The surgical release of the transverse carpal ligament for the uncomplicated carpal tunnel syndrome (CTS) can be acceptable for hands not requiring heavy, repetitive, complex or sophisticated work. Articles appear weekly in the popular press concerning carpal tunnel syndrome; for example, "if you have numb fingers at night or in the morning, don't suffer, call your doctor and have the miracle operation, why suffer any longer." A recent article by Raoul Tubiana, author of four volumes of hand surgery, states that "despite its high incidence and its reputation for simplicity and efficiency, carpal tunnel release does not invariably produce good results, and dissatisfied patients are not infrequently encountered." Unsatisfactory results are caused by inaccurate diagnosis and, all too frequently, iatrogenic surgical complications. Surgical technique plays an important role in the achievement of good results.

The diagnosis of CTS frequently requires only a complaint of numb fingers before surgery is contemplated. The surgical treatment of CTS is now undertaken by any surgeon capable of operating. There is no gold standard left to balance the scale to good or excellent results. Instead, acceptable and unacceptable is the margin for approval.

Looking over 20 years of carpal tunnel surgery in a large hand center practice, I have come to appreciate that if the patient had correction of numbness and tingling in the hand and no complications, that would be considered a good result. The complicated cases were always placed in another category of recovery, so results rarely became evaluated. Reports have been documented that deal with the weakness of pinch and grip after carpal tunnel ligament division. Hence, some hand surgeons have been concerned with the need to close the carpal ligament after repair. These techniques, i.e., Z- or N-plastics, are usually loose closures that ensure ample room in the canal for the median nerve. This plan enhances pinch, not grip, strength.

Recurrent carpal tunnel syndrome is becoming a real problem in increasing numbers, and numerous complications are also increasing. I am particularly concerned about the number of patients with CTS that do not return to the work force after surgery. Their complaints of pain in the hand and weakness of grip are often passed off as "compensationitis."

This article addresses certain factors that relate to less than optimum surgical results after carpal tunnel surgery and after recurrent carpal tunnel surgery. Some of the patients have had previous injuries, others multiple neuropathies or repeated surgeries; function is reduced and morale is low.

A new treatment plan proposes that complete median nerve mobilization permits anatomic surgical closure of the carpal ligament to preserve the full function of grip and pinch.

A therapy "solution" to the carpal tunnel recovery problem is the idea of a quick, intense work-hardening program. Those experienced in hand surgery and hand therapy know full well that as part of a progressive program, the concept of preparing a patient for work is sound in
future by physicians and therapists. The multi-
This situation promotes disuse atrophy, imbal-
he finally was unable to carry on any longer?
compensating for problems by substituting su-
In fact, was the patient
pation and pronation of the forearm, and even
erly and, in fact, did he have any history of past
get to a point where he couldn't work prop-
for surgery was made and carried out. For
has been very little information documented as
philosophy and results. A review of cases that
have failed to make the grade shows that there
has been very little information documented as
to where the patient was before the decision
for surgery was made and carried out. For
example, how many months did it take for him
to get to a point where he couldn't work prop-
erly and, in fact, did he have any history of past
injuries to the hand or the extremity? If so, had
he ever fully recovered? In fact, was the patient

to where the patient was before the decision

result following carpal tunnel syndrome sur-

ing to the upper extremity. The miracle of
carpal tunnel surgery falls short, as does post-
operative work-hardening programs in patients
who fall into these categories.

Many patients are made worse by rapid-pace
recovery programs: supination activities are un-
comfortable because they put the median nerve
on traction, so the patient compensates with
pronation, only to develop a radial neuropathy.
Depending on the demands of the work per-
formance, this unfortunate patient, now with a
double neuropathy, may find the only way out
is to use arm motions and shoulder and neck
substitutions to perform supination and pronation
and forearm activities with the arm in
internal and external rotations. This, of course,
is the step toward the "brachial plexus traction
problem" that may go unrecognized for long
periods. The complex pattern of the multiple
neuropathies is not uncommon today and,
therefore, must be looked for carefully in the
future by physicians and therapists. The multi-
ple neuropathy problem in the upper extremity
must be carefully reviewed in all patients who
complain of an unsatisfactory and incomplete
result following carpal tunnel syndrome sur-
gery.

