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REVIEW PAPER

Assessment of spasticity after stroke using clinical measures: a systematic review

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Abstract

Purpose: To identify and appraise the literature on clinical measures of spasticity that has been investigated in people after stroke. **Methods:** The literature search involved four databases (PubMed, CINAHL, Embase and The Cochrane Library) up to February 2014. The selected studies included those that aimed to measure spasticity using a clinical assessment tool among adult patients post-stroke. Two independent raters reviewed the included articles using a critical appraisal scale and a structured data extraction form. **Results:** A total of 40 studies examining 15 spasticity assessment tools in patients post-stroke were reviewed. None of the reviewed measurement tools demonstrated satisfactory results for all psychometric properties evaluated, and the majority lacked evidence concerning validity and absolute reliability. **Conclusion:** This systematic review found limited evidence to support the use of most of clinical measures of spasticity for people post-stroke. Future research examining the application and psychometric properties of these measures is warranted.

Keywords

Clinical assessment tools, muscle spasticity, psychometric properties, stroke rehabilitation, systematic review

History

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► Implications for Rehabilitation

- There is a need for objective clinical tools for measuring spasticity that are clinically feasible and easily interpreted by clinicians.
- This review identified various clinical measures of spasticity that have been investigated in people after stroke.
- Insufficient evidence of psychometric properties precludes recommending one tool over the others.
- Future research should focus on investigating the psychometric properties of clinical measures of spasticity.

Introduction

Following stroke, patients present with a variety of sensorimotor disorders such as spasticity, muscle weakness and impaired sensation [1,2]. Spasticity, a sequela present in 19% [3]–43% [4] of stroke survivors, is clinically manifested as a resistance to passive stretch [5,6]. This resistance may be attributed to neural and non-neural components [5,7,8]. The neural component – a velocity-dependent increase in the tonic stretch reflex [5,7–9] – is most often referred to as spasticity [7]. Non-neural factors such as changes in the mechanical properties of collagen, tendons and muscle fibers (e.g. loss of sarcomeres, sub-clinical contractures) also contribute to the resistance [10]. The co-occurrence of neural and non-neural causes of increased passive movement resistance makes measuring spasticity difficult.

The most commonly used clinical tools for measuring spasticity appear to be the original or modified Ashworth scale (AS) and Tardieu scale (TS) [11–13], which are ordinal scales that measure response to passive movement [14–20]. However, these non-instrumented, ordinal-based scales may not be considered objective because they are subject to the rater's interpretation [19,21,22]. As well the validity of AS has been questioned because they do not measure the neural (spasticity) component that contributes to the passive resistance [19,23,24]. On the other hand, instrumented approaches for measuring spasticity, by using different combinations of torque and electromyography (EMG) measurements, may more accurately quantify spasticity [25,26]. Nonetheless, the measurement protocols are often unstandardized and require specific training, expensive equipment and additional time, making clinical uptake challenging [8]. Clearly, there is a need for objective clinical tools that are clinically feasible and easily interpreted by the clinician [8]. Over the past few decades attempts have been made to address this gap but implementation in clinical settings has lagged [27–29]. Lack of uptake may be because the methods have not been fully developed for clinical use and the psychometric properties of these methods for

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application to specific diagnostic groups are not well known. Whether the assessment tools used to measure spasticity are instrumented or not, knowledge of the performance characteristics and limitations of spasticity measures for particular patient populations is necessary for accurate interpretation of assessment findings and subsequent clinical decision-making [30,31].

Given that stroke has a significant impact on long-term disability [32], spasticity may interfere with stroke recovery [33], and the clinical presentation of spasticity following stroke differs from other conditions [34], critical appraisal of clinical tools available to measure spasticity after stroke is warranted. To date, systematic review of clinical measures for assessing spasticity with a specific focus on post-stroke is lacking [25,26,35–37]. Therefore, the aim of our systematic review was to identify and appraise the literature on the psychometric properties of clinically usable measures of spasticity that have been investigated in people after stroke.

Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [38].

Literature search

A comprehensive literature search was conducted in (i) PubMed (1950–), (ii) CINAHL (1982–), (iii) Embase (1966–), and (iv) The Cochrane library (1993–). All searches included available records until February 2014 using the following keywords and Medical Subject Headings (MeSH terms): (1) Stroke OR Cerebrovascular Accident OR Hemipleg*, (2) Measur* OR Assess*, and (3) Spas* OR Hyperton*. The searches in all databases were combination as follows: 1 AND 2 AND 3. No limits were applied to the search.

Study selection

Two independent reviewers (S. A. and E. Y.) reviewed the title of each article for initial selection. Abstracts of articles that appeared to be related to the measurement of spasticity were then read and the full articles of relevant abstracts were retained for further examination. The same reviewers read the full text of the papers remaining from the previous stage and used a checklist to confirm that the studies met the inclusion criteria: (i) human adults (≥ 18 years of age); (ii) participants diagnosed with stroke; (iii) measurement of spasticity was conducted in a passive condition by eliciting the stretch reflex [9]; (iv) spasticity measurement under study was a clinical scale or a device for use in clinical practice as indicated by the authors (as opposed to a scale or device used mainly for research purposes); (v) original research articles written in English and published in peer-review journals. Reviews, reports, case studies and studies that involved <10 patients were not included. Discrepancies between reviewers were resolved through consensus. Measures of spasticity in this review were deemed “clinically usable” if they were either an ordinal scale that does not require sophisticated equipment or if it was a device that can be used clinically as stated by the authors (e.g. an instrument developed for clinical settings). In this review, we have relayed on the authors’ judgment on what is clinically usable and what is not without investigating this issue.

Data extraction and quality assessment

Data regarding patients’ characteristics, assessment tools used, tested segment(s), objective of the study and psychometric properties studied were extracted using a structured form. All measurement tools used in the studies were examined in terms of general qualities as measurement tools, practical quality,

and quality specific to the measurement of spasticity. The studies included in the review were also assessed using a 12-item critical appraisal scale that rates the quality of different aspects of the included studies [39]. This scale has been used in previous systematic reviews examining rehabilitation assessment tools [36,40].

Results

Forty articles describing 15 different instruments or measures met the selection criteria (Figure 1). The critical appraisal of the quality of each study is presented in Table 1, which shows a wide range of study quality, with the highest score on the 12 items ranging from 2 to 10. The frequency of high scores was greatest for “Data” ($n=34$ of 40 papers) and “Statistics” ($n=31$), whereas none of the studies included sample size justification and only seven ($n=7$) studies presented hypotheses.

Table 2 provides a summary of each of the 40 studies, 27 investigated non-instrumented measures of spasticity (i.e. ASs [$n=18$ studies], TSs [$n=5$], multi-item scales [$n=4$]) and 13 investigated instrumented measures (i.e. electrophysiological [$n=3$], pendulum test [$n=1$], and force/torque measurements [$n=9$]). Below is a brief description of each measure.

Non-instrumented measurement tools

Ashworth scales

The AS [14], the modified Ashworth scale (MAS) [15] and the modified modified Ashworth scale (MMAS) [21] are ordinal scales that qualify the resistance (tone increase) of muscles to passive movement.

