EDITOR'S CHOICE

Long-Term Outcome of Electrodiagnostic Values and Symptom Improvement After Carpal Tunnel Release: A Retrospective Cohort Study

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Continuing Medical Education

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Learning Objectives

Upon completion of this CME activity, the learner should achieve an understanding of:

- Electrodiagnostic outcomes after carpal tunnel release for moderate and advanced carpal tunnel syndrome (CTS).
- The pattern of clinical improvement after carpal tunnel release for moderate and advanced CTS.
- Current diagnostic guidelines for CTS.

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Purpose The aim of this study was to evaluate electrodiagnostic studies and clinical outcomes after carpal tunnel release surgery in moderate and severe cases of carpal tunnel syndrome (CTS).

Methods Seventy-two patients with moderate or severe CTS who underwent carpal tunnel release surgery (46 unilateral; 26 bilateral; total, 98 surgeries) between 2009 and 2014 were included in the study. The cases were divided into 2 groups according to electrodiagnostic results: those with moderate CTS and those with severe CTS. Michigan Hand Outcomes Questionnaire scores and electrodiagnostic data (sensory nerve action potentials and compound muscle action potentials) were recorded before surgery and in postoperative follow-up studies obtained at 3 months, 1 year, and 5 years.

Results There were 56 surgeries in the moderate CTS group and 42 surgeries in the severe CTS group. Sensory nerve action potentials and compound muscle action potentials were significantly lower in the severe CTS group when compared to the moderate CTS group at all follow-up times. There was a significant difference in Michigan Hand Outcomes Questionnaire scores between the groups before surgery, but no significant differences at the final follow-up. It was found that the values of all parameters (sensory nerve action potentials, compound muscle action potentials, and Michigan Hand Outcomes Questionnaire score) demonstrated significant improvements with time in both the severe and the moderate CTS groups.

Conclusions Carpal tunnel release surgery improves symptoms, regardless of the preoperative severity. Postoperative electrodiagnostic study results of patients with moderate CTS improve to a greater degree than those of patients with severe CTS, but all remain abnormal. *(J Hand Surg Am. 2022;47(8):727−735. Copyright © 2022 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Prognosis IIb.

Key words Carpal tunnel release, carpal tunnel syndrome, Michigan Hand Outcomes Questionnaire, nerve conduction study.

Although carpal tunnel syndrome (CTS) is the most common compressive neuropathy in the upper extremity, its prevalence has been reported at different frequencies according to widely accepted diagnostic criteria.[1] The incidence of CTS in women is higher than that in men, and the prevalence and severity of the disease increase with age. Work-related activities that require high-frequency repetition, force, or the use of hand-operated vibrating tools considerably increase the risk of CTS.[2]

Carpal tunnel syndrome symptoms are generally characterized by paresthesia in the area of the hand innervated by the median nerve.[3] Although the diagnosis of CTS is generally established clinically, electrodiagnostic studies such as nerve conduction studies (NCS) and electromyography (EMG) are widely used. Current guidelines indicate that clinical findings are sufficient for the diagnosis of CTS in most cases; however, electrodiagnostic tests can be performed to aid a CTS diagnosis when there is uncertainty.[4−6] Although nonsurgical treatment is preferred in mild CTS cases, it is less likely to be successful in moderate and severe CTS cases.

The hypothesis of this study was that the patient-reported outcome of carpal tunnel release (CTR) exceeds that of electrodiagnostic recovery in patients with moderate or severe CTS. Only a few studies have shown normalization of NCS values in parallel with clinical improvement in CTS after CTR.[7−11] Therefore, the relationships between preoperative CTS staging (according to NCS results) and postoperative clinical outcomes (patient-reported and electrodiagnostic) are largely unknown. The aim of this study was to evaluate NCS and clinical outcomes after CTR in moderate and severe cases of CTS.

MATERIALS AND METHODS

Seventy-two patients diagnosed with moderate or severe CTS who had undergone CTR surgery (46 unilateral; 26 bilateral; total, 98 surgeries) at the Maltepe University Orthopedics and Traumatology Clinic between January 1, 2009, and December 31, 2014, were included in the study. Ethics approval was obtained from the Clinical Research Ethics Committee of Maltepe University.

