Ulnar Nerve Morphology in Magnetic Resonance Imaging Predicts Nerve Recovery After Surgery for Cubital Tunnel Syndrome

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Abstract

Background: Magnetic resonance imaging (MRI) is helpful for the diagnosis of cubital tunnel syndrome (CuTS), but its prognostic value for surgical outcomes is unknown. We aimed to determine whether MRI parameters correlated with outcomes after surgery for CuTS.

Methods: We reviewed 40 patients who had electrodiagnostic tests and MRIs for CuTS preoperatively and had 6-month evaluations postoperatively. The MRI parameters were ulnar nerve cross-sectional area (UNCSA) measured at 6 different levels around the medial epicondyle (ME), signal intensity changes of innervated muscles of the ulnar nerve, and the presence of ganglion around the ulnar nerve. Other factors assessed were age, symptom duration, symptom severity, presence of diabetes mellitus, and electrodiagnostic parameters including motor nerve conduction velocity (mNCV). We analyzed the factors associated with fair or poor outcomes graded by Wilson-Krout classification.

Results: The UNCSA was the largest at ME level and smallest at 3cm distal to ME level. Increased ulnar nerve signal intensity changes were found in 34 subjects and increased forearm muscle signal intensity changes were found in two. Ten patients were found to have ganglia.

Twelve patients (30%) had excellent results, 19 (48%) had good, 8 (20%) had fair, and 1 (4%) had a poor result. In univariate analysis, fair or poor outcomes were associated with increased UNCSA 1 cm proximal and 1 cm distal from the ME, the presence of ganglion, and decreased mNCV. In multivariate analysis, fair or poor outcomes were associated with either increased UNCSA 1 cm distal from the ME (OR 11.15; $p = 0.019$), or increased UNCSA 1 cm proximal from the ME (OR 16.01; $p = 0.038$) and decreased mNCV (OR 0.92; $p = 0.044$).

Conclusions: This study demonstrated that increased ulnar nerve cross-sectional area on MRI correlated with suboptimal improvement after surgery for CuTS at 6 months follow up. MRI examination for morphologic changes of the ulnar nerve can be helpful for patient consultation on the prognosis of surgery for CuTS.

Background

Cubital tunnel syndrome (CuTS) is the second most common nerve entrapment syndrome affecting the upper extremity.[1, 2] The diagnosis of CuTS is based on clinical signs and symptoms, which include both motor and sensory abnormalities involving the ulnar nerve distribution over the forearm and hand. Electrodiagnostic test (EDX) and magnetic resonance imaging (MRI) can help confirm a diagnosis, quantifying the severity of the lesion, and identifying the exact site of the ulnar nerve compression.[3, 4]

Several prognostic factors for surgical outcomes have been evaluated for CuTS, including age, duration of symptoms, stage of the disease, smoking, diabetes mellitus (DM), and ulnar nerve cross-sectional area (CSA) measured by ultrasonography.[5–8] Factors that have been shown to have poor outcomes are

intraoperative intraneural fibrosis, preoperative intrinsic muscle weakness, prolonged duration of symptoms, and advanced age.[8]

While EDX can evaluate functional aspects of the ulnar nerve, MRI can show its morphological changes including the nerve size and signal changes independent of the proficiency of the examiner.[9] Although previous studies using MRI have shown its diagnostic value, studies are lacking on the value of MRI for surgical outcomes.[10, 11] Thus, the purpose of this study was to determine whether ulnar nerve morphology in MRI correlated with outcomes after surgery for CuTS.

Methods

Patients

We obtained approval from the Institutional Review Board of our institution for this study. We reviewed the medical records of patients who had surgery for CuTS at our hospital, a referral, training hospital located in an urban area, between January 2014 and June 2019. The inclusion criteria were a diagnosis of CuTS and the presence of both EDX and MRI examinations.

Initially, we identified 107 patients who underwent surgery for CuTS and included 78 patients who had both EDX and MRI examinations. Some of the EDX-positive patients did not have MRI examinations due to reasons such as claustrophobia, cardiac pacemakers, and inadequate insurance coverage, and thus were not included in the study. The exclusion criteria were revision surgery, the presence of other compressive neuropathies or cervical radiculopathy, neuromuscular disease, and lack of follow-up examination at 6 months. From this 78, we excluded 38 patients according to the exclusion criteria and finally analyzed 40 patients (Fig. 1). There were 27 men and 13 women in the study with the mean ($\pm$ SD) age of 48 ($\pm$ 17) years (range, 17–75 years).