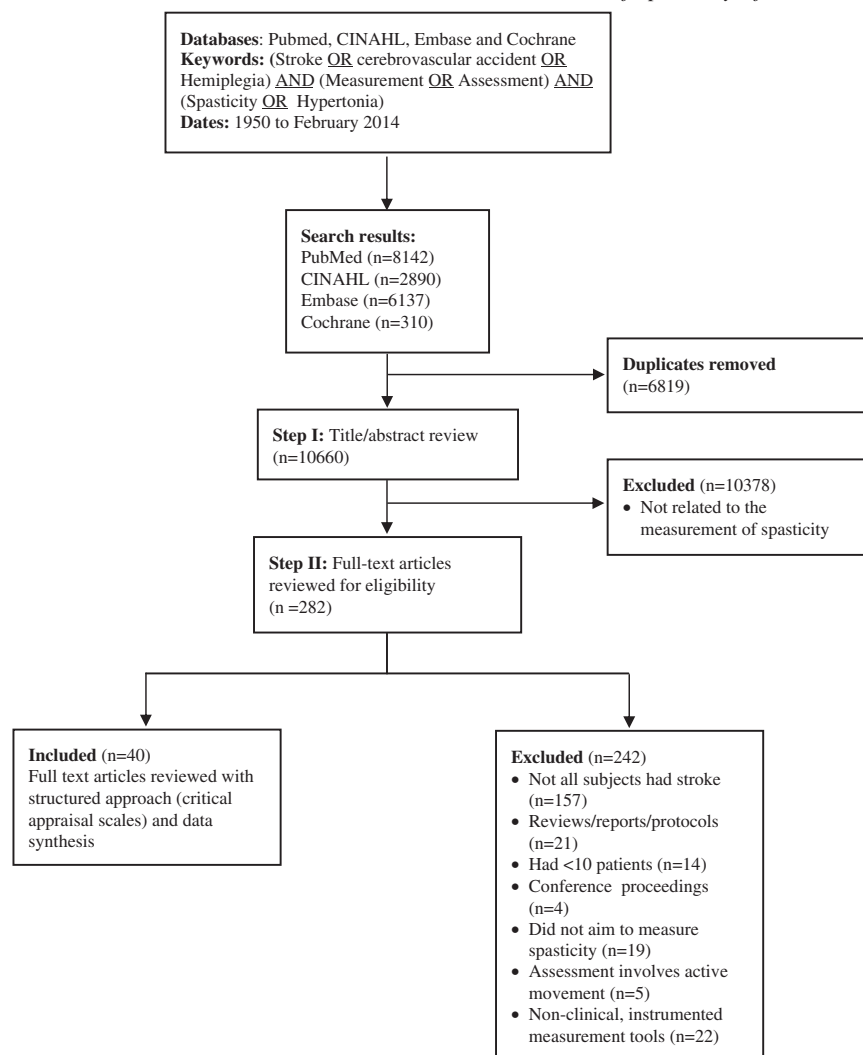
Tardieu scales

The TS [20] and its modified form (MTS) [16] are scales that involve testing the resistance of spastic muscles to passive stretching at different velocities and grading the resistance using an ordinal scale. Also, using a goniometer the full range of motion of the joint and the angle of catch resulting from passive stretch are measured to determine the level of dynamic contracture in the joint [16–18].

Multi-item scales

- (i) Tone Assessment Scale (TAS): The TAS consists of 12 items, sub-divided into three sections [41]. The first section (items 1–3) evaluates the resting posture of the patient. The second section (items 4–9) grades the response to passive movement in different joint of the body using the ordinal scale of the MAS. The final section (items 10–12) assesses movement in response to active efforts to check for abnormal movements (e.g. associated reactions).
- (ii) Categorization of tone and visual analogue scale (VAS): One study in our review described categorizing tone and using a VAS as two approaches to assess spasticity [42]. For tone categorization, the limb is classified as spastic, flaccid or normal. For the VAS, muscle tone is evaluated using a 100-mm vertical VAS with anchor points at the top and bottom for highest and lowest muscle tone, respectively [42].
- (iii) Ankle plantarflexors tone scale (APTS): The APTS is divided into three sub-tests [43]. The first sub-test grades the resistance of passive movement of planterflexors, the second sub-tests grades the resistance in the middle range of planterflexors and the third sub-test grades the resistance in the final range. Each sub-test has a specific 5-point (0–4) ordinal scale.

Figure 1. Flowchart of search and selection strategy.



- (iv) 3-item hypertonus measure: Worley et al. [44] suggested using a 3-item measurement tool for evaluating spasticity. The first item of this tool is measurement of the resting angle, the second item is the measurement of the resistance angle, which involves measuring the angle of catch, and the final item is the quality of resistance to passive movement (RTPM) which is rated using a 5-point ordinal scale.

Instrumented measurement tools

Electrophysiological measures

- The tonic stretch reflex threshold (TSRT) is obtained by using electrogoniometry and surface EMG to record the joint angle and the myoelectric response to manual stretch of the spastic muscle at various fast speeds [27,45]. The TSRT is estimated using linear regression (stretch reflex threshold angle and velocity) [27,45].
- With the patient attached to a wrist rig, manually imposed sinusoidal muscle stretches of the spastic muscle are performed at various speeds guided by a target trace on a monitor. Surface EMG amplitude is normalized to that of the maximal voluntary contraction (MVC) and used as a measure of spasticity [46].

Pendulum test

The knee pendulum test has been applied to measure tone of the elbow flexors muscles using electrogoniometry and EMG. Using an accessory apparatus to assist in performing the pendulum test

with the elbow joint, four variables are measured: (i) stiffness, (ii) threshold angle, (iii) viscosity, and (iv) damping ratio, with the latter defined as an index of spasticity [47].

Force/torque measurements

- A computer-controlled step motor system, the NeuroFlexor™, measures resistance induced by passive wrist extension references. Through biomechanical modeling, the reactive forces recorded during slow and fast velocities are used to estimate elastic, viscous, and neural components of the resistance [29].
- A force transducer and an electrogoniometer record the reactive forces and joint angles imposed by manual slow and fast ramp stretches [48–51]. The RTPM, which is difference between slope of the force-angle curve from slow and fast stretches obtained using linear regression techniques, is used as an index of spasticity [48–51].
- A force transducer records the reactive forces to manually imposed sinusoidal muscle stretches performed at various speeds [28,52,53]. Using a dynamic equation of movement the reactive resistance is divided into inertial, elastic and viscous components [28,52,53]. The viscous component is used as the measurement index of spasticity.

Validity

Approaches used to explore the validity included examining correlations between non-instrumented and instrumented

Table 1. Quality of studies rated with critical appraisal scale.

