In 1942, Learmonth [1] described the operation we today call “anterior submuscular transposition of the ulnar nerve at the elbow.” He developed this operation, we surmise, in response to the failure of anterior subcutaneous transposition to treat the problem of posttraumatic ulnar neuritis, because with that technique, described by Curtis [2] in 1898, the ulnar nerve had a tendency to return to its postcondylar location. The description of this operation presented by Learmonth would likely be considered unique in today’s environment of “evidence-based medicine.” His article was two pages long and contained 11 illustrations and two paragraphs of text, not including the figure legends (Fig. 1). Case reports, numbers of patients improved, and statistical analysis were not included. His paper is best viewed as anecdotal evidence. He wrote essentially that if you want to decompress the ulnar nerve, you should do it the way he did, which was to “transplant” the ulnar nerve into a position next to the median nerve. His technique included the first description of excision, not just simple division, of the medial intermuscular septum. He detached the flexor-pronator muscle mass from the medial humeral epicondyle, and then, after transplanting the ulnar nerve, reattached the flexor-pronator muscle mass in the original location (see Fig. 1).

Learmonth was a creative and insightful surgeon, and his research into the pathophysiology and treatment of peripheral nerve disorders gave him a place in history as the likely father of peripheral nerve surgery [3]. Perhaps the illustration of the Learmonth technique that influenced most hand surgeons up to that time was that presented in a 1978 book by Spinner [4], Injuries to the Major Branches of the Peripheral Nerves of the Forearm, in which the transposed ulnar nerve was shown in its new position completely covered by the flexor-pronator muscle mass (Fig. 2). Curtis, a close friend of Spinner, used this technique and taught it to his fellows, including the senior author (A.L.D.) in 1977.

It quickly became clear to the senior author that although classic Learmonth anterior submuscular transposition (ASMT) would successfully maintain the ulnar nerve in an anterior location, it required splinting the elbow in flexion for a period of time, because reattaching the flexor-pronator muscle mass to the medial humeral epicondyle required wrist flexion plus elbow flexion to keep the repair from being under too much tension. It also became clear that immobilization of the ulnar nerve in this extensive operative field would create fibrosis and diminish gliding of the ulnar nerve postoperatively. To resolve these two problems, the senior author, in approximately 1980, developed a modification of the Learmonth ASMT that would lengthen the flexor-pronator fascia, creating space for the ulnar nerve in its new location, permit reconstruction of the flexor-pronator muscle mass without tension, and allow immediate postoperative flexion and extension of the elbow. This technique, called “the musculo-fascial lengthening technique for ASMT of the ulnar nerve,” or sometimes “a Z-lengthening technique,” was first published in a series of color photographs taken by Kleinert, a fellow at the Raymond M. Curtis Hand Center in 1986 [5].
The surgical approach to decompression of the ulnar nerve at the elbow has always had supporters of several different anatomic approaches, and the table of contents of this issue of *Clinics in Hand Surgery* testifies to the persistence of the teaching of a particular technique by a particular master hand surgeon in many different hand surgery centers. In the mid 1980s, the first of what we would today call “a meta-analysis of the results of ulnar nerve decompression at the elbow” was conducted by using the concept that results should be reported related to the stage or degree of nerve compression present at the time of decompression [6]. Previously, little attention to staging the degree of nerve compression was reported. For the ulnar nerve, as an example, only the McGowan classification was used, which emphasized motor weakness and wasting with little consideration for sensory impairment [7]. That first meta-analysis [6] reviewed approximately 50 papers, including approximately 1400 patients. Regardless of the technique used for decompression, almost all studies reported 100% excellent results for patients with early or minimal degree of compression (ie, intermittent symptoms without weakness or abnormal two-point discrimination). For patients with a severe degree of ulnar nerve compression (ie, abnormal two-point discrimination and/or muscle atrophy), regardless of the technique used for the decompression, the success rates varied from 60% to 80% and the recurrence rates varied from 25% to 33%. In the few studies reported on the treatment of recurrent ulnar nerve entrapment at the elbow, all patients were treated with Learmonth submuscular transposition, and internal neurolysis usually was added [6]. No randomized controlled series comparing two different types of decompressions could be used to persuasively argue for the use of one surgical technique over the other. Hand

Fig. 1. Original figures by Learmonth [1] illustrate his technique for submuscular transposition of the ulnar nerve. Hand is to the left, and axilla is to the right. (A) Flexor-pronator flap is created. Note the straight cut dividing the origin of the flexor-pronator mass. It is not a lengthening release. (B) Repair of flap and origin of flexor-pronator mass. Note absence of lengthening. Entire nerve is covered by muscle, and tension is placed on repair. (Reprinted from Learmonth JR. Technique for transplantation of the ulnar nerve. Surg Gynecol Obstet 1942;75:792–3; with permission from the American College of Surgeons. Copyright © 1942, American College of Surgeons.)

