weinstein testing can help define the distribution and severity of sensory dysfunction.
- Persistent carpal tunnel syndrome may result from an incomplete release but is more commonly the result of chronic compression in compromised host, e.g., diabetic, elderly, and heavy smoker.
- Recurrent CTS is rare but is characterized by a symptom-free interval.

Y. Sela • L. Hess • M.E. Baratz (✉)
Department of Orthopaedic Surgery, University of Pittsburgh Medical Center, 2000 Oxford Drive, Bethel Park, 15102, Suite 510, Pittsburgh, PA 15102, USA
e-mail: mebaratz@gmail.com

L.K. Papatheodorou • D.G. Sotereanos
Department of Orthopaedic Surgery, University of Pittsburgh School of Medicine, Orthopaedic Specialists - UPMC, 9104 Babcock Blvd, 5th Floor, Pittsburgh, PA 15237, USA
e-mail: papatheodoroulk@upmc.edu; dsoterea@hotmail.com

Introduction

Carpal tunnel syndrome (CTS) is the most frequent compressive neuropathy in the upper extremity, with an incidence of 1–3 cases per 1000 patients per year [1]. The prevalence is 2.7% based on symptoms, clinical signs, and neurophysiology [2]. Carpal tunnel release (CTR) is the most common surgical procedure performed on the hand, and, fortunately, adverse sequelae are uncommon [3]. Decompression can be performed via open, mini-open, or endoscopic techniques with excellent success rates. Although most patients are satisfied with their result and have complete resolution of their symptoms, there are a certain percentage of individuals who have either recurrent or persistent symptoms. Traditionally, persistent symptoms have been attributed to an incompletely released transverse carpal ligament (TCL). It is our experience that persistent symptoms are more commonly the result of chronic compression in compromised host (e.g., diabetic, elderly, obese with thyroid gland disorders) [4]. Other causes for recurrent CTS are incorrect diagnosis, neuroma of a superficial nerve in the area (palmar cutaneous nerve), fibrous proliferation, recurrent tenosynovitis, and permanent nerve injury prior to surgery [5–8].

Recurrent CTS occurs in up to 19% of patients following CTR, with 12% requiring re-exploration [5]. Recurrence of symptoms is thought to be the

© Springer International Publishing AG 2017
S.F.M. Duncan, R. Kakinoki (eds.), *Carpal Tunnel Syndrome and Related Median Neuropathies*, DOI 10.1007/978-3-319-57010-5_16

result of progressive scar formation around the median nerve [9, 10]. Incomplete release of the TCL is cited as a cause of recurrence [3, 11, 12]; however, in our experience, the ligament quickly reconstitutes itself, and it is difficult to define "incomplete release." There are reports of a higher recurrence rates and poorer outcomes in patients with occupation-related CTS [5] and in patients who are involved in workers' compensation claims [9, 13].

Revision median nerve decompression alone or with neurolysis does not always result in sufficient relief of symptoms [14, 15]. Therefore, many different surgical techniques for coverage or wrapping of the median nerve have been proposed and reported in the literature for this recalcitrant condition. The goal of revision surgery for recurrent CTS is to decompress the nerve, prevent recurrent scar formation, and promote nerve recovery.

Various flaps have been used to cover the nerve including free omentum [16], subcutaneous tissue [14], hypothenar fat pad, synovial flap, abductor digiti minimi flap [14], pronator quadratus flap [17], pedicled reverse radial forearm flap [18], and vein wrapping [19, 20]. Some are technically demanding and use tissue that may be too small or poorly positioned to adequately cover the median nerve. Most published series are small, making it difficult to draw conclusions about the best technique.

Evaluation

Clinical Indicators for Failed CTR

Failed CTR manifests with either persistent symptoms or worsening symptoms. Persistent symptoms are common in the elderly and in patients with medical comorbidities, such as diabetes. Increased numbness after CTR should be cause for concern because it may reflect nerve injury. During revision surgery of the median nerve, iatrogenic injury was noted to have occurred in 3–6% of cases [3, 10]. These injuries can be due to lacerations of the palmar cutaneous branch, the median nerve proper, the recurrent motor branch, or one of the common digital nerves. Treatment is guided by the history and exam to a greater extent than imaging and nerve studies [21].

Clinical Indicators for Recurrent Symptoms

Initial improvement of preoperative symptoms suggests complete release of the TCL. In a retrospective review of 18 wrists in 17 patients with recurrent CTS, the average time between initial relief after the procedure and the presentation of recurrent symptoms was 21 months, with a range of 7 months to 8 years [3]. Table 16.1 summarizes the evaluation of recurrent CTS versus failed CTS with persistent or worsened symptoms.

The patient returning to the clinic after CTR complaining of symptoms consistent with median nerve compression can be difficult to assess. The patient's perception of symptoms preoperatively and postoperatively can be vague and inconsistent. A thorough history must be taken to evaluate for any new or undiagnosed disorders, such as hyperthyroidism, hypertension, or diabetes [22]. In a retrospective review of 2357 patients treated with CTR, 48 patients required secondary surgery for recurrent symptoms, and among these patients, hypertension and diabetes were found to be significantly associated with carpal tunnel recurrence [23]. It is important to delineate what the patient's symptoms were before the primary CTR. The most common presenting symptom in primary CTS is intermittent impaired sensation in the median nerve distribution. Pains in the hand and wrist are the next most common symptoms, with nighttime paresthesias and weakness as other common complaints [24].

In those cases in which patients return for their first postoperative visit and report that they are "not any better," specific questioning as to which symptoms persist is crucial to identifying the cause and treatment for these persistent symptoms. Many will report that they still have numbness, but their night pain and dysesthesias have resolved. This suggests complete release of the ligament and no immediate intervention is

Table 16.1 Evaluation of recurrent versus failed (persistent or worsened) CTS

	Symptoms	Examination	Etiology	Treatment options
Recurrent CTS	Numbness completely resolved then recurs	Findings range from normal to (+) Tinel's, Phalen's, carpal compression test, or expanded two-point discrimination	Most common: no obvious abnormality other that adjacent, compressive scar. Other reasons: tenosynovitis, masses, incomplete release	• Revision CTR • Neurolysis • Interposition graft • Synovial flap • Muscle flap • Hypothenar • Fat pad flap • Vein wrap
Failed (persistent) CTS	Symptoms persist	Key finding: normal or unchanged two-point discrimination	Advanced age, diabetes, intrinsic nerve disease, concurrent compression, e.g., cervical, radiculopathy, incomplete release of TCL	• Observation if symptoms reoccurred to advanced age patients or medical comorbidities • Revision CTR for incomplete release of TCL
Failed (worsened) CTS	Noticed by the patient in the immediate postoperative period	Tinel's over incision. Expanded or absent two-point discrimination	Suspected nerve injury	• Neurolysis • Nerve repair • Interposition • Graft

CTR carpal tunnel release, *TCL* transverse carpal ligament

necessary. With observation, this numbness will continue to improve in most patients. It is helpful to perform Semmes-Weinstein or two-point discrimination testing at this point as this can be a sensitive method to monitor progressive nerve recovery [25].

