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Predictors of functional outcome after peripheral nerve injury and compression

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ABSTRACT

Study Design: Retrospective cohort study.
Introduction: Upper-extremity peripheral nerve injuries can impact long-term pain, work performance, and disability, yet there are few studies evaluating treatment outcomes for a large sample of patients with varying peripheral nerve pathology.
Purpose of the Study: The purpose of this study was to identify outcomes of care and predictors of disability and health status in adults with peripheral nerve injuries.
Methods: We explored medical records from 364 patients treated by a plastic surgeon over a three-year period. Descriptive and inferential statistics compared the Disabilities of the Arm, Shoulder, and Hand, Short-Form 8, and routine intake data between baseline and discharge, diagnosis, and intervention group. Multivariate linear regression models predicted disability, work disability, and physical and mental health at discharge.
Results: We found significant improvements in disability, work disability, pain, depression, and stress. Health status changed minimally. Disability decreased most in patients who were working and who had symptoms fewer than six months. Outcomes were not statistically different between surgical and nonsurgical patients. Disability was the highest in patients with brachial plexus injuries. Multivariate models predicted 35 to 55% of the variance in the outcome measures. Factors that were highly predictive of functional outcomes included work status, household management, pain, depression, stress, and difficulty sleeping.
Conclusions: Patients with peripheral nerve injuries experience improved pain and disability whether treated surgically or nonsurgically. Maintaining engagement in meaningful home and work roles may improve outcomes. Helping patients manage pain remains important, along with combatting stress, depression, and sleep deprivation.
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Upper-extremity peripheral nerve injuries (PNI) result in pain, weakness, and paresthesias that can lead to functional loss and psychological stress.[1-3] Recent literature reveals that functional status among patients with PNI is largely predicted by psychosocial factors such as depression, stress, sleep disturbances, and problems with personal relationships.[4] Patients with PNI often have tremendous difficulty performing independent self-care, household tasks, recreational activities, and work.[5,6] Surgical options are increasing for all types and levels of nerve injuries, and timely surgical repair is optimal.[7,8] Recovery times vary depending on the location, severity, number of nerves damaged, and mechanism of injury. Carpal tunnel decompression may result in immediate resolution of symptoms,[9] whereas function can be impacted for years after brachial plexus injuries and procedures.[10] PNI are a common cause of long-term disability, poor return-to-work outcomes, and increasing health care costs.[6,11] There is increased focus on functional outcomes in patients with PNI due to emphasis on patient-centered care and value-based payment systems.

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Statement of informed consent: Written consent was obtained from all participants included in the study.
Statement of animal and human rights: Procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5). Informed consent was obtained from all patients for being included in the study.
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Treatment outcomes for the nerve-injured population can be promising, yet samples are often small and homogeneous.[12-14] Song and colleagues[15] measured functional ability in 39 patients with ulnar nerve entrapment at the elbow. At one year, disability rates decreased by 35% after surgical decompression, and other significant improvements were found for pain, work ability, and performance of activities of daily living. In a different subset of nerve patients, Al-Hashel found improved reports of pain, paresthesias, and disability 6 months after surgery for thoracic outlet syndrome.[8] Novak and colleagues[16] have made strides in this area of research—investigating disability, anxiety, and stress among adults with a variety of nerve conditions. However, the evidence has primarily explored these constructs at a single baseline time point.[4,16-18] There remains a critical need to capture a holistic view of patient function at follow-up, measuring longitudinal changes after medical intervention to enable health care professionals to collaborate care, compare outcomes, and determine effectiveness of interventions.

The objectives of the present study among patients with PNI are to 1) evaluate changes after treatment and compare between groupings of patients, 2) define residual impairments that remain after treatment, and 3) identify predictors of disability and health status using multivariate modeling.

