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ORIGINAL ARTICLE

Neurostimulation in severe carpal tunnel release: A more precise technique for opponensplasty decision-making

Zeki Günsoy, MD[1], Mustafa Dinç, MD[2], Ömer Cevdet Soydemir, MD[2]

[1]Department of Hand Surgery, Health Sciences University, Bursa, Türkiye
[2]Department of Orthopedics and Traumatology, Health Sciences University, Bursa, Türkiye

ABSTRACT

Objectives: In this study, we aimed to investigate the relationship between intraoperative thenar muscle neurostimulation responses and postoperative thumb function recovery in patients with severe carpal tunnel syndrome (CTS).

Patients and methods: Between January 2019 and December 2021, a total of 21 severe CTS cases in 20 patients (7 males, 13 females; mean age: 56.3±19.3 years; range, 52 to 76 years) based on clinical and electrophysiological findings were retrospectively analyzed. The median nerve motor branch (MNMB) was stimulated intraoperatively with a nerve stimulator. The patients were divided into two groups according to contraction response on abductor pollicis brevis (APB) muscle: Group C (contractile, n=13) and Group NR (non-responsive, n=7) with and without muscular contraction. The Levine Functional Severity Scale (LFSS) was used to measure the functional status of CTS patients. The Manual Muscle Testing (MMT) was used to assess muscle strength. Clinical outcomes were compared between the groups at one year of follow-up.

Results: The mean total preoperative LFSS score was significantly higher in Group NR than in Group C (p=0.010). The mean postoperative MMT score was significantly higher in Group C than in Group NR (p<0.001). There was no positive result in pick-up, button fastening, and needle pinch tests in Group NR (p<0.001). However, there were significant improvements in postoperative LFSS scores in Group C (p<0.05), while the scores remained unchanged in Group NR (p>0.05).

Conclusion: Direct stimulation of the median nerve motor branch and observation of contraction response on APB muscle can be used to predict clinical recovery and facilitates making the decision for opponensplasty in severe CTS.

Keywords: Abductor pollicis brevis, carpal tunnel syndrome, electric stimulation, muscle contraction, opponensplasty.

Severe carpal tunnel syndrome (CTS) is an entrapment neuropathy with variable surgical outcomes and accounts for 3% of all CTS cases.[1] Severe thenar eminence atrophy, particularly abductor pollicis brevis (APB) is responsible for thumb opposition, a fixed sensory deficit in the median nerve distribution, and the absence of median sensory and motor responses on electrophysiological evaluation are all symptoms of the most advanced stage of CTS. Sensorial disturbances and motor deficits may persist after surgical treatment of CTS, depending on the severity and duration of CTS and the type of surgical modalities applied for its treatment.[2] Numerous studies have made predictions about surgical outcomes based on clinical findings, patient features, and/or findings from nerve conduction investigations; these factors are frequently used to determine whether a patient is a candidate for primary opponensplasty.[3-5] In such cases, opponensplasty by a tendon transfer with carpal tunnel release (CTR) is another surgical modality resorted to correcting the thumb opposition.[2,4] Nevertheless, assessing the functional disability in severe CTS cases remains a challenging issue, along with the associated diagnostic difficulties.[5]

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Correspondence: Zeki Günsoy, MD. Sağlık Bilimleri Üniversitesi, El Cerrahisi Kliniği, 16059 Nilüfer, Bursa, Türkiye.

E-mail: zekigunsoy@gmail.com

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Preoperative needle electromyography (EMG) of thenar muscles particularly APB and nerve conduction studies are the gold standards for diagnosing CTS. In this way, it is possible to evaluate the functional aspects of the APB muscle.[2]

Direct stimulation of nerve fibers is needed during the exploration of multiple nerve fibers, e.g., brachial plexus surgery, and fascicular orientation, e.g., nerve transfer techniques.[6,7] Monopolar devices, such as nerve stimulators that utilize a controlled electrical potential, are the most commonly used tools for this purpose.[8,9]

