iatrogenic median and ulnar nerve injuries during carpal tunnel release: clinical, electrodiagnostic, and ultrasound features in 12 patients. Patient series

Lisa B. E. Shields, MD,1 Vasudeva G. Iyer, MD,2 Yi Ping Zhang, MD,1 and Christopher B. Shields, MD1,3

1Norton Neuroscience Institute, Norton Healthcare, Louisville, Kentucky; 2Neurodiagnostic Center of Louisville, Louisville, Kentucky; and 3Department of Neurological Surgery, University of Louisville School of Medicine, Louisville, Kentucky

BACKGROUND  Nerve injuries during carpal tunnel release (CTR) are rare. Electrodiagnostic (EDX) and ultrasound (US) studies may be helpful in evaluating iatrogenic nerve injuries during CTR.

OBSERVATIONS  Nine patients sustained a median nerve injury, and 3 patients experienced ulnar nerve damage. Decreased sensation occurred in 11 patients, and dysesthesia occurred in 1 patient. Abductor pollicis brevis (APB) weakness occurred in all patients with median nerve injury. Of the 9 patients with median nerve injury, the compound muscle action potentials (CMAPs) of the APB and sensory nerve action potentials (SNAPs) of the 2nd or 3rd digit were not recordable in 6 and 5 patients, respectively. Of the 3 patients sustaining ulnar nerve injuries, the CMAPs of the abductor digiti minimi (ADM) and SNAPs of the 5th digit were not recordable in 1 patient; 2 patients showed prolonged latency and decreased amplitude of CMAPs/SNAPs. US studies of 8 patients with a median nerve injury showed a neuroma within the carpal tunnel. One patient underwent surgical repair urgently, and 6 did so after variable intervals.

LESSONS  Surgeons should be cognizant of nerve injuries during CTR. EDX and US studies are useful in evaluating iatrogenic nerve injuries during CTR.

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KEYWORDS  neurosurgery; carpal tunnel release; iatrogenic nerve injury; median nerve; ulnar nerve; electrodiagnostic studies; ultrasound

With a prevalence of 1%–10% in the U.S. population, carpal tunnel syndrome (CTS) is the most common peripheral nerve disorder of the upper extremity caused by entrapment of the median nerve within the carpal tunnel at the wrist.1–5 A carpal tunnel release (CTR) involves the release of the median nerve from entrapment by sectioning the transverse carpal ligament (TCL) and is the most frequent peripheral nerve surgery, with approximately 600,000 cases performed annually in the United States.1,3,5 A CTR may be achieved by the conventional open technique or through an endoscopic procedure, with the latter often associated with less postoperative incisional pain, preservation of grip strength, shorter time to return to work, and a faster recovery time.6

Although CTR often boasts of a high success rate of 70%–90% with complete resolution of symptoms, adverse effects may ensue with a serious neurological complication rate (requiring admission to the hospital or further surgery) of less than 1%.2,6–9 Persistence of symptoms after CTR may be due to incomplete decompression of the median nerve (failure to cut the distal portion of the retinaculum), whereas worsening of or new onset of additional symptoms results from direct nerve injury with complete or partial transection or indirect injury via retraction or compartment syndrome.6,10,11 The most common risks of an open CTR involve inadequate or inappropriate skin incisions and incomplete sectioning of the TCL.1,12 Injury to the median nerve (often the palmar cutaneous branch or recurrent motor branch) is most frequent; ulnar nerve injury is rare.6,11,13,14 Failure of CTR may be divided into symptoms that are persistent (incomplete release of the flexor retinaculum due to inadequate exposure and visualization), recurrent (scar formation in the

ABBREVIATIONS  ADM = abductor digiti minimi; APB = abductor pollicis brevis; CMAP = compound muscle action potential; CSA = cross-sectional area; CTR = carpal tunnel release; CTS = carpal tunnel syndrome; EDX = electrodiagnostic; EMG = electromyography; FDI = first dorsal interosseus; MUP = motor unit potential; SNAP = sensory nerve action potential; TCL = transverse carpal ligament; US = ultrasound.

