Published in final edited form as:

Hand Clin. 2013 August ; 29(3): 349–361. doi:10.1016/j.hcl.2013.04.004.

How to Measure Outcomes of Peripheral Nerve Surgery

Yirong Wang, MD¹, Malay Sunitha, MPH², and Kevin C. Chung, MD, MS³

¹Plastic Surgery Hospital, Peking Union Medical College, Chinese Academy of Medical Science, Beijing

²Clinical Research Coordinator, Section of Plastic Surgery, Department of Surgery, The University of Michigan Health System; Ann Arbor, MI

³Professor of Surgery, Section of Plastic Surgery, Assistant Dean for Faculty Affairs, The University of Michigan Medical School

Synopsis

Evaluation of outcomes after peripheral nerve surgeries include a number of assessment methods that reflect different aspects of recovery, including reinnervation, tactile gnosis, integrated sensory and motor function, pain and discomfort, neurophysiological and patient-reported outcomes. This review makes a list of measurements addressing these aspects as well as advantage and disadvantage of each tool. Because of complexities of neurophysiology, assessment remains a difficult process, which requires researchers focus on measurements best relevant to specific conditions and research questions.

Keywords

Peripheral nerve; Hand surgery; Outcomes assessment

The outcomes movement, initiated in 1988 was stimulated by the national emphasis on cost containment and efforts to limit geographic differences in the use of various medical procedures.¹⁻³ Goals of the outcomes movement included “increased understanding of the effectiveness of different interventions, the use of this information to make possible better decision making by physicians and patients, and the development of standards to guide physicians and aid third-party payers in optimizing the use of resources, by investigating and comparing patient experiences.”^{1,4} Patient experiences can range from mortality, physiologic measures, reduction of symptoms, improvement in daily functioning, clinical events, to patient satisfaction.^{4,5} The outcomes chosen to evaluate care need to be carefully considered based on criteria that are most pertinent to the patient’s need. Additionally vital are the criteria for selecting outcome measurement instruments, which comprise of reliability, validity, and responsiveness of measures, their clinical utility, and relationship to the care under investigation.⁵

© 2013 Elsevier Inc. All rights reserved.

Corresponding Author: Kevin C. Chung, MD, MS, Section of Plastic Surgery, University of Michigan Health System, 2130 Taubman Center, SPC 5340, 1500 E. Medical Center Drive, Ann Arbor, MI, 48109-5340, kecchung@umich.edu, Phone 734-936-5885, Fax 734-763-5354.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Peripheral nerve injuries can be caused by trauma, accidental injuries during extensive surgery, nerve tumors, compressive disease or congenital anomalies, with the majority (81%) located on upper extremity.^{6,7} Among upper or lower-limb trauma, incidence of nerve injuries is reported to be 1.64%, with crush injuries having the highest rate at 1.9%.⁸ These injuries may lead to irreversible disabilities in patients, such as sensory loss, deficient motor function, pain problems in terms of cold intolerance and hyperesthesia, that ultimately impair hand function, and affect quality of life at work and in society.⁷ Despite marked advances in the neuroscience arena, peripheral nerve injuries continue to pose challenges for surgical reconstruction, as the clinical outcomes still appear unsatisfactory.^{6,7} Advances in this field will require accurate measures of treatment effectiveness to assess new treatments that are certainly on the horizon.

The assessment of recovery after peripheral nerve surgery remains a challenging process to therapists and surgeons. Numerous cellular and biochemical mechanisms that occur in peripheral and central nervous systems affect the outcomes and result in difficult evaluation of recovery.⁹ Measurement instruments for peripheral nerve surgery need to aid clinical diagnosis, assess and compare surgical repair techniques, track rehabilitation progress, provide feedback to both patient and therapist, as well as ascertain disability after injury.⁹ The list of objectives useful in evaluation of hand function after peripheral nerve repair is provided in Table 1. Outcomes research after nerve injury recently emphasizes more on functional results and patient-reported outcomes.¹⁰⁻¹³ This review focuses on the scope of outcomes assessment tools and the current choices of measurements in outcomes research of peripheral nerve surgery. Table 2 details available methods for assessing patient outcomes after peripheral nerve surgeries.

Outcomes Assessment

Outcomes assessment in peripheral nerve injuries can be broadly categorized into tests of sensory function, motor function, pain and discomfort, neurophysiological and patient-reported outcomes.

Sensory function

Sensory tests indicate the sensory acuity of the hand and how well the patient is able to use it.¹⁴ *Semmes-Weinstein monofilament test* is used to assess perception of cutaneous pressure threshold, which reflect reinnervation of peripheral targets.¹⁵ Compared with using a common tuning fork, the test provides quantitative data that can be used to follow a patient serially during the course of nerve regeneration.¹⁶ Tactile gnosis is the capability of the hand to recognize the character of objects, such as shapes, textures, and is a prime marker of functional recovery.¹⁷

Two-point discrimination (2-PD) is an established assessment tool for tactile gnosis.¹⁷ *The static two-point discrimination test (S2-PD)* measures the innervation density of the slowly-adapting receptor (fire continuously as long as pressure is applied) population.¹⁴ One study showed an age-related decline in the ability to discriminate two points and there was no significant difference between men and women.¹⁸ *The moving two-point discrimination test (M2-PD)* relies on the quickly-adapting receptor system (fire at onset and offset of stimulation), which recover sooner and in larger numbers.¹⁹ The threshold values are lower than those of the static test.²⁰ 2-PD outcome in nerve repair studies, however, is reported to be extremely variable, because there is a lack of standardization of the technique and the test is probably performed in different ways by different authors.²¹ It is a serious problem because the test is frequently used to compare different nerve repair techniques. Therefore, when 2PD results are reported in a study, a detailed and referenced description, especially the pressure applied and the testing protocol should be mandatory.²¹ Dellon has introduced a

