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The Effectiveness of Post-Offer Pre-placement Nerve Conduction Screening for Carpal Tunnel Syndrome

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Abstract

Objective—We evaluated post-offer pre-placement (POPP) nerve conduction studies (NCS) for carpal tunnel syndrome (CTS), testing diagnostic yield and cost-effectiveness.

Methods—1027 newly hired workers underwent baseline NCS, and were followed for an average of 3.7 years for diagnosed CTS. Measures of diagnostic yield included sensitivity, specificity, and positive predictive value (PPV). Cost-effectiveness of POPP screening was evaluated using a range of inputs.

Results—Abnormal NCS was strongly associated with future CTS with univariate hazard ratios ranging from 2.95 to 11.25, depending on test parameters used. However, PPV was poor, 6.4–18.5%. Cost-effectiveness of POPP varied with CTS case costs, screening costs, and NCS thresholds.

Conclusions—Although abnormal NCS at hire increases risk of future CTS, the PPV is low, and POPP screening is not cost effective to employers in most scenarios tested.

BACKGROUND

Carpal tunnel syndrome (CTS) is a common work related upper extremity musculoskeletal disorder and has the longest time away from work and the highest associated direct costs among upper extremity work-related injuries and musculoskeletal disorders^{1–4}. Direct medical costs are estimated to exceed \$1 billion per year^{1, 3}. CTS can also cause significant impairment in functional ability for workers in both work and daily activities^{2, 5, 6}. Some employers routinely use post-offer pre-placement (POPP) screening including nerve conduction studies (NCS) to identify workers at higher risk of developing CTS, so that these workers will not be hired into hand-intensive jobs at higher risk of CTS, thus reducing the employer's injury rates and workers' compensation costs⁷. It is difficult to estimate the

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Conflicts of Interest

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number of employers currently utilizing POPP NCS to make hiring decisions; to our knowledge there are no published scientific reports describing the prevalence of POPP testing by employers. Despite a lack of clear scientific evidence that pre-placement, post-offer screening with nerve conduction studies is sufficiently predictive of future carpal tunnel syndrome, this practice appears to be widespread based on publications in trade journals, advertisements by healthcare facilities offering “carpal tunnel testing or screening,”^{8–17} and promotion by device manufacturers.

Studies of active industrial workers have found a high prevalence of asymptomatic nerve conduction abnormalities, up to 15–20%^{18–26}. Available studies indicate that asymptomatic workers with abnormal nerve conduction studies are at a higher risk of developing CTS than asymptomatic workers whose nerve conduction studies are normal^{18, 27, 28}. However, the magnitude of the increased risk conferred by nerve conduction abnormalities, the cost benefit of doing such screening, and the effectiveness of different work placement strategies in preventing carpal tunnel syndrome all remain to be defined.

Another potential limitation of most existing studies is the possibility of a survivor bias resulting from selection of subjects who have worked for years in a hand-intensive industry; these studies may have evaluated those workers who remained asymptomatic despite work demands and abnormalities of nerve conduction²⁹. The predictive value of nerve conduction studies (NCS) may thus be different among job applicants than among active workers in hand intensive industries. Only one study to date has screened new employees at the time of hire and followed their development of CTS longitudinally. This study by Franzblau et al (2004)²⁸ studied workers in a single manufacturing plant who received NCS prior to hire, but were hired regardless of the results. Results from this study showed that abnormal NCS conferred a higher risk for a future workers’ compensation claim for CTS; however, the majority of the claims came from workers whose screening NCS were normal at the time of hire, and the cost of worker testing exceeded the potential savings that would have resulted from not hiring workers with abnormal NCS.

For the purposes of screening, it is unclear whether it is preferable to measure median nerve latency via sensory nerve latency, motor nerve latency, or in comparison to ulnar nerve latencies. Different testing techniques and different placement of electrodes can alter the results obtained^{30–32}. Another important issue in screening studies of asymptomatic persons is the need to define what constitutes an “abnormal” test result for working populations. The appropriateness of current normative values is questioned by studies showing higher prevalence of “abnormal” values among asymptomatic populations of active workers than the general population^{33, 34}. It is not clear if the populations from which normative values were drawn are truly representative of the worker populations in which the tests are being used.

