Functional Tests to Quantify Recovery Following Carpal Tunnel Release

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Background: An objective test is needed to evaluate outcome following carpal tunnel release. A method to evaluate sensory and motor function related to carpal tunnel syndrome was investigated.

Methods: Thirty-six candidates for carpal tunnel surgical procedures underwent a physical examination and nerve-conduction studies and completed a survey regarding symptoms. A battery of psychomotor and sensory tests was administered bilaterally immediately before surgery and again six weeks after surgery. The outcome variables included dynamic sensory gap-detection thresholds and rapid pinch-and-release rates.

Results: The average gap-detection threshold for the index finger in the surgical-treatment group demonstrated a 43% improvement, decreasing from 0.14 mm preoperatively to 0.08 mm at six weeks postoperatively ($p < 0.01$). The average gap-detection threshold for the index finger in the non-surgical-treatment group demonstrated no significant improvement, decreasing from 0.10 mm preoperatively to 0.08 mm postoperatively ($p = 0.10$). With the upper force level set at 10% of the maximum voluntary contraction, the average pinch rate in the surgical-treatment group demonstrated a 20% improvement, increasing from 6.65 pinches per second preoperatively to 7.96 pinches per second postoperatively ($p < 0.001$). The average pinch rate in the non-surgical-treatment group demonstrated a 7% improvement, increasing from 6.89 pinches per second preoperatively to 7.37 pinches per second at six weeks postoperatively ($p < 0.05$).

Conclusions: Measurable and significantly greater improvement was observed when the surgical-treatment group was compared with the non-surgical-treatment group in terms of these two sensory and psychomotor functional testing outcomes at six weeks.

Level of Evidence: Therapeutic study, Level II-1 (prospective cohort study). See Instructions to Authors for a complete description of levels of evidence.

The diagnosis of carpal tunnel syndrome frequently results in surgery and prolonged work disability[1,2]. In 1999, among major disabling workplace injuries and illnesses, carpal tunnel syndrome resulted in the highest median number of days away from work (twenty-seven) in the United States. Nancollas et al. found that six of twenty-two individuals who reported work-related carpal tunnel syndrome changed from heavy to lighter work following surgery[3]. Katz et al.[4] found that extended absence from work correlated with a worsening functional status of the hand as measured with use of a self-administered questionnaire[5]. An objective measure to quantify functional changes associated with carpal tunnel syndrome could quantify recovery and functional improvement and could permit quantitative evaluation of the capacity to return to work. The effect of work modifications on carpal tunnel syndrome could also be monitored.

A computer-controlled battery of tests for measuring subtle sensory and psychomotor deficits associated with carpal tunnel syndrome was developed[6-8]. The performance measures in these tests were based on functional activities performed in occupational tasks, such as tactually inspecting a surface for a defect or repeatedly pressing a key. The sensory test involved detecting a computer-controlled gap on a highly polished surface with use of the index finger pad, which is innervated by the median nerve[6]. The psychomotor task was a rapid pinch-and-release task involving specific median nerve-innervated muscles of the hand, including the index finger and thumb, that utilize proprioceptive and force feedback from afferent median nerve branches distal to the carpal tunnel[7,9]. The outcome of these tests can provide a quantitative assessment of function in manual tasks. Previous studies have demonstrated that this battery of sensory and psychomotor tests can differentiate patients with well-defined carpal tunnel syndrome from confirmed normal subjects[7,10] and also can differentiate

