Reliability of lower extremity strength measures in persons with chronic stroke

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Abstract

Objective—To determine the reliability of isokinetic concentric strength measures of both the hemiparetic and non-involved limbs for flexion and extension motions of the hip, knee, and ankle joints in individuals who have had a stroke.

Design—Test-retest, repeated-measures intraobserver reliability design.

Setting—Tertiary rehabilitation center.

Participants—20 community-dwelling individuals who have had a stroke, with motor deficits ranging from 3 to 6 on the Chedoke-McMaster Stroke Assessment; volunteer sample.

Interventions—Not applicable.

Main Outcome Measures—Peak torque and average torque (ie, mean over the range of motion tested) from an ensemble-averaged (three trials) torque-angle curve during isokinetic concentric extension and flexion movements of the ankle, knee, and hip.

Results—Although peak and average torque were significantly less for the hemiparetic limb compared with the non-involved limb, the intraclass correlation coefficients (ICCs) between the two test sessions were high (0.95–0.99 for peak torque, 0.88–0.98 for average torque) for both limbs for all 3 joints. However, there was a learning effect, as observed by the slightly greater values attained from the second test session.

Conclusions—Peak and average isokinetic torque can be used to assess reliably lower extremity strength in persons with chronic stroke. Practice sessions may be required before the actual test to reduce the effect of learning.

Keywords

cerebrovascular accident; rehabilitation; muscle; reproducibility of results

Introduction

Muscle weakness, defined as the inability to generate normal levels of muscle force¹, has been recognized as a common impairment following a cerebrovascular accident (CVA).²⁻⁴ Possible causes of muscle weakness following cerebral lesions include decreased number of motor units,⁵ disrupted recruitment order of motor units,⁶ and decreased motor unit firing rates,⁷ in addition to muscle atrophy following disuse.⁸

Until recently, strength testing and training in persons with chronic stroke have been controversial issues. Bobath⁹ advocated that decreased muscle power was not due to weakness but to the opposition of spastic antagonists and that muscle strengthening was not recommended as it was thought to increase spasticity and reinforce abnormal movement. Recent studies, however, have shown that strength training is not associated with increases in spasticity as measured by the H-reflex¹⁰, tendon reflex¹⁰, Modified Ashworth Scale¹¹ and pendulum test.¹²⁻¹³

Correlational studies involving individuals who have had a stroke have demonstrated the importance of muscle strength for the performance of functional tasks. Significant correlations have been reported between lower extremity muscle strength and gait performance,¹⁴⁻¹⁸ stair climbing ability,¹⁹ standing balance,¹⁹ and transfer capacity.²⁰ These correlational studies have fueled the hypothesis that interventions aimed at increasing muscle strength will result in improvements in functional performance for these individuals. Recent studies have demonstrated that lower extremity strengthening programs with individuals with chronic stroke can have positive effects on gait performance,^{10, 12, 13} stair climbing ability,¹³ rising from a chair,²¹ and quality of life.¹³

Muscle performance has been commonly measured by isokinetic dynamometers as their instrumentation accuracy has been established^{22,23}. In addition, excellent test-retest reliability has been achieved for flexion and extension motions of the ankle, knee and hip when using healthy adult individuals without any known pathology.²⁴⁻²⁷ Given the number of factors which have been shown to influence the reliability of isokinetic measurements (e.g., type of muscle contraction,²⁸ test velocity,²⁸ order of test velocity,²⁹ body position and stabilization,³⁰⁻³² and verbal encouragement³³), the protocol should be standardized in order to allow consistent estimation of the force output³⁴.

The reliability of strength measures in individuals with neurological conditions has not been well established. There are a number of reasons why one might speculate that the reliability of strength measures may be compromised in persons with chronic stroke. Impaired regulation of force levels and motor unit firing patterns has been reported in individuals who have had a stroke which could be in part due to altered peripheral feedback.¹⁷ Spasticity, which can fluctuate in response to a number of factors such as pain, fatigue, postural changes, effort, and anxiety³⁵ may also potentially influence measures of muscle strength.

