



Review Article

Relationship Between Sensibility Tests and Functional Outcomes in Patients With Traumatic Upper Limb Nerve Injuries: A Systematic Review



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KEYWORDS

Activities of daily living;
Correlation of data;
Peripheral nerve injuries;
Recovery of function;
Rehabilitation;
Touch

Abstract *Objective:* To investigate which tests of hand sensibility correlate with functional outcomes in patients with upper limb traumatic nerve injuries and to assess if composite scales of sensibility correlate with functions.

Data Sources: MEDLINE, Embase, and Cochrane Central Register of Controlled Trials were searched in May 2020, with a supplementary search in July 2020. Reference lists of the included publications were hand searched.

Study Selection: Database search found 2437 records. Eligible studies reported on inferential association between sensibility tests and functions pertaining to adults after upper limb nerve repair. Two reviewers independently assessed eligibility. Fifteen publications were included.

List of abbreviations: ADL, activities of daily living; CI, confidence interval; DASH, Disabilities of the Arm, Shoulder, and Hand; m, moving; MRC, Medical Research Council; PNI, peripheral nerve injury; PRWHE, Patient-Rated Wrist and Hand Evaluation; SF-36, Short Form-36 Health Survey; SHFT, Sollerman Hand Function Test; s, static; SWMF, Semmes-Weinstein monofilament; 2-PD, 2-point discrimination; WEST, Weinstein Enhanced Sensory Test.

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Data Extraction: Extracted data contain patient characteristics, surgical procedure, follow-up duration, sensibility tests, and functional assessments. Two reviewers independently assessed data quality.

Data Synthesis: Fifteen publications involving 849 patients were reviewed. All publications reported on median and/or ulnar nerve injuries. Monofilament tests correlated with Short-Form Health Survey ($r=0.548$, $P<.05$), pick-up test ($r=0.45$, $P<.05$), and function domain of Patient-Rated Wrist and Hand Evaluation Questionnaire (PRWHE) ($r=0.58$, $P<.05$). The 8 studies of static and moving 2-point discrimination provided conflicting correlations with activities of daily living (ADL) and/or the pick-up test. Data for area localization and object/shape identification were equivocal as well. No data were found for Ten test and vibration tests. Rosén score sensory domain correlated with ADL ($r=0.59$; 95% confidence interval [CI], 0.41-0.72) and PRWHE function domain ($r=-0.56$, $P<.05$). Medical Research Council sensory scale was related to pick-up test; return to work status; and Disabilities of the Arm, Shoulder, and Hand questionnaire.

Conclusions: Monofilament tests allow practitioners to gather sensibility data meaningful to patients' overall recovery of functions after upper limb nerve trauma. For 2-point discrimination and other sensibility tests, practitioners should be aware that improvement in test performance does not necessarily translate to improved hand function. Findings from the composite scales indicate that hand sensibility, in general, is related to functions. Future research on other common sensibility tests is recommended to explore how the test relates to patients' functions.

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Upper limb peripheral nerve injuries (PNIs) can often result in loss of sensory functions of the hand.^{1,2} A variety of clinical instruments have been developed to measure hand sensibility and studied on patients recovering from upper limb nerve trauma.^{3,4} These include Semmes-Weinstein monofilament (SWMF),⁵ static (s) and moving (m) 2-point discrimination (2-PD),^{6,7} vibratory sensation test,⁸ Ten test,⁹ shape/texture identification,¹⁰ area localization,¹¹ and more. There are also composite scoring systems, including the Medical Research Council (MRC) sensory scale¹² and Rosén score sensory domain,¹³ which incorporate 2 or more of the individual instruments to capture the broad construct of sensibility.

As far as we know, despite the popularity of some of these tests, no systematic discussion exists on if improvements in sensibility measured by these instruments translate to an improvement in patients' daily functions. It is well established that PNI of the upper limb can have a profound effect on patients' ability to perform activities of daily living (ADL), ability to perform work duties, and quality of life.¹⁴⁻¹⁸ Jaquet et al¹⁴ found that 24% of patients with median and/or ulnar injuries still had loss of income even after 17.7 months. A test that better correlates with the functional aspects of life could therefore offer more meaningful information about a patient's recovery.

To help health care professionals select the optimal tests of sensibility, there have been ongoing discussions on the psychometric properties of sensibility tests, such as reliability and validity, in a variety of injuries and other neurologic conditions.¹⁹⁻²² However, in the context of upper limb PNI, there still exist uncertainties in choosing the optimal sensibility tests. For example, Jerosch-Herold⁴ identified that 2-PD has limited validity and responsiveness yet remains widely used in the PNI setting. By gathering evidence on the correlation between sensibility tests and patients' functions, we hope to add a novel perspective to help health care professionals

make a more informed choice when selecting sensibility tests in the population with PNI. Although there have been studies that contain data of association between sensibility and functions,^{11,13-15} many focused on only 1 sensibility test or 1 functional outcome. On the other hand, our review provides an additional bird's-eye view on their correlations, and our results can also be used as a springboard to measure sensibility more robustly and comprehensively going forward.

