Test-Retest Reliability of Isokinetic Muscle Strength of the Lower Extremities in Patients With Stroke

An-Lun Hsu, MS, PT, Pei-Fang Tang, PhD, PT, Mei-Hwa Jan, MS, PT


Objective: To investigate the test-retest reliability of isokinetic strength measurements of 3 muscle groups of the lower extremities in stroke patients.

Design: Isokinetic strength tests of bilateral hip flexors, knee extensors, and ankle plantarflexors at 2 angular velocities, performed during 2 sessions scheduled 1 week apart for each subject.

Setting: Outpatient rehabilitation clinic of a local hospital in Taiwan.

Participants: Nine patients with mild spastic hemiparesis secondary to stroke and with poststroke onset time of at least 6 months. All subjects could communicate and voluntarily move the affected lower extremity.

Interventions: Not applicable.

Main Outcome Measures: The maximal peak torque, total work, and average power of the 3 muscle groups on the affected side examined during each test were quantified by using the normalization and the deficit methods. The normalization method divides the measured strength value by the patient’s body weight, whereas the deficit method divides the difference between the strengths of the unaffected and affected extremities by the strength of the unaffected extremity.

Results: The normalized strength measures for muscles on the affected side showed good to excellent test-retest reliability (intraclass correlation coefficient [ICC] range, .62-.94; P < .05), whereas the deficit strength measures did not always show good reliability (ICC range, .13-.91). The knee extensors and ankle plantarflexors, but not the hip flexors, on the affected side showed better test-retest reliability of isokinetic strength generated at faster velocity (ICC range, .73-.94) than that generated at slower velocity (ICC range, .62-.88). The normalized peak torque (ICC range, .76-.94) and total work (ICC range, .83-.91) were more reliable than the normalized average power (ICC range, .62-.90) for all 3 muscle groups on the affected side.

Conclusions: Quantitative assessment of muscle strength of the affected lower extremity in patients with mild spastic hemiparesis secondary to stroke is feasible using isokinetic testing. However, the test-retest reliability of isokinetic strength measures is affected by the quantifying method, testing velocity, and strength measures.

Key Words: Hemiparesis; Leg; Muscles; Rehabilitation; Reliability and validity.

Muscle weakness is among the most common problems in patients who have had cerebrovascular accidents (CVAs). Many researchers have reported significant relationships between muscle strengths of the affected extremities of these patients and both their functions and future outcomes. For example, Nadeau et al found that muscle strength of the hip flexors and ankle plantarflexors of the affected lower extremity significantly predicted the fastest walking speed of stroke patients. Moderate to high correlations between the strength of the knee extensors of the affected lower extremity and comfortable walking speed have also been reported in stroke patients. Because muscle strength of the affected lower extremity can account for part of the functional status of these patients, it is important to have accurate and reliable methods with which to quantify muscle strength.

Researchers and clinicians who believe that muscle strength of the affected extremities in stroke patients is affected by spasticity and abnormal movement synergies have questioned the reliability of muscle strength measures for these patients. However, in the past 2 decades, many investigators have reported high reproducibility of strength measures of the affected extremities in patients with central nervous lesions, whether they were using manual muscle testing (Spearman r = .87-.88), hand-held dynamometers (intraclass correlation coefficient [ICC] range, .90-.98), or isokinetic dynamometers (ICC > .82). Spasticity in stroke patients did not appear to interfere with the reliability of these quantitative measures of muscle strength. Thus, it is well accepted that muscle strength of the affected extremities of stroke patients is quantifiable and that these measures are reliable.

In general, there are 2 methods with which to quantify muscle strength of the affected extremities of stroke patients. In the first, the normalized method, the measured strength value is divided by the patient’s body weight. In the deficit method, the difference between the strengths of the unaffected and affected extremities is divided by the strength of the affected extremity or the strength of the affected extremity is divided by that of the unaffected extremity. The normalization method is a direct and absolute measure of the muscle strength of the affected extremity. Most research that has examined the relation between muscle strength and functions in stroke patients has used this method and found high correlations between normalized muscle strength measures and functional ability of patients, such as ambulatory capacity. The normalization method, however, does not provide information about the severity of strength loss for a patient after stroke. In contrast, the deficit method is an indirect, relative measure of the muscle strength of the affected extremity, permitting for comparison of strength between the unaffected and affected extremities in patients with stroke.
extremities. Research using this measure to quantify muscle strength has also shown significant correlations between the degree of muscle strength deficit of the affected extremity and the functional level of stroke patients. Although both quantification methods can be used to evaluate strength, little has been done to investigate which method is more appropriate in predicting later function of stroke patients. Bohannon showed that correlation between the deficit measures of knee extensors muscle strength of the affected lower extremity and walking speed \( r = -0.64 \) was slightly greater than that between normalized strength measures of the same muscle groups and walking speed \( r = -0.60 \). However, this result was inconclusive because the reliability of both strength quantification methods was not examined.

