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Diagnostic Methods

Test-retest reliability and responsiveness of isokinetic dynamometry to assess wrist flexor muscle spasticity in subacute post-stroke hemiparesis

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A B S T R A C T

Introduction: To overcome the limitations of clinical scales, objective measurement methods are becoming prominent in spasticity assessment. The aim of this study was to assess the test–retest reliability and responsiveness of isokinetic dynamometry to evaluate wrist flexor spasticity in patients with subacute stroke.
Methods: Twenty six patients with hemiparetic stroke (13 men, 13 women, mean age 51.38 ± 12.64 years) volunteered to take part in this study. Resistive torque in the wrist flexor muscles was measured twice, 1 day apart, with an isokinetic dynamometer. Wrist extension was tested at four speeds (5, 60, 120 and 180°/s). Torque response at the lowest speed (5°/s) was attributed to the non-neural component of the wrist flexor muscles, and was subtracted from the torque response at the higher speeds to calculate reflex torque (spasticity). The reliability of reflex torque measurements at 60, 120 and 180°/s was evaluated with the intraclass correlation coefficient ($ICC_{2,1}$) and standard error of measurement (SEM and SEM%), which reflect reproducibility and measurement error, respectively. Responsiveness was calculated as the smallest real difference (SRD and SRD%).
Results: Reproducibility was excellent at different movement speeds ($ICC_{2,1}$ 0.76–0.85). SEM% ranged from 11% to 21%, and SRD% ranged from 30% to 58%. ICC values increased, and SEM% and SRD% decreased, as test speed increased.
Conclusion: Our results support the reliability and responsiveness of isokinetic dynamometry to quantify spasticity in wrist flexor muscles in patients with subacute stroke. Reliability and responsiveness increased as the speed of wrist movement increased.

1. Introduction

Spasticity, a common symptom in upper motor neuron lesions (Trompetto et al., 2014), is characterized by velocity-dependent excessive resistance of the muscle to passive stretching (Lance, 1980). This increased resistance results from hyperexcitability of the stretch reflex, and is believed to occur due to the loss of descending inhibition pathways after stroke and several other neurological disorders (Sheean, 2002; Young, 2002). Spasticity has been considered a cause of errors in motor control, which can interfere with functional recovery and activities of daily living, and can lead to the development of pain and contracture (Sommerfeld et al., 2004; Dromerick, 2002).

To treat spasticity, a variety of therapeutic techniques have

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been developed to reduce its negative impacts (Bethoux, 2015). In order to evaluate the effectiveness of different treatments and choose the best option for each patient, precise quantification of the level of spasticity is needed (Burridge et al., 2005). Clinically, spasticity level is assessed with either the Modified Ashworth Scale (MAS) or the Modified Tardieu Scale (MTS). Subjectivity, low accuracy and low sensitivity to changes in patient status are shortcomings of these clinical scales (Pandyan et al., 1999). With the MAS, the examiner estimates muscle resistance by moving a joint based on an ordinal scale (Bohannon and Smith, 1987). The factors which may cause increased resistance to a passive movement can be either neural, i.e. resistance induced by the stretch reflex, or non-neural, i.e. passive stiffness of the muscle due to changes in intrinsic properties of the muscle itself (Katz and Rymer, 1989). The MAS does not distinguish between neural and non-neural components of resistance to passive movements (Lindberg et al., 2011). Spasticity is caused mainly by a hyperactive stretch reflex and is velocity dependent (Kim et al., 2005). The MTS considers velocity-dependent characteristics of spasticity by measuring muscle reaction to passive stretching at both slow (below which the stretch reflex would be induced) and fast speeds (to trigger the stretch reflex); however, it is affected by the operator's skill in manually imposing angular velocity (Mackey et al., 2004).

