Surgical options for recalcitrant carpal tunnel syndrome with perineural fibrosis

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Abstract Surgical release of the transverse carpal ligament for the treatment of carpal tunnel syndrome (CTS) is, in general, a very successful procedure. Some patients, however, fail this standard release and have persistent or recurrent symptoms. Such recalcitrance may relate to incomplete release but more often relates to perineural or intraneural fibrosis of the median nerve. While there is no good treatment for intraneural fibrosis, numerous procedures have evolved in an attempt to treat perineural fibrosis which restricts nerve gliding. These include procedures to isolate the nerve from scar as well as procedures to bring neo-vascularization to the median nerve. This review describes the various surgical treatment options for recalcitrant CTS as well as their reported outcomes.

Keywords Carpal tunnel syndrome · Recalcitrant carpal tunnel syndrome · Revision carpal tunnel · Carpal tunnel release

Introduction

Originally described in 1854, median nerve compression at the wrist, otherwise known as “carpal tunnel syndrome,” is

currently the most common compressive neuropathy in the upper extremity, affecting approximately 10% of the population [35]. Surgical options for carpal tunnel release include utilization of a fasciotomy, mini-open incisions, open incisions, and endoscopic release. All of these techniques involve incising the transverse carpal ligament and have reported success rates of 75% to 98% [3, 7, 15–17, 27]. Thus, 2–25% of patients remain symptomatic or have early recurrence of symptoms [3, 7, 15–17, 27].

The most common pathologic finding reported at reoperation for true persistent symptoms is incomplete release of the transverse carpal ligament [17]. However, this may be an overstatement as the transverse carpal ligament reconstitutes with scar and it is extremely difficult for the reoperating surgeon to define the difference between the virgin and reconstituted ligament. If necessary, a small portion of the ligament can undergo a pathologic evaluation to microscopically assess the tissue as normal ligament or reorganized scar. Therefore, if incomplete release is felt to be the cause of persistent symptoms, a complete release of the transverse carpal ligament can be performed with outcomes expected similar to primary carpal tunnel decompression [5, 21, 40]. If the transverse carpal ligament was adequately released during the index procedure, the second most commonly cited reason for recurrence is perineural fibrosis tethering the median nerve within the carpal tunnel [10, 14, 21, 27, 34, 36]. These recalcitrant carpal tunnel symptoms can be initially treated conservatively, akin to primary carpal tunnel syndrome, but Strickland and colleagues report that conservative measures will not provide adequate relief in the majority of patients [33]. Given our limited ability to control scar formation, revision decompression and neurolysis of the median nerve for treatment of perineural fibrosis often yield disappointing results [8, 17, 40].

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In an attempt to solve this dilemma, numerous surgical procedures have been proposed to protect the released median nerve from recurrent scarring. Some procedures aim to protect the median nerve from scarring by encompassing and isolating the nerve with either autograft or synthetic material. A second approach is to provide both interposition and neovascularization to improve nerve regeneration and gliding.

Surgical Options

Interposition

Vein Wrapping

The concept of interposing vein around a nerve as a barrier to prevent scar formation was originally described in a rat model where sciatic nerves were chronically compressed and then wrapped with autologous vein [26, 42]. Subsequently, Xu et al. performed this procedure in 50 rats, with a control group of 50 rats, to determine if scar was prevented and nerve function recovered [43]. This study demonstrated functional and electrophysiologic improvement in the group with the autogenous vein wrapping. Histologic evaluation demonstrated significant nerve degeneration and scar formation in the control group but not in the group with autogenous vein wrapping [43].

The procedure is currently utilized to treat recalcitrant carpal tunnel syndrome by making a standard approach to the carpal tunnel with extension across the wrist crease. The median nerve is identified and freed of surrounding scar, ensuring identification of the nerve in a normal bed proximally and distally. Once the median nerve is adequately exposed and free, attention is turned to either the ipsilateral or contralateral leg for harvest of the greater saphenous vein. A longitudinal incision is made 1 cm anterior to the medial malleolus, and the vein is identified. Subsequently, a vein stripper is utilized to obtain approximately 25 to 30 cm of vein, as it is necessary to have the vein length three to four times the length of the scarred nerve. An alternative is to utilize a superficial vein in the forearm by extending the incision proximally (Fig. 1a). Once

the vein is harvested, it is incised and opened in a longitudinal fashion. The intima portion of the vein is placed against the nerve and sutured with 7–0 or 8–0 nylon to tack the vein in place to the unscarred bed. The vein is then circumferentially wrapped around the median nerve from distal to proximal ensuring that constriction of the nerve is avoided. After each 360° wrap, the vein is loosely stabilized to the adjacent wrap with a 7–0 or 8–0 nylon stitch (Fig. 1b). Once the proximal normal nerve bed is reached, the vein is tacked down to local tissue. The wounds are then closed in a standard fashion [38]. It is imperative that the entire segment of scarred nerve is covered to prevent recurrent compression [22].