Among the various types of strength testing equipment, most researchers have advocated using isokinetic dynamometers in clinical and laboratory settings. In particular, isokinetic muscle strength testing provides 3 different strength variables: peak torque, total work, and average power. Peak torque represents the highest single torque output achieved by a muscle contraction that causes the extremity to move through a range of motion (ROM). Total work indicates the accumulated torque output produced as the extremity moves through a specified ROM, and average power refers to the average work done per unit of time. Thus, total work and average power provide additional strength information not offered by peak torque. Whereas total work measures consider the ROM through which a muscle is able to maintain contraction at a certain strength level, average power measures take into account the velocity of muscle contraction. Hence, some researchers have suggested that total work and average power are more representative and more functional measures of muscle strength during movements than is peak torque. In most research, peak torque measure has been used to evaluate muscle strength of the affected extremities in stroke patients, and it has shown high test-retest reliability. Although total work and average power may offer more valuable strength information than peak torque, the reliability of these 2 measures in stroke patients has not been studied.

In isokinetic muscle strength testing, angular velocity is among the primary factors that affect muscle strength. Several researchers have reported an inability of patients with central nervous system lesions to produce muscle torque at high velocities. Knutsson et al. showed that, in patients with spastic paresis, antagonist restraint was more common at fast speed of motion than at low speed. It was thus often believed that measurements of muscle strength of spastic muscles tested at high speed might be unreliable. However, Tripp and Harris found that test-retest reliability of the peak torque for the affected knee flexors of stroke patients measured at the angular velocity of 120°/s (ICC = .96) was greater than that measured at 60°/s (ICC = .91). Therefore, isokinetic strength measures tested at faster velocities may not necessarily be less reliable than those tested at slower velocities for some muscles of stroke patients. It is possible that because of the greater resistance encountered during the isokinetic testing at lower velocities, these patients may in fact have greater difficulty in generating consistent levels of force than when tested at faster velocities. Further investigation is needed to examine whether the test-retest reliability of other muscles of stroke patients is speed dependent.

Studies that have investigated test-retest reliability of isokinetic muscle strength in stroke patients have largely focused on knee muscles. Recently, Pohl et al. reported reliable isokinetic strength measures in stroke patients for the affected knee extensors and ankle plantarflexors and dorsiflexors (ICC range, .80-.90) but not for the affected knee flexors (ICC = .48). However, to date no studies have assessed the reliability of hip flexor strength of the affected lower extremity in stroke patients, although the strength of hip flexors have been shown to be an important factor in predicting their fastest walking speed.

This study investigated the test-retest reliability of the Cybex 6000 isokinetic dynamometer for measuring muscle strength of the hip flexors, knee extensors, and ankle plantarflexors at 2 angular velocities in stroke patients. Two quantifying methods (normalization, deficit) and 3 muscle strength measures (peak torque, total work, average power) were used. In addition, comparisons of the test-retest reliability were made between muscle strengths measured at 2 angular velocities, between 2 quantifying methods, and among 3 muscle strength measures. The angular velocities chosen for each muscle group (30°/s and 90°/s for the hip flexors and knee extensors, 15°/s and 30°/s for the ankle plantarflexors) were comparable to those that occur during functional activities such as walking or rising up from a chair at a comfortable or slow speed. Our thought was that isokinetic muscle testing performed at joint angle velocities comparable to those incurred in functional activities might be useful in predicting the influence of muscle strength on patients’ performance of daily activities.