Fig. 2. Illustration of Learmonth’s submuscular transposition of the ulnar nerve. Note the absence of lengthening of the muscle and fascia of the flexor-pronator muscle mass in the forearm. (Reprinted from Spinner M. Injuries to the major branches of the peripheral nerves of the forearm. Philadelphia: W.B. Saunders; 1978. p. 245–52; with permission.)
surgeons continued to be trained in the technique used at their site of training.

The results of this first meta-analysis reinforced the need for a surgical approach that created space for the ulnar nerve in its new anterior location and permitted early movement of the elbow. The technique for musculofascial lengthening was illustrated in the 1989 book Surgery of the Peripheral Nerve by Mackinnon and Dellon [8] and again in 1991 in the Neurosurgical Clinics of North America in an article titled “Successful Techniques in the Management of Ulnar Nerve Surgery” [9]. In that article, the surgical technique necessary to accomplish the musculofascial lengthening was clearly outlined, including resection of the periosteal origin of the flexor carpi ulnaris (FCU) from the ulna, which is the distal homolog of the medial intermuscular septum proximally (Figs. 3–5).

In 2000, Mowlavi and colleagues [10] repeated this type of analysis and arrived at the same general conclusions, with the exception that they included the first two series of patients for whom the Dellon musculofascial lengthening technique was used for the ASMT of the ulnar nerve at the elbow. Those two series [11,12] experienced similar long-term (means of 49 and 58 months) results: 90% good to excellent results in patients with moderate to severe degrees of ulnar nerve compression and 0% recurrences. Also in 2000, an illustrated description of the technique was published [13].

In 2003, a report of the senior author’s own series of patients from the 1980s was published [14], and in 2004, the series was updated and the technique illustrated in color [15]. The computer review of patients from 2000 through 2004 contained a list of 600 patients without recurrence.

**Technique for musculofascial lengthening**

General anesthesia is initiated, and a dose of preoperative antibiotics is intravenously administered. A well-padded tourniquet is placed as high as possible on the upper arm to allow proximal dissection of the ulnar nerve during the procedure. Under tourniquet control, a 6- to 8-cm incision is made in line with the posterior condylar groove of the humerus. The subcutaneous tissue is spread bluntly with tenotomy scissors and with loupe magnification, and care is taken to identify and preserve the posterior branches of the medial antebrachial cutaneous nerve and medial brachial cutaneous nerve that might cross the line of the incision (see Fig. 3). These branches should be swept anteriorly or posteriorly, depending on convenience. Injury to the cutaneous sensory nerves can cause painful neuroma, and if injury goes unrecognized, it will cause chronic pain in the distribution of medial elbow and forearm. If a nerve injury is recognized, the nerve should be divided and the proximal end implanted into the triceps muscle belly.

The subcutaneous tissue is lifted from the underlying fascia of the common flexor-pronator muscle mass, and bipolar cautery is used for hemostasis. The dissection of the anterior flap is carried to the lateral border of the pronator teres muscle to provide adequate exposure. The posterior adipocutaneous flap needs to be raised only to the posterior edge of the cubital tunnel.

The proximal cubital tunnel is opened and the ulnar nerve identified. If an anomalous muscle (the epitrochlearis anconeus) is present, it should be divided. The dissection then proceeds proximally, approximately 6 to 8 cm, incising the fascia

![Fig. 3.](image-url)
from the medial head of the triceps to the medial intermuscular septum. Three to 4 cm of the intermuscular septum is excised just proximal to the medial humeral epicondyle (see Fig. 3). This allows for smooth transition of the ulnar nerve from its posterior position to its new anterior position and prevents “kinking” of the ulnar nerve. Digital palpation should verify that the transition point is smooth proximally. Care is taken to obtain hemostasis from any vessels within or adjacent to the intermuscular septum.

