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Workplace Surveillance for Carpal Tunnel Syndrome: A Comparison of Methods

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A variety of screening procedures for carpal tunnel syndrome (CTS) were applied among workers in a manufacturing plant, and results were compared. The test procedures included a symptom survey, physical examination, limited electrodiagnostic testing at the wrists, quantitative vibratory threshold testing, 2-point discrimination, palmar pinch grip, and hand grip strength testing. When electrodiagnostic testing alone was used as "gold standard," the sensitivity and positive predictive value (PPV) of physical examination findings and quantitative test procedures were no better than, and usually worse than, the results on the symptom survey alone. Variation of the constellation of symptoms (i.e., numbness, tingling, pain or burning) and the anatomic distribution of reported symptoms (i.e., fingers, hand, wrist, or forearm) for inclusion in the screening symptom definition of CTS yielded modest changes in the sensitivity and PPV of the symptom survey. However, addition of the requirement for nocturnal symptoms as part of the screening symptom definition for CTS resulted in substantially higher PPV with only slight reduction in sensitivity. These results suggest that, in the absence of electrodiagnostic testing, the simplest test, and the procedure with the highest sensitivity and PPV for CTS is a symptom survey alone. Quantitative test procedures (vibrometry, pinch grip strength, hand grip strength) and physical examination for findings consistent with CTS (e.g., Phalen's test, Tinel's test, thenar muscle wasting, 2-point discrimination) appear to contribute little, if any, additional information when screening subjects in the work setting.

KEY WORDS: carpal tunnel syndrome; occupational medicine; screening; cumulative trauma disorders.

INTRODUCTION

There are a number of possible reasons for establishing a workplace-based program for injury or disease surveillance. They include: to monitor the incidence of disease, to identify causal determinants of disease, to identify jobs with high

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rates of disorders so that interventions can be targeted, and to determine if a control program has been effective in reducing incidence, severity, or cost of disease (1,2).

The challenges of implementing a workplace-based surveillance program for carpal tunnel syndrome (CTS) are magnified when compared to other occupational diseases. There is no "gold standard" for the medical diagnosis of CTS, and there are no universally accepted criteria for the clinical or laboratory diagnosis of CTS (3,4). It thus can be difficult to choose standardized components of the medical diagnostic evaluation to apply in a potential screening process for CTS: symptoms, physical examination findings, electrodiagnostic criteria, or other less traditional clinical features or test criteria (e.g., grip testing) which have been associated with CTS.

Attempts to create a simplified "surveillance case definition" for CTS have been frustrated by apparent low sensitivity, specificity or predictive values (5,6). Some clinicians, and certainly some patients, consider electrodiagnostic testing, and even nerve conduction studies alone, to be unpleasant, and so many people might not participate in workplace surveillance activities which included this modality, particularly if such testing were repeated on a regular basis.

We have completed a cross-sectional workplace-based medical survey which was designed, in part, to assess the utility of different techniques for surveillance of carpal tunnel syndrome in the workplace. A number of screening procedures were employed, thus permitting a direct comparison of methods.

METHODS

Clinical procedures employed in this study included a questionnaire survey, limited physical examination of the upper extremities, limited electrodiagnostic testing at both wrists, and a number of quantitative performance tests (vibrometry, 2-point discrimination, palmar pinch strength, and hand grip strength). Examiners who assisted with collection of data were blinded to data collected by other members of the study team. All study participants provided written informed consent which had been approved by the University of Michigan School of Public Health Human Subjects Review Committee. All aspects of the medical screening survey were performed on company time during normal work hours.

The self-administered questionnaire focused on demographic information, prior medical conditions, occupational history, current health status, and symptoms which may be related to upper extremity cumulative trauma disorders. For the purposes of this survey, subjects were instructed to report a symptom if it had been present on at least three separate episodes, or one episode had lasted more than 1 week, in the 12 months preceding the survey. The survey queried subjects about nine symptoms (burning, stiffness, pain, cramping, tightness, aching, soreness, tingling, and numbness) in each of 15 body locations (neck, right or left shoulder, right or left upper arm, right or left elbow, right or left forearm, right or left wrist, right or left hand, and right or left fingers). The questionnaire did not ask subjects to distinguish symptoms in the distribution of the median nerve from symptoms elsewhere in the fingers, hands, wrists, or forearms.