Methods

Patients with upper-extremity PNI recruited for this research were evaluated and treated by a plastic and reconstructive hand surgeon at a medical center in the Midwest United States between December 2010 and October 2013. Data from initial and final physician visits were extracted from electronic medical records and entered into REDCap (Research Electronic Data Capture) tools hosted on a secured institutional server. Exclusion criteria included 1) patients under age 18 years, 2) patients with upper motor neuron lesions, and 3) diagnoses without peripheral nerve involvement of the upper limb. We double-entered 10% of data, computed percentage agreement, and corrected systematic errors. This longitudinal cohort study was approved by the Institutional Review Board at Washington University School of Medicine. The baseline data included age, sex, diagnosis, marital status, body mass index, duration of symptoms (in months), employment status, and involvement in worker's compensation and/or litigation. Patients rated 26 items at the baseline and discharge on a pain questionnaire that has been previously published.[19] This questionnaire included ratings for pain, depression, and stress on 100-point visual analog scales (VAS), type of onset (sudden or slow), work status (full duty, light duty, or off work), ability to do household chores on a 4-point scale, and if pain affects intimate relationships and/or sleep quality. The baseline and discharge grip and pinch strength were extracted from office visit notes, as well as the baseline and discharge ratings on standardized outcome measures described in the following. Surgical interventions were logged, as well as referrals for hand therapy and pain management; however, we could not confirm if patients followed through with referrals.

Outcome measures

The Disabilities of the Arm, Shoulder, and Hand (DASH) is a 30-item self-report assessment of upper-extremity disability that includes 21 questions measuring difficulty performing activities of daily living on a 5-point Likert scale (none, mild, moderate, severe, unable), five questions exploring physical symptoms, and four questions measuring the impact of the injury on social activities, sleep, work, and self-esteem.[20] The Work-DASH is an optional 4-item module that measures difficulty performing job-related tasks. For both DASH instruments, higher scores indicate higher disability (0 = no disability and 100 = maximal disability). Psychometrics are well-established in the literature, as evidenced by excellent inter-rater reliability (ICC = 0.96) and internal consistency (Cronbach's alpha = .97).[20] Measures of validity are not reported among patients with PNI specifically, yet they are shown to be acceptable in patients with general musculoskeletal conditions, including fractures,[21] wrist disorders,[22] and arthritis.[23,24] The Short-Form 8 (SF-8) is a shortened version of the SF-36 Health Survey that assesses physical and mental health status. Eight items measuring general health, physical functioning, bodily pain, vitality, social functioning, mental health, role limitations due to physical health problems, and role limitations due to emotional problems are self-reported on a 5- or 6-point Likert scale. Test-retest reliability of the SF-8 is ICC = 0.73 to 0.74, alternative form reliability $r = 0.85$ to 0.90, and convergent validity with the SF-36 is $r = 0.93$.[25]

Data management

DASH and SF-8 scores were computed using standardized procedures described in administration manuals.[20,25] We converted SF-8 scores to a 0 to 100 scale for meaningful interpretation, with higher scores indicating poorer health status. We explored symptom duration in three groups: fewer than six months, six to 18 months, and greater than 18 months. Diagnoses were categorized into six groups: 1) median nerve compression, 2) ulnar neuropathy, 3) mixed median and ulnar nerve compression, 4) radial nerve palsy, 5) thoracic outlet syndrome, and 6) brachial plexopathy. Surgical types were categorized into six groups: 1) nerve release 2) nerve transfer, 3) nerve graft, 4) tendon transfer, 5) nerve and tendon transfer, and 6) nerve graft with nerve and/or tendon transfer.