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carpal tunnel), or new (additional hypesthesia, more severe lancinating and shooting pain, worsened numbness, new motor deficit) immediately or shortly after CTR.\textsuperscript{1,3,9,14}

We report 12 patients who sustained iatrogenic median or ulnar nerve injury during CTR, all of whom underwent electrodiagnostic (EDX) studies and 11 of whom had ultrasound (US) studies. The presenting symptoms, clinical and EDX findings, and US features are presented. The mechanism associated with iatrogenic nerve injury during CTR and the importance of EDX and US studies in the diagnostic evaluation of nerve injuries during CTR are discussed.

Study Description
We performed a 9-year (December 9, 2013 to April 26, 2022) retrospective analysis of patients referred to our neurodiagnostic center for EDX studies to evaluate nerve injuries during CTR. The inclusion criteria specified the appearance of new symptoms (muscle weakness or sensory disturbance) or worsening of (severity/ttopography) preexisting symptoms soon after CTR. Patients with a history of gradual worsening of symptoms after surgery (unsuccessful CTR) or those with initial improvement followed by gradual worsening (recurrence of CTS) were excluded. The patients did not undergo preoperative US studies. The patients underwent our protocol of an initial neurological examination followed by nerve conduction and electromyography (EMG) studies. An US study was also conducted using the GE LOGIQ E system and 8- to 18-MHz probe according to the standard protocol of our laboratory for median and ulnar nerves.\textsuperscript{15,16}

The EDX studies were performed in our American Association of Neuromuscular & Electrodiagnostic Medicine–accredited facility using the standard protocol of our laboratory.\textsuperscript{17} The EDX testing was done using the Nicolet Viasys Viking Select machine. For the patients who sustained median nerve injury during CTR, several EDX tests were performed, including recording of compound muscle action potentials (CMAPs; latency/amplitude) of the abductor pollicis brevis (APB) and 2nd lumbrical, sensory nerve action potentials (SNAPs) (latency/amplitude) of digits 2 and 3, and needle EMG of APB to look for the presence of fibrillations/positive sharp waves and assess motor unit morphology and recruitment. The patients who sustained ulnar nerve injury during CTR underwent EDX testing with recording of CMAPs of the abductor digitii minimi (ADM) and first dorsal interosseus (FDI), SNAPs of digit 5 and the dorsal cutaneous branch of the ulnar nerve, as well as needle EMG to detect the presence of fibrillations/positive sharp waves and study motor unit potentials (MUPs) of the ADM and FDI.

Clinical Findings and Neurological Examination of Patients With Nerve Injuries During CTR
Twelve patients were diagnosed with a nerve injury following CTR based on the clinical history, presenting symptoms, and neurological examination (Table 1), as well as EDX and US findings. The CTR was open in 11 and endoscopic in 1. The mean age was 62.1 years (range 26–79 years), and 10 (83.3%) were female. The CTR was on the right in 8 (66.7%) patients and on the left in 4 (33.3%) patients. All procedures were unilateral. All patients except the patient in case 9 had surgical incisions from the distal wrist crease to the proximal palm (2–3 cm). The patient in case 9 had small incisions (wrist and mid palm) for an endoscopic CTR.

Ten patients (83%) had postoperative weakness and worsening of numbness of the hand, and 8 (66%) developed pain in the digits, hand, wrist, and/or forearm. Three (25.0%) patients had thenar muscle atrophy. Decreased sensation of the digits was noted in 11 (92%) patients and dysesthesia of the digits in 1 patient. Weakness of the APB was noted in all 9 patients with median nerve injury. The FDI, ADM, and adductor pollicis showed weakness in all 3 patients with ulnar nerve injury, and 1 patient showed clawing of the ulnar 2 digits.

The specific nerve injured during CTR was the median nerve in 9 (75.0%) patients (axonotmesis partial/complete in 8) and the ulnar nerve in 3 (25.0%) patients (axonotmesis at Guyon’s canal).

Electrodiagnostic Studies in Patients With Nerve Injuries During CTR
The EDX findings of the patients with nerve injuries during CTR are presented in Table 2. Of the 9 patients who experienced median nerve injury during CTR, the CMAPs of the APB and SNAPs of the 2nd or 3rd digits were not recordable in 6 and 5 patients, respectively. All 9 patients showed denervation changes in the APB. Of the 3 patients who sustained ulnar nerve injury during CTR, the CMAPs of the ADM and SNAPs of the 5th digit were not recordable in 1 patient; the other 2 patients showed prolonged latency and decreased amplitude of CMAPs/SNAPs. All 3 patients showed denervation changes in ADM and FDI.