Intraoperative direct supramaximal stimulation of an accessible peripheral nerve and quantifying the muscle innervated by this nerve may increase accuracy in assessing functional motor deficits.[10] In the present study, we aimed to investigate the relationship between intraoperative thenar muscle neurostimulation responses and postoperative thumb function recovery in patients with severe CTS. In the light of forementioned intraoperative nerve stimulation of median nerve motor branch (MNMB) is useful in deciding to perform CTR with or without opponensplasty.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Bursa City Hospital, Department of Orthopedics and Traumatology, Hand Surgery Clinic between January 2019 and December 2021. All consecutive patients who underwent CTR for severe CTS were screened. Patients with nocturnal hand pain, negative coin pick-up, the button fastening, and a sewing needle pinch test result, positive provocative Phalen's maneuver, Tinel's sign, and Durkan's test results, thenar wasting on physical examination, and severe axonal injury on EMG examination were included in the study. Patients with rheumatoid arthritis, hypothyroidism, cervical myelopathy, syringomyelia, thoracic outlet compression syndrome, ulnar nerve palsy, post-traumatic wrist deformities, gout, cerebrovascular accident, pregnancy, or prior steroid injections, acupuncture, and previous CTR were excluded from the study. Finally, 21 severe CTS cases in 20 patients (7 males, 13 females; mean age: 56.3±19.3 years; range, 52 to 76 years) based on clinical and electrophysiological findings were included.

Data collection

Patients' demographic (age, sex, occupation) and clinical characteristics (side, hand preference, comorbidities) were recorded using the hospital information system. The patients were examined preoperatively. The clinical assessment was made using the coin pick-up, button fastening, and sewing needle pinch tests.[5,11,12] Then, all patients underwent an electroneuromyography examination. The median nerve conduction studies were performed in all patients who were clinically suspected of having CTS.

The CTS levels of the patients were determined as normal, mild, moderate, or severe according to the criteria developed by Kim et al.[1]

Surgical procedure

A single experienced hand surgeon performed all CTR procedures. A 2-cm long incision starting proximal to Kaplan's cardinal runs along the ulnar edge of thenar crease to wrist crease. During the procedure, the motor branch of the median nerve was exposed (Figures 1 and 2) and stimulated with

FIGURE 1. Isolation of the median nerve's motor branch in a carpal tunnel syndrome patient.

a stimulator at 2 Hz and 5 mA for 1 msec (MultiStim Sensor Nerve Stimulator, Pajunk Medical Produkte GmbH, Geisingen, Germany) (Figure 3). A disposable, sterile probe of the device was used intraoperatively. The technical data for the stimulation was 2 Hz, 5 mA, with a duration of 1 msec. A motor response on the APB muscle was observed as positive muscular contractions, or no response was observed at all. After observing the contraction of the muscle, it was confirmed by means of a repeated stimulus at 1 mA. The patients were divided into two groups based on the results of intraoperative direct stimulation, that is, whether the muscular contraction was observed on the APB muscle (Group C) or there was no response on the APB muscle following the nerve stimulation (Group NR).

Patient follow-up

The Manual Muscle Testing (MMT) Grading System, which is a six-point scale, was used to assess the APB muscle strength.[13,14] The grades determined by MMT have the following meanings: (0): zero, (1): trace, (2): poor, (3): fair, (4): good, and (5): normal. The MMT was performed using the index finger of the physician opposing the patients' thumb abduction or index finger abduction (FDI muscle).[15] Surgery was conducted by one surgeon, assessment was conducted by two different surgeons, results were evaluated according to interclass correlation coefficient (ICC).

The patients were re-examined in the outpatient clinics postoperatively at one year of follow-up examination. In this context, the MMT grade was re-evaluated and the provocative clinical tests were re-conducted to compare the changes in the thumb function. The Levine Functional Severity Scale (LFSS) was used to measure the functional status of CTS patients.[16,17] The eight multiple-choice questions available in LFSS are assigned a score between one (no difficulty in activity) and five (complete disability). Accordingly, patients' satisfaction levels with surgery were graded as either (0): very satisfied, (1): satisfied, (2): neither satisfied nor dissatisfied, or (3): dissatisfied.[16] Higher scores indicate lower satisfaction level.