The patients underwent ulnar nerve decompression at the elbow and an epicondylectomy under general anesthesia, followed by one week of immobilization and no formal physical therapy thereafter. All operations were performed by a single surgeon.

MRI evaluation

All patients were imaged in the supine position with the examined arm in an adducted and stretched position, using a 3-Tesla system MR unit (Ingenia or Ingenia Cx, Philips Healthcare, the Netherlands) with a dedicated elbow-coil. The MRI parameters evaluated were 1) ulnar nerve CSA, 2) nerve and muscle signal intensity changes, and 3) the presence or absence of ganglion.

The ulnar nerve CSA was measured on axial T2-weighted fast spin-echo sequences (TR/TE, 2,900–3,200/75–100, section thickness 2.5 mm, intersection gap 0.25 mm, number of Sect. 40, field of view 100 × 100 mm, and acquisition matrix 256 × 256). The CSA was measured at 6 points; 2 cm and 1 cm proximal from the medial epicondyle (ME), at the ME, and 1 cm, 2 cm, and 3 cm distal to the ME. We

measured the longer diameter (a) and shorter diameter (b) of the ulnar nerve and calculated the CSA by using formula $Area = \pi \times a/2 \times b/2$ (Fig. 2A).

Signal intensity changes of the ulnar nerve (Fig. 2B) and hand and forearm flexor muscles (Fig. 2C) were assessed on T2-weighted images in axial section views. We examined any space occupying lesion around the ulnar nerve including medial osteophyte, medial side joint fluid collection, and ganglia (Fig. 2D).

One radiologist specializing in musculoskeletal imaging recorded the signal intensity changes of the nerve and muscles and two orthopedic surgeons measured the CSA. We tested intra-rater reliability of the CSA measurement by repeating all measurements after two weeks and inter-rater reliability of the independent assessments by two examiners. There was no significant difference between the two examiners. The intraclass correlation coefficient of the intra-rater reliability and that of the inter-rater reliability were good-to-excellent (Table 1).[10] Therefore, we used the CSA measured by one of the raters.

Table 1. Intraclass coefficient (ICC) of inter & intra-rater reliabilities		
	Inter-rater reliability (95% CI)	Intra-rater reliability (95% CI)
CSA-3	0.98 (0.95, 0.99)	0.96 (0.92, 0.99)
CSA-2	0.92 (0.87, 0.97)	0.91 (0.81, 0.96)
CSA-1	0.96 (0.91, 0.98)	0.92 (0.83, 0.97)
CSA0	0.98 (0.95, 0.99)	0.95 (0.90, 0.98)
CSA1	0.92 (0.83, 0.97)	0.85 (0.68, 0.94)
CSA2	0.95 (0.88, 0.98)	0.92 (0.83, 0.97)
CSA = Cross sectional area of the ulnar nerve; CSA-3 = CSA at 3 cm distal to the medial epicondyle; CSA0 = CSA at the medial epicondyle; CSA2 = CSA at 2 proximal to the medial epicondyle.		

EDX evaluation

All EDXs were performed following the guidelines of the American Association of Electrodiagnostic Medicine at the EDX study laboratory in our institute.[12] The confirmatory criteria included: (1) motor nerve conduction velocity (mNCV) across the elbow of less than 50 m/s, (2) an mNCV difference of greater than 10 m/s between the elbow segment and the forearm segment, and (3) a decrease of the compound muscle action potential (CMAP) amplitude from below the elbow to above the elbow greater than 20%, suggesting a conduction block.

Clinical evaluation

Preoperatively, we evaluated the severity of the symptoms which was classified according to McGowan grades.[13] Patients with subjective symptoms and no abnormal objective findings were classified as

grade I, patients with good intrinsic strength and no detectable muscle atrophy as grade IIa, patients with fair intrinsic strength and detectable muscle atrophy as grade IIb, and patients with profound sensory and motor disturbances with marked intrinsic atrophy as grade III. Other clinical parameters evaluated were the age at surgery, gender, body mass index (BMI), the presence of diabetes mellitus (DM), and duration of the symptoms.