METHODS

Participants

A convenience and volunteer sample of 9 patients (8 men, 1 woman) with hemiparesis resulting from a single CVA accident were recruited from the outpatient rehabilitation clinic of the Mackay Memorial Hospital, Taipei, Taiwan, ROC. The sample’s mean age was 55.6 years (range, 35–68y), and the average postonset duration was 20.2 months (range, 6–43mo). Five subjects were left hemiparetic, the others were right hemiparetic. None presented with severe spasticity, as indicated by the Modified Ashworth Scale score (>2). The motor function score of the affected lower extremity, as rated by the Fugl-Meyer Assessment, was greater than 23 for all subjects (table 1). All participants met the following inclusion criteria: being able to communicate with others and follow verbal instructions, having a minimum of 6 months poststroke onset time, being able to actively flex the affected hip from full extension (0°) to at least 40° of flexion in the supine position, being able to actively extend the affected knee from 85° of knee flexion to at least 15° of flexion in semisupine position, being able to actively plantarflex the affected ankle from the ankle neutral position to at least 20° of plantarflexion in supine position, having nearly complete passive ROM for all these joints, and being pain free in the lower extremities. Patients with unstable medical conditions or other diagnosed neurologic or musculoskeletal disorders were excluded. All recruited subjects gave their informed consent and the study was approved by the institutional review board of the Mackay Memorial Hospital.

Measurements

We used a Cybex 6000 isokinetic dynamometer to measure isokinetic muscle strength for bilateral hip flexors, knee extensors, and ankle plantarflexors at 2 angular velocities. The angular velocities tested for the hip flexors and knee extensors were 30°/s (slower speed) and 90°/s (faster speed), and velocities tested for the ankle plantarflexors were 15°/s (slower speed) and 30°/s (faster speed).

Modified seating and positioning arrangements were used for the isokinetic strength testing, in consideration of patients’
comfort and functional positions of the hip, knee, and ankle joints in daily tasks such as walking. To test hip flexor strength, the subjects were supine (fig 1). The tested leg was supported with the knee maintained at 90° of flexion, whereas the non-tested leg was supported in an extended position. The hip angle in this testing position was similar to that in the early swing phase of the gait cycle. During walking, the hip flexors are primarily activated at this phase of the gait cycle. Therefore, it was expected that isokinetic muscle strength tested for the hip flexors at this angle might be more effective in predicting a patient’s performance in functional activities such as walking. To prevent back discomfort, the standard isokinetic testing position for the hip flexors, in which both knees hang over the edge of a chair, was not used. A strap placed just inferior to the anterosuperior iliac spine stabilized the pelvis. The axis of rotation of the dynamometer was aligned with the flexion and extension joint axis of the tested hip, and the input adapter pad was fixed at the distal end of the thigh, 5cm superior to the patella. The strength of the hip flexors was measured as the hip moved from the neutral position to 40° of flexion. Two stoppers controlled the starting and ending positions of the tested hip joint.

To test knee extensor strength, subjects sat on a chair with the upper back of the chair positioned at 30° of forward inclination from the horizontal plane (fig 2). Subjects’ knees hung over the edge of the chair. This testing position was generally similar to the standard isokinetic testing position for knee extensors except for the relative position between the trunk and hip, which simulated the angle formed between the trunk and hip in the early stance phase of the gait cycle. The knee extensors are highly activated in this phase of the gait cycle. Each subject was secured in the chair by a seat belt at the waist and a strap over each thigh proximal to the femoral condyle. The lateral femoral condyle of the tested knee was aligned with the axis of rotation of the dynamometer. The distal aspect of the input adaptor pad was positioned 5cm superior to the medial malleolus. Two stoppers were anchored to allow the knee to move from 85° to 15° of flexion.

