Surgical outcomes of 654 ulnar nerve lesions

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Object. In this article the authors present a retrospective analysis of 654 surgical outcomes in patients with ulnar nerve entrapments, injuries, and tumors during a 30-year period.

Methods. Data were gathered between 1968 and 1998 at Louisiana State University Health Sciences Center. Mechanisms of injuries or lesions included 460 entrapments at the elbow level (70%), 76 lacerations (12%), 52 stretches/contusions (8%), 34 fractures/dislocations (5%), 12 gunshot wounds (2%), two injection-induced injuries (0.3%), and 13 nerve sheath tumors (2%).

In cases of entrapment, direct operative recordings uniformly demonstrated a slowing of conduction at the elbow, even in cases in which preoperative noninvasive studies had been nondiagnostic. Intraoperative electrical “inching” studies also demonstrated significant conduction abnormalities that lie just proximal to and through the olecranon notch rather than distal, beneath the flexor carpi ulnaris muscle. There were only eight exceptions to this. Lesions not in continuity due to the injury required primary or secondary end-to-end sutures or graft repair. Aided by intraoperative nerve action potential recording, lesions in continuity received either external or internal neurolysis and split repair or resection followed by end-to-end suture or graft repair. Functional recoveries of Grade 3 or better were seen in 81 (92%) of 88 patients who underwent neurolysis, 42 (72%) of 58 patients who received suture repair, and 24 (67%) of 36 patients who received graft repair. Nevertheless, fewer Grade 4 or 5 recoveries were reached than those seen in patients with radial or median nerve injuries. Nerve sheath tumors were resected with preservation of preoperative function in five of seven patients.

Conclusions. Although difficult to obtain, useful functional recovery can be achieved with proper surgical management of ulnar nerve entrapments and injuries.

KEY WORDS • nerve action potential • nerve graft • ulnar nerve

T he ulnar nerve has its greatest importance at the hand level, where it innervates most of the intrinsic muscles. Complete loss of the ulnar nerve is quite severe and is usually accompanied by a clawlike appearance of the little and ring fingers (Fig. 1). Surgical timing is important for patients who have severe or poorly recovering ulnar nerve injuries that show little spontaneous improvement. When surgery is greatly delayed, the risks of permanent loss of sensory and motor function and the onset of muscular atrophy and contractures increase.

In the early literature, reports on repairs of the ulnar nerve were not encouraging, especially compared with the results of radial and median nerve repairs. Recovery of function in the intrinsic muscles of the hand has been difficult to achieve with surgical treatment, although recovery of the hypothenar and adductor pollicis muscles has been possible. Recent reports have been more optimistic because of advances in microsurgical techniques and the development of electrophysiological recordings. Many of these reports contain relatively small patient populations, however, and have primarily focused on wrist-level injuries with few observations of injuries at the arm or elbow–forearm level.

The purpose of this study was to review retrospectively the cases of 654 patients with ulnar nerve injuries, nerve sheath tumors, and ulnar nerve entrapment neuropathy. Postoperative surgical outcomes were evaluated with respect to the type of lesion (in continuity or not in continuity), the mechanism of injury, and the type of repair (external neurolysis, primary or secondary suture repair, or graft repair after resection of neuroma stumps). In contrast with findings in the early literature, this study supports surgical repair of the ulnar nerve and demonstrates that repairs should not be abandoned in favor of reconstructive procedures alone.

Clinical Material and Methods

Patient Population

Between 1968 and 1998, 654 patients with ulnar nerve injuries were evaluated and underwent surgery at LSUHSC. Of the 654 patients, 460 had nerve entrapments and 194 presented with unilateral ulnar nerve lesions at the arm,
forearm, wrist, or hand levels. Table 1 shows the LSUHSC muscle grading system. Both pre- and postoperative grades were documented. Tables 2 and 3 show mechanisms of ulnar nerve injuries at the arm, forearm, and wrist levels. In the nerve injury group, laceration was the most common cause of injury at all levels. Other causes included GSWs, contusions, fractures, and tumors. Injuries were most common at the forearm level.

Patient ages ranged from 4 to 81 years. The average follow-up period was 1.8 years. Preoperative and postoperative EMG studies were performed in all patients.

Surgical Anatomy and Exposure

Ulnar Nerve in the Arm. The ulnar nerve originates from the medial cord of the brachial plexus at an axillary level. Initially posterior to the brachial artery, it courses down the upper arm toward the olecranon notch. While descending, it lies posterior to the pectoralis major muscle and medial or posteromedial to the brachial artery. At the midarm level, the nerve diverges medially from the brachial artery and either passes beneath, or less frequently, pierces the medial epicondyle. The nerve is often accompanied by the superficial posterior ulnar collateral artery, a branch of the brachial artery. The medial surgical approach provides the most extensive exposure of the nerve in the arm. Proximally, the nerve is explored by performing a medial incision centered in the cleft between the biceps–brachialis and triceps muscles. A superficial incision is made to and over the distal axillary and proximal brachial artery. Because there are no branches of concern at the upper-midarm level, dissection along the nerve is straightforward. Depending on the level of the lesion, exposure of the medial cord, its branch to the median nerve, and the antebrachial cutaneous nerves and ulnar nerve proper may be necessary. The origin of the ulnar nerve is clearly defined, despite variations in its anatomy. When features of the proximal median nerve and its input to the lateral and medial cord become apparent, the ulnar nerve can be traced distally and somewhat obliquely as it runs toward the olecranon notch. This can be achieved in part by sharply dissecting and carefully sectioning the intermuscular septum at the midarm level.