One study which has examined strength reliability in individuals with neurological conditions was undertaken by Tripp and Harris³⁶. They measured the test-retest reliability of isokinetic concentric knee extension and flexion torque in individuals with spastic hemiparesis secondary to a CVA or traumatic brain injury. They reported excellent reliability

for the peak torque for both the hemiparetic and non-involved knee (ICCs > 0.95). Reliability studies of knee strength are abundant, both in healthy and pathological conditions, in part because of the frequency of injuries that occur at this joint, but also because of the ease of positioning and setup of this joint when using an isokinetic dynamometer. It is important to also establish reliability of torques measured at the ankle and hip joints, in addition to the knee joint in order to evaluate strengthening treatment protocols which are often aimed at the major lower extremity joints for individuals with stroke.^{10,13} Establishment of the reliability of the strength of the lower extremity motions would also allow one to examine relationships between strength outcome measures and the performance of functional mobility tasks which require multi-joint motions such as gait and rising from a chair.

The purpose of this study was to determine the test-retest intraobserver reliability of isokinetic strength measures of both the hemiparetic and non-involved limbs with individuals who have had a stroke for flexion and extension motions of all three major lower extremity joints (hip, knee and ankle). Test-retest reliability quantifies the stability of the score from session to session and is an important aspect of health outcome measures whose purpose is to assess the “true” change over time.

Methods

Participants

Twenty community-dwelling individuals who have experienced a stroke and had residual unilateral weakness, were recruited on a volunteer basis. The study was approved by the local university and hospital ethics board and informed consent was obtained from each participant. None of the participants had any previous experience with the use of an isokinetic dynamometer.

The inclusion criteria were as follows: 1) time since onset of stroke was a minimum of 6 months, 2) first stroke, 3) not participating in any formal therapy program, 4) a minimum of stage 3 for the leg and foot on the Chedoke-McMaster Stroke Assessment,³⁷ and 5) an activity tolerance of 45 minutes with rest intervals. Participants were excluded if they were not medically stable (e.g., uncontrolled hypertension, arrhythmia, congestive heart failure) or had musculo-skeletal problems due to conditions other than stroke. Participants were provided with the inclusion and exclusion criteria and could opt out of the study based on this information. In addition, their family physician was contacted by letter and followed up by phone to ensure that participants met the inclusion and exclusion criteria prior to commencing the study.

The participants were 15 males and 5 females, 10 with a right CVA and 10 with a left CVA, age of 60 ± 8 years (mean $\pm$ 1 standard deviation), duration of injury of 4.0 ± 2.6 years, mass of 76.3 ± 13.2 kg, and height of 172.6 ± 10.5 cm. On the Chedoke-McMaster Stroke Assessment for the leg and foot, participants ranged from stage 3 (active voluntary movement occurs without facilitation but stereotyped synergistic patterns persist) to stage 6 (coordination and patterns of movement are near normal, abnormal patterns of movement emerge when rapid or complex actions required). Resistance to passive movement in the

lower extremity measured by the Modified Ashworth Scale³⁸ (MAS) ranged from levels of 0 (no increase in muscle tone), 1 (slight increase in tone marked by minimal resistance at the end of the range of motion) to 2 (more marked increase in muscle tone through most of the range of motion). All participants, except for one, had the presence of increased muscle tone in the lower extremity as measured by the MAS.

