Journal of Hand Surgery Global Online 2 (2020) 232–239

Contents lists available at ScienceDirect

Journal of Hand Surgery Global Online

journal homepage: www.JHSGO.org

Original Research

Classification and Treatment of Ulnar Nerve Subluxation Following Endoscopic Cubital Tunnel Release

Ather Mirza, MD, [*,†] Justin B. Mirza, DO, [*,†] Terence L. Thomas Jr, BS [†]

[*] North Shore Surgi-Center, Smithtown, NY
[†] Mirza Orthopedics, Smithtown, NY

A R T I C L E I N F O

Article history:
Received for publication February 27, 2020
Accepted in revised form May 6, 2020
Available online June 23, 2020

Key words:
Classification
Cubital tunnel syndrome
Elbow
Endoscopic cubital tunnel release
Minimally invasive

Purpose: Endoscopic cubital tunnel release (ECuTR) is an effective procedure to alleviate cubital tunnel syndrome. To improve patient outcomes and lessen concerns regarding ulnar nerve subluxation (UNS) after ECuTR, the current study proposes an intraoperative UNS classification system and subsequent treatment protocol. We present a preliminary report of patients treated under these guidelines.
Methods: We retrospectively reviewed 87 patients (100 ECuTRs). Nerve mobility was classified during surgery, in which grade 1 = no movement or partial subluxation; deep retrocondylar groove and/or no generalized hypermobility (no further intervention); grade 2 = partial subluxation; shallow retrocondylar groove and/or inherent generalized hypermobility (required medial epicondylectomy); and grade 3 = complete anterior dislocation (required medial epicondylectomy or anterior transposition). Clinical outcomes at final follow-up (mean ± SD, 34 ± 20.3 weeks; range, 5–89 weeks) were collected and included Disabilities of the Arm, Shoulder, and Hand questionnaires, visual analog scale pain score, grip and pinch strength, 2-point discrimination, and range of motion.
Results: We report 37 patients (42 cases), grade 1 (n = 30), grade 2 (n = 1), and grade 3 (n = 11). Gross grip strength, lateral, 3-jaw chuck, and precision pinch strength recovered 87%, 90%, 105%, and 87%, respectively. Wrist and elbow range of motion returned to normal limits, 2-point discrimination improved to normal scores at final follow-up, Disabilities of the Arm, Shoulder, and Hand scores were reduced from 59.8 before to 29.9 after surgery, and visual analog scale pain score improved from 7.2 before to 2.5 after surgery ($P < .001$).
Conclusions: To our knowledge, this is the first study to classify UNS after ECuTR and describe a guideline for ensuing treatment. Our preliminary report of patients shows satisfactory outcomes, which suggests that our intraoperative UNS classification system has promise in preventing adverse complications of ulnar nerve hypermobility after ECuTR.
Type of study/level of evidence: Therapeutic IV.

The study of ulnar nerve compression has led to the development of age-old procedures such as anterior transposition and, more recently, medial epicondylectomy and *in situ* release. *In situ* release of the cubital tunnel can be performed using open, mini-open, extensile open, and endoscopic techniques.[1] Endoscopic cubital tunnel release (ECuTR) allows for enhanced visualization[2] and has shown comparable results in decompressing the ulnar nerve and improving symptoms.[3–5] Endoscopic cubital tunnel release also offers minimally invasive benefits because it allows the surgeon to minimize extensive dissection, ulnar nerve devascularization, and manipulation.[3,6] A drawback, however, is the presence of ulnar nerve subluxation (UNS) after this procedure and a paucity of literature regarding the most effective way to identify and treat UNS after ECuTR.

Ulnar nerve subluxation occurs when elbow flexion results in an anterior displacement of the ulnar nerve from the retrocondylar

Declaration of interests: Dr A. Mirza receives intellectual property royalties, financial or material support, and stock or stock options from A.M. Surgical, Inc; Dr J.B Mirza receives other financial or material support from A.M. Surgical, Inc. No benefits in any form have been received or will be received by the other author related directly or indirectly to the subject of this article.

Corresponding Author: Ather Mirza, MD, Mirza Orthopedics, 290 E Main Street, Suite 200, Smithtown, NY 11787.
E-mail address: research@amsurgical.com (A. Mirza).

https://doi.org/10.1016/j.jhsg.2020.05.001

groove of the medial epicondyle. The existent literature adjudicates UNS etiologies to include natural laxity, anatomical variation of the medial epicondyle and the retrocondylar groove, congenital disorders, developmental disorders, and/or trauma.[7] The release of Osborne ligament during an *in situ* decompression has been suspected as the cause of postoperative ulnar nerve instability.[8,9] Recent research supported this ideology and showed that UNS after an *in situ* decompression can result in both complications and revision surgery.[3,10–15] Mirza et al[3] reported a 12% incidence of UNS after endoscopic decompression. In addition, Krogue et al[12] found that subluxation was the culprit of further symptoms in 11.4% of *in situ* decompression revision cases. Boone et al[10] and Dellon et al[11] both reported that persistent tension on the ulnar nerve during elbow flexion and nerve irritability due to nerve movement about the medial epicondyle can result in potential ongoing symptoms after a decompression. Matzon et al[13] also spoke about this issue, stating that a notable percentage of patients with a stable nerve before surgery may present with ulnar nerve instability after decompression, and that identification factors correlating to instability can aid surgeons in treatment. Of the 363 patients whom those authors studied, 21% underwent further treatment of ulnar nerve instability and 12% were identified with instability during surgery after an *in situ* decompression.[13]