Over the years, it has been interesting to me
to have been asked many times, "Dr. Hunter,
when you place those tendon rods, don't you
ever get a carpal tunnel syndrome?" In over
700 staged tendon surgeries, approximately 200
multiple rods have been placed in the carpal
tunnel, and I have not been able to observe a
true compression neuropathy of the median
nerve, because the space in the carpal canal

hemostat through the ulnar side of the carpal
canal, press the instrument next to the hamate,
and transect the carpal ligament. If one
approaches the canal from the proper angle and
moves along either the superficial or deep level
of the flexor tendons, large instruments move
very easily, and it is possible to put two and
three Kelly hemostats in the space of the carpal
canal.

We should be thinking differently about the
narrow compartments that permit the "com-
pression neuropathy" of the median nerve. In
other words, there is, except in the situation of
tumors, displacement of carpal bones, or syno-
vitis, plenty of room in the bony carpal canal
for the nine flexor tendons, their sheaths, and
the median nerve. There must, therefore, be
other factors present. Why then does not the
routine carpal tunnel surgery correct the prob-
lem uniformly? Why do many patients complain
of hand weakness, and why are some patients
worse after carpal tunnel surgery?

Clinical records and data are being collected
at our hand center on the demography of over
1,000 cases of carpal tunnel surgery. There is a
strong suggestion that some 20% did not per-
form as expected. I have termed these "recur-
cent carpal tunnel syndromes." Our studies
show that there is a high incidence of previous
injury in recurrent carpal tunnel syndrome. It
moves some 27% in the general population to
46% of patients studied with recurrent carpal
tunnel syndrome. These findings suggest that
something different happens to these patients
to take them out of the simple category of a
compression neuropathy of the median nerve.
As surgeons, we should consider this group of
patients with previous injury to the hand or
wrist very carefully. This group of patients may
have fibrous fixations or neurabdesis to the epi-
neural nerve structures (Fig. 1). With gliding
limited, traction neuropathies develop with
wrist, hand, and forearm motion. The time of
onset and the intensity of symptoms vary, and
may be intermittent. Electromyographs (EMGs)
are frequently normal. The examining physician
must apply techniques of traction stress to the
nerve, and the electromyographer must do the
same (see the article in this issue by Richard
Read).

As centers become more adept at diagnosing
the neurologic thoracic outlet syndrome, or as
Dr. Schwartzman describes it in this issue's
"The Brachial Plexus Traction Injury," it will
be apparent that there is a high incidence of
this problem existing with CTS, with an in-
Recurrence of carpal tunnel syndrome can often be traced to previous injury to the hand and wrist, which may alter the anatomy and physiology of the median nerve by local or general fibrous fixation to surrounding tissues (the fibrous fix or neurodesis). When this is unrecognized at the time of carpal tunnel surgery, nerve fixation may become more severe, and new pathology may develop; hence the recurrent carpal tunnel syndrome.

Unrecognized secondary neuropathy in the forearm from misuse or overuse is also a factor; for example, the radial neuropathy and the ulnar neuropathy. Another problem is the unrecognized brachial plexus neuropathy or traction injury secondary to (1) work problems, especially lateral abduction or overhead lifting, that (2) falls on the outstretched arms and, for the 80s and 90s, (3) high-velocity vehicle injury and the computer keyboard.

The most common behind-the-scenes problem in CTS is nerve fixation that has occurred in the trail of life. For example, the forgotten injury when young, falling from a skateboard, the armed service injury, the sprained wrist, which is passed off and now forgotten; the car accident, perhaps many years ago, when the hand hyperextended on the dashboard; the fall on ice with a sprained wrist or possible fracture. These are examples of occasions where tension or traction of the median nerve may have occurred. Injury followed by repair gradually matures into fibrous changes in the epineural structures of the nerve and in the epineural structures around the nerve. Fibrous sheets or specific scar fixations can form anywhere along the nerve and block the ability of the nerve to be elastic and reform as joint and tendons move and contract.

One of the most common findings in series of carpal tunnel syndromes is the pattern for the median nerve to be fixed toward the volar surface and to the radial side of the carpal canal (Figs. 2 and 3). This is a position that creates ample room for the passage of the flexor tendons during the transmission of power grip in the hand with the wrist movement. The radial position of the median nerve presents the most advantageous position for the nerve to manage thenar motor innervation as well as thumb, index, and middle finger innervation.