Attention is then turned to the distal neurolysis of the ulnar nerve. Starting at the distal end of the cubital tunnel, just distal to the condylar groove, Osborne’s band, the thickened fascia between the two heads of the FCU, is divided longitudinally over the course of the ulnar nerve, along with the investing fascia overlying the FCU (see Fig. 3; Fig. 6). With blunt dissection and a muscle-splitting technique, the two heads of the FCU are spread longitudinally to expose approximately 4 to 6 cm of the distal ulnar nerve.

Next, a musculofascial lengthening step incision or “Z-plasty” is marked out on the common flexor-pronator fascia (see Figs. 4, 6). Each fascial flap of the “Z-plasty” should be at least 1.5 to 2.0 cm wide and 1.5 to 2.0 cm long to allow for generous lengthening of the fascia and to provide a strong, tensionless repair and a space for the ulnar nerve to glide (see Fig. 6). The proximal flap is based on the medial humeral epicondyle, whereas the distal flap includes the muscle bellies of the pronator teres, the flexor digitorum superficialis, and the FCU.

After division of the fascial flaps, the flexor-pronator muscle mass is cauterized with a bipolar device and then divided with scissors to minimize postoperative bruising. It is easiest to perform this maneuver by starting medially at the medial border of the FCU and then moving sequentially to the flexor digitorum and then the pronator. First, the periosteal origin of the FCU is detached from the ulna, because the FCU origin is the analog to the intermuscular septum proximally (see Fig. 4). If a high origin of the superficial head of the FCU is present, it must be taken down completely, and if attachments of muscle to the brachialis remain, they must be divided. Moving laterally and anteriorly, one must next completely divide the common flexor fascial origin attached.

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Fig. 4. (A) Outline of Z-cut for lengthening of the flexor-pronator fascia. (B) Release of common flexor tendon origin at epicondyle. (C) Distal release to permit muscular slide. (D) Release of the periosteal origin of FCU (lower left). (Reprinted from Dellon AL. Techniques for successful management of ulnar nerve entrapment at the elbow. Neurosurg Clin N Am 1991;2(1):57–73; with permission.)
Fig. 5. (A) Proximal flap dissected before transposition of ulnar nerve to anterior submuscular position. (B) Reconstruction of the lengthened fascial flaps over transposed nerve. (Reprinted from Dellon AL. Techniques for successful management of ulnar nerve entrapment at the elbow. Neurosurg Clin N Am 1991;2(1):57–73; with permission.)

Fig. 6. (A) Intraoperative view of Z-lengthening or “step cut” to allow lengthening of the musculofascial unit of the pronator-flexor mass. FCU, Flexor carpi ulnaris; FD, flexor digitorum; PT, pronator teres; ME, medial epicondyle; UN, ulnar nerve. (B) Completion of musculofascial flaps; note that the flaps are full thickness of muscle. The anterior head of the flexor carpi ulnaris (AFCU) is divided and the origin of the FCU (O-FCU) is clearly identified. The common flexor pronator mass (CFPM) is divided and the origin of the common flexor mass (O-CFM) is identified. The fascia of the underlying brachialis (Br) is completely exposed and is the base across which the ulnar nerve will run. The lower flap will become the proximal flap and is attached to the medial epicondyle. The upper flap is the distal flap and will slide further distal as the origin of the CFM and FCU are divided and as the back cut along the most lateral edge of the pronator through the lacertus has been released. Outline of proximal facial edges marked with black lines. (Reprinted from Dellon AL, Coert JH. Results of musculofascial lengthening for treatment of ulnar nerve compression at the elbow: surgical technique. J Bone Joint Surg Am 2004;86(supp 1, part 2):169–79; with permission.)
to the medial epicondyle, being careful not to injure the ulnar collateral ligament or enter the elbow joint (see Fig. 4; Fig. 7). Finally, the pronator is divided and lifted off the brachialis muscle beneath it. If a high origin of the pronator teres from the medial humerus is present, it should be divided and the entire width of the muscle belly included in the flap.

The last step in creating the distal musculofascial flap is to create the “back cut” of the lengthening Z-plasty. This allows the flap to rotate medially and slide distally. This maneuver is performed by grasping the cut end of the flap with forceps and rotating into its new position. At that point, the lacertus fibrosus is divided along the line of tension, which runs down the lateral border of the pronator teres muscle.