These results motivated a need to study ulnar nerve mobility and develop necessary treatment guidelines. To improve patient outcomes and quell concerns regarding UNS after ECuTR, the current study proposes an intraoperative UNS classification system to dictate subsequent treatment. Our purpose was to illustrate a grading scheme and corresponding surgical guidelines to evaluate UNS after an ECuTR technique. To help validate our classification system, we present a preliminary report of short- to intermediate-term clinical outcomes for patients treated under these guidelines. We hypothesize that our classification system will help produce satisfactory clinical outcomes across all UNS grades, aiding in an understanding of nerve mobility and improving how we clinically manage patients with UNS after ECuTR.

Materials and Methods

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. We obtained informed consent from all patients for inclusion in the study. This study was exempt from institutional review board (IRB) approval. There was no external source of funding for this study.

Surgical technique

Patients who presented with a Dellon and MacKinnon[16] classification of mild to severe cubital tunnel syndrome (CuTS) were indicated for an endoscopic technique. Contraindications included osteoarthritis of the elbow, cubitus valgus, recurrent CuTS, and pathology (including but not limited to unstable elbow, nerve tumors, and space-occupying lesions).

All surgeries were performed by the authors (A.M. and J.B.M.) at a single institution. Each procedure took place on an outpatient basis under regional intravenous block with an upper-arm tourniquet. The patient was arranged in a supine position and the tourniquet was positioned proximally to avoid interference with a proximal dissection. The shoulder was abducted to approximately 90° and the elbow flexed 70° to 90° with a bolster placed underneath the elbow. The surgical technique was performed as described by Mirza et al.[3,6] A small 2.5-cm incision was made near the posterior medial epicondyle and deepened to expose and then protect branches of the medial antebrachial cutaneous nerve. The ulnar nerve was identified followed by proximal dissection entering the medial intermuscular septum. A 4.0-mm endoscopic cannula/blade system called the Stratos (A.M. Surgical, Inc, Smithtown, NY) was used for all ECuTRs. Once the surgeon was satisfied with the visibility and protection of the nerve, the blade was deployed and the release was made. Subsequently, attention was drawn to the nerve distally. The medial epicondylar region was released by gentle dissection and a dissector was used to create a pathway underneath the flexor pronator aponeurosis. The scope was then introduced from the proximal to distal direction along the nerve. Once again, the nerve was protected, and upon clear visualization, the blade was deployed and complete division of the flexor pronator aponeurosis was ascertained. In every case after ECuTR, the elbow was taken through range of motion (ROM) tests during surgery to classify UNS and determine treatment afterward.

Classification system

Each elbow was flexed and extended repeatedly subsequent to ECuTR to identify and classify UNS. Subluxation was primarily classified using intraoperative visualization without the aid of other techniques or measurements (Fig. 1). Our classification system consisted of 3 distinct grades (Table 1). Each UNS classification grade was dependent on (1) intraoperative visualization of UNS, (2) preoperative findings of generalized hypermobility (assessed by a Beighton score greater than 5 out of 9), and (3) intraoperative evaluations of retrocondylar groove depth. We assessed retrocondylar groove depth using intraoperative visualization of the patient anatomy after endoscopic release. Grade 1 was given to patients who had minimal nerve mobility during flexion following ECuTR. For grade 1 patients, the ulnar nerve either remained in the retrocondylar groove (Fig. 2A), toggled mildly within the retrocondylar groove (Fig. 2B), or ascended the medial epicondyle but did not overcoming it (partial subluxation) (Fig. 2C). Second, a grade 1 classification was assigned to patients who presented with no signs of preoperative generalized hypermobility and/or showed a deep retrocondylar groove during surgery. Grade 1 patients required no further treatment, and the surgeon proceeded to closing. Grade 2 was given to patients who had moderate nerve hypermobility during flexion during surgery. Grade 2 was assigned when the ulnar nerve showed a partial subluxation after ECuTR (Fig. 2C), but the patient's preoperative assessment showed generalized hypermobility and/or revealed a shallow retrocondylar groove during surgery. In grade 2 patients, a medial epicondylectomy was performed. Grade 3 was given when the ulnar nerve ascended and overcame the medial epicondyle during flexion, presenting as complete anterior dislocation and severe nerve hypermobility (Fig. 2D). In grade 3 patients, an anterior transposition or medial epicondylectomy was required .

Because the previous literature does not show a notable difference in outcomes between medial epicondylectomy and anterior transposition,[10,17] we prefer the former, because it does not require us to extend beyond the original decompression incision. Medial epicondylectomy preserves the vascular supply to the nerve, and contrary to anterior transposition, it does not serve as a potential secondary site of nerve compression.[6] However, the patient's generalized hypermobility can have a role in the decision to perform an anterior transposition on a grade 3 patient. We recommend that grade 3 patients with inherent soft tissue laxity (ie, double-jointed patients) be treated with an anterior transposition.