The aim of our study was to determine if nerve conduction studies as part of POPP screening for new hires correctly identifies people at risk for CTS across a wide range of industries. This study examined the hypothesis that workers with baseline abnormalities of median nerve conduction would have a higher incidence of CTS than those with normal nerve conduction. In addition, we tested how the prediction yield varied across different case

definitions for determining normal and abnormal nerve conduction studies. Finally, we estimated the cost-benefit of screening from the perspective of the employer.

METHODS

The Predictors of CTS study (PrediCTS), is a prospective, longitudinal study that recruited 1107 subjects from eight employers and three trade unions between July 2004 and October 2006. Subject recruitment took place during company post-offer screenings, new employee orientations, or training classes depending upon each employer's established hiring procedures. Eligible subjects were newly hired or had become benefits eligible within the prior 30 days, were at least 18 years of age, worked a minimum of 30 hours weekly, and were able to speak English. Subjects were excluded if they had a prior diagnosis of CTS or peripheral neuropathy, were pregnant at the time of enrollment, or had a contraindication to nerve conduction testing. Subjects were recruited from both low and high hand intensive jobs and represented a range of industries: construction (carpenters, floor layers, sheet metal workers), healthcare (laboratory and hospital technicians), service (food service, housekeeping) and clerical work (computer and clerical workers). Detailed information about recruitment and data collection methods used for this prospective study has been described in several previous manuscripts³⁵⁻³⁸. The Washington University School of Medicine and the University of Michigan Institutional Review Boards approved this study. All subjects provided written informed consent and were compensated for their participation.

Data collection measures

At baseline, all study subjects received a structured physical examination of the upper extremities and bilateral nerve conduction studies. Subjects also completed surveys at baseline, 6 months, 18 months, 36 months, and annually thereafter. These surveys collected demographic and personal information, work history and physical and psychosocial work exposures, and health information including the presence of upper extremity symptoms. On each survey, subjects were asked if they had received a new diagnosis for any medical or musculoskeletal condition, including carpal tunnel syndrome, in the prior year.

All subjects received nerve conduction studies of the median and ulnar nerves across the wrist with the NC-stat automated testing device (Neurometrix Inc, Waltham, MA, USA). This device has shown to have good criterion validity compared to traditional electrodiagnostic testing methods in studies performed by the manufacturer and in a study performed by an independent academic group³⁸⁻⁴⁰. Testing was performed by trained research technicians according to the manufacturer's guidelines using techniques described in detail in previous publications^{38, 41, 42}. The NC-stat device utilizes preconfigured, nerve-specific electrodes with embedded temperature sensors. Electrodes were placed on the wrist with the distal sensors for the median nerve placed on the third digit and on the fifth digit for the ulnar nerve studies. The distance between the wrist sensors and distal finger sensors was recorded by the research technician. Distal motor latencies (DML) and distal sensory latencies (DSL) were recorded for each nerve and the median-ulnar differences for sensory latencies (MUDS) were calculated. Latencies were normalized to a skin temperature of 32

degrees Celsius using the manufacturer's guidelines. Results of NCS were given to each participating worker, but this information was not provided to participating employers; no hiring or job placement decisions were made based on NCS nor other study findings.

Statistical analysis

For the present study, the main outcome measure was a diagnosis of CTS by a healthcare provider as reported by the worker on any follow-up survey, similar to previous studies of national health surveillance data⁴³⁻⁴⁵. For calculating time to event and time of follow-up, workers were censored when a diagnosis of CTS was reported, or at the date of the last questionnaire completed for those lost to follow-up or for those without a diagnosis of CTS. Presence or absence of hand symptoms at baseline was not included in our case definition; in a setting where employment may be contingent upon the results of POPP screening, workers may have an incentive to underreport symptoms. The analysis in this study was designed to most closely replicate the use of NCS in POPP screening as performed by employers.

Chi-square analyses and t-tests were used to compare the mean values of the demographic and clinical characteristics, job category, and CTS outcome for workers with normal NCS results at baseline and workers with any NCS abnormality at baseline including either median DML (>4.5 ms), median DSL (>3.5 ms), or MUDES (>0.5)²⁴. To examine the predictive value of POPP NCS on diagnosis of CTS, bivariate survival analysis was conducted using time from the baseline survey date to the first survey date when CTS was reported. Risk factors were reported as Hazard Ratios (HR). Significant predictors ($\alpha=0.05$) were included in the multivariable Cox regression model. The Akaike information criterion (AIC) was calculated for each NCS parameter separately, and for the composite outcome of any abnormal NCS, to describe which NCS test was the best fit for predicting future CTS.