TABLE 1. Severity of Carpal Tunnel Syndrome According to Electrophysiological Findings*

Severity	Sensory NCS	Motor NCS	APB Needle EMG
Mild When at least 3 are present in patients with normal APB needle EMG	• 14-cm wrist stimulation; peak latency, >3.7 ms • 14-cm wrist stimulation; peak latency, proximal, 7 cm; peak latency, distal 7 cm • Transcarpal 5-cm short-segment latency (proximal latency − distal palm latency): onset > 1.3 ms, peak >1.5 ms • 14-cm wrist stimulation SNAP amplitude, 16−20 μV	• Distal latency, >4.2 ms • APB CMAP amplitude, 4.1−4.5 mV	• Normal
Moderate When mild CTS is fulfilled and at least 2 are present	• 14-cm wrist stimulation SNAP amplitude, 6−15 μV • Conduction blockade greater than 50% at wrist and palm stimulation if SNAP ≥ 10 μV with 14-cm wrist stimulation	• CMAP amplitude, 2.1−4 mV	• Fibrillation (±) • Abnormal MUAP with intermediate interference patterns
Severe When moderate CTS is fulfilled and these are present	• SNAP amplitude, ≤5 μV	• CMAP amplitude, ≤2 mV	• Fibrillation (+) • Abnormal MUAP with discrete activities or single unit patterns

*From Lee et al.[12] MUAP, motor unit action potentials.

Patients

All cases with complete records were included in the study by examining the files of CTS cases treated with CTR throughout the study period. According to the results of EMG analyses performed in the preoperative period, the cases were divided into 2 groups: those with moderate CTS and those with severe CTS. This classification was based on the study by Lee et al.[12] Mild CTS was defined as cases that had a normal abductor pollicis brevis (APB) needle EMG, but met at least 3 of the 6 criteria pertaining to sensory NCS (total of 4 items in this category) and motor NCS (total of 2 items in this category), meaning that these patients had a normal APB needle EMG but fulfilled 3 of the criteria in the first row of Table 1. Moderate CTS was defined as cases that met the mild criteria and also fulfilled at least 2 of the 5 items for sensory NCS (2 items), motor NCS (1 item), and APB EMG abnormality (2 items), meaning that these patients met at least 3 criteria from the first row of Table 1 and met an additional 2 criteria from the second row of Table 1; therefore, these patients had to meet at least 5 criteria. Finally, severe CTS was defined as cases that met the moderate criteria and also had all of the remaining 4 electrodiagnostic criteria, meaning these patients met at least 3 of the criteria in the first row of Table 1, met at least 2 of the criteria from the second row of Table 1, and met all of the criteria from the third row of Table 1; therefore, these patients had to meet at least 9 criteria.[12]

Inclusion and exclusion criteria: A total of 104 patients (154 wrists) who underwent CTR were evaluated for eligibility for the study. Among moderate and severe CTS cases, patients with complete preoperative and postoperative (3-month, 1-year, and 5-year) EMG and Michigan Hand Outcomes Questionnaire (MHQ) results were included in the study. Cases of CTS that developed after trauma, fracture, or nerve injury were excluded from the study. After exclusion, 72 patients (98 wrists) with idiopathic CTS were included in the study.

Variables

The age, sex, and side of involvement were recorded. All cases were evaluated before surgery (at baseline) and after surgery at 3 months, 1 year, and 5 years. Although electrodiagnostic testing is not recommended for follow-up assessments in patients treated with CTR, in our clinical environment, postoperative testing is often performed and may even be considered as standard practice. There are various reasons for this, including extreme physician workloads

TABLE 2. Summary of Characteristics of the Patients*

Characteristic	Severity of Carpal Tunnel Syndrome		Total (n = 98)
	Moderate (n = 56)	Severe (n = 42)	
Sex			
Female	40 (71.4%)	32 (76.2%)	72 (73.5%)
Male	16 (28.6%)	10 (23.8%)	26 (26.5%)
Age, y	78 (73–82)	76 (67–82)	77 (70–82)
Side			
Right	25 (44.6%)	19 (45.2%)	44 (44.9%)
Left	31 (55.4%)	23 (54.8%)	54 (55.1%)
Diabetes mellitus	15 (26.8%)	12 (28.6%)	27 (27.6%)

*Data are given as the median (first quartile–third quartile) for continuous variables and as the frequency (percentage) for categorical variables.

leading to a "need" for a supposedly objective evaluation, overwhelming patient requests for testing, orders by other clinics for diagnostic or exploratory purposes, and follow-up necessity owing to the continuation or re-emergence of symptoms. Sensory nerve action potentials (SNAP), compound muscle action potentials (CMAP), and MHQ scores were recorded at all scheduled follow-up studies.