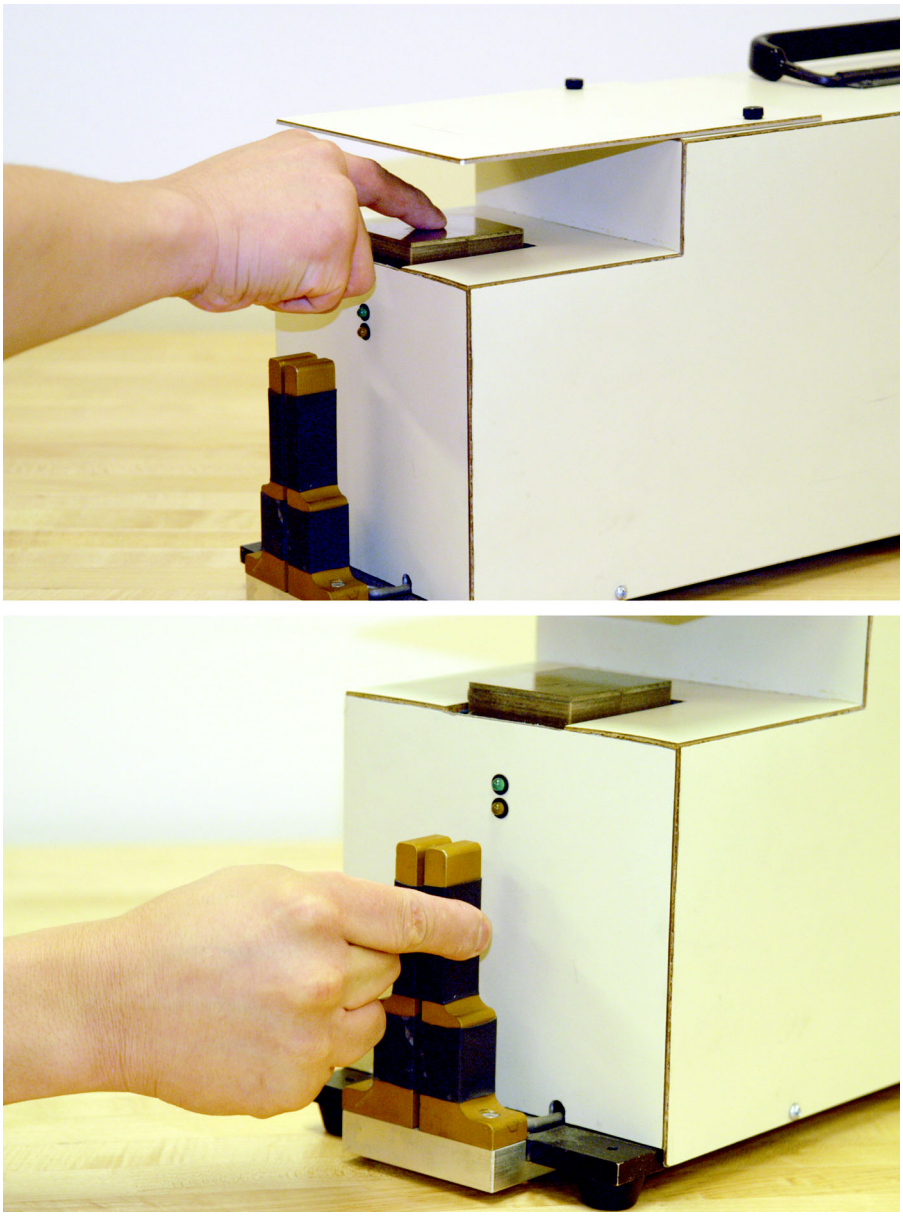

Fig. 1

The sensory and psychomotor tests are performed with use of one portable enclosure. The upper photograph depicts the sensory test. The patient actively probes a highly polished surface that is split, and the gap size is controlled with an electronic micropositioner. The entire platform is counterbalanced in order to control the contact force. The lower photograph shows the rapid pinch-and-release test. Two strain-gauge-instrumented bars are pinched, and the squeeze force is measured. The lower light-emitting diode illuminates when a pinch force less than the lower force level is achieved, and the upper light-emiting diode illuminates when a pinch force of greater than the upper force is achieved.

workers with carpal tunnel syndrome from controls in an industrial working population[11].

The purpose of the present study was to evaluate the results of these psychomotor and sensory tests in patients undergoing unilateral carpal tunnel release in order to quantify functional aspects of rehabilitation aimed at return to work. The contralateral hand was used as the control. Specifically, we hypothesized that the hands that received surgical treatment would show greater improvement in sensory and psychomotor performance than those that did not receive surgical treatment.

Materials and Methods

Patients

Participants were recruited sequentially from the office of two hand surgeons (S.V.Z. and S.L.O.) who assisted in subject recruitment from a clinic in the Midwestern United States. All subjects were scheduled to undergo unilateral carpal tunnel release, and all had findings on examination and on nerve-conduction studies that were consistent with carpal tunnel syndrome. A distal median sensory latency of >2.5 ms was considered to be abnormal. Motor and sensory latencies in the distributions of the median and ulnar nerves were compared. Electromyographic data were used to correlate the findings regarding nerve-conduction velocities. Patients with proximal abnormalities were excluded.