Besides individual sensibility tests, it is also important to elucidate if the composite such as the MRC sensory scale and Rosén score sensory domain correlate with patients' functions because they are often used to represent the general recovery of patients' sensibility. When Rosén and Lundborg¹³ constructed the Rosén score, they found a correlation between the sensory domain and patients' estimation of the effect of injury on ADL ($r=0.59$; 95% CI, 0.41-0.72). However, more work is needed to elucidate if patients with better sensibility have better daily functions. This may strengthen or reduce the value of the significant efforts being made to help regain sensibility, such as sensory reeducation,²³ neuroprotection of sensory neurons,²⁴ and sensory nerve transfer.²⁵

There are 2 objectives for this systematic review focused on traumatic upper limb PNI. The primary objective was to assess which individual tests of hand sensibility correlate with functional outcomes. The secondary objective was to assess if the MRC sensory scale and Rosén score sensory domain correlate with functions.

Methods

This systematic review was performed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses.²⁶

Criteria for considering studies for this review

The research question and eligibility criteria were established a priori. Inclusion criteria were (1) full-length publications; (2) English publications; (3) studies that involved adult patients (age > 18y); (4) patients had surgical repair of traumatic upper limb nerve injuries (traumatic brachial plexopathy and/or distal nerve injuries); and (5) studies reporting on sensibility and functional outcomes with inferential measures of association.

Examples of sensibility measures or sensory tests included in search terms were SWMF, s2-PD, m2-PD, vibratory sensation test, Ten test, object identification, localization, sensory nerve action potential,²⁷ sensory domain of Rosén score, and MRC sensory scales.

The scope of functional outcomes captured the ability to perform functional activities. We included hands-on tests derived from ADL, such as the Sollerman Hand Function Test (SHFT),²⁸ or quantitative questionnaires assessing ADL, such as the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire²⁹ and Patient-Rated Wrist and Hand Evaluation (PRWHE).³⁰ Tests that assess sensorimotor performance of the hand were also deemed relevant (eg, Moberg pick-up test³¹). To capture a broader perspective, return to work status and assessments of quality of life such as the Short Form-36 Health Survey (SF-36)³² were also considered. Simple motor measures such as strength and range of motion were not deemed to encompass the broad construct of functional outcome and were not included. Search terms used are presented in [appendices 1 and 2](#).

Exclusion criteria were (1) case reports and gray literature (eg, annual reports, theses, conference proceedings); (2) studies focused exclusively on pediatric patients; (3) isolated digital nerve injuries; (4) nerve compression and neuropathy; and (5) amputations and iatrogenic injuries. Isolated digital nerve injuries were excluded because they often result in very specific functional loss of a single digit rather than impairments in gross functions.³³ Nerve compression and neuropathy were excluded because they are usually unrelated to trauma.

Data sources and searches

The search was conducted on May 16, 2020, via Ovid^a on MEDLINE, Embase, Evidence-Based Medicine Reviews: Cochrane Central Register of Controlled Trials inception to search date. Search terms from sensibility measures were combined with OR: *monofilament* OR *2 point discrimination* OR . . .; keywords representing functional outcomes were combined with OR: *DASH* OR *PRWHE* OR . . .; keywords describing patient population were combined with OR: *median nerve* OR *ulnar nerve* OR . . . The 3 categories (sensibility, functions, patient population) were combined with AND. Limiters were “English Language” and “Humans.” A supplementary search was done on July 7, 2020, to include new search terms informed by the first round of review. Full search strategies are presented in [appendices 1 and 2](#).

Study selection

Screening and selection of studies was conducted on Covidence.^b Titles and abstracts were screened independently

by 2 study authors. References excluded by both reviewers were excluded. The studies remaining had their full texts assessed by each reviewer, and conflicts were resolved by discussion. Reference lists of the included studies were hand searched to identify additional eligible publications. Relevant reviews identified from the search results were also hand searched to identify eligible primary studies.

Data extraction and critical appraisal

Two reviewers (L.C. and E.O.) performed data extraction and quality appraisal. All data were obtained from published materials. Some included studies contained patient-level data, whereas some presented summarized data only. Major discrepancies were resolved by discussions. Data form and appraisal checklist ([appendix 3](#)) were adapted from the National Institute for Health and Care Excellence: *Methods for the Development of NICE Public Health Guidance* (Third edition), appendices K and G.³⁴ The appraisal checklist contains 3 items on external validity and 6 items on internal validity. Each item is rated 0-2. A score of 5 of 6 is needed for high external validity, and 9 of 12 is needed for high internal validity.