Moving distally, the raphe of Struthers is formed by the thickening of the deep, investing fascia of the distal portion of the arm and muscle fibers from the medial head of the triceps muscle. The nerve may pass beneath this arcade, distal to the intermuscular septum. When one dissects proximally from the medial epicondyle, the nerve is often covered by triceps fibers and by some fascia. The ligament of Struthers is infrequently present, but when it is, it arises from a distal medial humeral exostosis and crosses over the median and, in some cases, the ulnar nerve to insert on the epicondyle. It can be a source of proximal entrapment for the median and/or ulnar nerves. The nerve then passes into the ulnar groove or olecranon notch on the dorsal aspect of the triceps muscle. The nerve may pass beneath this arcade, distal to the intermuscular septum. When one dissects proximally from the medial epicondyle, the nerve is often covered by triceps fibers and by some fascia. The ligament of Struthers is infrequently present, but when it is, it arises from a distal medial humeral exostosis and crosses over the median and, in some cases, the ulnar nerve to insert on the epicondyle. It can be a source of proximal entrapment for the median and/or ulnar nerves. The nerve then passes into the ulnar groove or olecranon notch on the dorsal aspect of the triceps muscle. The nerve may pass beneath this arcade, distal to the intermuscular septum. When one dissects proximally from the medial epicondyle, the nerve is often covered by triceps fibers and by some fascia. The ligament of Struthers is infrequently present, but when it is, it arises from a distal medial humeral exostosis and crosses over the median and, in some cases, the ulnar nerve to insert on the epicondyle. It can be a source of proximal entrapment for the median and/or ulnar nerves. The nerve then passes into the ulnar groove or olecranon notch on the dorsal aspect of the intermuscular septum. In the distal arm, the nerve lies close to and beneath the proximal belly of the FCUM. Proximal to, as well as below the elbow, the FCUM is well supplied by branches from the dorsal surface of the ulnar nerve. Both arteries and veins run parallel to the nerve in this region and are usually adherent to it.

At this level the ulnar nerve is approached by exposing it in the olecranon notch area, just proximal to its entry point, and then tracing it proximally. Sectioning of the intermuscular septum and the raphe of Struthers is required for good exposure. The nerve may adhere, either by itself or by its branches, to the proximal FCUM. It is beneficial to dissect the nerve to the epineurial level and encircle it with Penrose drains at one or more distal levels of the arm. These drains are then used to shift the nerve as the surgeon clears branch-
Surgical outcomes of ulnar nerve repair

As the ulnar nerve leaves the cubital tunnel, it lies beneath the FCUM and on the palmar surface of the FDPs. It maintains this relationship until it reaches the midforearm. Branches to the medial half of the FDPs arise deep with regard to the two bellies of the PTM, courses distally for several centimeters before entering the muscle. The muscle bellies of the FCUM form the third part of the tunnel.

In this region, the nerve may be exposed by making an incision on the medial distal arm, passing over the volar elbow lateral to the medial epicondylar region and then tracking down to the medial and proximal forearm. The overlying extension of the epicondylar fascia is sectioned. The nerve is moved out of the notch by using a bipolar forceps to coagulate arteries and veins accompanying the nerve through this region. Small neural branches can be sacrificed. Manipulation of the nerve should be especially gentle, because the nerve is often entrapped at this level. The branches of the FCUM are usually maintained, but a portion is freed to aid mobilization of the ulnar nerve itself. The nerve is then traced distal to the notch by encircling it with a Penrose drain, dissecting it on every side while carefully sectioning overlying FCUM and related fascia. Branches of the ulnar FDPD need to be saved. They usually originate from the lateral or radial side of the nerve 2.5 to 5 cm distal to the olecranon notch. More superficially, originating branches of the FCUM can be dissected back up and into the main trunk of the nerve to gain length, or can be sectioned if necessary. To uncover the nerve adequately, the heads of the FCUM need to be split well distal to the level where the profundus branches exit the ulnar nerve.

As the ulnar nerve leaves the cubital tunnel, it lies beneath the FCUM and on the palmar surface of the FDPs. It maintains this relationship until it reaches the midforearm. Branches to the medial half of the FDPs arise deep with respect to the FCUM, approximately 2.5 to 5 cm distal to the notch and usually away from the radial surface of the nerve, where their course is relatively short. In the distal forearm, the nerve remains deep with respect to the FCUM, and medial to the flexor superficialis tendons. A straight line drawn from the medial epicondyle to the radial margin of the pisiform bone can be used to outline the course of the nerve in the forearm. The ulnar artery passes deep with regard to the two bellies of the PTM, courses medially to join the nerve in the middle third of the forearm, and lies close to the nerve in the distal forearm. Surgically, if one places the proximal phalange of the little finger into the groove and points the tip of the little finger toward the insertion of the FCUM insertion on the pisiform, the more distal course of the ulnar nerve is delineated.