US Findings in Patients With Nerve Injuries During CTR
The interval between the time of injury and the performance of tests varied from 4 weeks to 17 months. The findings included edema of the nerve leading to an increase in cross-sectional area (CSA), loss of fascicular pattern, and laceration leading to a neuroma and significant scarring (Table 2). Neuroma in continuity was identified when there was a hypoechoic enlargement of the nerve with a smaller diameter distally and without an hourglass type of appearance (Fig. 1). The nerve distal to the neuroma remained smaller, presumably from axon loss. The scar tissue often involved part of the flexor retinaculum, the nerve, and sometimes the flexor tendons, quite different from the appearance in unoperated CTS. The most common site of US abnormality was in the middle or distal portion of the carpal tunnel with the median nerve ensheathed within the hypechoic scar tissue involving the flexor retinaculum corresponding to the incision. In one patient (case 2), urgent exploration showed laceration injury involving the radially located fascicles. An US image 8 months later still showed loss of fascicles (Fig. 2). We looked for an aberrant course/abnormality of the recurrent nerve branch but could not find any anatomical variations.

EDX Studies Performed Pre- and Post-CTR
Five patients who sustained an iatrogenic nerve injury during CTR underwent both pre- and post-CTR EDX studies in our facility, including 4 with a median nerve injury and 1 with an ulnar nerve injury (Table 3). The most striking difference between the pre- and post-CTR EMG studies was the greatly decreased or complete absence of MUPs in the APB/ADM as well as the presence of denervation as evidenced by the presence of fibrillations postoperatively in all 5 patients.

Follow-Up of Patients With Nerve Injuries During CTR
Six patients with a median nerve injury underwent a revision CTR at intervals ranging from 1 week to 9 months following the initial CTR. In one case (case 2), the patient underwent a revision
<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)/Gender/Side</th>
<th>Type of CTR</th>
<th>Interval btwn CTR &amp; EDX</th>
<th>Sxs</th>
<th>Clinical Findings</th>
<th>Nerve Injured</th>
<th>FU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>79/M/Rt</td>
<td>Open</td>
<td>11 wks</td>
<td>N, M, P</td>
<td>TA, TW, HY</td>
<td>Median</td>
<td>Revision of CTR &amp; placement of hypothenar fat pad 6 mos later, dense scar tissue noted, no more pain w/ minimal improvement in sensations &amp; muscle strength</td>
</tr>
<tr>
<td>2</td>
<td>50/F/Lt</td>
<td>Open</td>
<td>8 mos</td>
<td>N, M, P</td>
<td>TW, HY</td>
<td>Median</td>
<td>Exploration &amp; repair of fascicular injury of median nerve after 1 wk w/ placement of nerve wrap, persistent W &amp; N at 8 mos</td>
</tr>
<tr>
<td>3</td>
<td>60/F/Lt</td>
<td>Open</td>
<td>1 mo</td>
<td>N, M, P</td>
<td>TW, HY</td>
<td>Median (mostly recurrent motor branch)</td>
<td>Resolution of Sxs 2 mos after CTR w/o treatment</td>
</tr>
<tr>
<td>4</td>
<td>56/F/Lt</td>
<td>Open</td>
<td>17 mos</td>
<td>N, M, P</td>
<td>TW, HY</td>
<td>Median</td>
<td>Repair of partial laceration of median nerve w/ nerve allograft after 3 mos, minimal improvement at 1 yr</td>
</tr>
<tr>
<td>5</td>
<td>75/F/Rt</td>
<td>Open</td>
<td>7 mos</td>
<td>N, P</td>
<td>TA, TW, HY</td>
<td>Median</td>
<td>2nd CTR after 9 mos, median nerve entrapped in scar tissue, neurolysis &amp; neurowrap &amp; fat pad flap, N persists after 7 mos</td>
</tr>
<tr>
<td>6</td>
<td>76/F/Rt</td>
<td>Open</td>
<td>3 mos</td>
<td>N, M</td>
<td>TW, DY</td>
<td>Median</td>
<td>No further surgery, no PT, continued N, W rt hand 7 yrs after CTR</td>
</tr>
</tbody>
</table>