Statistical analysis

Statistical analysis was performed using the Jamovi Project 2.2.5.0 (retrieved from https://www.jamovi.org) and JASP 0.16.1 software (Jeffreys' Amazing Statistics Program, retrieved from https://jasp-stats.org) software. Continuous data were expressed in mean ± standard deviation (SD) or median (min-max), while categorical variables were expressed in number and frequency. The Shapiro-Wilk, Kolmogorov-Smirnov, and Anderson-Darling tests were used to

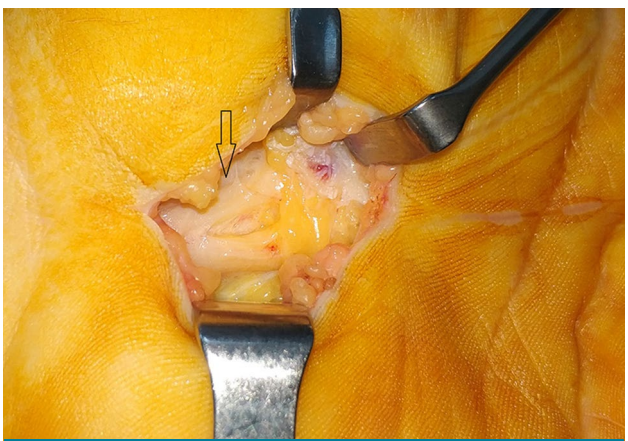

FIGURE 2. Intraoperative view of the motor branch of the median nerve (black arrow) using a palm incision.

FIGURE 3. A nerve stimulator for the direct stimulation of the motor branch of the median nerve to observe muscular contraction on the adductor pollicis brevis.

TABLE I
Demographic and baseline characteristics of the patients

	Group C (n=13)			Group NR (n=7)			
	n	%	Mean±SD	n	%	Mean±SD	*p*
Age (year)			52.0±12.1			64.3±6.4	**0.008****
Sex							0.329*
Male	6	46.2		1	14.3		
Female	7	53.8		6	85.7		
Affected hand							0.999*
Right	12	92.3		7	100		
Bilateral	1	7.7		0	0.0		
Hand preferences							-
Right-hand dominant	13	100		7	100		
Left-hand dominant	0	0.0		0	0.0		
Occupation							0.696*
Farmer	3	23.1		1	14.3		
Housewife	3	23.1		3	42.9		
Others	7	53.8		3	42.9		
Comorbidities	3	23.1		2	28.6		0.999*
Types of comorbidities							
Diabetes mellitus	2	66.7		2	100.0		0.587*
Chronic renal failure	1	33.3		0	0.0		0.999*

NR: Non-responsive; SD: Standard deviation; †: Health physician, laboratory worker, nurse, officer; Group C: Group contraction, Group NR: Group no-response; * Pearson chi-square or Fisher exact tests; ** Independent samples t-test.

analyze the normal distribution characteristics of the numerical variables. The Pearson chi-square and Fisher exact tests were used to compare the differences between categorical variables. The independent samples t-test and the Mann-Whitney U test were used to compare two independent groups where numerical variables were determined to conform to the normal distribution and not to conform to the normal distribution, respectively. The weighted kappa (κ) coefficient was used to assess the level of agreement between the two raters. The Wilcoxon signed-rank test was used to compare the pre- and postoperative LFSS scores between the groups. A *p* value of <0.05 was considered statistically significant.

RESULTS

A total of 20 patients were included in the study. Of the patients, one had bilateral CTS. Patients' demographic and clinical characteristics are summarized in Table I.

There were 13 (65.0%) and seven (35.0%) patients in Group C and NR, respectively. The patients in Group NR were significantly older than those in Group C (p=0.008). The groups did not significantly differ in other demographic and clinical characteristics (p>0.05) (Table I).