Statistical methods

We used descriptive statistics to compute measures of central tendencies and evaluate data normality. Statistical significance was assumed if $P \leq .05$. Wilcoxon signed-rank tests and Pearson chi-square evaluated changes in variables from the baseline to discharge. We measured differences in continuous variables between groups using *t*-tests or one-way analysis of variance. Data that were not normally distributed were analyzed using nonparametric Mann–Whitney *U* or Kruskal–Wallis tests with Bonferroni correction. Correlations between the baseline scores, demographics, treatment variables, and discharge scores were computed using Spearman's correlation coefficient. Any non-normal predictor variables were corrected using logarithmic transformation. We used stepwise linear regression (forward selection) to build multivariate models predicting disability (DASH), work disability (Work-DASH), physical health (SF-8 Physical), and mental health (SF-8 Mental) at discharge. Variables correlating with each outcome measure at $P \leq .05$ were included in each model. Variables were excluded if they were collinear (correlation coefficient ≥ 0.70) or intuitively tied to the dependent variable (such as work status with work-disability). Patient encounters that were missing outcome scores were excluded from analysis without multiple imputation. Our sample of 364 patients exceeded the minimum estimate to achieve an effect size of $F2 = 15$ with power of .80 and 2-tailed alpha = 0.01. We were over-powered to accommodate for potential missing data.

Results

Our sample included 192 males and 172 females; mean age = 51.1 years (SD = 14). During the initial year of recruitment,

less than 1% of patients refused to participate in this research, so refusal tracking was discontinued. Diagnostic categories are as follows: median nerve compression (23.1%), ulnar neuropathy (34.6%), mixed median and ulnar nerve compression (17.6%), radial nerve palsy (9.1%), thoracic outlet syndrome (4.7%), and brachial plexopathy (11.0%). Of the 295 patients who received surgery, 69% underwent a nerve release ($n = 204$). See Table 1 for additional information regarding surgical procedures. At discharge, approximately 43% of employed patients were not fulfilling their previous job demands. The mean period between the baseline and discharge was 7.09 months (SD = 6.5). The longest period was found for patients with brachial plexopathy (8.9 months), and the shortest period was found for those with radial nerve palsy (5.6 months). All outcome measures demonstrated high internal consistency in our sample (SF-8 $\alpha = .901$, DASH $\alpha = .975$, Work-DASH $\alpha = 0.989$).

Discharge status

There were a wide range of scores on outcome measures at the time of discharge, disability = 34.0 (SD = 22.3), work disability = 42.4 (SD = 30.1), physical health = 45.8 (SD = 8.1), and mental health = 34.8 (SD = 9.8), with higher ratings representing higher disability and poorer health status. Outcome scores between groups are presented in Table 2. Compared with patients working their same full-duty job, patients off work demonstrated higher disability by 21.1 points—whereas patients working light duty had higher disability by only 4.3 points. Employed patients who were at least working light duty experienced lower disability, pain, depression, stress at home, and better physical and mental health at discharge when compared with nonworking patients. Compared with other diagnoses, patients with brachial plexopathy had significantly higher disability (DASH = 42) and work disability (Work-DASH = 63) at discharge. When analyzing patients with nerve compressions only, those with mixed median and ulnar compression demonstrated poorer health status and higher disability, depression, and stress than those with median nerve compression, ulnar neuropathy, or radial nerve palsy. Scores on all four standardized measures were not statistically different between the surgical and nonsurgical groups at discharge. Compared with nonsurgical patients, surgical patients had similar DASH scores at discharge (34 versus 33), yet their baseline scores were also higher (44 versus 40). The impact of nerve conditions on personal relationships was more likely to exist if patients underwent reconstructive surgery (nerve transfer, nerve graft, or tendon transfer) compared with those who had a nerve release ($P < .05$). Interpersonal problems based on diagnostic group were not statistically significant.