Pressure-Specifying Sensory Device (PSD) to provide a standardized pressure, however it may be difficult to use this technique in routine clinical practice.²² 2PD test is not recommended as the only instrument to monitor sensory function. Localization of touch, and identification based on active touching are also recommended to be assessed for an over-all evaluation of sensory function.²¹ Other functional sensory tests include shape, texture identification,^{23,24} vibration, and temperature perception, sharp and dull discrimination, and thickness discrimination.^{25,26} These tests are timed and the results are converted into scores in multiple ways.²³⁻²⁶

Medical Research Council scale, published in 1954,²⁷ is commonly used, by including 2-PD for grading the sensory outcome after peripheral nerve surgery.^{17,23,28} This scale is categorized into S0-S4: S0 is the absence of sensibility; S1 is the recovery of deep cutaneous pain; S2 is the return of superficial cutaneous pain and some degree of tactile sensibility; S3 is the return of superficial cutaneous pain and tactile sensibility without over response; and S4 is the complete recovery.²³ This scale has also been criticized because it is based on subjective findings and vague nonstandardized data. It is recommended to be used with additional evaluation of motor recovery and pain.²³ Moberg proposed the *pick-up test* as an objective method to measure integrated function of the hand by scoring both the speed and accuracy of identification of the test objects.^{24,29}

Finger dexterity

The Sollerman hand function test consists of 20 activities that replicate the main hand grips in daily living, and is used to evaluate the quality of basic grip types.³⁰ Each subtest is scored depending on the quality of the hand grip and patient's difficulty in performing the task.⁹ This test can reflect integrated sensory and motor functions.⁹

Motor function

Manual muscle testing (MMT) is used to assess motor innervation using *British Medical Research Council muscle strength grading*.³¹ It can be conducted to assess larger muscles or muscle groups as well as intrinsic muscles of the hand. For median nerve, palmar abduction in the thumb is evaluated. For ulnar nerve, abduction in index, small finger, and adduction in small finger are tested.^{23,31} Brandsma made some modifications to the MRC grades definitions, which were defined by range of motion and resistance, and made it more practical for intrinsic muscles of the hand.³¹ Assessment of *grip strength* with dynamometry is a most common method of reporting motor outcome.³² Power grip requires synergistic function of intrinsic and extrinsic muscles of the hand, so it is difficult to determine muscle dysfunction in isolation with this test.⁴ It is also influenced by pain or increased sensitivity to pressure over the pillar region or scar, and should not be used where tissue healing is incomplete and testing would cause pain.³² *Pinch strength* tests include key pinch, tip pinch and tripod pinch. Tip pinch and tripod pinch dynamometry more specifically target the thenar musculature and appears to be more responsive for assessing motor function after carpal tunnel release, compared with grip and key pinch strength test.³²

Pain and discomfort

Pain is associated with disability in patients after peripheral nerve injury.³³ The evaluation of pain will always be a self-report by patients. *Numerical Rating Scale (NRS) for pain* and *Pain Visual Analog Scale (PVAS)* are used to determine pain intensity and are easy to use. However, there are some deficiencies about these measurements.³⁴ First, it assumes that pain is a linear continuous phenomenon, which is not tenable in most cases. Second, all patients cannot respond to these scales in a uniform manner, because of the high variability in the pain they experience.³⁴ *McGill Pain Questionnaire* is a multidimensional pain scale which provides much more information on dimensions of pain beyond the simple factor of

intensity, such as sensory components (tingling and hypersensitivity) as well as affective responses to pain.³³⁻³⁶ However, it is a long questionnaire and imposes a larger burden on patients and might be less responsive than VAS.³⁴ *The Pain Disability Index* assesses the impact of pain on life domains.³³ It includes seven categories of life activity: family/ home responsibility, recreation, social activity, occupation, sexual behavior, self-care and life support activity.³⁷ Consistency, validity and reliability of this questionnaire were tested and proved to be useful in nerve injury studies.³³ In patients with chronic nerve injury, pain intensity is only one component of pain, and the impact of pain in the disability should also be considered.³³ A clear understanding of the goal of the research question will help determine which measurement is appropriate.

Cold sensitivity is a complex symptom, which may present as pain, numbness, stiffness, weakness, swelling and change in skin color. *The Cold Sensitivity Severity Scale* (CSS) is used to evaluate sensitivity of cold intolerance during daily life.³⁸ *Potential Work-Exposure Scale* assesses exposure in the work place.³⁸ The CSS scale, in conjunction with *Potential Work-Exposure Scale* can be used to predict the likelihood of the patient's return to pre-injury employment.³⁹ The reliability and validity of these two questionnaires have been demonstrated in the development phase and in other studies.^{38,39} *The Cold Intolerance Symptom Severity questionnaire* is a reliable and valid measurement with the threshold value for pathological cold intolerance of 30⁴⁰ and 50 for population with Scandinavian climate.⁴¹