Studies	Item evaluation criteria ^a (minimum = 0; maximum = 2)											
	Background	Criteria	Hypothesis	Scope	Sample	Retention	Measure	Methods	Data	Statistics	Secondary	Conclusions
Calota et al. [27]	2	2	2	2	0	2	2	2	2	2	0	2
Ansari et al. [69]	2	1	2	2	0	2	2	2	2	1	1	2
Voerman et al. [51]	2	2	0	2	0	2	2	2	2	2	2	1
Blackburn et al. [70]	2	2	0	2	0	2	2	2	2	2	0	2
Gäverth et al. [77]	2	2	0	2	0	2	2	2	2	2	0	2
Kim et al. [45]	2	1	2	1	0	NA	2	2	2	2	2	2
Naghdi et al. [57]	2	2	0	2	0	NA	2	2	2	2	2	2
Ansari et al. [74]	2	2	1	2	0	1	2	2	2	1	0	2
Lindberg et al. [29]	1	2	0	2	0	NA	2	2	2	2	2	2
Naghdi et al. [59]	2	2	0	2	0	NA	2	2	2	2	1	2
Patrick and Ada [62]	1	2	2	2	0	NA	1	2	2	1	2	2
Paulis et al. [75]	1	2	2	2	0	2	1	2	2	2	0	1
Kaya, et al. [73]	2	2	0	2	0	NA	2	2	2	2	0	2
Malhotra et al. [48]	2	2	0	2	0	NA	2	2	2	2	0	2
Naghdi et al. [58]	1	2	0	2	0	NA	2	2	2	2	1	2
Singh et al. [76]	2	2	0	2	0	2	1	2	2	1	0	2
Sorinola et al. [46]	1	2	0	1	0	1	2	1	2	2	2	2
Naghdi et al. [60]	2	1	0	2	0	NA	2	2	2	2	1	1
Gregson et al. [71]	1	1	0	1	0	2	2	2	2	2	0	1
Kumar et al. [67]	1	1	0	2	0	NA	1	1	2	2	2	2
Takeuchi et al. [43]	2	2	0	2	0	2	1	1	2	1	0	1
Vattanasilp and Ada [63]	1	1	0	2	0	NA	2	2	2	2	0	2
Wu et al. [53]	1	1	0	1	0	2	1	2	2	2	0	2
Ansari et al. [68]	1	1	0	2	0	NA	1	2	2	2	0	2
Cooper et al. [64]	1	2	0	2	0	NA	1	1	2	2	0	2
Gregson et al. [72]	1	1	0	2	0	2	0	2	2	2	0	1
Min et al. [66]	1	2	0	2	0	1	2	0	2	2	0	1
Pandyan et al. [49]	2	1	0	2	0	NA	2	1	2	2	0	1
Bakheit et al. [54]	1	2	0	2	0	NA	2	2	1	1	0	1
Barnes et al. [41]	1	0	0	2	0	NA	2	2	1	2	0	2
Chen et al. [52]	1	2	0	1	0	2	1	1	1	2	0	1
Pandyan et al. [50]	1	1	0	1	0	NA	1	1	2	2	0	2
Lee et al. [28]	1	0	0	1	0	NA	2	0	2	2	0	2
Milanov I [56]	2	0	0	2	0	NA	0	1	2	2	0	1
Pandyan et al. [65]	0	2	0	2	0	NA	0	0	1	2	2	1
Pisano et al. [61]	2	1	0	2	0	NA	0	0	2	2	0	1
Pomeroy et al. [42]	1	1	1	1	0	NA	1	2	1	1	0	1
Worley et al. [44]	1	1	0	1	0	NA	2	1	2	1	0	1
Ghotbi et al. [55]	0	0	0	1	0	NA	0	1	2	2	0	2
Lin et al. [47]	0	1	0	0	0	NA	2	2	1	1	0	1

^aItem evaluation criteria: Background: Relevant background on spasticity measurement and research question; Criteria: Inclusion/exclusion criteria; Hypothesis: Specific hypothesis; Scope: Appropriate scope of psychometric properties; Sample: Appropriate sample size calculation; Retention: appropriate retention/follow-up; Measure: Specific descriptions of the measures (administration, scoring, interpretation procedures); Methods: Standardization of methods; Data: Data presented for each hypothesis or purpose; Statistics: Appropriate statistical tests; Secondary: Appropriate secondary analyses; Conclusions: Conclusions/clinical recommendations supported by analyses and results; NA, not applicable.

measures and the ability to discriminate between measured responses in affected and non-affected muscles. The MAS was used as a benchmark of spasticity in eight studies [27–29,45,46,49,51,53], and surface EMG was used in eight other studies [54–61]. Surface EMG was used as a benchmark for spasticity in these studies by using the following parameters: amplitude, latency, ratio between the H-reflex amplitude and muscle response to an electrical impulse to a peripheral nerve ($H_{\max}:M_{\max}$ ratio), and ratio between the H-reflex slope and M-response recruitment curves ($H_{\text{slope}}:M_{\text{slope}}$ ratio). Both ratios have been used to quantify the excitability of the motor neurons [25].

Ashworth scales

Patrick and Ada [62] reported 63% agreement ($\kappa = 0.24$, $p = 0.02$) between the presence of spasticity measured using the AS and EMG but did not find a significant correlation between the AS and fast stretch-induced EMG-activity [62]. Conversely,

Vattanasilp and Ada [63] reported a significant correlation between the AS and RTPM measured using a torque system ($\rho = 0.52$ – 0.64 , $p < 0.01$).

Significant correlations have been reported between the MAS and magnitude of EMG response to stretch test ($\rho = 0.21$, $p = 0.022$) [64], and between the MAS and stretch reflex latency ($\rho = -0.37$, $p < 0.01$) and stretch reflex area ($\rho = 0.36$, $p < 0.01$) [61]. Similarly, RTPM has been shown to be significantly correlated with MAS ($\rho = 0.51$, $p < 0.01$; $\rho = 0.55$, $p < 0.01$, respectively) [61,65]. Finally, the MAS was found to have a significant negative correlation with the speed of the stretch reflex test ($\rho = -0.46$, $p < 0.001$) [61].

The MAS has not been shown to be significantly correlated with any H-reflex parameters (latency, amplitude, $H_{\max}:M_{\max}$ ratio and $H_{\text{slope}}:M_{\text{slope}}$ ratio) [55,56,59,61] or any EMG-measured manual tendon reflex parameters (amplitude and latency) [56]. Min et al. [66] reported that the MAS was significantly correlated with amplitude, but not latency, of the biceps brachii tendon reflex ($\rho = 0.46$ – 0.57 , $p < 0.01$).

Table 2. Summary of studies.