Importantly, this type of pre-existing fibrous fixation surrounding the epineural surface of the median nerve is functional until stressed with excessive work traction or a new injury. Dr. George Phalen, in his classic article on carpal tunnel syndrome noted that the com-

Figure 1. Traction neuropathy of the median nerves in the forearm. The patient originally sustained a contusion of the forearm at work. Scar fixation of the median nerve was proximal to the site of two wrist surgeries. This is finally recognized at the third surgery. A. On the left of the illustration, note the smooth sheath surface of nerve gliding following surgery II with wrist motion. In the center, note epineural scar fixation of the median nerve at the site of original injury occurring two years earlier. On the right, observe a proximal forearm traction neuropathy of the median nerve. The nerve is thin, and the surface is fibrous (the thumb abduction stress test positive in 30 seconds). B. Median nerve free from scar; gliding sheath on nerve surface distal; fibrous sheath on traction nerve proximal. This patient disabled by pain in the hand and forearm became progressively worse in therapy. Traction neuropathy of the median nerve caused the hand to be used in pronation resulting in radial neuropathy.
Figure 2. Cross-section anatomy of wrist. Note #11 median nerve and incision site. (From Tubiana R, McCullough CJ, Masquelet AC. An Atlas of Surgical Exposures of the Upper Extremity. London, Martin Dunitz, 1990, p 249; with permission.)
Recurrent Carpal Tunnel Syndrome, Epineural Fibrous Fixation, and Traction Neuropathy

Figure 3. Anatomy of hand: Flexor tendons beneath major retinaculum of hand. (From Tubiana R, McCullough CJ, Masquelet AC: An Atlas of Surgical Exposures of the Upper Extremity. London, Martin Dunitz, 1990, p 263; with permission.)

pression neuropathy with hourglass effect was the prevalent finding at surgery. After surgery, patients went through uneventful recovery and minimal complications after this carpal tunnel release. Phalen believed that, diagnostically, the wrist flexion test was due to a swelling of the median nerve at the proximal edge of the transverse carpal ligament. Eighty percent of his cases had positive flexion tests. The wrist extension test was not mentioned as aggravating the symptoms of CTS. There is no reference prior to surgery of cumulative trauma. A review of our series of cases in 1990 suggests that the demography of patients with CTS has changed. Some of the complaints are similar, particularly the numbness at night and in the mornings. The pain and burning paresthesias, weaknesses and disuse that seem to follow work adjustment neuropathies of the extremities are not discussed.

The hyperextension wrist and finger test, not referred to in Phalen's discussion, has become a most useful test, indicating the probability of a traction neuropathy or scar fixation of the nerve along the course from palm to wrist to forearm.

The traction neuropathy of the median nerve may present symptoms that coexist with compression neuropathies, but if they can be singled out, an additional problem to compression is suggested: that of underlying traction neuropathy. Importantly, traction neuropathy may exist in the background while compression neuropathy is treated by carpal tunnel release. Traction neuropathy symptoms related to fixation of the nerve slowly continue to present symptoms of weakness and, finally, pain. They lead to recurrent carpal tunnel syndrome.

An additional test that may assist should be discussed: the thenar muscle abduction test is often positive with a traction median nerve neuropathy. The technique is as follows: if the forearm is supinated, the wrist and fingers are extended and the thumb is adducted to the side. The patient must be instructed to keep the flexor pollicis longus tendon at rest. Prior to starting this test, the abduction is reviewed. The size of the thenar muscle is identified and,
using thumb pressure against the thumb, a strength measurement is made from 0 to 4+. Timing of this test starts when all three factors are in place: the wrist extended, fingers extended, and the thumb adducted, all under tension by the observer. The results should be positive in approximately 1 minute. The patient may complain to some extent during the test. If the nerve is very sensitive, the observer may have to adjust tension during the test. The final observation is after 30 seconds or 1 minute: a drop in the power of the thenar muscle as the patient attempts to raise the thumb against the observer’s thumb. The thumb fails or falls to the side, i.e., pretest observation of 3+ may drop to 1+ as the thumb is tested with the wrist in neutral.

This test can be duplicated in the operating room, with direct stimulation of the motor branch of the median nerve, and can be used as a motor stretch test during EMG. Scar fixation and traction neuropathy of the median nerve are important behind-the-scene problems in CTS that may lead to less than satisfactory results.