Test protocol

Participants were tested on two separate test days ranging from 2–4 days apart for isokinetic concentric hip, knee and ankle flexion and extension. A number of factors were considered in adapting standard strength testing protocols to persons with chronic stroke. The major consideration was for the safety of this population which typically has hypertension. As heavy resistance exercise can cause an acute increase in both systolic and diastolic blood pressure,^{39,40} a non-supine posture was used in all conditions to minimize stress on the cardiovascular response. A supine position causes larger systemic pressure responses to lower extremity static or dynamic exercises in comparison to a non-supine posture.⁴¹ Participants were also encouraged to breathe regularly and avoid a Valsalva maneuver. Secondly, selecting a range of motion common to all participants would have severely limited the joint range for some participants. Constraining the range of motion to a specific range may have eliminated many otherwise eligible participants. Thus, participants were tested in their available range (as assessed by their active range) which was kept constant for that individual for both test sessions. Thirdly, isokinetic strength assessment was initiated at an angular velocity of 60°/s. This particular velocity has been shown to be reliable in healthy subjects^{29,42} and was selected because the majority of our stroke participants had difficulty generating faster movements. If a participant was not able to achieve an angular velocity of 60°/s, 30°/s was used for that specific joint for both limbs at test session one and two.

The Kin-Com Isokinetic Dynamometer^a was used to assess the concentric strength of hip flexors and extensors, knee flexors and extensors, and ankle dorsiflexors and plantarflexors of the hemiparetic and non-involved lower extremity. This instrument has been shown to be accurate for position, velocity and force.^{22–23} The calibration of the instrument was tested prior to the study with known weights and was accurate to within ± 1 N. Three submaximal cycles and one maximal cycle was completed as practice on the Kin-Com as per Kramer's²⁵ protocol.

Preloading is the magnitude of the activation force and is defined as the force that must be applied to the load cell in order to initiate the movement and has been shown to affect the torque-angle curve generated from isokinetic contractions.^{43,44} The preload was individualized⁴⁵ for each subject, joint and direction of motion and was set at a minimum of 50% of the peak torque values observed during the warm-up trials and kept constant across the two test sessions. Across all strength evaluations (20 subjects, three joints, two limbs, two directions), the preload was a mean of $66\% \pm 17$ of the peak torque value. Optimum preload values have not been established in the literature, however, the preloads used in this study were similar in magnitude to the high preload conditions used by Kramer et al.⁴³ and

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Jensen et al.⁴⁴ Their high preload conditions were equivalent to 70 to 75% of the peak torque values and were found to increase average torque over lower preload conditions.

Participants were asked to “push or pull as hard as possible” throughout their available range of motion for a minimum of four repetitions or until consistency of the force-angle profile (i.e., pattern) was found across three repetitions (the maximum number of repetitions experienced by any one subject was six). At the end of each repetition of motion, participants rested for approximately 2 seconds. Positioning and stabilization are documented below:

Hip—Participants were in a semi-reclined (30° angle from horizontal) position, with the pelvis fixed by a strap and the back supported. The contralateral thigh was supported by a pad attached to the seat. The greater trochanter of the leg being tested was aligned with the Kin-Com system’s rotation axis. The cuff of the force transducer was placed three fingerbreadths proximal to the popliteal fossa.

Knee—Participants were seated with the back support set at a 90° sitting angle. Large straps were applied horizontally across the pelvis and diagonally across the trunk to minimize body movement during testing. Participants were asked to place their hands on their lap. The lateral femoral condyle was aligned with the dynamometer’s rotation axis. The cuff of the force transducer was placed three fingerbreadths proximal to the lateral malleoli. This positioning protocol has been used with individuals with spastic hemiparesis and it was found to have high test-retest reliability when tested at an angular velocity of 60°/s.³⁶

Ankle—Participants were in a semi-reclined (45°) position with their back supported. The leg being tested was placed on a pad attached to the seat which allowed the knee to flex slightly. The foot was secured in a metal brace attached to the Kin-Com dynamometer with the lateral malleolus aligned with the dynamometer’s rotation axis. The contralateral foot rested on a foot support attached to the seat.

