Outcomes of Revision Surgery for Cubital Tunnel Syndrome

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Purpose To compare both validated patient-rated and objective outcomes of patients following revision cubital tunnel surgery to a similar group of patients who underwent primary surgery.

Methods This case-control investigation enrolled 56 patients treated surgically for cubital tunnel syndrome (28 revision cases, 28 primary controls) at a tertiary center. Patients with a minimum of 2 years of follow-up were eligible. All patients completed an in-office study evaluation. Revision participants represented 55% of potential patients in our practice and controls (treated only with primary surgery) were chosen at random from our practice to reach a 1:1 case to control ratio. Preoperative McGowan grading was confirmed similar between the groups. Outcome measures included validated patient outcome questionnaires (Patient-Rated Elbow Evaluation, Levine-Katz questionnaire), symptoms, and physical examination findings. Statistical analyses were conducted to compare the patient groups.

Results Despite 79% of revision patients reporting symptomatic improvement, revision patients reported worse outcomes on all measured standardized questionnaires compared with primary patients. The Levine-Katz questionnaire indicated mild residual symptoms in the primary group (1.6) versus moderate remaining symptoms following revision surgery (2.3). The Patient-Rated Elbow Evaluation also indicated superior results for the control group (9 ± 10) compared with the revision group (32 ± 22). Revision patients had a higher frequency of constant symptoms, elevated 2-point discrimination, and diminished pinch strength. McGowan grading improved after 25% of revision surgeries versus 64% of primary surgeries, and 21% of revision patients had deterioration of their McGowan grade.

Conclusions Subjective and objective outcomes of revision patients in this cohort were inferior to outcomes of similar patients following primary surgery. Revision surgery can be offered in the setting of persistent or recurrent symptoms that are unexplained by an alternative diagnosis, but patients should be counseled that complete resolution of symptoms is unlikely.
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Cubital tunnel syndrome is the second most common compressive neuropathy in the upper extremity with approximately 75,000 new cases reported annually.[1,2] Surgical treatment of cubital tunnel syndrome remains diverse with multiple accepted procedures.[3−5] No procedure has proved superior, and surgical failure occurs in 10% to 25% of patients.[4,6,7] Potential causes of failure include incorrect diagnosis, incomplete decompression, persistent traction on the nerve, postoperative compression secondary to scar or new areas of compression, and recalcitrant advanced disease.[2,4,7]

Regardless of the cause, persistent or recurrent symptoms can lead to revision surgery.[2,7] Most authors recommend either subcutaneous or submuscular transposition for revision.[2,7] Multiple studies have attempted to identify patient or surgical factors that predict failure of primary cubital tunnel surgery.[1,2,4,8] Despite interest in those factors predictive of revision surgery, it remains unclear how the outcomes following revision cubital tunnel surgery compare with those after primary surgery.

The purpose of this study was to compare both validated patient-rated and objective outcomes in patients following revision cubital tunnel surgery to a similar group of patients who underwent primary surgery at a minimum of 2 years later. We tested the null hypothesis that revision patients would have similar outcomes to those patients treated with a single operation.

MATERIALS AND METHODS

We identified eligible participants for this case-control investigation by querying a departmental electronic billing database for Current Procedural Terminology code 64718 (ulnar nerve surgery at the elbow) recorded between January 2006 and July 2011 to ensure minimum 2 years of follow-up. That code is used by all surgeons in our practice for both primary and revision surgeries. Medical records were reviewed to determine if patients had undergone primary or revision cubital tunnel surgery. This search found 448 eligible primary patients and 51 eligible revision patients. All surgeries (ie, primary and revision) were performed by 1 of 5 hand fellowship–trained surgeons in our practice. Of the 51 revision patients, 28 agreed to participate in the study.

Among the revision cohort, 50% of patients had recurrent symptoms and 50% had persistent symptoms following primary surgery. Of the 14 patients with recurrence, 7 cited pain as their primary symptom prior to revision and 7 reported numbness. Similarly, 50% of the patients with persistence complained of pain and 50% complained of numbness. Despite 3 patients citing weakness as their primary complaint prior to primary surgery, none of them complained of weakness as the main reason for requesting revision surgery. Twenty-six of the 28 patients underwent one revision and 2 underwent 2 revisions.