Behind the scenes of recurrent carpal tunnel syndromes are congenital variations and anomalies of the median nerve tendons and muscles in the carpal canal. I have often had the privilege of teaching hand fellows about the problem of the small incision, because the congenital pattern is observed through a large generous incision. It becomes clear as a new nerve pattern is observed how easy it would be to have injured a segment of the nerve, if one was not able to see clearly and widely the operative field (Fig. 4). There is little wonder that there are iatrogenic nerve problems with small incision release of the carpal ligament.

Figure 4. Many anomalies or anatomy variations are related to the median nerve in the carpal tunnel. This example shows a large palmaris longus tendon in the carpal canal, fixed to the epineurium of the median nerve. This could be a hazard with a small incision.

To elaborate on the problem of nerve fixation and traction neuropathy, the statistics from review of a large number of recurrent carpal tunnel syndromes show that the percentage of patients with previous injury in the general demography of patients is approximately 27%. This rises to approximately 46% in patients with recurrent carpal tunnel syndrome; this suggests that nerve fixation sites are predictably present and should be studied at every setting of carpal tunnel surgery (Fig. 5). The pattern of fixation of the nerve to the radial side of the carpal tunnel usually shows intimate attachment to the thickened flexor synovium of the flexor pollicis longus, the flexor profundus of the index finger, and the lumbrical muscle surface of the index finger (Fig. 5C). It is not unusual to find the nerve fibrous fixed as it curves toward the palm in relation to the palmar fascia, where it is led into the intertendinous spaces. Spinner has pointed out the importance of freeing the nerve at this level in carpal tunnel surgery. The sensory nerve to the middle and ring fingers usually is well separated, working freely with spreading of the fingers and thumb. Fixation of the radial side of the median nerve as it passes just distal to the transverse carpal ligament to the palmar fascia and through the preosseous bands is frequently seen at the time of surgery (Fig. 5D). Studies on 40 consecutive carpal tunnel surgeries show, after the transverse carpal ligament has been divided, that if one holds the wrist at neutral and pulls on the fibrous epineurium of the nerve with an instrument from distal to proximal, 2 to 6 mm of motion is generally the rule. Distal movement from the forearm to the carpus is 8 to 12 mm before nerve mobilization (Table 1). These ranges are similar to Wilgus and Murphy’s prior to mobilization. This reflects fixation distal in the carpal canal and looser fixation proximally, a fairly consistent finding in primary and recurrent carpal tunnel surgery.

The normal anatomy of the uninjured hand is one of a splay of the sensory nerves of the median nerve in the palm (Fig. 5D). This easily permits the thumb and the fingers to spread without discomfort in the hand. This would be critical in the functions of the pianist or the violinist. This splay effect is lost following injury and fibrous adhesions. With fixation such as this, when the wrist is placed in full extension and thumb and finger extension are added at the same time, there is essentially no movement of the nerve, because it is tractioned against the carpal bones like a bow string. This pattern may be reversed by pronation of the forearm.
Recurrent Carpal Tunnel Syndrome, Epineural Fibrous Fixation, and Traction Neuropathy

This easily spreads to spread mist or the wrist or the wrist injury. The traction effect may be further enhanced by flexor tendon synovial fixation on the dorsal surface of the median nerve. The adherence of the flexor tendon synovium to the epineurium of the median nerve (Fig. 6) can preset the nerve with tension; extension of the wrist produces traction on the nerve. Repeated use at the workplace now produces numbness and weakness, followed by pain and cramping.
The diagnosis of traction neuropathy of the median nerve may be subtle and difficult to diagnosis. Stress nerve conduction electromyography will help make the diagnosis. The routine EMG is usually normal, but becomes positive after putty exercise and positional stress testing (see the article in this issue by Richard Read). This is a frequent behind-the-scenes problem in recurrent carpal tunnel syndrome.

When the diagnosis of traction neuropathy is suspected, the approach to therapy and surgical management must be revised and new treatment instituted. Patients with significant nerve fixation or traction neuropathy problems are unlikely to respond to routine carpal tunnel surgery. I am troubled by the term neurolysis, often used in many variations from one surgeon to another. Frequently heard comments related to neurolysis include “it is inappropriate to free the median nerve completely at the level of the carpal tunnel, and one should always leave the fibrous structure around the nerve or on the floor of the nerve, for this carries the important blood supply to the nerve.” My personal observation is that the median nerve, in fact, handles mobilization from the sensory nerve splay in the palm through the carpal canal to the fascia.