At 6-months postoperatively, clinical evaluation of nerve recovery was conducted using the modified Wilson–Krout criteria.[14] Patients with complete return of sensation and function to the hand without discomfort were graded as excellent; return of a functional hand without discomfort, but with residual weakness or diminished sensation were graded as good; and improvement in only one area, comfort, strength, or sensation, were graded as fair; and those with no improvement or a worsened condition were graded as poor.

Statistical Analysis

We evaluated the surgical outcomes by logistic regression analyses. The dependent variable was the postoperative Wilson-Krout grades and the independent variables were the MRI parameters (ulnar nerve CSA at 6 levels, signal intensity changes of the ulnar nerve and forearm muscles, and presence of space occupying lesion), EDX parameters (mNCV and CMAP amplitude), and clinical parameters (age at surgery, BMI, presence of DM, symptom duration, and preoperative symptom severity as assessed by McGowan grade). We performed univariate and multivariate logistic regression analyses for the variables associated with fair or poor Wilson-Krout grades. Variables with p-values less than 0.1 in univariate analyses were selected for multivariate analysis. We also calculated the area under the curve (AUC) for the ulnar nerve CSA to determine a cutoff value for fair or poor outcomes with maximum sensitivity and specificity.

P-values less than 0.05 were considered significant. This analysis was performed using open-source statistical software R, version 3.5.1.

Results

MRI findings

The ulnar nerve CSA was the largest at ME level and smallest at 3 cm distal to ME level (Fig. 3). Increased ulnar nerve signal intensity changes were found in 34 subjects and increased forearm muscle signal intensity changes were found in two. Ten patients were found to have space occupying lesions around the ulnar nerve (Table 2).

Table 2
Baseline characteristics and surgical outcome

Characteristics	Value or number
Age (years)	48 ± 17
Sex (Male : Female)	27 : 13
Body mass index (kg/m ²)	26.4 ± 4.0
Right / Left	22 / 18
Diabetes mellitus	8
Symptom severity (McGowan grade)	0 (0%)
Grade I	15 (38%)
Grade IIa	19 (48%)
Grade IIb	6 (15%)
Grade III	
Motor nerve conduction velocity (m/s)	35.1 ± 13.1
Compound muscle action potential amplitude (m/V)	6.2 ± 5.2
Surgical outcome (Wilson-Krouts criteria)	12 (30%)
Excellent	19 (48%)
Good	8 (20%)
Fair	1 (4%)
Poor	
Values are expressed as the mean ± standard deviation or number (percentage).	

Predictors of nerve recovery

Preoperatively, 15 patients were classified as grade IIA, 19 grade IIB, and six grade III by McGowan grade. At 6-months postoperatively, 12 patients (30%) had excellent results, 19 (48%) had good, eight (20%) had fair and one (4%) had a poor result according to the Wilson-Krout criteria (Table 3).

Table 3
MRI findings

	Value or number
<i>Ulnar nerve cross sectional area (CSA, mm²)</i>	
CSA2	14.1 ± 3.9
CSA1	17.8 ± 5.7
CSA0	19.8 ± 6.7
CSA-1	17.5 ± 7.5
CSA-2	14.0 ± 6.4
CSA-3	12.6 ± 6.6
Signal change	34
Ulnar nerve	3
Forearm muscle	
Space occupying lesion	10
CSA2 = CSA at 2 cm proximal to the medial epicondyle; CSA0 = CSA at the medial epicondyle; CSA-3 = CSA at 3 cm distal to the medial epicondyle	

In univariate analyses, fair or poor outcomes were significantly associated with increased ulnar nerve CSA 1 cm proximal (OR 11.08 [95% CI 1.73 to 218.86]; $p = 0.032$) and 1 cm distal from the epicondyle (OR 8.33 [95% CI 1.71 to 49.86]; $p = 0.012$), the presence of space occupying lesion (OR 6.50 [95% CI 1.31 to 36.07]; $p = 0.024$), and decreased mNCV (OR 0.93 [95% CI 0.85 to 0.99]; $p = 0.035$). No association was found for factors such as age at surgery, BMI, the presence of DM, symptom duration, symptom severity (McGowan grade), ulnar nerve CSA at other sites, signal intensity changes of the ulnar nerve and forearm muscles, and CMAP amplitude (Additional file 1).