Analysis

All torques were corrected for the effect of gravity on the lower extremity segment and the effect of gravity on the cuff of the dynamometer. This gravity-correction procedure has been shown to be accurate.⁴⁶ The three torque-angle curves of each set of contractions were ensembled to obtain a mean curve (i.e., ensemble-averaged with a mean torque value calculated at each angle). Peak torque and average torque over the range were extracted from this single curve as these are the measures most frequently used to assess human muscle performance. Since these measures are derived from three trials, they are more correctly denoted as “mean peak torque” and “mean average torque”, however, the simpler terms of “peak torque” and “average torque” are used in any following discussion to minimize confusion. Repeated measures analysis of variance were used to determine whether these values differed between the hemiparetic and non-involved limb. To assess the intraobserver reliability between the two test sessions, peak torque values and average torque values were entered into a repeated measures analysis of variance (ANOVA) for each joint and the results used to calculate the intraclass correlation coefficients (ICCs, [1,1])⁴⁷ for flexion and

extension motions of the ankle, knee and hip joints for both the hemiparetic and non-involved limbs. Multiple repeated ANOVAs (for each joint) were also used to assess whether a significant difference existed between the means of the first and second test sessions⁴⁸ ($\alpha = 0.05$). All statistical analyses were performed with SPSS 8.0^b software.

Results

The joint ranges of motion used during the isokinetic assessment across the 20 participants was $22 \pm 4^\circ$ (mean $\pm$ 1 standard deviation) for the ankle, $60 \pm 6^\circ$ for the knee, and $54 \pm 6^\circ$ for the hip. Table 1 provides the absolute start and end joint values for each movement. All participants were able to complete the test condition at an angular velocity of $60^\circ/\text{sec}$ at the hip. However, seven and eighteen participants were only able to complete the test condition at an angular velocity of $30^\circ/\text{sec}$ at the knee and ankle joint, respectively. No participants reported any significant muscle soreness after the first or second test sessions. Of the 480 strength evaluations (20 subjects, two test sessions, three joints, two limbs, two directions), four repetitions were required in the majority of these evaluations to achieve three consistent force-angle curves. This method resulted in low variability across trials for all strength evaluations; the coefficient of variation (mean $\pm$ 1 standard deviation) for the peak torque for test session one was $7.0\% \pm 12$ (240 strength evaluations from 20 subjects, three joints, two directions and two limbs) and test session two was $6.8\% \pm 11$. Low trial variability was also observed for the average torque with a coefficient of variation of $10.2\% \pm 24.4$ for test session one and $8.8\% \pm 15.5$ for test session two.

Peak and average torque were significantly less for the hemiparetic limb compared to the non-involved limb for the flexion and extension motions of all three lower extremity joints (Figures 1 and 2) ($p < 0.001$). ICCs for the peak torque and average torque between the two test sessions were high (0.95–0.98 for the peak torque; 0.88–0.96 for the average torque) for the non-involved hip, knee and ankle flexion and extension motions (Table 2 and 3). ICCs for the hemiparetic limb were of comparable ranges (0.97–0.99 for the peak torque; 0.96–0.98 for the average torque) (Tables 2 and 3), suggesting that reliability was similar between the hemiparetic and non-involved limbs.

The peak and average torque for the second test session was slightly greater than the first test session for 11 of the 12 conditions (three joints and two directions of motion for the hemiparetic and non-involved limbs) (Figures 3–6). However, for peak torque, the only conditions which reached statistical levels less than 0.05 (Table 3) were hip extension of the hemiparetic limb and hip extension, hip flexion and ankle plantarflexion of the non-involved limb. The same conditions were significant for average torque, except hip extension of the non-involved was not significant. Peak and average torque for hip extension of the hemiparetic limb increased 10% and 16%, respectively, from values achieved during the first test session. For the non-involved limb, peak torque increased 6%, 10% and 13% from the first test session for hip extension, hip flexion and ankle plantarflexion, respectively. Average torque of the non-involved limb increased 12% and 14% from the first test session for hip flexion and ankle plantarflexion, respectively.

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Discussion

The results of this study demonstrate that peak and average concentric torque measurements can be attained reliably in individuals with chronic stroke for the lower extremity flexion and extension movements. The range of ICCs (0.88–0.99) were of similar or higher magnitude to those reported for healthy subjects.^{20,24,25,27} Several adaptations to the strength testing protocol were necessary to accommodate stroke participants including a non-supine position, a self-selected range of motion, and a relatively low angular velocity.