Sotereanos et al. initially reported the outcome of this procedure in 1995 in a case series of three patients [32]. All patients were noted to have significant improvement on electromyograms. Additionally, two of the three patients had significant improvement in subjective and objective findings. This technique was further reported on in 2001 with a series of 19 patients. All patients were noted to have reduction in pain and sensory disturbance. Two-point discrimination and electrodiagnostic findings were also noted to be improved [38].

Synthetic Devices

In a similar manner, synthetic devices can be utilized to provide interposition around the scarred nerve. Synthetic devices, such as Neuragen (Integra) and Axoguard (Stryker), are composed of an absorbable semipermeable collagen that is absorbed by the body over time via normal metabolic pathways. During this process no scar tissue forms nor does an inflammatory reaction occur, as the device is composed of a semipermeable membrane which blocks fibroblasts and thus lessens perineural fibrosis [1, 19]. These synthetic devices have the advantages of eliminating donor site morbidity, reducing operative time, and eliminating additional dissection that may produce additional scar formation. However, no data currently exist as to whether such nerve wraps perform as well as autograft vein wrapping.

Fig. 1 **a** Identification of a superficial vein in the forearm. **b** The vein has been split longitudinally and the intima portion has been placed against the median nerve. Subsequently, the vein was wrapped around the median nerve multiple times (courtesy of Shriners Hospital for Children, Philadelphia, PA)

The surgical procedure involves performing a standard open carpal tunnel approach with proximal extension across the wrist flexion crease. The median nerve is then identified and freed of surrounding scar tissue. Once the nerve is adequately free, the synthetic nerve conduit or wrap is placed around the nerve starting at the normal wound bed proximally and extending along the scarred nerve distally (Fig. 2).

Interposition with Neovascularization

Hypothenar Fat Pad Flap

The hypothenar fat pad flap procedure was initially described in 1985 by Cramer in a correspondence newsletter and subsequently modified by Strickland [33]. The procedure was designed to be a pedicled flap of hypothenar fat that is mobilized and interposed between the neurolysed median nerve and the remaining leaves of the transverse carpal ligament [33]. It is felt that the interposed fat would encompass the median nerve, prevent readherence to the leaves of the transverse carpal ligament, and provide a smooth gliding bed for the median nerve [33].

The hypothenar fat pad procedure is performed utilizing either regional or general anesthesia. A curvilinear incision is made parallel to the hypothenar eminence, and dissection is carried down through the palmar aponeurosis and reconstituted transverse carpal ligament. Once the median nerve is identified, an external neurolysis is performed. Following neurolysis, sharp dissection is utilized to identify a plane between the dermis of the hypothenar skin and underlying adipose tissue. It is important to keep the dermal flap sufficiently thick to prevent devascularization. Once the correct plane is identified, dissection is continued in an ulnar direction until the dermal insertion of the palmaris brevis is reached. Subsequently, the digital nerves to the ring and small fingers are identified distally, and the ulnar nerve and artery are identified proximally. With the aforementioned structures

Fig. 2 Synthetic device placed around the median nerve (courtesy of Joshua Abzug, MD)

protected, the fat pad is elevated by sharp dissection beginning at the ulnar edge. Once adequate mobilization of the fat pad is present, it is transposed over the median nerve to the radial wall of the carpal canal (Fig. 3). The fat pad is then sutured to the radial wall of the carpal canal, thus providing an interposition between the median nerve and remaining leaves of the transverse carpal ligament [33]. It is also believed to provide neovascularization to the median nerve since the fat pad remains attached to its pedicle.

The results of 62 hands in 58 patients treated with this procedure were reported by Strickland et al. in 1996. During reoperation it was noted that the median nerve was consistently adherent to the radial leaf of the divided transverse carpal ligament. Additionally, significant epineural thickening, a pseudoneuroma, was present. 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. Of the 43 patients who worked prior to surgery, 37 returned to work. Three transient complications were noted during the study period, which all resolved within 3 months of surgery, including one ulnar digital nerve paresthesia in the small finger, one patient with numbness over the hypothenar eminence, and one case of cellulitis [33].

Additional reports by Mathoulin et al. and Craft et al. have also shown promising results. Mathoulin et al. had good or excellent results in 94% of patients and failure in 4.5% [24]. Craft et al. had complete disappearance of pain in 83% of patients, subjective improvement of pain in 93%, subjective improvement in numbness in 83%, and subjective improvement in tingling in 85%. No patients were subjectively worse postoperatively [6].