At the proximal forearm level, there may be a Martin–Gruber anastomosis. Under these circumstances, the anteri-
or interosseous branch of the median nerve can give rise to a branch that extends to the ulnar nerve. This branch can take median fibers, destined for the abductor pollicis brevis and opponens pollicis muscles, from the median-to-forearm level of the ulnar nerve. These fibers can then return to the distal median at a wrist or palmar level. The latter is called a Riche–Cannieu anastomosis. More commonly, ulnar motor fibers descend into the proximal median nerve and return to the ulnar nerve at a forearm level through a branch from the anterior interosseous nerve. Thus, transection of the ulnar nerve at the elbow, in such a case, can spare many intrinsic muscles of the hand.

For midforearm-level exposure of the ulnar nerve, some of the muscle belly of the FCUM may have to be split. For distal forearm exposure, a skin incision parallel to the superior edge of the FCU tendon is made. The tendon and the muscle belly are retracted medially after being encircled with Penrose drains. From the posteromedial or ulnar aspect of the nerve, the dorsal cutaneous branch of the ulnar nerve arises and can usually be isolated and encircled with a plastic loop. The dorsal cutaneous branch provides sensation on the ulnar side of the dorsum of the hand. The ulnar artery, which runs adjacent and parallel to the nerve, is generally involved in nerve injuries. It may have to be isolated for subsequent repair or obliteration. The nerve is elevated by drains and is sharply cleared of investing tissues or scar; the veins in this area are coagulated.

Ulnar Nerve in the Wrist and Hand. After emerging from under the FCUM at the wrist level, the ulnar nerve enters the Guyon canal or tunnel. This tunnel is formed by the pisiform bone and the pisohamate ligament on the ulnar side of the hand. On the radial side, it is bound by the hook of the hamate. Proximally, the nerve is covered by an expansion of the FCU tendon and the antebrachial fascia. Distally, it is bordered by the pisohamate and pisometacarpal ligaments on either side, the opponens digiti quinti minimi muscle dorsally and superficially, and by overlying hypothenar fat and the palmar fibrous arch. The nerve then passes radial to the pisiform, palmar to the transverse carpal ligament, and dorsal to the superficial palmar carpal ligament. In the middle portion of the tunnel, it divides into deep terminal and superficial palmar branches at the base of the hypothenar eminence. At this level, exposure requires a distal forearm incision on the radial side of the FCUM. This incision runs along the radial side of the hypothenar eminence toward the...
interval between the ring and little fingers. As the nerve approaches the wrist, the palmar carpal ligament is sectioned and the transverse carpal ligament and the palmar surface of the profundus tendons are usually preserved as a bed for the nerve. In the more distal tunnel, the overlying fibrous arch of the palmar fascia should be incised for adequate exposure. Both the artery and nerve branch at this point and are often intertwined. Their relations should be assessed with the aid of magnification and careful placement of Alm retractors.

The superficial branch of the nerve exits the ulnar tunnel with the superficial terminal branch of the ulnar artery. Before becoming purely sensory, it provides small motor branches to the palmaris brevis muscle after crossing the flexor digiti quinti brevis muscle. It supplies the skin of the medial side of the hand by giving off several small twigs. It then divides into the proper digital nerve, which courses to the ulnar side of the little finger, and the common palmar digital nerve, which extends to the fourth web space. This common digital nerve again divides into two proper digital nerves at the level of the metacarpal shafts. They supply the palmar skin of the fingers and skin distal to the distal interphalangeal joints dorsally. In the palm, the nerves lie dorsal to the superficial palmar arch and toward the palm with respect to the flexor tendons. After dividing, the proper digital nerves lie superficial to the digital arteries.

The deep or terminal branch of the ulnar nerve exits the ulnar tunnel and passes around the hook of the hamate, under the fibrous arch of the hypothenar muscle origin. It passes downward and backward between the heads of the flexor and abductor digiti quinti minimi muscles and runs toward the thumb, along with the ulnar artery, within the concavity of the palmar arch. After supplying the two aforementioned muscles, it pierces the opponens digiti minimi muscle. The deep branch divides early to supply the hypothenar muscles, which include the abductor digiti quinti minimi and the opponens digiti minimi muscles. Occasionally, a hypothenar branch may arise from the ulnar nerve proximal to the takeoff of the superficial and deep branches. After crossing the palm, the deep branch provides additional branches that supply all the interosseous muscles, the third and fourth lumbrical muscles, the adductor pollicis muscle, and the flexor pollicis brevis muscle, sharing the latter innervation with the median nerve. The deep terminal branch also provides sensory afferents to the ulnarpalmar, intercarpal, and carpometacarpal joints.

Exposure of the ulnar nerve as it exits the ulnar tunnel can be achieved in the following manner. The superficial palmar branch, which exits the distal tunnel along with an arterial branch, is first mobilized along with more distal sensory branches. The deep palmar branch of the ulnar nerve is then exposed, usually beneath and slightly lateral to, or on the ulnar side of, the deep or terminal branch of the artery. Dissection in the palmar area needs to be performed with the aid of magnification, fine instruments, bipolar forceps, and, often, small Alm retractors.

