Revision Carpal Tunnel Surgical Options

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Carpal tunnel syndrome (CTS) is one of the most common upper extremity procedures performed. Historically carpal tunnel release (CTR) was reported to have a high success rate. Prior to a study by Langloh and Linscheid in 1972, re-exploration of the carpal canal was not reported on in the literature [1]. The current literature includes studies reporting a failure rate of 2–25% [2–4] with a 3–12% rate of revision surgery [5, 6].

It is important to define "failure" and "recurrence." Failure after nerve surgery can occur for many reasons including a wrong diagnosis, wrong procedure, improperly performed procedure, or following surgery for a patient who, because of age or medical co-morbidities, lacks the capacity to regain normal nerve function in spite of an adequate release. Recurrence is typically defined as a return of numbness after a symptom-free interval following carpal tunnel release. A study of 28 patients by Craft et al. (2007) had an average interval of 7 years between original carpal tunnel release and re-exploration [7]. Zieske et al. (2013) observed a symptom-free interval of approximately 10 years in patients with recurrent CTS [8].

In this chapter we will review the etiology of recurrent carpal tunnel syndrome along with the evaluation, principles of surgical treatment, surgical technique, expected outcome, and outcomes of comparative studies.

Etiology of Recurrent Carpal Tunnel

The causes of recurrent carpal tunnel are most commonly believed to be perineural scarring, reconstitution of the transverse carpal ligament, subsequent trauma or a space occupying lesion such as tenosynovitis or mass that forms within the carpal canal [9] (Fig. 8.1).

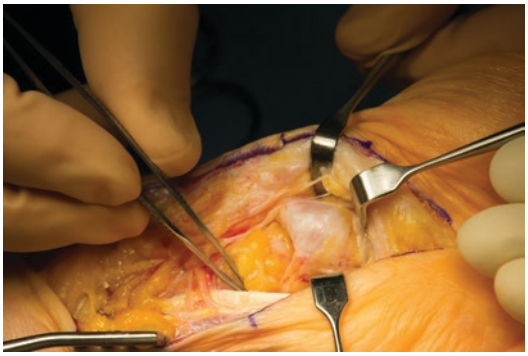

Fig. 8.1 Osteochondroma in the carpal canal

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One of the first studies looking specifically at recurrent CTS was in 1993 by Chang and Dellon. Underlying medical conditions such as diabetic peripheral neuropathy, cervical radiculopathy, multiple sclerosis and Charcot-Marie-Tooth can mimic recurrent carpal tunnel syndrome [10].

Evaluation

The key to an accurate diagnosis is a thorough history. Patients with recurrent carpal tunnel syndrome most commonly present with numbness (60%), paresthesia (50%), and, less commonly, with pain (42%) [7]. Similarly, Zieske et al. (2013) reported that patients with recurrent carpal tunnel were less likely to present with pain [8]. It is our bias that pain alone is rarely sufficient to invoke the diagnosis of recurrent carpal tunnel syndrome. We look for numbness in all or a portion of the median nerve distribution.

A Tinel's, Phalen's, Carpal Compression test may reproduce the symptoms of numbness in a median nerve distribution. The exception is elderly patients who often will not have symptoms with provocative maneuvers.

We typically document two-point discrimination in patients with suspected recurrent CTS even though Semmes-Weinstein monofilament testing has been shown to be more sensitive for compressive neuropathies [11]. We have been ordering fewer electrodiagnostic studies when evaluating primary carpal tunnel syndrome. In suspected recurrent carpal tunnel, we typically order nerve studies.

A diagnostic steroid injection in the carpal tunnel can help confirm the diagnosis of recurrent CTS. Beck et al. (2012) found 87% positive predictive value for successful revision surgery with a corticosteroid injection in the carpal tunnel. They also showed increased sensitivity and specificity when combining preoperative injection results with physical examination findings to 100% and 80% respectively [12].

Imaging studies have been used to evaluate patients with recurrent CTS. The use of MR imaging can be particularly helpful in cases when recurrent symptoms are accompanied by fullness in the region of the carpal canal [13] (Figs. 8.2, 8.3, and 8.4).