Care must be taken when raising the distal musculofascial flap to avoid injury to the median nerve, if it lies in a medial location. Also one must not divide any motor branch to the pronator teres. Release and elevation of the proximal musculofascial flap attached to the medial epicondyle is performed as necessary to allow smooth transposition of the ulnar nerve (see Fig. 4).

The ulnar nerve is then elevated from the posterior condylar groove of the humerus. Segmental vessels are preserved if possible but divided if necessary, and the nerve is transposed anteriorly onto the brachialis muscle. The ulnar nerve should then travel from the posterior compartment of the triceps, over the resected intramuscular septum, over the brachialis muscle, anterior and medial to the epicondyle, over the newly resected ulnar periosteal origin of the FCU, and finally back under the FCU (see Fig. 7). The proximal and distal transitions should be smooth with no kinks or points of constriction on the nerve.

A helpful adjunct to allow adequate anterior transposition of the ulnar nerve, in case it is tethered posteriorly by the first motor branch to the FCU, is a simple, distal, intramuscular neurolysis of this motor branch. This will allow approximately 1.0 to 1.5 cm additional anterior transposition to prevent the ulnar nerve from being pulled directly against the medial epicondyle.

After transposition is complete, the flexor-pronator fascial flaps are secured in their newly lengthened position (see Fig. 5; Fig. 8). The flaps are sutured together, superficial to the nerve, with three to four horizontal mattress sutures of 3-0 nonabsorbable braided suture material (see Fig. 8). No tension should exist across the repair, even with full arm extension, and one finger should be able to pass easily beneath the newly constructed flexor-pronator muscle fascia (see Fig. 8). The arm is then flexed and extended to check for any entrapments on irregular edges. The wound is irrigated, and hemostasis is confirmed. The skin is then closed, with care taken not to include the medial antebrachial cutaneous nerve within the sutures. A soft, well-padded compressive dressing is applied, and the tourniquet is deflated. The elastic bandage applied in the operating room is removed after 30 minutes by the recovery room staff.

Postoperative management is critical to the success of the surgery. In brief, the elbow is placed into a sling and no plaster is used. The sling is worn only while sleeping and while walking, to prevent full extension for 7 to 10 days. The ulnar nerve can begin gliding from the first postoperative day. By the end of the second postoperative week, the elbow should be completely extended. At 3 weeks, scar massage with a topical steroid-containing ointment is begun twice a day and continued for 3 months. Muscle strengthening begins at 3 weeks. Referral for formal therapy is reserved for failure to obtain elbow extension, a painful scar, or inability of the patient to regain strength.
Correction of pathophysiology of ulnar compression

Implicit in the concept of treatment of ulnar nerve compression at the elbow is that the ulnar nerve is subjected to increased pressure within the cubital tunnel as a result of normal physiology, anatomic variability, trauma, or some combination of these. It has been well studied that pressure applied to the ulnar nerve increases with increasing elbow flexion and that the pressure further increases with shoulder abduction (Table 1) [16,17]. The shape of the cubital tunnel changes with elbow flexion; it becomes flatter. Also, the ulnar nerve stretches with elbow flexion and with shoulder abduction. The elongation and stretching of the ulnar nerve with elbow flexion are part of the problem with standardizing a traditional electrodiagnostic test of ulnar nerve function before surgery and interpreting the results of the tests once the ulnar nerve has been transposed [18]. The elbow flexion test, a provocative test, produces numbness and tingling in the little fingers of patients with cubital tunnel syndrome [19], confirming that elbow flexion increases pressure, and therefore decreases blood flow, on the ulnar nerve in the cubital tunnel. The nonoperative approach to cubital tunnel syndrome—altering activities of daily living to keep the elbow from flexing, and adapting nighttime strategies to keep the elbow largely extended—produce relief of symptoms in 80% of patients with an early or minimal degree of ulnar nerve compression within 3 months of therapy (Fig. 9) [20].