Workup prior to revision surgery included clinical evaluation with provocative maneuvers including a Tinel and an elbow flexion compression test as well as repeat electrodiagnostic studies depending on the clinical situation. Eleven revision surgeries (39%) were performed without repeat electrodiagnostic testing as revision surgery was often performed within 1 year of the index procedure. All revision patients had clinical evidence of ulnar nerve dysfunction with at least one provocative maneuver reproducing symptoms. In 17 patients, repeat electrodiagnostic studies were performed to confirm the diagnosis and exclude alternative sources of symptoms. Electrodiagnostic studies included both nerve conduction velocity assessment and electromyographic assessment. Nerve conduction velocity across the elbow was the most consistently reported data point. However, this was not the only variable considered by the attending surgeons when deciding on treatment. No revision surgeries were performed in the setting of comorbid diabetic neuropathy, although patients with diabetes without signs of neuropathy were offered revision. The decision to proceed with revision surgery was a shared decision between each patient and their surgeon based on patient dissatisfaction with the symptoms and objective evidence of ulnar nerve dysfunction on physical examination with electrodiagnostic testing providing secondary confirmation when needed. Infrequently, revision surgery was performed despite normal conduction velocity in face of positive physical examination findings and a lack of alternative diagnosis on electrodiagnostic testing.

The type of surgical procedure for both primary and revision cases was chosen at the discretion of the treating surgeons. The majority of revision surgeries were submuscular transpositions. Subcutaneous transpositions were performed by one surgeon if the nerve appeared to be completely tension free after being transposed anterior to the flexor pronator origin. At the patient's request, one revision surgery involved a repeat *in situ* decompression based on years of symptomatic relief following the initial decompression. The 2 patients with multiple revisions had submuscular transpositions performed as their initial revisions. During all revision surgeries, the ulnar nerve was examined for causes of failure including incomplete release, scarring, and instability. In our practice, patients with *in situ* decompressions are placed in a soft dressing and encouraged to actively move their elbow; the elbows in patients undergoing transposition are immobilized for 10 to 14 days.

Patients were contacted by telephone for enrollment, and all study participants were then met one-on-one by 1 of 2 members of the research team for an in-office interview and physical examination. The research team was blinded in regard to the outcome of surgery when contacting patients but not to the type of surgery (primary vs revision). All willing patients with a history of revision surgery were enrolled in the study. Eligible control patients were contacted by telephone via random selection until a 1:1 ratio of cases and controls was reached. Controls were defined by having undergone only a primary cubital tunnel surgery without any selection based on subjective or objective outcome experienced.

Data collected from patients' records included demographics, preoperative symptoms, preoperative electrodiagnostic studies, review of all clinical notes to determine indications for surgery, and review of operative notes to determine type of surgery or surgeries performed. For the purpose of this manuscript, the motor conduction velocity across the elbow is reported because it was the most consistently reported value on electrodiagnostic studies. Data collected at the time of in-office study evaluation included history of the patient's preoperative symptoms (verified with medical record), current symptoms, patient-rated outcome scores (ie, Levine-Katz questionnaire and Patient-Rated Elbow Evaluation) and physical examination findings. Physical examinations documented elbow flexion-extension arc, grip strength (maximal single effort on Jamar dynamometer in the second setting), key pinch strength (single maximal effort), and ulnar nerve provocative signs about the elbow (Tinel test, flexion compression test). The Levine-Katz questionnaire is a series of questions that grades patients based on a scale of 1 (mild) to 5 (severe) and can be broken down into scores for subscales of symptoms and function.[9,10] The questionnaire has been validated in carpal tunnel syndrome and has been used in one prior study evaluating cubital tunnel syndrome treatment outcomes.[11] The Patient-Rated Elbow Evaluation rates patients on a scale of 0 (no disability) to 100 (severe disability) with regards to both pain and function with elbow-associated activities.[12] A McGowan grade (0−III), which is based on objective physical examination findings, was assigned to each patient based on preoperative clinical records and postoperative in-office evaluation.[13,14] No preoperative McGowan grade was based on a patient's recollection of their symptoms. If a patient underwent bilateral surgeries, only the extremity operated on first was eligible for study inclusion.