Because of the lack of a "gold standard" definition of carpal tunnel syndrome, eight different constellations of symptoms potentially consistent with CTS were analyzed to assess the utility of each for surveillance of CTS in the workplace setting. The symptom constellations are: Definition 1 = numbness, tingling or pain in the fingers or hands; Definition 2 = numbness, tingling, pain or burning in the fingers or hands; Definition 3 = numbness, tingling, pain or burning in the fingers, hands or wrists; Definition 4 = numbness, tingling, pain or burning in the fingers, hands, wrists or forearms; Definition 5 = numbness, tingling or pain in the fingers or hands, *and* awakened at night by these symptoms ("nocturnal symptoms"); Definition 6 = numbness, tingling, pain or burning in the fingers or hands, *and* nocturnal symptoms; Definition 7 = numbness, tingling, pain or burning in the fingers, hands or wrists *and* nocturnal symptoms; and, Definition 8 = numbness, tingling, pain or burning in the fingers, hands, wrists or forearms *and* nocturnal symptoms. Note that definitions 1, 2, 3, and 4 are ordered sets, as are 5, 6, 7, and 8 (i.e., definition 4 includes definition 3, which includes definition 2, which includes definition 1). Also, definition 5 is a subset of definition 1; the same relationship holds for the pairs 2 and 6, 3, and 7, and 4 and 8.

The screening physical examination was adapted from *Evaluation of Upper Extremity and Low Back Cumulative Trauma Disorders: A Screening Manual*, by Silverstein and Fine (7). The physical examination included inspection, palpation, active and passive range of motion of joints, elicitation of reflexes (biceps, triceps, and brachioradialis), Tinel's test, Phalen's test, Finkelstein's test, and 2-point discrimination. Two-point discrimination was performed using a 3-point anesthesiometer, and was considered normal if a subject could correctly perceive 2 points which were 4 millimeters apart at the tip of the index finger.

Quantitative vibration thresholds were determined in the 2nd finger of each hand with a Vibratron II (Physitemp, Clifton, New Jersey) using a standard psychophysical technique and published normal values based on age and height (8). A vibratory threshold was considered abnormal if it was more than 1.65 standard deviations above the mean for persons of that age and height. The Vibratron II was calibrated with an accelerometer and oscilloscope immediately prior to the field study.

Hand grip strength was measured using a Jamar Hydraulic Hand Dynamometer (J.A. Preston Corporation, Jackson, Michigan), and palmar pinch grip was measured with a B&L Pinch Gauge (B&L Engineering, Santa Fe Springs, California). Both strength measurements were determined in accordance with published procedures, and were compared to normal values corrected for age and gender (9). Hand grip and palmar pinch grip results were considered abnormal if they were more than 1.65 standard deviations below the mean for persons of the same age and sex.

Bilateral limited electrophysiologic testing of each subject consisted of assessing sensory function of the median and ulnar nerves at the wrists using surface electrodes and fixed distances. Measured parameters included sensory amplitude, peak latency and takeoff latency in each nerve tested (10). Needle electromyography examinations were not performed. The electrophysiologic criterion for diagnosis of median mononeuropathy at the wrist was a difference of at least 0.5 milliseconds

between median and ulnar sensory peak latencies in the same wrist. Almost all hands were successfully tested (259/260); one hand of one participating subject was not tested because he was wearing a cast which covered the wrist at the time of the survey. Mid-palm temperatures were monitored in each hand during all electrodiagnostic examinations. If hand temperatures were below 32°C, the hands were warmed to increase the temperature; however temperatures still varied from 30°C to 35°C, with means of 32.7°C and 32.9°C in the left and right upper extremities, respectively. Although it has been suggested that temperature correction can be applied to an absolute latency (10), there have been no studies which have investigated the impact of temperature on sensory latency differences which were calculated in the present study. Therefore, no correction for temperature was applied to raw latency results in this study.

Employment-related data (date of hire and number of hours worked per week) were obtained from personnel records made available by management. Analyses were performed using SYSTAT version 5.01. Most analyses involved descriptive statistics or arithmetic calculations. Some *t*-tests were performed, and were considered statistically significant if $p < 0.05$.