Study	Measure(s)	Population	n	Segment	Objective of study
Ashworth scales Ansari et al. [68]	MMAS	Mean age = 60y, 5 F/16 M; median time since stroke = 11m	21	Elbow	Inter-rater reliability of the MMAS.
Ansari et al. [69]	MMAS	Mean age = 67y, 8 F/7 M; mean time since stroke = 14.1m	15	Knee	Inter-rater and intra-rater reliability of the MMAS
Bakheit et al. [54]	MAS and H-reflex	Mean age = 60.8y, 8 F/17 M; mean time since stroke = 13.7m	25	Ankle	Investigate correlation between MAS and neuro-physiological tests of spasticity
Blackburn et al. [70]	MAS	Mean age = 76.1y, 19 F/17 M; time since stroke = 2w–12w.	36	Knee and Ankle	Inter-rater and intra-rater reliability of MAS
Cooper et al. [64]	MAS and EMG	Mean age = 65y; mean time since stroke = 29m	31	Knee and ankle	Validity of the MAS by comparing to surface EMG
Ghotbi et al. [55]	MAS and H-reflex	Mean age = 61.8y, 3 F/17 M; mean time since stroke = 20.7m	20	Ankle	Validity of the MAS by comparing to H-reflex
Gregson et al. [71]	MAS and TAS	Median age = 74y, 14 F/18 M; median time since stroke = 48d	32	Elbow	Inter-rater and intra-rater reliability of the TAS and MAS.
Gregson et al. [72]	MAS	Median age 73y, 15 F/20 M; median time since stroke = 40d	35	Elbow, wrist, knee and ankle	Inter-rater and intra-rater reliability of the MAS
Kaya, et al. [73]	MAS and MMAS	Mean age = 60.5y, 23 F, 41 M; mean time since stroke = 15.7w	64	Elbow	Inter-rater reliability of MAS and MMAS.
Kumar et al. [67]	MAS and torque measurement	Median age = 72y, 45 F/66 M; median time since stroke = 11m	111	Elbow	Validity of the MAS by comparing it to resistance to passive movement
Milanov I [56]	MAS, T-reflex, H-reflex and EMG	Mean age = 57.9y, 87 F/33 M; mean time since stroke = 36.3m	120	Not specified	Correlation between neuro-physiological and clinical methods for evaluating spasticity
Min et al. [66]	MAS, T-reflex and EMG to measure response	Mean age = 58y, 8 F/14 M; mean time since stroke = 32.2d	21	Elbow	Correlation between MAS and amplitude and latency of T-reflex.
Naghdi et al. [60]	MMAS and H-reflex	Mean age = 58.9y, 7 F/5 M; mean time since stroke = 27.2m	12	Wrist	Validity of the MMAS by comparing to H-reflex
Naghdi et al. [58]	MMAS and H-reflex	Mean age = 57.9y, 14 F/13 M; mean time since stroke = 20.8m	27	Wrist	Validity of the MMAS by comparing to H-reflex
Naghdi et al. [59]	MAS and H-reflex	Mean age = 57.9y, 14 F/13 M; mean time since stroke = 20.8m	27	Wrist	Validity of the MAS by comparing to H-reflex
Pandyan et al. [65]	MAS and torque measurement	Patients post-stroke. Characteristics not reported.	63	Elbow	Validity of the MAS by comparing it resistance to passive movement
Pisano et al. [61]	MAS, H-reflex, EMG and torque measurement	Mean age = 45.3y, 14 F/39 M; mean time since stroke = 30.7m	53	Wrist	Correlating MAS with EMG and biomechanical measures
Vattanasilp and Ada [63]	AS, tendon jerk, EMG and torque measurement	Mean age = 66.5y; time since stroke = 2w–5y.	44	Ankle	Examine relationship between two clinical and two laboratory measures of spasticity
Tardieu scales Ansari et al. [74]	MTS	Mean age = 57.5y, 13F/17 M; mean time since stroke = 28.5m	30	Ankle	Inter-rater and intra-rater reliability of the MTS
Naghdi et al. [57]	MTS, H-reflex and EMG	Mean age = 52.7y, 9 F/11 M; mean time since stroke = 33m	20	Wrist	Validity of the MTS by comparing to H-reflex
Patrick and Ada [62]	AS, TS, EMG and torque measurement	Mean age = 63y, 5 F/11 M; mean time since = 3y	16	Elbow and Ankle	Validity of the TS by comparing it to AS and to EMG and resistance to passive movement
Paulis et al. [75]	TS	Mean age = 70.2y, 6 F/7 M.	13	Elbow	Test-retest and inter-rater reliability of TS.
Singh et al. [76]	MTS	Mean age = 64y, 37 F/54 M; mean time since stroke = 57.5d	91	Elbow and ankle	Intra-rater reliability of the MTS

(continued)

Table 2. Continued

Study	Measure(s)	Population	n	Segment	Objective of study
Multi-item scales					
Barnes et al. [41]	TAS	Median age = 72y, 9 F/6 M; median time since stroke = 5m	15	General	To develop a reliable, multi-item, ordinal scale and assess inter-rater reliability
Pomeroy et al. [42]	Categorization of tone and VAS	Patients post stroke. Characteristics not reported.	39	Elbow and knee	Inter-rater reliability of clinical categorization of tone (spastic/normal/flaccid) and VAS
Takeuchi et al. [43]	MAS, TS, APTS and torque measurement	Mean age = 77.5y, 43 F/31 M; mean time since stroke = 1084.2 d	74	Ankle	To develop and evaluate the reliability and validity of the APTS
Worley et al. [44]	3-item, hypertonus measure	Mean age = 66.6y, 28 F/17 M; mean time since stroke = 41d	45	Elbow	Determine reliability of a potential measure of hypertonus
Electrophysiological measures					
Calota et al. [27]	TSRT	Mean age = 62.9 y; 4 F/16 M; mean time since stroke = 77.9 m	20	Elbow	Intra-rater and inter-rater reliability of TSRT; correlation with MAS
Kim et al. [45]	TSRT	Mean age = 63.5 y; 8 F/7 M; mean time since stroke = 6.7 m	15	Elbow	Development of portable system to quantify spasticity; correlation with MAS
Sorinola et al. [46]	Normalized EMG by MVC	Mean age = 53.7 y; 4 F/6 M; mean time since stroke = 30.9 m	10	Wrist flexors	Reliability of rig to measure spasticity and relationship with EMG and MAS
Pendulum test					
Lin et al. [47]	Damping ratio	Mean age = 57.7 y; 11 M	11	Elbow	Modification of pendulum test for elbow joint
Force/torque measurements					
Lindberg et al. [29]	NeuroFlexor	Mean age = 61.3 y, 14 F/17 M; mean time since stroke = 5.3 y	31	Wrist	Development and validation of NeuroFlexor™
Gäverth et al. [77]	NeuroFlexor	Mean age = 53.8 y, 7 F/27 M; mean time since stroke = 5 y	34	Wrist	Test–retest and inter-rater reliability of NeuroFlexor™
Pandyan et al. [49]	RTPM	Mean age = 67.3 y, 6 F/10 M	16	Elbow	Development of measure of spasticity
Pandyan et al. [50]	RTPM and EMG	Median age = 61 y, 6 F/8 M; median time since stroke = 48 m	14	Elbow flexors	Validity of a biomechanical device for measuring spasticity
Voerman et al. [51]	RTPM and EMG	Mean age = 56.6 y; 2 F/10 M; mean time since stroke = 3.9 y	12	Wrist	Sensitivity, inter-rater/test–retest reliability and validity of device
Malhotra et al. [48]	RTPM and EMG	Median age = 74 y; 46 F/54 M; median time since stroke = 3 w	100	Wrist flexors	Quantification of agreement with MAS and EMG
Lee et al. [28]	Viscosity Component	Mean age = 57 y; time since stroke = 2 w – 5 y	15	Elbow	Development of device for quantifying spasticity
Wu et al. [53]	Viscosity Component	Mean age = 57.5 y, 8 F/5 M; mean time since stroke = 31 m	13	Elbow	Measurement of spasticity before and after Botox
Chen et al. [52]	Viscosity Component	Mean age = 57.3 y; 6 F/4 M; mean time since stroke = 37.7 m	10	Elbow	Responsiveness of device before and after Botox

n, Number of participants; MMAS, Modified-Modified Ashworth Scale; F, female; M, male; MAS, Modified Ashworth Scale; H-reflex, Hoffman's reflex; EMG, electromyography; TAS, tone assessment scale; T-reflex, tendon jerk reflex measured using EMG; AS, Ashworth scale; MTS, modified Tardieu scale; TS, Tardieu scale; VAS, visual analogue scale; APTS, ankle planter flexors tone scale; TSRT, tonic stretch reflex threshold; F, female; M, male; RTPM, resistance to passive movement; EMG, electromyography; y, years; m, months; w, weeks; d, days.

Investigations of the discriminative ability of the MAS have reported conflicting results, with two studies revealing no significant differences in resistance to passive stretch among groups with different MAS scores [65,67], and another study noting a significant correlation between MAS and EMG response (Cramer's $V = 0.27$, $p = 0.023$) [64]. Pandyan et al. [65] reported a significant difference ($p < 0.01$) in RTPM between patients with MAS scores of "0" versus ">0".

Only two studies investigated validity of the MMAS [58,60], with the first reporting no significant correlations between MMAS and the H-reflex parameters [60], and the second reporting significant correlations between MMAS with the H-reflex $H_{\max}:M_{\max}$ and $H_{\text{slope}}:M_{\text{slope}}$ ratios, and H-reflex H_{slope} ($\rho = 0.39$, $p = 0.04$; $\rho = 0.39$, $p = 0.04$; $\rho = 0.45$, $p = 0.02$) [58].