Ankle plantarflexors strength was measured with the subject lying supine on the isokinetic machine with hips and knees bilaterally stabilized in full extension (fig 3). The tested foot was tightly fixed on the footplate of the dynamometer, and the ankle was maintained in neutral position. This testing position was similar to the standard isokinetic testing position for these muscles, except that patients were supine rather than prone because the prone position may cause discomfort. Furthermore, the hip, knee, and ankle joint angles in this testing position were similar to those in the mid-to-late stance phase of the gait.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Age (y)</th>
<th>Postonset (mo)</th>
<th>Side Affected</th>
<th>Etiology</th>
<th>Plantarflexors Spasticity*</th>
<th>Fugl-Meyer Score†</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>68</td>
<td>34</td>
<td>R</td>
<td>Infarction</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>55</td>
<td>14</td>
<td>R</td>
<td>Infarction</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>67</td>
<td>9</td>
<td>R</td>
<td>Infarction</td>
<td>0</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>49</td>
<td>19</td>
<td>R</td>
<td>Infarction</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>35</td>
<td>6</td>
<td>L</td>
<td>Infarction</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>56</td>
<td>43</td>
<td>L</td>
<td>Infarction</td>
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<td>24</td>
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<tr>
<td>7</td>
<td>M</td>
<td>60</td>
<td>13</td>
<td>L</td>
<td>Hemorrhage</td>
<td>1</td>
<td>29</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>50</td>
<td>36</td>
<td>L</td>
<td>Hemorrhage</td>
<td>1</td>
<td>32</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>60</td>
<td>6</td>
<td>L</td>
<td>Infarction</td>
<td>0</td>
<td>31</td>
</tr>
</tbody>
</table>

Table 1: Subject Characteristics

Abbreviations: M, male; F, female; R, right; L, left.
* Rated by the Modified Ashworth Scale.
† The lower-extremity motor score of the Fugl-Meyer Assessment.

Fig 1. Subject’s position for testing the strength of hip flexors.

Fig 2. Subject’s position for testing the strength of knee extensors.
cycle, during which the plantarflexors are highly activated. The plantarflexion and dorsiflexion joint axis of the ankle joint was aligned with the axis of the dynamometer. The plantarflexor strength was tested as the ankle moved from neutral position to 20° of ankle plantarflexion. The starting and ending positions of the tested ankle were controlled by 2 stops.

Protocol

To evaluate the test-retest reliability of isokinetic muscle strength testing, each subject was tested on 2 separate occasions at the same time of day 1 week apart. The same warm-up routine and testing protocol were used to enhance consistent strength generation level.

At each testing session, maximal isokinetic muscle strength for bilateral hip flexors, knee extensors, and ankle plantarflexors at slower and faster velocities were tested. Testing order of the 3 muscle groups was randomized to reduce order effects. For each muscle group, isokinetic strength of the unaffected lower extremity was tested before the affected lower extremity, and the isokinetic testing at the slower velocity was performed before that at the faster velocity.

Before the test, all subjects practiced 3 trials of concentric isokinetic tests, consisting of 2 submaximal and 1 maximal muscle contractions, to familiarize themselves with the dynamometric device and testing procedure. This process took approximately 2 minutes. Then, when each muscle was tested at a particular velocity during each trial, subjects were asked to push as hard and as fast as possible. Four trials were given for each muscle group tested at each velocity, with a 30-second rest between trials. A 1-minute rest was permitted between each testing velocity. Each subject needed approximately 30 to 35 minutes to complete these tests. Three muscle strength measures, the peak torque (in Nm), total work (in J), and average power (in W), were recorded for each test trial.

Data Analysis

Descriptive statistics were used to depict subjects’ basic characteristics. The maximal peak torque, total work, and average power of the hip flexors, knee extensors, and ankle plantarflexors generated in the 4 trials of isokinetic testing for each angular velocity of each lower extremity were selected for further statistical analysis. Two methods were used to quantify the maximal muscle strength of the affected lower extremity. The first, the normalization method, calculated the normalized maximal peak torque (Nm/kg), total work (J/kg), and average power (W/kg) by dividing each maximal muscle strength measure by each subject’s body weight. In the strength deficit method, the maximal muscle strength measure of the affected lower extremity was subtracted from that of the unaffected lower extremity; this difference was then divided by the corresponding maximal muscle strength measure of the unaffected lower extremity. Thus, a deficit muscle strength measure of 0.5 for an affected muscle group indicated that the muscle strength on the affected side was half of that on the unaffected side.

To determine the test-retest reliability of all maximal strength measures at each testing velocity for each muscle group across the 2 testing sessions, the ICCs, of Shrout and Fleiss was used. It has been suggested that an ICC value greater than .75 represents excellent reliability, whereas an ICC value between .40 and .75 represents fair to good reliability.