RESULTS

The plant had been in operation for approximately 2.5 years, and is a supplier to one of the "Big 3" auto makers. There is no union representation at the plant. The primary manufacturing process performed at the plant is assembly of a combined window sash and door lock mechanism which is inserted into automobile door frames at the time of final assembly of automobiles. One hundred fifty-two persons were employed in the plant at the time of the medical survey, including hourly assembly workers, maintenance workers, front office workers, management personnel, and workers who were out on medical disability leave. Work at the plant normally was scheduled for two shifts (day and evening) on 5 days per week. Two almost identical assembly lines operated during each shift. During normal production on each assembly line the mean cycle time was about 12 seconds, or approximately 2400 cycles per worker per 8 hour shift. Real-time observations and analyses of videotapes revealed few differences in hand movements among job stations on each line.

All workers in the plant were invited to participate in the medical survey. Demographic characteristics of workers in the plant are listed in Table I. One hundred thirty workers participated in the medical screening (85.5%). Eight of 22 nonparticipants were absent on the day of the survey. A majority of workers in the plant was female (57.2%), but the participation rates among men and women were similar (87.7% and 83.9%, respectively). Study participants were slightly older than those who chose to not participate, although this difference was not statistically significant. The mean tenure at the plant was slightly less than 13.5 months among all workers (not shown). The mean tenure of participants was almost identical to the mean tenure of nonparticipants. The mean number of hours worked in the week prior to participating in the survey, and the mean number of hours worked

Table I. Demographic and Employment Characteristics of Study Subjects and Non-Participants at the Plant

	Participants (N = 130)	Non-participants (N = 22)	p-values[a]
Males n, (%)	57 (43.8)	8 (36.4)	—
Females n, (%)	73 (56.2)	14 (63.6)	—
Age (mean years, SD)	34.1 (11.0)	29.5 (9.6)	.069
Tenure (mean months, SD)	13.3 (8.4)	13.4 (1.3)	.970
Mean hours worked:	—	—	—
Previous week (mean, SD)	40.0 (13.3)	23.6 (17.3)	.001
Previous 4 months (mean, SD)	34.2 (7.9)	29.4 (8.9)	.016

[a]All comparisons are based on t-tests; SD = standard deviation.

per week in the 4 months prior to the survey, were greater among study participants. The differences in hours worked are, in part, related to medical disability leave. Nonparticipants included a greater proportion of workers who had experienced lost work time due to medical disability leave prior to the medical screening (4/22 vs. 3/130).

Descriptive results of the medical screening as they pertain to CTS are summarized in Table II. A total of 31 of the 130 subjects (23.8%) fulfilled the electrodiagnostic criterion for median mononeuropathy in at least one wrist (right only = 8; left only = 5; bilateral = 18). Thirteen subjects (10%) had a positive Phalen's sign in at least one hand, and a similar number had a positive Tinel's sign. Abnormal 2-point discrimination was found in one or both hands of 17 subjects (13.1%). Muscle wasting of the thenar eminence was not noted in any subject. Overall, 35 subjects

Table II. Results of Medical Screening

Medical screening test	Subjects (N)	Percent[a]
Median mononeuropathy in wrist(s)[b]	31	23.8
Symptoms consistent with CTS[c]	—	—
Definition 1: numbness, tingling or pain in hands or fingers only	63	48.5
Definition 2: definition 1, or burning in hands or fingers only	64	49.2
Definition 3: definition 2, or those symptoms in the wrists	71	54.6
Definition 4: definition 3, or those symptoms in the forearm	76	58.5
Definition 5: definition 1 *and* nocturnal symptoms	41	31.5
Definition 6: definition 2 *and* nocturnal symptoms	41	31.5
Definition 7: definition 3 *and* nocturnal symptoms	43	33.1
Definition 8: definition 4 *and* nocturnal symptoms	43	33.1
Physical Exam Findings	—	—
Positive Phalen's sign	13	10.0
Positive Tinel's sign	13	10.0
Abnormal two-point discrimination	17	13.1
Any of the above	35	26.9
Abnormal vibratory threshold(s)	10	7.7
Abnormal palmar pinch grip strength	10	7.7
Abnormal hand grip strength	13	10.0

[a]Calculated as percentage of participating subjects (n = 130).
[b]See text for explanation of median mononeuropathy.
[c]See text for explanation of surveillance symptom definitions.

(26.9%) had at least one positive finding possibly related to CTS on the physical examination. Quantitative vibratory threshold testing had a low yield: only 10 subjects (7.7%) had abnormal vibratory thresholds. Pinch and hand grip strength testing identified 10 (7.7%) and 13 (10%) subjects, respectively, with abnormal findings in one or both hands.