Table 1
Characteristics of sample (total $n = 364$)

Patient group	n	%
Diagnosis		
Median nerve compression	84	23.1
Ulnar neuropathy	126	34.6
Mixed median and ulnar compression	64	17.6
Radial nerve palsy	33	9.1
Thoracic outlet syndrome	17	4.7
Brachial plexopathy	40	11.0
Symptom duration		
Fewer than 6 months	123	33.8
6 Months to 18 months	75	20.6
Greater than 18 months	166	45.6
Work status[a]		
Full duty	133	57.4
Light duty	51	21.6
Off work	49	21.0
Treatment group		
Nonsurgical	69	19.0
Surgical	295	81.0
Nerve release	204	69.2
Nerve transfer	47	15.9
Nerve graft	7	2.4
Tendon transfer	12	4.1
Nerve and tendon transfer	16	5.4
Graft with nerve or tendon transfer	9	3.1

[a] Based on the 233 patients who completed the work status variable.

Baseline to discharge changes

Our overall sample demonstrated a 9.1-point decrease in disability and 12.8-point decrease in work disability between the baseline and discharge ($P < .001$). Physical and mental health status were unchanged. The greatest improvements from baseline to discharge for individual activities measured on the DASH were for sleep quality and social activities. Statistically significant ($P < .001$) improvements in VAS score for pain (18.7 points), depression (12.3 points), and stress (10.5 points) were noted for the entire sample (Figure 1). When we compared changes between groups, the following statistically significant differences were found. Disability ($P < .05$) improved the most among patients who were working, had lower depression, and a sudden onset of injury. Work disability ($P < .05$) improved the most in females, patients with brachial plexopathy, and those with a significant other. Patients with thoracic outlet syndrome demonstrated the fewest improvements in pain, but greatest improvements in stress ($P < .05$). Those with median nerve compression had similar improvements in pain, depression, and stress compared with the whole sample (Figure 1). Pain improved the most in patients with radial nerve palsy and brachial plexopathy ($P < .05$). Although not statistically significant, depression improved the most in patients with mixed median and ulnar nerve compression.

Employed patients had greater improvements in physical health ($P = .037$). Mental health ($P < .05$) was worse in patients with a sudden injury onset, ulnar neuropathy, and those who had difficulty sleeping. Depression ($P < .001$) decreased in patients who were working (from 26 to 16) and not working (from 50 to 30). Similar improvements in disability and work disability were noted in the surgical versus nonsurgical groups from the baseline to discharge, whereas health status changed minimally in either group. Statistically significant differences were not found for treatment group (surgery/no surgery; surgical type), body mass index, therapy referral, workers' compensation, or litigation status.

Correlations

The DASH and Work-DASH correlated strongly ($r = 0.781$). The SF8-Physical scale correlated with the DASH ($r = 0.699$) and Work-DASH ($r = 0.707$). The SF8-Mental scale correlated moderately with all outcome measures ($r = 0.308$-0.400). Work status, ability to do household chores, pain, depression, stress at home, ability to cope with stress at home, effects on relationships, and pain management referral correlated with all outcome measures. Of the 27 independent variables examined, 23 variables correlated with at least one of the four outcomes measures at $P \leq .05$ in the univariate analyses. The variables that were significant in the univariate analysis were therefore included in the multivariate regression.

Multivariate models

The variable “off work” is the only variable that remained in three of the four final multivariate models. Household management, pain, depression, and stress remained in two models (Table 3). Five variables predicted 55% of the variance in disability at

Table 2
Disability and work disability scores from the baseline to discharge: group comparisons (total $n = 364$)