The primary outcome measure was the Levine-Katz questionnaire total score. Initial sample size analysis determined that 40 patients would be required in each group to demonstrate a minimally clinical important difference defined as 0.66 times the SD of the total score with a beta of 0.8 and an alpha of 0.05.[9]

All data were collected and managed using Research Electronic Data Capture tools (http://project-redcap.org/), which is hosted in the biostatistics division of our university.[15,16] Following all patient study evaluations, comparative data were analyzed. Continuous variables were analyzed using a 2-tailed Student *t*-test, and categorical data were analyzed using either a chi-square value or a Fisher exact test. A *P* value of less than .05 defined statistical significance.

To examine for selection bias, an analysis of all revision patients eligible for the study but who were not enrolled was also performed. Of the 23 revision patients that did not enroll, 12 refused enrollment, 8 either moved out of the local area or were not located, and 3 agreed to participate but failed to attend the in-office evaluation. Data collected for this analysis included a review of the medical records to query demographics, preoperative symptoms, preoperative electrodiagnostic data, indications for surgery, and a review of operative notes. Similarly, postoperative clinical records were reviewed to assess patients' outcomes, symptoms, and satisfaction at latest follow-up. McGowan grades based on preoperative and postoperative clinical records were assigned and compared with those of the enrolled revision group.

RESULTS

The final groups of 28 revision patients and 28 control patients demonstrated similar demographics, preoperative McGowan grading, and electrodiagnostic data (Table 1). Sixteen controls and 14 revision patients had abnormal nerve conduction velocities (< 50 m/s) prior to their index procedure. The revision group had a higher proportion of open *in situ* decompressions (93% vs 61%) performed as their primary surgery ($P = .02$).

Table 2 presents the electrodiagnostic findings prior to revision surgery. During revision, 2 of 26 nerves were unstable, and 3 were incompletely decompressed following prior *in situ* decompression. The other 21 revision cases all had scarring around the nerve but no single explanation for failure.

Total Levine-Katz scores averaged 1.6 (mild symptoms) among controls versus 2.3 (moderate symptoms) after revision ($P = .001$). This difference exceeded the threshold for clinical relevance (minimal clinically important difference = 0.6 based on

TABLE 1. Demographics of Study Cohorts*

	Controls (n = 28)	Revisions (n = 28)	*P* Value
Age (y)	58 (39−71)	55 (32−72)	.26
Sex (female)	16 (57%)	17 (61%)	.27
Length of follow-up (y)	4.3 (2.0−7.4)	3.4 (2.0−6.2)	.01
Duration of symptoms (mo)	31 (2−240)	39 (1−240)	.59
Constant or intermittent symptoms before surgery			.13
Constant	18 (64%)	23 (82%)	
Intermittent	10 (36%)	5 (18%)	
Predominant symptom prior to primary surgery			.28
Weakness	10 (36%)	3 (11%)	
Pain	7 (25%)	12 (43%)	
Paresthesia	11 (39%)	13 (46%)	
Predominant symptom prior to revision surgery			
Weakness	−	0 (0%)	
Pain	−	14 (50%)	
Paresthesia	−	14 (50%)	
Worker's compensation	1 (4%)	4 (14%)	
Diabetes	3 (11%)	2 (7%)	
Preoperative McGowan grade†			.26
I	13 (47%)	13 (47%)	
IIA	11 (39%)	9 (32%)	
IIB	2 (7%)	6 (21%)	
III	2 (7%)	0 (0%)	
Preoperative ulnar nerve motor conduction velocity across elbow (m/s)‡	44.7 (26.0−83.3)	45.6 (17.0−68.0)	.81
Type of primary surgery			.02
Open *in situ* decompression	17 (61%)	26 (93%)	
Medial epicondylectomy	3 (11%)	0 (0%)	
Subcutaneous transposition	5 (18%)	2 (7%)	
Intramuscular transposition	3 (11%)	0 (0%)	
Submuscular transposition	0 (0%)	0 (0%)	
Type of revision surgery			
Revision open *in situ* decompression	−	1 (4%)	
Subcutaneous transposition	−	5 (17%)	
Intramuscular transposition	−	1 (4%)	
Submuscular transposition	−	21 (75%)	

*Parentheses indicate either percentage or range.
†Preoperative McGowan grade for revision cohort prior to primary surgery.
‡Nerve conduction studies with quantitative values for conduction velocity available for 25 of 28 control patients and 24 of 28 revision patients.