Ultrasound can be similarly helpful as a relatively quick, cost-effective tool to look for space

Fig. 8.2 Fullness proximal to carpal canal causing median nerve compression

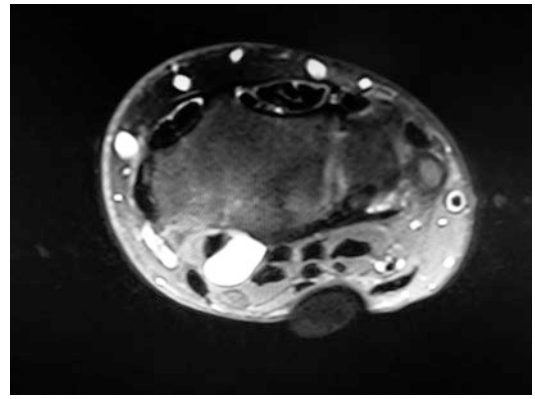

Fig. 8.3 Axial view of fluid filled lesion proximal to the carpal canal

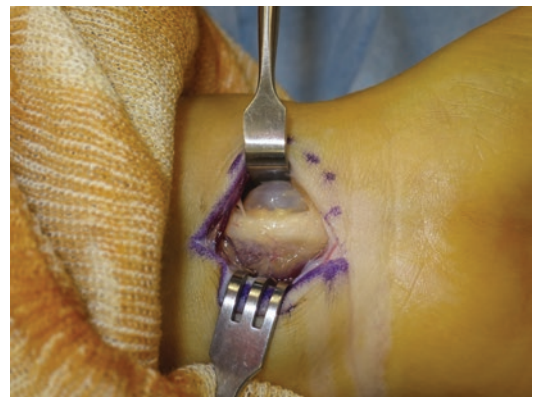

Fig. 8.4 Cyst emanating from the radial carpal joint compressing the median nerve

occupying lesions and to examine the cross-sectional area of the median nerve [14].

Principles of Surgical Treatment for Revision Carpal Tunnel Syndrome

1. Find the median nerve in normal tissue proximal and distal to the carpal canal. We will typically extend our exposure about 2 cm on either end of the existing scar.
2. "Surf the nerve". Most iatrogenic injuries are "side swipe" injuries. It is difficult to injure any longitudinal structure when you expose it from above.
3. Follow the anterior ulnar border of the median nerve. With the exception of aberrant branches, the motor branch exits the radial border of the median nerve (Fig. 8.5).
4. Separate the median nerve from the radial leaflet (Fig. 8.6).
5. Expose all terminal branches of the median nerve (Fig. 8.7).

Techniques with Expected Outcomes

There are numerous techniques that have been proposed for treatment of revision carpal tunnel release. These different "strategies" will be discussed in detail in the techniques section.