Tardieu scales

Patrick and Ada [62], reported 100% agreement ($\kappa = 1.0$) between the presence of spasticity on the TS (score of 2 or higher) and EMG, as well as a significant correlation between the TS and fast stretch-induced EMG activity (Pearson's $r = 0.62$ – 0.86 , $p < 0.01$) [62]. Naghdi et al. [57], noted significant differences ($p < 0.001$) in R1, R2 and R2–R1 of the MTS between patient groups with MTS scores of 0 and 2 but no significant correlations between the MTS and the H-reflex parameters.

Multi-item scales

None of the studies investigated the validity of the TAS, categorization of tone and VAS and the 3-item hypertonus measure. Takeuchi et al. [43] found that the APTS stretch reflex sub-test had significant correlations with TS ($\rho = 0.85$ – 0.94 , $p < 0.01$) and with MAS ($\rho = 0.26$ – 0.41 , $p < 0.05$) but not with RTPM. Further, the middle range sub-test showed significant correlations with TS ($\rho = 0.31$ – 0.42 , $p < 0.01$), MAS ($\rho = 0.59$ – 0.62 , $p < 0.01$) and RTPM ($\rho = 0.44$ – 0.50 , $p < 0.01$). Finally, the final range sub-test showed significant correlations with TS ($\rho = 0.30$ – 0.31 , $p < 0.01$), MAS ($\rho = 0.67$ – 0.68 , $p < 0.01$) and RTPM ($\rho = 0.55$, $p < 0.01$) [43].

Electrophysiological measures

Conflicting findings exist regarding the validity of TSRT, with one study reporting a strong association between TSRT and MAS ($\rho = -0.74$, $p < 0.05$) [45], while another study reported a low correlation ($\rho = -0.26$, $p > 0.44$) [27]. A strong association was found between normalized EMG amplitude of the low speed stretch test and MAS ($\rho = 0.72$, $p < 0.05$) although such an association was not present at higher speeds [46].

Pendulum test

The damping ratio derived from the pendulum test for hemiparetic elbow flexors was significantly different from that of the contralateral side ($p = 0.0015$) and also different when compared to non-disabled individuals ($p < 0.001$) [47].

Force/torque measurements

Lindberg et al. [29] reported that the neural component of passive movement resistance measured using the NeuroFlexor method was found to be both velocity-dependent and associated with integrated EMG ($\rho > 0.58$, $p < 0.001$). Authors also reported that the EMG response and the neural component were significantly reduced during an ischemic nerve block test and that the neural component and MAS scores were significantly correlated ($\rho > 0.6$, $p < 0.001$) [29].

Contradictory evidence regarding the validity of the force/torque measurements (manual slow and fast ramp stretches) was noted. Although Voerman et al. [51] reported that RTPM parameters were not significantly different between patients with spasticity and non-disabled individuals, Pandyan et al. [49] found significant differences in RTPM parameters between affected and contralateral sides of people with spastic hemiparesis. Voerman et al. [51] reported positive correlations of RTPM and MAS only at low speed testing ($\rho = 0.73$, $p < 0.05$), whereas two other studies did not find any significant associations between MAS scores, RTPM and EMG parameters [48,50]. Pandyan et al. [50] did find that EMG parameters were significantly different during slow and fast speed stretching but Voerman et al. [51] showed that EMG responses were significantly different between patients post-stroke and non-disabled subjects.

Evidence of the validity of manual sinusoidal motion has been more consistently presented, albeit in only a few studies. The viscosity component derived using this method was highly correlated with the MAS ($\rho = 0.86$, $\rho = 0.99$, $p < 0.001$) [28,53] and could distinguish between subjects who suffer from spasticity and non-disabled individuals [28], as well as between measurements pre- and post-treatment with botulinum toxin type A [52].

Reliability

Table 3 summarizes the reliability of spasticity measures included in this review. In total, the reliability of ASs was reported in six studies [68–73], TSs in three [74–76], multi-item scales in five [41–44,71], electrophysiological measures in two [27,46], and force/torque measures in two [51,77]. There were no reports on the reliability of the elbow pendulum test or the manual sinusoidal method. Further, only one study reported on absolute reliability (stability or precision of the measure [78]), the coefficient of variation of the neural component of the NeuroFlexor was 32% for both test–retest and inter-rater reliabilities [77].

Discussion

The aim of our systematic review was to identify and appraise the literature on clinical measures of spasticity that have been investigated in people after stroke. We identified 15 tools (or instruments) for the measurement spasticity divided into two broad categories: non-instrumented (i.e. ASs, TSs, and multi-item scales) and instrumented (i.e. electrophysiological scales, pendulum test, and torque/force measures). These measures ranged from ordinal scales to biomechanical and neurophysiological tests. Thus, our review provides a comprehensive view of all those types of spasticity assessments in patients after stroke.

Overall, this review indicates that little evidence exists on psychometric properties of clinical spasticity assessment tools in the patients post-stroke. For most tools, data on validity and reliability were insufficient to make informed clinical decisions during the assessment and management of spasticity among patients after stroke. We also noted that the majority of the included studies ($n = 28$, 70%) assessed the level of spasticity in upper extremity muscles. Few studies addressed spasticity in the lower extremity.

The quality appraisal of the included studies outlined in Table 1 indicates that the methodological quality was moderate to adequate for the majority of the studies. In general, the quality of studies using instrumented measure had higher scores than studies involving non-instrumented measures. The item "sample" of all studies was the most limiting factor, due to the absence of adequate sample size calculations for all studies.

In the absence of a gold standard for the measurement of spasticity, most studies used the MAS as a comparator as to assess criterion validity, possibly because the MAS is the most

Table 3. Reliability of spasticity measures.