**Surgical Technique**

External neurolysis is the cornerstone for almost all peripheral nerve operations. With the aid of magnification, it is performed in a circumferential fashion, proximal and distal to the site of injury or entrapment. This exposes the extent of the injured segment before intraoperative NAPs are recorded. Before suture or graft repair can be performed, any epineurial scarring must be resected using fine dissecting scissors, microscissors, or a scalpel blade; bleeding points at the epineurial or subepineurial level are coagulated using an irrigating bipolar forceps. When performing intraoperative NAP studies on a lesion in continuity, stimulating and recording electrodes are placed on the nerve proximal to the lesion to assess the NAP. The recording electrodes are then moved into the region of injury or entrapment, as well as distal to the lesion, and changes in the evoked NAP are observed. If an NAP is present, external neurolysis, with or without internal neurolysis, is sufficient to achieve a satisfactory outcome (Fig. 2). When no NAP is recorded across a lesion in continuity, resection and repair of the injured ulnar nerve is usually indicated.11,12

Internal neurolysis is indicated when an injury is more severe on one portion of the nerve than on another and an NAP is transmitted across the lesion. Split or partial graft repairs may be necessary when individual fascicles or bundles of fascicles do not transmit NAPs. In some cases, split repairs will help otherwise pharmacologically resistant neuralgia in cases in which function is present.

For transected nerves or in cases in which a segment not transmitting an NAP requires resection, end-to-end epineural repair can sometimes be achieved. Sharp dissection is necessary to mobilize proximal and distal stumps with adequate cross-sections to healthy epineural and fascicular structure before suture or graft repairs can be made. After careful hemostasis and avoidance of excessive tension at the suture site, the repair is performed using an appropriate caliber (6-0 to 8-0) monofilament interrupted nylon or prolene suture. Meticulous attention must be used to achieve anatomical alignment of the fascicles during apposition of the two stumps. If the distance between the stumps does not allow for a direct end-to-end suture repair without excessive tension despite mobilization, a graft repair is necessary.12

If a submuscular transposition is required (Figs. 3 and 4), the radial border of the PTM is freed, which usually exposes the elbow and proximal forearm portion of the median nerve. A trough is made by sectioning the PTM and the proximal FCUM an inch or so to the radial side of the medial epicondyle; this is usually done with a No. 10 scalpel blade. The section is taken down to the flexor mass of the upper forearm. The interval between the cut PTM and the FCUM is lifted with forceps and eventually held with Allis clamps, rolled back, and undermined with the larger Metzenbaum scissors. Care is taken to spare the median branches to the pronator muscle. It is also important to undermine the FCUM several inches distal to the elbow so that the transferred nerve has a smooth, nonangulated course across the elbow and to the level of the midforearm. The ulnar nerve is transposed deep to the transacted muscles. We customarily release some of the fibrous origin of the PTM from the medial epicondyle so that it can be moved laterally toward the radial side of the forearm to reach the disconnected pronator muscle and the FCUM. The disconnected muscle and fascia are retrieved and sewn back together with heavy sutures.20

**Results**

Ulnar Nerve Injuries at the Arm Level

Sixty-two patients with ulnar nerve injuries at the arm...
level were evaluated. The mechanisms of injuries included lacerations, fractures, GSWs, stretches/contusions, and tumors. After clinical or EMG studies indicated no functional recovery, 47 (76%) of the 62 patients underwent surgical explorations. Fifteen patients (24%) did not undergo surgery because they experienced spontaneous recoveries or there were delays in referral lasting beyond 14 months.

The lesions were divided into complete transections (lesions not in continuity) and lesions in continuity. Eleven lesions not in continuity were associated with complete loss of function of the distal ulnar nerve, both clinically and electrically. Table 4 shows the types of repairs made for complete transections of the ulnar nerve at the arm level and the number of patients in each group. Primary (≤ 72 hours) end-to-end suture repairs were possible in five cases; three resulted in Grade 3 or better outcomes. Secondary suture and graft repairs were less successful, with only one in three patients attaining a Grade 3 or better outcome. Split repair was possible because of partial transection in three cases. Each of these patients experienced excellent functional recovery.

Thirty-one patients with lesions in continuity underwent surgery (Table 4). Seven lesions in continuity were associated with GSWs, six with blunt soft-tissue contusions, and 11 with fractures. Other lesions were caused by relatively blunt injuries from a fan, propeller blade, or automobile metal, and were either partially lacerated or contused over a length. In these cases, exploration was delayed for 4 months to determine whether early signs of spontaneous recovery would occur.

There were 11 stretch/contusion ulnar nerve injuries at the arm level. Five (45%) of these improved spontaneously and did not require surgical intervention. Following surgery, five (83%) of six patients achieved Grade 3 or better functional recovery. Gunshot wounds that involved ulnar nerves were more common at the arm level than at other levels. Seven of the 11 patients with GSWs at this level underwent surgery. In the majority of GSW cases, the lesions were in continuity, with neuromas resulting from focal contusion. There were 12 fracture-related injuries at this level. Of these, 11 required surgery.

Lesions in continuity were found intraoperatively close to the site of the fracture. If a positive NAP was detected across the lesion intraoperatively, lesions were managed with neurolysis and/or more distal transposition. If there was no recordable NAP, resection and graft repair or suture repair was performed.

In 17 cases, intraoperative recordings revealed positive NAP recordings across lesions in continuity. Subsequent neurolysis resulted in Grade 3 functional outcomes or better in 15 (88%) of the patients. One lesion in continuity associated with a lacerating injury was treated with a split repair because one portion of the cross-section of the nerve was more severely involved than the rest. In the 13 patients in whom no NAPs were recorded across the lesions, four underwent suture repairs and six graft repairs. Three patients who underwent suture repair and three patients who underwent graft repair recovered to Grade 3 function or better. Despite the absence of NAPs, in three cases neurolysis was performed alone because of the extensive length of the lesion. In one of these three cases, the patient recovered function, but only to a Grade 3 level.