CONTINUED ON PAGE 4 »
CTR 1 week after the initial CTR with no EDX or US studies between the 2 procedures. Fascicular injury to 30% of the median nerve was noted, and an epineural repair with placement of a nerve wrap was performed. The patient continued to experience motor and sensory symptoms when seen 8 months later for EDX testing. Four patients underwent rerelease along with procedures such as placement of a nerve allograft, neurolysis, and placement of a hypothenar fat pad around the nerve; another patient underwent a tendon transfer. Only 2 patients with a median nerve injury noted significant improvement of symptoms; others continued to experience weakness/numbness. Among patients with an ulnar nerve injury, 1 underwent exploration of Guyon’s canal, but no significant abnormality was found. Significant improvement in symptoms occurred in another patient without surgical intervention.

**Discussion**

A clinical history and focused neurological examination are the first steps in the investigation of patients who complain of worsening of or appearance of new symptoms after CTR. Rapid recognition of nerve injury is crucial in managing these cases. The immediate concern is whether a laceration of the nerve has occurred, causing significant loss of motor and sensory function. US and magnetic resonance
neurography can be useful for confirming neurotmesis, which will need immediate surgical repair. In cases of less severe injuries, serial EDX studies can be used to assess progress and determine if surgical intervention is needed. In such cases, physical therapy including electrical stimulation of the affected muscles may be helpful. For painful paresthesia or neuralgic pain, transcutaneous electrical stimulation may be useful in the detection of a perioperative nerve injury that may need immediate surgical repair. In cases of less severe injuries, serial EDX studies can be used to assess progress and determine if surgical intervention is needed. In such cases, physical therapy including electrical stimulation of the affected muscles may be helpful. For painful paresthesia or neuralgic pain, transcutaneous electrical stimulation may be useful in the detection of a perioperative nerve injury that may need immediate surgical repair.

EDX studies are highly useful in differentiating between neuropraxia, which carries a favorable prognosis for spontaneous recovery, from axonal injury with a less favorable outcome, as well as for monitoring spontaneous recovery or response to treatment following nerve injury. Axonal injury leads to denervation of muscles, which is characterized by the appearance of increased insertional activity, positive sharp waves, and fibrillations, usually 7–10 days after injury. Reinnervation by terminal sprouting of the remaining intact axons occurs in partial injuries and is characterized by the appearance of large polyphasic motor units. In complete injuries, early reinnervation is heralded by the appearance of small, short-duration polyphasic nascent motor units.

High-resolution US has the advantage of being readily available, inexpensive, and noninvasive and is an excellent tool to identify substantially decreased or total absence of MUPs in the APB or the ADM as well as the appearance of fibrillations after the CTR.

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High-resolution US has the advantage of being readily available, inexpensive, and noninvasive and is an excellent tool to identify substantially decreased or total absence of MUPs in the APB or the ADM as well as the appearance of fibrillations after the CTR.