Ultimately, the hypothesis that an operative strategy to treat ulnar nerve compression at the elbow will reduce pressure on the ulnar nerve must depend on direct experimental proof. Proof was obtained in a fresh cadaver study in which the intraneural ulnar nerve pressure was obtained at points proximal to the cubital tunnel, within the cubital tunnel, and distal to the cubital tunnel, in several different degrees of elbow flexion, with the tunnel intact [21]. The same measurements were repeated after the typical operations to treat cubital tunnel syndrome were performed: in situ decompression, anterior subcutaneous transposition, medial epicondylectomy, a Learmonth ASMT, and the Dellon musculofascial lengthening approach to ASMT [21]. Fig. 10 shows that for any degree

Table 1
Intraneural cubital tunnel ulnar pressures related to elbow position [17]

<table>
<thead>
<tr>
<th>Position</th>
<th>Mean pressure, mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow at side</td>
<td></td>
</tr>
<tr>
<td>0 degrees flexed</td>
<td>7.2 (2.7–13.8)</td>
</tr>
<tr>
<td>90 degrees flexed</td>
<td>11.2 (6.3–16.4)</td>
</tr>
<tr>
<td>Same and wrist extended</td>
<td>17.9 (8.2–28.5)</td>
</tr>
<tr>
<td>Shoulder abducted and elbow flexed</td>
<td>24.0 (13.8–32.2)</td>
</tr>
<tr>
<td>and wrist extended</td>
<td></td>
</tr>
<tr>
<td>Hand overhead</td>
<td>45.7 (28.5–72.6)</td>
</tr>
<tr>
<td>with elbow flexed</td>
<td></td>
</tr>
<tr>
<td>and wrist extended</td>
<td></td>
</tr>
</tbody>
</table>

*From* Pechan J, Julius I. The pressure measurement in the ulnar nerve: a contribution to the pathophysiology of the cubital tunnel syndrome. J Biomech 1975;8(1): 75–9; with permission.
of elbow flexion, intraneural ulnar pressure was decreased significantly ($P < .001$) only when the Dellon musculofascial lengthening approach to ASMT of the ulnar nerve was used [21].

Results

Staging of ulnar nerve compression at the elbow

It is inappropriate to report the results for any surgical procedure related to chronic nerve compression without describing the degree of functional nerve impairment. This implies some degree of combining patient symptoms and measurements of ulnar nerve sensory and motor function. This approach was introduced in 1983 in a report of the use of quantitative vibrometry with the biothesiometer [22]. These observations built on the even earlier observations that during the earliest stage of nerve compression (and during the very early period after nerve decompression), the peripheral nerve is hypersensitive (lower threshold for simulation) to vibratory stimulation [23]. An early strategy for clinically staging the degree of nerve compression is presented in Table 2 and relates to the most common method of understanding the progressive pathophysiology of chronic nerve compression. Attempts to apply statistical analysis to results of surgery with this type of preoperative staging are difficult, usually leading to the traditional surgical approach of reporting the percentage of patients with poor, fair, good, or excellent results, again based on a similar assessment of symptoms and physical findings.

Statistical analysis is best applied when a numerical grading system is introduced. An example of this for the ulnar nerve at the elbow is presented in Table 3. A numerical grading system requires actual measurements of sensory and motor functions [24]. The grading system creates a sensory, a motor, and an overall numerical value that can be treated mathematically by using parametric statistics and can be analyzed, therefore, with the Student $t$-test for statistical significance. The utility of such a grading system has been shown for the surgical results of recurrent carpal tunnel syndrome [25], and also for the nonoperative management of cubital tunnel syndrome using Kaplan-Meier proportional hazards [20].

Results of musculofascial lengthening technique

Several retrospective studies have been published of the same technique of ASMT with Z-musculofascial lengthening of the flexor-pronator mass. Dellon and Coert [14] reported their results in a consecutive series of 121 patients (161 extremities) with a mean follow-up duration of 45 months. In that study, measurements of sensory and motor function were prospectively obtained, allowing the authors to create a staging system to determine the severity of the compression. Repeat measurements were then obtained postoperatively to determine results of decompression and transposition. Based on other traditional criteria, the authors reported excellent results in 65% of limbs, good results in 23%, fair results in 4%, and failure in 7.5%. One limb experienced recurrence (0.5%). The authors also reported significant improvement in ulnar nerve function in terms of both the sensory ($P < .001$) and motor ($P < .001$) components of the grading
Furthermore, even patients with the worst symptoms, those with workers’ compensation claims, and those with diabetes had significant improvement in symptoms.