SD). Levine-Katz subscale scores indicated less residual symptoms in controls (1.6 vs 2.4; $P < .001$) and superior function in the control group (1.7 vs 2.2; $P = .02$). The Patient-Rated Elbow Evaluation indicated superior ratings for the control group (9 ± 10) compared with the revision group (32 ± 22) ($P < .001$).

Final patient-reported symptoms are shown in Table 3. Following revision surgery, 79% of revision patients reported some degree of symptomatic relief. Despite similar rates of subjective symptoms and paresthesias, the control group had a lower proportion of patients reporting constant symptoms ($P = .03$).

TABLE 2. Electrodiagnostic Findings Prior to Revision Surgery

Electrodiagnostic Testing Not Performed (n = 11)
- Revision based on symptomatology ≤ 1 y from index surgery (8)
- Revision offered after transposition successful on opposite side as primary treatment (1)
- Revision for isolated ulnar nerve symptoms in association with elbow contracture release planned (1)
- Revision offered for symptoms at > 3 years but no repeat electrodiagnostic testing elected per surgeon discretion (1)

Electrodiagnostic Testing Performed (n = 17)
- Results missing from chart (1)
- Decreased motor conduction velocity (9)
  - Mean 36 m/s (range, 12–49 m/s)
- Normal motor conduction velocity (7)
  - Late reinnervation changes (1)
  - Denervation (1)
  - Relative slowing vs opposite side (1)
- Other findings at time of repeat testing
  - Carpal tunnel syndrome (4)
  - Irritable triceps on electromyography not meeting criteria for radiculopathy (1)
  - Chronic cervical polyradiculopathy involving deltoid/biceps/triceps (1)
  - Secondary chronic cervical level 8 radiculopathy (1)
  - Mild radial neuropathy with reduced recruitment in extensor carpi radialis brevis (1)

TABLE 3. Final Subjective Symptoms According to Patient Group

	Controls	Revisions	*P* Value
Relief after primary surgery	27 (96%)	14 (50%)	< .001
Relief after revision surgery	–	22 (79%)	
Symptoms currently	22 (79%)	24 (85%)	.48
Paresthesias	17 (61%)	20 (71%)	.39
Symptoms constant, intermittent, or absent			.03
Constant	5 (18%)	15 (53%)	
Intermittent	17 (61%)	9 (32%)	
Absent	6 (21%)	4 (15%)	

The revision group lost 10° of elbow extension compared with the control group ($P < .01$; Table 4), and a smaller total arc of active elbow motion ($P < .01$). Control group patients who underwent anterior transposition had an average 7° loss of elbow extension compared with the rest of the control group ($P < .001$). Physical examination also revealed that revision cases had more frequent residual ulnar nerve tenderness at the surgical site, weaker key pinch, increased 2-point discrimination in the ring and little fingers, and a more frequent Wartenberg sign, all statistically significant. Two patients in the revision group had persistent claw posturing of the hand versus none in the control group ($P = .25$).

TABLE 4. Physical Examination Findings According to Patient Group*

	Controls	Revisions	*P* Value
Elbow extension (°)	2 (0–20)	12 (0–35)	< .001
Elbow flexion (°)	142 (120–145)	137 (125–150)	.09
Positive Tinel sign	15 (54%)	14 (50%)	.79
Nerve tender at elbow	4 (14%)	12 (43%)	.02
1st DI strength (out of 5)	4.5 (2–5)	4.4 (3–5)	.87
Grip strength (kg)	33 (11–54)	28 (8–63)	.13
Key pinch strength (kg)	8 (4–15)	5 (3–16)	.03
Ring/little finger 2-point discrimination (mm)	6 (5–15)	7 (6–15)	.02
Wartenberg sign	2 (7%)	9 (32%)	.02
Froment sign	4 (14%)	7 (25%)	.31

1st DI, First dorsal interosseous muscle strength on British Medical Counsel score 0–5/5.
*Parentheses indicate range.