The number of subjects who fulfilled each of the 8 surveillance symptom definitions for CTS are also listed in Table II. Not surprisingly, the number of subjects who fulfilled definition 1 is less than definition 2 (which is less than definition 3, which is less than definition 4). A similar order relationship holds for definitions 5, 6, 7, and 8. The addition of the requirement that subjects must report nocturnal symptoms resulted in reductions of 35% to 43% in the number of cases which fulfilled each surveillance symptom definition (compare definitions 1 and 5, 2 and 6, 3 and 7, and 4 and 8).

For comparison purposes, different "case" definitions of CTS were used in different analyses. A subject was identified as a "case" if, in at least one extremity, she/he fulfilled one of the symptom constellations *and* had electrodiagnostic evidence of a median mononeuropathy (MM). Alternatively, a subject was identified as a "case" if, in at least one extremity, she/he fulfilled one of the symptom constellations *and* had positive findings on physical examination (2-point discrimination, Phalen's test, or Tinel's test).

Table III lists the number of subjects who fulfilled each of the CTS surveillance case definitions. Overall, the number of cases of CTS ranged from 14 to 22% of the cohort, depending on which CTS surveillance definition was applied. In each instance, "expansion" of the symptom definition resulted in a larger number of subjects who fulfilled the CTS case surveillance definition. Among CTS surveillance

Table III. "Cases" of Carpal Tunnel Syndrome Using Different Definitions

Case definitions of carpal tunnel syndrome[a]	Subjects (*N*)	Percent[b]
Carpal tunnel syndrome: Symptoms and electrodiagnostic results	—	—
Symptoms definition 1 and median mononeuropathy	20	15.4
Symptoms definition 2 and median mononeuropathy	20	15.4
Symptoms definition 3 and median mononeuropathy	23	17.7
Symptoms definition 4 and median mononeuropathy	24	18.5
Symptoms definition 5 and median mononeuropathy	18	13.8
Symptoms definition 6 and median mononeuropathy	18	13.8
Symptoms definition 7 and median mononeuropathy	20	15.4
Symptoms definition 8 and median mononeuropathy	20	15.4
Carpal tunnel syndrome: Symptoms and physical examination findings	—	—
Symptoms definition 1 and physical examination findings	26	20.0
Symptoms definition 2 and physical examination findings	26	20.0
Symptoms definition 3 and physical examination findings	27	20.8
Symptoms definition 4 and physical examination findings	28	21.5
Symptoms definition 5 and physical examination findings	19	14.6
Symptoms definition 6 and physical examination findings	19	14.6
Symptoms definition 7 and physical examination findings	19	14.6
Symptoms definition 8 and physical examination findings	19	14.6

[a]See text for explanation of surveillance symptom definitions.
[b]Calculated as percentage of participating subjects (n = 130).

definitions which included electrophysiologic tests, inclusion of nocturnal symptoms reduced the number of cases by 10–17% (e.g., compare symptom definition 1 and MM with symptom definition 5 and MM). When physical examination findings were used as a basis of defining CTS for surveillance purposes, inclusion of nocturnal symptoms reduced the number of cases by 27–32% (e.g., compare symptom definition 4 and physical examination findings with symptom definition 8 and physical examination findings). Although 31 subjects met the criterion for MM in at least one limb, even with the most expanded surveillance symptom definition (definition 4) only 24 subjects met the case definition of CTS. Thus, a substantial fraction of subjects with electrophysiological impairment of median nerve function did not report symptoms considered to be typical of CTS. Similarly, 35 subjects had at least one physical finding consistent with CTS, but seven of these subjects did not report symptoms typical of CTS.

Any discussion of sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of a test assumes comparison with a "gold standard" test procedure. As indicated above, no universally accepted "gold standard" exists for the diagnosis of CTS. Therefore, we used different "gold standards" for judging the efficacy of the various screening methods used for detecting CTS: electrodiagnostic test results alone; electrodiagnostic test results combined with the various surveillance symptom definitions for CTS; and physical examination findings combined with various surveillance symptom definitions for CTS.