In the multivariate analysis, we analyzed each CSA separately because ulnar nerve CSAs measured in the same patient have collinearity. In the multivariate analysis model 1 including ulnar nerve CSA 1 cm distal from the epicondyle, fair or poor outcomes were associated with increased ulnar nerve CSA 1 cm distal from the epicondyle (OR 11.15 [95% CI 1.74 to 112.75]; $p = 0.019$) only. In multivariate analysis model 2 including ulnar nerve CSA 1 cm proximal from the epicondyle, fair or poor outcomes were associated with both increased ulnar nerve CSA 1 cm proximal from the epicondyle (OR 16.01 [95% CI 1.76 to 461.14]; $p = 0.038$) and decreased mNCV (OR 0.92 [95% CI 0.83 to 0.99]; $p = 0.044$).

The AUC was calculated for the ulnar nerve CSA to detect fair or poor outcomes. The cut-off value of CSA at distal 1 cm was 18.9mm², whereas the cut-off value of CSA at proximal 1 cm was 16.7mm². Sensitivity and specificity at distal 1 cm were 80.6% and 66.7%, and those at proximal 1 cm were 92.9% and 50.0%,

respectively. The AUC for CSA at distal 1 cm was 0.729 and the AUC for CSA at proximal 1 cm was 0.724 (Fig. 4).

Discussion

MRI can evaluate morphology of the ulnar nerve in patients with CuTS while EDX evaluates functional aspects of the nerve. This study demonstrated that fair or poor outcomes after surgery was strongly associated with increased ulnar nerve CSA in MRI (OR = 11.15 at 1 cm distal from the ME and OR = 16.01 at 1 cm proximal from the ME), while the association was minimal with preoperative EDX (OR = 0.92) and no association was seen with preoperative symptom severity as McGowan grades. This result suggests that morphologic changes of the ulnar nerve can better predict delayed nerve recovery after surgery for CuTS than preoperative symptom severity or EDX examination.

In our study, ulnar nerve CSA was increased 1 cm proximal to the ME, at the level of the ME, and at 1 cm distal to the ME, which is consistent with previous studies of MR neurography or ultrasonography.[3, 15–17] An MRI study by Bäumer et al reported that the mean ($\pm$ SD) ulnar nerve CSA across the cubital tunnel was $15.4 \pm 0.9 \text{ mm}^2$, whereas the mean ($\pm$ SD) of healthy control subjects was $11.0 \pm 0.7 \text{ mm}^2$. They also suggested that nerve caliber enlargement discriminated severe from mild disease preoperatively and that the mean ($\pm$ SD) ulnar nerve CSA was significantly higher in patients with severe disease ($19.4 \pm 2.5 \text{ mm}^2$) than the mean ($\pm$ SD) ulnar nerve CSA in patients with mild disease ($12.7 \pm 1.2 \text{ mm}^2$).[15]

Previous animal model studies have suggested that in compressive neuropathy, peripheral nerves compressed at a local level interfere with both anterograde and retrograde axonal transport and undergo perineurial thickening, fibrosis, and swelling proximal and distal to the compressed segment.[18, 19] Studies have also postulated that increases in nerve caliber are associated with extrinsic injury in which peripheral nerves undergo degenerative demyelination and compensatory remyelination, increasing myelin sheath thickness.[20, 21] In CuTS, these pathological alterations occur along the ulnar nerve proximal and distal to the cubital tunnel, and thus increase the ulnar nerve CSA.[17] In this study, fair or poor outcomes were associated with increased ulnar nerve CSA, which reflected morphological changes in the nerve and the severity of the disease. This association has been reported in previous studies using ultrasound.[22, 23] Beekman et al.[22] showed that significant nerve enlargement found during sonography at the time of diagnosis was associated with a poor outcome with an odds ratio of 2.9. A similar study by Domenico et al.[23] also showed that increased ulnar nerve CSAs in preoperative ultrasounds were associated with poor outcomes.