It is important to distinguish persistent or recurrent pain from persistent or recurrent numbness. There are many reasons for these symptoms, including arthritis in adjacent joints and scar-related pain. An increase in numbness suggests nerve compromise. It is helpful to ask the patient whether the main complaint before the operation was numbness or pain. Nerve decompression for numbness is predictable, decompression for pain is not. Preoperative nerve studies and the operative report can help define the original problem and the extent of the surgical release. The incision should be inspected and a Tinel's sign test performed proximal to, along, and distal to the scar from the release. Worsened or absent Semmes-Weinstein monofilament or two-point discrimination as compared to preoperative measurement is consistent with intraoperative nerve injury. Objective measures, such as grip strength or sensory testing, should be used when possible to quantify deficits in the affected hand. Provocative maneuvers, such as Phalen's test, and carpal tunnel compression test can be performed and compared with the contralateral side and with any preoperative findings.

The use of cortisone injections has been advocated in the diagnosis of recurrent CTS. In a retrospective series of 28 wrists in 23 patients, Beck et al. [26] studied whether the result of cortisone injection predicted the outcome of revision CTR. Of the 23 wrists that had relief from injection, 20 had symptom improvement with surgery. The sensitivity and positive predictive value for injection alone predicted outcome of revision CTR in 87%. The results of injection as a predictor of successful revision CTR showed a positive trend, although they did not achieve statistical significance. The authors concluded that relief from injection as a diagnostic test for predicting successful revision CTR was found to have both a high sensitivity and a positive predictive value. Coupled with the components of the physical examination, injection seems to provide a good screening test to establish surgical success with revision CTR. The specificity of the test was lower, at 40%.

Even with careful preoperative evaluation and precise surgical release, revision CTR remains less successful than primary CTR [5]. Consequently, the treating surgeon must combine a thorough history, diligent examination, and information from adjunct tests to estimate the likelihood of success with revision CTR.

The Role of Diagnostic Tools

Supportive accessory studies take a secondary role in the management of failed or recurrent CTS. Nerve conduction studies (NCS) with electromyography (EMG) can help support a diagnosis though should not be relied on to determine the diagnosis. Electrodiagnostic studies are not always helpful in diagnosing recurrent CTS because electrical changes can persist even after successful releases [27, 28]. The use of these studies in the context of recurrent CTS can be useful if the patient had preoperative studies done. If the repeated NCS are worse or show signs of denervation of the thenar muscles, surgery may be indicated [3]. Unfortunately, worsened electrical studies don't predict the success of revision surgery [24].

Magnetic resonance imaging (MRI) can reveal extrinsic compression from a mass or bony excrescence. Stutz and colleagues [10] reported on 4 cases, out of 200 revision CTR surgeries, where a mass was found in the carpal tunnel (2 ganglions, 1 lipoma, and 1 fibroma). In our opinion, MRI is not accurate enough for diagnosis of recurrent compression or nerve injury. The AAOS guidelines recommend against the use of MRI in the routine evaluation of patients with CTS.

In a retrospective study of 34 patients who presented with CTS and underwent CTR, Karabay et al. [29] assessed the usefulness of ultrasonography for determining the potential causes of ongoing symptoms following CTR. An abnormal finding was detected by ultrasonography in 25 (74.5%) patients. The most common pathological findings were median nerve swelling (70.6%), incomplete transection of the TCL (23.5%), and perineural fibrosis (17.6%). The authors concluded that in the majority of the patients, the pathology related to the ongoing symptoms was detected by ultrasonography, suggesting that ultrasonography could be used as a complementary imaging method for identifying the causes of failure following CTR.

In a prospective study of 36 patients, Karabay et al. [30] sonographically evaluated the anatomy of the TCL after open CTR, in order to establish new ultrasonographic criteria for the completeness of TCL release. Patients were evaluated with physical examination and ultrasonography before and after the operation. All patients' symptoms resolved after surgery. TCL was found to be diffusely thickened and to have lost its smooth form after surgery. Postoperative TCL thickness showed a statistically significant increase when compared with preoperative values ($p < 0.05$). The authors concluded that sonography is a capable imaging method for assessment of the TCL after open CTR. In addition, ultrasound may be considered as a complementary tool to exclude diagnosis of incomplete transection of TCL in patients with persistent symptoms.

High-definition ultrasound has improved in its ability to delineate peripheral nerves and the surrounding tissues. It has been increasingly used to localize the anatomical causes of nerve compression in patients with persistent or recurrent CTS [31].

Nonoperative Care

In most cases of recurrent CTS, conservative measures will not provide adequate relief [32]. Scar modification, splinting, and other exercises to promote nerve and tendon glide can be instituted. Nonoperative treatment of recurrent CTS may provide symptomatic relief for a small number of patients but fail to benefit most patients in the long term, as reported by Strickland et al. [33]. Given our limited ability to control scar formation, revision decompression and neurolysis of the median nerve for treatment of perineural fibrosis are frequently disappointing [14, 15]. Wadstroem et al. evaluated the causes of unsatisfactory results after surgery for carpal tunnel syndrome in a retrospective analysis of 40

patients. Their most common pathological finding was fibrosis and adhesions in the carpal canal. In 30% of patients, other neuropathies were present, and bilateral operations had been performed in 55%. We offer revision surgery to patients with worsening numbness immediately after their first operation, patients with recurrent numbness after a previously successful operation, and a select subgroup of patients with persistent numbness after surgery.

Re-operative Strategies

Principles of Revision Nerve Surgery

We use nerve autograft for complete or partial nerve lacerations that cannot be sutured together without tension. Our choice of nerve graft includes medial antebrachial cutaneous (MABC) nerve and sural nerve. Before surgery, be sure to obtain consent to harvest nerve graft or to use a nerve conduit. Loupe magnification or a dissecting microscope is advocated.

The incision is planned so that it extends into normal tissue at least 2 cm on either end. The median nerve is recognized in the distal forearm straight beneath the palmaris longus tendon. The nerve is traced toward the carpal canal working on the anterior, ulnar margin of the nerve. As the scarred region comes nearer, care is taken to recognize the plane between the nerve and the scar. The existence of perineural fat forms a natural plane except in those occasions when the nerve has been lacerated. If you lose the plane between nerve and scar, proceed with the dissection distal to the carpal tunnel starting in normal tissue. Start on the anterior margin of the third common digital nerve and trace that nerve to the anterior, ulnar margin of the median nerve proper. When there is no clear plane between the nerve and scar, you can infer the line of dissection from the distal and proximal anterior, ulnar margins of the nerve. Dissect just ulnar to this line keeping a cuff of synovial tissue on the nerve. Once the nerve is released from scar, check the nerve for signs of injury such as disruption of fascicles or proximal neuroma (Fig. 16.3a). Identify the motor branch and common digital nerve. Adequate exposure of the median nerve and carpal tunnel is required. The revision CTR begins by extending the previous incision into normal tissue to allow proximal or distal identification of the median nerve to first facilitate exploration.