Neurophysiological outcome measurements

Neurophysiological examinations include electroneurography (ENG), also known as nerve conduction studies (including sensory nerve conduction velocity and amplitude, motor nerve velocity, distal motor latency), and electromyography (EMG). They measure the electrical activity of muscles and nerves, and are the primary studies used to gain information on the location, number, and pathophysiology of lesions affecting the peripheral nerve.⁴² In evaluation of carpal tunnel syndrome (CTS), distal motor latency (DML) and sensory nerve conduction velocity (SCV) are often performed. American Association of Electrodiagnostic Medicine, American Academy of Neurology, and the American Academy of Physical Medicine and Rehabilitation published the parameters for performing CTS electrodiagnostic (EDX) testing to address the best EDX studies to confirm the diagnosis and guide clinical researches.⁴³ Studies of ENG in CTS patients have presented contradictory results between neurophysiological findings, patient symptoms and clinical improvements.⁴⁴⁻⁴⁷ However, they did not refute the necessity of conducting ENG when evaluating patients with CTS.⁴⁴⁻⁴⁷ Grading scales for the neurophysiological changes of median nerve entrapment were also introduced to facilitate comparison of the severity of the disease.^{47,48} A study showed that both ENG and patient-oriented questionnaires were highly responsive to treatment of CTS, but no correlation was observed between them. Therefore both outcome measurements are recommended to provide a multifaceted assessment.⁴⁹ ENG test can also be used to evaluate outcomes of nerve grafting,⁵⁰ nerve repair,²⁵ and cubital tunnel syndrome.^{51,52} Patients showed continued improvement in sensory and motor nerve conduction velocity even beyond 2 years in cubital tunnel syndrome.⁵¹ In brachial plexus injury, EMG is commonly used to evaluate muscle reinnervation.⁵³

Patient reported outcomes

There is a shift towards using patient-reported outcome with valid and reliable measurement tools in hand surgery. In a systematic review of hand surgery outcomes studies, quality of life outcomes were reported in 31% of the studies, comprising of symptoms, patient satisfaction, and time to return to work and data from quality-of-life-related questionnaires.² Questionnaires commonly used in peripheral nerve surgery outcome studies include Short

Form 36, Disability of the Arm, Shoulder and Hand (DASH), Boston Carpal Tunnel questionnaire (BQ or CTQ), the Michigan Hand Outcomes Questionnaire (MHQ), Stothard and Kamath questionnaire.

The Short Form- 36 (SF-36) is a validated measure for patient's functional health and quality of life, to assess the extent to which a patient's day-to-day life is affected by their health.⁵⁴ It includes 8 domains: physical functioning, social functioning, role limitations due to physical functioning, role limitations due to emotional problems, energy and vitality, mental health, bodily pain, and general perception of health.⁵⁵ Although a general health assessment questionnaire and not sensitive enough to evaluate regional conditions,¹³ SF-36 is used in combination with other region specific questionnaires to evaluate peripheral nerve injury. In Novak's study, SF-36 bodily pain is proved to be a predictor of the DASH score, indicating that long-term disability in patients after nerve injury can be predicted by more pain.¹⁰ Other studies used SF-36 to evaluate functional outcome by assessing quality of life.^{11,54}

DASH questionnaire is designed to measure disability for any region of the upper extremity and can be used for single or multiple disorders.⁵⁶ It consists of 30 core questions and an optional additional 8 questions assessing work, sports and performing arts activities, with a higher score indicating more disability.⁵⁶ The DASH score is a subjective instrument to estimate the patient's view of disability.⁵⁷ It is used for evaluation of brachial plexus surgery,^{11,58,59} nerve transfer, peripheral neuromas surgery,⁶⁰ nerve repair,¹¹ carpal tunnel release,⁶¹ and ulnar nerve transposition.⁶² The QuickDASH was developed in 2005 to minimize time and responder burden.⁶³ It demonstrated reliability, validity and responsiveness when used for patients with either a proximal or distal disorder of the upper extremity. Compared to DASH, it is a more efficient version and retains its measurement properties.⁶³

Boston carpal tunnel questionnaire (Levine and Katz questionnaire) is a self-administered questionnaire for the assessment of severity of symptoms and functional status in patients who have carpal tunnel syndrome.⁶⁴ It consists of symptom severity and functional status subscales. The first scale includes 11 questions of pain, altered sensibility and weakness. The second assesses the patient's self-reported ability to perform 8 tasks.⁵⁶ It is proved to be useful in quantifying severity of symptoms and functional state of patients before and after surgery. But it was not possible to predict the outcome results in CTS from the preoperative scores because there was no statistically significant relationship between them.⁶⁵ A study indicates that BQ score at 2 weeks is a reliable, responsive and practical instrument for outcome measure in carpal tunnel surgery, and it is equivalent to 6 months postoperative score.⁶⁶ The questionnaire has also been used to identify potential prognostic factors influencing outcome,⁴⁷ and predictor of scar pain after carpal tunnel release.⁶⁷ In relation with objective measurements, both scales had a positive, but modest or weak correlations with 2-PD and Semmes-Weinstein monofilament testing,⁶⁴ and no relation with nerve conduction studies pre and postoperatively.^{65,68,69} Some authors recommend that BQ and nerve conduction data should be used together to monitor CTS patients.⁶⁵

The Michigan Hand Outcomes Questionnaire (MHQ) is a 37-item self-assessment instrument that measures disability along 6 domains: function, activities of daily living, pain, hand appearance, patient satisfaction, and work disability.⁷⁰ It is used to assess different hand disorders, including carpal tunnel syndrome (CTS). In assessing CTS, the MHQ is more specific than the DASH, because it has questions only relating to the hand, and can measure symptom and function separately. It is more versatile than BQ but also less specific, because questions relating to pain are not phrased explicitly for CTS, such as tingling and numbness. MHQ may be more useful when independent score from multiple

domains are required or when comparison with an unaffected control hand is needed. A study also revealed that the MHQ might be more sensitive to functional changes; the DASH seems more correlated with disability days.⁷¹

Summary

Because of the complexities of neurophysiology, assessment of recovery after peripheral nerve surgery remains a complex process to therapists and surgeons. A combination of tests, which correlate with neurophysiological parameters and integrated hand function, are required to provide a valid, reproducible and comprehensive assessment of outcomes. Measurement instruments for peripheral nerve surgery generally include sensory tests, motor function tests, integrated hand function tests, pain and discomfort assessments, neurophysiological outcome measurements, and patient reported outcomes. With a plethora of tests to choose from, researchers need to focus on measurements best relevant to specific conditions and research questions. These data will help researchers have a better understanding of the recovery process and provide the best possible outcomes for the patients.