When the agreement of the two surgeons in the MMT scoring was evaluated, a statistically

TABLE II
Preoperative and clinical assessment findings of the study groups

	Group C (n=13)				Group NR (n=7)				
	n	%	Median	Min-Max	n	%	Median	Min-Max	*p*
Preoperative MMT grade of APB muscle strength			1.0	0.0-1.0			0.0	0.0-1.0	0.093*
Preoperative MMT grades									0.158**
0 (zero)	6	46.2			6	85.7			
1 (trace)	7	53.8			1	14.3			

Group C: Group contraction, Group NR: Group no-response; MMT: Manual muscle testing; APB: Adductor pollicis brevis; * Mann-Whitney U test; ** Fisher exact test.

significant agreement was found both in the pre- and postoperative evaluations of the two surgeons (κ=0.490, p=0.028; κ=0.558, p<0.001). There was also no significant difference between the groups in the median preoperative APB muscle strength based on the MMT grades (p=0.093). Although there were more patients with a Grade zero motor score in Group NR, the difference between the groups was insignificant

TABLE III
Postoperative results of the Levine Functional Severity Scale

	Group C (n=13)		Group NR (n=7)		
	Median	Min-Max	Median	Min-Max	*p**
Writing					
Preoperative	5.0	5.0-5.0	5.0	4.0-5.0	0.173
Postoperative	2.0	1.0-3.0	5.0	4.0-5.0	**<0.001**
*p***	**0.001**		0.999		
Buttoning clothes					
Preoperative	5.0	4.0-5.0	5.0	4.0-5.0	0.370
Postoperative	2.0	1.0-3.0	5.0	4.0-5.0	**<0.001**
*p***	**0.001**		0.999		
Holding a book while reading					
Preoperative	4.0	4.0-5.0	5.0	4.0-5.0	0.291
Postoperative	2.0	1.0-3.0	5.0	4.0-5.0	**<0.001**
*p***	**0.001**		0.999		
Gripping a telephone handset					
Preoperative	4.0	4.0-5.0	5.0	4.0-5.0	0.093
Postoperative	1.0	1.0-3.0	5.0	4.0-5.0	**<0.001**
*p***	**0.001**		0.999		
Opening jars					
Preoperative	5.0	4.0-5.0	5.0	4.0-5.0	0.493
Postoperative	2.0	1.0-3.0	5.0	4.0-5.0	**<0.001**
*p***	**0.001**		0.317		
Household chores					
Preoperative	4.0	3.0-5.0	5.0	4.0-5.0	**0.014**
Postoperative	1.0	1.0-2.0	5.0	4.0-5.0	<0.001
*p***	**0.001**		0.999		
Carrying grocery plastic bags					
Preoperative	4.0	2.0-5.0	5.0	4.0-5.0	**0.019**
Postoperative	1.0	1.0-2.0	5.0	4.0-5.0	**<0.001**
*p***	**0.001**		0.999		
Bathing and dressing					
Preoperative	3.0	3.0-5.0	5.0	5.0-5.0	**0.001**
Postoperative	1.0	1.0-2.0	5.0	5.0-5.0	**<0.001**
*p***	**0.001**		0.999		
Total item average					
Preoperative	34.0	33.0-40.0	38.0	38.0-39.0	**0.010**
Postoperative	12.0	8.0-20.0	38.0	38.0-39.0	**<0.001**
*p***	**0.002**		0.317		

Group C: Group contraction; Group; NR: Group no-response; * Mann-Whitney U test; ** Wilcoxon test.

TABLE IV
Comparison of the postoperative outcomes in the study groups

	Group C (n=13)				Group NR (n=7)				
	n	%	Median	Min-Max	n	%	Median	Min-Max	*p**
Follow-up time (month)			14.0	10.0-22.0			14.0	10.0-18.0	0.686
Postoperative MMT grade of APB muscle strength			4.0	3.0-5.0			0.0	0.0-0.0	**<0.001**
Postoperative MMT grades									**<0.001**
0 (zero)	0	0.0			7	100.0			
3 (fair)	4	30.8			0	0.0			
4 (good)	6	46.2			0	0.0			
5 (normal)	3	23.1			0	0.0			
Postoperative coin pick-up test									**<0.001**
Negative	0	0.0			7	100.0			
Positive	13	100.0			0	0.0			
Postoperative button fastening test									**<0.001**
Negative	0	0.0			7	100.0			
Positive	13	100.0			0	0.0			
Postoperative sewing needle pinch test									**<0.001**
Negative	0	0.0			7	100.0			
Positive	13	100.0			0	0.0			
Patient satisfaction score			1.0	1.0-2.0			3.0	3.0-3.0	**<0.001**

Group C: Group contraction; Group NR: Group no-response; * Mann-Whitney U test.