Recently, Fusetti et al. reported on an additional 20 patients treated with a hypothenar fat pad flap. Sixteen of these patients had adherence of the median nerve to the radial leaf of the divided transverse carpal ligament, with the remaining four having an unidentifiable plane between the epineurium and the remnants of the transverse carpal ligament. Subjectively, 18 of the 20 patients had complete resolution of their hyperesthesia and allodynia by 6 months postoperatively. One patient was noted to have no improvement and would not recommend the procedure whereas the remaining 19 patients would recommend the procedure. Seventeen of the 20 patients had resolution of the irritation signs, including Phalen's, Durkan's, and Tinel's. Seven of the nine worker's compensation patients returned to work postoperatively [11].

Reverse Radial Artery Fascial Flap

Tham et al. describe utilizing a reverse radial artery fascial flap to provide adequate tissue enabling coverage over the entire length of scarred median nerve. Prior to utilizing this

Fig. 3 **a** Elevation of the hypothenar fat pad. **b** Placement of the hypothenar fat pad over the median nerve. (Courtesy of Shriners Hospital for Children, Philadelphia, PA)

technique, it is imperative to perform an Allen test to ensure patency of the ulnar artery. Following median nerve neurolysis, the incision is extended to the proximal third of the forearm utilizing a point 4 cm proximal to the radial styloid as the anticipated pivot point. This incision will enable a fascial flap measuring 4 cm wide and 5 cm in length to be harvested. Dissection is carried down just superficial to the antebrachial fascia for the aforementioned dimensions. The fascia is then incised at its periphery and elevated superficial to the epimysium of the forearm muscles while ensuring preservation of the vascular connections to the radial vessels. Next, the radial artery and its venae comitans are divided proximally allowing for adequate 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. Suture is utilized to tack the flap in place and the wounds are closed primarily [35].

Tham et al. reported on this procedure in six patients after an average of 2 year follow-up. All patients had improvement of their symptoms with two patients having complete resolution of pain and paresthesias, and the remaining four having only mild intermittent pain or paresthesia [35].

Posterior Interosseous Artery Flap

The posterior interosseous artery flap is a fasciocutaneous island flap supplied by branches of the posterior interosseous artery [23, 29, 44–46]. The flap can be based proximally or distally, however retrograde flow requires an intact distal communicating artery between the anterior and posterior interosseous arteries proximal to the distal radioulnar joint (DRUJ) [28]. This communicating artery is absent in approximately 5% of the population, therefore it is necessary to ensure it is present prior to raising the flap [28]. The technique is performed by marking the desired template, utilizing a pivot point 2 cm proximal to the DRUJ and an axis along the line joining the lateral epicondyle and DRUJ. The middle (median) perforator of the posterior interosseous

artery, located at the midpoint of the axis, should be included in the flap [28].

Once the landmarks are drawn out, the next step is to explore the pedicle by identifying the vessels on the interosseous membrane in the base of the septum between the fifth and sixth dorsal extensor compartments. If there is no distal arterial communication between the posterior interosseous and anterior interosseous arteries, the procedure should be abandoned and an alternative flap utilized. If communication is present, dissection of the pedicle is performed in a distal to proximal direction leaving a cuff of tissue to preserve the fine venae comitantes. The ulna border is subsequently incised and elevated in a subfascial plane followed by incision and elevation of the radial border in a subfascial plane. Dissection of the septum and pedicle continues by ligating or cauterizing muscular arterial branches until the septum is attached by only the posterior interosseous artery. The flap is now rotated over the carpal tunnel and sutured in place ensuring no kinking of the pedicle [28].

Utilization of the posterior interosseous artery flap in recalcitrant CTS has been limited to the European literature with good results demonstrated in the majority of cases [20, 39]. Vogelien and colleagues reported on the results of the technique in 14 patients with a mean follow-up of 2 years. Twelve of the 14 patients had significant improvement with pain scores averaging 6.7 preoperatively and 1.5 at follow-up. The duration of symptoms before the reoperation did not influence the outcome with the best results noted in patients without extensive median nerve damage [39].

Synovial Flap

A vascularized synovial flap can also be used to provide interposition and neovascularization to a scarred median nerve. After median nerve neurolysis, the tenosynovium deep to the median nerve is elevated as a flap in a radial to ulnar direction utilizing the ulnar aspect as the vascularized pedicle (Fig. 4a). The flap is then placed superficial to the median nerve and the radial leaf is tacked down to the

Fig. 4 **a** Elevation of the tenosynovial flap utilizing the ulnar aspect as the vascularized pedicle. **b** Placement of the vascularized tenosynovial flap over the median nerve (courtesy of The Philadelphia Hand Center, Philadelphia, PA)

wound bed [41] (Fig. 4b). This technique has the advantage of being able to bring vascularized interposing tissue through the same incision without the need for extensive further dissection.