If medial epicondylectomy or anterior transposition was deemed necessary, the procedure was performed subsequent to the ECuTR. The medial epicondylectomy was exacted through a

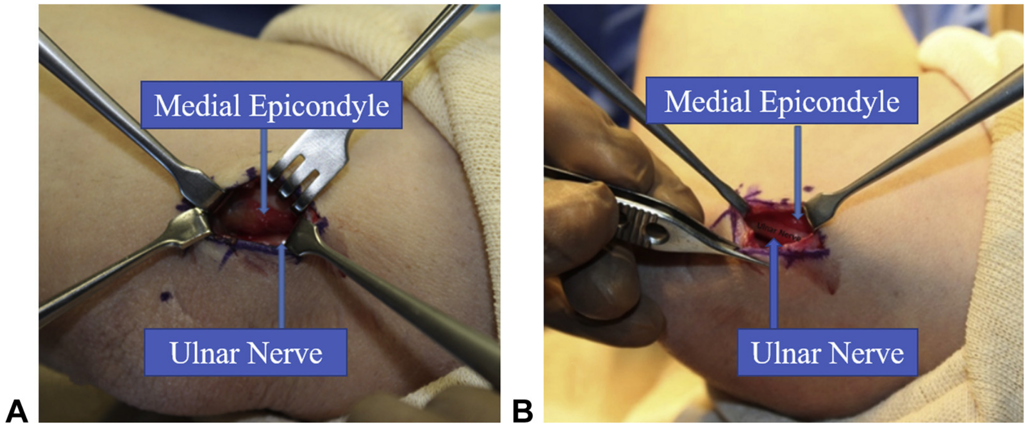

Figure 1. Visualization of UNS through ECuTR (2.5-cm) incision site. **A** Elbow in extension. **B** Elbow in flexion.

Table 1
Ulnar Nerve Subluxation Classification Breakdown and Treatment Guidelines

UNS Classification Grade	Description	Treatment Guidelines	Patients, n
1	Ulnar nerve remains in retrocondylar groove, toggles mildly, or ascends medial epicondyle but does not overcome it (partial subluxation). Intraoperative findings show deep retrocondylar groove and/or preoperative findings show minimal soft tissue laxity; Beighton score < 5/9. Minimal nerve mobility.	No further treatment required	30
2	Ulnar nerve ascends medial epicondyle but does not overcome it (partial subluxation). Intraoperative findings show shallow retrocondylar groove and/or preoperative findings show inherent soft tissue laxity; Beighton score > 5/9. Moderate nerve hypermobility	Required medial epicondylectomy	1
3	Ulnar nerve ascends and overcomes medial epicondyle (complete anterior dislocation) Severe nerve hypermobility	Required medial epicondylectomy or anterior transposition	11

subperiosteal dissection, in which 2 flaps were elevated anteriorly and posteriorly, exposing 4 to 5 mm of the medial epicondyle. A 3- to 4-mm portion of the medial epicondyle was osteotomized superiorly, making sure not to compromise the ulnar collateral ligament.[18,19] A rasp was used to smooth the raw surface of the medial epicondyle. Then, a subperiosteal and soft tissue closure was accomplished using 4-0 bioabsorbable sutures. The elbow was then flexed and extended to confirm no further impingement of the ulnar nerve was present. Contrarily, an anterior transposition was performed by further extending the incision, exposing the flexor pronator aponeurosis anterior to the medial epicondyle. The flexor pronator aponeurosis was then divided to create a bi-lobe pedicle, the nerve was fixated anterior to the medial epicondyle, and the bi-lobe pedicle was sutured over the nerve using 4-0 bioabsorbable sutures. The elbow was then flexed and extended to confirm no further UNS was occurring. Once these conditions were satisfied for both procedures, the wound was closed with a subcuticular closure. Sterile pieces of medical tape were applied and soft dressings were administered with the provision of an ulnar nerve sleeve with bulky cushion for the ulnar nerve.

All patients returned 5 to 7 days after surgery, were fitted with an ulnar nerve sleeve with a built-in cushion to protect the ulnar nerve, and were prescribed occupational therapy. At this point, patients who underwent ECuTR or ECuTR plus medial epicondylectomy were permitted to perform usual activities of daily living. Patients were also advised to return to work at that time. Those whose jobs required heavy manual labor were advised to return to work after 3 to 4 weeks. Anterior transposition patients required 3 additional weeks of immobilization for further soft tissue healing. Upon soft tissue healing, anterior transposition patients were advised to return to work.

Case series

A single-institution, retrospective chart review was performed on all patients who were endoscopically treated for CuTS by A.M. and J.B.M. between April 2017 and August 2019. Patients who presented with preoperative anterior nerve dislocations were ineligible for an ECuTR and were treated using an open technique. These patients were excluded from the chart review. A total of 87 consecutive patients (100 CuTSs), who failed conservative management and were eligible for an ECuTR presented to our office for surgical treatment. We excluded 50 patients (58 cases): 43 cases lacking proper grading documentation and 13 cases with comorbidities and/or unrelated surgical treatment on the same hand, wrist, elbow, or shoulder. Cases were also excluded if they had a revision ECuTR performed ($n = 2$). Previous literature shows that 20% to 25% of patients simultaneously present with concomitant carpal tunnel syndrome and CuTS.[20–22] This was true at our institution, where patients were often surgically treated with dual-endoscopic carpal and cubital tunnel release. A study performed by Cross and Matullo[20] reported that patients treated with dual-endoscopic carpal and cubital tunnel release showed results comparable to when those procedures were performed in isolation. Therefore, owing to the frequency of this occurrence and the minor effects on patient outcomes, cases of dual-endoscopic carpal and cubital tunnel release were included in the patient cohort and