Peak and average torque reliability was high and similar for both limbs, despite the lower values for the hemiparetic limb. Tripp and Harris³⁶ examined the knee peak torque reliability in individuals with spastic hemiparesis and their ICC values were of similar magnitudes (> 0.90) to that found in this study. This research extends these findings to the ankle and hip joints in individuals with chronic stroke. Furthermore, we found that the average torque was also a reliable measure of strength. Clinicians may select the peak torque to provide a measure of maximum strength at an instant in time, while the average torque provides a measure of strength over a range of motion.

Although central mechanisms underlying force generation such as recruitment and rate coding may be altered in individuals with stroke,^{6,7} the reliability of the peak and average torque strength measures used in this study was high. In addition, the presence of increased muscle tone, as quantified by the Modified Ashworth Scale, did not interfere with the reliability of force production for the participants in this study.

The lack of reported muscle soreness in the participants of this study following maximal leg muscle contractions was an intriguing observation. Given this observation, one did not have to be concerned that muscle soreness might reduce the torque values for the second test session. A number of factors might underlie this lack of muscle soreness. It is possible that the strength potential of individuals with stroke may be limited by central mechanisms rather than peripheral mechanisms. However, one cannot eliminate the influence of other factors which might affect muscle soreness such as type of contractions (e.g., eccentric versus concentric), number of repetitions and intensity of the exercise.^{51,52} A concentric contraction was used in this study which is known to produce less muscle soreness than an eccentric contraction. Furthermore, although participants were utilizing maximal effort, a relatively low number of these maximal repetitions was performed.

It was encouraging to find that peak and average torque reliability was high across all three joints since some previous investigations have reported lower ICCs (0.6–0.8) for hip flexion and extension motions,⁵³ which may be in part due to the difficulties in the set-up of the hip joint. Alignment of the multi-axis hip joint with the dynamometer axis of rotation is more difficult than that of the single axis knee joint. In addition, compensatory strategies are often possible during the hip motion despite straps to stabilize the pelvis, e.g., small shifts in stabilization can allow substitution by hip internal or external rotator muscles.

What were some of the factors which lead to good reliability of the strength measures, given that none of the participants had any experience with isokinetic testing or exercise? Although the available joint ranges differed across individuals, a well-defined clinical

protocol which standardized the positioning, stabilization, sequencing and instructions may have resulted in high reliability in these individuals who have had a stroke. However, caution must be used when generalizing these data. Concentric contractions were evaluated in this study and the results cannot be generalized to other types of contractions (e.g., eccentric or isometric). The task velocity was low (30° or 60°) which may have reduced effects of any velocity-dependent spasticity. Furthermore, individuals in this study demonstrated relatively low clinical levels of increased muscle tone. Specific scores on the MAS were not part of the inclusion criteria, however, the low levels in this group may have been a consequence of the stage 3 requirement on the Chedoke-McMaster Stroke Assessment.³⁷ This stage was selected to ensure that participants would be able to complete the movements. One must also be cautious when drawing conclusions about these results and the presence of spasticity because the Ashworth Scale measures the resistance to passive movement, and spasticity (velocity-dependent increase in the tonic stretch reflex) is only one factor which may influence this scale.⁴⁸ Some studies have demonstrated that the resistance to movement experienced post-stroke may have a significant contribution from mechanical mechanisms, and not just from reflex-mediated spasticity.^{49,50}

There did appear to be a learning effect for this group who had never had any experience with a strength dynamometer because the magnitude of the peak and average torque increased from the first to second test session for 11 of 12 conditions (three joints, two limbs, and two directions of motion) although statistical significance was only achieved for some of the conditions. We do recognize that there was an increased risk of a type I error as multiple ANOVA tests were performed. The learning effect was substantial in some conditions, with the second test session resulting in values that were 16% greater from the first test session. A learning effect has been reported in healthy individuals for knee extension.⁵⁴ Note that high reliability can be achieved despite a significant difference between the two test sessions since the ICC determines the degree of agreement between the sessions while the F-Test assesses the magnitude of the mean differences. One might consider introducing at least two practice sessions prior to the actual assessment to reduce this learning effect.