Study participants were scheduled to undergo carpal tunnel release in only one hand during the course of the study. Each hand was used as its own control for the evaluation of changes that occurred longitudinally following surgery. The contralateral hand was used as a control to compare the effects of elapsed time without surgical intervention. Some subjects reported bilateral symptoms of carpal tunnel syndrome but underwent surgical treatment of only one hand. Although some subjects may have had other maladies in addition to carpal tunnel syndrome, all of the patients in the study group claimed that the carpal tunnel symptoms predominated.

Volunteer participants provided informed consent and were compensated $15 for their service at each session. Subjects were not compensated on the basis of their performance. The protocol was reviewed and approved by both university and hospital institutional review boards. Subjects were informed that the goal of the study was to evaluate their performance and the nature of the tasks that they were performing, but they were not advised with regard to how performance was to be quantified or with regard to the expected outcomes of the study. Subjects were not provided feedback on their performance.

The majority of subjects were tested immediately before or after their scheduled physician appointments. Subjects were tested one to two days before surgery and at the time of their scheduled six-week return visit, which took place six to eight weeks postoperatively. A total of seventy-two hands were tested in thirty-six subjects (ten men and twenty-six women). The mean age of the subjects was 49.0 ± 13.5 years (range, twenty-six to eighty-five years). Five subjects had filed Workers' Compensation claims. Thirty subjects were right-hand dominant, and six were left-hand dominant. The surgical procedure was performed on the dominant hand in twenty-three patients (64%). Fifteen patients (42%) underwent endoscopic carpal tunnel release with use of the two-portal Chow technique[12]. The remaining twenty-one patients underwent open carpal tunnel release through a small incision distal to the wrist crease.

Finger motion was encouraged immediately after surgery. Sutures were removed seven to ten days after surgery. Strengthening exercises with use of putty were started at three weeks after surgery. Patients were encouraged to exercise both hands.

Data Collection

Preoperatively and postoperatively, all subjects completed a survey that included questions about symptoms in the upper extremities, occupation, and medical history (with specific questions pertaining to diabetes, arthritis, thyroid disease, cervical disc rupture, and renal failure). Specific information also was obtained with regard to the frequency, duration, and magnitude of symptoms (such as numbness, tingling, or pain) in the hand. Each subject also completed a self-reported hand diagram. The intensity of symptoms was measured by asking

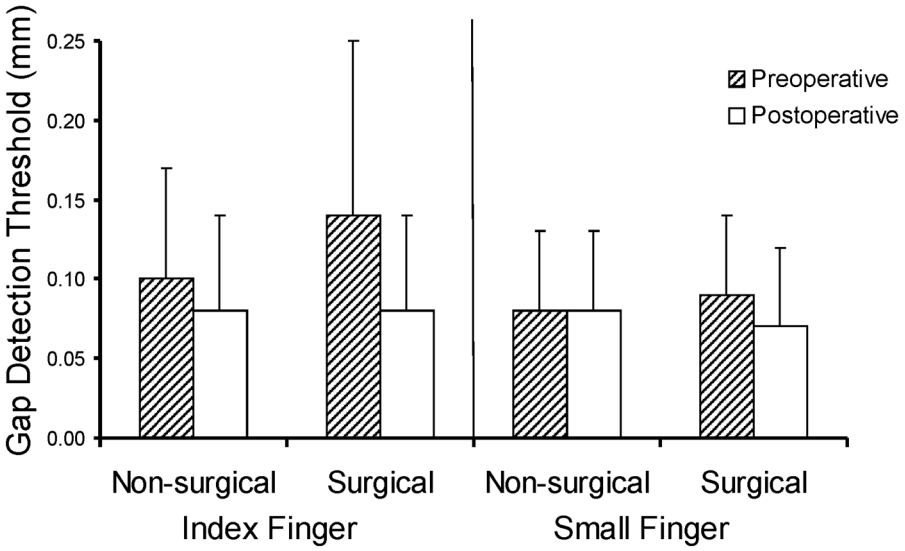

Fig. 2

Illustration showing the average preoperative and postoperative gap-detection thresholds for the index and small fingers in the surgical-treatment and non-surgical-treatment groups. The I-bars indicate the standard deviation.

subjects to rate the symptoms on a scale of 1 to 5, with 1 indicating "no pain at all" and 5 indicating "worst pain ever." The frequency of symptoms was measured by asking subjects to rate the symptoms on a scale of 1 to 6, with 1 indicating that the symptoms occurred "almost never (every six months)" and 6 indicating that they occurred "almost always (daily)."