Acknowledgments

Supported in part by a Midcareer Investigator Award in Patient-Oriented Research (K24 AR053120) from the National Institute of Arthritis and Musculoskeletal and Skin Diseases (to Dr Kevin C. Chung).

References

1. Epstein AM. The outcomes movement--will it get us where we want to go? *N Engl J Med.* 1990; 323:266–70. [PubMed: 2366836]
2. Chung KC, Burns PB, Davis Sears E. Outcomes research in hand surgery: where have we been and where should we go? *The Journal of hand surgery.* 2006; 31:1373–9. [PubMed: 17027802]
3. Relman AS. Assessment and accountability: the third revolution in medical care. *The New England journal of medicine.* 1988; 319:1220–2. [PubMed: 3173460]
4. Waljee JF, Chung KC. Outcomes research in rheumatoid arthritis. *Hand clinics.* 2011; 27:115–26. [PubMed: 21176806]
5. Greenfield S. The state of outcome research: are we on target? *The New England journal of medicine.* 1989; 320:1142–3. [PubMed: 2710176]
6. Lundborg G. A 25-year perspective of peripheral nerve surgery: evolving neuroscientific concepts and clinical significance. *The Journal of hand surgery.* 2000; 25:391–414. [PubMed: 10811744]
7. Scholz T, Krichevsky A, Sumarto A, et al. Peripheral nerve injuries: an international survey of current treatments and future perspectives. *Journal of reconstructive microsurgery.* 2009; 25:339–44. [PubMed: 19301234]
8. Taylor CA, Braza D, Rice JB, Dillingham T. The incidence of peripheral nerve injury in extremity trauma. *American journal of physical medicine & rehabilitation / Association of Academic Physiatrists.* 2008; 87:381–5. [PubMed: 18334923]
9. Rosen B. Recovery of sensory and motor function after nerve repair. A rationale for evaluation. *J Hand Ther.* 1996; 9:315–27. [PubMed: 8994006]
10. Novak CB, Anastakis DJ, Beaton DE, Katz J. Patient-reported outcome after peripheral nerve injury. *The Journal of hand surgery.* 2009; 34:281–7. [PubMed: 19181228]
11. Ahmed-Labib M, Golan JD, Jacques L. Functional outcome of brachial plexus reconstruction after trauma. *Neurosurgery.* 2007; 61:1016–22. discussion 22-3. [PubMed: 18091278]
12. Choi PD, Novak CB, Mackinnon SE, Kline DG. Quality of life and functional outcome following brachial plexus injury. *J Hand Surg Am.* 1997; 22:605–12. [PubMed: 9260614]
13. Kitajima I, Doi K, Hattori Y, Takka S, Estrella E. Evaluation of quality of life in brachial plexus injury patients after reconstructive surgery. *Hand Surg.* 2006; 11:103–7. [PubMed: 17405192]

14. Jerosch-Herold C. Measuring outcome in median nerve injuries. *J Hand Surg Br.* 1993; 18:624–8. [PubMed: 8294829]
15. Bell-Krotoski J, Tomancik E. The repeatability of testing with Semmes-Weinstein monofilaments. *The Journal of hand surgery.* 1987; 12:155–61. [PubMed: 3805636]
16. Imai H, Tajima T, Natsuma Y. Interpretation of cutaneous pressure threshold (Semmes-Weinstein monofilament measurement) following median nerve repair and sensory reeducation in the adult. *Microsurgery.* 1989; 10:142–4. [PubMed: 2770515]
17. Shooter D. Use of two-point discrimination as a nerve repair assessment tool: preliminary report. *ANZ J Surg.* 2005; 75:866–8. [PubMed: 16176227]
18. Shimokata H, Kuzuya F. Two-point discrimination test of the skin as an index of sensory aging. *Gerontology.* 1995; 41:267–72. [PubMed: 8537010]
19. Dellon AL. The moving two-point discrimination test: clinical evaluation of the quickly adapting fiber/receptor system. *The Journal of hand surgery.* 1978; 3:474–81. [PubMed: 568154]
20. Menier C, Forget R, Lambert J. Evaluation of two-point discrimination in children: reliability, effects of passive displacement and voluntary movements. *Developmental medicine and child neurology.* 1996; 38:523–37. [PubMed: 8647332]
21. Lundborg G, Rosen B. The two-point discrimination test--time for a re-appraisal? *J Hand Surg Br.* 2004; 29:418–22. [PubMed: 15336741]
22. Dellon ES, Mourey R, Dellon AL. Human pressure perception values for constant and moving one- and two-point discrimination. *Plastic and reconstructive surgery.* 1992; 90:112–7. [PubMed: 1615069]
23. Rosen B, Lundborg G. A model instrument for the documentation of outcome after nerve repair. *J Hand Surg Am.* 2000; 25:535–43. [PubMed: 10811759]
24. Marsh D. The validation of measures of outcome following suture of divided peripheral nerves supplying the hand. *J Hand Surg Br.* 1990; 15:25–34. [PubMed: 2307877]
25. Haug A, Bartels A, Kotas J, Kunesch E. Sensory recovery 1 year after bridging digital nerve defects with collagen tubes. *The Journal of hand surgery.* 2013; 38:90–7. [PubMed: 23261191]
26. Ozkan T, Ozer K, Gulgonen A. Restoration of sensibility in irreparable ulnar and median nerve lesions with use of sensory nerve transfer: long-term follow-up of 20 cases. *The Journal of hand surgery.* 2001; 26:44–51. [PubMed: 11172367]
27. Medical Research Council. Nerve injuries committee: results of nerve suture. In: Seddon, HJ., editor. *Peripheral nerve injuries.* London: Her Majesty's Stationery Office; 1954.
28. Novak CB, Kelly L, Mackinnon SE. Sensory recovery after median nerve grafting. *The Journal of hand surgery.* 1992; 17:59–68. [PubMed: 1311345]
29. Moberg E. Objective methods for determining the functional value of sensibility in the hand. *J Bone Joint Surg Br.* 1958; 40-B:454–76. [PubMed: 13575459]
30. Sollerman C, Ejekær A. Sollerman hand function test. A standardised method and its use in tetraplegic patients. *Scandinavian journal of plastic and reconstructive surgery and hand surgery / Nordisk plastikkirurgisk forening [and] Nordisk klubb for handkirurgi.* 1995; 29:167–76.
31. Brandsma JW, Schreuders TA, Birke JA, Piefer A, Oostendorp R. Manual muscle strength testing: intraobserver and interobserver reliabilities for the intrinsic muscles of the hand. *Journal of hand therapy : official journal of the American Society of Hand Therapists.* 1995; 8:185–90. [PubMed: 8535479]
32. Geere J, Chester R, Kale S, Jerosch-Herold C. Power grip, pinch grip, manual muscle testing or thenar atrophy - which should be assessed as a motor outcome after carpal tunnel decompression? A systematic review. *BMC musculoskeletal disorders.* 2007; 8:114. [PubMed: 18028538]
33. Novak CB, Anastakis DJ, Beaton DE, Mackinnon SE, Katz J. Relationships among pain disability, pain intensity, illness intrusiveness, and upper extremity disability in patients with traumatic peripheral nerve injury. *The Journal of hand surgery.* 2010; 35:1633–9. [PubMed: 20888499]
34. Badalamente M, Coffelt L, Elfar J, et al. Measurement scales in clinical research of the upper extremity, part 1: general principles, measures of general health, pain, and patient satisfaction. *The Journal of hand surgery.* 2013; 38:401–6. [PubMed: 23351912]
35. Melzack R. The McGill Pain Questionnaire: major properties and scoring methods. *Pain.* 1975; 1:277–99. [PubMed: 1235985]