Data analysis

Interrater reliability for study selection was assessed by Cohen’s κ .³⁵ Study level data on associations between sensibility and functional outcomes were identified for each sensibility test and presented in tabular format.

Results

Study selection

Study selection is summarized in [figure 1](#). Interrater agreement for title and abstract screening was moderate ($\kappa=0.43$), and agreement for full-text selection was substantial ($\kappa=0.78$).³⁷ Fifteen studies were included.

Update of literature search and results

To ensure the results of the review is up to date, an updated literature search was performed on July 10, 2021, with the same strategy and databases outlined in [appendices 1 and 2](#). An additional limiter of publication year of 2020 to present was added. A total of 209 records were found; stepwise screening of title, abstract, and full-text identified no eligible studies.

Study characteristics

Study characteristics are summarized in [table 1](#). Of the 15 included studies, all were published between 1987 and 2019. Nine studies were level IV evidence, 3 were III, and 3 were II, according to the Oxford Centre for Evidence-based Medicine classification.⁵⁰ The 15 studies reported on 849 patients, most of which were male. Mean age of patients in each study ranged from 20-42 years. Sample sizes ranged from 14-220 (mean, 53±51). The nerves injured were either

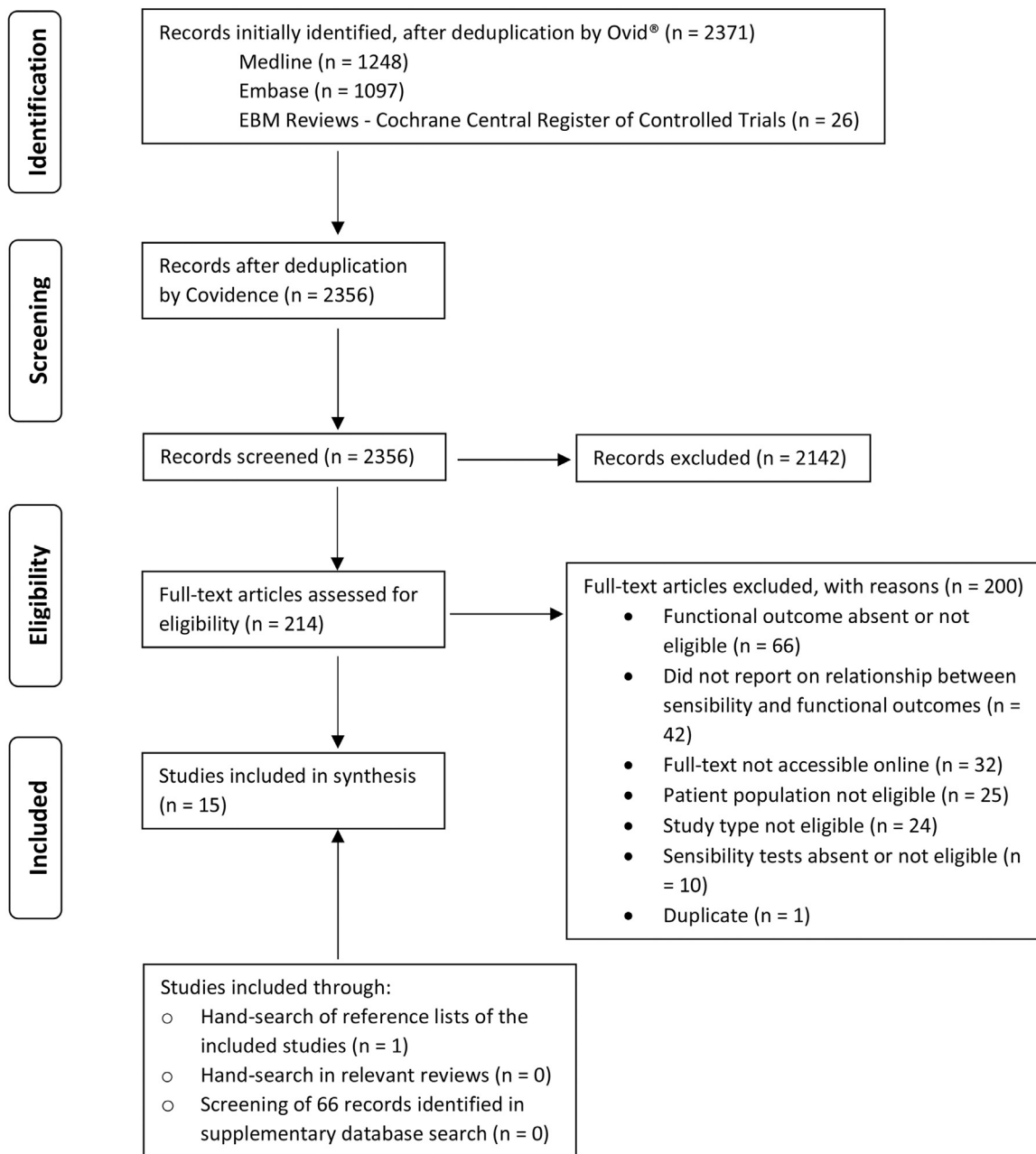


Fig 1 Adapted flow diagram from Preferred Reporting Items for Systematic Reviews and Meta-Analyses.³⁶ Abbreviation: EBM, Evidence-Based Medicine.