Study	Measure	Muscle group(s)	Test–retest ^a	Inter-rater
Ashworth scales				
Ansari et al. [68]	MMAS	Elbow flexors	NA	Kw = 0.81
Ansari et al. [69]	MMAS	Knee extensors	K = 0.82	K = 0.72
Blackburn et al. [70]	MAS	Lower extremity muscles ^b	Tau-b = 0.57	Tau-b = 0.06
Gregson et al. [71]	MAS	Elbow flexors	Kw = 0.83	Kw = 0.84
Gregson et al. [72]	MAS	Wrist flexors	Kw = 0.80–0.88	Kw = 0.84–0.89
Gregson et al. [72]	MAS	Elbow flexors	Kw = 0.77–0.83	Kw = 0.77–0.96
Gregson et al. [72]	MAS	Ankle planter flexors	Kw = 0.59–0.64	Kw = 0.45–0.51
Gregson et al. [72]	MAS	Knee flexors	Kw = 0.77–0.94	Kw = 0.73–0.79
Kaya, et al. [73]	MMAS	Elbow flexors	NA	Kw = 0.89
Kaya et al. [73]	MAS	Elbow flexors	NA	Kw = 0.87
Tardieu scales				
Ansari et al. [74]	MTS	Ankle planter flexors	ICC = 0.68	ICC = 0.71
Paulis et al. [75]	TS ^c	Elbow flexors	ICC = 0.86	ICC = 0.66
Paulis et al. [75]	TS ^d	Elbow flexors	ICC = 0.76	ICC = 0.84
Singh et al. [76]	MTS	Elbow flexors	ICC = 0.85	NA
Singh et al. [76]	MTS	Ankle planter flexors	ICC = 0.86	NA
Multi-item scales				
Barnes et al. [41]	TAS (Q4–Q9)	Elbow flexors	NA	Kw = 0.66–0.94
Gregson et al. [71]	TAS (Q4–Q9)	Elbow flexors	Kw = 0.59–0.86	Kw = 0.79–0.92
Pomeroy et al. [42]	Categorizing Tone	Elbow flexors	NA	K = –0.046 to 0.56
Pomeroy et al. [42]	VAS	Elbow flexors	NA	ICC = 0.56
Pomeroy et al. [42]	Categorizing Tone	Knee extensors	NA	K = –0.25–0.48
Pomeroy et al. [42]	VAS	Knee extensors	NA	ICC = 0.45
Takeuchi et al. [43]	APTS	Ankle planter flexors	K = 0.72–0.94	K = 0.63–0.82
Worley et al. [44]	3-item, hypertonus measure	Elbow flexors	NA	ρ = 0.57–0.79
Electrophysiological measures				
Calota et al. [27]	TSRT	Elbow flexors	ICC = 0.46–0.68 Three raters, 2–7 d interval	ICC = 0.53 – 0.60 Three raters
Sorinola et al. [46]	Normalized EMG by MVC	Wrist flexors	ICC = 0.71–0.81 Six speeds 60–360 degrees/second	NA
Force/torque measurements				
Gäverth et al. [77]	NeuroFlexor, (neural component)	Wrist flexors	ICC = 0.90, 0.96 Two raters	ICC = 0.90, 0.94 Two raters
Voerman et al. [51]	EMG amplitude and slope (force-angle curve)	Wrist flexors	EMG: 0.65–0.82 Slope: 0.67–0.89 Three speeds	EMG: 0.73–0.79 Slope: 0.96–0.99 Three speeds

MMAS, modified-modified Ashworth scale; MAS, modified Ashworth scale; MTS, modified Tardieu scale; TS, Tardieu scale; TAS, tone assessment scale questions 4 to 9; VAS, visual analogue scale; APTS, ankle planter flexors scale; TSRT, tonic stretch reflex threshold; EMG, electromyography; MVC, maximal voluntary contraction; Kw, weighted kappa statistic; K, kappa statistic; Tau-b, Kendall tau rank correlation coefficient; ICC, intra-class correlation coefficient; NA, no data available; rho, Spearman's rank correlation coefficient.

^aTest–retest reliability and intra-rater reliability were considered as one, as the reviewed studies referred to them interchangeably.

^bCombined values for quadriceps femoris, gastrocnemius and soleus muscles.

^cR2–R1 measured using a goniometer.

^dR2–R1 measured using an inertial sensor.

commonly used clinical scale [11]. However, as mentioned earlier, various studies have reported that ordinal scales, especially the ASs, rely on the interpretation of the assessor, which can result in subjective and inaccurate grading of the level spasticity [19,21,23,24]. Thus, use of the MAS as the comparator measure may have contributed to the inconclusive and often conflicting results in the validity of the measures included in our review.

We noted that, in addition to over-reliance on the MAS, assessment of validity was lacking. One measure (pendulum test) was not investigated in relation to any other spasticity scale or EMG [47]. Of the studies involving instrumented tools, three measures (TSRT, EMG normalized by MVC and manual sinusoidal motion) restricted validity testing to examining the correlation with the MAS [27,28,45,46,52,53]. It could be argued that because two of these measures (i.e. TSRT and EMG normalized to MVC) were obtained using EMG, validation of measurement was not necessary. Indeed, EMG is a more direct way of measuring the reflex response to stimuli, which is consistent with the definition of spasticity defined by Lance [9]. Nevertheless, use of other physiological measures (e.g. H-reflex)

as comparators would have helped clarify issues regarding validity. Another concern is use of the MVC to normalize EMG data collected on people post-stroke, because the MVC may not be an accurate reflection of the actual maximal torque generating capacity of paretic muscles [79].

Our review found that, in general, the spasticity measures had the ability to discriminate between the affected and unaffected sides as well as between patients with spasticity and non-disabled individuals. However, the measures lacked the more clinically useful ability to discriminate among different levels of spasticity.

Three previous systematic reviews on measures for spasticity and associated phenomena published in 2005 concluded that robust evidence of reliability for many of the scales reviewed was lacking [25,26,37]. Today, this still holds true – we noted absence of reliability testing for two measures (AS and manual sinusoidal method) and a wide range of reliability for the other measures. Furthermore, only one measure (NeuroFlexor) reported on absolute reliability [77]. To interpret results of reliability studies, it is helpful to classify the strength of agreement of findings using the classification by Munro et al. [80], where 0.26 to 0.49 is a low

correlation, 0.50 to 0.69 is moderate, 0.70 to 0.89 is high, and 0.90 to 1.00 is very high, or the classification by Brennan and Silman [81] $\kappa < 0.21$, poor; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, good; 0.81–1, very good agreement. The reliability of spasticity measures was low to very high for ASs and the multi-item scales, moderate to high for the TSs and electrophysiological measures, and moderate to very high for torque/force measurements. Lack of standardization of test procedures may have contributed to high variability among studies.

Reliability was often reported in the form of the intra-class correlation coefficient (ICC). However, there are issues when using the ICC to report on the repeatability of spasticity measures. Most importantly, when the ICC is applied to ordinal data, the assumption is that the spacing between each level of spasticity is equal (e.g. the level of spasticity between MAS 0 and 1 is equal to the level between MAS 1 and 1+), which is not correct [78,81,82]. The appropriate statistical method to use for ordinal data is the Kappa statistic [78,81]. Further, we noted substantial heterogeneity in terms of the level of spasticity of subjects in most of the studies. Reliability determined using the ICC will appear to be higher for a group of subjects with a wide range of spasticity levels compared to a group with a narrow range [82].

Limitations of this review

One limitation of this review is the number of included studies. Study eligibility was necessarily restricted by our focus on instrumented and non-instrumented measures used in clinical practice or clinical research with people post-stroke. Further, we included only those studies in which spasticity was measured in the passive, relaxed state. Although the extent of spasticity during functional, multi-joint movements such as walking is of clinical significance, the superimposition of active movement makes it difficult to determine the relative contributions of the willed active movement and underlying spasticity on the level of excitability of the stretch reflex arc.

Recommendations and conclusion

In this review, we found a number of instrumented and non-instrumented clinical measures for assessing spasticity among patients post-stroke. However, the evidence in support of the validity and reliability of these measures is lacking. We were unable to find sufficient psychometric evidence to recommend one tool over the others. Given the importance of spasticity assessment for accurate evaluation of the functional capacity and appropriate intervention of patients after stroke, further study of the psychometric properties of clinical measures is warranted.

Declaration of interest

One of the co-authors (JG) of this systematic review is the first author and co-author of 2 articles included in this review. These two articles were not reviewed or rated by JG. No funding has been received for the conduct of this study.