Patient group	Initial DASH	Discharge DASH	Change	$n=$	Initial Work-DASH	Discharge Work-DASH	Change	$n=$
Entire sample	43.1	34.0	9.1	293	55.6	42.8	12.8	192
Surgery								
Yes	43.9	34.4	9.5	235	55.0	41.8	11.8	149
No	40.4	33.3	7.1	58	57.9	45.6	8.6	43
Work [a]								
Full duty	34.0	25.9	8.1	114	46.8	34.6	12.2	101
Light duty	41.5	30.2	11.3	37	62.8	51.1	11.7	31
Off work	58.9	47.0[b]	11.9	37	91.4	79.3[b]	21.1	26
Diagnosis								
Median nerve compression	39.6	30.4	9.2	65	49.5	33.2	16.3	49
Ulnar neuropathy	43.5	34.0	9.5	100	55.2	42.9[b]	12.3	63
Median and ulnar compression	48.0	39.4	8.6	53	68.5	51.1	17.4	29
Radial nerve palsy	31.9	25.7	6.2	29	44.9	34.2	10.7	20
Thoracic outlet syndrome	41.4	33.5	7.9	15	71.5	52.1	19.4	13
Brachial plexopathy	50.2	42.2[b]	8.0	31	56.7	62.5[b]	−5.8	18
Symptom duration								
Fewer than 6 months	46.2	32.6	13.6	105	54.9	36.0	18.9	65
6-18 months	40.7	37.6	3.1	58	57.7	54.6[b]	3.1	39
Greater than 18 months	41.9	34.6	7.3	130	55.2	42.6	12.6	88
Type of onset								
Sudden	49.2	36.9	12.3	138	62.4	49.1[b]	13.3	93
Slow, progressive	38.3	32.8	5.5	115	50.1	38.8[b]	11.3	74

Mann–Whitney U or Kruskal–Wallis test with Bonferroni correction were used for analyses.
[a] Based on the number of employed patients with complete data for work status and DASH.
[b] $P < .05$.

discharge: depression, off work, pain, interpersonal problems, and grip strength. In Table 3, the high beta value of 13.212 recorded for patients who were off work highlights the large influence work status has on disability scores. Five variables predicted 46% of work disability: household management, depression, difficulty sleeping, stress at home, and brachial plexopathy. Three variables predicted 53% of physical health status: pain, household management, and off work. Three variables predicted 35% of mental health status: stress at home, ability to cope with stress, and off work. In summary, the variables in our multivariate models were unable to predict 45% to 65% of the variance in our sample's discharge scores on the outcome measures.

Discussion

Our sample demonstrated significant improvements after surgical and nonsurgical treatment by a nerve specialist, including 1) lower disability and work disability, 2) decreased pain, depression, and stress, and 3) improved sleep and performance of household chores. Outcome scores improved among those who were working full duty, modified duty, and off work. However, fewer than half of employed patients returned to work. The present study highlights the role of timing after nerve injury and its relationship to functional recovery. We found that patients demonstrated larger improvements in disability scores if they had an onset of injury that