RESULTS

Tables 2, 3, and 4 present the means and standard deviations (SDs) of normalized maximal peak torque, total work, and average power, respectively, of the affected and unaffected muscle groups at 2 testing velocities of the 2 testing sessions. Tables 5, 6, and 7 present the means and SDs of deficit strength measures of the peak torque, total work, and average power, respectively, of the affected muscle groups. In general, muscle strength of the affected lower extremity was lower than that of the unaffected side. All of the normalized muscle strength measures of the affected knee extensors and ankle plantarflexors were significantly lower than their counterparts (independent t test, P<.01). Results showed that most of the normalized muscle strength measures of the hip flexors on the affected side were lower than their counterparts on the unaffected side, although not all of them reached significant differences. These findings confirm that muscle strength of the affected lower extremity was indeed impaired in these stroke patients.

Table 8 shows the ICCs for the normalized muscle strength measures of the affected and unaffected muscle groups tested at 2 velocities. The reliability of all of these normalized muscle strength measures was good to excellent and reached significant levels (ICC range, .62–.94; P<.05). The ICCs for the
This study investigated the test-retest reliability of the Cybex 6000 isokinetic dynamometer for measuring hemiparetic patients’ muscle strength of bilateral hip flexors, knee extensors, and ankle plantarflexors at 2 angular velocities. These subjects presented with mild to moderate impairment in the motor recovery of the affected lower extremity and either no or mild muscle spasticity of the affected ankle plantarflexors. Two quantifying methods (normalization, deficit) and 3 muscle strength measures (peak torque, total work, average power) were used. In general, the 3 muscle strength measures, tested at 2 angular velocities and quantified with the normalization method, all showed good to excellent test-retest reliability for the 3 investigated muscle groups of both lower extremities. In contrast, not all of the strength measures quantified with the deficit method showed significant test-retest reliability. Thus, the normalization method appeared to provide more reliable strength measures than the deficit method. Among the 3 normalized muscle strength measures, the normalized peak torque and total work were more reliable than normalized average power. In addition, between the different angular velocities, the normalized strength measures tested under faster angular velocity tended to be more reliable than those tested under slower angular velocity. These results suggest that by using the normalization method, isokinetic muscle strength of hemiparetic patients with mild to moderate impairment of motor function and muscle tone of the affected lower extremity is quantifiable and reliable. In addition, the extent of test-retest reliability of isokinetic strength measures is influenced by the strength measure used.

### DISCUSSION

The normalization method, isokinetic muscle strength of hemiparetic patients with mild to moderate impairment of motor function and muscle tone of the affected lower extremity is quantifiable and reliable. In addition, the extent of test-retest reliability of isokinetic strength measures is influenced by the strength measure used.
sures used and by the angular velocity at which the strength is tested.

Our results support the recent contention that muscle strength of the affected extremities of hemiplegic patients is quantifiable and its measurement is reliable even in the presence of mild spasticity.17 McLellan35 and Knutsson and Mårtensson27 reported that stretch reflexes during voluntary movements could be suppressed by voluntary efforts in stroke patients with mild spasticity. In our study, although some subjects presented mild spasticity in the affected ankle plantarflexors, all were capable of exerting voluntary plantarflexion movement with the affected ankle. Thus, the test-retest reliability of isokinetic strength measures of this muscle group remained moderate to high. Therefore, for a paretic muscle that preserves the ability to exert a considerable amount of muscle strength, low levels of spasticity do not appear to have a significant effect on the consistency of torque production.

Researchers16,17 testing isokinetic muscle strength of hemiplegic patients have mainly studied the knee muscle groups. Only 1 study25 has investigated the isokinetic muscle strength of the ankle plantarflexors and dorsiflexors of stroke patients. We simultaneously investigated all 3 muscle groups of the affected lower extremity, and our results showed that the normalized isokinetic strength measures were reliable, regardless of the testing angular velocities and the strength measures. These findings suggest that, with proper positioning, fixation, and testing protocol, isokinetic testing for stroke patients is feasible for measuring the strength of muscles spanning multiaxis joints, such as the hip and ankle joints, of the affected lower extremity.