References

- Mohr JP, Choi DW, Grotta JC, et al., eds. *Stroke: pathophysiology, diagnosis, and management*. 4th ed. New York: Churchill Livingstone; 2004.
- Stein J, Harvey RL, Macko RF, et al., eds. *Stroke recovery and rehabilitation*. 1st ed. New York: Demos Medical; 2009.
- Sommerfeld DK, Gripensdet U, Welmer AK. Spasticity after stroke: an overview of prevalence, test instruments, and treatments. *Am J Phys Med Rehabil* 2012;91:814–20.
- Urban PP, Wolf T, Uebele M, et al. Occurrence and clinical predictors of spasticity after ischemic stroke. *Stroke* 2010;41:2016–20.
- Sheean G. The pathophysiology of spasticity. *Eur J Neurol* 2002;9: S3–9.
- Ward AB. A literature review of the pathophysiology and onset of post-stroke spasticity. *Eur J Neurol* 2012;19:21–7.
- Barnes MP, Johnson GR, eds. *Upper motor neurone syndrome and spasticity: clinical management and neurophysiology*. 2nd ed. Cambridge: Cambridge University Press; 2008.
- Burridge JH, Wood DE, Hermens HJ, et al. Theoretical and methodological considerations in the measurement of spasticity. *Disabil Rehabil* 2005;27:69–80.
- Lance JW. The control of muscle tone, reflexes, and movement: Robert Wartenberg Lecture. *Neurology* 1980;30:1303–13.
- O'Dwyer NJ, Ada L. Reflex hyperexcitability and muscle contracture in relation to spastic hypertonia. *Curr Opin Neurol* 1996;9: 451–5.
- van Wijck FM, Pandyan AD, Johnson GR, Barnes MP. Assessing motor deficits in neurological rehabilitation: patterns of instrument usage. *Neurorehabil Neural Repair* 2001;15:23–30.
- Alhusaini AA, Dean CM, Crosbie J, et al. Evaluation of spasticity in children with cerebral palsy using Ashworth and Tardieu Scales compared with laboratory measures. *J Child Neurol* 2010;25: 1242–7.
- Thibaut A, Chatelle C, Ziegler E, et al. Spasticity after stroke: physiology, assessment and treatment. *Brain Inj* 2013;27:1093–105.
- Ashworth B. Preliminary trial of carisoprodol in multiple sclerosis. *Practitioner* 1964;192:540–2.
- Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. *Phys Ther* 1987;67:206–7.
- Boyd RN, Graham HK. Objective measurement of clinical findings in the use of botulinum toxin type A for the management of children with cerebral palsy. *Eur J Neurol* 1999;6:S23–35.
- Haugh AB, Pandyan AD, Johnson GR. A systematic review of the Tardieu scale for the measurement of spasticity. *Disabil Rehabil* 2006;28:899–907.
- Held JP, Pierrot-Deseilligny E. *Reeducation motrice des affections neurologiques*. Paris: Baillière; 1969.
- Pandyan AD, Johnson GR, Price CIM, et al. A review of the properties and limitations of the Ashworth and modified Ashworth Scales as measures of spasticity. *Clin Rehabil* 1999;13: 373–83.
- Tardieu G, Shentoub S, Delarue R. A la recherche d'une technique de mesure de la spasticité. *Rev Neurol (Paris)* 1954;91:143–4.
- Ansari NN, Naghdi S, Moammeri H, Jalaie S. Ashworth Scales are unreliable for the assessment of muscle spasticity. *Physiother Theory Pract* 2006;22:119–25.
- MacKenzie CR, Charlson ME. Standards for the use of ordinal scales in clinical trials. *Br Med J* 1986;292:40–3.
- Fleuren JF, Voerman GE, Erren-Wolters CV, et al. Stop using the Ashworth Scale for the assessment of spasticity. *J Neurol Neurosurg Psychiatr* 2010;81:46–52.
- Malhotra S, Pandyan AD, Day CR, et al. Spasticity, an impairment that is poorly defined and poorly measured. *Clin Rehabil* 2009;23: 651–8.
- Voerman GE, Gregoric M, Hermens HJ. Neurophysiological methods for the assessment of spasticity: the Hoffman reflex, the tendon reflex, and the stretch reflex. *Disabil Rehabil* 2005;27: 33–68.
- Wood DE, Burridge JH, van Wijck FM, et al. Biomechanical approaches applied to the lower and upper limb for the measurement of spasticity: a systematic review of the literature. *Disabil Rehabil* 2005;27:19–32.
- Calota A, Feldman AG, Levin MF. Spasticity measurement based on tonic stretch reflex threshold in stroke using a portable device. *Clin Neurophysiol* 2008;119:2329–37.
- Lee HM, Chen JJ, Ju MS, et al. Validation of portable muscle tone measurement device for quantifying velocity-dependent properties in elbow spasticity. *J Electromyogr Kinesiol* 2004;14:577–89.
- Lindberg PG, Gaverth J, Islam M, et al. Validation of a new biomechanical model to measure muscle tone in spastic muscles. *Neurorehabil Neural Repair* 2011;25:617–25.
- Everitt BS. *Statistical methods in medical investigations*, 2nd ed. London: Edward Arnold; 1994.
- Wilkin D, Hallam L, Doggett M. *Measures of need and outcome for primary health care*, 1st ed. Oxford: Oxford Medical Publ; 1992.
- Adamson J, Beswick A, Ebrahim S. Is stroke the most common cause of disability? *J Stroke Cerebrovasc Dis* 2004;13:171–7.