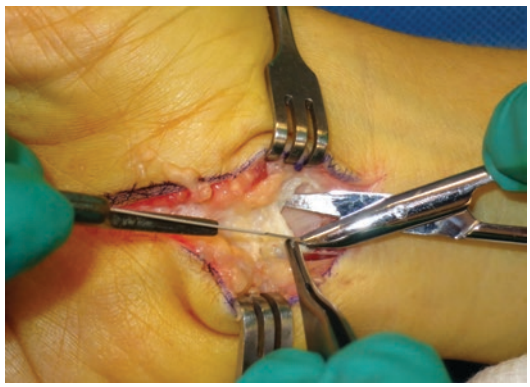

Fig. 8.5 Releasing the median nerve along its ulnar border

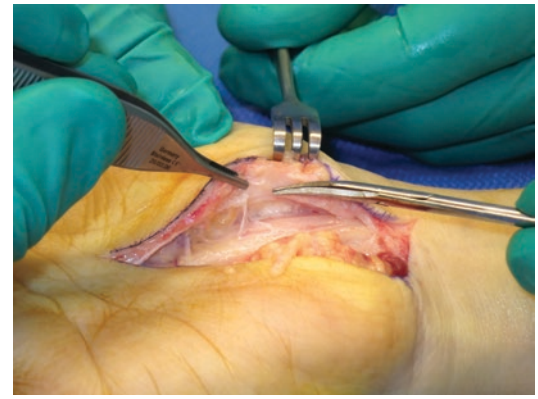

Fig. 8.6 Release adhesions between the median nerve and the radial leaflet

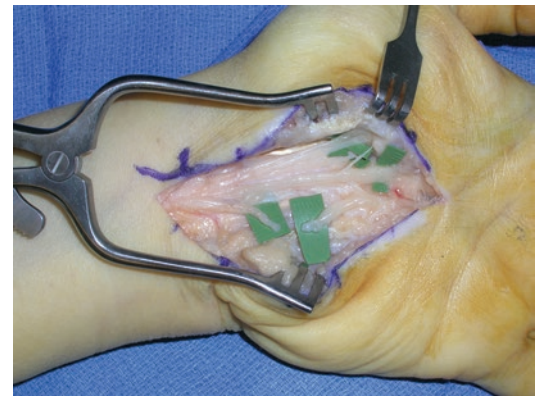

Fig. 8.7 Expose terminal branches of the median nerve

Repeat Simple Decompression

Beck et al. (2012) showed an 82% improvement in symptoms with simple decompression alone in a small sample size of 23 patients [12]. Similar results were found in a large meta-analysis by Soltani et al. in 2013. This study showed a 75% success rate in a heterogeneous cohort of 364 patients who underwent repeat open decompression for recurrent carpal tunnel syndrome. The second cohort included several different types of flaps in 294 patients in 14 different studies. The study concluded that an 86% rate of success could be achieved with decompression in conjunction with a vascularized flap. This was an 11% improvement in symptoms as compared to decompression alone [15]. A recent study by Pace et al. (2018) reviewed revision

CTR with or without hypothenar fat flap and concluded a trend, although not statistically significant, towards improved symptom severity score in patients undergoing simple decompression alone [16].

Historically percutaneous, mini open, and endoscopic carpal tunnel release were believed to have no role in the revision setting. A study by Luria et al. (2008) treated 41 patients with endoscopic revision after failed open release. Of the 41 patients, 37 reported improvement in symptoms, pinch strength and sensation, and reported a decrease in scar sensitivity along with satisfaction [17].

Synovial and Tenosynovial Flap

Revision carpal tunnel release with synovial flap uses locally available tissue with low morbidity. Gannon et al. (2007) described raising a flap of synovium off of the superficial flexors starting on the ulnar aspect of the ulnar canal. The flap is raised from ulnar to radial until the median nerve is encountered. Two transverse limbs are then made from ulnar to radial at the level of the wrist crease proximally and the superficial arch distally (Fig. 8.8). The flap is then laid over the median nerve and sutured to the radial aspect of the transverse carpal ligament (Fig. 8.9). They reviewed 36 patients with a successful outcome in 34/36 [18]. A similar flap is the vascularized tenosynovial flap reported on by Murthy et al. in 2013 [19]. This uses the original incision extended in a zig zag fashion ulnarly across the wrist flexion crease. Once the nerve is decompressed attention is turned towards the tenosynovial flap. The ulnar based pedicle of this flap comes from the palmar carpal branches of the ulnar artery. Therefore, this flap is raised from the synovium over the superficial flexors from radial to ulnar until there is enough mobilization of the flap to cover the nerve. Occasionally this requires a back cut to translate the flap proximally or distally. The proposed advantage of this flap is its vascularized nature and ability to allow neovascularization. This study reported good results in their series of 45 cases with complete pain relief in 96% and complete or near complete resolution of numbness and tingling in 80% of patients [19]. One critique of this method is it lacks substantial padding for a hypersensitive median nerve. However, proponents of this technique believe this serves as a barrier over the nerve to prevent the formation of a constrictive scar, which many contend to be the primary cause of recurrent CTS. Post operatively most surgeons recommend a short period of immobilization in a splint.

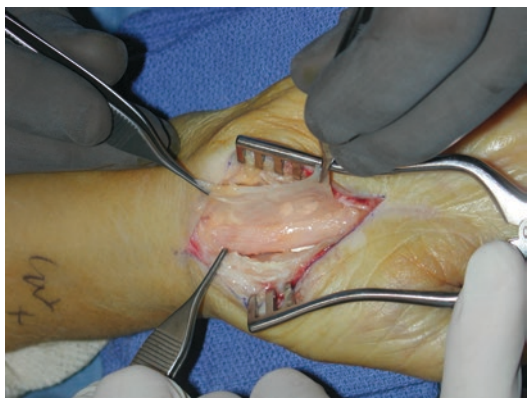

Fig. 8.8 Synovial flap elevated off of the superficial flexor tendons

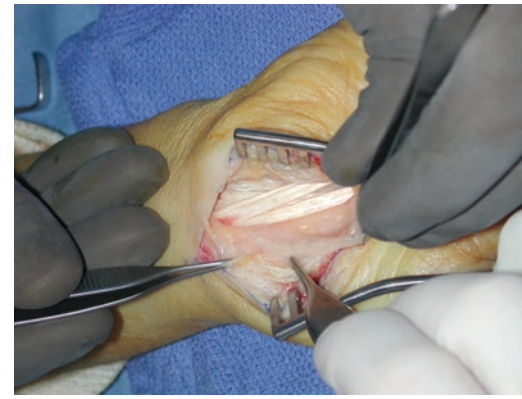

Fig. 8.9 Synovial flap inset between the median nerve and the radial leaflet of the transverse carpal ligament