Several reasons may account for the moderate to high test-retest reliability found in our study. First, the test and retest sessions of muscle strengths were scheduled 1 week apart, which may have prevented both learning and fatigue effects on the reproducibility of muscle strength measures. Previous studies16,36 have shown that the test-retest reliability of isokinetic muscle testing is generally higher when the intersession interval ranges between 24 hours and 7 days. In contrast, using an intersession interval as short as 10 minutes, Wennberg39 found that the test-retest reliability of ankle muscle strength measures for healthy athletes was very low. Second, this study’s 30-second resting interval between trials may have also prevented muscle fatigue. Similarly, Stratford et al40 found that an isokinetic testing protocol with 30-second intertrial resting intervals resulted in higher test-retest reliability (ICC range, 97–98) than a protocol with no intertrial rest (ICC range, 92–93). Third, practice for the 2 submaximal and 1 maximal muscle contractions before data recording may have effectively familiarized the subjects with the dynamometer and testing protocol which, in turn, may have enhanced the reproducibility of muscle strength measures. Finally, the use of consistent testing protocol, positioning, stabilization, environment, and instructions during the 2 testing sessions may have also contributed to the test-retest reliability of isokinetic muscle strength measures.

### Normalized Strength Measures Were More Reliable Than Deficit Measures

In this study, all muscle strength measures quantified with the normalization method showed moderate to high reliability, whereas not all of the measures quantified with the deficit method had significant test-retest reliability. Thus, the strength deficit measures appeared to be less reliable than the normalized muscle strength measures. The lower test-retest reliability of strength deficit measures may be partly because of the fact that the deficit quantifying method relied on the accuracy of strength measures for both the affected and unaffected extremities. For example, if the affected muscle strength measured in the second testing session was smaller than that measured in the first testing session, while the unaffected muscle strength showed the opposite result, then there would be a significant difference in the strength deficit measures between the 2 testing sessions. Thus, the test-retest reliability of strength deficit measures would significantly decrease. Our results suggest that because of its lower test-retest reliability, the deficit method may not be appropriate to quantify strengths of the affected lower extremity.

### Table 7: Average Power Deficit for the Affected Muscle Groups in Tests 1 and Test 2

<table>
<thead>
<tr>
<th>Muscle Groups</th>
<th>Test 1</th>
<th>Test 2</th>
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</thead>
<tbody>
<tr>
<td>Hip flexors</td>
<td>.22±.12</td>
<td>.21±.10</td>
</tr>
<tr>
<td>30°/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90°/s</td>
<td>.21±.21</td>
<td>.19±.18</td>
</tr>
<tr>
<td>Knee extensors</td>
<td>.37±.07</td>
<td>.36±.08</td>
</tr>
<tr>
<td>30°/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90°/s</td>
<td>.47±.12</td>
<td>.42±.11</td>
</tr>
<tr>
<td>Ankle plantarflexors</td>
<td>.49±.15</td>
<td>.41±.20</td>
</tr>
<tr>
<td>15°/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30°/s</td>
<td>.53±.14</td>
<td>.48±.17</td>
</tr>
</tbody>
</table>

NOTE. Values are mean ± SD.

### Table 8: ICCs for Normalized Maximal Peak Torque, Total Work, and Average Power at 2 Angular Velocities

<table>
<thead>
<tr>
<th>Muscle Groups</th>
<th>Peak Torque</th>
<th>Total Work</th>
<th>Average Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slower Angular Velocity</td>
<td>Faster Angular Velocity</td>
<td>Slower Angular Velocity</td>
<td>Faster Angular Velocity</td>
</tr>
<tr>
<td>Unaffected</td>
<td>Hip flexors</td>
<td>.89†</td>
<td>.91†</td>
</tr>
<tr>
<td></td>
<td>Knee extensors</td>
<td>.91†</td>
<td>.91†</td>
</tr>
<tr>
<td></td>
<td>Ankle plantarflexors</td>
<td>.74†</td>
<td>.89†</td>
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<tr>
<td>Affect ed</td>
<td>Hip flexors</td>
<td>.91†</td>
<td>.91†</td>
</tr>
<tr>
<td></td>
<td>Knee extensors</td>
<td>.86†</td>
<td>.88†</td>
</tr>
<tr>
<td></td>
<td>Ankle plantarflexors</td>
<td>.76†</td>
<td>.83†</td>
</tr>
</tbody>
</table>

NOTE. The slower velocities at which the hip flexors, knee extensors, and ankle plantarflexors were tested were 30°, 30°, and 15°/s, respectively, whereas the faster velocities at which these 3 muscle groups were tested were 90°, 90°, and 30°/s, respectively.