Function of the intrinsic muscles of the hand did not recover well after ulnar nerve repairs were performed at the arm level. The flexor profundus and/or hypothenar muscles did recover in some cases, however. Some sensory function returned in response to suture or graft repairs, which allowed patients to gain a Grade 3 level of function. Among
five patients with benign neural sheath tumors, four underwent total resection of the nerve, resulting in preservation of their preoperative function.

Ulnar Nerve Injuries at the Elbow and Forearm Level

Mechanisms of injury were more variable at this level than at the arm level, but lacerations, contusions, and fracture-associated lesions predominated. One hundred fifteen of 169 patients underwent surgery (Table 2). There were 31 lesions not in continuity at this level (Table 4).

Most injuries caused by laceration were reparable by end-to-end suture. An early primary end-to-end suture was performed for nerves severed by glass or a knife, and a secondary suture was required for more bluntly transected nerves. Lacerating injuries, which consisted of nerves that had been contused and stretched or partially lacerated, but not transected, were included in the lesions-in-continuity group. Patients in whom NAPs were recorded across the lesion underwent neurolysis or split repairs. Those in whom NAPs were not recorded required repair, usually by suture or graft. Almost all operations at this level included transposition and submuscular placement.

Most contusions and fracture-associated injuries were either partial or were associated with a recordable NAP, thus needing only neurolysis and a transposition. At this level, one of five patients with a GSW required graft repair and subsequent transposition, whereas the others only needed neurolysis and transposition. If a positive NAP was recorded intraoperatively or stimulation produced a distal muscle contraction, lesions were managed with neurolysis and/or transposition. If there was no recordable NAP, resection and graft repair or suture repair was performed.

Only one patient with an injection-induced nerve injury required repair, 3.5 months after injection; in the other NAPs were recorded across a lesion in continuity. That patient underwent neurolysis alone and, over the next 1.5 years, experienced acceptable recovery for function, but not always for pain. In one patient with a Volkmann contracture, the injury involved the median and radial nerves as well as the ulnar nerves. Neurolysis was performed on all three nerves and transposition of the ulnar nerve and a fasciectomy were performed relatively early, but the outcome was only fair.

In the one case of electrical injury at the elbow involving the ulnar nerve, the nerve was repaired 4 months after injury. A graft repair was performed, with only a Grade 2 level achieved. An electrical injury to the nerve tends to result in lesions along the length of the nerve, which are often associated with severe soft-tissue damage, making these lesions difficult to treat.

In response to suture or graft repair, 21 (68%) of 31 patients with lesions that were not in continuity achieved functional recoveries of Grade 3 or better. Of 21 cases, 16 patients (76%) with lesions in continuity not associated with recordable NAPs who underwent surgical repair attained a Grade 3 or greater improvement in function. The best results with lesions in continuity had positive NAPs and required only neurolysis. Of these, 54 (95%) of 57 patients achieved Grade 3 or better functional recoveries.

Ulnar Nerve Injuries at the Wrist Level

The leading mechanism of injury at the wrist level was laceration, just as it was at other levels (Table 2). Forty-eight patients were evaluated, and 32 of them underwent surgical exploration. Of the 12 lesions found not to be in continuity, six were sharp and acute enough to warrant primary repair. Two patients received secondary repairs; in one case this led to at least a Grade 3 recovery and in the other to a Grade 4 level of function. The other laceration-associated lesions left nerves in some degree of continuity; two patients in whom NAPs could be recorded underwent neurolysis with recovery and two underwent split repairs based on differential fascicular recordings.

Ten median–digital nerve repairs were performed; the results were variable, but enough sensation to be protective was usually recovered. Digital nerve neuromas were resected without repair in five other patients; these patients experienced improvement in both pain and hypersensitivity. In patients who suffered electrical injuries, graft repair was performed at surgery, and only one patient regained Grade 3 function. In five patients with contusions and in two of four patients harboring lesions associated with wrist fracture or dislocation there were lesions in continuity with positive NAPs. As a result, neurolysis was performed. There were two patients with GSWs and two patients with tumor. If a positive intraoperative NAP could be detected, the le-
lesion was treated with neurolysis; otherwise, resection and graft repair or suture repair was performed.

**Summary of Ulnar Nerve Injuries Across Levels**

Tables 3 and 5 show the mechanisms and outcomes of ulnar nerve injuries at various levels. The most common mechanism of injury was laceration (39% of patients). The frequencies of other injury mechanisms included 52 stretches/contusions (27%), 34 fractures/dislocations (18%), 12 GSWs (6%), 13 nerve sheath tumors (7%), three electrical injuries (2%), and two injection-induced injuries (1%). Surgical results were generally better for lesions in continuity than for lesions not in continuity. Thirty-seven (69%) of 54 repaired lesions that were not in continuity regained Grade 3 or better function, whereas 108 (85%) of 127 lesions in continuity that were surgically treated regained Grade 3 or better function.