Muscle Flaps

Numerous muscle flaps have been proposed for recalcitrant carpal tunnel syndrome to provide interposition around a scarred nerve as well as to bring neovascularization in the hope of restoring function to the damaged nerve. The majority of these muscle flaps have been taken from the intrinsic muscles of the hand including the palmaris brevis flap [31], the abductor digiti minimi flap [18, 25, 30], the pronator quadratus flap [9], and the first or second radial lumbrical flaps [37] and thus cover the distal half of the carpal tunnel. These muscle flaps bring vascularized tissue that provides interposition, however the amount of tissue provided may be inadequate to cover the entire length of the scarred median nerve. Since the fibrosis is most commonly in the proximal half of the carpal tunnel, our preference is to perform a vascularized muscle flap utilizing the flexor digitorum superficialis (FDS) muscle.

The FDS muscle flap is performed by utilizing a standard open carpal tunnel approach to identify and free the scarred median nerve. The incision is then extended proximally to allow access to the FDS muscle. Proximal to the myotendinous junction, the muscle is separated from tendon to either the long or ring finger, ensuring that the myotendinous junction is not disrupted (Fig. 5a). The freed muscle is then

rotated 180° to allow coverage of the scarred median nerve (Fig. 5b). Once the muscle is overlying the entire segment of scarred median nerve, it is tacked down to the radial and ulnar wound beds, thus encircling 270° of the nerve.

Free Flaps

Performing a free flap is the most technically demanding procedure for treating recalcitrant carpal tunnel syndrome; however, it can be utilized as a last resort in the patient who has had multiple prior procedures including vascularized pedicle flap transfer. The omentum is the tissue discussed as being utilized for free flap coverage of a scarred nerve. The rationale is that the omentum contains fibroblast growth factor which has been shown to stimulate axon growth and nerve regeneration [2]. Additionally, fibroblast growth factor has been shown to have significant angiogenic potential through chemotactic and mitogenic activity in endothelial cells [13]. Utilization of omentum has also been shown to prevent perineural fibrosis [4].

Following the extended incision, microvascular omental transfer is initiated by neurolysis of the median nerve and flexor tenosynovectomy to reduce bulk in the carpal canal. The radial artery and cephalic veins are exposed in the proximal portion of the wound in preparation for anastomosis. The omentum with its gastroepiploic artery and vein is harvested through an open laparotomy. Once the omentum is harvested, it is placed around the median nerve on the volar, radial, and ulnar aspects along the entire course of the scarred nerve. The omentum is then loosely tacked down in

Fig. 5 **a** Elevation of the FDS muscle belly without disturbing the myotendinous junction. **b** Rotation of the vascularized FDS muscle belly 180° to cover the median nerve (courtesy of The Philadelphia Hand Center, Philadelphia, PA)

these areas, and attention is turned to the anastomosis. The gastroepiploic vein is anastomosed in an end to end fashion to the cephalic vein, and the gastroepiploic artery is anastomosed to the radial artery in an end to side fashion. A partial thickness skin graft is then placed over the omentum to prevent compression of the vascular repairs [12].

Postoperatively, Goitz and Steichen recommend monitoring the transfer by Doppler examination and placing the patient on low molecular weight dextran for 5 days and aspirin for 4 weeks. In their series the wrist was immobilized for 3 weeks while early mobilization of the digits was permitted [12].

Goitz and Steichen reported on nine procedures in six patients utilizing the omental transfer after the patients had previously failed local pedicle tissue coverage. They found that most symptoms were improved but not completely alleviated. Improved sensibility and two-point discrimination was present in about half of the patients. Five of the six patients reported satisfaction and improved quality of life. Four complications were noted, including three wound healing delays and one ventral hernia [12].

Conclusion

Recalcitrant carpal tunnel syndrome can occur in a significant number of patients who have previously undergone primary carpal tunnel release. Numerous procedures have been advocated to treat this problem, all of which demonstrate satisfactory results but none of which have level 1 data. Our current algorithm in patients with recalcitrant carpal tunnel syndrome is to perform a standard open carpal tunnel incision. The next step is to identify the transverse carpal ligament to ensure that an adequate release has been performed. Once an adequate release is present, the median nerve is isolated and freed of any surrounding scar tissue. If the nerve appears healthy without significant perineural fibrosis, a synthetic device is placed around the median nerve in the carpal tunnel to prevent scar formation. Utilization of a synthetic device causes no additional morbidity to the patient and is a quick way to perform an interposition procedure. If significant scarring/perineural fibrosis is present, the incision is extended proximally and a pedicled FDS muscle flap procedure is performed to provide interposition with neovascularization. This technique ensures adequate tissue for coverage of the entire length of the scarred median nerve and is not technically demanding.

Conflict of interest The authors declare that they have no conflict of interest.

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