The psychomotor and sensory testing apparatus is shown in Figure 1. The automated aesthesiometer, fully described in a previous report by one of us (R.G.R.) and colleagues[6], measured tactile sensitivity as the finger freely probed a tiny gap on an otherwise smooth surface[6,8]. Gap-detection sensory thresholds were used to estimate the minimum separation needed to detect the gap. Both the index and the small finger were tested in each hand. This allowed for comparisons between areas innervated by the median and ulnar nerves. Subjects probed the gap for five seconds. Gap size was changed with use of a micropositioner and digital encoder that were controlled by a microcomputer. Contact force was controlled at 50 g. A white-noise auditory signal masked the noise of the motor so that the subject would not be aware if movement of the plates had occurred. As the gap size was changed, the subject responded verbally if he or she could detect a gap with use of a converging-staircase method-of-limits psychophysical paradigm in which the subject is presented with a titrating series of stimuli that ascend and descend in magnitude by progressively smaller increments every time the gap is detected by the subject[6]. The threshold is the average of the upper and lower gap sizes. The software was programmed to randomly introduce catch trials to test whether the subject was cooperating.

The rapid pinch-and-release test measured psychomotor performance in terms of speed and force control[7]. An aluminum strain-gauge dynamometer was pinched with use of the index finger and the thumb[13]. The objective of the pinch-and-release test was to pinch the dynamometer with a force greater than an upper level (F_{upper}) and then to release at a force less than a lower level (F_{lower}) as quickly as possible. A pinch-strength test was first conducted to ascertain the maximum voluntary contraction level. The subjects then performed the test with use of alternate hands and completed two tests for each hand (with F_{upper} being set at 10% and 20% of the maximum voluntary contraction); F_{lower} was fixed at 4% of the maximum voluntary contraction for all tests. One-half of the subjects were tested with F_{upper} set at 20% of the maximum voluntary contraction first, and one-half were tested with F_{upper} set at 10% of the maximum voluntary contraction first.

Statistical Analysis

The data were analyzed for differences between and within the surgical-treatment and non-surgical-treatment groups with regard to gap-detection thresholds and pinch rates. A full factorial analysis of variance[14] with repeated measures was used to evaluate the significance of the differences in functional performance variables, gap-detection thresholds, and pinch rates when the hands in the surgical-treatment group were compared with those in the non-surgical-treatment group as well as when the preoperative values were compared with the postoperative values. The level of significance was set at $p < 0.05$.

Results

The preoperative and postoperative gap-detection thresholds for the index finger are shown in Figure 2. Preoperatively, the average gap-detection threshold for the index finger was 40% larger in the surgical-treatment group than in the non-surgical-treatment group (0.14 mm compared with 0.10 mm; $p < 0.05$). In the surgical-treatment group, the average