Hypothenar Fat Pad Flap

Revision carpal tunnel release with a vascularized hypothenar fat flap is one of the most common flaps used in the revision carpal tunnel

release. This flap was first described by Cramer in 1985 in a study on four patients and has undergone numerous modifications since that time [20]. The hypothenar fat pad flap receives multiple segmental vessels, usually three vessels, from the ulnar artery in Guyon's canal allowing the flap to be mobilized radially. Some advantages of this flap are that it is locally available, well vascularized, and allows coverage of the median nerve in the carpal tunnel. A limitation of this flap is that it has limited excursion proximally and distally [20]. This fat flap commonly measures three by four cm in size [21]. Once this flap is mobilized it is sutured to the radial leaflet of the transverse carpal ligament. In a study of 28 patients by Craft et al. (2007), they found fibrosis and adherence of the median nerve to the radial leaflet of the transverse carpal ligament in all patients undergoing revision surgery [7].

This technique begins with an incision extending 2 cm proximal and distal to existing zone involved in the initial release (Fig. 8.10). Next, identify the median nerve in the distal forearm (Fig. 8.11) and release it to level of the superficial arch (Fig. 8.12). Afterwards, develop a plane between the ulnar skin and the hypothenar fat tissue. Leave a small layer of adipose tissue on the skin, the subdermal plexus, to avoid skin necrosis (Fig. 8.13). The dissection is carried ulnarly until the dermal attachment of the palmaris brevis muscle is encountered. At this point one must

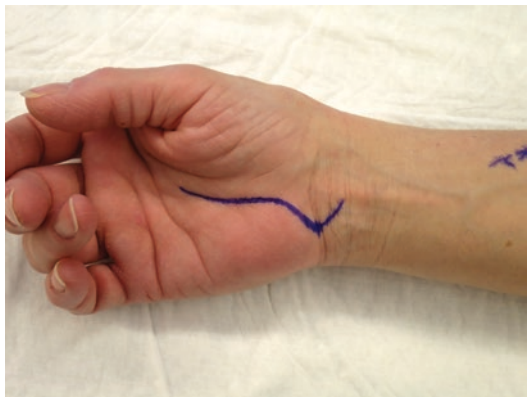

Fig. 8.10 Marked incision for the hypothenar fat pad flap

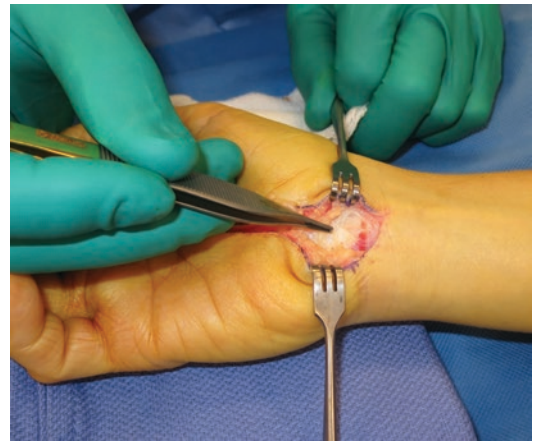

Fig. 8.11 Reconstituted ligament compressing the median nerve

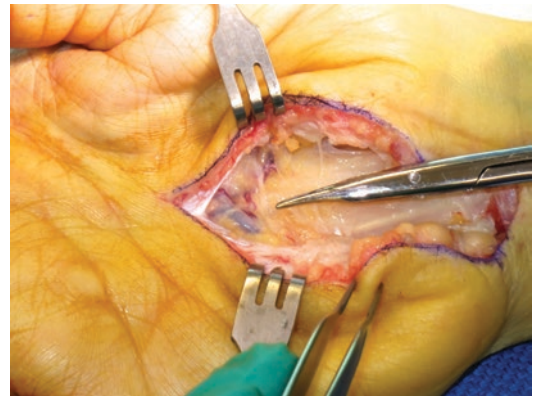

Fig. 8.12 Extending the distal exposure to the superficial arch

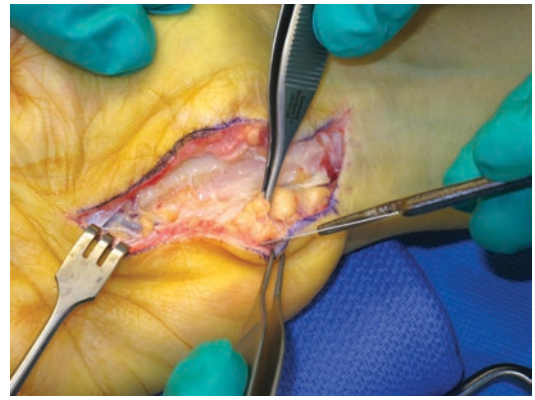

Fig. 8.13 Developing a plane of dissection between the hypothenar fat and the subdermal plexus