In addition to determining whether baseline NCS was predictive of CTS diagnosis, we also examined whether prediction varied based upon the varying definitions of an "abnormal" NCS result derived from baseline DML, DSL, and MUDES. We used a range of thresholds previously used to identify incident CTS in worker populations and epidemiological studies^{24, 46, 47}, in order to show the range of sensitivity and specificity values obtained in POPP screening using different thresholds. We computed measures of diagnostic yield between future CTS diagnosis and baseline NCS, including sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Using different thresholds and NCS tests, we observed how many new workers would need to be screened to correctly identify one future CTS case, and how many workers would be incorrectly identified as a future CTS case. We repeated these analyses for the right hand only, to determine if testing only one hand could be equally predictive as bilateral testing.

Based on these measures, we completed a simple cost-benefit analysis to model a strategy of POPP screening from the perspective of the employer, and compared a strategy of not screening versus a strategy of performing POPP NCS and not hiring workers whose test results were abnormal. In each scenario we calculated the number of workers who would need to be screened to attain the same number of workers initially hired. The no screening

strategy incurred no screening costs at baseline, but we assigned a cost for each case of CTS occurring while employed by the original employer or trade union. The POPP NCS strategy was assigned costs for baseline screening, and costs of future CTS cases that were incurred only for those subjects screening normal at baseline. Cost-benefit analysis used cost estimates of screening and workers compensation costs from a previous cost benefit analysis of POPP screening for CTS⁴⁸. Baseline inputs to our model included a cost per case of CTS of \$20,000, to represent the total cost of a claim including medical and indemnity costs⁴⁹, and a cost of screening of \$150. In addition to the base model, we conducted a sensitivity analysis varying the cost of screening and the cost of treatment, to evaluate the degree to which our model was affected by assumptions for the cost of screening, the cost of a CTS claim, and NCS test characteristics. Different cost estimates for screening were based on published reports of actual screening costs from one employer, which included not only the cost of NCS screening but other hiring costs such as drug testing, medical evaluations and administrative costs²⁸. Different treatment costs were based on published figures for average treatment costs for work-related CTS claims in Washington and Ohio states^{1, 50}.

RESULTS

Of the original 1107 newly hired workers screened in the PrediCTS study cohort, 1,027 (92.8%) completed at least one follow-up survey. Five subjects were excluded because baseline NCS results were indeterminate for median DML, DSL, and MUDS. Of the 1,022 subjects remaining, 35 had partially missing NCS data and were excluded from analyses requiring the missing parameters as seen in Tables 2–4. The majority of workers were male (64.5%) with a mean age of 30.3 years and a mean BMI of 28.5 (Table 1). A quarter of workers had abnormal POPP NCS at baseline. Subjects with abnormal NCS at baseline were significantly older, more likely to be male, and to work in the construction trades. The mean length of follow-up for the cohort was 3.7 years (range 0.4–6.2). Over the study period 33 workers reported having received a diagnosis of CTS with a mean time to first report of diagnosis of 2.4 years (range 0.4–5.1). Workers with any NCS abnormality at baseline were significantly more likely to report a diagnosis of CTS at follow-up. The overall incidence rate of CTS diagnosis in the cohort was 8.7 per 1000 person years (PYs). The rate of CTS diagnosis was higher among workers with abnormal POPP NCS versus workers with normal POPP NCS (22.2 cases per 1000 PYs versus 4.0 cases per 1000 PYs, rate ratio of 5.5 (95% CI: 2.6–11.5)).

Baseline NCS abnormality was a statistically significant predictor of future CTS diagnosis for all nerve test parameters using our pre-defined cut-points of median DML > 4.5 ms, median DSL > 3.5 ms, or MUDS > 0.5 (Table 2). Workers with abnormal MUDS were at the highest risk of becoming diagnosed with CTS over the study period, followed by abnormal median DSL, any NCS abnormality, or abnormal median DML. Age, gender, and BMI were statistically significant predictors of CTS diagnosis. There were no substantial changes in the hazard ratios of NCS tests when we repeated these analyses adjusting for age, gender, and BMI. Using the AIC to describe the goodness of fit, MUDS had the lowest AIC value and thus was a better predictor of CTS than the screening parameters of any NCS abnormality, median DML, or median DSL.