* Significant ICC at P<.05 level.
† Significant ICC at P<.01 level.
muscles in mild hemiparetic stroke patients. Although Bohannon\textsuperscript{18} showed that the strength deficit measures of the paretic muscles had a slightly greater correlation with gait performance than the normalized measures, our findings suggest that not all strength deficit measures are reliable and that they should be used with caution.

**Strength Measures Tested at Faster Angular Velocities**

Strength of each muscle group was measured at 2 angular velocities in this study. The slower velocities at which the hip flexors, knee extensors, and ankle plantarflexors were tested were $30^\circ$, $30^\circ$, and $15^\circ$/s, respectively, whereas the faster velocities at which the muscle groups were tested were $90^\circ$, $90^\circ$, and $30^\circ$/s, respectively. The ICCs of the affected knee extensors and ankle plantarflexors at faster velocities were all slightly greater than those at slower velocities, although for the affected hip flexors there was no apparent speed-related difference in the corresponding ICCs (table 8). These findings are contrary to the concept that hemiplegic patients have greater difficulty generating force at faster speed.\textsuperscript{27,28,41} Dietz et al\textsuperscript{41} reported a significant increase in the percentage of slow-twitch muscle fibers in spastic gastrocnemius muscle and thus assumed that patients with central nervous lesions were unable to produce torque at high velocities. Knutsson et al\textsuperscript{27,28} also observed that stretch reflexes of antagonists increased with the agonist muscle contraction speed during voluntary movements in patients with spastic paresis. These studies indicated that patients with spasticity might experience greater difficulty in generating force at a higher velocity. However, in our study, the ICC values obtained at slower velocities were smaller than those obtained at faster velocities, suggesting that the results from tests at faster velocities were more reliable. One possible reason for these results is that the faster angular velocities we used were actually not fast compared with the fast angular velocities (>180°/s) commonly used in isokinetic muscle testing on healthy subjects or in patients with musculoskeletal disorders.\textsuperscript{42} Instead, these faster velocities were comparable to the angular speed in a patient’s daily functional activities, such as walking or rising from a chair. Thus, all of the subjects were capable of producing measurable strength at the tested faster velocities. Another possibility is that because of the greater resistance encountered during the isokinetic testing at the slower velocities, most subjects felt it was more difficult to maintain maximal effort throughout the entire ROM at slower velocities. Thus, the consistency in producing maximal muscle strength was poorer at slower velocities than at faster velocities.

### Normalized Peak Torque and Total Work Were More Reliable Than Normalized Average Power

This study shows that the ICCs of the normalized peak torque and total work were greater than those of the normalized average power. Li et al\textsuperscript{43} showed that, in healthy subjects, the test-retest reliability of the peak torque muscle strength measures were significantly greater than the total work and average power muscle strength measures. However, none of the studies that compared the reproducibility of the muscle strength of the affected extremities in stroke patients concurrently measured all of these 3 variables. Our finding that the average power muscle strength measure was less reliable than the peak torque and total work measures in hemiparetic patients may indicate the patients’ difficulty in consistently maintaining sustained muscle contraction while performing the same movement throughout the testing ROM. This inconsistent contraction time may result from the irregular motor unit recruitment patterns in hemiplegic patients, as documented by Rosenfalck and Andreassen.\textsuperscript{44}

### CONCLUSION

This study showed that muscle strength measures of affected and unaffected lower extremities in patients with mild to moderate motor function deficits after stroke can be quantitatively assessed with the Cybex 6000 system. In this tested patient pool, the strength measures were reliable when quantified with the normalization method, and measures tested at faster velocities were more reliable than those tested at slower velocities. In addition, the normalized peak and total work measures appeared to be more reliable than the normalized average power measures. Isokinetic muscle strength measures thus are feasible and reliable clinical and research tools with which to assess muscle performance of stroke patients with mild to moderate level of impairment in muscle tone and motor function. Given these quantitative and reliable measures, clinicians may use the information to detect changes in muscle performance of such patients. Researchers may use it to examine the relationship between muscle performance and other quantitative functional measures in these patients; however, the results of isokinetic strength testing should be used with caution because they may be affected by the quantifying method, testing velocity, and the strength variables used.

### References


**Supplier**

a. Cybex International Inc, 10 Trotter Dr, Medway, MA 02053.