median (n=524, 62%), ulnar (n=219, 26%), or both (n=106, 12%). Types of transection were either complete, partial, or not reported. Locations of lesion were mostly at wrist, forearm, or elbow. Most injuries were repaired by primary suture. Some studies did not specify surgery delay, but primary suture usually implied direct suture of nerve ends within 1 week of injury.⁵² The mean follow-up time ranged from 1-8.1 years.

Quality assessment

Internal and external validity are presented in [table 1](#). A total of 67% of studies demonstrated high internal validity. Inadequate control of extraneous variables and omission of

correlation strength were recurring limitations identified. Ratings of internal validity only pertained to the relevant analysis of correlations and/or associations and are not applicable to other results reported by the studies. A total of 38% demonstrated high external validity. For some studies, the reporting of study design or recruitment method were incomplete. Details on individual quality items are presented in [appendix 3](#).

Results for sensibility measures

Associations between sensibility measures and functional outcomes are presented in [table 2](#). Correlation coefficient (*r*) denotes correlation strength. There is no defined

Table 1 Characteristics and quality of included studies

Author, Region	Level of Evidence*	Sample Size, Mean Age and Range (Y)	Nerves Injured (Location)	Surgery Technique (Delay)	Mean Follow-Up and Range (Y)	External/Internal Validity [†]
Brink and Mackel, ³⁸ US	Prognostic IV	26, NA (adults)	Median and/or ulnar complete [‡] (wrist)	Suture or graft (NA)	1 (0.5-1.9)	Mid/mid
Bruyns et al, ³⁹ Netherlands	Prognostic III	81, 31 (18-58)	Median and/or ulnar (elbow to wrist)	Primary repair	NA	High/high
Chassard et al, ⁴⁰ France	Prognostic IV	22, 30 (5-66)	Median and ulnar (forearm to wrist)	Primary nerve suture; nerve graft (1-6m)	6.7 (1-14.7)	Low/mid
Emamhadi et al, ¹⁵ Iran	Prognostic II	106, 33 (12-68)	Median complete/partial (between shoulder and wrist)	Primary suture; external neurolysis or graft (< 29m)	<2 y, n=25 2-5 y, n=43 >5 y, n=38	Mid/high
Fonseca et al, ⁴¹ Canada	Diagnostic III	32, 42±16	Median or ulnar, complete/partial (about half at volar wrist)	Suture or nerve reconstruction (<2wk)	4.7 (1-8)	High/high
Jaquet et al, ¹⁴ Netherlands	Prognostic II	220, 31 (5-73)	Median and/or ulnar, complete/partial (elbow to wrist)	Primary repair	1.5 (0.1-14.4)	High/high
Jerosch-Herold, ⁴² 1993, UK	Prognostic IV	14, 38 (19-61)	Median complete/partial (wrist)	Primary repair	4 (2-7.5)	High/high
Jerosch-Herold, ⁴³ 2000, UK	Prognostic IV	41, 33 (12-72)	Median complete (forearm to wrist)	Epineural/perineural suture or grafting, or both (average 3d)	2.8 (0.8-7.5)	Mid/high
Marsh ¹¹ UK [§]	Prognostic IV	21, 23 (6-57)	Median and/or ulnar complete (elbow to wrist)	Nerve suture (0-111d)	3.9 (0.6-11.2)	High/high
Onne, ⁴⁴ NA	Not applicable	30, 20 (4-46)	Median complete (NA)	NA (NA)	≥4y	Mid/high
Rosén, ⁴⁵ Sweden	Prognostic IV	25, 27 (10-53)	Median/ulnar complete (distal forearm)	Conventional suture or tubulization (≤2wk)	3 (2-5)	Mid/mid
Rosén and Lundborg, ¹³ Sweden	Diagnostic III	70, median =28 (5-72)	Median and/or ulnar, complete/partial (distal forearm to wrist)	Primary suture; primary silicone tube; grafting (NA)	2 (0.3-5.7)	Mid/high
Sahin et al, ⁴⁶ Turkey	Prognostic IV	40, 29 (18-57)	Median/ulnar complete (wrist)	Epineural suture (average 9.3d)	1 (0.5-2.5)	Mid/high
Selma et al, ⁴⁷ Turkey	Prognostic IV	28, 25 (4-45)	Median (wrist)	Epineural suture (0d for most)	2.1 (1-4)	High/mid
Vordemvenne et al, ⁴⁸ Germany	Prognostic II	65, 28 (2-69)	Median complete/partial and/or ulnar complete (forearm to wrist)	Microsurgical or group fascicular suture (≤1d)	8.1 (1-12.9)	Mid/high
Wong et al, ⁴⁹ Netherlands	Prognostic IV	28, 28±12	Median (mean distance between lesion and index fingertip was 25cm)	Primary repair; autologous nerve grafts (NA)	5.2 (1.5-10.7)	Mid/mid