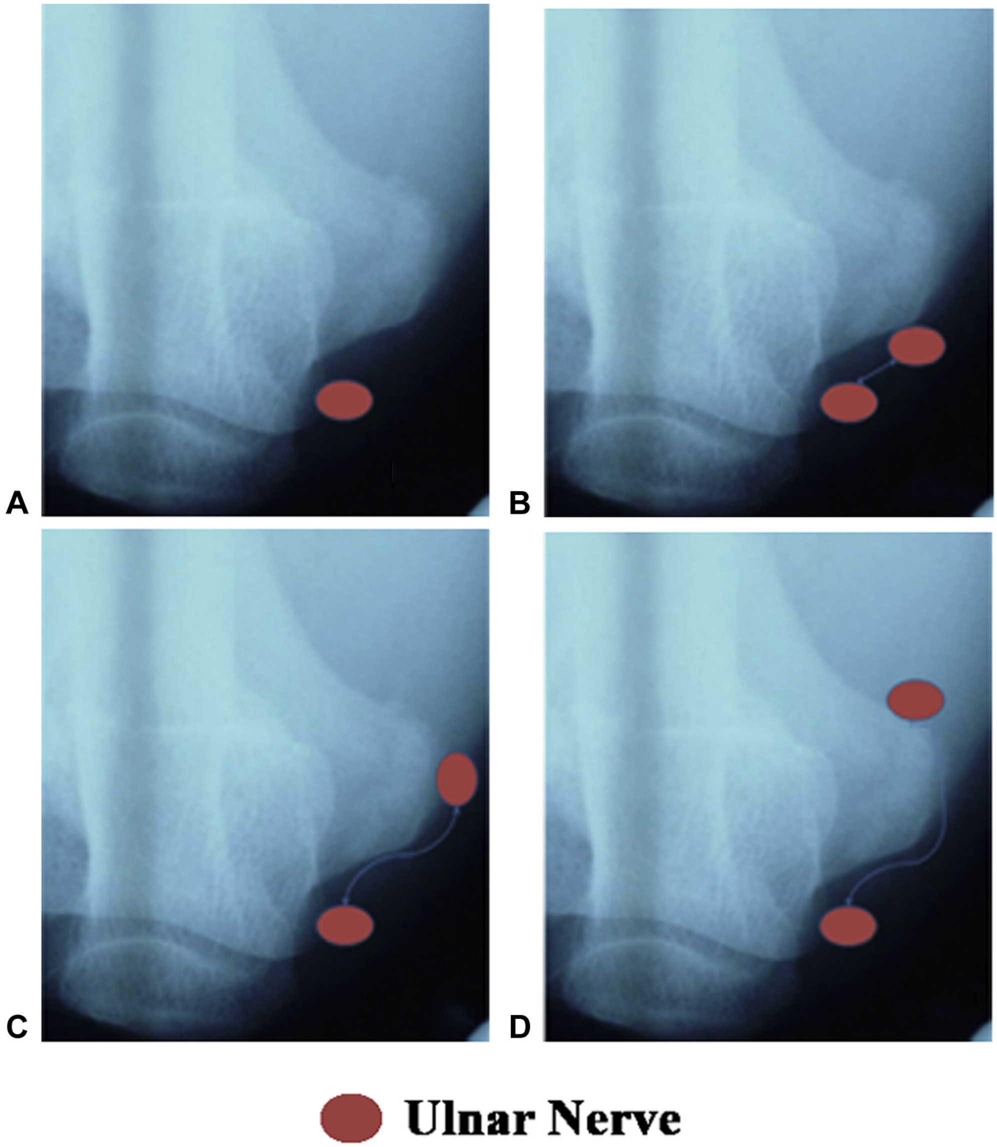

Figure 2. Degrees of ulnar nerve mobility and classification after ECuTR. **A** Grade 1 UNS: no nerve movement. **B** Grade 1 UNS: slight toggle of the nerve. **C** Grade 1 to 2 UNS: partial subluxation ascending the medial epicondyle. The depth of each patient's retrocondylar groove and patient-generalized hypermobility differentiates the classification of grade 1 or 2. **D** Grade 3 UNS: full dislocation of the nerve overcoming the medial epicondyle.

analysis (n = 18). Fourteen of these patients underwent preoperative EMG testing, resulting in 11 mild and 3 moderate cases of carpal tunnel syndrome.

We report the remaining 37 graded patients (16 males and 21 females, mean age [±SD], 52.8 ± 13.3 years [range, 21.5–77.4 years]), who underwent 42 ECuTRs. Mean (±SD) follow-up was 34 ± 20.3 weeks (range, 5–89 weeks). Seven patients were lost to follow-up and 8 were satisfied with the outcomes after the 3-month visit and did not return to our office for further follow-up. Twenty-six surgeries were performed on dominant hands and 16 on nondominant hands; 6 patients underwent bilateral treatment. Patient information was collected anonymously and stored in a database. Patient data included age, sex, injured hand, hand dominance, surgeon name, concomitant diagnoses and surgeries, UNS classification grade, subsequent treatment (if applicable), any new injuries after ECuTR, and clinical outcomes. Short- to intermediate-term clinical outcome measures were recorded before and after surgery at final follow-up. Subjective outcome measures included visual analog scale (VAS) pain scale (0–10) and Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaires. Objective outcome measures included gross grip strength, lateral pinch, precision pinch, and 3-jaw chuck strength, active ROM (AROM) of the wrist and elbow, and 2-point discrimination. All objective outcome measures were evaluated by our authors (A.M. and J.B.M) and our in-house certified occupational hand therapists at postoperative follow-up visits of 10 days, 8 to 12 weeks, 6 months, and final follow-up.