Lesions not in continuity required primary or secondary end-to-end suture or graft repair. Aided by intraoperative NAP recordings, patients with ulnar nerve lesions in continuity underwent either external or internal neurolysis, or resection of the lesion followed by end-to-end suture or graft repair. Functional recoveries of Grade 3 or better were seen in 42 (72%) of 58 nerves that received suture repairs, 23 (70%) of 33 nerves that received graft repairs, and 80 (94%) of 85 nerves treated with neurolysis alone because a positive NAP was observed. Eleven of 13 patients with nerve sheath tumors underwent resection with preservation of preoperative baseline function.

### Ulnar Entrapment

Among 460 patients in whom surgery was performed to treat ulnar nerve entrapments, 65 patients (14%) underwent bilateral procedures and 147 patients had previously undergone unsuccessful ulnar neurolysis and/or subcutaneous or intramuscular transposition or epicondylectomy performed by other surgeons. The patients who had undergone previous operations underwent repeated neurolysis and submuscular transposition. The grading system used to evaluate ulnar entrapment is found in Table 6.

A subset of 364 patients who had not undergone previous treatment was followed for 1.5 years or longer. Table 7 provides a comparison of preoperative and postoperative grades for these patients. Fourteen patients (4%) had preoperative Grade 1 function, 78 (21%) Grade 2, 154 (42%) Grade 3, 107 (29%) Grade 4, and 11 (3%) Grade 5 function. At the follow-up examination, 212 patients (58%) were found to have improved by one functional grade, 95 patients (26%) by two grades, and 33 patients (9%) by three or four grades. Twenty-four patients experienced no improvement. Twenty-two of these experienced no changes in function following surgery. In two patients nerve function decreased one grade postoperatively; one patient had been assigned Grade 5 and the other Grade 4 before surgery. This decrease in function may have been caused by manipulation of the nerve during the operation.

Table 8 shows the postoperative course 1.5 years after follow up in 96 patients who had undergone surgery previ-
Surgical outcomes of ulnar nerve repair

**TABLE 6**
Grading for ulnar nerve entrapments

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
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<tbody>
<tr>
<td>0</td>
<td>intrinsic muscles of the hand display no motor function; sensation</td>
</tr>
<tr>
<td></td>
<td>Grade 0 or 1</td>
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<tr>
<td>1</td>
<td>intrinsic muscles of the hand display no motor function; sensation</td>
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<td></td>
<td>Grades 1–3</td>
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<tr>
<td>2</td>
<td>intrinsic muscles of the hand display trace (Grade 1) or antigravity</td>
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<td></td>
<td>(Grade 2) motor function; sensation Grades 2–4</td>
</tr>
<tr>
<td>3</td>
<td>intrinsic muscles of the hand display Grade 3 motor function;</td>
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<tr>
<td></td>
<td>sensation Grade ≥ 3</td>
</tr>
<tr>
<td>4</td>
<td>intrinsic muscles of the hand display Grade 4 motor function;</td>
</tr>
<tr>
<td></td>
<td>sensation Grade 4 or 5</td>
</tr>
<tr>
<td>5</td>
<td>intrinsic muscles of the hand display Grade 5 motor function;</td>
</tr>
<tr>
<td></td>
<td>sensation Grade 4 or 5</td>
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Electromyography studies demonstrated fibrillation potentials indicative of denervation within 3 to 4 weeks after the injury and sometimes, but not always, demonstrated reinnervation activity in the intrinsic muscles during the recovery period, before there was clinical evidence of functional recovery.13 Following an operation, evidence of electrophysiological recovery can be detected within 5 to 9 months, depending on the level of the injury, whether neurolysis, end-to-end repair, or graft repair has been performed, and if the latter, depending on the length of the graft.

After adequate external neurolysis is performed, the use of intraoperative NAP recordings can play an integral part in surgical decision making, because they can indicate useful recovery.11,19 An algorithm for surgical management of the peripheral nerve injury that can be applied to ulnar nerve injury is found in Fig. 5.

**TABLE 7**
Comparison of pre- and postoperative grades in 364 cases in which patients underwent surgery for ulnar nerve entrapment for the first time*

<table>
<thead>
<tr>
<th>Postop Grades</th>
<th>Preop Grades</th>
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* Motor function improved one grade in 212 patients (58%), two grades in 95 patients (26%), and three or four grades in 33 patients (9%). No change in functions was observed in 22 patients (6%) and function worsened in two patients (0.5%).

**TABLE 8**
Comparison of pre- and postoperative grades in 96 cases in which patients underwent surgery for ulnar nerve entrapment after previously undergoing other surgery*

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* Motor function improved one grade in 48 patients (50%), two grades in 16 patients (17%), and three grades in one patient (1%). No change in function was observed in 30 patients (31%) and function worsened in one patient (1%).

> Ously. Each patient had undergone one or more surgeries before entering this study. Of the 96 patients, 50% improved by one functional grade, 17% by two grades, and 1% by three grades. Thirty-two percent of the patients experienced no improvement. Only one seventh of these were assigned Grade 5 initially. One patient in this repeated surgery category experienced a decrease in function from the preoperative grade.