Table IV lists the sensitivity, specificity, PPV, and NPV of various screening test procedures when electrodiagnostic testing alone (i.e., median mononeuropathy) was used as the basis of comparison. The PPVs and NPVs were calculated assuming a 15% prevalence of MM. All of the surveillance symptom definitions, which are based on subjects' responses on the questionnaire, appear to have substantially greater sensitivity (58–77%) than physical examination findings alone (41%) for detection of workers with electrophysiologic abnormalities of the median nerve. The specificities of the surveillance symptom definitions were variable, but those definitions which included nocturnal symptoms (definitions 5, 6, 7, and 8) had specificities (77%) which were indistinguishable from the specificity of physical examination findings alone (76%). All combinations of symptoms with physical examination findings had even lower sensitivities, with only modest increase in the specificities. Vibratory threshold testing, palmar pinch grip and hand grip each had markedly lower sensitivity for detecting MM. These latter tests had very high specificities.

The PPV for the surveillance symptom definitions for CTS ranged from 0.20 to 0.33, while for physical examination findings alone the PPV was 0.23 (see Table IV). Physical examination findings combined with each of the surveillance symptom definitions yielded PPVs which ranged from 0.21 to 0.29. In all cases, addition of nocturnal symptoms to the surveillance symptom definition, with or without inclusion of physical examination findings, served to substantially increase the PPV (by as much as 57%, 0.21–0.33). The PPVs of vibratory threshold testing, palmar pinch grip and hand grip were all less than or equal to 0.20. All quantitative test procedures had high NPVs (at or above 0.84).

Table IV. Sensitivity, Specificity, and Predictive Values of Screening Test Procedures for Detection of CTS (Electrodiagnostic Testing Used as Basis of Comparison)

Screening test procedures[a]	Sensitivity	Specificity	PPV[b]	NPV[c]
Symptoms consistent with CTS	—	—	—	—
Symptoms definition 1	.65	.57	.21	.90
Symptoms definition 2	.65	.57	.20	.90
Symptoms definition 3	.74	.52	.21	.92
Symptoms definition 4	.77	.48	.21	.92
Symptoms definition 5	.58	.77	.31	.91
Symptoms definition 6	.58	.77	.31	.91
Symptoms definition 7	.65	.77	.33	.93
Symptoms definition 8	.65	.77	.33	.93
Physical examination (PE) findings	.41	.76	.23	.88
Sx def. 1 and PE findings	.29	.83	.23	.87
Sx def. 2 and PE findings	.29	.83	.23	.87
Sx def. 3 and PE findings	.29	.82	.22	.87
Sx def. 4 and PE findings	.29	.81	.21	.87
Sx def. 5 and PE findings	.26	.89	.29	.87
Sx def. 6 and PE findings	.26	.89	.29	.87
Sx def. 7 and PE findings	.26	.89	.29	.87
Sx def. 8 and PE findings	.26	.89	.29	.87
Vibratory threshold	.03	.91	.06	.84
Palmar pinch grip strength	.10	.93	.20	.85
Hand grip strength	.10	.90	.15	.85
Pinch or hand grip strength	.16	.88	.19	.86

[a]See text for explanation of surveillance symptom definitions.
[b]PPV = positive predictive value (assumes prevalence of MM of 15%).
[c]NPV = negative predictive value (assumes prevalence of MM of 15%).

The results listed in Table V are the sensitivities, specificities, PPVs, and NPVs for the various CTS screening test procedures in which the "gold standard" for comparison was MM *and* appropriate symptoms. Again, all calculations of PPV and NPV assume a prevalence of disease (i.e., CTS) of 15%. The sensitivities and NPVs of 1.00 achieved for each of the surveillance symptom definitions for CTS are an artifact due to inclusion of the symptom definitions in the gold standard in each case. The PPV of physical examination findings alone was 0.22 which was lower than the PPVs of the surveillance symptom definitions. For each surveillance symptom definition for CTS the addition of physical examination results did not markedly alter the PPV. With inclusion of nocturnal symptoms (as in symptom definitions 5, 6, 7, and 8), the PPVs of symptoms alone was better than when combined with physical examination findings. Again, the quantitative test procedures had relatively poor performance (lower sensitivities and/or PPVs) when compared to symptoms alone.