36. Macdermid JC, Richards RS, Roth JH, Ross DC, King GJ. Endoscopic versus open carpal tunnel release: a randomized trial. *The Journal of hand surgery*. 2003; 28:475–80. [PubMed: 12772108]
37. Pollard CA. Preliminary validity study of the pain disability index. Perceptual and motor skills. 1984; 59:974. [PubMed: 6240632]
38. McCabe SJ, Mizgala C, Glickman L. The measurement of cold sensitivity of the hand. *The Journal of hand surgery*. 1991; 16:1037–40. [PubMed: 1748748]
39. Carlsson I, Cederlund R, Hoglund P, Lundborg G, Rosen B. Hand injuries and cold sensitivity: reliability and validity of cold sensitivity questionnaires. *Disability and rehabilitation*. 2008; 30:1920–8. [PubMed: 19061118]
40. Ruijs AC, Jaquet JB, Daanen HA, Hovius SE. Cold intolerance of the hand measured by the CISS questionnaire in a normative study population. *J Hand Surg Br*. 2006; 31:533–6. [PubMed: 16808991]
41. Carlsson IK, Nilsson JA, Dahlin LB. Cut-off value for self-reported abnormal cold sensitivity and predictors for abnormality and severity in hand injuries. *The Journal of hand surgery, European volume*. 2010; 35:409–16.
42. Harper CM. Preoperative and intraoperative electrophysiologic assessment of brachial plexus injuries. *Hand clinics*. 2005; 21:39–46. vi. [PubMed: 15668064]
43. Jablecki CK, Andary MT, Floeter MK, et al. Practice parameter: Electrodiagnostic studies in carpal tunnel syndrome. Report of the American Association of Electrodiagnostic Medicine, American Academy of Neurology, and the American Academy of Physical Medicine and Rehabilitation. *Neurology*. 2002; 58:1589–92. [PubMed: 12058083]
44. Higgs PE, Edwards DF, Martin DS, Weeks PM. Relation of preoperative nerve-conduction values to outcome in workers with surgically treated carpal tunnel syndrome. *The Journal of hand surgery*. 1997; 22:216–21. [PubMed: 9195417]
45. Bronson J, Beck J, Gillet J. Provocative motor nerve conduction testing in presumptive carpal tunnel syndrome unconfirmed by traditional electrodiagnostic testing. *The Journal of hand surgery*. 1997; 22:1041–6. [PubMed: 9471073]
46. Padua L, Pazzaglia C, Caliandro P, et al. Carpal tunnel syndrome: ultrasound, neurophysiology, clinical and patient-oriented assessment. *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology*. 2008; 119:2064–9. [PubMed: 18620908]
47. Gong HS, Oh JH, Bin SW, Kim WS, Chung MS, Baek GH. Clinical features influencing the patient-based outcome after carpal tunnel release. *The Journal of hand surgery*. 2008; 33:1512–7. [PubMed: 18984332]
48. Bland JD. A neurophysiological grading scale for carpal tunnel syndrome. *Muscle & nerve*. 2000; 23:1280–3. [PubMed: 10918269]
49. Itsubo T, Uchiyama S, Momose T, Yasutomi T, Imaeda T, Kato H. Electrophysiological responsiveness and quality of life (QuickDASH, CTSI) evaluation of surgically treated carpal tunnel syndrome. *Journal of orthopaedic science : official journal of the Japanese Orthopaedic Association*. 2009; 14:17–23. [PubMed: 19214683]
50. Yamano Y. Electrophysiological study of nerve grafting. *The Journal of hand surgery*. 1982; 7:588–92. [PubMed: 6757312]
51. Matsuzaki H, Yoshizu T, Maki Y, Tsubokawa N, Yamamoto Y, Toishi S. Long-term clinical and neurologic recovery in the hand after surgery for severe cubital tunnel syndrome. *The Journal of hand surgery*. 2004; 29:373–8. [PubMed: 15140474]
52. Svernlöv B, Larsson M, Rehn K, Adolfsson L. Conservative treatment of the cubital tunnel syndrome. *The Journal of hand surgery, European volume*. 2009; 34:201–7.
53. Zheng MX, Xu WD, Qiu YQ, Xu JG, Gu YD. Phrenic nerve transfer for elbow flexion and intercostal nerve transfer for elbow extension. *The Journal of hand surgery*. 2010; 35:1304–9. [PubMed: 20619558]
54. Dolan RT, Butler JS, Murphy SM, Hynes D, Cronin KJ. Health-related quality of life and functional outcomes following nerve transfers for traumatic upper brachial plexus injuries. *The Journal of hand surgery, European volume*. 2012; 37:642–51.