TABLE 5. Final McGowan Grading According to Patient Group

	Controls	Revisions	*P* Value
Final McGowan grade			.01
0	10 (36%)	6 (21%)	
I	12 (43%)	5 (18%)	
IIA	2 (7%)	12 (43%)	
IIB	3 (11%)	3 (11%)	
III	1 (3%)	2 (7%)	
Change in McGowan grade after surgery			.003
Improved	18 (64%)	7 (25%)	
No change	8 (29%)	15 (54%)	
Worse	2 (7%)	6 (21%)	

TABLE 6. Comparison of Eligible Revision Patients Enrolled and not Enrolled*

	Enrolled (n = 28)	Not Enrolled (n = 23)	*P* Value
Age (y)	55 (32–72)	40 (19–63)	< .001
Sex (female)	17 (61%)	8 (35%)	.01
Predominant symptom prior to primary surgery			.66
Weakness	3 (11%)	1 (4%)	
Pain	12 (43%)	11 (48%)	
Paresthesia	13 (46%)	11 (48%)	
Preoperative McGowan grade			.48
I	13 (47%)	12 (52%)	
IIA	9 (32%)	8 (35%)	
IIB	6 (21%)	3 (13%)	
III	0	0	
Preoperative motor conduction velocity across elbow	46 (17–68)	43 (25–63)	.5
Worker's compensation	4 (14%)	3 (13%)	.9
Type of primary surgery			.16
Open *in situ* decompression	26 (93%)	17 (74%)	
Subcutaneous transposition	2 (7%)	5 (22%)	
Intramuscular transposition	0 (0%)	1 (4%)	
Type of revision surgery			.46
Revision open *in situ* decompression	1 (4%)	0 (0%)	
Subcutaneous transposition	5 (17%)	7 (30%)	
Intramuscular transposition	1 (4%)	0	
Submuscular transposition	21 (75%)	16 (70%)	
Change in McGowan after surgery			.16
Improved	7 (25%)	9 (39%)	
No change/worse	21 (75%)	14 (61%)	

*Parentheses indicate either percentage or range.

Final postoperative McGowan grades are reported in Table 5. Control patients were more likely to have either a grade 0 or I nerve dysfunction (79% vs 39%; $P = .01$). When compared with preoperative grading, 64% of control patients had improvement of at least one grade compared with 25% in the revision group ($P = .003$). Following revision surgery, 6 patients (21%) had a worse postoperative McGowan grade. For the 5 patients with either subluxation or incomplete decompression following their index procedure, 1 showed improvement, 2 had no change, and 2 had a worse postoperative McGowan grade.

Revision patients who were enrolled in our study were significantly older and more often women compared with those not enrolled (Table 6). The groups had similar preoperative symptomatology, McGowan grade, nerve conduction velocity, and surgery types. A similar percentage of patients had improved McGowan grading after surgery (25% vs 39%; $P = .16$).

DISCUSSION

The causes of failed cubital tunnel surgery vary, but studies often cite incorrect diagnosis or improper release of the ulnar nerve.[1,2,5,7,17–19] Following *in situ* decompression, failure may result from persistent nerve tension.[20,21] However, several studies have reported near equivalent outcomes comparing surgical procedures, and no consensus predictors of the need for surgical revision exist.[1,4,5,8]

In addition to difficulty predicting the need for revision surgery, it is unclear how revision ulnar nerve surgery outcomes compare with those of primary surgery. Goldfarb et al[20] reviewed 69 cases of *in situ* decompression with 5 failures that improved after revision submuscular transposition. The outcomes of