Table VI lists the sensitivities, specificities, PPVs, and NPVs of CTS screening procedures in which the "gold standard" for comparison was physical examination findings and symptoms consistent with CTS. Again, the sensitivities and NPVs of 1.00 for each surveillance symptom definition for CTS are artifactual. Electrodiagnostic testing for MM yielded a sensitivity and PPV which were lower than symptoms alone. The PPV for each of the symptom definitions with nocturnal symptoms alone was greater than if MM was added (e.g., compare PPV of symptom definition

Table V. Sensitivity, Specificity, and Predictive Values of Test Procedures for Detection of CTS (Electrodiagnostic Testing *and* Symptoms[a] Consistent with CTS Used as Basis of Comparison)

Screening test procedures[b]	Sensitivity	Specificity	PPV[c]	NPV[d]
Symptoms consistent with CTS	—	—	—	—
Symptoms definition 1	1.00	.61	.31	1.00
Symptoms definition 2	1.00	.60	.31	1.00
Symptoms definition 3	1.00	.55	.28	1.00
Symptoms definition 4	1.00	.51	.27	1.00
Symptoms definition 5	1.00	.80	.46	1.00
Symptoms definition 6	1.00	.80	.46	1.00
Symptoms definition 7	1.00	.79	.46	1.00
Symptoms definition 8	1.00	.79	.46	1.00
Physical examination (PE) findings[e]	.40	.76	.22	.88
Sx def. 1 and PE findings	.45	.85	.34	.90
Sx def. 2 and PE findings	.45	.85	.34	.90
Sx def. 3 and PE findings	.39	.83	.29	.89
Sx def. 4 and PE findings	.38	.82	.27	.88
Sx def. 5 and PE findings	.44	.90	.44	.90
Sx def. 6 and PE findings	.44	.90	.44	.90
Sx def. 7 and PE findings	.40	.90	.41	.90
Sx def. 8 and PE findings	.40	.90	.41	.90
Vibratory threshold[e]	.05	.92	.10	.85
Palmar pinch grip strength[e]	.20	.95	.39	.87
Hand grip strength[e]	.10	.90	.15	.85
Pinch or hand grip strength[e]	.20	.88	.23	.86

[a]The set of symptoms used in the "gold standard" always matches the symptoms in the comparison test procedure. So, for example, when determining the sensitivity, specificity, PPV, and NPV for surveillance symptom definition 4, the "gold standard" used for comparison was MM *and* surveillance symptom definition 4.
[b]See text for explanation of surveillance symptom definitions.
[c]PPV = positive predictive value (assumes prevalence of CTS of 15%).
[d]NPV = negative predictive value (assumes prevalence of CTS of 15%).
[e]The gold standard used for these comparisons was MM and symptom definition 8.

8 and symptom definition 8 *and* MM). Although the PPV of some quantitative test procedures (e.g., hand grip) was comparable to the PPV of the symptoms alone, the sensitivity was substantially lower in all cases.

DISCUSSION

This study involved application of a standardized medical protocol to all workers in the study plant who volunteered to participate. The high rate of participation among workers at the plant mitigates against substantial selection bias affecting the results. In addition, this study was performed in the workplace, and therefore may provide a more realistic assessment of the efficacy of various screening test procedures for CTS among active workers in comparison to clinic-based studies.

The various "gold standards" for CTS in this study are somewhat arbitrary, and are not intended to be interpreted as "gold standards" for clinical purposes. Rather, the purpose was to make comparisons between different test procedures. In the absence of a totally independent procedure for classifying subjects with re-

Table VI. Sensitivity, Specificity, and Predictive Values of Test Procedures for Detection of CTS (Physical Examination Findings *and* Symptoms[a] Consistent with CTS Used as Basis of Comparison)

Screening test procedures[b]	Sensitivity	Specificity	PPV[c]	NPV[d]
Symptoms consistent with CTS	—	—	—	—
Symptoms definition 1	1.00	.64	.33	1.00
Symptoms definition 2	1.00	.64	.33	1.00
Symptoms definition 3	1.00	.57	.29	1.00
Symptoms definition 4	1.00	.53	.27	1.00
Symptoms definition 5	1.00	.80	.47	1.00
Symptoms definition 6	1.00	.80	.47	1.00
Symptoms definition 7	1.00	.78	.45	1.00
Symptoms definition 8	1.00	.78	.45	1.00
Median mononeuropathy[e]	.42	.79	.26	.89
Sx def. 1 and MM	.35	.89	.37	.89
Sx def. 2 and MM	.35	.89	.37	.89
Sx def. 3 and MM	.33	.86	.30	.88
Sx def. 4 and MM	.32	.85	.28	.88
Sx def. 5 and MM	.42	.91	.45	.90
Sx def. 6 and MM	.42	.91	.45	.90
Sx def. 7 and MM	.42	.89	.41	.90
Sx def. 8 and MM	.42	.89	.41	.90
Vibratory threshold[e]	.11	.93	.21	.86
Palmar pinch grip strength[e]	.21	.95	.41	.87
Hand grip strength[e]	.32	.94	.47	.89
Pinch or hand grip strength[e]	.32	.90	.36	.88