The diagnosis now is “Traction Neuropathy,” and comes on slowly with use of the hand. This is a more complex problem than compression neuropathy. Patient complaints begin to include “my hand hurts,” “I have pain on use” and, at times, “I have burning in my fingertips.” Phalen’s test diminishes, Tinel’s test at the wrist increases with wrist extension, and the median nerve now becomes tender in the carpal tunnel, and in the volar forearm. Many of these patients are happy to rest their forearms in pronation with the palm down. The tension-sensitive median nerve, when tractioned during forearm supination, becomes uncomfortable. These undiagnosed patients will regress in a hand therapy program. They are also set up to develop a radial neuropathy from using the forearm in protective pronation.

Table 2. **Vascular Recovery of Median Nerve at Carpal Tunnel, Following Complete Nerve Mobilization**

<table>
<thead>
<tr>
<th>Cases studied:</th>
<th>Grade I — Uncomplicated carpal tunnel history</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade II — Complicated by previous injury to hand or wrist or traction injury and thoracic outlet syndrome</td>
<td></td>
</tr>
<tr>
<td>Grade III — Complicated by previous failed surgery at carpal tunnel</td>
<td></td>
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</table>

**Mobilization of median nerve** with (a minimum of 40 mm angular lift at the proximal hamate)

**Vascular recovery after tourniquet release**

Tourniquet time = average, 55 to 75 min

**Recovery average**

| Grade I — Immediate to 15 seconds |
| Grade II — 5 to 30 seconds average |
| Grade III — Variation with significant epineural scar fixation requiring epineurolysis 30 sec to 2 + min |

Vascular recovery data recorded at end of operative procedure under 3.5 power loops. Observation based on visible median nerve segment usually from sensory splay in palm to 1 inch proximal to wrist crease.

Pink shading throughout nerve = recovery. Wrist neutral or slightly flexed.

Database, 100 cases.
Recurrent Carpal Tunnel Syndrome, Epineural Fibrous Fixation, and Traction Neuropathy

The importance of the median nerve in the upper extremity. This implies that\footnote{carpal tunnel syndrome, epineural fibrous fixation, and traction neuropathy}.

Vascular recovery predictability returns within 30 seconds after tourniquet release (Table 2). The exception to this clinical observation is the occasional case of recurrent carpal tunnel syndrome where severe circumferential scarring has clearly compromised a segment of the nerve. (This fact should give surgeons another reason to look beyond the ligament when doing surgery at this level.)

Considering that the median nerve is left partially fixed at some point during routine carpal tunnel surgery, the scar fix (see Fig. 1) may be out of sight of the surgeon, proximal to the forearm or distal in the palm. Gliding movements of the nerve, therefore, occur only a minimal way after surgery. New scar fixation occurs on the nerve at the site of surgery, often placing the nerve into the edges or the undersurface of the wound. The patients later often complain of tenderness along their incision in the palm and in the wrist. The Tinel’s findings are common, deep pressure produces pain, and supination and extension of the wrist produce traction phenomena on the median nerve with symptoms. Generally, this symptom complex develops after the first 6 postoperative weeks in recurrent carpal tunnel syndrome, and may become progressive in the months that follow. The fibrous fix or neurodesis matures with the daily functions of the hand, wrist, and forearm. Many patients of strong stamina and good muscle ability are able to produce effective adjustments in the length of the nerve beyond a fibrous fix point. This calls on the innate ability of the nerve to lengthen and glide within the planes in and around the perineural, epineural, and endoneural structures. This biologic change has been well described by Landborg.\footnote{Haftek showed that the epineurium had a high degree of elasticity and resistance to stretching, but could also be the first nerve structure to change has been well described by Lundborg.}

The incidence of thoracic outlet syndrome, or brachial plexus traction neuropathy, is increasing in my statistics. This could reflect the fact that I have become more aware, and our service has become more attentive, to the methods and procedure of diagnosing this important problem. This brings up the relationship of the carpal tunnel syndrome and the thoracic outlet syndrome, and the question of the double-crush problem. Is it really a factor, or are these merely complex neuropathies in the same extremity? Some of the cases that failed to show full recovery after carpal tunnel surgery in reality are complaining of a higher nerve problem in the brachial plexus. They may have, on lateral abduction of their extremity, a C fiber burn in the lateral trunk of the brachial plexus, probably from the large sensory fibers in the C7 route to the plexus, through the median nerve. This may closely approximate the complaints of severe carpal tunnel pain. Generally, however, this sensory pattern will be more intense in the index finger, secondly the thumb, and paresthesia may actually split the middle finger. This pattern is fairly reliable, and has been mentioned by Schwartzman in his article on brachial plexus traction injury in this issue.