To overcome the limitations of clinical scales, a variety of neurophysiological and biomechanical techniques have been developed. One instrumental technique is isokinetic dynamometry (ID), which enables the investigator to standardize both velocity and range of motion and to objectively quantify spasticity by measuring the amount of resistive torque generated by the muscle at different constant angular velocities (Starsky et al., 2005). The device is simple to use, interpretation of the findings is straightforward, and the procedure can be applied to a variety of muscles (Kim et al., 2005). The reliability of ID for measuring spasticity has been examined in individuals with various neurological pathologies, and several studies have reported high reliability in the elbow flexors of stroke patients (Starsky et al., 2005; Condliffe et al., 2005; Sin et al., 2018). However, to the best of our knowledge, only one study has investigated the reliability of spasticity measurement with ID in wrist flexor muscles after a stroke. Cetin and colleagues reported that ID cannot be used to assess wrist muscle spasticity in stroke patients (Cetin et al., 2008). Although they found high reproducibility, this was accompanied by large measurement errors and low responsiveness in measuring writ flexor spasticity. Reliability refers to the reproducibility of repeated measurements and the absence of measurement errors (Chen et al., 2009). Responsiveness indicates that changes in measurements are due to a real changes and not only to measurement error (Chen et al., 2009). These authors measured resistive torque at three slow velocities of 10, 30 and 45°/s. Other studies that investigated the reliability of spasticity measurements with ID reported greater reliability at higher speeds (Condliffe et al., 2005; Pierce et al., 2006). Condliffe and colleagues investigated the reliability of quantitative measurements of spasticity in the elbow joint with ID at seven speeds between 30 and 210°/s in patients with chronic post-stroke hemiparesis, and found high reproducibility and low measurement error at speeds ≥60°/s (Condliffe et al., 2005). Pierce and colleagues found acceptable test–retest reliability for measurements of spasticity in the knee flexors and knee extensors at 180°/s in children with cerebral palsy (Pierce et al., 2006).

As noted, the previous study by Cetin and colleagues investigated the reliability of wrist spasticity measurements with ID at three slow velocities of 10, 30 and 45°/s. Accordingly, the present study was designed to investigate whether measuring spasticity at higher velocities increased the reliability and responsiveness of ID in assessments of wrist flexor muscle spasticity after a stroke. The purpose of this study was to evaluate the test–retest reliability and responsiveness of ID to measure wrist flexor muscle spasticity in patients after a stroke. We hypothesized that ID would be a reliable and responsive instrument to measure wrist flexor spasticity, and that both reliability and responsiveness would increase as speed increased.

2. Methods

2.1. Study design and participants

A cross-sectional observational test–retest design was used to examine the test–retest reliability and responsiveness of ID to measure wrist flexor muscle spasticity. Stroke patients admitted to the neurorehabilitation clinics affiliated with Shiraz University of Medical Sciences in Shiraz, Iran were recruited from December 2016 to April 2018 for participation. Out of 84 patients who were screened with inclusion and exclusion criteria, 26 patients were included in this study (Fig. 1). The inclusion criteria were: 18 years of age or older, hemiplegia secondary to a single hemorrhage or ischemic stroke, time elapsed since the stroke between 1 and 6 months, muscle tone in the wrist flexor muscles with MAS ≥1 in the hemiparetic arm, and ability to sit safely and comfortably on a chair. Participants were excluded if they had other neurological conditions, were unable to understand the test instructions due to cognitive impairment or deficit in language comprehension, used any antispasticity drugs, or had a history of injected antispasticity drugs.

The study protocol was approved by the Ethics Committee of Shiraz University of Medical Sciences in Shiraz, Iran. Written informed consent was obtained from all participants prior to the measurements.

2.2. Procedures

Spasticity in the wrist flexor muscles was measured quantitatively with a Biodex system 4 (Biodex Medical System, Shirley, NY, USA) isokinetic dynamometer. The standard wrist unit attachment was used for all measurements. Participants were instructed to sit on the system chair and were firmly stabilized with straps across the shoulders and waist. The participant's forearm was pronated and rested on a flat surface attached to the chair. The shoulder was positioned at about 0°–5° flexion and 10°–15° abduction. The elbow was positioned at 90° flexion. The participants grasped the wrist attachment of the dynamometer, and the dynamometer axis was aligned with the axis of the wrist joint. The experimental setup is shown in Fig. 2.