[a]The set of symptoms used in the "gold standard" always matches the symptoms in the comparison test procedure. So, for example, when determining the sensitivity, specificity, PPV, and NPV for surveillance symptom definition 4, the "gold standard" used for comparison was MM *and* surveillance symptom definition 4.
[b]See text for explanation of surveillance symptom definitions.
[c]PPV = positive predictive value (assumes prevalence of CTS of 15%).
[d]NPV = negative predictive value (assumes prevalence of CTS of 15%).
[e]The gold standard used for these comparisons was physical examination findings and symptom definition 8.

spect to CTS, it was necessary to arbitrarily define various combinations of symptoms and test procedures as "gold standards." Therefore, the sensitivities, specificities, PPVs, and NPVs presented in the tables should be interpreted on a relative, and not an absolute, basis.

Using symptoms and abnormal electrodiagnostic testing as diagnostic criteria for CTS, between 14 and 18% of workers in the present study had CTS in at least one hand (see Table III). Overall, the electrodiagnostic abnormalities were relatively mild. This is consistent with the finding that none of the subjects had clinical evidence of thenar muscle atrophy.

There are few plant-based studies with which to compare the crude results of the present study. In a study of ski manufacturing workers Barnhart *et al.* (11) used the same electrodiagnostic definition of median nerve impairment as in the present study, thus enhancing the comparability of results. Based on electrodiagnostic results alone (MM in our study, and their case definition 1), 23.8% of subjects in the present study had abnormalities in at least one hand, while their results ranged from 18.8 to 33.7%, depending on the ergonomic exposure classification

(approximately 28% overall when exposure groups are combined). With the requirement of MM *and* Phalen's or Tinel's signs in at least one hand (their case definition 2), 3.1% of subjects in the present study had abnormalities which met this case definition, while among the ski manufacturing workers the numbers ranged from 3.1 to 15.4%.

Katz *et al.* (12) examined the diagnostic utility of various clinical features of CTS among patients referred to a hospital-based neurophysiology laboratory. Calculations of predicted values assumed a disease prevalence of 15%, as in the present study. If Phalen's and Tinel's signs were combined, they found sensitivity = 0.88, specificity = 0.41, PPV = 0.21, and NPV = 0.95. The results of the present study which are most comparable are in Table V. Physical examination findings (Phalen's, Tinel's or 2-point discrimination) had sensitivity = 0.40, specificity = 0.76, PPV = 0.22, and NPV = 0.88. While the predicted values are similar, the sensitivity and specificity differ. The latter may be related to the nature of the study populations investigated. As noted above, the electrophysiologic abnormalities among CTS cases in the present study of active workers were mild. While the severity of disease among patients in the Katz study is not described, patients referred to a hospital-based clinic may have more severe disease. It may be that physical examination findings may have better sensitivity among patients with more severe impairment of median nerve function.

As noted in the "Methods" section, the questionnaire did not attempt to distinguish symptoms localized to the distribution of the median nerve, and symptoms elsewhere in the distal upper extremity. While this may appear crude or imprecise, the results (sensitivity, specificity, PPV, and NPV) are similar to what has been found in previous studies. For example, Katz *et al.* (12) evaluated the clinical utility of symptoms of CTS as reported on self-administered hand diagrams. Hand diagrams were scored in a manner which took into consideration the distribution of symptoms relative to the region innervated by the median nerve (13). The findings were as follows: sensitivity = 0.61, specificity = 0.71, PPV = 0.27, and NPV = 0.91. Though a different survey instrument was employed in the present study (and the "gold standard" used as a basis of comparison also differed), the results are similar (see Table IV). The similarity of results suggests that symptom surveys are a relatively robust tool for eliciting complaints related to CTS.

In a study of 500 randomly selected subjects from a community, De Krom *et al.* (14) examined the efficacy of a variety of clinical examination procedures which have been promoted for the diagnosis of CTS, including Phalen's and Tinel's tests. Both of these provocative tests had poor validity in comparison to a gold standard consisting of symptoms and electrophysiologic abnormalities. The authors concluded that "There is little evidence to support the notion that provocative tests are useful for the differential diagnosis of CTS." The findings in the present study are similar, in that physical examination findings appeared to add little to information gathered by the symptom questionnaire alone.