55. McHorney CA, Ware JE Jr, Raczek AE. The MOS 36-Item Short-Form Health Survey (SF-36): II. Psychometric and clinical tests of validity in measuring physical and mental health constructs. *Medical care*. 1993; 31:247–63. [PubMed: 8450681]
56. Smith MV, Calfee RP, Baumgarten KM, Brophy RH, Wright RW. Upper extremity-specific measures of disability and outcomes in orthopaedic surgery. *J Bone Joint Surg Am*. 2012; 94:277–85. [PubMed: 22298061]
57. Vordemvenne T, Langer M, Ochman S, Raschke M, Schult M. Long-term results after primary microsurgical repair of ulnar and median nerve injuries. A comparison of common score systems. *Clinical neurology and neurosurgery*. 2007; 109:263–71. [PubMed: 17175096]
58. Kretschmer T, Ihle S, Antoniadis G, et al. Patient satisfaction and disability after brachial plexus surgery. *Neurosurgery*. 2009; 65:A189–96. [PubMed: 19927067]
59. Liu Y, Lao J, Gao K, Gu Y, Zhao X. Functional outcome of nerve transfers for traumatic global brachial plexus avulsion. *Injury*. 2012
60. Guse DM, Moran SL. Outcomes of the Surgical Treatment of Peripheral Neuromas of the Hand and Forearm: A 25-Year Comparative Outcome Study. *Annals of plastic surgery*. 2012
61. Kadzielski J, Malhotra LR, Zurakowski D, Lee SG, Jupiter JB, Ring D. Evaluation of preoperative expectations and patient satisfaction after carpal tunnel release. *The Journal of hand surgery*. 2008; 33:1783–8. [PubMed: 19084178]
62. Fitzgerald BT, Dao KD, Shin AY. Functional outcomes in young, active duty, military personnel after submuscular ulnar nerve transposition. *The Journal of hand surgery*. 2004; 29:619–24. [PubMed: 15249085]
63. Beaton DE, Wright JG, Katz JN. Development of the QuickDASH: comparison of three item-reduction approaches. *J Bone Joint Surg Am*. 2005; 87:1038–46. [PubMed: 15866967]
64. Levine DW, Simmons BP, Koris MJ, et al. A self-administered questionnaire for the assessment of severity of symptoms and functional status in carpal tunnel syndrome. *The Journal of bone and joint surgery American volume*. 1993; 75:1585–92. [PubMed: 8245050]
65. Mondelli M, Reale F, Sicurelli F, Padua L. Relationship between the self-administered Boston questionnaire and electrophysiological findings in follow-up of surgically-treated carpal tunnel syndrome. *J Hand Surg Br*. 2000; 25:128–34. [PubMed: 11062567]
66. Mallick A, Clarke M, Kershaw CJ. Comparing the outcome of a carpal tunnel decompression at 2 weeks and 6 months. *The Journal of hand surgery*. 2007; 32:1154–8. [PubMed: 17923295]
67. Kim JK, Kim YK. Predictors of scar pain after open carpal tunnel release. *The Journal of hand surgery*. 2011; 36:1042–6. [PubMed: 21636023]
68. Green TP, Tolonen EU, Clarke MR, et al. The relationship of pre- and postoperative median and ulnar nerve conduction measures to a self-administered questionnaire in carpal tunnel syndrome. *Neurophysiologie clinique = Clinical neurophysiology*. 2012; 42:231–9. [PubMed: 22632871]
69. Heybeli N, Kutluhan S, Demirci S, Kerman M, Mumcu EF. Assessment of outcome of carpal tunnel syndrome: a comparison of electrophysiological findings and a self-administered Boston questionnaire. *J Hand Surg Br*. 2002; 27:259–64. [PubMed: 12074615]
70. Chung KC, Pillsbury MS, Walters MR, Hayward RA. Reliability and validity testing of the Michigan Hand Outcomes Questionnaire. *The Journal of hand surgery*. 1998; 23:575–87. [PubMed: 9708370]
71. Horng YS, Lin MC, Feng CT, Huang CH, Wu HC, Wang JD. Responsiveness of the Michigan Hand Outcomes Questionnaire and the Disabilities of the Arm, Shoulder, and Hand questionnaire in patients with hand injury. *J Hand Surg Am*. 2010; 35:430–6. [PubMed: 20138712]

Key Points

- Outcomes assessment tools and the current choices of measurements in outcomes research of peripheral nerve surgery
- Several aspects relating to function, pain, and patient perception of outcomes are evaluated after peripheral nerve repair
- Choice of specific measures depend on the researchers' interest and the disease or treatment under investigation

Table 1List of Objectives to Evaluate Hand Function after Peripheral Nerve Repair^{*}

	Name of the objective	Objective
1.	Reinnervation	To demonstrate regeneration of the nerve and reinnervation of muscles and cutaneous receptors
2.	Tactile Gnosis	To determine the ability to interpret the new sensory input
3.	Dexterity, Grip strength and ADL capacity	To assess skills requiring integrated sensory and motor functions of the hand
4.	Pain, Discomfort	To quantify the degree of pain and discomfort in terms of hypersensitivity and cold intolerance