Conclusions

The assessment of muscular strength is an important component in the evaluation of individuals with neurological conditions. This study demonstrated that the peak and average isokinetic torque can be used to reliably assess lower extremity strength in individuals with chronic stroke, and in turn, be used to measure the effectiveness of interventions in stroke rehabilitation. Clinicians are advised that practice sessions before the actual test may reduce the effect of learning.

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Figure 1.

Peak torque in Nm for the hemiparetic and non-involved side (N=20) for test session one.

Error bars indicate one standard deviation across the 20 participants. All torques of the non-involved side were greater than the hemiparetic side ($p < 0.001$).

Figure 2.

Average torque in Nm for the hemiparetic and non-involved side (N=20) for test session one. Error bars indicate one standard deviation across the 20 participants. All torques of the non-involved side were greater than the hemiparetic side ($p < 0.001$).

Figure 3. Peak torque in Nm for the hemiparetic limb for test session 1 and 2 (N=20). Error bars same as in Figure 1. * $p < 0.05$.

Figure 4.

Peak torque in Nm for the non-involved limb for test session 1 and 2 (N=20). Error bars same as in Figure 1. * $p < 0.05$.

Figure 5.

Average torque in Nm for the hemiparetic limb for test session 1 and 2 (N=20). Error bars same as in Figure 1. * $p < 0.05$.

Figure 6.

Average torque in Nm for the non-involved limb for test session 1 and 2 (N=20). Error bars same as in Figure 1. * $p < 0.05$.

Table 1

Mean angle values for each movement (N=20)

	Ankle	Knee	Hip
Start position for extension/plantarflexion motion = End position for flexion/dorsiflexion motion	9.9° (2.3)	75.5° (4.6)	93.8° (6.3)
End position for extension/plantarflexion motion = Start position for flexion/dorsiflexion motion	32.8° (3.4)	15.5° (2.8)	39.9° (2.1)
Range of motion	22.9° (4.4)	60.0° (6.1)	53.8° (6.5)

Hip: 0° = neutral position (pelvis and thigh segment aligned) with positive value indicating increasing flexion; Knee: 0° = neutral position (thigh and shank segment aligned) with positive value indicating increasing flexion; Ankle: 0° = neutral position (foot segment perpendicular to shank segment) with positive value indicating increasing plantarflexion. Standard deviation in parentheses.

Table 2

ICC and p-values from the F-Test (test session one versus test session two) for the peak torque

	Hemiparetic side		Non-involved side	
	ICC [*]	p-value from F-Test [†]	ICC	p-value from F-Test
Hip extension	0.97	0.030	0.98	0.030
Hip flexion	0.98	0.14	0.95	0.012
Knee extension	0.99	0.10	0.95	0.71
Knee flexion	0.99	0.30	0.98	0.56
Ankle plantarflexion	0.98	0.40	0.95	0.02
Ankle dorsiflexion	0.98	0.51	0.98	0.94

* ICC measures the degree of agreement between test session one and test session two

[†] F-Test determines whether a significant difference exists between the mean of test session one and two

Table 3

ICC and p-values from the F-Test (test session one versus test session two) for the average torque

	Hemiparetic side		Non-involved side	
	ICC [*]	p-values from F-Test [†]	ICC	p-values from F-Test
Hip extension	0.97	0.006	0.96	0.094
Hip flexion	0.98	0.53	0.92	0.017
Knee extension	0.98	0.39	0.96	0.61
Knee flexion	0.97	0.53	0.96	0.57
Ankle plantarflexion	0.96	0.26	0.88	0.020
Ankle dorsiflexion	0.97	0.74	0.92	0.31

* ICC measures the degree of agreement between test session one and test session two

[†] F-Test determines whether a significant difference exists between the mean of test session one and two