The wrist range of motion was set at 60° of wrist flexion and 60° of wrist extension, thus the wrist joint was passively moved through a total range of 120° starting from 60° wrist flexion and ending at 60° extension (Marley and Thomson, 2000). Four velocities of 5, 60, 120 and 180°/s were used with three trials at each velocity (Karakuş et al., 2013; Nam et al., 2017). The participants were asked to remain completely relaxed during the test and to avoid assisting or resisting the passive movements of the hand. Resistance to passive movements of wrist extension was recorded as resistance torque in Newton meters (Nm). For each participant peak resistive torque was measured in each trial and the mean of three trials was calculated for each velocity.

Slow velocity (5°/s) passive movement was tested first in all participants (Gäverth et al., 2013). Torque during slow velocity movement determined passive stiffness of the wrist flexor muscles (non-neural component) (Bhadane et al., 2015). Then the fast

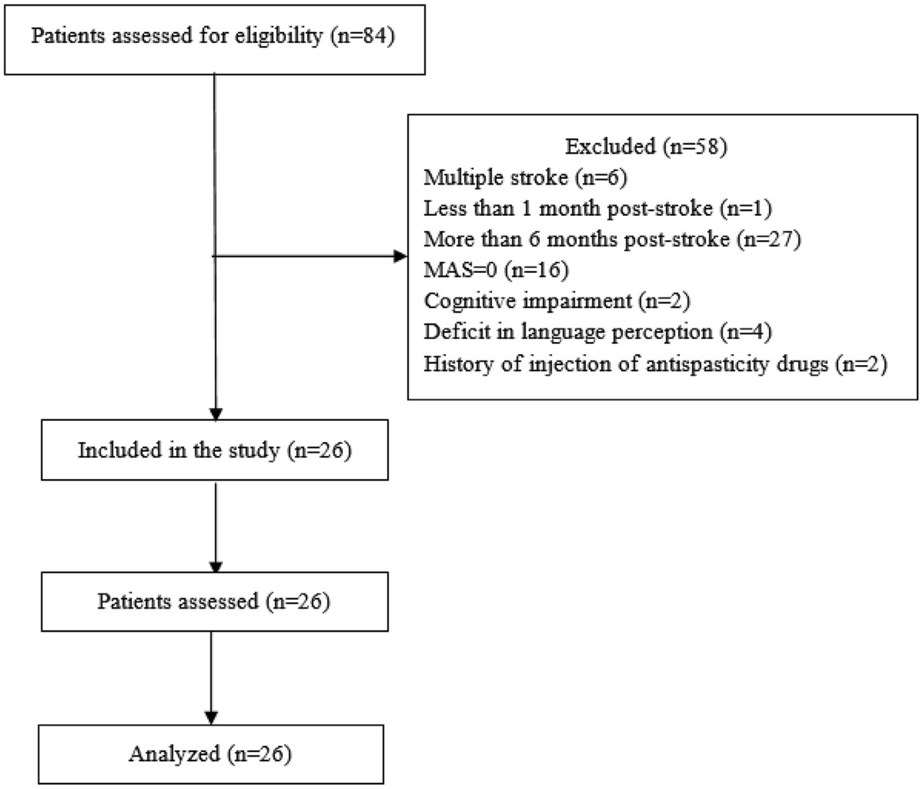

Fig. 1. Flow chart of study implementation. MAS, Modified Ashworth Scale.