Intraoperative NAP recordings performed on exposed nerves revealed the following. 1) There were no acute significant changes in NAP velocity or amplitude before and after release from the olecranon notch and cubital tunnel. 2) Operative NAP studies that focused on shorter distances than those covered by preoperative conductive studies often showed significant slowing in locations where the nerve conduction had been present preoperatively. 3) Nerve action potential “inching” studies indicated decrease in velocity and amplitude just proximal to or in the proximal portion of the olecranon notch, and not in distal nerve beneath FCUM bundles. There were only eight exceptions to this.

**Discussion**

**General Issues**

Compared with the median nerve, in which it is difficult to regain lost nerve length, the ulnar nerve can be transposed anterior to the elbow, usually deep with respect to the pronator muscle and the FCUM, a maneuver that gains 2.5 to 3.8 cm of length. Even with this advantage, positive results of ulnar nerve repair at almost any level occur less frequently than they do with median or radial repairs. Thus, there are fewer Grade 4 or 5 recoveries in function with ulnar nerve repair. Surgical timing remains important for surgical results, as can be seen in Table 5. Even with this advantage, positive results of ulnar nerve repair at almost any level occur less frequently than they do with median or radial repairs. Thus, there are fewer Grade 4 or 5 recoveries in function with ulnar nerve repair. Surgical timing remains important for surgical success,10 and the outcome is worse if surgery is delayed beyond 3 months after the injury.

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Electromyography studies demonstrated fibrillation potentials indicative of denervation within 3 to 4 weeks after the injury and sometimes, but not always, demonstrated reinnervation activity in the intrinsic muscles during the recovery period, before there was clinical evidence of functional recovery.13 Following an operation, evidence of electrophysiological recovery can be detected within 5 to 9 months, depending on the level of the injury, whether neurolysis, end-to-end repair, or graft repair has been performed, and if the latter, depending on the length of the graft.

After adequate external neurolysis is performed, the use of intraoperative NAP recordings can play an integral part in surgical decision making, because they can indicate useful recovery.11,19 An algorithm for surgical management of the peripheral nerve injury that can be applied to ulnar nerve injury is found in Fig. 5.

Associated injuries to tendons, bones, vessels, or other nerves can downstage results, as can a fixed, clawlike hand, even if a successful repair returns nerve fibers to the intrinsic muscles of the hand.2 Most of the ulnar nerve’s input goes to the fine intrinsic muscles of the hand, which are immensely important for useful hand function, but are difficult to reinnervate. Although the function served by the FDPM goes to the fine intrinsic muscles of the hand, which are immensely important for useful hand function, but are difficult to reinnervate. The intrinsic muscles of the hand, these functions are still use-

**TABLE 7**
Comparison of pre- and postoperative grades in 364 cases in which patients underwent surgery for ulnar nerve entrapment for the first time*

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J. Neurosurg. / Volume 98 / May, 2003
Injury-Specific Issues

Entrapment Neuropathy. The most common lesion involving the ulnar nerve is entrapment at the level of the elbow, and, in this series, the predominant involvement was within the olecranon notch. The aponeurotic arch overlying this notch and extending to the medial epicondyle can thicken and compress the nerve. Flexion of the elbow moves the nerve through this tight area and may produce a frictional injury. More distal cubital tunnel syndrome occurs less frequently and, when it does, the ulnar nerve is compressed beneath or just distal to the origin of the OCUM heads. Occasionally, the ulnar nerve rides up and out or translocates out of the olecranon groove or notch when the arm is flexed, and can be irritated as it rides up over the epicondyle.

Patients commonly complain of paresthesias in the distribution of the ulnar nerve, particularly in the little finger and, sometimes, in the ring finger. Examination usually shows hyposthesia in the ulnar distribution of the hand. Some degree of weakness in the intrinsic muscles of the hand is present. Weakness of the FDPM in the little and, especially, ring finger usually occurs later than weakness of the intrinsic muscles of the hand. An ulnar claw may also develop in the course of severe entrapment. An electrophysiological workup usually, but not always, reveals a slowing of conduction at the elbow level of the entrapped ulnar nerve. In this series, focal intraoperative recordings demonstrated abnormal conduction across the olecranon notch, even in those patients in whom EMG indicated normal conductivity. Such direct operative recordings can be made over shorter distances than the usual conductive velocity studies. Intraoperative recordings also indicated that the conductivity was most abnormal either within, or just proximal, to the olecranon groove and not more distally located beneath the two heads of the FCUM.

Lacerations. The most common mechanism of injury at all levels of the ulnar nerve was laceration. Of 98 patients evaluated for lacerating injuries to ulnar nerves, 76 required surgical repair. Functional recovery following injury to the ulnar nerve from sharp or blunt laceration differed considerably. Lesions not in continuity that were caused by a sharp laceration that could be repaired with an end-to-end suture within 72 hours of injury (primary repair) usually attained favorable Grade 3 or better outcomes. This was seen in 16 (73%) of 22 patients. In patients in whom delays in repair occurred, mobilization of both nerve stumps and secondary end-to-end suture resulted in Grade 3 or better functional outcomes for 11 (69%) of 16 patients. When delays resulted in retraction of the proximal and distal stumps, end-to-end suture repairs were not possible. Despite extensive mobilization of the stumps, those patients required graft repair. Blunt lacerations caused by a chain saw or propellers often resulted in the complete transection of the ulnar nerve, with varying degrees of contusion or stretch. The extent of damage and secondary neuromas required a lengthy resection length and longer graft repair. Only five (56%) of nine such patients recovered Grade 3 function. This is not surprising because these blunt injuries were more severe than the sharp injuries.