identify the digital nerves to the ring and middle finger distally and the ulnar artery and nerve proximally. The dissection then proceeds vertically between the palmaris brevis ulnarly and the ulnar neurovascular bundle radially (Figs. 8.14 and 8.15). This will allow the hypothenar fat pad to be elevated off the hypothenar muscles and translated radially to cover the median nerve. Lastly, use a horizontal mattress with chromic suture to apply the flap to the under surface of the radial leaflet (Figs. 8.16 and 8.17).

Multiple modifications have been described to allow increased mobility of the fat flap so that the flap is not under excess tension. One method is to ligate distally based deep arterial branches of the ulnar artery which allows further radial translation of the ulnar artery away from the ulnar nerve [22]. Another option described by Chrysopoulo et al. (2006) is to also dissect deep to the ulnar neurovascular bundle and to allow separation of the hypothenar fat flap off the underlying transverse carpal ligament. The ulnar portion of the transverse carpal ligament is then resected off of the hamate to allow easier and more complete elevation of the fat pad along with the ulnar neurovascular bundle [23] (Fig. 8.18).

Fig. 8.14 Mobilization of the hypothenar fat pad flap along the course of the superficial arch

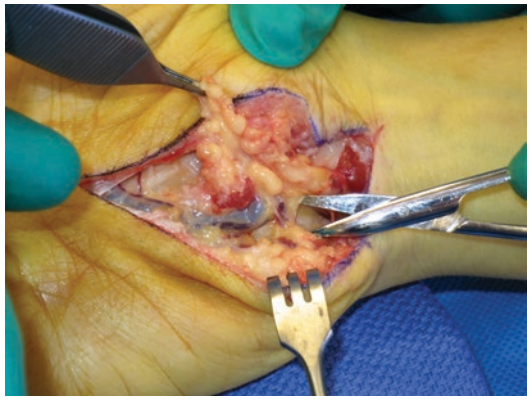

Fig. 8.15 Identifying and protecting the ulnar nerve

Fig. 8.16 Passing sutures from the flap to the undersurface of the radial leaflet

Fig. 8.17 Insetting hypothenar fat flap

Craft et al. (2007) showed that the hypothenar fat flap was most reliable for reducing pain (83%), and less effective in reducing tingling (50%), and numbness (42%). Importantly, no patients reported being worse off after revision [7]. Mathoulin et al. (2000) reported excellent or good results in 95% of patients (49% and 45% respectively) [22]. Strickland et al. (1996) reported excellent results in 62 patients [24]. More recently Wichelhaus et al. (2015) reported more modest results in a smaller series of 18

Fig. 8.18 A horizontal mattress suture tucks the flap beneath the radial leaflet

patients with 83% patient satisfaction, and complete pain relief in only 44% [21].

Synthetic Wraps

Another less commonly used technique for median nerve wrapping are the synthetic devices. There are a number of different commercially available synthetic materials that are marketed for revision CTR and nerve wrapping. Some contain an absorbable semipermeable collagen that works by blocking fibroblast and thereby decreasing perineural fibrosis. The synthetic collagen is then broken down by the body's normal metabolic pathways without producing an inflammatory reaction. This not unlike an autologous vein wrapping, in that once the nerve has been decompressed the nerve is wrapped circumferentially along the entire portion of the scarred nerve. Other synthetic nerve wraps are made of polyglycolic acid, placenta, porcine, and caprolactones. The presumed advantage of these synthetic materials is decreased donor site morbidity, and surgical time, compared with the use of local and remote autologous tissues.

Vein Wrapping

Vein wrapping is another option for coverage of the median nerve following revision CTR. The proposed mechanism of vein wrapping is to insulate the peripheral nerve from scar. A second possible benefit derives from placing the intimal side of the vein adjacent to the nerve to enhance nerve gliding. See Chap. 25 for vein wrapping technique. Varitimidis et al. (2001) presented on 15 patients treated with autologous vein insulator in the setting of revision CTR. They reported improved pain and sensation in all patients. They also noted improved objective parameters: nerve conduction velocities in eight patients and improved two-point discrimination in 14/15 patients [25].