Carpal Tunnel Release Alters Normal Hand Functions

Surgical opening of the transverse carpal ligament causes significant relaxation of the origin of the muscles of opposition and pinch. The hamate bone is the origin of the strong ligament that holds the radial ray in proper alignment. Opening the transverse carpal ligament permits the radial side of the hand or the thumb ray to fall away from the ulnar side of the hand. These factors produce weakness of thumb pinch that some patients complain about following carpal tunnel surgery.

Dividing the carpal ligament allows the flexor tendons to drift more volar than usual, when gripping in neutral and partial flexion. This change in anatomy supports certain patient’s complaints that they have difficulty with their grip strengths. This problem has been recognized, but until this time it has not been possible to offer a significant change to affect better recovery.

Following injury to the carpal tunnel, a group of factors must be considered if improvement of the patient is to be realized. The median
nerve generally presents in a radial location along the radial wall of the carpal tunnel. However, when postsurgery scarring occurs, the median nerve may present in a more volar position, and may be traction-fixed in the healing scar of the ligament. This is one of the problems seen during recurrent carpal tunnel surgery. The nerve may also be fixed beyond the carpal ligament, proximally in connective tissue, or on the dorsal side of the anterior synovium of the flexor tendons by fibrous sheathing. The median nerve may have a major fix by fibrous scar to the radial wall and to the tight sheaths of the flexor pollicis longus and flexor digitorum profundus of the index finger. The sensory nerves normally splay open in the palm. They may become fixed together by fibrous tissue and by the unyielding palmar fascia distally. In addition to these distal fixation points, there may be proximal fibrous fixations beyond the wrist to the forearm fascia.

A New Plan for Recurrent Carpal Tunnel Problems

The median nerve in recurrent carpal tunnel syndrome, following trauma or failed surgery, may actually be fixed in adhesions, in the palm through the carpal tunnel, wrist, and into the forearm. The approach to this delicate problem is complete mobilization of the median nerve through the hand and wrist. To accomplish this, epineural fibrous fixation is removed from the nerve, so that the median nerve can be lifted 40 to 50 mm in the anteroposterior plane at the wrist (see Fig. 5E, Table 1). This permits the nerve to move without tension on full ranges of motion of the hand, wrist, and forearm. This program has proven successful in recovering salvage problems, sufficiently that it has now been applied to the uncomplicated CTS. The uniformity of improvement has been borne out in the postoperative recovery, recorded by sensibility, nerve conduction studies, and clinical assessment. This information, importantly, implies that the vascular nutrition of the median nerve became better as the biologic bed for gliding was uniformly established.

A plan to reverse the negative side of carpal tunnel surgery can be established. Return the median nerve and the nine flexor tendons to their natural, anatomic location deep in the carpal canal, out of harm’s way. This would honor the professional musician, the artist, and give the working hand a new dimension of recovery following carpal tunnel surgery. The weakness of prehension and grip from division of the transverse carpal ligament could be eliminated by reconstructing the central flexor retinaculum of the hand. The results of 40 consecutive cases, in which a combination of complete mobilization of the median nerves and reconstruction of the transverse carpal ligament have been reviewed. The early return of dexterity and strength has been impressive. Palm tenderness is minimal to absent. Nerve recovery seems ahead of schedule. The probability of improved long-term results is such that this approach could be used for the heavy worker and the performing artist.

MEDIAN NERVE MOBILIZATION AND CARPAL LIGAMENT RESTORATION

Median nerve mobilization of the hand and wrist permits the median nerve and the flexor tendons to return to normal anatomic positions, which enhances comfort and function.

The purpose of mobilization is based on the following:

Perineural fibrous fixation is present, significantly in patients with a history of previous injury to the hand and wrist, and patients with recurrent carpal tunnel syndrome, i.e., patients with one or more previous surgeries for CTS.

If the tension fixing sites of epineural fibrous fixation (EFF) are not removed from the nerve so that the nerve can move freely with wrist and finger movements, the nerve will become fixed in the healing bed of the released transverse carpal ligament. Depending on the degree of fixation, nerve gliding programs may fail and the patient may remain disabled.