To examine the effect of defining different NCS cut-points for abnormality on the yield of screening, including the positive predictive value (PPV) and number needed to test to avoid 1 future case of CTS, we examined the sensitivity and specificity for the cut-points shown in Table 3. As expected for a relatively rare condition, specificity and NPV were high (75.9 – 93.1%) and (97.5 – 98.8%), respectively; however, sensitivity was low (36.4–65.5%) and PPV very low (6.4–18.5%). The most sensitive cut-point, MUDS > 0.5, detected 65.5% of those who would later be diagnosed with CTS. While reasonably sensitive, this measure had a very poor PPV: only 13.1% of those with an abnormal value based on this cut-point reported a diagnosis of CTS over the study period. We repeated these analyses using the right hand only; results were similar to the findings of bilateral testing; as expected, sensitivity decreased slightly and specificity improved slightly with unilateral testing.

In order to assess the preventive effectiveness of POPP NCS for CTS, we calculated the number of job candidates who would need to be screened to avoid 1 future case of CTS among the screened workforce using the simple methods previously described by de Kort and van Dijk⁵¹. Using our pre-defined cut-points, the most sensitive screening parameter, MUDS > 0.5, only detected 65.5% of those who would later be diagnosed with CTS, and would have required testing 54 subjects to detect 1 future case of CTS in the workforce. At the same time, the lower specificity of the MUDS >0.5 parameter would have inappropriately denied employment to 7 workers among the 54 who would not have developed CTS despite having an “abnormal” NCS test.

In assessing the predictive validity of POPP NCS for predicting future CTS, the analyses reported above followed the full cohort of workers including those who changed employers, and recorded all cases of CTS during the study period (n=33). We conducted cost-benefit analysis from the perspective of the employer, and thus only the 23 CTS cases that occurred while a subject screened at baseline was still working for the original employer and had complete NCS data were relevant for inclusion in the cost models. In our base case scenario using the criterion of “any NCS abnormality” at baseline, 987 newly hired workers were screened with POPP NCS; 247 workers would have been rejected for hire, a failure rate of 25%. In order to attain a work pool of 987 workers who tested normal, a total of 1,317 workers would need to be screened (987 + 247 replacements from failed screens + 83 additional replacements due to a continuous failure rate of 25% among replacement workers screened). Sixteen of the 23 future CTS cases would have been avoided under a screening strategy, as they occurred in the population of workers testing abnormal at baseline using this criterion. Seven of 23 CTS cases occurred in the 740 workers screening normal at baseline; we used a cumulative incidence rate of CTS in the population screening normal at baseline to calculate the expected number of cases in a population of 987 workers screening normal at baseline (10 CTS cases when using the testing criterion of any NCS abnormality). These case counts and number of workers screened were entered in to our cost model using base screening costs of \$150 per worker and CTS treatment cost of \$20,000 per case, as shown in Table 4. The NCS failure rate and number of CTS cases that would have been avoided varied with the sensitivity of the NCS parameter used as the screening criterion. Cost benefit analysis showed that screening was favored when NCS test sensitivity was high (any abnormal NCS, DSL, and MUDS) and cost of screening was low (\$150). Using the same low screening cost, but a less sensitive NCS measure (median DML >4.5 ms), a no

screening strategy was favored. With a higher screening cost (\$358), modeled to account for the other costs associated with hiring new workers²⁸, a no screening strategy was favored in all models, regardless of NCS parameters. These findings were also sensitive to changes in treatment cost for CTS. When the treatment cost for a CTS case was varied (\$13,253 and \$5605), using published workers' compensation data from Ohio for 1999–2004⁵⁰, and Washington State¹, a no screening strategy was favored for all NCS screening parameters except when using a selection criteria of MUDS >0.5ms with the higher Ohio State costs.

DISCUSSION

The aim of this study was to determine if NCS performed at the time of hire were predictive of a future CTS diagnosis among a cohort of workers in a variety of industries. Results showed that newly hired workers with abnormal baseline NCS were significantly more likely to report a CTS diagnosis during the study period, which is consistent with previous studies^{18, 27, 28}. Despite this finding, the predictive validity of such POPP NCS screening is at best low or modest. We tested how the prediction yield varied across different thresholds for defining normal and abnormal nerve conduction studies, and consistently found low positive predictive value across all screening parameters. POPP NCS screening appears to be widely used by employers, but our cost-benefit models of screening conducted from the perspective of the employer showed that the costs of screening did not outweigh the savings for CTS cases that would have been avoided in the majority of scenarios modeled.