Dissection of the median nerve from proximal to distal should be performed along the ulnar border of the nerve to avoid damage to the motor branch. If dense scar is encountered during the proximal to distal dissection, stop and find the nerve in normal tissue distal to the densely scarred area. Alternate the exposure from proximal to distal and then distal to proximal until the nerve has been safely mobilized.

Repeat Simple Decompression

Unfortunately, given our limited ability to control scar formation, revision decompression and neurolysis of the median nerve for treatment of perineural fibrosis frequently yield unsatisfactory results [14, 15].

In patients with a significant interval between primary CTR and recurrent symptoms, Mosier et al. [22] treated recurrence of symptoms with simple repeat CTR. They define a “significant interval” as more than 1 year with resolution of carpal tunnel symptoms during this time. Beck et al. [26] demonstrated good relief with repeat decompression at many time intervals.

Revision Decompression with Interposition of Local or Remote Flaps

Interposition of a biologic barrier between the nerve and surrounding tissues may discourage scarring and provide a nutrient bed for axonal regeneration [34]. The advantage of local flaps like the ADQ, pronator quadratus, hypothenar fat flap [35], and palmaris brevis muscle flap [36, 37] is the ease with which they can be used. Unfortunately, length limitations may restrict their utility. Our preference is to use a hypothenar fat flap when possible (Fig. 16.1). After simpler techniques have

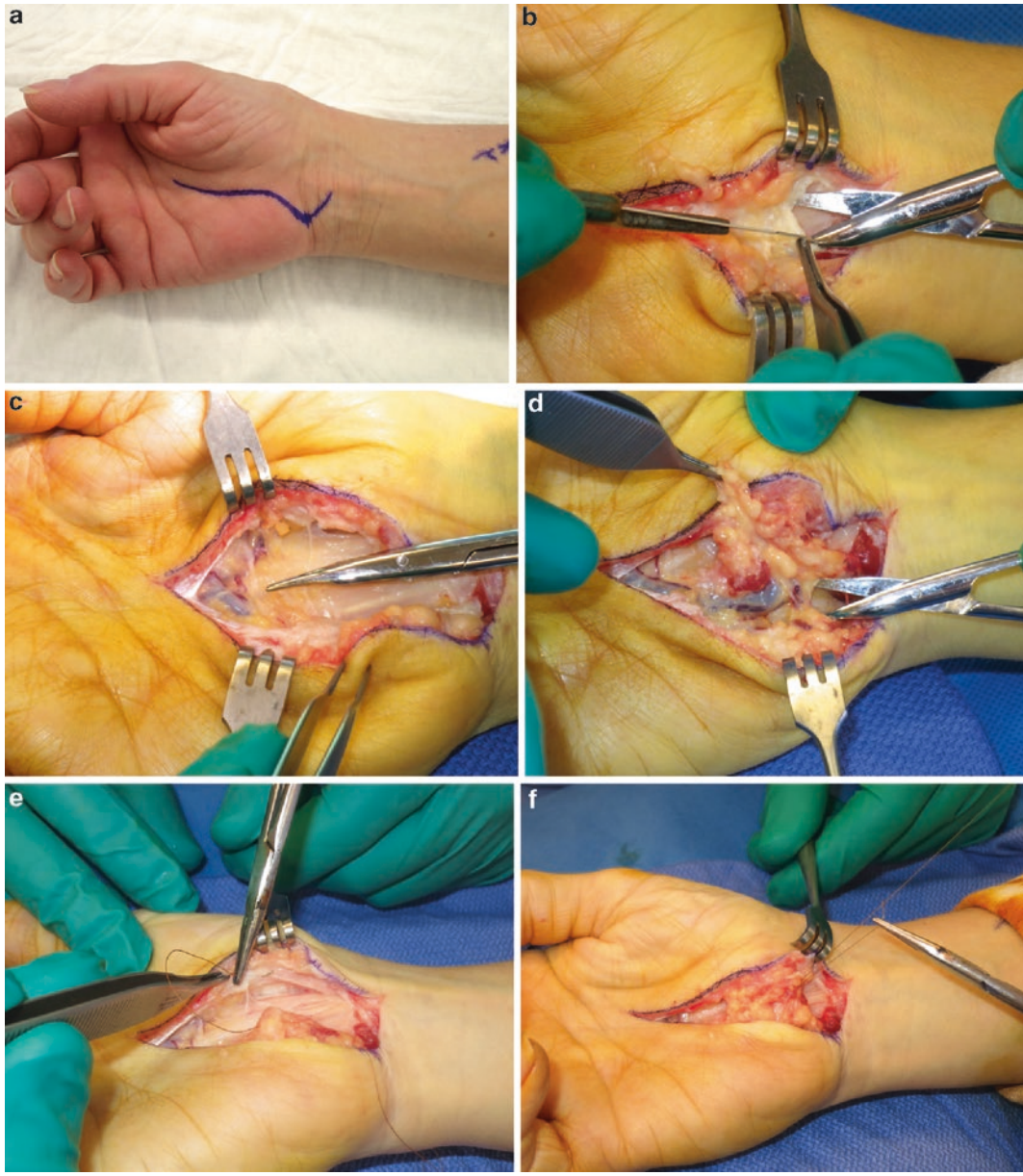

Fig. 16.1 Hypothenar fat pad flap. This patient had failed CTR and presented with a very sensitive median nerve. The hypothenar fat was mobilized to cover the scarred median nerve. (**a**) Extended approach. (**b**) Nerve exposure along the ulnar margin of the median nerve. (**c**) Identification of the superficial palmar arch. (**d**) Mobilization of fat flap. (**e**) Secure flap underneath TCL and suturing it to the radial leaflet of TCL. (**f**) Inset flap

been ruled out as options, it may be necessary to employ more complex free tissue transfers [12].

When the surgeon feels that the local tissue environment is fibrotic and/or avascular, several procedures may be performed to help protect the nerve from recurrent scarring, including autologous and synthetic nerve wraps and vascularized soft tissue coverage. Other factors to consider are also ease by which the tissue can be obtained and the comorbidities associated with its harvest. There are generally two categories of these procedures, as explained by Abzug et al. [38]:

1. Flaps that provide neovascularization, such as hypothenar fat pad flaps and synovial flaps, can help to improve nerve regeneration and gliding
2. Interposition materials, such as vein grafts and synthetic implants, help prevent scar formation by providing a mechanical barrier

Vascularized Flaps

Hypothenar Fat Pad Flap

The hypothenar fat pad flap interposes adipose tissue from the hypothenar eminence between the median nerve, the remnant of the TCL and surrounding scar. First described by Cramer [35] and refined by Strickland et al. [33], the hypothenar eminence includes a generous layer of adipose tissue of sufficient width and thickness to provide coverage for the median nerve within the carpal canal. Dissections of the hypothenar fat pad have demonstrated arterial branches to the fat pad arising from the medial side of the ulnar artery in Guyon's canal and more distally from branches of the ulnar artery to the small finger and fourth web space. These transverse and somewhat tortuous branches occurr approximately every 1 cm beginning at the distal wrist flexion crease. Additional arterial branches to the fat pad arise from arterial branches to the hypothenar muscles and palmaris brevis muscles [33].