Mobilization of the median nerve done carefully under magnification preserves the basic epineurium and the internal blood supply to the nerve. The routine, 4-inch segments mobilized in this procedure can be expected to recover visual circulation in 5 to 15 seconds (Table 2), except in unusual circumstances.

Contracted sections of perineural fibrosis have been removed up to 2 inches, with vascular recovery slowed 1 to 2 minutes under visual magnification. This closes the margin of safety in median nerve mobilization at the carpal tunnel level. In my opinion, if done carefully, this is acceptable and good results can be expected. This treatment permits the internal mobilization of the perineural and endoneural layers to begin gliding in soft tissue patterns, as described by Lundborg. I recommend that...
TECHNIQUE OF NERVE MOBILIZATION
AND RESTORATION OF TRANSVERSE CARPAL LIGAMENT

The purpose of this procedure is to return the gliding bed of the median nerve and to protect the nerve from outside trauma while working. Of parallel importance is to return the major pulley retinaculum of the flexor tendon system of the hand (see Fig. 3) and preserve the fascial origin of the thenar muscles of the thumb. The ultimate purpose, of course, is to restore the function and neurovascular nutrition of the nerve and the disabled hand to optimum. This means the best opportunity for hand rehabilitation.

All incisions are placed as cosmetically as possible, but they are generous, placed from the distal palmar crease to the wrist and the thenar muscle abductor. All these points must be observed and followed distally to the motor branch. The motor branch is stimulated, identified, and labeled. Properly prepared, patients accept this incision, in that the structural ligaments will be returned to their proper position and scar tenderness is relieved (see Fig. 5A).

The median nerve trunk is visually identified in the proximal end of the incision and marked. The palmar sensory branch of the median nerve can be seen and mobilized. The palmar fascia is spread in the palm, and excessive thickenings are excised. The most ulnar branch of the median nerve is identified by tugging and tagging just distal to the transverse carpal ligament (see Fig. 5C).

The transverse arterial arch is protected and a large, blunt Kelly hemostat is placed in line with the hamate bone. The instrument is angled 30 degrees radially and passes deep to the radial surface of the hamate. The instrument is then placed in a straight line to the carpal wrist crease, and the tip of the instrument is palpable on the ulnar side of the median nerve in the antebrachial fascia (see Fig. 5B). To incise the volar and transverse carpal ligaments, the instrument is held securely against the hamate, and the scalpel follows the closed teeth of the instrument carefully through the ligament structure. At the distal edge of the transverse carpal ligament, maximum light and special attention are directed to the possibility of a sensory nerve anomaly; this does exist and should be constantly checked. Also just distal to the ulnar edge of the transverse carpal ligament runs a consistent small sensory nerve connection from the ulnar nerve to the median nerve. The ligament is then opened longitudinally just radially to the hook of the hamate (see Fig. 5C).

The appearance and mobility of the nerve is now studied in preparation for mobilization. A marker dot is placed at the proximal edge of the hamate using a pick-up tooth forcep. The fibrous epineurium is pinched, and the distal to proximal and proximal to distal excursion is noted (see Table 1). The fascial fix from the ligament of the nerve to the carpal tunnel is gently opened at the marker site around the nerve. The angular lift from the proximal edge of the hamate bone is noted with wrist neutral, flexed, and extended (see Fig. 5E–G).

The nerve is gently mobilized in the carpal canal under magnification. Dissections are carried distally to the motor branch. The motor branch is stimulated, identified, and labeled. Multiple variations in the anatomy of the motor branch are often noted. The motor nerve may pass through the carpal ligament, around the edge of the carpal ligament, or leave the radial border of the median nerve or any other quadrant of the median nerve. The nerve may have as many as three branches before it enters the muscle. All these points must be observed and the median nerve protected with a colored loop. Stimulation of the motor branch will measure the function of the thenar muscle; it should be done early in the procedure to overcome the effect of the tourniquet. The response of the muscle is recorded on a scale of 0 to 4+, and this can be charted. The thenar muscle abduction test, which has proved useful in the clinical examination of the traction median nerve, can be confirmed at this time. The wrist, fingers, and thumb are extended and held for 30 to 60 seconds. The wrist is brought to neutral and the motor branch is stimulated electrically at 2 MA. If the test had been positive prior to
surgery, it is likely to be positive at this time. A reduction of approximately 2+ may be seen; for example, if the nerve was 3+ on initial observation, it may go to 1+. Generally, the recovery is very rapid on release of nerve traction.