Carpal tunnel release surgery procedure

All operations were performed under local anesthesia, without tourniquet application. Briefly, the transverse carpal ligament was divided using a 4-cm longitudinal incision. The median nerve was observed macroscopically. In bilateral CTS cases, the operations were performed at least 3 months apart, rather than simultaneously. Therefore, only 1 hand was treated in each operation, and follow-up studies were scheduled separately for the 2 extremities in these cases.

Electrophysiological analysis

The Neuro-MEP-Micro (v. 2009) EMG device (Neurosoft Medical diagnostic equipment) was used for electrophysiological evaluations. Measurements were begun after patients had rested for 15 minutes in a temperature-controlled room at 24 °C.

In all electrophysiological measurements, the sampling frequency of the Neuro-MEP-Micro (v.2009) EMG device was chosen as 25,000 Hz. Filter settings were determined as 5–10,000 Hz in motor nerve measurements. Motor nerve latency measurements were made with a screen sensitivity of 2 ms/div, and amplitude measurements at a screen sensitivity of 1–2 mV/div. Filter settings were determined as 5–2,000 Hz in sensory nerve measurements. Sensory nerve latency measurements were made with a screen sensitivity of 1 ms/div, and amplitude measurements at 5–10 μV. Latency and amplitude values were measured after supramaximal stimulation.[13] In all measurements, the grounding electrode was placed on the back of the hand.

The amplitude, latency, and conduction velocity values of the median nerve SNAPs were obtained using a ring electrode from the middle finger and recording from the wrist antidromically. The amplitude, latency, and conduction velocity of the median nerve CMAPs were obtained by stimulation from the wrist and the antecubital fossa through the superficial electrode placed on the APB muscle.[14]

Michigan Hand Outcomes Questionnaire

The MHQ is a patient-reported evaluation of hand-related conditions, and it has been validated for use in CTS.[15] Both hands are examined separately in the questionnaire. It consists of 63 items classified into 6 sections (function, activities of daily living, pain, work performance, aesthetics, and patient satisfaction). Each question is scored on a scale of 1 to 5. Higher scores indicate better status. A Turkish-language validity and reliability study of the scale has been established.[16] Since there was at least 3 months between surgeries in bilateral CTS cases, the MHQ was obtained for each hand. There were no missing data in the MHQ scores.

Statistical analysis

For the normality check, the Shapiro-Wilk test was used. Data are given as medians (interquartile ranges) for continuous variables and as frequencies (percentages) for categorical variables. Non-normally distributed variables were analyzed with the Mann-Whitney U test (between-group comparisons) and

TABLE 3. Summary of Clinical Results of the Patients*

Measure	Severity of Carpal Tunnel Syndrome		*P* Value†
	Moderate (n = 56)	Severe (n = 42)	
SNAP, μV			
Preoperative	10.0 (8.5−12.0)‡	3.0 (2.0−4.0)‡	<.05
Third mo	21.0 (19.0−22.0)§	5.0 (4.0−6.0)§	<.05
First y	22.0 (21.0−23.0)‖	6.0 (5.0−6.0)§	<.05
Fifth y	22.0 (21.0−23.0)‖	6.0 (5.0−6.0)§	<.05
P value¶	<.05	<.05	
CMAP, mV			
Preoperative	3.00 (2.85−3.40)‡	1.55 (1.20−1.90)‡	<.05
Third mo	5.00 (4.70−5.00)§	1.85 (1.60−2.00)§	<.05
1 First y	5.00 (5.00−5.35)‖	2.00 (1.80−2.10)§	<.05
5 Fifth y	5.05 (5.00−5.45)‖	2.00 (1.80−2.00)§	<.05
P value¶	<.05	<.05	
MHQ score			
Preoperative	52.5 (46.0−56.0)‡	43.5 (38.0−46.0)‡	<.05
3 Third mo	78.0 (75.5−80.0)§	77.5 (74.0−80.0)§	0.442
1 First y	80.0 (78.0−84.0)§	79.5 (78.0−87.0)§	0.948
5 Fifth y	79.0 (78.0−81.5)§	80.0 (78.0−82.0)§	0.338
P value¶	<.05	<.05	

CMAP, compound motor action potentials; MHQ, Michigan hand outcomes questionnaire; SNAP, sensory nerve action potentials

*Data are given as median (1st quartile−3rd quartile) for continuous variables.

†Comparison between groups.