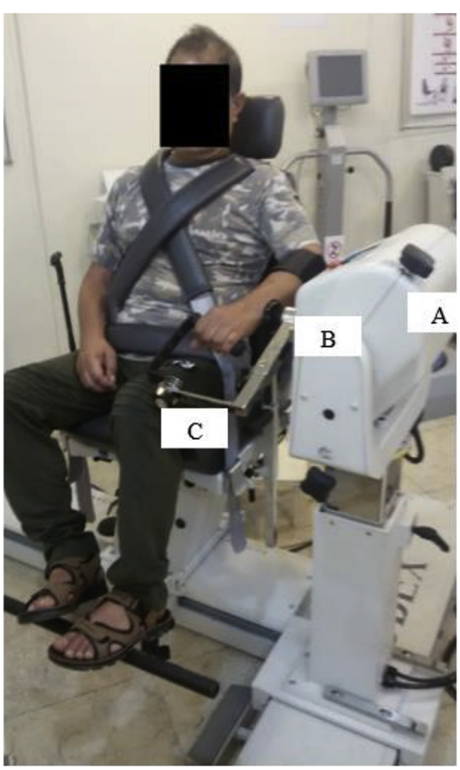

Fig. 2. Experimental set-up to assess wrist flexor spasticity with isokinetic dynamometry. Legend: A, Dynamometer; B, axis of wrist joint rotation; C, wrist attachment.

movement velocities were tested in random order (60, 120 and 180°/s) (Gäverth et al., 2013). Spasticity or stretch reflex torque was calculated by subtracting toque response at these high velocities from torque response at 5°/s (Bhadane et al., 2015). It has been demonstrated that at velocities lower than 25°/s, the stretch reflex is not triggered; however, at higher velocities the stretch reflex is readily activated (Singer et al., 2003). A 30-s rest was allowed between trials to avoid adaptation and minimize the influence of stretch history on the responses to subsequent stretches (Bhadane et al., 2015). The primary researcher (N.S.D.) performed all measurements in two separate sessions 1 day apart at the same time of day. She was a physiotherapist with 5 years of clinical experience in stroke rehabilitation who was well trained in using the Biodex system 4 ID to perform measurements. Details of the position were recorded and used in the second testing session. During the first day of testing, paretic upper extremity function was assessed with the Fugl-Meyer Assessment of upper extremity tool (FMA-UE, scores 0–66). This instrument consists of 33 items each scored from 0 to 2, where 0 = could not perform, 1 = could partially perform, and 2 = could fully perform (Fugl-Meyer et al., 1975). The degree of upper extremity motor impairment was defined on the basis of FMA-UE scores as follows: severe = 0–22, moderate = 23–52, and mild = 53–66 (Hoonhorst et al., 2015).

2.3. Statistical analysis

All analyses were done with the Statistical Package for the Social Sciences version 17 (SPSS, Inc., Chicago, IL, USA). Continuous data were described as means ± SD. Absolute numbers were used to describe categorical variables. Test–retest reliability was calculated with the intraclass correlation coefficient ($ICC_{2,1}$) based on two-way random effects analysis of variance (Lexell and Downham, 2005). For all ICCs, the 95% confidence interval (CI) was calculated. The ICC values were interpreted according to the criteria reported by Fleiss: values below 0.40 were categorized as poor, while values between

Table 1
Mean, standard deviation (SD) and reproducibility of reflex torque measurements in two sessions.

Reflex torque	Mean ± SD		$ICC_{2,1}$ (95% CI
	Session 1	Session 2	
60°/s	0.88 ± 0.39	0.83 ± 0.33	0.76 (0.54–0.88)
120°/s	1.08 ± 0.43	1.06 ± 0.37	0.82 (0.65–0.92)
180°/s	1.24 ± 0.4	1.29 ± 0.36	0.85 (0.7–0.93)

ICC, intraclass correlation coefficient; 95% CI, 95% confidence interval.

0.40 and 0.75 were categorized as fair to good, and values above 0.75 were categorized as excellent reliability (Fleiss, 1986). The standard error of measurement (SEM) was calculated as a further measure of reliability. SEM indicates the variability between measurements obtained from the two sessions, and was calculated as the square root of total within-subject variance ($SEM = \sqrt{total\ WMS}$). Responsiveness was calculated as the smallest real difference (SRD), also called minimal detectable change (MDC). SRD determines the smallest change that indicates a real change in a given participant. This index was calculated as $1.96 \times SEM \times \sqrt{2}$. Both SEM and SRD were also expressed as a percentage of the mean for all measurements from both sessions (SEM% and SRD%), since these values are easier to interpret and to compare with other studies.