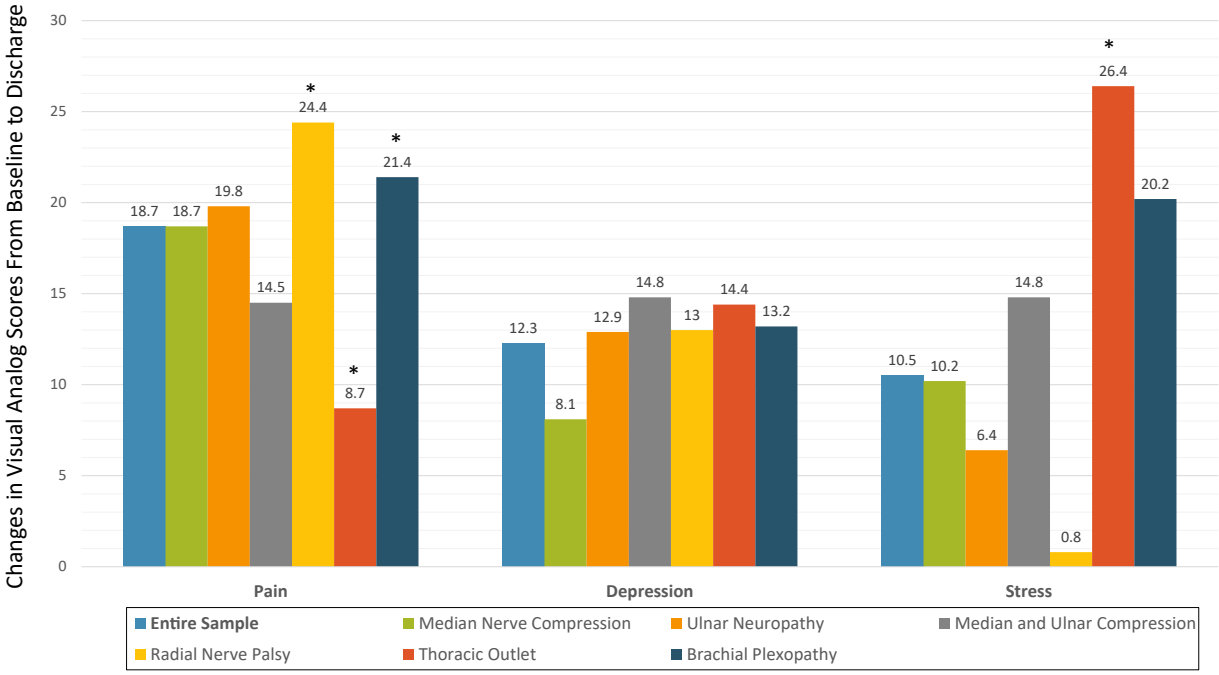

Figure 1. Improvements in psychosocial outcomes. Graph represents the *change* in visual analog scores from baseline to discharge among the whole sample and by diagnosis. * $P < .05$.

Table 3
Final stepwise linear regression models: disability and health status at discharge ($n = 364$)

Disability ($R^2 = .550$)			Work disability ($R^2 = .459$)		
Step	Variable	β	Step	Variable	β
1	Depression	.290[a]	1	Household management	9.197[a]
2	Off work	13.212[a]	2	Depression	.398[a]
3	Pain	.341[a]	3	Difficulty sleeping	2.991[a]
4	Interpersonal problems	9.006[a]	4	Stress at home	.274[a]
5	Grip strength	−0.161[a]	5	Brachial plexopathy	8.845[a]
Physical health status ($R^2 = .531$)			Mental health status ($R^2 = .349$)		
Step	Variable	β	Step	Variable	β
1	Pain	.444[a]	1	Stress at home	.192[a]
2	Household management	8.663[a]	2	Ability to cope with stress	.555[a]
3	Off work	9.871[a]	3	Off work	7.800[a]

Variables with that correlated with the outcome variable at 0.5 or higher were put into the model.
[a] $P < .001$; R^2 = coefficient of determination; β = unweighted Beta coefficient.

was fewer than six months and/or an onset that was sudden (as opposed to slow/progressive). These findings correspond with prior research, suggesting that long delays in operative or nonoperative treatment can compromise outcomes.[26-28] Similarly, Novak (2011) found that the time from onset largely predicted DASH scores among patients with PNI.[16]

Despite the improvements found after treatment, disability and work disability remained above the general population norms[29] at discharge, suggesting higher than average disability, and average pain ratings were 35 on a 100-point scale. Similar results have been documented in smaller, homogenous samples of patients with PNI. Liu and colleagues found a 12-point decrease in pain and disability after nerve transfer surgery in 37 young males with brachial plexus injuries,[30] which is consistent with the 11.5-point decrease found in our sample of patients with brachial plexopathy after nerve transfer. Stutz and colleagues found decreased pain and disability following both operative and nonoperative management of cubital tunnel in 35 adolescents.[31] Similar to our cohort of patients with ulnar neuropathy, surgical patients experienced greater improvements in disability and pain, yet their pretreatment ratings were higher than the nonsurgical group.[31] Despite improvements in outcome scores, data suggest that many patients will continue to have symptoms, impairments, and disabilities after discharge, pointing to the importance of long-term self-management, maintenance of functional gains, and prevention of further nerve damage.