Muscle Flaps

A number of local muscle flaps have been studied for coverage of the median nerve. These include pronator quadratus, palmaris brevis and abductor digiti minimi. Tung and Mackinnon (2001) described the pronator quadratus flap [6]. Palmaris brevis has been shown to be effective in the setting of revision CTR [26]. However, Strickland et al. (1996) stated that more often than not the palmaris brevis muscle was either absent or too small to provide adequate coverage.

Abzug et al. (2012) described the flexor digitorum superficialis muscle flap. Once the median nerve has been decompressed the incision is extended proximally past the myotendinous junction of the flexor digitorum superficialis. The muscle belly of the superficial flexor digitorum to either the ring or long finger is elevated off of the flexor digitorum carefully to preserve the myotendonous junction. The muscle belly is rotated 180° and used to cover the median nerve distally. This muscle flap should cover approximately 75% of the circumference of the median nerve and is then tacked down both radially and ulnarly [27].

Vascularized Fascial Flaps

The reversed radial artery fascial flap is a pedicle flap described for recurrent CTS by Tham et al. (1996). This technique requires sacrificing the radial artery which could lead to cold intolerance

or ischemia. A pre-operative Allen test is critical to ensure adequate ulnar arterial blood supply [28]. This flap has more recently been modified to a perforator-based radial forearm fascial flap. This can be done in either a single or two-incision technique with the use of an arm tourniquet. After performing an external neurolysis and epineurotomy of the median nerve dissection proceeds to the middle of the forearm by extending the carpal tunnel incision proximally or by making a second incision over the planned flap. The radial artery has 6–10 septocutaneous distal perforators off the radial artery. The most proximal perforator is reliably located five to eight centimeters proximal to the radial styloid and this is most commonly the pivot point for this flap. This perforator usually allows coverage of the median nerve in the forearm all the way to the distal end of the scarred median nerve in the palm. This can be modified and pivoted off of a more distal perforator if needed as these perforators are reliably located approximately every 0.4–1.5 cm distally ending 1.5 cm proximal to the radial styloid. The flap is raised ulnarly from the fascia over the flexor carpi ulnaris and extended laterally raising the fascia over the extensor carpi radialis brevis until the perforators off of the radial artery are encountered. The lateral antebrachial cutaneous nerve must be protected in the forearm. Mahmoud et al. (2013) reported good medium-term results in a small series of eight patients [29].

Remote Pedicle or Free Flaps

There have also been a number of remote pedicle or free flaps proposed for median nerve coverage in revision CTR. Goitz and Steichen (2005), reviewed a long term follow up in a small series of nine patients who underwent microvascular omental transfer. They reported on nine extremities in six patients who had previously failed a minimum of two procedures including a failed local pedicle flap coverage. The technique requires a large extensile open approach to the carpal tunnel extending approximately 7 cm proximal to the wrist crease with an external neurolysis, flexor tenosynovectomy, and exposure of the cephalic vein and radial artery in the proximal forearm. The omental flap is harvested from the gastroepiploic vessels by an abdominal or peripherial vascular surgeon. A microvascular anastamosis is then performed in the forearm with an end-to-end technique from the gastroepiploic vein to the cephalic vein. Additionally, the gastroepiploic artery is sutured end-to-side into the radial artery. Lastly the omentum in the forearm is then covered by a partial-thickness skin graft. They showed patient satisfaction and improved quality of life in five of the six patients. There were four complications, all relating to the omental harvest site, in this small series of nine extremities [30].

Outcomes Including Comparative Studies

Outcomes following revision carpal tunnel surgery are less predictable compared to primary CTR. Cobb et al. (1996) reported on 131 patients who underwent reoperation for CTS. This included a heterogeneous group of revision procedure ranging from simple decompression to flap coverage. They concluded no difference in outcomes based on the type of surgical procedure. They also found poor outcomes in one quarter of the patients with over 10% requiring a third operation [5].

When comparing the results of CTR following previous open verses endoscopic surgery, Hulsizer et al. (1998) found that patients having undergone previous endoscopic release had significantly better results than those who underwent open release. A total of 23 patients (30 wrists) were included in this study. Of the 23 patients, 14 (17 wrists) had a previous open CTR surgery and 9 patients (13 wrists) had a previous endoscopic CTR surgery. All patients underwent a standard open CTR for revision surgery. In the open surgery group, 47% reported improved or completely resolved symptoms, whereas, 77% patients in the endoscopic group had improved or completely resolved symptoms [31].