(p=0.158). However, the duration of functional loss before surgery was significantly longer in Group NR (p=0.015) (Table II).

The preoperative LFSS scores are given in Table III. There were significant differences between the groups in scores obtained from the household chores, carrying grocery plastic bags, and bathing and dressing subscales (p<0.05). The median preoperative total LFSS scores were 34.0 and 38.0 in groups C and NR, respectively (p=0.010).

There were two (14.3%) and one (14.3%) patient with postoperative pillar pain in Groups C and NR, respectively (p=0.999).

The postoperative outcomes are detailed in Table IV. There was no significant difference between the groups in terms of follow-up times (p=0.686). The median postoperative MMT grade score was significantly higher in Group C than in Group NR (p<0.001). In Group NR, all patients had a Grade zero postoperative motor score. The comparison of the MMT grades revealed a significant difference between the groups (p<0.001). The rates of patients with positive coin pick-up, button fastening, and needle pinch test results were significantly higher in Group C than in Group NR, since there was no patient with positive coin pick-up, button fastening, and needle pinch test results in Group NR, (p<0.001). The median patient satisfaction score was significantly lower in Group C than in Group NR, indicating a higher satisfaction level (p<0.001) 3 of Group C patients thenar atrophy recovered. None of the cases in group NR recovered. No statistically significant difference was observed between two groups in terms of recovery of atrophy (p>0.05) (Table IV).

The distribution of postoperative LFSS scores are given in Table III. All postoperative total LFSS scores and scores obtained from the LFSS subscales were significantly lower in Group C than in Group NR (p<0.001) (Table III). In addition, there was a significant difference between the pre- and postoperative LFSS scores in Group C (p<0.05), but not in Group NR (p>0.05) (Table III).

DISCUSSION

In the present study, we attempted to investigate the role of neurostimulation in predicting motor recovery and assessed its value. There are studies about the recovery of symptoms after CTR investigating variables that can predict future clinical

improvement.[2,18,19] Investigated diagnostic and clinical variables, including duration of symptoms, electrophysical severity, grip strength, thenar muscle atrophy, EMG abnormalities, Phalen's and Tinel's test results are used to predict clinical outcomes and classifying diseases severity, as well as to determine indication for opponensplasty.

Opponensplasty is a surgical technique recommended for severe cases of CTS with lack of opposition.[2] The indications of this technique show variations, including disease severity, nerve conduction studies, thumb function score, functional tests and patient demand.[5,20] Kamiya et al.[21] and Hasegawa and Matsubara[18] concluded that motor unit potential (MUP) and distal motor latency of second lumbrical muscle are the predictors to decide opponensplasty. Yip et al.[5] used the pick-up coin test to decide opponensplasty quickly. There is a need for more objective findings that may help to decide to perform opponensplasty. In this regard, the intraoperative observation made in this study may be an indicative factor in opponensplasty.

Review of the literature regarding the recovery of thumb function after CTR revealed the study of Hara et al.[22] that showed that the MUP of the APB muscle in needle EMG was regarded as an essential factor in predicting long-term thumb function recovery in CTS patients following surgery. In needle EMG preoperative 57% of MUP(-) and 100% of MUP(+) APB muscle recovered within a year after CTR. They attempted to explain this controversial finding based on several technical and physiological aspects of needle EMG. Nonetheless, they suggested that the recovery of APB muscle can be predicted via preoperative needle EMG. This criterion may be used in classifying the disease severity and tailoring the intraoperative management including opponensplasty in severe CTS patients. Padua et al.[23] reported that median motor and sensory responses remained absent at the follow-up in two patients with end-stage disease; however, one patient had functional improvement.[1] According to Sugioka et al.,[24] 56% of patients with severe CTS and unrecordable compound muscle action potential of the APB (APB-CMAP) made a full recovery one year following surgery. Nobuta et al.[25] concluded that preoperative APB-CMAP was not a significant predictor of severe CTS. The findings of our study are consistent with those of above in that the intraoperative contractility of the thenar muscles, after neurostimulation was associated with significant functional recovery and increased patient satisfaction levels. All clinical assessment variables showed a considerable difference between the study groups.