TABLE 7. Prior Studies Investigating Outcomes of Revision Cubital Tunnel Surgery

Reference	Design	n	Treatment	Follow-up	Outcome Measure	Results
Gabel and Amadio[17]	Retrospective case series	30	Varied; 80% submuscular	3.6 y	Novel point system based on objective findings of pain, sensation, and motor function	Excellent or good results in 22 of 30 Age > 50 y, electromyographic evidence of denervation, and prior submuscular transposition found to be negative predictors.
Rogers et al[19]	Retrospective case series	14	Submuscular transposition with external neurolysis	19 mo	Pain, paresthesias, sensory loss, grip and pinch strength	McGowan grades I and II patients had improvement in all evaluated measures. Grade III patients did not have improvement in sensory or motor loss.
Caputo and Watson[18]	Retrospective case series	20	Subcutaneous transposition	2.7 y	Same as Gabel and Amadio[17]	Excellent or good outcomes in 15 patients. Worse outcomes associated with increasing age and number of previous surgeries.
Dagregorio and Saint-Cast[23]	Retrospective case series	9	Neurolysis for failed submuscular transposition	2 y	Subjective symptoms, physical examination, and electromyographic findings. Classification system used by Wilson and Krout.[24]	Complete alleviation in 4 patients, fair results in 4, and poor outcome in 1 patient.
Vogel et al[22]	Retrospective case series	18	Submuscular transposition with Z-lengthening for failed subcutaneous transposition	42 mo	Subjective symptoms and physical examination in 15 patients	Improvement in grade in 14 of 15 patients examined; 78% satisfied 53% good to excellent final outcomes. Results did not mirror primary submuscular surgery from authors.

revision cubital tunnel surgery are predominantly reported in retrospective series without comparative groups (Table 7). Most report largely positive results using ad hoc scoring systems with pain and paresthesias most reliably improved.[2,18,19,22,23] Fair and poor results have been associated with advanced patient age, electromyographic evidence of denervation, or prior submuscular transposition.[17] Vogel et al[22] found a 78% satisfaction rate after revision submuscular transposition, which was lower than satisfaction for primary submuscular transposition in their practice.

Our data indicate poorer outcomes than expected for patients following revision cubital tunnel surgery based on the literature. Our use of validated patient outcome questionnaires as opposed to surgeon-based assessments may contribute to this disparity. In addition, directly comparing outcomes of revision surgery against a control cohort from the same surgeons may have clarified differential outcomes between primary and revision surgeries. This allowed us to distinguish differences in symptom quality with 53% of revision patients noting constant symptoms compared with 18% of controls.

With mounting evidence of equivalent outcomes across multiple cubital tunnel procedures, the rate of *in situ* decompressions performed has increased.[5,8,25] Brauer and Graham's decision analysis[26] determined the utility of different surgical procedures. Owing to concern for potential incomplete decompression and not changing the position of the nerve, they assigned a high value of probability of bad outcome to *in situ* decompressions. Despite this, *in situ* decompression had the highest expected utility based on minimal surgical morbidity coupled with good results following revision surgery (modeled as equivalent to primary submuscular transposition). Our modest outcomes following revision surgery raise doubt as to how successfully a poor outcome following *in situ* decompression can be salvaged with revision; this should be considered when deciding whether to decompress or transpose the ulnar nerve.

Admittedly, ulnar nerve transposition increases the risk of nerve devascularization.[2,5,8,25,27] This has led some surgeons to transpose the nerve in a vascular sling or pedicle, although superior outcomes have not been documented.[28,29] Zimmerman et al[30] reported 89% good to excellent results at minimum 6-year follow-up after primary submuscular transposition. Comparing our data and these studies suggests outcomes of primary submuscular transposition may exceed those realized when transposition is performed in the revision setting. In either instance, immobilization and increased surgical dissection required for submuscular transposition may contribute to the mild loss of elbow extension noted in these patients and could contribute to the deterioration in ulnar nerve function seen after 21% of revisions.

There are limitations to this study. To minimize recall bias, all patient charts were queried to verify their histories and preoperative McGowan grading was based solely on medical records despite their imperfections. In addition, a greater proportion of revision patients underwent *in situ* decompression as their primary surgery. Ideally, the types of primary surgeries performed on the 2 groups would be homogeneous. However, we did not identify any clear difference in baseline disease characteristics between the groups. Less than 100% enrollment among revision patients also introduced risk of selection bias. We cannot prove that patients enrolled were representative of all revision patients in our practice. However, our comparison of data between participants and nonparticipants demonstrating similar disease characteristics, operative procedures, and recorded outcomes suggested that our results would be unlikely to change if all revision patients were enrolled. Further, the Levine-Katz questionnaire was chosen to rate neurological dysfunction in the hand despite no formal validation testing for cubital tunnel syndrome. Finally, the number of patients in each group was smaller than our initial sample size goal after maximizing enrollment of revision cases. Had our results indicated the expected subtle, but potentially clinically relevant, differences between the groups, we planned to modify our study to enroll 2 controls per revision. However, given the significant differences between the groups on our primary outcomes, a type II statistical error was no longer a concern.