Abbreviations: NA, not available; UK, United Kingdom; US, United States.

* Based on Levels of Evidence by Oxford Centre for Evidence-Based Medicine.⁵⁰

† Criteria of assessment reported in [appendix 3](#).

‡ Complete/partial denotes the extent of transection, if mentioned by the study.

§ A portion of the data on patient recruitment was extracted from a previous publication by Marsh and Barton.⁵¹

|| The study by Marsh¹¹ contained secondary analysis of the data from this study. Data extraction and appraisal were conducted based on the analysis by Marsh.¹¹

Table 2 Relationship between sensibility measures and functional outcomes

Study	Functional Outcomes	Relationship With Sensibility Tests	Factors Controlled
Monofilament tests			
Bruyns et al ³⁹	RTW within 1 y	Groups of RTW and no RTW had SWMF score of 2.9 and 3.5 ($P=.001$) (SWMF scored from 1-5, 5 representing the largest diameter).	Sex, age, hand dominance
Emamhadi et al ¹⁵	SF-36	Correlation with SWMF: $r=0.548$, $P=.0001$, Spearman.	\
Fonseca et al ⁴¹	PRWHE—function domain	Correlation with SWMF: $r=0.58$, $P<.01$, 2-tailed, Pearson.	\
Jerosch-Herold, ⁴³ 2000	Modified pick-up	Correlation with Weinstein Enhanced Sensory Test: $r=0.45$, $P=.009$, Spearman.	\
Onne ^{44,*}	Pick-up test	Correlation with von Frey hair: $r=-0.66$, $P<.01$, Pearson.	Age
Rosén and Lundborg ¹³	Finger dexterity (task 4, 8, 10 of SHFT)	By factor analysis, SWMF and finger dexterity both have meaningful loadings (0.58, 0.63) to the sensory factor.	NA
Static 2-PD			
Brink and Mackel ³⁸	Simplified pick-up test	No association between 2-PD (<18 vs >18mm) and pick-up (normal/satisfactory vs mediocre/poor performance), $P>.1$, Fisher exact test.	\
Chassard et al ⁴⁰	Functional score defined as the mean of modified pick-up test, shape recognition, texture recognition	$r=unk$, $P<.005$, multiple regression.	Age
Onne ^{44,*}	Pick-up test	$r=-0.22$, $P=.22$, Pearson.	Age
Jerosch-Herold ⁴² 1993	Modified pick-up ADL tests with 4 daily tasks	$r=0.81$, $P<.001$, partial correlation analysis. $r=-0.524$, $P=$ nonsignificant, partial correlation analysis.	Age, surgery delay, time since injury
Jerosch-Herold ⁴³ 2000	Modified pick-up	$r=-0.38$, $P=.015$, Spearman.	Age
Rosén ⁴⁵	ADL questionnaire	$r=unk$, $P>.05$, Spearman.	\
Rosén and Lundborg ¹³	Finger dexterity	By factor analysis, s2-PD and finger dexterity both had meaningful loadings (0.84, 0.63) to the sensory factor.	NA
Moving 2-PD			
Chassard et al ⁴⁰	Functional score	$r=unk$, $P<.005$, multiple regression.	Age
Marsh ¹¹	Modified pick-up	$r=0.13$, $P=0.21$, Pearson.	Age, surgery delay, time since surgery
Wong et al ⁴⁹	Modified pick-up	$r=0.19$, $P=unk$, Spearman.	\
Jerosch-Herold ⁴² 1993	Modified pick-up ADL test	$r=0.78$, $P<.001$, partial correlation analysis. $r=-0.553$, $P=0.041$, partial correlation analysis.	Age, surgery delay, time since injury
Rosén ⁴⁵	ADL questionnaire	Influence of m2-PD on ADL was weak with stepwise multiple regression.	Grip strength, cold intolerance, age
Area localization			
Marsh ¹¹	Modified pick-up	$r=0.48$, $P=.001$, Pearson.	Age, surgery delay, time since surgery
Jerosch-Herold ⁴² 1993	Modified pick-up	$r=0.516$, $P=$ nonsignificant, partial correlation analysis.	Age, surgery delay, time since injury
Jerosch-Herold ⁴³ 2000	ADL test Modified pick-up	$r=-0.57$, $P=.045$, partial correlation analysis. $r=0.29$, $P=.07$, Spearman.	\
Rosén ⁴⁵	ADL questionnaire	$r=unk$, $P>.05$, Spearman.	\