Once sufficient mobilization of the fat pad has been accomplished, it is transposed over the median nerve and sutured to the undersurface of the radial leaflet of the TCL [33] (see Fig. 16.1).

In a retrospective series of 58 patients with 62 hands, Strickland et al. [33] showed excellent results in relieving recurrent symptoms with use of the hypothenar fat pad flap at an average follow-up of 33 months, with 37 of the 43 patients returning to their pre-surgery employment. Subjectively, the vast majority of patients had improvement of proximally referred pain, hypersensitivity, and nocturnal symptoms. There was also significant improvement in the Phalen's and Tinel's signs, and relief of dysesthesia and paresthesia was seen in 89% of patients. This relief was not immediate and in some cases took as long as 2.5 years to achieve. Two-point discrimination remained normal in 35 patients, improved from an expanded range to normal (<6 mm) in 21 patients, and remained expanded in 5 patients.

In a retrospective study of 28 patients, Craft et al. [34] showed significant improvement in the average two-point discrimination tests, the grip tests, and in the number of cases with positive Tinel's sign. Pain resolved in 83% of patients and numbness resolved in 42% of patients. The subjective complaint of "tingling" disappeared in 50% of patients.

Fusetti et al. reported on 20 patients who were treated with a hypothenar fat pad flap. Sixteen patients had adherence of the median nerve to the radial leaf of the divided TCL. The remaining four patients had an unidentifiable plane between the epineurium and the remains of the TCL. Subjectively, 18 of the 20 patients had complete resolution of their hyperesthesia and allodynia by 6 months after surgery. One patient had no improvement and would not recommend the procedure, while the remaining 19 patients stated that they would recommend the procedure. Seventeen of the 20 patients had resolution of provocative signs, including Phalen's, Durkan's, and Tinel's. Seven of the nine workers' compensation patients returned to work [39].

Wichelhaus et al. [40] conducted a retrospective study of 18 patients with recurrent CTS due to fibrotic adhesions of the median nerve, with scar formation of 3 to 5 cm in length. The hypothenar fat pad flap was used in all the cases, as it covered the entire length of the scarred nerve. Pain disappeared after the surgery in 14 patients, and the Tinel's sign disappeared in 16 patients. Hand function, grip strength, and pinch strength improved in all patients, as well as two-point discrimination recorded from the fingertips. Fifteen of the 18 patients would elect to have the operation done again if necessary. None of the patients reported hypothenar pain, none deteriorated after surgery, and all of the patients reported complete resolution of nighttime symptoms.

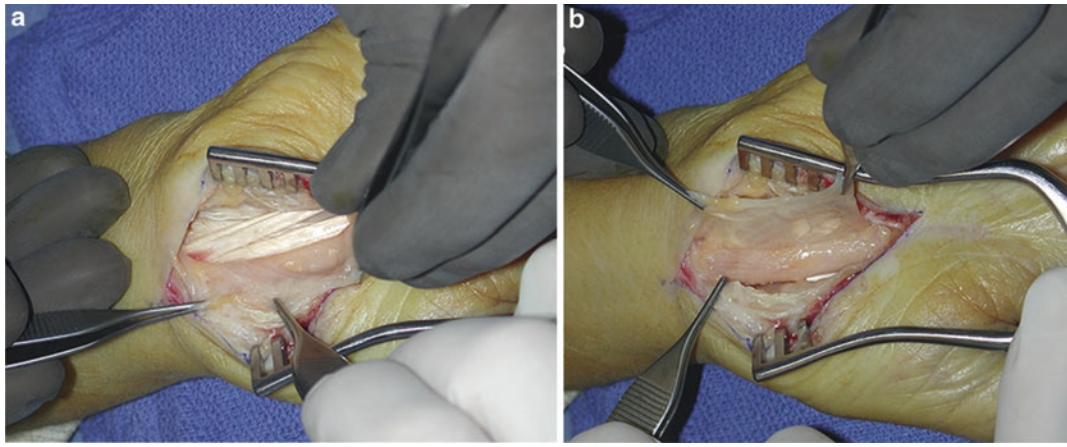

Fig. 16.2 (**a**) Synovial flap being elevated off of the FDS tendons. (**b**) Synovial flap before interposition placement on the median nerve

Synovial Flap

A vascularized synovial flap can be used to supply interposition and neovascularization to a scarred median nerve. This technique has the advantage of being able to be performed over the same incision without the requirement for expanded additional dissection. The synovial flap, raised off of the superficial flexor tendons deep to the median nerve, is a barrier to scar formation. The surgical technique is described in Figs. 16.2 and 16.3.

To make a synovial flap, raise a flap of synovium from the superficial flexors starting on the ulnar aspect of the carpal canal (Fig. 16.3b). Continue raising the flap from the level of the superficial arch to the wrist crease. At the proximal and distal margins of the flap, cut transversely to allow the flap to be mobilized. Continue to raise the flap to the margin of the median nerve (Fig. 16.3c). The flap is then draped over the nerve and sewn to the inner surface of the radial remnant of the TCL (Fig. 16.3d). The wrist is immobilized for 10 to 14 days post-surgery. If there is an associated nerve injury that was repaired or grafted during the procedure, the wrist is immobilized for 4 weeks. Splints and casts are kept low in the palm to permit full and prompt finger motion. Scars are treated with massage and elastomer.

In a retrospective series of 36 hands in 20 patients, Gannon et al. [21] demonstrated good results in relieving recurrent symptoms with use of the synovial flap. During the course of 6 years, eight patients had complete relief of their symptoms, ten had partial relief, and two had no improvement in symptoms. The average age of patients who had full relief was 53.5 years, in comparison with 61.8 years for patients with partial relief and an average age of 61.5 years for patients with no improvement.

Stutz et al. [28] compared clinical outcomes and electrophysiologic results of the hypothenar fat pad flap to the synovial flap, and the hypothenar flap appeared to produce superior clinical results, although statistical significance was not achieved.

Vascularized Fascial Flap

Indications for this procedure include recurrent CTS with soft tissue deficiency. The physical exam should include Allen's test and, if needed, an arteriogram test. Another important preoperative test is the NCS/EMG.