33. Sommerfeld DK, Eek EU, Svensson AK, et al. Spasticity after stroke: its occurrence and association with motor impairments and activity limitations. *Stroke* 2004;35:134–9.
34. Sheean G, McGuire JR. Spastic hypertonia and movement disorders: pathophysiology, clinical presentation, and quantification. *PM R* 2009;1:827–33.
35. Bar-On L, Aertbelien E, Molenaers G, et al. Manually controlled instrumented spasticity assessments: a systematic review of psychometric properties. *Dev Med Child Neurol* 2014;56:932–50.
36. Flamand VH, Masse-Alarie H, Schneider C. Psychometric evidence of spasticity measurement tools in cerebral palsy children and adolescents: a systematic review. *J Rehabil Med* 2013;45:14–23.
37. Platz T, Eickhof C, Nuyens G, Vuadens P. Clinical scales for the assessment of spasticity, associated phenomena, and function: a systematic review of the literature. *Disabil Rehabil* 2005;27:7–18.
38. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Ann Intern Med* 2009;151:264–9.
39. Law MC, MacDermid J, eds. Evidence-based rehabilitation: a guide to practice. 2nd ed. New Jersey: Slack Incorporated; 2008.
40. Roy JS, Desmeules F, MacDermid JC. Psychometric properties of presenteeism scales for musculoskeletal disorders: a systematic review. *J Rehabil Med* 2011;43:23–31.
41. Barnes S, Gregson J, Leathley M, et al. Development and inter-rater reliability of an assessment tool for measuring muscle tone in people with hemiplegia after a stroke. *Physiotherapy* 1999;85:405–9.
42. Pomeroy VM, Dean D, Sykes L, et al. The unreliability of clinical measures of muscle tone: implications for stroke therapy. *Age Ageing* 2000;29:229–33.
43. Takeuchi N, Kuwabara T, Usuda S. Development and evaluation of a new measure for muscle tone of ankle plantar flexors: the ankle plantar flexors tone scale. *Arch Phys Med Rehabil* 2009;90:2054–61.
44. Worley JS, Harmon N, Miller GJ, et al. Reliability of potential clinical measures of muscle tone in the elbows of patients after stroke. *Am J Occup Ther* 1996;50:554–60.
45. Kim KS, Seo JH, Song CG. Portable measurement system for the objective evaluation of the spasticity of hemiplegic patients based on the tonic stretch reflex threshold. *Med Eng Phys* 2011;33:62–9.
46. Sorinola IO, White CM, Rushton DN, Newham DJ. Electromyographic response to manual passive stretch of the hemiplegic wrist: accuracy, reliability, and correlation with clinical spasticity assessment and function. *Neurorehabil Neural Repair* 2009;23:287–94.
47. Lin CC, Ju MS, Lin CW. The pendulum test for evaluating spasticity of the elbow joint. *Arch Phys Med Rehabil* 2003;84:69–74.
48. Malhotra S, Cousins E, Ward A, et al. An investigation into the agreement between clinical, biomechanical and neurophysiological measures of spasticity. *Clin Rehabil* 2008;22:1105–15.
49. Pandyan AD, Price CI, Rodgers H, et al. Biomechanical examination of a commonly used measure of spasticity. *Clin Biomech* 2001;16:859–65.
50. Pandyan AD, Van Wijck FM, Stark S, et al. The construct validity of a spasticity measurement device for clinical practice: an alternative to the Ashworth scales. *Disabil Rehabil* 2006;28:579–85.
51. Voerman GE, Burridge JH, Hitchcock RA, Hermens HJ. Clinometric properties of a clinical spasticity measurement tool. *Disabil Rehabil* 2007;29:1870–80.
52. Chen JJ, Wu YN, Huang SC, et al. The use of a portable muscle tone measurement device to measure the effects of botulinum toxin type A on elbow flexor spasticity. *Arch Phys Med Rehabil* 2005;86:1655–60.
53. Wu YN, Huang SC, Chen JJ, et al. Spasticity evaluation of hemiparetic limbs in stroke patients before intervention by using portable stretching device and EMG. *J Med Biol Eng* 2004;24:29–35.
54. Bakheit AM, Maynard VA, Curnow J, et al. The relation between Ashworth scale scores and the excitability of the alpha motor neurones in patients with post-stroke muscle spasticity. *J Neurol Neurosurg Psychiatr* 2003;74:646–8.
55. Ghotbi N, Hadian MR, Olyaei GR, et al. The investigation of criterion validity of the modified Ashworth scale using the alpha motoneuron excitability indicators. *Acta Medica Iranica* 2007;45:290–4.
56. Milanov I. Clinical and neurophysiological correlations of spasticity. *Funct Neurol* 1999;14:193–201.
57. Naghdi S, Ansari NN, Abolhasani H, et al. Electrophysiological evaluation of the Modified Tardieu Scale (MTS) in assessing poststroke wrist flexor spasticity. *NeuroRehabilitation* 2014;34:177–84.
58. Naghdi S, Ansari NN, Mansouri K, et al. Neurophysiological examination of the Modified Modified Ashworth Scale (MMAS) in patients with wrist flexor spasticity after stroke. *Electromyogr Clin Neurophysiol* 2008;48:35–41.
59. Naghdi S, Ansari NN, Mansouri K, et al. The correlation between Modified Ashworth Scale scores and the new index of alpha motoneurons excitability in post-stroke patients. *Electromyogr Clin Neurophysiol* 2008;48:109–15.
60. Naghdi S, Ebrahimi I, Asgari A, et al. A preliminary study into the criterion validity of the Modified Modified Ashworth Scale using the new measure of the alpha motoneuron excitability in spastic hemiplegia. *Electromyogr Clin Neurophysiol* 2007;47:187–92.
61. Pisano F, Miscio G, Del Conte C, et al. Quantitative measures of spasticity in post-stroke patients. *Clin Neurophysiol* 2000;111:1015–22.
62. Patrick E, Ada L. The Tardieu Scale differentiates contracture from spasticity whereas the Ashworth Scale is confounded by it. *Clin Rehabil* 2006;20:173–81.
63. Vattanasilp W, Ada L. The relationship between clinical and laboratory measures of spasticity. *Aus J Physiothera* 1999;45:135–9.
64. Cooper A, Musa IM, van Deursen R, Wiles CM. Electromyography characterization of stretch responses in hemiparetic stroke patients and their relationship with the Modified Ashworth scale. *Clin Rehabil* 2005;19:760–6.
65. Pandyan AD, Price CI, Barnes MP, Johnson GR. A biomechanical investigation into the validity of the modified Ashworth Scale as a measure of elbow spasticity. *Clin Rehabil* 2003;17:290–3.
66. Min JH, Shin YI, Joa KL, et al. The Correlation between Modified Ashworth Scale and Biceps T-reflex and Inter-rater and Intra-rater Reliability of Biceps T-reflex. *Ann Rehabil Med* 2012;36:538–43.
67. Kumar RT, Pandyan AD, Sharma AK. Biomechanical measurement of post-stroke spasticity. *Age Ageing* 2006;35:371–5.
68. Ansari NN, Naghdi S, Hasson S, et al. Inter-rater reliability of the Modified Modified Ashworth Scale as a clinical tool in measurements of post-stroke elbow flexor spasticity. *NeuroRehabilitation* 2009;24:225–9.
69. Ansari NN, Naghdi S, Younesian P, Shayeghan M. Inter- and intrarater reliability of the Modified Modified Ashworth Scale in patients with knee extensor poststroke spasticity. *Physiother Theory Pract [Validation Studies]* 2008;24:205–13.
70. Blackburn M, van Vliet P, Mockett SP. Reliability of measurements obtained with the modified Ashworth scale in the lower extremities of people with stroke. *Phys Ther* 2002;82:25–34.
71. Gregson JM, Leathley M, Moore AP, et al. Reliability of the Tone Assessment Scale and the modified Ashworth scale as clinical tools for assessing poststroke spasticity. *Arch Phys Med Rehabil* 1999;80:1013–16.
72. Gregson JM, Leathley MJ, Moore AP, et al. Reliability of measurements of muscle tone and muscle power in stroke patients. *Age Ageing* 2000;29:223–8.
73. Kaya T, Karatepe AG, Gunaydin R, et al. Inter-rater reliability of the Modified Ashworth Scale and modified Modified Ashworth Scale in assessing poststroke elbow flexor spasticity. *Int J Rehabil Res* 2011;34:59–64.
74. Ansari NN, Naghdi S, Hasson S, et al. Clinical assessment of ankle plantarflexor spasticity in adult patients after stroke: inter- and intra-rater reliability of the Modified Tardieu Scale. *Brain Inj* 2013;27:605–12.
75. Paulis WD, Horemans HL, Brouwer BS, Stam HJ. Excellent test-retest and inter-rater reliability for Tardieu Scale measurements with inertial sensors in elbow flexors of stroke patients. *Gait Posture* 2011;33:185–9.
76. Singh P, Joshua AM, Ganeshan S, Suresh S. Intra-rater reliability of the modified Tardieu scale to quantify spasticity in elbow flexors and ankle plantar flexors in adult stroke subjects. *Ann Indian Acad Neurol* 2011;14:23–6.
77. Gaverth J, Sandgren M, Lindberg PG, et al. Test-retest and inter-rater reliability of a method to measure wrist and finger spasticity. *J Rehabil Med* 2013;45:630–6.

78. Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med* 1998;26:217–38.
79. Horstman AM, Beltman MJ, Gerrits KH, et al. Intrinsic muscle strength and voluntary activation of both lower limbs and functional performance after stroke. *Clin Physiol Funct Imaging* 2008;28: 251–61.
80. Munro BH, Visintainer MA, Page EB, (eds). *Statistical methods for health care research*, 2nd ed. Philadelphia (PA): JB Lippincott; 1993.
81. Brennan P, Silman A. Statistical methods for assessing observer variability in clinical measures. *BMJ* 1992;304:1491–4.
82. Bruton A, Conway JH, Holgate ST. Reliability: what is it, and how is it measured? *Physiotherapy* 2000;86:94–9.