(continued)

Table 2 (Continued)

Study	Functional Outcomes	Relationship With Sensibility Tests	Factors Controlled
Object/shape identification			
Brink and Mackel ³⁸	Sensory component of a simplified pick-up test	No correlation between the no. of errors in object identification (round vs edgy) and pick-up, $r=-0.039$, $P>.1$, Spearman.	\
Wong et al ⁴⁹	Modified pick-up	Moberg recognition test and pick-up did not correlate well, $r=0.35$, $P>.05$, Spearman.	\
Jerosch-Herold ⁴² 1993	Modified pick-up	Identification time and accuracy correlated with pick-up, $r=0.683$ and 0.697 , $P<.001$, partial correlation analysis.	Age, surgery delay, time since injury
	ADL test	Identification time did not correlate with ADL, $r=-0.369$, P =nonsignificant; accuracy did correlate, $r=-0.471$, $P=0.042$, partial correlation analysis.	
Rosén ⁴⁵	ADL questionnaire	Shape identification, object identification, and the number of correctly identified items in a modified pick-up test were not significantly related to ADL, r =unk, $P>.05$, Spearman.	\
Rosén and Lundborg ¹³	Finger dexterity	By factor analysis, shape/texture identification and finger dexterity both had meaningful loadings (0.70, 0.63) to the sensory factor.	NA
Sensory nerve action potential amplitude			
Sahin et al ⁴⁶	SHFT	$r=0.111$, $P=.50$, Pearson.	\
Rosén score sensory domain			
Fonseca et al ⁴¹	PRWHE—function domain	$r=-0.56$, $P<.01$, 2-tailed, Pearson.	\
Rosén and Lundborg ¹³	Estimation of effect of injury on ADL via visual analog scale	$r=0.59$; 95% CI, 0.41-0.72; Spearman.	\
Vordemvenne et al ⁴⁸	DASH	In a 3-factor analysis (factors: sensory, motor, ADL), sensory domain of Rosén score and DASH both had meaningful loadings (0.874, 0.552) on the sensory factor. Sensory domain of Rosén score loaded weakly (0.195) on the ADL factor (a factor primarily contributed by the pain/discomfort domain of Rosén score and DASH).	NA
MRC sensory scales [†]			
Jaquet et al ¹⁴	RTW-yes/no	Poor sensory recovery had an odds ratio of 2.94 for inability to return to work; 95% CI, 1.50–5.76; $P=.002$.	Age, sex
Selma et al ⁴⁷	Moberg's pick-up	Means of the pick-up performance between 2 groups (S3+, S4 vs S1, S2, S2+, S3) were different, $P<.05$, Mann-Whitney U .	\
Vordemvenne et al ⁴⁸	DASH	In the 3-factor analysis, MRC sensory score and DASH both had meaningful loadings (0.863, 0.552) on the sensory factor. MRC sensory score loaded weakly (0.123) on the ADL factor.	NA

Abbreviations: \, no control; NA, not applicable; RTW, return to work; unk, unknown.

* Data extracted from secondary analysis by Marsh.¹¹

† Versions used indicated by the studies, in the order of presentation: unspecified, version by Waylett-Rendall,⁵³ version by Mackinnon and Dellon.⁵⁴

nomenclature for correlation strength, but some guidelines have been proposed: absolute value of $r < 0.25$, little relationship; 0.25-0.50, low to fair; 0.50-0.75, moderate to good; > 0.75 , strong.⁵⁵ Some studies used factor analysis. Factor loadings measure the correlation between the variable of interest and the factor, with loadings > 0.4 generally considered meaningful.⁵⁵ Each factor represents a cluster of items highly correlated among themselves.⁵⁵

Monofilament tests

Monofilament tests consistently demonstrated correlation with functional assessments. SWMF correlated with SF-36 ($r = 0.548$, $P = .0001$) and PRWHE function domain ($r = 0.58$, $P < .01$).^{15,41} Factor analysis by Rosén and Lundborg¹³ also suggested a correlation between SWMF and finger dexterity. In the study by Bruyns et al,³⁹ a significant difference in SWMF score was present between patients who returned to work vs those who did not ($P = .001$). In addition, Weinstein Enhanced Sensory Test ($r = 0.45$, $P = .009$) and von Frey hair ($r = -0.66$, $P < .01$) both correlated with the pick-up test.^{11,43,44}