Clinical and statistical analysis

Owing to the retrospective nature of this analysis, objective outcome measures of grip strength, pinch strength, and AROM were available only after surgery. Therefore, final follow-up grip and pinch strengths were compared with their contralateral (uninjured) sides at final follow-up and AROM was compared with standard values.[23–25] Grip and pinch strength measurements were

Table 2
Subjective and Objective Clinical Outcomes Between Group 1 (Grade 1) and Group 2 (Grades 2 and 3) Patients*

Variable	All Patients (n = 42)	Group 1 (n = 30)	Group 2 (n = 12)	*P* Value
Grip and pinch strength recovery (%) (mean				
Gross grip	87.2 ± 36.4	90.5 ± 43.1	83.6 ± 29.6	.7
Lateral pinch	89.9 ± 30.3	97 ± 38.3	81.8 ± 16.8	.3
Three-jaw chuck	105.1 ± 30.4	104.8 ± 27.6	105.3 ± 35.2	.98
Precision pinch	86.7 ± 31.2	77.5 ± 35.7	97 ± 23.3	.2
Follow-up, wk	23.6 ± 28.6	28.6 ± 34.7	17.9 ± 20.6	.45
Active ROM (degrees)				
Wrist				
Dorsiflexion	58.0 ± 12.6	57.8 ± 11.4	58.4 ± 17.4	.95
Volar flexion	57.0 ± 14.7	57.3 ± 12.4	56 ± 22.1	.9
Radial deviation	20.8 ± 5.3	19.9 ± 5.8	23.4 ± 2.3	.07
Ulnar deviation	29.9 ± 8.8	28.9 ± 5.2	32.8 ± 16	.62
Supination	82.5 ± 8.3	81.2 ± 9.3	86 ± 3.7	.1
Pronation	87.4 ± 4.3	87.8 ± 3.7	86.3 ± 5.9	.6
Elbow				
Extension	3.5 ± 25.1	4 ± 28.6	2 ± 13.6	.83
Flexion	133.3 ± 28.8	140.5 ± 23.9	114.2 ± 34	.13
Follow-up, wk	17.0 ± 28.6	11.7 ± 25.6	31.2 ± 27	.16
Two-point discrimination				
Thumb	4.0 ± 0.6	4.1 ± 0.5	3.5 ± 0.7	.44
Index	4.0 ± 0.6	4.1 ± 0.5	3.5 ± 0.7	.44
Middle	4.0 ± 0.6	4.1 ± 0.5	3.5 ± 0.7	.44
Ring	4.0 ± 0.6	4.1 ± 0.5	3.5 ± 0.7	.44
Little	4.2 ± 0.7	4.4 ± 0.7	3.5 ± 0.7	.3
Follow-up, wk	17.0 ± 28.6	11.7 ± 25.6	31.2 ± 27	.16
Postoperative DASH				
Mean ± SD	29.9 ± 26.0	23.3 ± 19.1	37.8 ± 38.2	.41
Follow-up, wk	34.9 ± 26.0	40.9 ± 31.5	27.6 ± 18.2	.41
Postoperative VAS				
Mean ± SD	2.5 ± 2.5	2.9 ± 3	1.9 ± 1.5	.31
Follow-up, wk	11.9 ± 15.1	9.8 ± 16.1	15.7 ± 13.3	.36

* Data are shown as mean ± SD. Statistical comparisons and *P* values represent comparisons only between groups 1 and 2 at final follow-up. $P < .05$ represents significant differences.

corrected for using the 10% rule, which states that in right-handed patients, the dominant hand is roughly 10% stronger than the nondominant hand.[26] Therefore, dominant hand grip and pinch strength measurements were reduced 10% for right-handed patients. After this correction, we calculated each patient's percent strength recovery by dividing the injured hand measurements at final follow-up by the measurements of the contralateral (uninjured) hand. Patient AROM measurements at final follow-up were compared with the standard, healthy limits.[23–25] Average 2-point discrimination before surgery and at final follow-up were measured and compared. Two-point discrimination values were also scored using a static 2-point discrimination scoring table in which 1 to 5 mm is normal, 6 to 10 mm is fair, 11 to 15 mm is poor, 1 point perceived is protective sensation only, and no points perceived is anesthetic.[27] Subjective outcome measures of DASH (minimum 8-week follow-up) and VAS pain scores compared preoperative and postoperative (final follow-up) values. Changes in subjective outcome measures were assessed using Student *t* tests. Statistical tests were 2-tailed; they assumed unequal variances and were deemed significant at $P < .05$.

To aid in further validating the consistency and accuracy of our classification system, we performed a statistical analysis comparing patients who did not undergo further treatment (group 1 [grade 1 patients]) with those did (group 2 [grades 2 and 3 patients]). With this analysis, we compared each subjective and objective outcome measure, along with their respective follow-up times, to determine whether one group of patients produced better short- to intermediate-term outcomes. These comparisons were made using 2-tailed Student *t* tests, assuming unequal variances, with statistical significance at $P < .05$. We hypothesized that both groups would present similar satisfactory outcomes at final follow-up, showing that our grading system produced both consistent and accurate results.