The operating room setup includes upper extremity nerve block, or other suitable anesthesia, hand table, tourniquet, and loupe or microscope magnification. The incision planning includes identification of the course of radial artery by landmarks or handheld Doppler. It is important to template the expected fascial flap

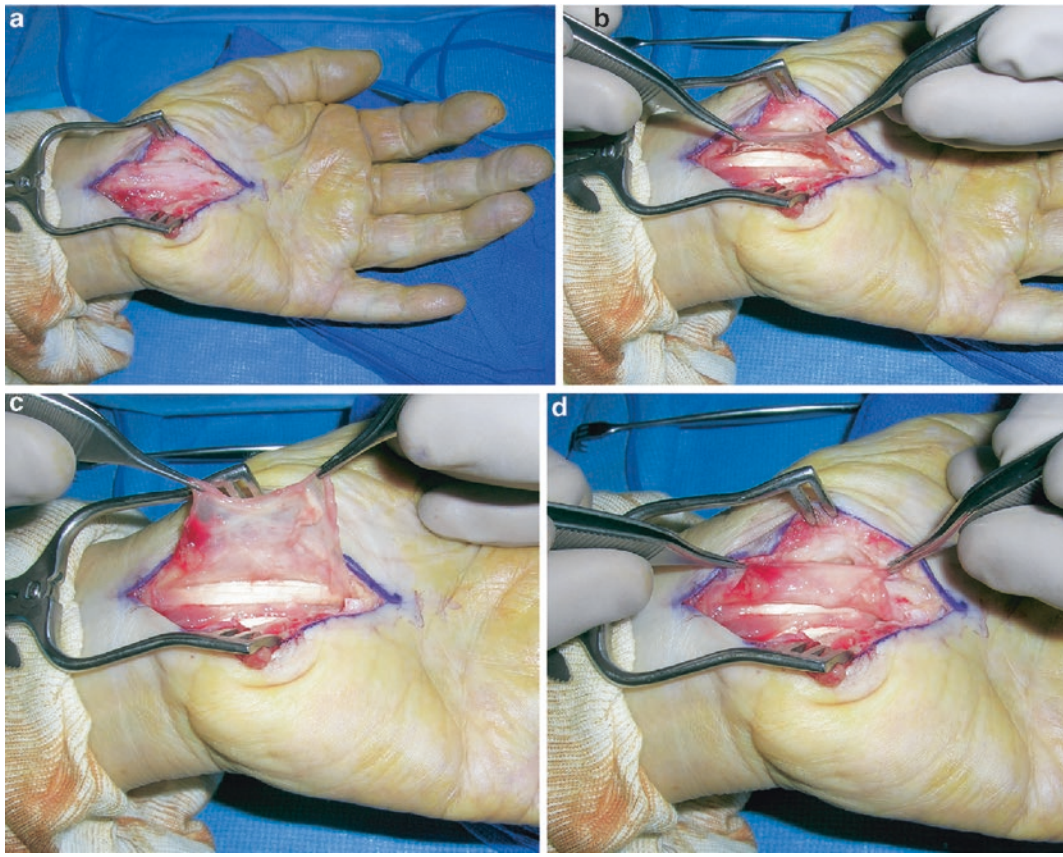

Fig. 16.3 Synovial flap technique. (**a**) Median nerve re-released. The dissection was extended approximately 2 cm on either end of the original incision into normal tissue. (**b**) The synovial flap raised from ulnar to radial side off the superficial flexors. (**c**) The synovial flap raised to the level of the median nerve. The distal border is at the level of the superficial arch. The proximal border is at the level of the wrist crease. (**d**) The synovial flap wrapped loosely about the median nerve

length in order to transpose it over the course of the radial artery. It is beneficial to overestimate pedicle length with an expected pivot point at the radial styloid. Diagram the planned incision as an extended open CTR with a Brunner-type incision across the wrist crease with proximal extension over the radial artery. A skin flap of subcutaneous tissue is raised as a single layer. Mark the underlying fascia with the outline of the previously designed template with surgical marking pen. The neurolysis involves exposing the median nerve at the carpal tunnel with neurolysis of the scarred nerve. The fascial flap is elevated by incising the fascia at the proximal and distal margins of fascia, identifying the radial artery at both margins, and confirming location deep to flap. Incise the remaining fascial flap along the margins of the underlying muscle.

Reverse Radial Artery Fascial Flap (Distally Based Radial Forearm Flap)

Tham et al. [41] defined making use of a reverse radial artery fascial flap to cover the whole length of scarred median nerve. It is critical to perform an Allen's test to guarantee patency of the ulnar artery. Following median nerve neurolysis, the incision is lengthened to the proximal third of the forearm using a point that is 4 cm proximal to the radial styloid as the expected pivot point. This incision will allow a

fascial flap measuring 4 cm wide and 5 cm long to be harvested. Dissection is carried down just superficial to the antebrachial fascia. The fascia is then incised at its periphery and elevated superficial to the epimysium of the forearm muscles while protecting the vascular connections to the radial vessels. The radial artery and its vena comitans are divided proximally to allow sufficient mobilization of the fascial flap. The fascial flap is then turned distally, passed deep to the flexor carpi radialis, and wrapped around the median nerve with the gliding surface of the flap in contact with the nerve. It is important to have a tension-free flap transposition. Suture is utilized to tack the flap in place [41].

Tham et al. reported on this procedure in six patients with an average of 2-year follow-up. All patients had previously sustained two or more decompressions. Operative findings reported evidence of chronic scarring of the median nerve with flattening and perineural fibrosis. All patients had improvement of their symptoms. Two patients had full resolution of pain and paresthesias, and the remaining four had only mild infrequent pain or paresthesia [41].

Distally Based Radial Forearm Perforator Flap

The lateral portion of fascial flap is reflected to expose the radial artery. Perforating vessels are identified as they branch perpendicular to the main axis of the radial artery. The flap is elevated in the subfascial plane from proximal to distal until adequate flap length is obtained leaving one or two dominant distal perforators.

In a study by Mahmoud et al. [42], the perforator-based radial forearm fascial flap was performed when patients had either already undergone a revision carpal tunnel surgery or if fibrosis around the median nerve extended proximally into the distal forearm. Out of eight patients, none reported dissatisfaction or worsening of symptoms after the surgery. Tinel's sign was fully resolved in four patients and greatly improved in the other four. The Phalen's sign disappeared in all patients. Two-point discrimination, grip strength, and pinch strength improved overall.

Dahlin et al. [43] noted that 3 out of 14 patients considered themselves cured or almost cured after this type of surgery, 7 patients improved, 1 patient was unchanged, and 3 patients were worse. Overall, pain and sensitivity at the wrist decreased significantly, and no patient experienced worse tingling or impaired sensation in the hand and fingers. However, ten of the patients reported problems from the donor site.

Interposition Materials

The ideal wrapping material should protect the nerve from compression by scar tissue, inhibit tissue adhesions to the nerve, improve gliding of the nerve during motion of the extremity, and decrease the scarring within the nerve trunk [34].

Autologous Vein Wrapping

Experimental studies in a rat model have shown that the autologous vein wrap can improve the functional recovery of the nerve and prevent scar formation around the previously scarred segment of the nerve [44–46]. Even though the mechanism still remains uncertain, human histopathologic analysis from re-exploration of autologous vein-grafted nerves further confirmed the inhibition of adhesions between the vein and the nerve. These biopsies also revealed neovascularization of the autologous vein graft and structural transformation of the vein endothelium [47, 48].

The autologous vein wrapping procedure is indicated for recurrent CTS in patients with at least two previous failed operations. The technique is also indicated in patients with severe nerve scarring or neuroma formation. However, it is not recommended in patients with chronic lower extremity venous insufficiency.

General anesthesia is used for this procedure because two operating fields are required, one for the median nerve re-exploration and one for the greater saphenous vein harvesting. The revision

surgery with the autologous vein wrapping technique involves revision decompression of the median nerve with neurolysis, greater saphenous vein harvesting from the lower extremity, and wrapping the vein graft around the previous compressed median nerve segment.