The overall rate of CTS in our cohort was 8.7 cases per 1000 person years (PYs), slightly higher than the rate of 7.8 per 1000 PYs reported by Franzblau et al²⁸. The slightly higher rate of CTS observed in our study population may be partly attributable to our case definition of CTS diagnoses reported by workers rather than accepted workers' compensation claims for CTS²⁸. The rates reported in our study and by Franzblau likely both underestimate the true occurrence of disease due to untreated or unreported cases^{33, 52}. Not all workers who have symptoms are likely to seek treatment, and of those workers who seek treatment, not all will file a workers' compensation claim or have an accepted claim. The slightly higher incidence rate in our study may also be attributable to differences in the nerve conduction parameters used to identify abnormalities for workers. Our rate is based on the screening definition of "any NCS abnormality" (median DSL, DML, or MUDS) at baseline, whereas actual test results (latencies, amplitudes, or conduction velocities) were not available in the Franzblau study, and thus prediction models were based solely on test summaries defined as normal or abnormal. In addition, our study had a longer mean follow-up time of 3.7 years versus 2.1 years²⁸.

A potential limitation of existing studies is the possibility of a survivor bias resulting from selection of subjects who were working for years in a hand-intensive industry^{18, 27}; these studies may have evaluated those workers who remained asymptomatic despite heavy work demands and abnormalities of nerve conduction²⁹. Jobs in hand-intensive industries often have high turnover rates creating a natural selection bias against workers at greater risk of developing CTS. Our study and that of Franzblau et al (2004) avoid this potential bias that the predictive value of nerve conduction studies (NCS) may be different among job applicants than among active workers in hand intensive industries, and thus more closely

models the use of NCS as a screening tool during POPP testing. Results from our study included workers from a wide variety of industries and employers, while Franzblau's study (2004) included workers from a single employer.

To determine whether the prediction yield of screening for future CTS cases could be improved, we evaluated 6 definitions of an "abnormal" NCS result from baseline DML, DSL, and MUDS using published thresholds previously used in working populations^{46, 47}. Our results showed that the percentage of future CTS cases that were correctly predicted was highly dependent upon the definition used to define an abnormal screening result. The sensitivity and specificity and positive and negative predictive values of POPP NCS have varied, in part because different criteria were used to define normal and abnormal NCS measures^{18, 28}. The increased risk of CTS diagnosis in our study varied widely depending upon the measure chosen to define an abnormal result from a hazard ratio of 2.95 (95% CI: 1.45–6.01, $p < 0.01$) for median DML (>4.5 ms) to 11.25 (5.22–24.21, $p < 0.0001$) for abnormal MUDS (>0.5 ms). As with any diagnostic test, there are explicit trade-offs between sensitivity and specificity as seen with use of different criteria for defining abnormal nerve conduction studies. As parameter cut-points used to predict the outcome of future CTS diagnosis were made more specific, the employers in the study would have assumed more risk of potentially hiring workers with greater risk of developing CTS, whereas when the cut-points were more sensitive, more healthy workers would have been inappropriately excluded from employment. Our results showed very different results between different nerve tests and different criteria for defining abnormality. CTS POPP screening is often based on testing only the median nerve; in our study we found the highest sensitivity and specificity using the median ulnar difference. In our experience, POPP testing programs in industry have not formally considered the effects of different cut-points or nerve conduction testing techniques in assessing the likely yield and cost-benefit of their screening programs, nor have such programs acknowledged the very low positive predictive value of POPP testing.