‡Significant differences between repeated measurements within groups with this footnote symbol. The thresholds for significance were calculated based upon Bonferroni correction with the number of pairwise tests (in all instances, 6 tests); therefore, significance thresholds for these pairwise tests were 0.05 ÷ 6 = 0.00833.

§Significant differences between repeated measurements within groups with this footnote symbol. The thresholds for significance were calculated based upon Bonferroni correction with the number of pairwise tests (in all instances, 6 tests); therefore, significance thresholds for these pairwise tests were 0.05 ÷ 6 = 0.00833.

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¶Comparison within groups.

the Friedman test (for repeated measurements). The threshold for statistical significance was adjusted with the Bonferroni correction method. Categorical variable distributions were evaluated using chi-square tests. Two-tailed *P* values less than .05 were considered statistically significant. *Post hoc* power analyses were performed based on minimal clinically important difference (MCID) values reported in the literature, and revealed power values of 100% for SNAP (MCID = 1.8), 100% for CMAP (MCID = 1.2), and 98.5% for MHQ scores (MCID = 14.7).[17,18]

RESULTS

There were 40 patients (24 unilateral; 16 bilateral; total, 56 surgeries) in the moderate CTS group and 22 patients (22 unilateral; 10 bilateral; total, 42 surgeries) in the severe CTS group. The median age of cases was 77 years (interquartile range, 70−82 years). The groups were similar in terms of sex, age, and the laterality of CTS (Table 2).

The SNAP and CMAP values, as measured by NCS analysis, were significantly lower in the severe CTS group compared to the moderate CTS group at baseline and at all follow-ups ($P < .05$ for each). Within-group paired comparisons of SNAP and CMAP values demonstrated that all parameters had improved after treatment in both groups (all *P* values <.001). In the moderate CTS group, SNAP and CMAP values both improved significantly between the 3-month and 1-year postoperative follow-ups ($P < .05$ for each), whereas the changes over the same time were nonsignificant in the severe CTS group.

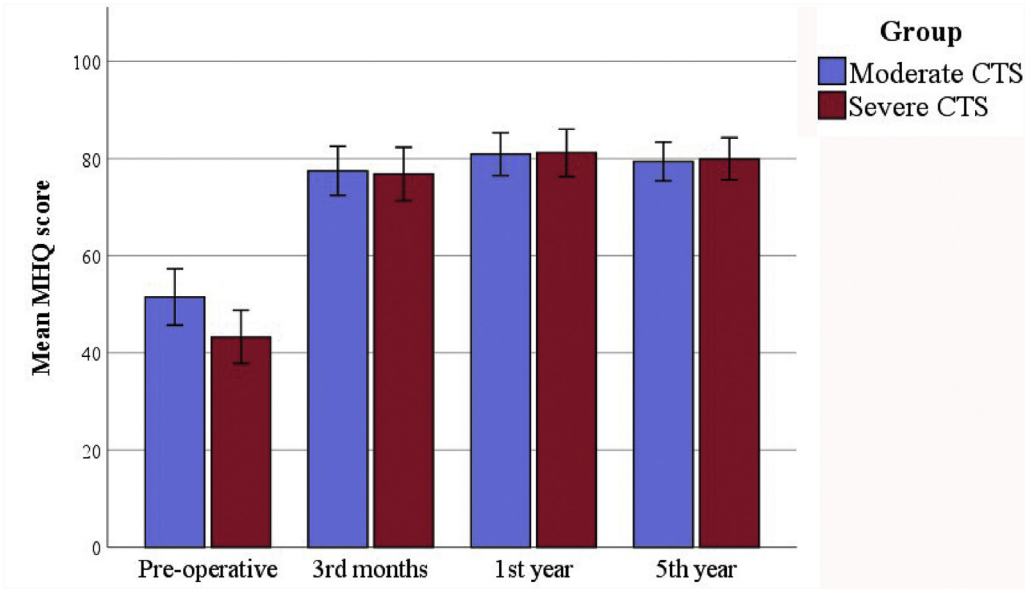

FIGURE 1: Michigan Hand Outcomes Questionnaire scores in groups with regard to follow-up time. Error bars represent the standard deviation of means.

Also, there was no significant difference in terms of SNAP and CMAP values between the 1-year and 5-year results ($P > .05$ for each) in the severe CTS group. The SNAP values were similar at the 1- and 5-year follow-ups in both the moderate and severe CTS groups. Again, CMAP values at the 1- and 5-year follow-ups were similar in both groups.