The median nerve in the wrist is exposed and released from the surrounding scar tissue. It is important to measure the length of the median nerve that needs to be covered. The length of the greater saphenous vein graft must be four to five times the scarred length of the nerve. The vein length harvested is usually 25–30 cm. A vein stripper can be used to harvest the greater saphenous vein graft minimizing the length of the incision in the lower extremity. After the saphenous vein graft is harvested, it is incised and opened longitudinally. The vein is circumferentially wrapped around the scarred segment of the median nerve from distal to proximal with the intima of the vein against the nerve. The two ends of the graft are tacked distal and proximal to the scarred segment of the median nerve on an immobile tissue. Each loop of the vein is stabilized with the adjacent loop using a loose 7-0 nonabsorbable, monofilament stitch. It is important to ensure that the intima of the vein graft is opposed to the nerve after each loop. Wrapping should not be too snug. The entire segment of the scarred nerve must be completely covered with the vein graft to prevent recurrence (Fig. 16.4). The wrist is immobilized in slight extension for 2 weeks postoperatively. Active and passive range of motion exercises are started after the splint is removed.

Several clinical studies have shown that the autologous vein wrapping technique is an effective treatment method for recurrent CTS [20, 49, 50]. After autologous vein wrapping, significant improvement of pain and grip strength has been noticed in the majority of patients. Most patients also showed improved two-point discrimination postoperatively. Nerve conduction studies revealed improvement of findings postoperatively in several patients, although they did not return to normal values. No complications due to the saphenous vein graft harvesting were noted other than transient swelling at the donor site that resolved in approximately 6 months.

Synthetic Wraps

In a similar fashion, synthetic devices can be utilized to supply interposition around the scarred nerve and inhibit scar reformation. Currently, there are available synthetic devices from bovine collagen (NeuraWrap, Integra LifeSciences, Plainsboro, NJ) and porcine extracellular matrix (Axoguard, Axogen Inc., Alachua, FL). Synthetic devices, such as Neuragen (Integra) and Axoguard (Stryker), are composed of an absorbable semipermeable collagen that is absorbed by the body over time through normal metabolic pathways [38]. During this process, no scar tissue forms nor does an inflammatory reaction arise, as

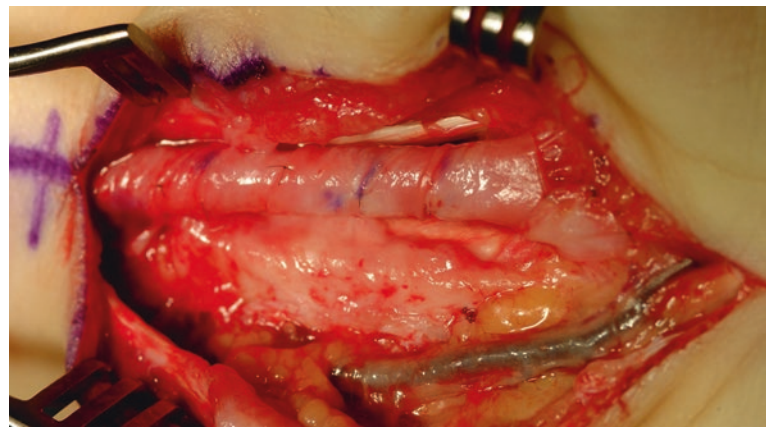

Fig. 16.4 Vein wrap technique. Wrapping the median nerve with autologous saphenous vein graft with its intima against the nerve. Each loop of the wrapped vein is stabilized to the adjacent loops with a 7-0 nonabsorbable, monofilament stitch. The entire scarred portion of the median nerve is covered with the vein graft

the device is composed of a semipermeable membrane which blocks fibroblasts and in this manner lessens perineural fibrosis [51, 52].

Synthetic nerve wraps used for revision carpal tunnel surgery have the advantages of decreased operative time and donor site morbidity. However, the cost of allograft nerve wrap may be considered a relative contraindication at some facilities. Currently, there is not sufficient data to demonstrate that these synthetic wraps are better than autologous vein wraps [38].

The surgical procedure involves revision median nerve decompression through a typical open carpal tunnel approach with proximal extension across the wrist flexion crease. The median nerve is recognized and freed of surrounding scar tissue. Once the nerve is sufficiently free, the synthetic nerve wrap is placed around the decompressed segment of the median nerve. The entire segment of scarred nerve must be completely covered to prevent recurrence. The synthetic nerve wrap is secured around the nerve with sutures. Care is taken to avoid suturing the synthetic nerve wrap to the nerve.

Clinical Outcomes

The results of revision CTR are variable, and many patients will experience some improvement, but 41% to 90% of patients will report persistent symptoms [25]. There is little evidence to help the physician know what clinical features or diagnostic studies are helpful in predicting a good outcome after surgery. There are many variables, such as physiologic and anatomic factors, as well as psychosocial contexts, that can preclude a favorable outcome.

Zieske et al. [13] evaluated intraoperative findings and outcomes of revision CTR in order to identify predictors of pain outcomes. In their retrospective study of 97 hands in 87 patients who presented with persistent, recurrent, or new symptoms, the recurrent group demonstrated a higher incidence of diabetes and a longer interval from primary CTR. This group was also less likely to present with pain. Incomplete release of the flexor retinaculum and scarring of the median nerve were common intraoperative findings. Nerve injury was more common in the "new symptoms" group. Higher levels of preoperative pain, use of pain medication, and workers' compensation were significant predictors of greater postoperative pain. They concluded that number of prior CTRs, baseline pain, pain medications, and workers' compensation status are important predictors of outcomes in this population.

Stutz et al. [10] described a number of causes for recurrent or unresolved CTS. Of the 200 patients included in their study, 108 (54%) experienced persistent or recurrent symptoms as a result of incomplete transection of the flexor retinaculum. In 65 cases, the distal edge of the retinaculum was intact, in 27 the proximal edge was intact, and in 5 the entire ligament was felt to be intact. Twelve patients experienced iatrogenic nerve lacerations from their initial procedure: four patients had incomplete lacerations, one had complete laceration of the motor branch, two had complete lacerations of the median nerve, two patients had lacerated motor branches, and three had lacerated palmar branches. The incomplete release and iatrogenic groups were thought to compose the patients with persistent CTS (120 patients). In the remaining 80 cases, the authors felt that symptoms were recurrent. In 46 patients, symptoms were caused by the constriction of the nerve as the result of scar tissue (23%). A mass within or adjacent to the carpal canal was responsible for symptoms in four patients (2%). The remaining 13 patients (7%) had no identifiable reason for recurrence.

Similarly, in a retrospective review of the surgical findings and outcomes of 50 consecutive patients who had undergone 55 revision CTRs, Jones and colleagues [3] reported incomplete release of the flexor retinaculum in 32 patients (58%) as the most common finding. Complete relief of symptoms following revision surgery was similar after open (57%) or endoscopic (56%) techniques. Ten patients (20%) showed no improvement and five patients required a third operation. This study also demonstrated that the precise location of the incomplete release did not correlate with the original technique (endoscopic or open).