**TABLE 2. EDX and US Findings in Median and Ulnar Nerve Injuries During CTR in Patients Evaluated**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>CMAP APB Lat (msec)/Amp (mV)</th>
<th>CMAP 2nd Lumbral Lat (msec)/Amp (mV)</th>
<th>CMAP FDI Lat (msec)/Amp (mV)</th>
<th>CMAP ADM Lat (msec)/Amp (mV)</th>
<th>SNAP Digit 2 or 3 Lat (msec)/Amp (µV)</th>
<th>SNAP Digit 5 Lat (msec)/Amp (µV)</th>
<th>SNAP Dor Cut Lat (msec)/Amp (µV)</th>
<th>nEMG APB Fibs/ MUPs</th>
<th>nEMG ADM Fibs/ MUPs</th>
<th>nEMG US Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Median</td>
<td>NR* 5.4*/0.93*</td>
<td>ND</td>
<td>3.3/3.96</td>
<td>NR* 3.7/5.2*</td>
<td>ND</td>
<td>3++/C</td>
<td>ND</td>
<td>0/Norm</td>
<td>I, L, S, N</td>
<td></td>
</tr>
<tr>
<td>2 Median</td>
<td>6.0*/1.3*</td>
<td>ND</td>
<td>3.5/2.2</td>
<td>ND</td>
<td>2.6/9.3*</td>
<td>ND</td>
<td>3++/D</td>
<td>ND</td>
<td>0/Norm</td>
<td>I, L, F</td>
</tr>
<tr>
<td>3 Median</td>
<td>NR* 4.0/2.05</td>
<td>ND</td>
<td>4.1*/14.3*</td>
<td>3.2/43.3</td>
<td>ND</td>
<td>3++/D</td>
<td>0/Norm</td>
<td>I, L, N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Median</td>
<td>NR*</td>
<td>ND</td>
<td>3.2/10.86</td>
<td>4.4*/2.1*</td>
<td>ND</td>
<td>1+/A</td>
<td>ND</td>
<td>0/Norm</td>
<td>I, L, S, N</td>
<td></td>
</tr>
<tr>
<td>5 Median</td>
<td>11.8*/0.06*</td>
<td>ND</td>
<td>3.1/6.36</td>
<td>NR*</td>
<td>ND</td>
<td>1+/A</td>
<td>ND</td>
<td>0/Norm</td>
<td>I, L, S, N</td>
<td></td>
</tr>
<tr>
<td>6 Median</td>
<td>7.6*/0.03*</td>
<td>ND</td>
<td>3.3/7.46</td>
<td>NR*</td>
<td>3.0/22.6</td>
<td>ND</td>
<td>1+/A</td>
<td>ND</td>
<td>0/Norm</td>
<td>I, L, S, N</td>
</tr>
<tr>
<td>7 Median</td>
<td>NR*</td>
<td>ND</td>
<td>3.26/0.5</td>
<td>4.8*/14.3*</td>
<td>3.2/33.8</td>
<td>ND</td>
<td>2+/D</td>
<td>ND</td>
<td>0/Norm</td>
<td>I, L, N</td>
</tr>
<tr>
<td>8 Median</td>
<td>NR* 7.7*/0.41*</td>
<td>ND</td>
<td>3.2/5.57</td>
<td>NR*</td>
<td>ND</td>
<td>1+/A</td>
<td>ND</td>
<td>I, L, N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Median</td>
<td>NR*</td>
<td>ND</td>
<td>2.97/7.11</td>
<td>NR*</td>
<td>2.7/13.6</td>
<td>ND</td>
<td>3+/A</td>
<td>ND</td>
<td>0/Norm</td>
<td>ND</td>
</tr>
<tr>
<td>10 Ulnar</td>
<td>4.8*/2.03*</td>
<td>ND</td>
<td>5.5/2.38</td>
<td>3.7*/0.48*</td>
<td>3.7*/11.1*</td>
<td>3.7*/9.5*</td>
<td>1.9/18.4</td>
<td>1+/B</td>
<td>1+/B</td>
<td>I</td>
</tr>
<tr>
<td>11 Ulnar</td>
<td>8.3*/0.86*</td>
<td>ND</td>
<td>5.4*/0.80*</td>
<td>4.7*/0.58</td>
<td>NR</td>
<td>3.8*/9.2*</td>
<td>2.4/18.3</td>
<td>0/D</td>
<td>1+/D</td>
<td>I, L</td>
</tr>
<tr>
<td>12 Ulnar</td>
<td>4.0/8.2</td>
<td>ND</td>
<td>NR</td>
<td>3.6/21.4</td>
<td>NR</td>
<td>3.3/3.7*</td>
<td>0/D</td>
<td>1+/D</td>
<td>1+/D</td>
<td>I, L, S</td>
</tr>
</tbody>
</table>

A = no motor units; Amp = amplitude; B = decrease in MUP, normal morphology; C = decrease in MUPs, small polyphasias; D = decrease in MUPs, large polyphasias; Dor cut = dorsal cutaneous; F = fascicular injury; Fib = fibrillation; I = increase in CSA; Inj = injury; L = loss of fascicular pattern; Lat = latency normal; N = neurona in continuity; nEMG = needle EMG; ND = not done; NR = not recordable; PSW = positive sharp wave; S = scar tissue.