Systematic bias in test–retest data should be considered in reliability analyses. This bias refers to predictable errors in measurement that occur in the same direction (under-over estimation). These errors occur if the test is systematically performed better (or worse) on the second test occasion as a result of, for example, learning effects or changes in behavior. Plotting a Bland–Altman graph is one method to determine whether systematic bias has occurred in the measurements. This graph shows the difference between test sessions 2 and 1 (2 minus 1) against the mean of the two test sessions for each participant, including the mean difference and 95% CI for mean difference (Lexell and Downham, 2005). If the 95% CI does not include 0, this indicates systematic bias in the measurements.

3. Results

A total of 26 patients (13 men, 13 women) with a mean age of 51.38 ± 12.64 years (range 28–73 years), mean height of 167.42 ± 5.66 cm (157–178 cm) and mean weight of 68.77 ± 7.19 kg (range 60–83 kg) participated in this study. The mean time elapsed since the stroke was 98.77 ± 34.26 days (range 35–147 days). Hemiplegia was on the left side in 16 patients and on the right side in 10 patients. The type of stroke was ischemic in 23 patients and hemorrhagic in 3 patients. Mean FMA-UE score was 22.54 ± 9. All participants had severe to moderate upper extremity impairment (scores ranging from 4 to 38). The MAS score was between 1 and 2 for all patients, indicating a slight to moderate increase in spasticity.

Table 1 shows the mean values and SDs for reflex torque measurements at three angular velocities in the wrist flexor muscles in the two test sessions. All reflex torque measurements showed excellent reproducibility: the ICC values ranged from 0.76 to 0.85, and the 95% CI for ICC ranged from 0.54 to 0.93 (Table 1). SEM and SRD values are presented in Table 2. SEM (SEM%) ranged from 0.14 to 0.18 Nm (11%–21%) and SRD (SRD%) ranged from 0.38 to 0.49 Nm (30%–58%). Bland–Altman plots showed that the mean differences were generally small, and 0 was included in the 95% CIs, which suggested the absence of systematic biases between sessions for all reflex torque measurements (Fig. 3).

Table 2
Measurement error (SEM and SEM%) and responsiveness (SRD and SRD%) of reflex torque measurements.

Reflex torque	SEM	SEM%	SRD	SRD%
60°/s	0.18	21	0.49	58
120°/s	0.16	15	0.44	41
180°/s	0.14	11	0.38	30

SEM, standard error of measurement; SRD, smallest real difference.

4. Discussion

Spasticity results in uncontrolled involuntary movements which interfere with function. Also, uncontrolled and sustained spasticity may lead to secondary disabling contractures, abnormal posture and disturbed motor performance (Boyd and Ada, 2001; Rojhani-Shirazi et al., 2015). Therefore, appropriate assessment and management of spasticity are important goals for clinicians. To quantify spasticity, biomechanical measurements have frequently been used. The aim of the present study was to determine the test–retest reliability and responsiveness of ID to assess spasticity in the wrist flexor muscles in patients with subacute stroke. ID measures reflex torque, which indicates resistance torque to passive movement induced by stretch reflex activity, i.e. the mechanism underlying spasticity (Lance, 1980). Reflex torque has been reported as a clinically acceptable parameter to quantify spasticity (Ju et al., 2000). Our results support the reliability and responsiveness of ID for this purpose. The ICC values for all reflex torque measurements were high, and SEM% and SRD% ranged from 11% to 21% and 30%–58%, respectively. In addition, reliability and responsiveness increased as movement speed increased. Our ICC findings are consistent with a previous test–retest reliability study of spasticity measurement in wrist flexors with ID in post-stroke patients (Cetin et al., 2008). However, no clear benchmark exists for interpreting SEM% and SRD %. SRD represents the smallest change that can be distinguished from measurement error. SRD is linked to measurement error, thus large measurement errors necessitate greater changes in individual patients to indicate a real change. In previous studies of stroke patients, SEM% values less than 10% and SRD% values less than 30% were suggested as acceptable; however, these values were reported in studies that measured the reliability of other variables such as muscle strength or function (Flansbjer et al., 2005; Chen et al., 2009). Larger measurement errors in spasticity measurements may be due to the nature of spasticity, which is known to fluctuate over time. Several factors including day-to-day variability in stretch reflex behavior, recovery stage, level of arousal, and other environmental factors contribute to variations in muscle tone (Starsky et al., 2005; Stam and Tan, 1987).