Results

All 37 graded patients (42 cases) were successfully treated with ECuTR. No nerve injuries were noted. The UNS grades given to the study cohort were: grade 1, n = 30; grade 2, n = 1; and grade 3, n = 11 (Table 1). Subsequent treatment of UNS with a medial epicondylectomy was performed on 12 of 42 cases (28.6%); no anterior transpositions were done. All patients treated with medial epicondylectomy were classified as either grade 2 (n = 1; 100%) or grade 3 (n = 11; 100%).

On average, patient gross grip strength recovered 87%, lateral pinch strength recovered 90%, 3-jaw chuck strength recovered 105%, and precision pinch strength recovered 87% at final follow-up (Table 2). Mean AROM returned to normal limits for wrist dorsiflexion, volar flexion, ulnar deviation, radial deviation, supination, pronation, and elbow flexion and extension measurements[23–25] (Fig. 3, Table 2). Average preoperative 2-point discrimination values were scored as fair for all digits of the hand, except the middle finger, which scored normal (Table 3). Two-point discrimination values improved to normal at final follow-up for the thumb and index, ring, and little fingers, whereas the middle finger remained normal (Table 3). Patient DASH scores were reduced from 59.8 before surgery to 29.9 at a minimum 8-week follow-up (Table 2). Roy et al[28] deemed a clinically significant change in DASH score to be 10.2. Therefore, although not statistically significant ($P = .14$), the cohort experienced clinically significant improvements in DASH scores. On average, patient pain improved significantly from 7.2 before surgery to 2.5 at final follow-up ($P < .001$) (Table 2).

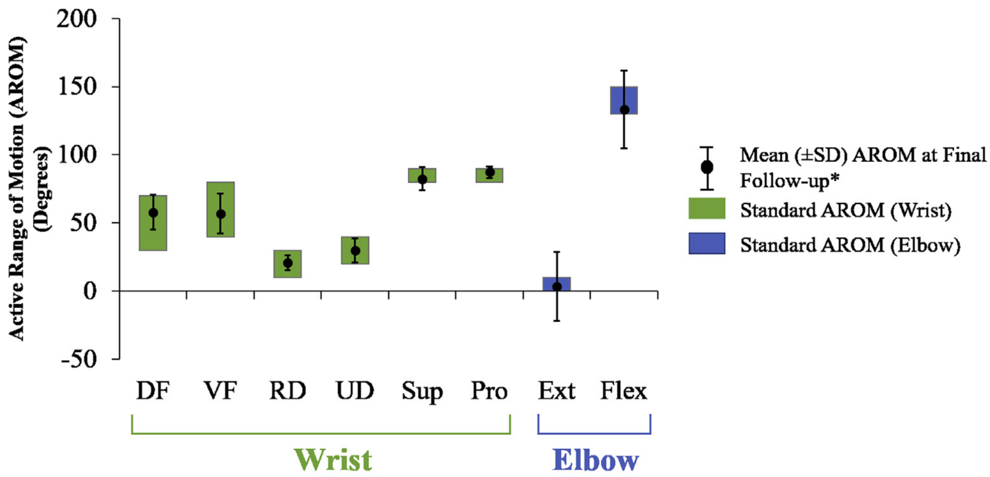

Figure 3. Mean (±SD) AROM of the wrist and elbow at final follow-up compared with standard limits of AROM.[23–25] *Mean (±SD) final follow-up, 17 ± 28.6 weeks. DF, dorsiflexion (wrist extension); Ext, elbow extension; Flex, elbow flexion; Pro, pronation of wrist; RD, radial deviation; Sup, supination of wrist; UD, ulnar deviation; VF, volar flexion (wrist flexion).

Table 3
Changes in 2-Point Discrimination Before Surgery to Final Follow-Up*

Two-Point Discrimination	Preoperative Value	Preoperative Score	Final Follow-Up Value	Final Follow-Up Score
Thumb	5.8 ± 1.7	Fair	4.0 ± 0.6	Normal
Index	6.2 ± 2.5	Fair	4.0 ± 0.6	Normal
Middle	4.8 ± 1.2	Normal	4.0 ± 0.6	Normal
Ring	7.6 ± 3.4	Fair	4.0 ± 0.6	Normal
Little	5.8 ± 1.7	Fair	4.2 ± 0.7	Normal

* Data are shown as mean ± SD. Final follow-up: 17 ± 28.6 weeks. Two-point discrimination scoring is based on a static 2-point discrimination scoring table.[27]

Table 2 also shows results of the statistical comparison of group 1 (grade 1) patients who did not undergo further treatment versus group 2 (grades 2 and 3) patients who did. Results from the analysis revealed that the 2 groups were similar in terms of clinical outcome measures and follow-up times (Table 2). However, according to Roy et al,[28] clinically significant differences in mean DASH scores favored group 1 patients (Table 2).

Patients treated under isolated ECuTR (n = 24), excluding those who underwent a dual ECTR/ECuTR procedure (n = 18), are presented in Table 4. Isolated patients showed results comparable to those treated with the dual procedure, recovering 78% to 124% in grip and pinch strength, returning to normal limits in ROM, presenting with normal 2-point discrimination values, and decreasing in VAS pain and DASH at final follow-up (Table 4).