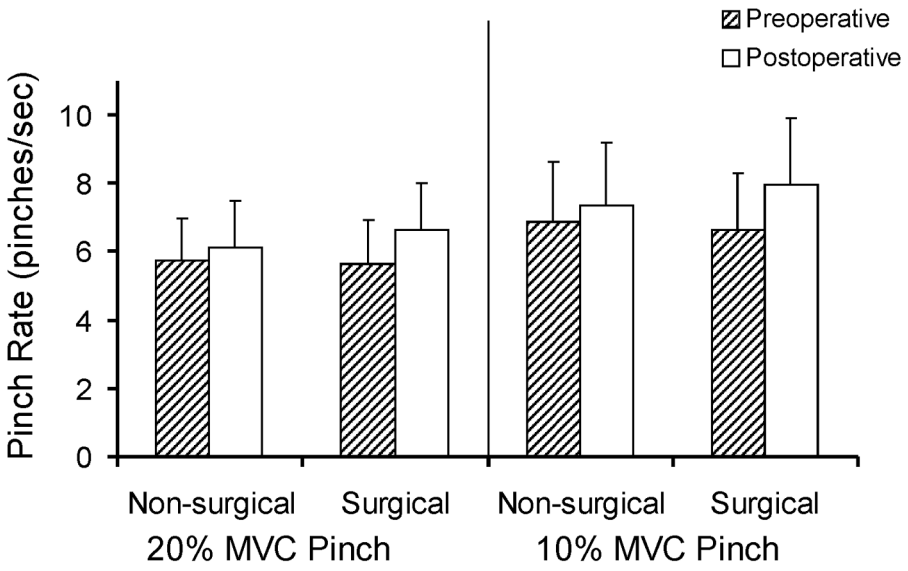

Fig. 3

Illustration showing the average preoperative and postoperative pinch rates, with the upper force level set at 20% and 10% of the maximum voluntary contraction, in the surgical-treatment and non-surgical-treatment groups. The I-bars indicate the standard deviation.

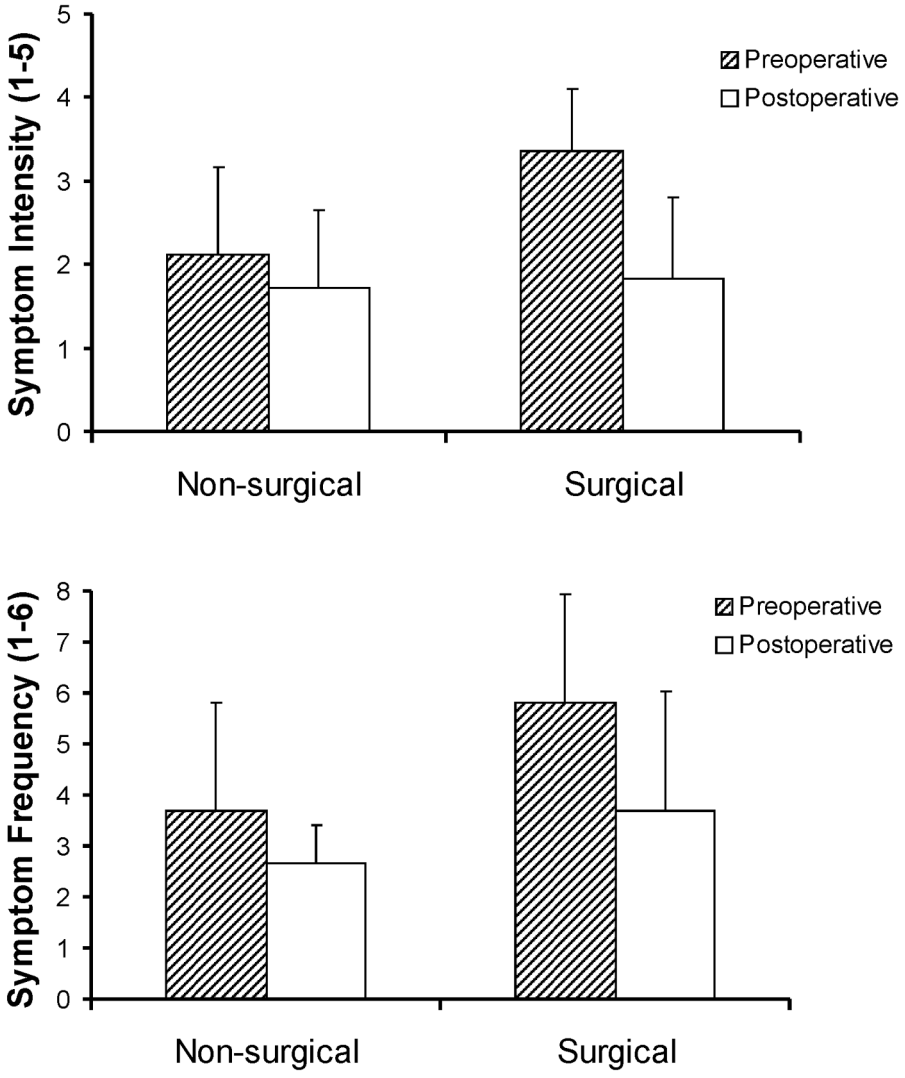

Fig. 4

Illustration showing the average preoperative and postoperative intensity and frequency of symptoms in the surgical-treatment and non-surgical-treatment groups. The I-bars indicate the standard deviation.

gap-detection threshold for the index finger improved by 43%, from 0.14 mm preoperatively to 0.08 mm postoperatively ($p < 0.01$). In the non-surgical-treatment group, the average gap-detection threshold for the index finger improved by only 20%, from 0.10 mm to 0.08 mm ($p = 0.10$). Postoperatively, no significant difference was observed between the surgical-treatment group and the non-surgical-treatment group with regard to the average gap-detection threshold (0.08 for both groups; $p > 0.05$).