Partial lacerations requiring split-graft repairs resulted in excellent outcomes for all three patients who received this repair. Sharp, clean transections of the ulnar nerve are best repaired during the acute period, whereas blunt transections with associated contusions are best surgically explored af-
Surgical outcomes of ulnar nerve repair

...after a delay of several weeks; the extent of resection needed to reach healthy tissue can then be accurately determined.

**Stretch/Contusion Injuries.** Stretch/contusion injuries to the ulnar nerve can result in lesions in continuity that have intraneural derangement over a significant length. Such injuries were most often seen at the elbow/forearm level of the ulnar nerve. In some patients function improved spontaneously and the injury did not require surgical management. Among surgically treated patients, 43 patients (86%) with severe preoperative deficits without significant improvement achieved Grade 3 or better function based on clinical and electrophysiological criteria after neurolysis. Most contusions were either partial initially or were associated with a recordable NAP, and thus needed only neurolysis or transposition at the elbow level. The presence of NAPs across the injured segment of the ulnar nerve following exploration and external neurolysis suggested that there was either some preservation, or enough regrowth to produce electrophysiological function and, hopefully, eventual clinical function. In patients in whom the lesion was in continuity, but no recordable NAP could be detected, the lesion required resection and graft repair.

**Fractures.** Most of the 34 patients we saw who had fracture-related ulnar nerve injuries experienced clinical and electrophysiological improvement during the follow-up examinations, thus avoiding the need for surgical repair. Those who did not exhibit significant improvement underwent surgical exploration. Although midhumeral fractures are more commonly associated with radial nerve injuries, ulnar nerve injuries were also seen with humeral fractures at the arm level and radial and/or ulnar fractures at the forearm level. Eleven patients underwent surgical exploration and neurolysis at the arm level, four required surgical exploration and neurolysis at the level of the wrist, and 19 received neurolysis with submuscular transposition at the elbow and forearm level. Lesions in continuity that had been created by stretching and contusion were usually found intraoperatively, close to the site of the fracture. These lesions were often associated with recordable NAPs across the lesion and only required neurolysis, usually with transposition and submuscular placement.

**Gunshot Wounds.** Gunshot wounds that involved the ulnar nerve were most commonly seen at the arm level. The majority of patients with GSWs had lesions in continuity, with neuromas resulting from focal contusion and stretch caused by the transfer of kinetic energy from the projectile to the nerve. If there was little or no improvement in EMG studies and in clinical findings after 3 to 4 months, surgical exploration was recommended. Thus, neurolysis and intraoperative NAP recording were recommended for patients with persistent severe deficits. When an irregular neuroma was present, suggesting more damage to one portion of the nerve than another, internal neurolysis and intraoperative recordings were performed on the fascicles to identify and preserve any functioning ones. The nonfunctioning fascicles were resected and a split graft repair was performed. Most patients in whom GSWs were repaired only with neurolysis or a split or short segment graft repair had successful functional recoveries.

**Electrical Injuries and Nerve Sheath Tumors.** Electrical injuries required graft repair 4 months after the injury. Only a Grade 2 outcome was achieved with graft repair. Burns due to electricity cause lengthy, extensive lesions and damage to surrounding tissue; they are notoriously difficult to treat. There were 13 nerve sheath tumors; each presented as a palpable mass with an insidious onset of neurological symptoms (Fig. 6). Gross-total resection was achieved in each case by using microsurgical techniques with minimal complications.

![Fig. 6. Imaging studies demonstrating an ulnar nerve sheath tumor at the arm level.](image)
or no deterioration in neurological function. In such cases surgery is indicated for pain, neurological symptoms (such as paresthesias), progression of the size of the mass, or concern about malignancy. Surgery is based on carefully identifying the fascicles entering and exiting the tumors. Typically, sequential NAP recordings made before and after excision show that the fascicles involved are usually non-functioning and are not associated with distal muscle contraction.

Conclusions

The type of surgical repair that is recommended—external or internal neurolysis, primary or secondary suture repair or graft repair—depends on the nature of the lesion. Injuries that result in a lesion in continuity with positive NAP recordings have the most favorable outcomes of Grade 3 or better. When a lesion not in continuity is caused by a sharp laceration, relatively early or primary end-to-end anastomosis achieves better functional outcomes than delayed repairs, either by suture or graft. In cases of blunt laceration or lesions in continuity with no recordable NAP, resection of the neuromatous segment and subsequent end-to-end suture or graft repair also results in relatively favorable outcomes, although not as favorable as outcomes of sharp lacerations (Fig. 6).

Ulnar entrapment neuropathies may demonstrate defects in the NAP intraoperatively, even when preoperative EMG and conduction velocity studies indicate that the responses are within normal limits. Notably, intraoperative inching studies of the nerve not only show a conductive defect, but also show that these changes begin just proximal to the elbow and reach their maximum level in the region of the olecranon notch, not distally under the FCUM. These electrical changes are usually correlated with thickening, thinning, or, in some cases, swelling of the nerve in the notch region. This suggests that, when there is significant and symptomatic ulnar entrapment, the problem is usually in the area of the olecranon notch and, therefore, our preferred surgical method for elbow level entrapment is not only neurolysis but also transfer of the nerve out of the notch and to a sub-muscular level.

References


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