POPP screening with NCS appears to be widely used by employers, but only 2 published studies have evaluated its cost-benefit to employers. Evaluation of POPP screening using cost data from a manufacturing plant²⁸ found that the cost of screening outweighed potential savings from averting workers' compensation costs for CTS. A cost-benefit modeling study⁴⁸ found that POPP screening for CTS would not be cost beneficial for the majority of employers, though could be cost beneficial under circumstances where there was a high cost per case and high incidence of CTS. Using these published models, we compared the cost of screening the workers in our cohort and not hiring those with abnormal baseline NCS, versus a policy of no screening. Our results were consistent with these previous studies, showing that POPP NCS screening would not have been cost beneficial to the employer in the majority of screening scenarios. When the cost of screening was high, a no screening strategy was favored in all cases. As Franzblau (2004) described, there are a number of other potential costs associated with screening in addition to a nerve conduction test, which will vary depending upon each employer's hiring practices. These costs may include a medical physical examination, drug test (which may or may not be done concurrently with other POPP screening), and administrative costs associated with new hire paperwork and orientation. In addition, we assigned the same cost of screening regardless of NCS

parameter, however, screening parameters which require testing of both the median and ulnar nerves (MUDS) would likely cost more than median nerve testing only (DML, DSL). Our simplified cost model did not account for screening costs in subsequent years of hiring to replace workers lost to turnover, and thus may have not have fully captured costs of pursuing a POPP screening strategy.

Cost of treatment for CTS is also highly variable. A 2005 study of work-related CTS claims in Washington State¹ found a median cost per claim of \$5605 over a five-year period, though costs for individual cases ranged from \$359 to \$79,265, depending upon whether surgery was performed and when the CTS diagnosis occurred in the course of the claim. Our base cost of \$20,000 per diagnosed case is very likely to be an overestimate of the costs of CTS to employers, as not all diagnosed cases would be claimed under workers' compensation, and not all would be surgical cases. The lower costs seen in Ohio and Washington State are more likely to reflect true costs of CTS claims under workers' compensation.

The main limitation of our study was the use of self-reported CTS diagnosis as the outcome. As our study was designed to replicate employer practices, CTS diagnosis was a more appropriate outcome than an epidemiological case definition, which would have included workers who had symptoms and abnormal NCS findings, but who never sought treatment or filed a workers' compensation claim. A similar case definition of self-reported CTS has been used in several previous studies of national health surveillance data⁴³⁻⁴⁵. Survival models were censored at survey date as the actual date of diagnosis was not available. The use of an absolute latency for defining an abnormal NCS consistent with CTS has been criticized because many factors such as age, temperature, co-morbidities, and BMI can influence the absolute latency of the median nerve⁴⁶. Comparison on the median and ulnar latencies controls for these confounding factors and our analysis demonstrated this model was the strongest predictor of future CTS. We included all three definitions of abnormal NCS because they are still widely used in clinical practice.

Our model showed that screening could be favorable only if the average treatment cost was high and the screening cost was low. As discussed in other papers^{48, 51}, for screening to be cost beneficial the prevalence of the disorder must be high among new hires, and the incidence high following hire. High employee turnover also increases the cost of screening and decreases potential employer cost savings as screened workers may leave employment before developing the disease of interest⁴⁸. Our results highlight the sensitivity of the cost-benefit model to the cost of screening, the cost per CTS case, and the sensitivity of the screening test. This relationship highlights the need for employers who utilize POPP screening to pick appropriate test cut-points for their workforce rather than a clinical or general population. Finally, the cost-benefit of screening should be considered within the larger societal context of not hiring otherwise qualified workers. Due to the low PPV of POPP NCS screening for future CTS, data from this study showed that each workplace case of CTS avoided for the employer would come at the cost of inappropriate denial of employment or job placement for 4-15 workers who would not develop CTS during the course of their employment. This raises another consideration for employers, the several court cases claiming that employers violated the Americans with Disabilities Act or other

laws when applicants were excluded from production jobs based on POPP testing for future risk of CTS. Although some past cases were settled in favor of the employer (EEOC vs. Woodbridge Corporation, 8th Circuit No. 01-L045, August 24th, 2001; EEOC vs. Rockwell International Corporation, 7th Circuit Nos. 00–1897 & 00–2034, March 8, 2001), the EEOC recently won a discrimination case against an employer who excluded a worker from employment based on perceived risk of future CTS.⁵³ While this case was based on violation of the Genetic Information Nondiscrimination Act, at least one other lawsuit in progress addresses discriminatory aspects of POPP screening by median nerve conduction studies.