Numerous studies demonstrate that open revision carpal tunnel release is successful in treating

patients after failed endoscopic CTR [31, 32]. In 22 patients (24 wrists) that underwent open revision CTR for recurrent CTS after primary endoscopic release, Varitimidis et al. (1999), found that 20 patients (22 wrists) had an incomplete release of the flexor retinaculum. Pre-revision, 22 patients did not return to work after primary endoscopic release. After open revision 15 patients (16 wrists) returned to their previous employment and 5 patients (6 wrists) began working at different jobs with lighter duties. These results demonstrate that patients with persistent carpal tunnel syndrome after incomplete endoscopic release can experience improvement of symptoms with expected return to work after open revision [32].

In conclusion, revision carpal tunnel surgery has modest results as compared to primary carpal tunnel release. However, many authors have shown improvement in 50–85% of revision cases in small retrospective studies. O'Malley et al. (1992) showed 60–70% improvement in a study in 1998 [33]. Simple decompression alone has shown to be effective for treatment of revision carpal tunnel syndrome. Often the nerve shows significant scarring, and many recommend some type of coverage or interoposition to provide a barrier to scar tissue and to help with tendon gliding.

Our senior author's preference is a hypothenar fat flap in most cases of revision carpal tunnel release. The advantage of this flap is that it is locally available vascularized flap with low morbidity and good reproducibility. Post operatively early range of motion is initiated to help with nerve gliding. One other consideration is our senior author performs the majority of carpal tunnel surgery utilizing a Wide Awake Local Anesthesia No Tourniquet (WALANT) technique. The locally available hypothenar fat pad flap as well as the synovial flaps can easily be performed under WALANT.