Nouhan and Kleinert [12] presented the reports of 31 patients (33 extremities) with a mean follow-up duration of 49 months. They used the same preoperative grading system as that described by Dellon [9] and a modified Bishop rating system postoperatively. They reported excellent results in 36% of limbs and good results in 61%, for a total of 97% good to excellent results in a patient population with 61% having severe compression, 21% moderate compression, and 18% mild compression. All patients with mild to moderate compression achieved good or excellent results, and 19 of 20 patients with severe compression achieved good or excellent results. Overall, patients were satisfied with the operation; 94% of patients stated that they had subjective improvement.

Pasque and Rayan [11] presented a series of 48 patients (50 extremities) with cubital tunnel syndrome with a mean follow-up duration of 58 months (range, 12 to 156 months). Patients were graded pre- and postoperatively based on

Fig. 10. Comparison of mean intraneural ulnar nerve pressure changes after different surgical strategies were performed for the treatment of ulnar nerve compression at the elbow. The independent effect of varying elbow position is shown for the medial epicondylectomy (ME), musculofascial lengthening technique of submuscular transposition (MFL), simple decompression (SD), Learmonth technique of submuscular transposition (SM), and subcutaneous transposition (ST). Note that only the musculofascial lengthening technique showed a decrease in the intraneural pressures in all ranges tested. (Reprinted from Dellon AL, Chang ET, Coert JH, Campbell K. Intraneural ulnar nerve pressure changes related to operative techniques. J Hand Surg [Am] 1994;19(6):923–30; with permission. Copyright © 1991, The American Society for Surgery of the Hand.)
severity of subjective complaints and objective findings. An interview questionnaire was used to evaluate results and satisfaction. Preoperatively, 54% were graded as poor and 46% as fair. Postoperatively, using the same scale, 84% had excellent or good postoperative grades and only 16% had fair postoperative grades. No limbs experienced recurrence, and no postoperative grades were poor. Ninety percent of patients stated they would undergo the operation again. Fifty-four percent reported that they were completely satisfied, and 38% were “satisfied with reservations” [11].

Novak and colleagues [26] reported a series of 100 patients (119 extremities) with a follow-up duration of at least 24 months. The authors focused mainly on “self-reported” outcomes for patients with ulnar nerve submuscular transposition with Z-musculofascial lengthening. By conducting telephone interviews, the authors found that of the 81 patients with unilateral cubital tunnel syndrome, 75% stated that their symptoms improved postoperatively and 83% stated that they would undergo surgery again. Of the 19 patients with bilateral operations, 68% experienced improvement in both arms and 26% experienced improvement in one arm. Based on a four-level scale (normal, improved, no difference, and worse), 43% of patients reported normal sensation and an additional 30% reported improved sensation. Thirty-eight percent reported normal strength, and an additional 16% experienced improved strength. No significant difference was shown in outcome for patients involved or not involved with workers’ compensation or litigation [26].

Table 2
Non-numerical grading of ulnar nerve compression at the elbow [8]

<table>
<thead>
<tr>
<th>Degree of Compression</th>
<th>Sensory</th>
<th>Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>Intermittent paresthesias, vibratory perception increased</td>
<td>Subjective weakness, clumsiness</td>
</tr>
<tr>
<td>Moderate</td>
<td>Intermittent paresthesias, vibratory perception decreased</td>
<td>Weakness in pinch and/or grip strength</td>
</tr>
<tr>
<td>Severe</td>
<td>Persistent paresthesias, abnormal two-point discrimination</td>
<td>Weakness in pinch and/or grip plus muscle atrophy</td>
</tr>
</tbody>
</table>

Table 3
Numerical grading of ulnar nerve compression at the elbow [24]