Intraoperative findings that have been shown to have poorer outcomes are severe circumferential fibrosis around the median nerve, proliferative tenosynovitis, and amyloidosis [3]. The outcome ultimately lies with the pathology causing mechanical compression. Patients with an incompletely released TCL can expect to have outcomes similar to primary CTR. Outcomes are less predictable in more severe cases with circumferential fibrosis causing decreased vascularity or traction injury to the median nerve.

Based on the literature, it seems that median nerve re-decompression coupled with placement of a flap is an adequate treatment for recurrent CTS. Pedicled flaps seem to be preferable to free flaps, but there is no evidence in the articles arguing for the specific donor. Although there are no prospective data differentiating which treatment algorithm is the best for recurrent CTS, there is a trend in the literature favoring vascularized coverage with flaps, with the hypothenar fat pad flap appearing to have equal or better results than the others in clinical results and electrophysiologic testing [28, 53]. Unfortunately, we are not aware of any prospective study that examines the value of decompression alone versus decompression with placement of a flap.

Soltani et al. [54] compared two general treatment groups: decompression with flap interposition and repeated open decompression in a systematic review of the literature on the outcomes of treatment for recurrent and persistent CTS. They presented higher success rate with decompression and vascular flap coverage over simple repeated decompression (86% vs. 75% success rate, respectively). The difference in success rate between flap and nonflap was highly significant ($p = 0.001$). Our approach has evolved to the following algorithm:

1. Re-release, hypothenar fat flap
a. Recurrent carpal tunnel
b. Nerve injury
c. Atrophic subcutaneous tissue over carpal canal

2. Re-release, pedicle flap
a. Above with atrophic skin and subcutaneous tissues

3. Re-release, nerve wrap
a. Autologous vein wrap: recurrent symptoms, excessive scar, and/or two or more previous surgeries

Summary

Recurrent and persistent CTS can be a debilitating and difficult disease process with imperfect surgical results. The clinical examination and workup after primary CTR can be confusing and fraught with a number of confounding variables. In patients with persistent or recurrent symptoms, exploration with repeat TCL release and median nerve neurolysis may be performed. If severe scarring is noted, the use of an interposition material or flap is warranted. If the patient presents with new or worsening symptoms of numbness or weakness after CTR, then the physician must be concerned for iatrogenic nerve injury and exploration with repair should be considered.

Although patients may not obtain complete relief of symptoms as readily as after primary CTR, the literature supports repeat surgery, as improvement often occurs. However, one should keep in mind that the optimal treatment for this condition is not clear and there is not an established superior surgical option.

Acknowledgments The authors would like to thank Joelle Tighe, BS, and Edward Donley, BS, for their assistance in preparing this manuscript.

Disclosure The authors have no financial interest to declare in relation to the content of this chapter.

References

1. American Academy of Orthopaedic Surgeons Work Group Panel. Clinical guidelines on diagnosis of carpal tunnel syndrome. Available at: www.aaos.org/research/guidelines/CTS_guideline.pdf. Accessed 1 Feb 2011.
2. Atroshi I, Gummesson C, Johnsson R, et al. Prevalence of carpal tunnel syndrome in a general population. JAMA. 1999;282:153–8.
3. Jones NF, Ahn HC, Eo S. Revision surgery for persistent and recurrent carpal tunnel syndrome and for failed carpal tunnel release. Plast Reconstr Surg. 2012;129(3):683–92.

4. Karpitskaya Y, Novak CB, Mackinnon SE. Prevalence of smoking, obesity, diabetes mellitus, and thyroid disease in patients with carpal tunnel syndrome. Ann Plast Surg. 2002;48(3):269–73.
5. Botte MJ, et al. Recurrent carpal tunnel syndrome. Hand Clin. 1996;12:731–43.
6. Baranowski D, Klein W, Grunert J. Revision operations in carpal tunnel syndrome. Handchir Mikrochir Plast Chir. 1993;25:127–32.
7. Kern BC, et al. The recurrent carpal tunnel syndrome. Zentralbl Neurochir. 1993;54:80–3.
8. Kretschmer T, et al. Pitfalls of endoscopic carpal tunnel release. Part 2: conclusions from findings of open surgery. Chirurg. 2004;75(12):1207–9.
9. Cobb TK, Amadio PC, Leatherwood DF, Schleck CD, Ilstrup DM. Outcome of reoperation for carpal tunnel syndrome. J Hand Surg [Am]. 1996;21(3):347–56.
10. Stütz N, Gohritz A, van Schoonhoven J, Lanz U. Revision surgery after carpal tunnel release--analysis of the pathology in 200 cases during a 2 year period. J Hand Surg (Br). 2006;31(1):68–71.
11. Assmus H, Dombert T, Staub F. Reoperations for CTS because of recurrence or for correction. Handchir Mikrochir Plast Chir. 2006;38:306–11.
12. Pizzillo MF, Sotereanos DG, Tomaino MM. Recurrent carpal tunnel syndrome: treatment options. J South Orthop Assoc. 1999;8:28–36.
13. Zieske L, Ebersole GC, Davidge K, Fox I, Mackinnon SE. Revision carpal tunnel surgery: a 10-year review of intraoperative findings and outcomes. J Hand Surg [Am]. 2013;38(8):1530–9.
14. Wadstroem J, Nigst H. Reoperation for carpal tunnel syndrome. A retrospective analysis of forty cases. Ann Chir Main. 1986;5:54–8.
15. De Smet L. Recurrent carpal tunnel syndrome. Clinical testing indicating incomplete section of the flexor retinaculum. J Hand Surg (Br). 1993;18(2):189.
16. Goitz RJ, Steichen JB. Microvascular omental transfer for the treatment of severe recurrent median neuritis of the wrist: a long-term follow-up. Plast Reconstr Surg. 2005;115(1):163–71.
17. Dellon AL, Mackinnon SE. The pronator quadratus muscle flap. J Hand Surg. 1984;9A:423–7.
18. Jones NF, Shaw WW, Katz RG, et al. Circumferential wrapping of a flap around a scarred peripheral nerve for salvage of end-stage traction neuritis. J Hand Surg. 1997;22A:527–35.
19. Sotereanos DG, Xu J. Vein wrapping for the treatment of recurrent carpal tunnel syndrome. Tech Hand Upper Extrem Surg. 1997;1:35–40.
20. Varitimidis SE, Riano F, Vardakas DG, et al. Recurrent compressive neuropathy of the median nerve at the wrist: treatment with autogenous saphenous vein wrapping. J Hand Surg. 2000;25:271–5.
21. Gannon C, Baratz K, Baratz ME. The synovial flap in recurrent and failed carpal tunnel surgery. Oper Tech Orthop. 2007;17:102–5.
22. Mosier BA, Hughes TB. Recurrent carpal tunnel syndrome. Hand Clin. 2013;29(3):427–34.
23. Schreiber JE, Foran MP, Schreiber DJ, et al. Common risk factors seen in secondary carpal tunnel surgery. Ann Plast Surg. 2005;55:262–5.
24. Unglaub F, Wolf E, Goldbach C. Subjective and functional outcome after revision surgery in carpal tunnel syndrome. Arch Orthop Trauma Surg. 2008;128:931–6.
25. Steyers C. Recurrent carpal tunnel syndrome. Hand Clin. 2002;18:339–45.
26. Beck JD, Brothers JG, Maloney PJ, Deegan JH, Tang X, Klena JC. Predicting the outcome of revision carpal tunnel release. J Hand Surg [Am]. 2012; 37(2):282–7.
27. Melvin JL, Johnson EW, Duran R. Electrodiagnosis after surgery for carpal tunnel syndrome. Arch Phys Med Rehabil. 1968;49:502–7.
28. Stütz N, Gohritz A, Novotny A. Clinical and electrophysiological comparison of different methods of soft tissue coverage of the median nerve in recurrent carpal tunnel syndrome. Neurosurgery. 2008;62:194–8.
29. Karabay N, Toros T, Çetinkol E, Ada S. Correlations between ultrasonography findings and surgical findings in patients with refractory symptoms after primary surgical release for carpal tunnel syndrome. Acta Orthop Traumatol Turc. 2015;49(2):126–32.
30. Karabay N, Kayalar M, Ada S. Sonographic assessment of transverse carpal ligament after open surgical release of the carpal tunnel. Acta Orthop Traumatol Turc. 2013;47(2):73–8.
31. Tan TC, Yeo CJ, Smith EW. High definition ultrasound as diagnostic adjunct for incomplete carpal tunnel release. J `. 2011;16(3):289–94.
32. Varitimidis S, Herndon J, Sotereanos D. Failed endoscopic carpal tunnel release. J Hand Surg (Br). 1999; 24:465–7.
33. Strickland JW, Idler RS, Lourie GM, Plancher KD. The hypothenar fat pad flap for management of recalcitrant carpal tunnel syndrome. J Hand Surg [Am]. 1996;21(5):840–8.
34. Craft RO, Duncan SF, Smith AA. Management of recurrent carpal tunnel syndrome with microneurolysis and the hypothenar fat pad flap. Hand. 2007;2(3):85–9.
35. Cramer LM. Local fat coverage for the median nerve. In: Lankford LL, editor. Correspondence Newsletter for hand surgery, vol. 35. Chicago, IL: ASSH; 1985.
36. Rose EH. The use of the palmaris brevis flap in recurrent carpal tunnel syndrome. Hand Clin. 1996;12:389–95.
37. Rose EH, et al. Palmaris brevis turnover flap as an adjunct to internal neurolysis of the chronically scarred median nerve in recurrent carpal tunnel syndrome. J Hand Surg [Am]. 1991;16:191–201.
38. Abzug JM, Jacoby SM, Osterman AL. Surgical options for recalcitrant carpal tunnel syndrome with perineural fibrosis. Hand. 2012;7(1):23–9.
39. Fusetti C, Garavaglia G, Mathoulin C, et al. A reliable and simple solution for recalcitrant carpal tunnel syndrome: the hypothenar fat pad flap. Am J Orthop. 2009;38:181–6.
40. Wichelhaus A, Mittlmeier T, Gierer P, Beck M. Vascularized hypothenar fat pad flap in revision