We do not know of a revision procedure in hand surgery that provides comparable outcomes to primary surgery, and our data affirm this statement for cubital tunnel surgery. Revision and control patients in this study were comparable by demographics, disease characteristics, and electrodiagnostic data. Despite baseline similarity, those patients requiring revision ulnar nerve surgery experienced worse patient-rated symptoms, function, and more residual nerve dysfunction at final evaluation. Our fellowship-trained hand surgeons have considerable experience with both primary and revision ulnar nerve surgery. It is plausible that those patients who failed to experience symptomatic improvement after primary nerve surgery have nerve dysfunction that was intrinsically less likely to respond to surgery. Alternatively, revision surgery itself, even if transposing the nerve for the first time, imparts a second nerve insult that disrupts vascularity and impairs recovery. Nonetheless, revision surgery on most areas of the musculoskeletal system is more likely to yield inferior results with greater residual symptoms.[31−36] We still offer revision surgery for recurrent or persistent cubital tunnel symptoms. We counsel patients that nearly 80% of revision surgeries improve symptoms, but the majority of patients continued to experience ulnar nerve dysfunction.

REFERENCES

1. Shi Q, MacDermid JC, Santaguida PL, Kyu HH. Predictors of surgical outcomes following anterior transposition of ulnar nerve for cubital tunnel syndrome: a systematic review. *J Hand Surg Am.* 2011;36(12):1996−2001.e1−6.
2. Nellans K, Tang P. Evaluation and treatment of failed ulnar nerve release at the elbow. *Orthop Clin North Am.* 2012;43(4):487−494.
3. Chung KC. Treatment of ulnar nerve compression at the elbow. *J Hand Surg Am.* 2008;33(9):1625−1627.
4. Dellon AL. Review of treatment results for ulnar nerve entrapment at the elbow. *J Hand Surg Am.* 1989;14(4):688−700.
5. Zlowodzki M, Chan S, Bhandari M, Kalliainen L, Schubert W. Anterior transposition compared with simple decompression for treatment of cubital tunnel syndrome. A meta-analysis of randomized, controlled trials. *J Bone Joint Surg Am.* 2007;89(12):2591−2598.
6. Bartels RH. History of the surgical treatment of ulnar nerve compression at the elbow. *Neurosurgery.* 2001;49(2):391−399; discussion 399−400.