CONCLUSIONS

Although abnormal NCS at the time of hire is strongly associated with increased risk of future CTS, the predictive value of such testing is poor, even when using optimal criteria as screening thresholds. The cost of screening and rejecting large numbers of healthy workers from employment is high, and in most cases seems to outweigh potential employer cost savings from reducing the incidence of CTS in a given workforce. The social costs of rejecting otherwise qualified healthy workers from employment should also be considered. In all scenarios described above, the vast majority of workers with “abnormal” screening results did not develop CTS, and thus would be inappropriately placed or denied employment based on a test with demonstrably poor positive predictive value for future disease. POPP screening for CTS appears to be widely used, despite ongoing uncertainty about ideal screening procedures, appropriate cut-points for screening versus diagnosis of clinical median neuropathy, and cost-benefits of the procedure for employers. Employers should be cautious in implementing any broad worker screening programs without careful consideration of the costs and benefits of such programs. Available evidence shows that POPP screening for CTS is poorly predictive of future disease, and published studies to date have failed to show that this practice is effective. Occupational health professionals should not endorse screening programs that are not based on evidence of benefit to workers’ health.

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Table 1

Demographic and clinical characteristics for the entire cohort at baseline and workers with normal and abnormal nerve conduction studies at baseline.

Characteristic	Entire cohort (n=1022)	Normal NCS [§] (n=740)	Abnormal NCS ^{*†§} (n=247)	<i>p</i> [‡]
	Mean(SD)	Mean(SD)	Mean(SD)	
Age	30.3 (10.3)	29.1 (9.6)	34.2 (11.5)	0.0002
Body mass index	28.5 (6.4)	28.0 (6.2)	30.0 (6.8)	0.08
	N (%)	N (%)	N (%)	
Gender				0.03
Female	363 (35.5)	277 (38.4)	74 (30.0)	
Male	659 (64.5)	463 (62.6)	173 (70.0)	
Industry				<0.0001
Construction	424 (41.5)	281 (38.0)	133 (53.9)	--
Clerical	366 (35.8)	308 (41.6)	43 (17.4)	--
Service/Technical	232 (22.7)	151 (20.4)	71 (28.7)	--
Diagnosis of CTS, number	33	11	20	<0.0001
Person Years of follow-up (PYs)	3777.5	2733.0	900.3	--
Diagnosis of CTS/1000 PYs	8.7	4.0	22.2	--

NCS- Nerve conduction studies, SD- standard deviation, CTS- Carpal tunnel syndrome, ms-milliseconds

* Temperature and length adjusted, absent values considered abnormal.

† Abnormal NCS= Any of the following: Median distal motor latency (DML) > 4.5 ms or Median distal sensory latency (DSL) > 3.5 ms or Median-
ulnar sensory latency difference (MUDS)>0.5 ms.

‡ used t-tests for continuous data and chi-square tests for categorical data, comparing those with normal and abnormal NCS at baseline.

§ 35 subjects were excluded due to partially missing NCS data.

Table 2

Univariate and adjusted predictors of incident carpal tunnel syndrome at follow-up among all job categories.

	N	CTS (n=33)		No CTS (n=989)		HR (95% CI)	P	Adjusted HR [§] (95% CI)	P	AIC
		Mean (SD)	N (%)	Mean (SD)	N (%)					
Age	1022	35.9 (10.2)	30.1 (10.2)	1.04 (1.02, 1.07)	<0.01	---	---	---	---	
Body mass index	1022	31.4 (7.4)	28.4 (6.3)	1.06 (1.02, 1.10)	<0.01	---	---	---	---	
Male gender	1022	13 (39.4)	646 (65.3)	0.33 (0.17, 0.67)	<0.01	---	---	---	---	
Any abnormal NCS findings ^{*†‡}	987	20 (60.6)	227 (22.8)	5.42 (2.60, 11.32)	<0.0001	5.36 (2.44, 11.75)	<0.0001	374.4		
Median DML >4.5 ms ^{*‡}	1000	12 (36.4)	143 (14.4)	2.95 (1.45, 6.01)	<0.01	3.29 (1.50, 7.19)	<0.01	413.6		
Median DSL >3.5 ms ^{*‡}	1008	19 (57.6)	177 (17.8)	6.57 (3.19, 13.54)	<0.0001	6.44 (2.99, 13.86)	<0.0001	370.8		
MUDES >0.5 ms ^{*‡}	983	19 (57.6)	126 (12.7)	11.25 (5.22, 24.21)	<0.0001	11.36 (4.88, 26.43)	<0.0001	336.2		

CTS- Carpal tunnel syndrome, HR- Hazard ratios, CI- Confidence intervals, AIC- Akaike Information Criterion, SD- Standard deviation, NCS- Nerve conduction study, DML- Distal motor latency; DSL- Distal sensory latency, MUDES- Median ulnar sensory latency difference.