Normal values on EMG: median nerve: CMAP APB latency: ≤4.4 msec, Amp: ≤4.0 mV; CMAP 2nd lumbrical latency: ≤4.4 msec, Amp: ≤2.5 mV; SNAP (digit 2 or 3) latency: ≤3.4 msec, Amp: ≤25.0 µV; ulnar nerve: CMAP ADM latency: ≤3.5 msec, Amp: ≤2.5 mV; CMAP FDI latency: ≤4.4 msec, Amp: ≤4.0 mV; SNAP digit 5 latency: ≤3.4 msec, Amp: ≤10 µV.

Normal values on US: CSA at carpal tunnel inlet for median nerve: ≤12 mm²; CSA at carpal tunnel inlet for ulnar nerve at wrist: ≤8 mm².

* Abnormal value.
Several factors contribute to the occurrence of iatrogenic nerve injury during CTR. Detailed knowledge of the local anatomy and its variations is imperative in increasing the likelihood of a successful CTR. An incision placed too radially will predispose to injury of the distal median nerve branches. A transverse incision may pose the risk of injury to the palmar cutaneous branches of the median/ulnar nerve, and severing of the thenar motor branch of the median nerve may lead to thenar atrophy and loss of opposition. When the TCL is cut, the curve of the scissors should be placed in an ulnar direction to decrease the chance for both recurrent and palmar branch injury. Variations of the median nerve in the vicinity of the carpal tunnel are observed in 3%–12% of cases. High division of the median nerve proximal to the carpal tunnel (bifid median nerve) has an incidence rate of 2.8% and should be considered when performing either an open or endoscopic CTR. Figure 3 highlights the potential injuries that may occur during a CTR.

The reported incidence of injury to the median or ulnar nerves is 0.11% for an open CTR and 0.13% for an endoscopic CTR. Early identification and treatment of an iatrogenic nerve injury occurring during CTR is crucial for preventing the development of permanent neurological deficits and/or chronic pain syndrome. Most surgeons who perform CTRs in our metropolitan community use the open technique, which may explain why only 1 case with nerve damage from an endoscopic CTR was evaluated in our neurodiagnostic center. Over the 9-year period of our study (2013–2022), the largest hand surgery group in our community reported that 94% of their patients underwent an open CTR compared with 6% who had an endoscopic CTR. In this respect, 15 times more patients had an open versus endoscopic CTR. Newer techniques such as US-guided incision-less CTR have been developed to minimize recovery time and decrease pillar pain. This approach involves loop ing an abrasive thread around the TCL while avoiding injury to neurovascular structures, the palmar aponeurosis, and skin.

Injury to the ulnar nerve during CTR is less common than that of the median nerve. The ulnar nerve and artery lie radial to the hook of the hamate and volar to the ulnar aspect of the TCL in 15% of individuals. Inadvertent encroachment into the Guyon’s canal and transection of the ulnar nerve are known to occur during CTR. If the palmar skin crease used to make the incision is situated close to the ulnar side of the hand, there may be an increased risk of ulnar neuropathy, particularly if vigorous retractor pressure is used. Entering the ulnar aspect of the carpal canal to approach the flexor retinaculum may decrease the risk of both scarring over the median nerve and damage to the palmar cutaneous branches of the median nerve; however, this approach may increase the likelihood of injury to the palmar cutaneous branch of the ulnar nerve. An ulnar nerve injury should be considered after CTR with the postoperative appearance of hypothenar and interosseous muscle weakness, ulnar nerve sensory abnormalities, and poor hand function.

**Observations**

The strength of the present case series is the large number of patients who experienced either a median or ulnar nerve injury during CTR and underwent both EDX and US testing. The limitations
of this case series include its retrospective nature and the nonavailability of preoperative EDX tests in more than 50% of patients. The patients also did not undergo preoperative US studies. Additionally, we are unable to provide the actual complication rate for CTR because we cannot determine among how many patients undergoing CTR these 12 cases of nerve injuries occurred. Finally, we did not see patients with the most common nerve injury after CTR, specifically injury to the palmar cutaneous branch of the median nerve; therefore, we cannot determine the actual complication rate for CTR.