Two-point discrimination

Results for s2-PD were equivocal. No significant correlation was demonstrated with ADL.^{42,45} Two studies demonstrated strong and low to fair correlations with pick-up test ($r = 0.81$, $P < .001$; $r = -0.38$, $P = .015$),^{42,43} whereas 2 others found no association.^{11,38,44} Chassard et al⁴⁰ showed a significant correlation with their functional score ($r = \text{unknown}$, $P < .005$). Factor analysis suggested a correlation with finger dexterity.¹³

For m2-PD, Jerosch-Herold⁴² found a moderate correlation with ADL ($r = -0.553$, $P = .041$), whereas Rosén⁴⁵ demonstrated that the correlation may be accounted for by covariates including grip strength and cold intolerance. Evidence on its relationship with pick-up test was mixed, with both significant ($r = 0.78$, $P < .001$)⁴² and nonsignificant or weak correlations.^{11,49} Chassard et al⁴⁰ demonstrated a significant correlation with their functional score ($r = \text{unknown}$, $P < .005$).

Area localization

For the ability to localize touch stimulus applied to distinct skin areas, 1 study found a moderate correlation with ADL ($r = -0.57$, $P = .045$),⁴² whereas another found no correlation.⁴⁵ Its correlation with pick-up test was demonstrated with fair association by Marsh¹¹ ($r = 0.48$, $P = .001$), but 2 other studies found no significance.^{42,43}

Object and/or shape identification

Accuracy of object identification was shown to correlate with ADL ($r = -0.471$, $P = .042$), but the speed of identification was not.⁴² Rosén⁴⁵ found no aspect of object identification correlated with the ADL questionnaire. The correlations with pick-up test were demonstrated with significance in 1 study ($r = 0.683$ and 0.697 , $P < .001$)⁴² but nonsignificance in another 2.^{38,49} Factor analysis suggested that shape and/or texture identification and finger dexterity were related.¹³

Sensory nerve action potential amplitude

Sahin et al⁴⁶ addressed the relationship between sensory nerve action potential and SHFT, and no significant correlation was demonstrated.

Rosén score sensory domain and MRC sensory scales

Although factor analysis suggested equivocal results for their correlation with DASH,⁴⁸ other evidences were all supportive. Rosén score sensory domain correlated with PRWHE function domain ($r = -0.56$, $P < .01$) and ADL ($r = 0.59$; 95% CI, 0.41-0.72).^{13,41} Lower score on MRC sensory scale predicted inability to return to work (odds ratio, 2.94; 95% CI, 1.50-5.76; $P = .002$) and was also associated with poorer pick-up performance ($P < .05$).^{14,47}

Discussion

Monofilament tests correlated with various functional assessments in all studies. Evidences for s2-PD, m2-PD, area localization, and object identification were each equivocal. Evidences for vibratory sensory test, Ten test, sensory nerve action potential, and other sensibility measures were scarce. For MRC sensory scale and Rosén score sensory domain, most studies demonstrated their association with functional outcomes.

Heterogeneity in sensibility tests and functional outcomes

The lack of standardization in some sensibility measures makes it difficult to generalize results across studies. The objects used and the procedures in testing object and/or shape identification were not consistent.^{13,38,42,45,49} The outcomes of identification also measured different aspects of the performance, such as accuracy and speed.⁴² For the MRC sensory scale, different versions have also been used.^{14,47,48}

A similar problem exists for ADL and pick-up test. The concept of ADL was quantified differently, including questionnaire,⁴⁵ visual analog scale,¹³ and observed performance of daily tasks.⁴² For the pick-up test, 1 study simplified the test by using balls.³⁸ Another study reported the test results differently, where a combined score was reported as the mean score of the pick-up test, shape recognition, and texture recognition.⁴⁰ The score of the pick-up test was therefore diluted. The variability in functional outcomes reported in literature makes it unfeasible to quantitatively aggregate the data for each sensibility test, which limits the robustness of our findings.

It is also important to examine the psychometric properties of the functional assessments. Pick-up test has high interrater reliability and test-retest reliability.^{56,57} Validity and reliability of PRWHE is supported by systematic review.⁵⁸ These properties for DASH and SHFT are also well supported.^{28,59} Some functional assessments on ADL were developed or validated by the study authors,^{13,42,45} and their psychometric properties may vary.

Interpretation of correlation and confounding variables

Some studies reported statistical significance only, and the strength of correlation or effect size cannot be assessed.^{40,45,47} In contrast, there were correlations with moderate strength but statistically nonsignificant.⁴² The

nonsignificance may be because of small sample size,⁴² and the results may still have clinical value.