Regarding SEM% and SRD%, our findings contrast with a previous study which found a large SEM (24.3%–30.6%) and SRD (67.4%–85%) for the reliability of ID in measuring wrist flexor spasticity in stroke patients (Cetin et al., 2008). There are several methodological differences between the present study and the previous one. Cetin and colleagues measured spasticity at three slow velocities of 10, 30 and 45°/s. Also, they reported resistive torque without calculating reflex torque. Finally, they performed three consecutive passive wrist motion tests without a rest between trials. Another earlier study reported adaptation in reflex torque responses after repeated passive movements (Schmit et al., 2000).

Our second hypothesis was that the reliability and responsiveness of ID would increase as movement speed increased, and the present findings also confirm this. The ICC values tended to increase, while SEM% and SRD% decreased, as speed increased. Greater reliability at higher velocities was also reported by Condliffe et al. in adults with stroke, and by Pierce et al. in children with

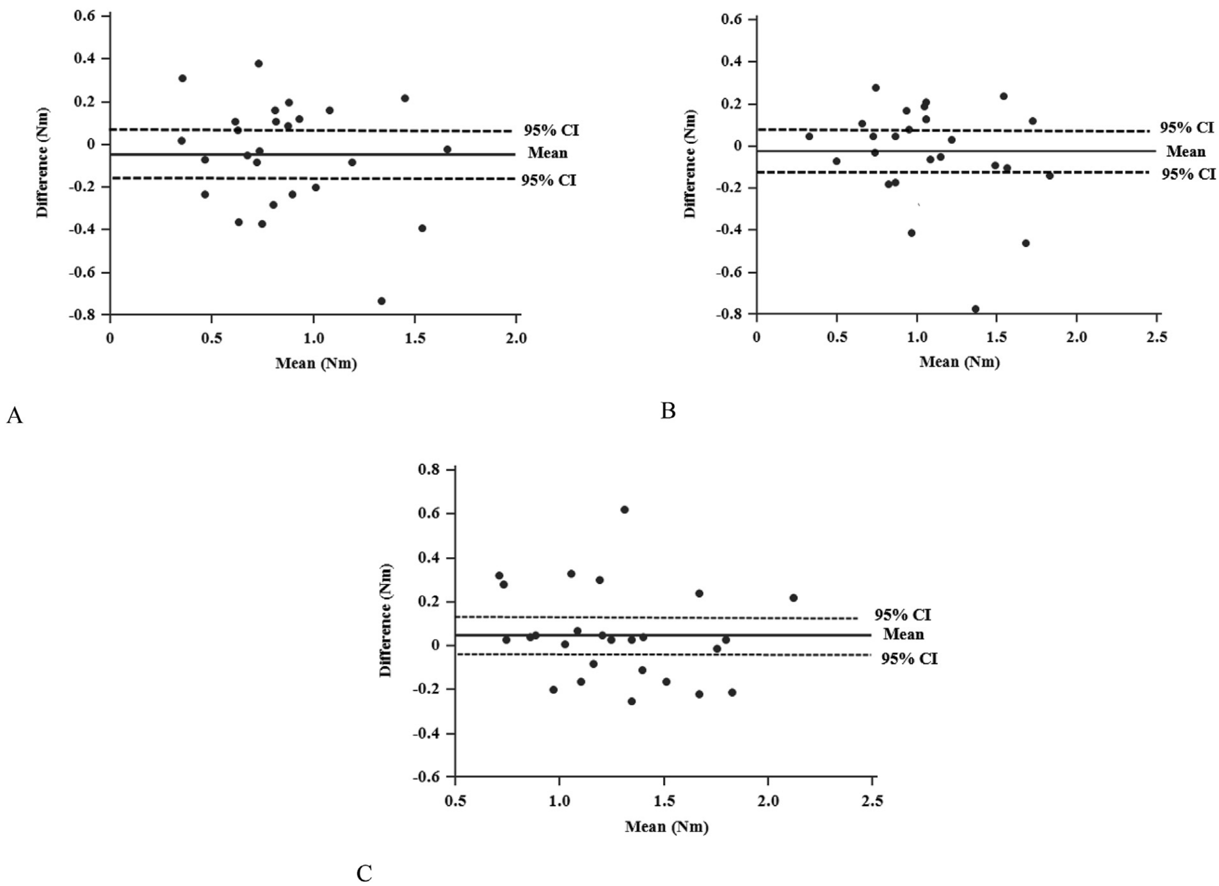

Fig. 3. Bland–Altman plots for reflex torque measurements, including references lines for the mean difference (test occasion 2 minus 1) and 95% confidence interval (95% CI). A: Reflex torque at a velocity of 60°/s, B: Reflex torque at a velocity of 120°/s, C: Reflex torque at a velocity of 180°/s.

cerebral palsy (Condliffe et al., 2005; Pierce et al., 2006). The greater reliability of ID at higher movement speeds may be a result of speed dependence – one of the defining characteristics of spasticity which has been attributed to stretch reflex activity, given that the intensity of this activity increases at higher velocities (Condliffe et al., 2005). In the present study, reflex torque increased with movement speed, which is compatible with the speed dependence of spasticity. This characteristic has also been reported in other studies that tested ID at different velocities (Condliffe et al., 2005; Wu et al., 2010). It has been suggested that greater response magnitudes at higher speeds cause greater between-subject variability and less within-subject variability, which lead, respectively, to higher ICCs and lower measurement errors (Wolf et al., 1996; Condliffe et al., 2005).

4.1. Limitations