* Temperature and length adjusted.

† Median DML > 4.5 ms or median DSL > 3.5 ms or MUDES > 0.5 ms or absent value.

‡ 35 subjects were excluded due to partially missing nerve conduction data.

§ Adjusted for age, gender, and body mass index.

Table 3

Prediction of future carpal tunnel syndrome by different nerve conduction parameters.

NCS Cut-point	Non-Missing*	Abnormal NCS	CTS Diagnosis	Cases detected by NCS	Sensitivity	Specificity	Positive predictive value	Negative predictive value	N Screened per case [†]	N Non-case Workers Denied Employment per case [‡]
Median DML > 4.2 ms	1,001	249	33	16	48.5%	75.9%	6.4%	97.7%	63	15
Median DML > 4.5 ms	1,000	155	33	12	36.4%	85.2%	7.7%	97.5%	83	12
Median DSL > 3.5 ms	1,008	196	31	19	61.3%	81.9%	9.7%	98.5%	53	9
Median DSL > 3.7 ms	1,005	137	31	18	58.1%	87.8%	13.1%	98.5%	56	7
MUDS > 0.5 ms	983	145	29	19	65.5%	86.8%	13.1%	98.8%	52	7
MUDS > 0.8 ms	980	81	29	15	51.7%	93.1%	18.5%	98.4%	65	4

CTS- Carpal tunnel syndrome, NCS- Nerve conduction study, ms- milliseconds, DML- Distal motor latency; DSL- Distal sensory latency, MUDS- Median ulnar sensory latency difference.

* 5 subjects had indeterminate baseline NCS results for median DML, DSL, and MUDS. 35 subjects had partially missing NCS data and were excluded from relevant analyses.

[†] n Non-missing / Cases detected = N Screened per case

[‡] (Abnormal NCS – Cases detected by NCS) / Cases Detected = N Non-cases Denied Employment per case

Results comparing the cost-effectiveness of a post-offer pre-placement nerve conduction study screening strategy versus a no screening strategy.

Table 4

Strategy	N	Test Sensitivity	Test Specificity	N Screened per CTS case	N Non-case workers denied employment per CTS case	Total Cost of screening plus treatment of CTS cases in the workforce (\$)			
						Screening cost= \$150* Cost per CTS case=\$20,000	Screening cost= \$358† Cost per CTS case=\$20,000	Screening cost= \$150* Cost per CTS case = \$13,253\$	Screening cost= \$150* Cost per CTS case=\$5,605//
<i>Ary NCS abnormality</i> ‡	987	69.6%	76.0%	64	14				
Screening						400,250	674,186	331,869	254,357
No Screening						460,000	460,000	304,819	128,915
<i>Median DML >4.5 ms</i>	1000	40.0%	85.1%	103	15				
Screening						558,800	806,736	430,607	285,295
No Screening						500,000	500,000	331,325	140,125
<i>Median DSL >3.5 ms</i>	1008	65.2%	81.6%	68	12				
Screening						407,200	666,784	332,983	248,855
No Screening						460,000	460,000	304,819	128,915
<i>MUDS >0.5 ms</i>	983	69.6%	86.6%	64	8				
Screening						353,850	594,922	293,127	224,295
No Screening						460,000	460,000	304,819	128,915

NCS- Nerve conduction study, CTS- Carpal tunnel syndrome, ms- milliseconds, DML- Distal motor latency, DSL- Distal sensory latency, MUDS- Median ulnar sensory latency difference.

* Based on base model from Evanoff & Kymes, 2010.

† Based on model D from Franzblau et al, 2004.

‡ Point of indifference for screening cost= \$199.

§ Based on average total cost per CTS claim for Ohio state from 1999–2004, from Dunning et al, 2010.

// Based on average total cost per CTS claim for Washington state from 1990–1994, from Daniell et al, 2005.

Total Cost of screening=[Initial N screened + (of initial rejected workers + additional replacements by failure rate) X screening cost] Treatment of CTS cases in the workforce= cost per CTS case X CTS cases not detected by baseline NCS