^{*} Adapted from Rosen B. Recovery of sensory and motor function after nerve repair. A rationale for evaluation. Journal of hand therapy : official journal of the American Society of Hand Therapists 1996;9:315-27

Table 2
Outcomes Assessment Tools for Measuring Outcomes after Peripheral Nerve Surgeries

Measurement	Characteristics								
Sensory Function									
The static two-point discrimination test (S2-PD) ^{14,18}	The minimal distance at which two points can be discriminated is measured. The two points of a caliper are applied at the same time using the weight of the caliper alone. ("Just blanching the skin" ²¹)	Normal values (Age, years)	10-19	20-29	30-39	40-49	50-59	60-69	70-79
		Men (mm) (Mean ± SD)	6.1±2.7	6.7±2.5	7.2±3.6	7.9±2.6	8.8±4.9	9.3±3.8	9.1±2.7
		Women (mm) (Mean ± SD)	6.5±2.5	7.5±4.0	7.6±3.1	8.1±3.1	9.0±3.4	9.3±3.7	10.9±4.8
		ASSH classification: less than 6mm is normal, 6 to 10mm is fair, and 11 to 15mm is poor. ⁷²							
The moving two-point discrimination test (M2-PD) ^{14,19}	Performed by moving the calipers over the skin surface.	The threshold values are lower than those of the static test.							
Area localization ^{14,24}	The territory of the injured nerve is divided into different zones, with the hand hidden from patient's sight. Patients are tested on their ability to localize a light touch applied to each zone in random order.								
The pick-up test ²⁹	Patients are required to pick up small objects and place them in a container with and without vision.								
British Medical Research Council Score of sensory recovery modified by Mackinnon and Dellon ^{28,23, a}	S0: absence of sensibility in the autonomous area of the nerve								
	S1: recovery of deep cutaneous pain and tactile sensibility								
	S1+: recovery of superficial pain sensibility								
	S2: Recovery of some degree of superficial cutaneous pain and tactile sensibility								
	S2+: As in S2, but with over response								
	S3: return of pain and tactile sensibility with disappearance of over response, s2PD>15mm, m2PD>7mm								
	S3+: return of sensibility as in S3 with some recovery of 2-point discrimination, s2PD: 7-15mm, m2PD: 4-7mm								
Semmes-Weinstein monofilament test ⁹	S4: complete recovery, s2PD: 2-6mm, m2PD: 2-3mm								
	Used to evaluate cutaneous pressure thresholds. Detection threshold defined as perceived sensation after application of the smallest S/W monofilament at the affected fingertip.								

Measurement	Characteristics		
	1 (filament marking 6.65) = perception of deep pressure 2 (filament marking 4.56) = loss of protective sensation 3 (filament marking 4.31) = diminished protective sensation 4 (filament marking 3.61) = diminished perception of light touch 5 (filament marking 2.83) = normal perception of touch and pressure		
Vibration perception ²⁶	Evaluated with tuning forks.		
Temperature perception ^{25,26}	Test ability to discriminate warm and cold objects.		
Recognition of textures ^{23,24,26}	Differentiation between different textures with the patient wore protective earmuffs to eliminate auditory input.		
Recognition of shape ^{26,24,26}	Differentiation between small, easily manipulated, three-dimensional shapes.		
Sharp and dull discrimination ²⁵	Test ability to discriminate sharp and dull stimuli.		
Thickness discrimination ²⁶	Differentiation between blocks 1,2, and 3cm thick.		
Finger Dexterity			
Sollerman hand function test ²³	Consists of 20 tasks based on the most common hand grips.		
Motor Function			
Manual muscle testing (MMT) ³¹	Conducted to assess motor innervation using MRC muscle strength grading system.		
British Medical Research Council muscle strength grading system ^b	M0: No contraction		
	M1: Flicker or trace of contraction		
	M2: Full range of active movement, with gravity eliminated		
	M3: Active movement against gravity		
	M4: Active movement against gravity and resistance		
	M5: Normal power		
Modified Medical Research Council muscle strength scale ³¹	Grade	Range of movement	Resistance
	0	None	No palpable contraction
	1	None	Palpable contraction only
	2	Reduced	None
	3	Normal	None
	4	Normal	Reduced
	5	Normal	Normal