The baseline MHQ scores were significantly different between the moderate and severe CTS groups. The follow-up MHQ scores demonstrated significant improvement after surgery in both groups, but intergroup comparisons of postoperative measurements did not demonstrate any significant differences. In addition, although the MHQ score was significantly higher at baseline in the moderate CTS group, there were no significant differences between the moderate and severe CTS groups in terms of MHQ scores at the 3-month, 1-year, and 5-year follow-ups (Table 3; Fig 1).

DISCUSSION

Although the benefit of CTR surgery has been demonstrated in many studies, there is limited evidence as to whether there is a relationship between the level of functional improvement reported after surgery in moderate and severe CTS cases and postoperative electrodiagnostic outcomes.[19,20] This may be because of limited data reporting postoperative NCS results in patients with CTS who improved clinically after undergoing surgical treatment, since these measurements are considered to be unnecessary. This study shows that CTR surgery resulted in statistically significant improvements in NCS values and MHQ scores in both groups; however, NCS measurements did not return to normal despite considerable clinical improvement, as measured by MHQ scores. The NCS values were closer to normal in moderate CTS cases compared to severe CTS cases in the preoperative period and at all postoperative follow-ups. Although the MHQ score was higher in the moderate CTS group at baseline, it was similar between the groups in postoperative follow-ups. These findings indicate that NCS results are largely unassociated with the clinical improvement observed after CTR; thus, postoperative SNAP and CMAP values cannot be used as measures of treatment success in patients with moderate and severe CTS.

A few studies have shown that NCS values tend to normalize after CTR surgery. Studies demonstrate that the recovery of sensory latency may take up to 2 years.[8] In our study, we observed that improvements in both SNAP and CMAP values continued during the first year after surgery in the moderate CTS group, while improvement was limited to the first 3 months after surgery in the severe CTS group, and no changes were observed in the 1-year and 5-year measurements. This finding indicates that although functional recovery appears to be similar at postoperative evaluations for moderate and severe CTS, electrodiagnostic findings do not improve in a similar

manner, especially in patients with severe CTS. Therefore, it is again evident that early diagnosis and prompt surgical treatment are highly beneficial for patients with CTS; however, clinicians should not expect continuous improvement in NCS parameters among patients with severe CTS, whereas those with moderate CTS may demonstrate sustained improvement in NCS parameters, albeit without complete normalization. In other studies, cases were not grouped according to CTS severity, and overall results were reported. Based on the results of our study, we believe that one reason for the varying recovery of NCS reported in the literature may be variation in the CTS severity of subjects included in those studies. Our results indicate that NCS measures cannot be used for the assessment of CTR treatment efficacy, especially in patients with severe CTS, who are shown to have similar clinical improvement when compared to those with moderate CTS, even though their NCS values do not return to levels that are comparable to those of patients with moderate CTS.

Consistent with our study, Lee et al[12] showed that the SNAP values of severe CTS cases were significantly lower than those of patients with moderate CTS. In our study, we found that SNAP values improved only in the moderate CTS group at the first year follow-up, and improvement was limited to the first 3 months in patients with severe CTS. At the 5-year follow-up, neither patients with moderate CTS nor those with severe CTS demonstrated further improvement. Most importantly, our study showed that clinical improvement and electrophysiological improvements were not in parallel, indicating that even when CTR achieves its intended purpose of improving clinical function, it does not result in normalization of NCS parameters. Similarly, previous reports indicate that CMAP values differ between severe CTS cases and moderate CTS cases.[12] We found that CMAP values were significantly higher in the moderate CTS group than in the severe group at baseline and improved in all follow-up measurements. Postoperative improvements have been reported previously, while some studies do not show significant results in this context.[21–24] In our study, we determined that the CMAP value continued to increase until 1 year in only the moderate CTS group, whereas 3-month and 1-year CMAP values were similar to the preoperative values in severe CTS.

We found that the MHQ score increased significantly in both groups after CTR, and that scores were similar at the final follow-up. Chatterjee and Price[9] showed that the MHQ score increased significantly after CTR (from 50.1 to 63.3). Similarly, Wi et al[10] reported that all subsection scores of the MHQ increased significantly at a 6-month follow-up after CTR. In a study examining MHQ score changes in CTS cases following 3 different surgery types, Zhang et al[11] reported that MHQ scores increased significantly after all surgeries.