surgery for carpal tunnel syndrome. J Neurol Surg. 2015;76(6):438–42.
41. Tham SK, Ireland DC, Riccio M, Morrison WA. Reverse radial artery fascial flap: a treatment for the chronically scarred median nerve in recurrent carpal tunnel syndrome. J Hand Surg [Am]. 1996;21(5): 849–54.
42. Mahmoud M, El Shafie S, Coppola EE, Elfar JC. Perforator-based radial forearm fascial flap for management of recurrent carpal tunnel syndrome. J Hand Surg [Am]. 2013;38(11):2151–8.
43. Dahlin LB, Lekholm C, Kardum P, Holmberg J. Coverage of the median nerve with free and pedicled flaps for the treatment of recurrent severe carpal tunnel syndrome. Scand J Plast Reconstr Surg Hand Surg. 2002;36(3):172–6.
44. O'Brien JP, Mackinnon SE, MacLean AR, Hudson AR, Dellon AL, Hunter DA. A model of chronic nerve compression in the rat. Ann Plast Surg. 1987;19(5):430–5.
45. Xu J, Sotereanos DG, Moller AR, Jacobsohn J, Tomaino MM, Fischer KJ, Herndon JH. Nerve wrapping with vein grafts in a rat model: a safe technique for the treatment of recurrent chronic compressive neuropathy. J Reconstr Microsurg. 1998;14(5):323–30.
46. Xu J, Varitimidis SE, Fisher KJ, Tomaino MM, Sotereanos DG. The effect of wrapping scarred nerves with autogenous vein graft to treat recurrent chronic nerve compression. J Hand Surg [Am]. 2000;25(1):93–103.
47. Chou KH, Papadimitriou NG, Sarris I, Sotereanos DG. Neovascularization and other histopathologic findings in an autogenous saphenous vein wrap used for recalcitrant carpal tunnel syndrome: a case report. J Hand Surg [Am]. 2003;28(2):262–6.
48. Vardakas DG, Varitimidis SE, Sotereanos DG. Findings of exploration of a vein-wrapped ulnar nerve: report of a case. J Hand Surg [Am]. 2001;26(1):60–3.
49. Varitimidis SE, Vardakas DG, Goebel F, Sotereanos DG. Treatment of recurrent compressive neuropathy of peripheral nerves in the upper extremity with an autologous vein insulator. J Hand Surg [Am]. 2001;26(2):296–302.
50. Sotereanos DG, Giannakopoulos PN, Mitsionis GI, Xu J, Herndon JH. Vein graft wrapping for the treatment of recurrent compression of the median nerve. Microsurgery. 1995;16(11):752–6.
51. Archibald SJ, Krarup C, Li ST, et al. A collagen-based nerve guide conduit for peripheral nerve repair: an electrophysiological study of nerve regeneration in rodents and nonhuman primates. J Comp Neurol. 1991;307:1–12.
52. Li ST, Archibald SJ, Krarup C, et al. Peripheral nerve repair with collagen conduits. Clin Mater. 1992;9: 195–200.
53. Tollestrup T, Berg C, Netscher D. Management of distal traumatic median nerve painful neuromas and of recurrent carpal tunnel syndrome: hypothenar fat pad flap. J Hand Surg [Am]. 2010;35:1010–4.
54. Soltani AM, Allan BJ, Best MJ, Mir HS, Panthaki ZJ. A systematic review of the literature on the outcomes of treatment for recurrent and persistent carpal tunnel syndrome. Plast Reconstr Surg. 2013;132(1):114–21.
55. Leslie BM, Ruby LK. Coverage of a carpal tunnel wound dehiscence with the abductor digiti minimi muscle flap. J Hand Surg. 1988;13A:36–9.
56. Sarris I, Sotereanos D. Vein wrapping for recurrent median nerve compression. Hand. 2004;4:189–94.
57. Chang B, Dellon AL. Surgical management of recurrent carpal tunnel syndrome. J Hand Surg (Br). 1993;18:467–70.
58. Mathoulin C, Bahm J, Roukoz S. Pedicled hypothenar fat flap for median nerve coverage in recalcitrant carpal tunnel syndrome. J Hand Surg. 2000;5:33–40.