The sensory splay of the palmer nerve anatomy is checked by abducting the fingers and extending the thumb. All fibrous traction fixations are excised under magnification. The sensory branches should spread to the distal edge of the transverse carpal ligament. These nerves should move freely in all planes, sufficient to be lifted in the anteroposterior plane for inspection (see Fig. 5D).

As the median nerve is mobilized at the wrist crease, fixation planes at the wrist, beneath the antebrachial fascia, are lysed. Blunt finger exploration of the median nerve is carried out in the forearm, where the nerve passes under fascia and is fixed to the flexor digitorum superficialis muscle. Any additional fixed points are freed. In instances of severe trauma to the extremity, the surgeons should look for a dense fibrous fixed point or true neurodeses beyond the incision. It may be necessary to extend the incision more proximally to get forearm median nerve trunk mobilization. The linear and anterior posterior movements of the nerve are now measured at the proximal edge of the hamate (see Table 1):

Measurements of the nerve at the proximal hamate mark are taken with a neutral wrist, extension of the wrist with finger extension, and flexion of the wrist with fingers relaxed. Importantly, the mobilization goal in the anterior/posterior plane should be approximately 40 mm; depending on the patient’s anatomy, this could be 50 mm. The angular lift is done either with a rubber loop or a rounded instrument.

The anteroposterior angular measurement from a fixed point of the median nerve at this level closely approximates mobilization of the lateral trunk of the brachial plexus. In the clinical evaluation of mobilization of approximately 40 brachial plexus at the supraclavicular level, the flat curve of the first rib is used as the bony fixed point to measure mobilization of the three nerve trunks from their transverse process fixed point to the fascial fix beyond the first rib. Mobilizations of the three trunks are between 45 mm and 55 mm for the upper trunk, 32 mm and 38 mm for the middle trunk, and 28 mm and 35 mm for the lower trunk. At both ends of the peripheral nervous system in the upper extremity, the mobility or elasticity of the nerve trunk and the biology to support nutrition and internal circulation is similar. This observation deserves further study.

The wound is irrigated and prepared for transverse carpal ligament closure. Care is taken to prepare the radial and ulnar borders of the ligament and to be especially observant to the contents of the Guyon canal ulnarily and to the motor branch of the median nerve at the distal edge of the ligament radially. Closure of the transverse carpal ligament is carried out using four 2-0 Dacron double-whip stitches (Fig. 7).

The marker loop is seen on the motor branch of the median nerve as the first stitches are placed. With the stitches in the transverse carpal ligament, two or three chromic sutures may be placed in the proximal fascia, however, this is optional based on nerve mobility. Before closure of the carpal canal, the wrist is placed in a neutral position, all digits are relaxed, and the tourniquet is released. The tourniquet time is recorded, as is the visual vascular recovery of the median nerve (Table 2, Fig. 8).

Before ligament closure, all moving structures around the nerve are checked for gliding. Any tissue that has become fixed in the sutures is removed, and bleeding is controlled. In certain posttraumatic cases, it may be necessary to drain the wound. When the wound is closed, a

Figure 7. A, B, C. Closure of the transverse carpal ligament is carried out using four 2-0 Dacron double-whip stitches (2-0 chromic is optional).
median nerve traction, governed by hand, wrist, and forearm movements. Traction and tension suggest the intermittent disturbance of nerve nutrition and nerve conduction as the elastic limits of the nerve are approached. These factors accumulate and, in time, cause traction neuropathies with pain. This is followed by a reduced work capability. This impairment can be reversed by surgical nerve mobilization followed by functional nerve gliding therapy. A background history injury to the hand and wrist may be significant, as well as factors such as overuse and misuse of the hand and extremity. Prior to surgery, the careful application of diagnostic stress tests are essential, for the differential diagnosis of fixation traction and positional peripheral neuropathies.

Nerve mobilization supported by magnification and the techniques of hand surgery has been successful by the methods discussed and has permitted, importantly, the restoration of the anatomic retinaculum for the flexor tendon system. This can be restored in carpal tunnel surgery and reconstructed with basic ligament material in recurrent carpal tunnel surgery.

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Address reprint requests to
James M. Hunter, MD
Hand Rehabilitation Center
901 Walnut Street
Philadelphia, PA 19107