The potential limitations of the present study should be noted. Possible assessment bias should be considered because the measurements were recorded by the primary researcher. Another consideration is that our results are not generalizable to all adults with stroke, given that we included only individuals with moderate to severe upper limb paresis according to their FMA-UE scores. Moreover, we assessed spasticity at three angular velocities in the wrist flexor muscles, thus limiting the generalizability of our findings to other velocities and other muscles. Further studies with larger sample sizes are thus needed. Additional research is warranted to explore the reliability of spasticity measurements with ID in patients with chronic stroke, at other angular velocities and in other muscle groups. In addition, because spasticity can fluctuate over the course of a day due to personal and environmental factors, tests should be carried out at different times of day.

5. Conclusion

The results of this study provide evidence for the test–retest reliability and responsiveness of ID to measure wrist flexor spasticity in patients with subacute stroke. The reliability and responsiveness increased at higher speeds of wrist movement.

6. Clinical relevance

- The results support the test–retest reliability and responsiveness of isokinetic dynamometry at movement speeds equal to or greater than 60°/s to measure wrist flexor spasticity in stroke patients.
- Reliability and responsiveness increased as movement speed increased.
- Isokinetic dynamometry could be useful to assess the efficacy of therapeutic interventions aimed at modifying spasticity.

Author contributions

Study concept and design: Nasrin Salehi Dehno, Fahimeh Kamali Sarvestani, Abdolhamid Shariat, Shapour Jaberzadeh.

Data acquisition: Nasrin Salehi Dehno.

Analysis and interpretation of the data: Nasrin Salehi Dehno, Fahimeh Kamali Sarvestani, Abdolhamid Shariat, Shapour Jaberzadeh.

Drafting of the manuscript: Nasrin Salehi Dehno.

Critical revision of the manuscript for important intellectual content: Fahimeh Kamali Sarvestani, Abdolhamid Shariat, Shapour Jaberzadeh.

Final approval of the manuscript: Nasrin Salehi Dehno, Fahimeh Kamali Sarvestani, Abdolhamid Shariat, Shapour Jaberzadeh.

Declaration of competing interest

The authors have no conflicts of interest to declare.

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