References

1. Langloh ND, Linscheid RL. Recurrent and unrelieved carpal-tunnel syndrome. Clin Orthop Relat Res. 1972;83:41–7.
2. Bande S, De Smet L, Fabry G. The results of carpal tunnel release: open verse endoscopic technique. J Hand Surg. 1994;19B:14–7. https://doi.org/10.1016/0266-7681(94)90039-6.
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;129:683–92. https://doi.org/10.1097/PRS.0b013e3182402c37.
4. 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. 2010;35A:1010–4. https://doi.org/10.1016/j.jhsa.2010.03.035.
5. Cobb TK, Amadio PC, Leatherwood DF, Schleck CD, Ilstrup DM. Outcome of reoperation for carpal tunnel syndrome. J Hand Surg. 1996;21A:347–56. https://doi.org/10.1016/S0363-5023(96)80341-8.
6. Tung TH, Mackinnon SE. Secondary carpal tunnel surgery. Plast Reconstr Surg. 2001;107:1830–43.
7. Craft RO, Duncan SFM, Smith AA. Management of recurrent carpal tunnel syndrome with microneurolysis and the hypothenar fat pad flap. Hand. 2007;2:85–9. https://doi.org/10.1007/s11552-007-9025-7.
8. 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. 2013;38A:1530–9. https://doi.org/10.1016/j.jhsa.2013.04.024.
9. 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. 2006;31B:68–71. https://doi.org/10.1016/j.jhsb.2005.09.022.
10. Chang B, Dellon AL. Surgical management of recurrent carpal tunnel syndrome. J Hand Surg. 1993;18B:467–70.
11. Padua L, Coraci D, Erra C, Pazzaglia C, Paolasso I, Loreti C, et al. Carpal tunnel syndrome: clinical features, diagnosis, and management. Lancet Neurol. 2016;15:1273–84. https://doi.org/10.1016/S1474-4422(16)30231-9.
12. Beck JD, Brothers JG, Maloney PJ, Deegan JH, Tang X, Klena JC. Predicting the outcome of revision carpal tunnel release. J Hand Surg Br. 2012;37A:282–7. https://doi.org/10.1016/j.jhsa.2011.10.040.
13. Taghizadeh R, Tahir A, Stevenson S, Barnes DE, Spratt JD, Erdmann MW. The role of MRI in the diagnosis of recurrent/persistent carpal tunnel syndrome: a radiographical and intraoperative correlation. J Plast Reconstr Aesthet Surg. 2011;64:1250–2. https://doi.org/10.1016/j.bjps.2011.03.019.
14. Duetzmann S, Tas S, Seifert V, Marguardt G, Dombert T, Staub F. Cross-sectional area of the median nerve before revision carpal tunnel release – a cross-sectional study. Oper Neurosurg. 2018;14:20–5. https://doi.org/10.1093/ons/opx079.
15. 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;132:114–21. https://doi.org/10.1097/PRS.0b013e318290faba.
16. Pace GI, Zale CL, Gendelberg D, Taylor KF. Self-reported outcomes for patients undergoing revision carpal tunnel surgery with or without hypothenar fat pad transposition. Hand. 2018;13(3):292–5. https://doi.org/10.1177/1558944717701243.
17. Luria S, Waitayawinyu T, Trumble TE. Endoscopic revision of carpal tunnel release. Plast Reconstr Surg. 2008;121:2029–36. https://doi.org/10.1097/PRS.0b013e31817123de.
18. Gannon C, Baratz K, Baratz M. The synovial flap in recurrent and failed carpal tunnel surgery. Oper Tech Orthop. 2007;17:102–5. https://doi.org/10.1053/j.oto.2007.01.010.
19. Murthy PG, Abzug JM, Jacoby SM, Culp RW. The tenosynovial flap for recalcitrant carpal tunnel syndrome. Tech Hand Up Extrem Surg. 2013;17:84–6. https://doi.org/10.1097/BTH.0b013e318281d0e8.
20. Cramer LM. Local fat coverage for the median nerve. ASSH Corresp. Newsl. 1985;35:246.
21. Wichelaus A, Mittlmeier T, Gierer P, Beck M. Vascularized hypothenar fat pad flap in revision surgery for carpal tunnel syndrome. J Neurol Surg. 2015;76:438–42. https://doi.org/10.1055/s-0035-1551831.
22. Mathoulin C, Bahm J, Roukoz S. Pedicled hypothenar fat pad flap for median nerve coverage in recalcitrant carpal tunnel syndrome. J Hand Surg. 2000;5:33–40. https://doi.org/10.1142/S0218810400000120.
23. Chrysopoulo MT, Greenberg JA, Kleinman WB. The hypothenar fat pad transposition flap: a modified surgical technique. Tech Hand Up Extrem Surg. 2006;10:150–6. https://doi.org/10.1097/01.bth.0000225004.56982.42.
24. Strickland JW, Idler RS, Lourie GM, Plancher KD. The hypothenar fat pad flap for management of recalcitrant carpal tunnel syndrome. J Hand Surg. 1996;21A:840–8. https://doi.org/10.1016/S0363-5023(96)80201-2.
25. 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. 2001;26A:296–302. https://doi.org/10.1053/jhsu.2001.22528.
26. Rose EH, Norris MS, Kowalski TA, Lucas A, Flegler EJ. Palmaris brevis turnover flap as an adjunct to internal neurolysis of the chronically scarred median nerve in recurrent carpal tunnel syndrome. J Hand Surg. 1991;16A:191–201. https://doi.org/10.1016/S0363-5023(10)80096-6.
27. Abzug JM, Jacoby SM, Osterman AL. Surgical options for recalcitrant carpal tunnel syndrome with perineural fibrosis. Hand. 2012;7:23–9. https://doi.org/10.1007/s11552-012-9391-7.
28. Tham SK, Ireland DC, Riccio M, Morrison WA. Reverse radial artery fascial flap: a treatment for the chronically scarred median nerve is recurrent carpal tunnel syndrome. J Hand Surg. 1996;21:849–54. https://doi.org/10.1016/S0363-5023(96)80202-4.
29. Mahmoud M, Shafie SE, Coppola EE, Elfar JC. Perforator-based forearm fascial flap for management of recurrent carpal tunnel syndrome. J Hand Surg. 2013;38A:2151–8. https://doi.org/10.1016/j.jhsa.2013.06.034.
30. 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;115:163–71. https://doi.org/10.1097/01.PRS.0000138808.77038.D7.
31. Hulsizer DL, Stabler MP, Weiss APC. The results of revision carpal tunnel release following previous open verses endoscopic surgery. J Hand Surg. 1998;23A:865–9. https://doi.org/10.1016/S0363-5023(98)80164-0.
32. Varitimidis SE, Herndon JH, Sotereanos DG. Failed endoscopic carpal tunnel release: operative findings and results of open revision surgery. J Hand Surg Br. 1999;24B(4):465–7. https://doi.org/10.1054/jhsb.1999.0243.
33. O'Malley MJ, Evanoff M, Terrono AL, Millender LH. Factors that determine re-exploration treatment of the carpal tunnel syndrome. J Hand Surg. 1992;17A:638–41. https://doi.org/10.1016/0363-5023(92)90307-B.