In our study, the baseline status was worse in the severe CTS group compared to the moderate CTS group, as expected; however, all postoperative evaluations showed improvement at the first follow-up after CTR, regardless of severity. Coggon et al[25] showed that the frequency of numbness and tingling did not improve significantly in CTS cases with normal NCS values before CTR, but these symptoms were found to have significantly improved in CTS cases with abnormal NCS before CTR, suggesting that abnormal median nerve conduction could have predictive capacity for the identification of patients who would benefit from CTR. Aksekili et al[26] reported that regardless of preoperative electrodiagnostic staging, improvement in clinical function with CTR was similar in moderate and severe CTS groups, although NCS improvements were limited in severe CTS cases. It has been suggested that clinical findings predict prognosis in CTS better than electrophysiological staging, and the relationship between NCS findings and clinical symptoms is not clear.[27,28] Other studies show both that an abnormal NCS may be associated with a poor postoperative outcome and that there is no direct relationship between these assessments.[29,30] One study has suggested that the increased sensory latency caused by CTS may become permanent with time, and that CTR may not result in an NCS improvement despite being associated with functional improvement.[31] Our results indicate a similar conclusion.

Due to the retrospective design of the study, various variables that could affect the results could not be examined. Concomitant diseases, such as diabetes; a poor general health status; alcohol consumption; smoking; thoracic outlet syndrome; and postoperative physiotherapy may affect the postoperative prognosis of CTS.[32] Such variables were not examined in our study, and different distributions between groups may have affected the results. It must also be noted that measuring NCS values from different fingers may produce variable results, especially in the presence of CTS.[33,34] In our study, all measurements were standardized, but this may not have been taken into account in all other studies. Finally, since NCS measurements were routinely ordered for the follow-up of almost all patients with CTR (owing to reasons explained previously), we

believe the current group of patients accurately represents the general population with CTS and that the data are not biased to a specific patient subset.

In conclusion, patients with severe CTS had significantly lower preoperative and postoperative NCS values (SNAP, CMAP) compared to those with moderate CTS. After CTR, the NCS values of both the moderate and severe CTS groups increased significantly but did not normalize. Although the MHQ scores were worse in patients with severe CTS at baseline, the MHQ scores demonstrated significant improvement within the first 3 months in both groups, and the postoperative scores were similar in the moderate and severe CTS groups. Our findings show that clinical improvement after CTR may not be mirrored by NCS improvement in patients with severe CTS, suggesting that severe CTS may cause permanent damage to nerve function that is not reflected in clinical symptoms.

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JOURNAL CME QUESTIONS

Long-Term Outcome of Electrodiagnostic Values and Symptom Improvement After Carpal Tunnel Release: A Retrospective Cohort Study

1. When considering current clinical guidelines, what is necessary to diagnose carpal tunnel syndrome (CTS)?

a. Abnormal sensory nerve action potentials on electrodiagnostic testing
b. Clinical (history and physical examination) findings are sufficient.
c. Ultrasound documented enlargement of the median nerve
d. MRI evidence of a thickened transverse carpal ligament
e. Combined clinical and electrodiagstic abnormalities

2. When considering carpal tunnel release surgery for patients with moderate and severe CTS, what can be expected in the first postoperative year?

a. On average, patients in each group will report improved symptoms
b. Patients with severe CTS will not improve on the Michigan Hand Questionnaire.
c. Patients with moderate CTS improve less than those with severe CTS.
d. Niether of these patient groups are benefited by carpal tunnel release.
e. Carpal tunnel release produces unpredictable results for each group.

3. According to this study, what is the most likely electrodiagnostic outcome after carpal tunnel release in patients with moderate and severe CTS?

a. Electrodiagnostic parameters will be normal by 1 year.
b. Electrodiagnostic parameters will be normal by 5 years.
c. Electrodiagnostic parameters will improve but not reach normal.
d. Electrodiagnostic parameters will remain unchanged by 1 year.
e. Only sensory electrodiagnostic parameters will be normal by 1 year.

4. When assessed with the Michigan Hand Questionnaire, which best describes the pattern of improvement after carpal tunnel release for moderate CTS?

a. Slow improvement in the first 3 months and then substantial change from 3 months to 1 year
b. Limited improvement in the first year but then a gradual improvement by 5 years
c. Clinical change that lags behind electrodiagnostic change
d. Substantial improvement by 3 months with maintenance through 5 years
e. The Michigan Hand Questionnaire does not capture clinical change after carpal tunnel release in this population.

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