The patients in Group NR were diagnosed with severe CTS, as in Group C; yet, they were significantly older, had a longer duration of the symptoms, and had higher preoperative total LFSS and LFSS subscale scores. However, there was no intraoperative thenar muscle contraction due to nerve stimulation. In addition, no improvement was observed in Group NR following CTR in the first-year follow-up evaluation. Given these findings, the absence of intraoperative muscular contraction of thenar muscles by direct stimulation may be considered a candidate for opponensplasty.

In addition to electrodiagnostic tests, mostly used clinical finding is thenar atrophy to decide opponensplasty. Motor recovery after CTR is unpredictable due to long-term thenar muscle atrophy and chronic median nerve compression. Regarding the thenar muscle loss and the time needed for recovery after CTR in patients with thenar atrophy, there has been some debate. Despite the thenar muscle's ongoing atrophy, recovery of thumb function after CTR has been documented in the literature. Mondelli et al.,[26] Leite et al.,[27] and Nagaoka et al.[28] showed a considerable neurophysiological and clinical improvement in thumb opposition of severe CTS patients after CTR. Even in individuals with missing motor nerve function on preoperative nerve conduction testing, Park et al.[29] found that thenar atrophy could improve concurrently with motor recovery after CTR alone. According to Durban et al.[30] and Hattori et al.,[31] more than one-third of patients with severe CTS and thenar atrophy showed electrophysiological recovery of APB during the postoperative period. In our study, in three hands in contractile group, thenar atrophy recovered, while non-stimulated group showed no recovery.

Considering the comorbidities affecting CTR results, Capasso et al.[32] reported that associated diseases did not necessarily imply a poor surgical outcome. In our study, three patients with comorbidities in Group C recovered, while two patients with comorbidities in Group NR did not. Consistent with the literature, comorbidities do not affect the recovery results.

Carpal tunnel release is effective and sufficient for the relief of symptoms of pain, paresthesia, tingling and numbness. However, for severe CTS cases with thenar atrophy and opposition deficiency, CTR alone may not be sufficient, if the motor end plate degeneration occurred before. The

innervation period is considered varying from 12 to 18 months.[21,33,34] The time window for sensory reinnervation is longer, but not infinite. All patients with severe CTS would experience the relief of sensory symptoms after release. Motor reinnervation is not possible due to irreversibly degenerated motor end-plate. This study elicits the contractility of thenar muscles which is crucial for opposition of the thumb. Surgeons assess the impaired thenar muscles by clinical examination and EMG results to perform opponensplasty. Intraoperative observation of thenar muscle contractility by direct stimulation confirms whether the nerve-motor end-plate is intact or not and is helpful for decision-making in opponensplasty. Our study findings suggest that the contractility in the thenar muscles as evidenced by direct MNMB stimulation is a reliable finding to predict long-term thumb functional recovery in patients after CTR. Therefore, neurostimulation may play a role in deciding to perform opponensplasty in addition to CTR in these patients.

One of the major strengths of our study is that intraoperative direct stimulation of the nerve causing contraction of the related muscle helps physicians to overcome such controversies.[35] A clear distinction between the groups in terms of clinical outcomes is a direct consequence of the technique used in this study. The discrepancies between the clinical and EMG evaluations can be avoided using objective diagnostic approaches similar to the ones adopted in this study.

The main limitations are its single-center, retrospective design with a relatively small sample size. In addition, although it was initially planned to assess the degree of motor recovery, postoperative needle EMG could not be performed, since the patients were unwilling to undergo an invasive procedure.

In conclusion the majority of surgeons make their decision of CTR based on the severity of the condition, the results of nerve conduction examinations, and scores on the thumb function. Using a stimulator during CTR helps the surgeon to distinguish whether the motor end-plate is irreversibly demised or not and facilitates making the decision for opponensplasty.

Ethics Committee Approval: The study protocol was approved by the Bursa State Hospital Ethics Committee (date: 14.07.2021, no: 2021-13/1). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: Written informed consent could not be taken from the patients due to the study's retrospective design and the data's anonymity.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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