7. Lowe J, MacKinnon S. Management of secondary cutibal tunnel syndrome. *Plast Reconstr Surg*. 2004;113(1):e1−e16.
8. Macadam SA, Gandhi R, Bezuhly M, Lefaivre KA. Simple decompression versus anterior subcutaneous and submuscular transposition of the ulnar nerve for cubital tunnel syndrome: a meta-analysis. *J Hand Surg Am*. 2008;33(8):1314.e1−12.
9. Levine DW, Simmons BP, Koris MJ, et al. A self-administered questionnaire for the assessment of severity of symptoms and functional status in carpal tunnel syndrome. *J Bone Joint Surg Am*. 1993;75(11):1585−1592.
10. Storey PA, Fakis A, Hilliam R, et al. Levine-Katz (Boston) Questionnaire analysis: means, medians or grouped totals? *J Hand Surg Eur Vol*. 2009;34(6):810−812.
11. Osei DA, Padegimas EM, Calfee RP, Gelberman RH. Outcomes following modified oblique medial epicondylectomy for treatment of cubital tunnel syndrome. *J Hand Surg Am*. 2013;38(2):336−343.
12. MacDermid JC. Outcome evaluation in patients with elbow pathology: issues in instrument development and evaluation. *J Hand Ther*. 2001;14(2):105−114.
13. Goldberg BJ, Light TR, Blair SJ. Ulnar neuropathy at the elbow: results of medial epicondylectomy. *J Hand Surg Am*. 1989;14(2 Pt 1):182−188.
14. McGowan AJ. The results of transposition of the ulnar nerve for traumatic ulnar neuritis. *J Bone Joint Surg Br*. 1950;32(3):293−301.
15. Harris PA, Taylor R, Thielke R, et al. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. 2009;42(2):377−381.
16. Obeid JS, McGraw CA, Minor BL, et al. Procurement of shared data instruments for Research Electronic Data Capture (REDCap). *J Biomed Inform*. 2013;46(2):259−265.
17. Gabel GT, Amadio PC. Reoperation for failed decompression of the ulnar nerve in the region of the elbow. *J Bone Joint Surg Am*. 1990;72(2):213−219.
18. Caputo AE, Watson HK. Subcutaneous anterior transposition of the ulnar nerve for failed decompression of cubital tunnel syndrome. *J Hand Surg Am*. 2000;25(3):544−551.
19. Rogers MR, Bergfield TG, Aulicino PL. The failed ulnar nerve transposition. Etiology and treatment. *Clin Orthop Relat Res*. 1991;269:193−200.
20. Goldfarb CA, Sutter MM, Martens EJ, Manske PR. Incidence of reoperation and subjective outcome following in situ decompression of the ulnar nerve at the cubital tunnel. *J Hand Surg Eur Vol*. 2009;34(3):379−383.
21. Gelberman RH, Yamaguchi K, Hollstien SB, et al. Changes in interstitial pressure and cross-sectional area of the cubital tunnel and of the ulnar nerve with flexion of the elbow. An experimental study in human cadavera. *J Bone Joint Surg Am*. 1998;80(4):492−501.
22. Vogel RB, Nossaman BC, Rayan GM. Revision anterior submuscular transposition of the ulnar nerve for failed subcutaneous transposition. *Br J Plast Surg*. 2004;57(4):311−316.
23. Dagregorio G, Saint-Cast Y. Simple neurolysis for failed anterior submuscular transposition of the ulnar nerve at the elbow. *Int Orthop*. 2004;28(6):342−346.
24. Wilson DH, Krout R. Surgery of ulnar neuropathy at the elbow: 16 cases treated by decompression without transposition. Technical note. *J Neurosurg*. 1973;38(6):780−785.
25. Soltani AM, Best MJ, Francis CS, Allan BJ, Panthaki ZJ. Trends in the surgical treatment of cubital tunnel syndrome: an analysis of the national survey of ambulatory surgery database. *J Hand Surg Am*. 2013;38(8):1551−1556.
26. Brauer CA, Graham B. The surgical treatment of cubital tunnel syndrome: a decision analysis. *J Hand Surg Eur Vol*. 2007;32(6): 654−662.
27. Ogata K, Manske PR, Lesker PA. The effect of surgical dissection on regional blood flow to the ulnar nerve in the cubital tunnel. *Clin Orthop Relat Res*. 1985;193:195−198.
28. Nakamura K, Uchiyama S, Ido Y, et al. The effect of vascular pedicle preservation on blood flow and clinical outcome following ulnar nerve transposition. *J Hand Surg Am*. 2014;39(2):291−302.
29. Danoff JR, Lombardi JM, Rosenwasser MP. Use of a pedicled adipose flap as a sling for anterior subcutaneous transposition of the ulnar nerve. *J Hand Surg Am*. 2014;39(3):552−555.
30. Zimmerman RM, Jupiter JB. Gonzalez del Pino J. Minimum 6-year follow-up after ulnar nerve decompression and submuscular transposition for primary entrapment. *J Hand Surg Am*. 2013;38(12): 2398−2404.
31. Rihn JA, Harrod C, Albert TJ. Revision cervical spine surgery. *Orthop Clin North Am*. 2012;43(1):123−136, ix−x.
32. Sadoghi P, Liebensteiner M, Agreiter M, et al. Revision surgery after total joint arthroplasty: a complication-based analysis using worldwide arthroplasty registers. *J Arthroplasty*. 2013;28(8): 1329−1332.
33. Dennis DA, Berry DJ, Engh G, et al. Revision total knee arthroplasty. *J Am Acad Orthop Surg*. 2008;16(8):442−454.
34. Denard PJ, Burkhart SS. Arthroscopic revision rotator cuff repair. *J Am Acad Orthop Surg*. 2011;19(11):657−666.
35. Getelman MH, Friedman MJ. Revision anterior cruciate ligament reconstruction surgery. *J Am Acad Orthop Surg*. 1999;7(3):189−198.
36. Mosier BA, Hughes TB. Recurrent carpal tunnel syndrome. *Hand Clin*. 2013;29(3):427−434.