The preoperative and postoperative gap-detection thresholds for the small finger also are shown in Figure 2. In the surgical-treatment group, the average gap-detection threshold for the small finger improved by 22%, from 0.09 mm preoperatively to 0.07 mm postoperatively ($p < 0.01$). In the non-surgical-treatment group, the average gap-detection threshold for the small finger did not change, measuring 0.08 at both time-points ($p = 0.09$).

The preoperative and postoperative pinch rates with F_{upper} set at 20% and 10% of the maximum voluntary contraction are presented in Figure 3. With F_{upper} set at 20% of the maximum voluntary contraction, the average pinch rate in the surgical-treatment group improved by 18%, from 5.62 pinches per second preoperatively to 6.63 pinches per second at six weeks postoperatively ($p < 0.001$). With F_{upper} set at 10% of the maximum voluntary contraction, the average pinch rate in the surgical-treatment group also improved by 20%, from 6.65 pinches per second preoperatively to 7.96 pinches per second postoperatively ($p < 0.001$). With F_{upper} set at 20% of the maximum voluntary contraction, the average pinch rate in the non-surgical-treatment group improved by 7%, from 5.76

pinches per second preoperatively to 6.14 pinches per second postoperatively ($p < 0.05$). With F_{upper} set at 10% of the maximum voluntary contraction, the average pinch rate in the non-surgical-treatment group also improved by 7%, from 6.89 pinches per second preoperatively to 7.37 pinches per second postoperatively ($p < 0.05$). No significant differences in average pinch rates were observed between the surgical-treatment and non-surgical-treatment groups before or after surgery ($p > 0.05$) (Fig. 3).

No significant changes in maximum voluntary contraction were observed in either the surgical-treatment group or the non-surgical-treatment group ($p = 0.20$). Preoperatively, the average maximum voluntary contraction (and standard deviation) was 42.14 ± 14.6 N in the surgical-treatment group and 45.06 ± 16.3 N in the non-surgical-treatment group. Postoperatively, the average maximum voluntary contraction in the surgical-treatment group decreased by 8% (to 38.68 ± 15.7 N) whereas that in the non-surgical-treatment group increased by 2% (to 46.09 ± 15.6 N).

The intensity and frequency of symptoms decreased following surgery. The average symptom-intensity score in the surgical-treatment group improved significantly, from 3.35 before surgery to 1.83 after surgery ($p < 0.01$). The average symptom-intensity score in the non-surgical-treatment group also improved significantly, from 2.11 before surgery to 1.71 after surgery ($p < 0.01$). The average symptom-frequency score in the surgical-treatment group improved significantly, from 5.81 before surgery to 3.68 after surgery ($p < 0.01$) (Fig. 4). The average symptom-frequency score in the non-surgical-treatment group also improved significantly, from 3.68 before surgery to 2.65 after surgery ($p < 0.05$) (Fig. 4). No significant differences in the intensity or frequency of symptoms were observed following surgery between the surgical-treatment group and the non-surgical-treatment group ($p > 0.05$). The correlations between the intensity of symptoms and the gap-detection threshold for the index finger ($r = 0.371$, $p < 0.001$), the pinch rate with F_{upper} set at 20% of the maximum voluntary contraction ($r = -0.314$, $p < 0.001$), and the pinch rate with F_{upper} set at 10% of the maximum voluntary contraction ($r = -0.264$, $p < 0.01$) were significant but small. Similar correlations were observed between the frequency of symptoms and the gap-detection threshold for the index finger ($r = 0.224$, $p < 0.01$), the pinch rate with F_{upper} set at 20% of the maximum voluntary contraction ($r = -0.322$, $p < 0.001$), and the pinch rate with F_{upper} set at 10% of the maximum voluntary contraction ($r = -0.262$, $p < 0.01$).