We found that decreased mNCV correlated with fair or poor surgical outcomes in univariate analysis. However, this correlation disappeared in the multivariate model 1 and the OR was only 0.92 in the multivariate model 2. Previous studies have reported on the relationship between preoperative EDX and CSA or between EDX and grip/pinch strength.[16, 19] The relationship between preoperative EDX and postoperative outcomes has been contradictory. A systematic review of the predictors of surgical outcomes after anterior transposition of the ulnar nerve for CuTS found that out of nine articles available,

four case series and one cohort study reported no association between preoperative EDX and outcomes, whereas one randomized controlled trial, two cases series, and one cohort study reported a significant association.[24]

There were several limitations to this study. First, this study involved patients who underwent surgery, and thus the MRI findings may not apply to the general population of CuTS patients, including those with early symptoms. In addition, many patients had to be excluded due to the exclusion criteria, which may limit the applicability of the study findings. Second, the 6-month follow up period is short to evaluate the final surgical outcomes. Hironori et al.[25] reported that symptoms had improved in 14 out of 15 patients within 4.5 years and nerve conduction velocity had recovered two years after surgery. However, the 6-month outcome can be helpful for patient consultation regarding their expectations about recovery speed.

Conclusions

This study demonstrated that increased ulnar nerve cross-sectional area on MRI correlated with suboptimal improvement after surgery for CuTS at 6 months follow up. This study also suggests that morphologic changes of the ulnar nerve can better predict delayed nerve recovery than preoperative symptom severity or EDX examination. Assessment of morphologic changes of the ulnar nerve can be helpful for patient consultation on the prognosis of surgery for CuTS.

Abbreviations

MRI

Magnetic resonance imaging; CuTS:Cubital tunnel syndrome; EDX:Electrodiagnostic test; UNCSA:Ulnar nerve cross-sectional area; ME:Medial epicondyle; mNCV:Motor nerve conduction velocity; OR:Odds ratio; DM:Diabetes mellitus; CSA:Cross-sectional area; SD:Standard deviation; CMAP:Compound muscle action potential; BMI:Body mass index; AUC:Area under the curve.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of the Seoul National University Bundang Hospital.

Consent for publication

Not applicable.

Availability of data and materials

All relevant data are included in this manuscript. Additional data may be requested by contacting the corresponding author.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

JSK and GSM equally contributed to the drafting of manuscript. JSK processed and analyzed the data, added in interpreting the results, worked on the manuscript. YJC designed figures and tables and worked out the technical details. HSG conceived and supervised the study with critical revision. All authors have read and approved the manuscript.

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Figures

Figure 1

This flowchart details the patients who were included in this study. EDX = Electrodiagnostic test.

Figure 2

(A) This section of MRI shows the measurement of the ulnar nerve diameter for calculation of ulnar nerve cross sectional area in T1 axial sequence image of MRI. (Long diameter: 8.3mm, Short diameter: 3.7mm)
(B) This section of MRI indicates the nerve signal intensity change marked by white arrow in T2 axial sequence image of MRI. (C) This section of MRI indicates the muscle signal intensity change of FCU marked by white arrow in T2 axial sequence image of MRI. FCU = Flexor carpi ulnaris muscle. (D) The presence of ganglion causing compression of the ulnar nerve was detected at cubital tunnel (marked by white arrow) in T2 axial sequence image of MRI.

Figure 3

This chart shows the distribution of ulnar nerve CSA. CSA = cross-sectional area; CSA2 = CSA at 2cm proximal to the medial epicondyle; CSA0 = CSA at the medial epicondyle; CSA-3 = CSA at 3cm distal to the medial epicondyle.

(A)

(B)

Figure 4

This graph shows the cutoff value and receiver operating characteristic curve. (A) The cut-off value of CSA at distal 1cm was 18.9mm². Sensitivity and specificity at distal 1cm were 80.6% and 66.7%. The AUC for CSA at distal 1cm was 0.729. (B) The cut-off value of CSA at proximal 1cm was 16.7mm². Sensitivity and specificity at proximal 1cm were 92.9% and 50.0%. The AUC for CSA at proximal 1cm was 0.724.

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