Ideally, individuals identified as "positive" in a surveillance program should be referred for clinical evaluation. Such standard practice is predicated on screening procedures that have relatively high PPV and NPV. Our results suggest that caution should be exercised if any combination of nonelectrodiagnostic test procedures is

to be used as a preliminary medical screening technique, and a basis for referral of subjects with positive findings for further confirmatory medical tests. The low positive predictive values would result in a large fraction of the referred population (without CTS) being subjected to time consuming, expensive, and unpleasant test procedures. This is concordant with Katz *et al.* (6).

However, if "screening" is conducted in the context of a workplace surveillance program with the goal of monitoring possible trends or patterns of CTS among groups of workers, then we believe the results of this study are more encouraging. In this context, surveillance is intended to reflect the underlying prevalence of disease, even if the surveillance procedures do not precisely enumerate individual cases (or non-cases). The results suggest that without application of electrodiagnostic tests, none of the screening procedures, individually or in combination, has substantially better sensitivity, specificity, PPV, or NPV than a questionnaire which elicits symptoms. Use of a questionnaire is certainly less expensive and less time consuming than other procedures employed in this study, and a questionnaire requires no specially trained medical personnel to complete. Questionnaires are also non-aversive to subjects, and so would be better suited for repeated application.

Questionnaires may have other strengths as well. Like many previous studies, the present study is focused on CTS, although this diagnosis is just one of many which can afflict the upper extremities of workers. Tendinitis, epicondylitis, sprains, strains, bursitis, and other diagnoses may comprise the majority of upper extremity cumulative trauma disorders among workers. Electrodiagnostic testing and physical examination findings related to CTS (e.g., Phalen's sign, Tinel's sign, thenar muscle wasting, loss of 2-point discrimination) provide little diagnostic information related to these other conditions. Nevertheless, these other conditions can produce symptoms that overlap with symptoms of CTS. Therefore, a possible explanation for the low PPV for symptoms related to CTS may be that persons who report such symptoms may have other, work-related upper extremity cumulative disorders in addition to, or instead of, CTS. The PPV of a questionnaire survey for all upper extremity cumulative trauma disorders may be much higher than for CTS alone. Further work is needed to assess this speculation.

Despite the potential strengths outlined above, the results of symptom questionnaires are subjective, and potentially may be influenced by psychosocial factors. Unfortunately, we are not aware of any published data which address how workers' perception and reporting of symptoms in the upper extremities may be affected by job stress, job satisfaction, or other organizational or psychological factors. This is an area which needs more research.

Expansion of the surveillance symptom definition to include burning, or extension beyond the hands and fingers to the wrist and forearm, did not substantially alter the predicted values. However, requirement of nocturnal symptoms appeared to result in only a small decrease in sensitivity despite substantially increasing the PPV. It would appear that requiring nocturnal symptoms in a surveillance symptom definition for CTS would be an improvement.

Case counting for purposes of surveillance should be distinguished from medical screening for detection of disease and actual clinical diagnosis of disease. Although it may be desirable to include only confirmed cases when conducting

surveillance, the personnel time and cost of medical tests required to establish a full medical diagnosis frequently can make this prohibitive. However, the goal to keep in mind is: what is the simplest, easiest, and most cost-effective approach to conducting workplace-based surveillance for CTS? Surveillance is intended to monitor trends in disease occurrence among workers; this is not equivalent to definitively ruling-in or ruling-out CTS in each individual worker who participates in a surveillance program. Usually there is a trade-off between diagnostic accuracy (regardless of what case definition one chooses to apply) and the cost (medical personnel time, costs of medical tests, lost productivity among workers) of any program of surveillance. In the context of a surveillance program it may not be necessary to achieve the same level of diagnostic accuracy as would be desired or required in a clinical setting.

It would appear that the simplest method for monitoring CTS in the workplace is via use of a self-administered questionnaire. Such a survey instrument could be used to help identify "high risk jobs," to assess the effectiveness of job interventions, and to assess the overall effectiveness of medical treatment and rehabilitation programs. Symptoms surveys might also be a valid tool for monitoring all upper extremity cumulative disorders among workers, although support for this broader recommendation would require additional study.

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