Discussion

Ulnar nerve entrapment has been extensively studied and its treatment has changed over time.[17,29] It is accepted that when conservative measures fail, surgical treatment is necessary.[17] In our prior study,[3] we presented outcomes of ECuTR while highlighting its advantages over other techniques. Most notably, compared with open and subcutaneous techniques, ECuTR provides increased ulnar nerve and compression site visualization while maintaining a small incision size.[6,30] However, our previous work did not address the prominent occurrence of ulnar nerve hypermobility after ECuTR. We therefore believed it was necessary to extend the ECuTR treatment protocol by studying factors causing ulnar nerve hypermobility[7] and how best to treat these pathologies. By establishing a UNS classification system, we were able to grade and subsequently treat ulnar nerve hypermobility during surgery. The development

Table 4
Clinical Outcomes of Patients Treated Under Isolated ECuTR (Final Follow-Up)*

Variable	ECuTR Patients (n = 24)
Grip and pinch strength recovery (%)	
Gross grip	81.5 ± 43.4
Lateral pinch	86.7 ± 35.7
Three-jaw chuck	124.2 ± 60
Precision pinch	78.3 ± 35.1
Follow-up, wk	18.4 ± 17.9
Active ROM (degrees)	
Wrist	
Dorsiflexion	55.6 ± 12
Volar flexion	54.3 ± 14.5
Radial deviation	20.1 ± 5.8
Ulnar deviation	29.5 ± 10.1
Supination	82.0 ± 8.9
Pronation	87.3 ± 4.4
Elbow	
Extension	7.4 ± 26.5
Flexion	132.2 ± 32.3
Follow-up, wk	11.0 ± 16.1
Two-point discrimination	
Thumb	4.0 ± 0.5
Index	4.0 ± 0.5
Middle	4.0 ± 0.5
Ring	4.0 ± 0.5
Little	4.0 ± 0.7
Follow-up, wk	11.0 ± 16.1
Postoperative DASH	
Mean ± SD	37.0 ± 30.9
Follow-up, wk	28.0 ± 7.5
Postoperative VAS	
Mean ± SD	2.9 ± 2.9
Follow-up, wk	9.6 ± 11.5

* Data are shown as mean ± SD.

and implementation of our classification system aided in our inclination to present this follow-up study.

Available literature regarding techniques for ulnar nerve decompression proved useful in the formation of our classification system. Specifically, it drove our propensity to perform a medial epicondylectomy as opposed to an anterior transposition in all grade 2 patients and most grade 3 patients. Although anterior transposition prevents subluxation and simultaneously decompresses the nerve, this intervention has inherent risks and complications: (1) it requires a larger incision[17]; (2) it increases the risk for damage to the medial antebrachial cutaneous nerve[17]; (3) dissection can lead to devascularization and nerve injuries, particularly the vasa nervosum[31]; (4) it creates a potential secondary site of entrapment and traction during elbow flexion[13]; and (5) It may cause transient neurapraxia to permanent nerve injury.[32] Patel et al[33] used magnetic resonance imaging to reveal a tortuous course by the ulnar nerve as it becomes progressively linear and flattens behind the medial epicondyle from extension to flexion (Fig. 1). By minimizing protrusion of the medial epicondyle and smoothing the surface with a rasp, the ulnar nerve can subluxate anteriorly without irritation, lessening the possibility of future pathology.[34] Medial epicondylectomy requires minimal manipulation and does not call for an extensive incision, because the 2.5-cm ECuTR incision can be used. Given this key advantage, we treat medial epicondylectomy as the superior method and reserve anterior transposition for particular circumstances. For instance, anterior transposition should be performed in certain grade 3 cases in which patients have generalized hypermobility. Generalized hypermobility is determined by the presence of a Beighton score greater than 5 out of 9.[35]

To our knowledge, this is the first classification system to address UNS after ECuTR and detail treatment guidelines for each resultant grade. Previous UNS grading systems were designed, such as the one created by Childress,[36] to describe subluxation during clinical examination. He classified two degrees of nerve hypermobility. Type A, the more common type, entailed nerve movement out of the postcondylar groove and transposition to the tip of the humeral epicondyle when the elbow was flexed. Type B represents a greater passage by the nerve completely over and anterior to the medial epicondyle during flexion past 90°. An additional grading system, described by Tang,[14] illustrates a 4-grade system (0–3) along with a unique blocking flap technique to prevent further subluxation after *in situ* cubital tunnel release. Although seemingly similar to our classification system, Tang presented a more extensive and complex treatment protocol with the development of a blocking flap. Tang used his grading system after an open *in situ* release (4- to 5-cm incision), whereas our classification system is designed specifically for endoscopic *in situ* release (2.5-cm incision). Our goal remains to minimize dissection while addressing UNS after ECuTR. The development of a blocking flap, in contrast to performing a medial epicondylectomy, would cause a greater incision and further tissue manipulation. Therefore, the methods presented by Tang would not be optimal after our endoscopic approach, which makes it necessary for a UNS classification system after ECuTR to be properly described.