<table>
<thead>
<tr>
<th>Numerical score</th>
<th>Sensory</th>
<th>Motor</th>
<th>Description of impairment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>1</td>
<td>Paresthesia, intermittent</td>
<td>Weakness: pinch/grip</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Weakness: pinch/grip female, 10–14/26–39 lb</td>
<td>male, 13–19/31–59 lb</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Abnormal, threshold SW filament 3.22–3.61</td>
<td>Biothesiometer 3–10 μ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pressure-specified sensory device</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;45 years old,</td>
<td></td>
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<tr>
<td></td>
<td>≤3 mm at 1.0–20.0 gm/mm²</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>≥45 years old,</td>
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<tr>
<td></td>
<td>≤4 mm at 1.9–20.0 gm/mm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Weakness: pinch/grip female, 6–9/15–25 lb</td>
<td>male, 6–12/15–30 lb</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Paresthesia, persistent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Abnormal two-point discrimination:</td>
<td>5th finger</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pressure-specified sensory device</td>
<td></td>
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<tr>
<td></td>
<td>&lt;45 years old,</td>
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<tr>
<td></td>
<td>≥4 mm &lt;8 mm, at any gm/mm²</td>
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<tr>
<td></td>
<td>≥45 years old,</td>
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<tr>
<td></td>
<td>≥5 mm &lt;9 mm, at any gm/mm²</td>
<td></td>
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</tr>
<tr>
<td>7</td>
<td>Muscle wasting (1–2/4)</td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>Abnormal two-point discrimination:</td>
<td>5th finger</td>
<td></td>
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<tr>
<td></td>
<td>Pressure-specified sensory device</td>
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<tr>
<td></td>
<td>&lt;45 years old,</td>
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<td></td>
<td>≥8 mm at any gm/mm²</td>
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<tr>
<td></td>
<td>≥45 years old,</td>
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<tr>
<td></td>
<td>≥9 mm at any gm/mm²</td>
<td></td>
<td></td>
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<tr>
<td>9</td>
<td>Anesthesia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Muscle wasting (3–4/4)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Complications

Failure to achieve good results with an anterior transposition of the ulnar nerve at the elbow most often is caused by technical problems, which largely can be avoided if the surgeon keeps an anatomic checklist in mind during the operative procedure (Box 1) [27–30]. In cadaver dissections, anatomic variations about the medial humeral epicondyle identified the primary variables for which the surgeon must be aware [31]. The most common variables include a high origin for the superficial head of the pronator teres (20%), which means that if the “Z” is outlined in the manner illustrated in Fig. 3, the ulnar nerve will first cross over this most proximal portion of the pronator teres muscle and then cross beneath the newly configured, lengthened musculofascial origin, thereby creating a new space for entrapment. Therefore, the “Z” flap must include the entire pronator muscle.

Another anatomic consideration is the thick common flexor origin, which is within the flexor-pronator muscle mass. Failure to divide or adequately resect the muscle origin is the most common reason for failure of the anterior intramuscular transposition of the ulnar nerve. The point can be made that those reports with high success rates and low recurrence rates after anterior intramuscular transposition are related to how deeply the nerve is placed within or beneath the muscle mass and how extensively the fibrous organ of the common flexor digitorum origin is resected [32,33]. One could argue that intramuscular transpositions that resect an adequate amount of muscle origin are in effect submuscular transpositions, even though they leave a few muscle fibers deep to the ulnar nerve.

The distal analog of the medial intermuscular septum is the periosteal origin of the FCU from the ulna. This fibrous band is more medial than the origin of the common flexor mass, and is a distinct structure that must be resected.

When a patient is seen with any form of anterior transposition of the ulnar nerve and tapping over the distal portion of the incision causes a radiating Tinel sign to the little finger, it is clear that the ulnar nerve is entrapped at the distal site. The most common reason for this is

Box 1. Anatomic check list for musculofascial lengthening

Division of roof of cubital tunnel
Division of Osborne’s band between two heads of FCU
High division of fascia from medial intermuscular septum to medial head triceps
(Absence of arcade of Struthers) [27]
Excision of sufficient portion of medial intermuscular septum
Take down high origin of superficial head of pronator teres; include in “Z”
Lengthen origin of flexor-pronator muscle mass
Divide and slide common flexor tendon within flexor-pronator muscles
Distally dissect, eliminate tethering, of first motor branch to FCU
Release distally periosteal origin of FCU from ulna
Divide any distal fibrous bands within FCU
Integrity of medial antebrachial cutaneous nerve [28]
Integrity of medial brachial cutaneous nerve [14]
Integrity of nerve to medial humeral epicondyle [29]
Permit early postoperative gliding of ulnar nerve [30]

Fig. 11. Zig-zag pattern in recurrent ulnar nerve compression. Note neuromas of medial antebrachial cutaneous nerve, which commonly is present. Note compression of ulnar nerve proximally at retained medial intermuscular septum. Note that failure to dissect motor branch distally to FCU pulls ulnar nerve proximally at a distal edge of medial humeral epicondyle, kinking the nerve and restricting its glide. (Reprinted from Dellon AL. Techniques for successful management of ulnar nerve entrapment at the elbow. Neurosurg Clin N Am 1991;2(1):57–73; with permission.)
failure to originally release this periosteal origin of the FCU. The second most common reason is tethering of the ulnar nerve proximally against the medial humeral epicondyle by the first motor branch to the FCU. This branch can be dissected distally intramuscularly to facilitate adequate ulnar nerve mobility. If it is not, the “zig-zag” deformity of the ulnar nerve results (Fig. 11) [9].