Employment and work status emerged as the most poignant factors in this research. Patients who were off work had higher disability, pain, depression, and stress, and poorer physical and mental health. Patients who maintained modified work roles experienced much lower disability and work disability at discharge than patients who were off work. Maintaining work roles was a predictor in three of the four final multivariate models: disability, physical health, and mental health. Helping patients continue to perform their jobs to some extent is an important facet of medical management that should be emphasized when treating patients with PNI.

The diagnosis of brachial plexopathy was a final predictor in the work disability multivariate model. Compared with other diagnoses, patients with brachial plexopathy demonstrated significantly higher disability and work disability at discharge. Similarly, those with thoracic outlet syndrome had the smallest improvements in pain. These findings emphasize that patients with proximal nerve involvement may require more extensive medical care to reach their goals and achieve satisfactory work performance. Household management was the top predictor of work disability in this research, and it was also the top predictor of baseline disability scores in our previous study.[4] These results suggest that helping patients learn strategies that make it possible to perform daily household activities may impact long-term outcomes in this population.

In recent years, there has been emerging evidence that depression predicts long-term outcomes in patients with PNI, including disability,[32] quality of life,[32] and patient satisfaction.[33] Depression was the top predictor of disability in this study, which suggests a role for routine monitoring of depressive symptoms in patients with PNI. As a final predictor in both the work disability and mental health multivariate models, stress emerged as an important construct that is just beginning to be explored in this population. Patients with mixed median and ulnar compression had the highest stress levels at the baseline and discharge, which is contradictory to other research indicating those with nerve compressions have lower stress and anxiety compared with more severe conditions such as brachial plexopathy.[34] People with isolated median nerve compression had the smallest improvements in depression, which may be tied to their lower baseline scores compared with other diagnoses. We did not aim to identify the causes of stress reported by our sample nor explore the role of stress in pain, depression, or disability ratings. We believe that the relationship between emotional constructs, such as depression and stress, and outcomes deserves further examination in this population. Our finding that pain was a significant predictor of discharge disability, work disability, and physical health corresponds with prior research.[17,18,32] Neuropathic pain remains a factor that should be emphasized both clinically and in future research.

This research was adequately powered to identify differences in disability and health status in our sample; however, we may have been underpowered to find statistical significances between subgroups, for example, workers' compensation, litigation, and treatment received (surgical/nonsurgical; type of surgery). We were unable to confirm if patients followed through with therapy or pain management referrals. In addition, we did not have access to the degree of nerve damage and/or results of electrodiagnostic testing, so this variable was therefore unable to be used as a predictor of outcomes. The pain questionnaire used in this research has not undergone thorough psychometric evaluation,[19] but has been cited several times in prior research.[16,34,35] The strengths of this research include the large sample size resulting in six well-represented diagnostic groups and six surgical groups, and our ability to build four predictive models using standardized outcome measures commonly used in clinical practice.

Conclusions

To address the multifaceted issues that impact long-term outcomes of patients with PNI, health care professionals must expand beyond the sensorimotor and structural impairments that are commonly the focus of care with this population. It is recommended that screening for emotional status become a part of routine care, as well as discussion of problems performing everyday activities and fulfilling home, community, and work roles. Collaborative models of care that can better address the wide range of factors impacted in patients with PNI should be explored and tested in clinical trials.

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1. Study design is
   a. RCTs
   b. case series
   c. prospective cohort
   d. retrospective cohort

2. Disability was highest in patients with
   a. ulnar nerve injuries
   b. median nerve injuries
   c. brachial plexus injuries
   d. combined lower ulnar and median nerve injuries

3. Outcomes were
   a. not statistically different between surgical and nonsurgical patients
   b. better for surgical patients
   c. better for nonsurgical patients
   d. inconsistent

4. Disability improved most in patients who
   a. had good insurance coverage
   b. returned to work
   c. received adequate support from their spouse
   d. received hand therapy on a TIW basis

5. The authors identified numerous emotionally related complications
   a. false
   b. true

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