Measurement	Characteristics				
Grip strength ^{4,32}	Measured with a dynamometer. The result from the noninjured hand is considered normal. Can measure standard dynamic grip strength; time to achieve 95% of maximum grip strength; maximum power outputs.				
Pinch strength ³²	Key (lateral) pinch: influenced by thumb interphalangeal joint position, 1th dorsal interosseous muscle, FPL, FPB. Tip to tip (thumb pulp to index pulp) pinch and tripod (thumb pulp to index and middle finger pulps) pinch: rely on thenar muscles.				
Pain and discomfort					
Numerical Rating Scale (NRS) for pain ^{39,c,d}	Consists of asking the patient to rate his or her perceived level of pain intensity on a numerical scale from 0 to 100, with the 0 representing “no pain”, and the 100 representing “pain as bad as it could be”.				
Pain visual Analog Scale (PVAS) ^{11,54,e,f}	Consists of a 10cm line anchored by 2 extremes of pain, including “no pain” and “pain as bad it could be”. The scale is scored by measuring the distance from the beginning to the patient’s mark.				
Pain Disability Index ³³	7-items questionnaire designed to assess the extent to which pain interferes with daily life domains.				
McGill pain questionnaire ^{35,f}	Designed to provide quantitative measures of clinical pain.				
McCabe Cold Sensitivity Severity Scale (CSS) ^{39,f,g}	Consists of 4 questions about events in the home that cause cold-related symptoms. Patients are asked to mark on a 10cm line to reflect the severity of cold intolerance during the activities. The score is summed by measuring the distance from the beginning to the patient’s mark of each question.				
McCabe Potential Work-Exposure Scale (PWES) ³⁹	Consists of 3 questions about exposure of the hands to cold in the workplace. Patients are asked to mark on a 10cm line to reflect the severity of cold intolerance during the activities. The scale is scored by measuring the distance from the beginning to the mark, and then sum up.				
Cold intolerance Symptom Severity (CISS) questionnaire ^f	Consists of 6 questions that highlight the impact of cold intolerance on daily life. The first question concerns pattern of cold intolerance and severity of symptoms, which is not included in the final score.				
Electroneurophysiologic Outcomes Measures					
Electroneurography examinations ⁵¹	Include sensory and motor nerve measurements, such as sensory nerve conduction velocities (SCVs) and amplitude, motor nerve conduction velocities (MCVs), distal motor latency (DML)				
Electromyogram examinations ⁵³	Used to test muscle innervation.				
Grading scales for neurophysiological changes of median nerve entrapment classified by Bland ⁴⁸	Grade 0 Normal				
	Grade 1 (Very mild) CTS demonstrable only with most sensitive tests				
	Grade 2 (Mild) SCVs slow on finger/wrist measurement, normal terminal motor latency				
	Grade 3 (Moderate) distal motor latency to abductor pollicis brevis (APB) <6.5 milliseconds with preserved sensory nerve action potential				
	Grade 4 (Severe) absent sensory nerve action potential but motor response preserved, and distal motor latency to APB < 6.5 milliseconds,				
	Grade 5 (Very severe) motor terminal latency >6.5 milliseconds,				
	Grade 6 (Extremely severe) sensory and motor potentials effectively unrecordable (surface motor potential from APB<0.2mV amplitude)				
Overall hand function classification for ulnar nerve injury					
Akahori’s Classification for Staging of ulnar nerve injury preoperative status ⁵¹	Nerve conduction velocity				
	Motor nerve	Sensory nerve			
			Motor nerve	Motor weakness	Finger deformity
			Muscle atrophy		

Measurement	Characteristics						
	Stage I	Normal	Normal	Elbow flexion test (positive +) Hypesthesia (slightly +)	Only in first dorsal interosseous muscle (1 st IOM) (+or-)	(+ or -)	
	Stage II	Normal	Delayed	Hypesthesia (+) commonly preceded by hypalgesia	1 st IOM (+) other muscles (+ or -)	(+ or -)	
	Stage III	Lower limit or delayed	Delayed or immeasurable	Hypesthesia (+)	(+)	(+)	
	Stage IV	Delayed	Immeasurable	Hypesthesia (2+), sometimes analgesia	(2+)	(2+)	
	Stage V	Delayed or immeasurable	Immeasurable	Hypesthesia (2+), mostly analgesia	(2+)	(2+)	
	Excellent	Normal; no motor weakness, can include slight muscle atrophy, coldness in fingers, subtle hypesthesia					
	Good	Muscle strength rated 4 or 5 in MMT, no residual deformity, some hypesthesia that does not impair activities of daily living (ADLs)					
	Fair	Clinical improvement, but the claw finger deformity, disability of small finger adduction, and Froment's sign may remain; hypesthesia that impairs ADLs					
	Poor	No improvement or worsening					
	McGowan's classification for ulnar nerve injury ^h	Grade I	Minimal lesions, with no detectable motor weakness of the hand				
Grade II		Intermediate lesions					
Grade III		Severe lesions, with paralysis of one or more of the ulnar intrinsic muscles					
Patient reported outcomes							
Disability of the Arm, Shoulder, and Hand (DASH) questionnaires ^{10,59}	30-item questionnaire that addresses arm-specific symptoms and disability during the preceding week. Used to estimate the patient's view of disability.						
Boston carpal tunnel questionnaire ^{47,66}	Include symptom severity score (SSS) and function score (FS), assess severity of symptoms and functional status in patients who have carpal tunnel syndrome.						
Michigan Hand outcome questionnaire ⁵⁶	37-item questionnaire assess disability along 6 domains: function, activities of daily living, pain, hand appearance, patient satisfaction, and work disability.						
Short Form-36 ¹⁰	General health assessment questionnaire, assess patient's quality of life, including 8 domains.						

^aLeechavengvongs S, Ngamlamiat K, Malungpaishrope K, et al. End-to-side radial sensory to median nerve transfer to restore sensation and relieve pain in C5 and C6 nerve root avulsion. The Journal of hand surgery 2011;36:209-15.

^bCarlson BT, Kircher MF, Spinner RJ, et al. Comparison of single versus double nerve transfers for elbow flexion after brachial plexus injury. Plastic and reconstructive surgery 2011;127:269-76.

^cVranceanu AM, Jupiter JB, Mudgal CS, et al. Predictors of pain intensity and disability after minor hand surgery. The Journal of hand surgery 2010;35:956-60.

^dJensen MP, Karoly P, Braver S. The measurement of clinical pain intensity: a comparison of six methods. Pain 1986;27:117-26.

- ^eTerzis JK, Konofaos P. Radial nerve injuries and outcomes: our experience. Plastic and reconstructive surgery 2011;127:739-51.
- ^fGalanakos SP, Zoubos AB, Johnson EO, et al. Outcome models in peripheral nerve repair: time for a reappraisal or for a novel? Microsurgery 2012;32:326-33.
- ^gMacDermid JC. Measurement of health outcomes following tendon and nerve repair. Journal of hand therapy : official Journal of the American Society of Hand Therapists 2005;18:297-312.
- ^hMc GA. The results of transposition of the ulnar nerve for traumatic ulnar neuritis. The Journal of bone and joint surgery British volume 1950;32-B:293-301.