Eight studies did not control for extraneous variables when examining the relationship between sensibility and functional outcomes.^{13,15,38,41,46-49} Seven studies controlled for 1 or more of age, surgery delay, follow-up time, sex, hand dominance, grip strength, and cold intolerance, as shown in table 2.^{11,14,39,40,42,43,45} These variables may or may not be related to sensibility test performance or function outcomes; below are what the included studies found. Age correlated with SWMF, s2-PD, and m2-PD for median nerve lacerations at wrist.⁴⁷ The effect of age on ADL and DASH was found equivocal.^{45,48} The nerves injured (median vs ulnar)^{46,48} and the extent of injury (partial vs complete transection)^{41,42} had no significant association with ADL performance, although 1 study showed significant difference in SHFT results between median and ulnar nerve injuries.⁴⁵ The prognostic value of the number of nerves injured (combined median-ulnar injuries vs isolated nerve injuries) on return to work status was inconsistent.^{14,39} Surgery delay (0-111 days) was not found to affect pick-up test performance.¹¹ The timing of follow-up since surgery did not correlate with pick-up performance.⁴³

Study limitations

A limitation is the literature search only yielded studies related to median and ulnar nerve injuries. There were no studies pertaining to other upper limb nerve injury distributions, such as brachial plexus injury. Although the sensory innervation of hand is mostly supplied by median and ulnar nerve,⁶⁰ it is also important to examine more proximal injuries on the brachial plexus. This limits the generalizability of our systematic review and also identifies a potential gap in the literature on upper limb nerve injuries for further exploration. This review targeted adults. Some studies included pediatric patients,^{11,13,15,40,43,45,47-49} but they were usually a small proportion. Although only studies in English were considered, this review still captured studies from 9 different countries. Eight studies did not control for extraneous variables as shown in table 2.^{13,15,38,41,46-49} The relationship between these variables and sensibility tests or functional outcomes is equivocal as previously discussed.

Study strengths

The search strategy was thoughtfully designed. The search terms included a wide array of functional assessments to encapsulate their diversity, although many did not yield relevant results. Besides specific names of sensibility tests and functional assessments, general terminologies such as “sensibility,” “sensory,” and “recovery of function” were used to increase sensitivity of the search. The reviewers also conducted a supplementary search to capture additional relevant terms informed by the original search to further pursue comprehensiveness.

Clinical implications and future research

When choosing a sensibility test, one also needs to consider its psychometric properties and simplicity of use.⁶¹

Reliability of SWMF to measure hand sensibility has been demonstrated by 2 systematic reviews.^{4,62} Responsiveness of SWMF and Weinstein Enhanced Sensory Test (WEST) was demonstrated by Rosén et al⁶³ and Jerosch-Herold⁶⁴ with effect size of 1.5 between 3 and 48 months, and 1.2 between 6 and 18 months, respectively. Although the use of SWMF apparatus was reported to be time consuming in busy clinics,⁶⁵ WEST was subsequently developed for improved portability and more rapid testing.⁶⁶ Given these attributes, along with their correlations with SF-36, PRWHE function domain, and pick-up test ($r=0.548, 0.58, 0.45$ respectively; $P<.05$),^{15,41,43} SWMF and WEST allow rehabilitation professionals to reliably gather data on hand sensibility that are meaningful to patients' functions.

The validity and responsiveness of 2-PD have been challenged by previous study.⁴ In this review, the correlations between s2-PD or m2-PD and pick-up test or ADL were equivocal, it is therefore questionable if improved 2-PD translates to improved functions. The widespread use of 2-PD to assess hand sensibility remains to be justified by future research. For other sensibility tests, evidences from this review are equivocal and limited by the lack of standardization of tests. Their clinical use is subject to practitioners' discretion.

Interestingly, MRC sensory scale and Rosén score sensory domain demonstrate correlations with functions in this review, although both contain 2-PD as a component. The use of 2-PD may therefore be more appropriate in conjunction with other sensibility tests to represent the broad construct of sensibility rather than used alone.

Among the sensibility tests with limited data for their correlation with functions, Ten test is gaining popularity for its simplicity without special equipment,⁹ and its use in hand trauma patients was recently shown to have high inter-rater reliability and responsiveness.⁶⁷ Future research is recommended to explore its relationship with hand functions.

Conclusions

Monofilament tests demonstrated consistent correlations with assessments on patients' hand functions, quality of life, and ability to work. They allow practitioners to gather hand sensibility data relevant to patients' overall recovery of functions after nerve injury. For 2-PD and other sensibility tests, improvement in test performance does not necessarily translate to improved hand function in trauma patients, and practitioners should be aware of this limitation. MRC sensory scale and Rosén score sensory domain demonstrated correlations with hand functions and activities of daily living. Results from these composite scores indicate that patients with better sensibility in general tend to have better hand functions and capacity for daily activities, and this bolsters the value of the endeavors made to improve sensibility recovery in patients with upper limb PNI.

Suppliers

- Ovid; Ovid Technologies Inc.
- Covidence; Veritas Health Innovation Ltd.

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