### TABLE 3. EDX Findings Pre- Versus Post-CTR in Patients Evaluated at Our Electrodiagnostic Center

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Median Nerve CMAP DL (msec)/Amp (mV)</th>
<th>Median Nerve Digital SNAP Lat (msec)/Amp (µV)</th>
<th>Ulnar Nerve CMAP DL (msec)/Amp (µV)</th>
<th>Ulnar Nerve Digital Sensory Lat (msec)/Amp (µV)</th>
<th>nEMG APB</th>
<th>nEMG ADM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Preoperative: 3.7/6.3</td>
<td>3.5*/39.3</td>
<td>2.7/6.5</td>
<td></td>
<td>E</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Postoperative: 6.0*/1.3*</td>
<td>3.5*/19.8*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Preoperative: 6.0*/5.54</td>
<td>4.3*/39.1</td>
<td>3.2/7.89</td>
<td>3.2/40.4</td>
<td>D</td>
<td>C, Fib</td>
</tr>
<tr>
<td></td>
<td>Postoperative: NR*</td>
<td>4.1*/14.3*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Preoperative: 6.5*/4.5</td>
<td>NR*</td>
<td>3.2/9.1</td>
<td></td>
<td>D</td>
<td>A, Fib</td>
</tr>
<tr>
<td></td>
<td>Postoperative: 7.6*/0.03*</td>
<td>NR*</td>
<td>3.3/7.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Preoperative: 6.9*/6.2</td>
<td>NR*</td>
<td>3.0/9.6</td>
<td>3.0/28.9</td>
<td>E</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Postoperative: 4.9*/15.7*</td>
<td>NR*</td>
<td>3.2/6.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Preoperative: 6.6*/2.03*</td>
<td>NR*</td>
<td>2.9/8.54</td>
<td>3.3/15.5</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td></td>
<td>Postoperative: 8.3*/0.86*</td>
<td>NR*</td>
<td>4.7*/0.58*</td>
<td>3.8*/9.2*</td>
<td>D</td>
<td>C, Fib</td>
</tr>
</tbody>
</table>

A = no motor units; B = decrease in MUPs, normal morphology; C = decrease in MUPs, small polyphasics; D = decrease in MUPs, large polyphasics; DL = distal latency; E = normal pattern.

* Abnormal value.

A = no motor units; B = decrease in MUPs, normal morphology; C = decrease in MUPs, small polyphasics; D = decrease in MUPs, large polyphasics; DL = distal latency; E = normal pattern.

* Abnormal value.

Sites of potential injury during CT release:

1. Palmar cutaneous branch of median N
2. Median N motor & sensory within CT
3. Recurrent (motor) branch
4. Digital sensory branches
5. Ulnar deep (motor) branch
6. Palmar cutaneous branch of ulnar N
7. Ulnar motor & sensory

**FIG. 3.** Sites of potential injury during a CTR. CT = carpal tunnel; N = nerve.
it is likely that such patients were not referred for EDX studies postoperatively because surgeons can easily recognize this complication and often do not send them for additional tests.

Lessons
While ensuring adequate decompression of the median nerve at the carpal tunnel, all precautions such as the appropriate site for skin incision and good visualization of the nerve should be taken to avoid perioperative nerve injuries because significant morbidity can result. Our case series demonstrates the value of incorporating EDX and US findings to the clinical features in the diagnosis of iatrogenic nerve injuries occurring during CTR. US studies helped in preoperative planning, had the potential to precisely locate the site of injury, provided insight into the nature and extent of the injury, and guided further management. When nerve injury is suspected, surgeons should promptly use EDX and US studies to ascertain the nature of the injury and proceed with the appropriate intervention.

References

Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions
Conception and design: CB Shields, LBE Shields, Iyer. Acquisition of data: CB Shields, LBE Shields, Iyer. Analysis and interpretation of data: CB Shields, LBE Shields, Iyer. Drafting the article: CB Shields. Critically revising the article: All authors. Reviewed submitted version of manuscript: All authors. Approved the final version of the manuscript on behalf of all authors: CB Shields. Administrative/technical/material support: CB Shields, LBE Shields. Study supervision: CB Shields, LBE Shields.

Correspondence
Christopher B. Shields: Norton Neuroscience Institute, Norton Healthcare, Louisville, KY. cbshields1@gmail.com.