Discussion

Improvement in the results of both sensory and psychomotor functional tests was observed six weeks following carpal tunnel release. The magnitude of change in functional performance on the psychomotor and sensory tests ranged from 18% to 43% in the surgical-treatment group and from 7% to 20% in the non-surgical-treatment group. It is interesting to note that many of the subjects either were on restricted duty or were off work following surgery (average time to return to work, 3.5 weeks). The sustained rest and reduction in physical activities following surgery may have contributed to the improvement in the sensory function of the index and small fingers in the non-surgical-treatment group.

Although no significant differences between the surgical-treatment and non-surgical-treatment groups were observed before or after surgery, this effect may be due to the fact that many of the subjects reported having symptoms of carpal tunnel syndrome bilaterally. Subjects who were either on restricted duty or off work following surgery may have had an overall reduction in stress for both hands.

The level of activity decreased in all patients after surgery because the patients were kept out of work for two to four weeks. We believe that this period of rest benefitted the hands in both the surgical-treatment and non-surgical-treatment groups. The improvements in performance in the non-surgical-treatment group were not as great as those in the surgical-treatment group. The benefit was only temporary in most patients who later went on to have surgery on the contralateral side. Within one year, eighteen patients (50%) underwent subsequent surgery on the contralateral hand. The differences and improvements that were observed in the non-surgical-treatment group indicate that the test battery may be sensitive to subtle recovery following conservative treatment involving rest. Even greater improvement was observed following surgery. Future studies should follow patients for a longer period of time after surgery, particularly in cases of bilateral carpal tunnel syndrome.

Another possible explanation for the improved performance that was observed in both the surgical-treatment and non-surgical-treatment groups is that the improvements that were noted at the time of the retest may have been due to learning or training effects rather than to improved nerve function. Jeng et al.[7] found no significant changes in performance when subjects repeated the rapid pinch-and-release test one week after the initial test. Similar results were observed for the tactility test[8]. Therefore, a training effect was not anticipated in the current study.

With regard to the sensory improvements that were observed in the small finger, previous investigators have observed that distal ulnar nerve compression can be improved with carpal tunnel release, which may improve function in the ulnar distribution. Silver et al.[15] observed that patients with carpal tunnel syndrome had sensory abnormalities of both the median and the ulnar nerve on either two-point discrimination testing, Semmes-Weinstein monofilament testing, or both. Most patients had improvement in the function of both the median and the ulnar nerve after carpal tunnel release alone. The current study affirms that observation.

The current study did not include a control group of healthy subjects; however, in previous studies[7,8], healthy volunteers have been extensively evaluated with both of these tests. Small effects of hand dominance (8%) and age (6%) were previously observed on the pinch test. These effects are much smaller than the improvements that were observed after surgery in the current study.

A history, physical examination, and nerve-conduction studies are all part of the standard evaluation for the diagnosis of carpal tunnel syndrome[16-18]. Nerve-conduction studies are rarely repeated following surgery because of the perceived noxious nature of the test and its associated costs. The psychomotor and sensory tests described in the present study may provide an alternative, noninvasive measure to quantify recovery.

The results of the present study indicate that the battery of psychomotor and sensory tests may be useful for monitoring functional improvement following surgical, medical, and ergonomic interventions. This information is useful because worsening upper-extremity functional status has been reported to be a predictor of absence from work[4]. The observed changes were measured over a relatively short time-interval (six weeks) following surgery. Future studies should also measure functional changes for a longer period (such as six months) following surgery.

Although group differences were observed, the functional importance of performance in these tests on an individual basis is not yet known. It is notable that although significant correlations were observed between the psychomotor and sensory function measures used in this study and the intensity and frequency of symptoms, these correlations were small. This finding suggests that functional performance and symptoms are not directly related, indicating that objective functional measures, such as the psychomotor and sensory measures used in this study, provide additional information regarding rehabilitation from surgery.

The ability of patients to return to work, and variables that supported or prevented patients from returning to work, were not evaluated in this study. These topics should be investigated in future studies. It is possible that a quantitative evaluation of functional recovery following surgery for carpal tunnel syndrome may be beneficial for assessing rehabilitation and the capacity to work.

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