Our current study presents a preliminary report of short- to intermediate-term clinical outcomes from patients who underwent an ECuTR under our novel classification guidelines. On average, patients showed satisfactory results at final follow-up. Grip and pinch strength recovered well, AROM and 2-point discrimination returned to normal limits, DASH scores showed clinically notable improvements, and VAS pain scores were reduced significantly from before to after surgery. These patient outcomes illustrate the overarching success of our UNS classification system and their respective treatment protocols. To validate our classification protocol further, we found it was also important to determine whether patients who received further intervention (grades 2 and 3) differed in outcomes compared with those who did not (grade 1). Results showed that patients with and without additional treatment at the time of surgery achieved similar outcomes. We believe this helps support our hypothesis and assists in determining the usefulness of our established treatment protocol.

Our presented case series does not include recordings of preoperative nerve instability or a correlation between preoperative and intraoperative UNS findings. This is primarily because the intent of our presented classification system is to grade UNS during surgery and instability after ECuTR. Although preoperative UNS can be assessed, it is our belief that not until the operating surgeon performs a full ECuTR can UNS be accurately graded and then treated. Furthermore, patients who presented before surgery with complete anterior dislocation of the ulnar nerve were not treated with ECuTR. These patients were treated using an open technique and medial epicondylectomy or anterior transposition based on intraoperative findings.

One may also question our preference to classify subluxation without a physical unit of measurement. The UNS grading system explained by Tang[14] uses specific measurements of subluxation (in millimeters) to distinguish mild from moderate subluxation. In our experience, it is more feasible to assess subluxation grade by observing ulnar nerve movement with reference to the retrocondylar groove on the basis of both the physical difficulty of using a measuring device and its futility. The presented classification system aims to have an intraoperative focus through which naked-eye clinical observation is used to assess both UNS and retrocondylar groove depth. Many factors contribute to ulnar nerve mobility, including the depth or shallowness of the groove, inherent laxity of the tissues, and prominence of the medial epicondyle. Thus, measuring the distance of travel of the nerve alone does not truly indicate the treatment options. For instance, a nerve will not travel far to overcome the medial epicondyle if its journey began in a shallow groove compared with in a deep groove. It is our belief that once the endoscopic release is made and the operating surgeon can visualize the nerve mobility and groove depth during surgery, the ensuing treatment becomes more apparent. Using the classification system as a guide, the operating surgeon should then use clinical judgment to determine whether the presenting UNS within the retrocondylar groove and the depth of the groove warrant further treatment.

This study had limitations. A main shortcoming is our retrospective review and the relatively small patient sample from just 2 operating surgeons. Increasing the patient sample size and studying our treatment protocol across multiple sites will aid in increasing its power, validity, and reliability. For example, our case series presents outcomes from only one patient treated under grade 2 guidelines. Although we treated many grade 2 patients who showed similar recoveries, they were not included in our final analyses owing to exclusion criteria of concomitant surgeries. We understand that one patient cannot fulfill the power to perform a proper treatment recommendation and that additional studies will need to be performed to strengthen the power of the presented guidelines. Another limitation resides in our decision to use intraoperative naked-eye visualization of the retrocondylar groove depth to determine ensuing treatment. Although we believe that this method is more feasible than using a rigid measuring system, the strategy introduces subjectivity and variation in determining a sufficient depth of the retrocondylar groove. The pool of patients was also not randomized, and neither the experimenters nor the participants were blinded to the study protocol. In addition, our outcome measures lacked a consistent average follow-up time owing to the retrospective nature of the data collection. Longer, more consistent follow-up time is required to show the long-term effects of our treatment protocol. Finally, some clinical parameters were not present in all medical records before surgery, such as grip strength, pinch strength, AROM, and 2-point discrimination. Although we found promising short- to intermediate-term outcomes, we are aware that our classification system requires further validation. Improvements in limiting factors such as the lack of long-term follow-up and a study of the application of our UNS classification system among multiple sites and surgeons will strengthen its overall validity.

The presented classification system proposes a treatment plan for patients showing intraoperative nerve subluxation after decompression. Altogether, ECuTR avoids extensive and unnecessary dissection for patients who do not show UNS. The presented classification system was used for all grades of preoperative ulnar nerve compression and may be a useful guideline to help mitigate concerns regarding UNS after ECuTR. Our preliminary report shows promise that the UNS classification system can improve the current treatment protocol, providing clinicians with the guidelines necessary to improve patient outcomes. Future research would be beneficial in establishing its reliability.

Regarding IRB exemption

Because of the retrospective nature of this study, we did not seek IRB approval. As a private practice, we have historically been unable to obtain IRB approval from local institutions. Nevertheless, we understand the importance of practicing quality research and the use of an IRB. Therefore, we are currently in collaboration with a central IRB company. Although we have not officially submitted for exemption, our retrospective chart review fits their criteria for exemption: (1) The research involves no more than minimal risk to subjects. (2) If there is recording of identifiable information, there are adequate provisions to maintain the confidentiality of data. (3) If there are interactions with subjects, there is a consent process that discloses appropriate information. (4) There are adequate provisions to maintain the privacy interest of subjects. (5) Subjects are equitably selected to participate in the research.

All patients reported in our study properly gave consent, and record-keeping was in compliance with the Health Insurance Portability and Accountability Act. All procedures were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 and 2008.

Acknowledgments

We would like to thank Patricia A. Meyer, MOT, OTR/L, CHT, for exceptional occupational therapy work and postoperative evaluations, as well as Joseph Pavlik, III, and Jonathan Muratori for assistance with early stages of the project. We would also like to acknowledge A.M. Surgical, Inc for covering publication fees for this scientific article.

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