The most common complication related to the musculofascial lengthening procedure remains bruising. Actual hematoma formation requiring drainage did occur when patients were allowed to travel long car distances home after surgery [14]. A tender or painful scar is the second most common complication caused by neuromas of the medial antibrachial cutaneous nerve, the medial brachial cutaneous nerve, or the nerve to the medial epicondyle. In a series of 38 patients with recurrent ulnar nerve entrapment who presented to the American Society for Surgery of the Hand at the annual meeting in 1991 (A. L. Dellon, unpublished observations, 1991), 36 had painful neuroma of the ulnar nerve and three additionally had painful neuroma of the medial brachial cutaneous nerve.

Other authors have reported similar complications. Pasque and Rayan [11] reported a 2% rate of neuroma of the medial antibrachial cutaneous nerve, a 2% rate of reflex sympathetic dystrophy that resolved with stellate ganglion blocks, and a 4% rate of hematoma that resolved spontaneously. Nouhan and Kleinert [12] reported a 3.2% rate of reflex sympathetic dystrophy. Loss of elbow extension can occur if the patient does not begin early postoperative mobilization. Care must be taken with mobilization, as rupture of the lengthened pronator-flexor mass has also been reported as occurring in 4% of patients, but all were associated with falls and not with normal activity [11].
Recurrence of ulnar nerve compression is rare. In the most recent series of more than 600 patients undergoing the musculofascial lengthening technique for ASMT, no recurrences were reported [15].

**Approach to the patient for whom ulnar nerve surgery has failed**

The most common presentation is that of a patient who has had one or more ulnar nerve transpositions and who not only still has numbness and weakness in the hand but also has a painful scar (Fig. 12). As discussed above, the most appropriate approach is to plan an external neurolysis of the ulnar nerve, beginning proximal to the previous surgical incision, and to relocate the ulnar nerve deep to the flexor-pronator muscle mass, reattaching it with a musculofascial lengthening approach. The approach to painful neuroma is to identify and resect and to relocate the proximal end into the triceps muscle (see Fig. 12) [34].

The longitudinal blood supply to the ulnar nerve is sufficiently robust that the length of nerve separated from its segmental blood supply during the anterior transposition does not present a problem. If sufficient intraneural fibrosis is identified during a primary ulnar nerve transposition, the longitudinal blood supply usually is sufficiently robust for a microsurgical intraneural dissection to be performed. However, in the experience of the senior author (A.L.D.), the longitudinal blood supply is not sufficient during repeat ulnar nerve surgery. In two patients, each older than 60 years, one undergoing second and one undergoing third “redo” ulnar nerve surgery, the complication of true infarct in the ulnar nerve occurred, leaving complete ulnar palsy. Therefore, the current philosophy is not to perform intraneural microdissection during surgery for recurrent ulnar nerve entrapment.

When the fourth palmar interosseous muscle fails to reinnervate sufficiently to correct the abduction deformity of the little finger (Wartenburg sign), a transfer of the extensor digiti mini from the ulnar to the radial side of the extensor hood is a useful adjunct (Fig. 13) [35].

**Acknowledgment**

The authors thank Dori Kelly, MA, for professional manuscript editing.

**References**


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Fig. 13. Diagram of tendon transfer. The ulnar slip of the extensor digiti minimi has been divided from the ulnar side of the extensor hood and its attachment to the abductor tubercle of the proximal phalanx. The tendon is then passed deep to its adjacent tendon to be inserted into the radial side of the extensor mechanism. *(Reprinted from Dellon AL. Extensor digiti minimi tendon transfer to correct abducted small finger in ulnar dysfunction. J Hand Surg [Am] 1991;16(5):819–23; with permission. Copyright © 1991, The American Society for Surgery of the hand.)*


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