Reliability and Precision of Isokinetic Strength and Muscular Endurance for the Quadriceps and Hamstrings

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The importance of accurately reproducing isokinetic strength values is critical for the assessment of training induced changes in muscle function. The purpose of this study was to determine the test re-test reliability of the Biodex System 2 Isokinetic Dynamometer for concentric quadricep and hamstring strength and muscular endurance. Twenty-one healthy volunteers underwent isokinetic testing on 2 occasions separated by 7 days. Each subject performed 5 repetitions at 60 degrees/second followed by a muscular endurance test which consisted of 30 repetitions at 180 degrees/second. The results demonstrated high ICC values ranging from $r = 0.88$ to $r = 0.97$ and $r = 0.82$ to $r = 0.96$ for variables measured at 60 degrees/second and 180 degrees/second, respectively. SEM values were found to range from low to moderate, 4.8 % to 11.6 % and 5.6 % to 10.8 %, at 60 and 180 degrees/second, respectively. ICC coefficients were found to be low, $r = 0.52$ to $r = 0.74$, and SEM values were found to be high, 9.8 % to 20.8 %, for the work fatigue index at 180 degrees/second. The results demonstrate that isokinetic values obtained at 60 and 180 degrees/second are highly reproducible with the Biodex System 2 Dynamometer provided that adequate calibration, gravity correction and patient positioning is recorded and standardized. However, the work fatigue index as a measure of muscular endurance has not been shown to be reliable or precise. Changes in muscular strength over time should be considered valid if these differences lie beyond the SEM values reported in this study.

Key words: Isokinetic, reliability, endurance, precision, quadriceps, hamstrings

Introduction

Since the inception of the isokinetic concept by Hislop and Perrine (8), this form of exercise has proved to be a valuable tool for the assessment and evaluation of muscular function and pathology. Some of the advantages of isokinetic exercise and assessment are that it permits the isolation of muscle groups, provides accommodating resistance to maximal exercise throughout the range of motion and presents quantifiable data for peak torque, work and power (12). However, some of the limitations to this form of exercise include non-specificity of functional training for the lower extremity in the closed kinetic chain fashion in addition to angular velocity movements that do not appropriate functional speeds (12). Perhaps one of the most widely used examples of this latter disadvantage refers to the fact that during the throwing motion, the shoulder can exceed an angular velocity of 5000 degrees/second where most commercial dynamometers do not exceed speeds of 450 degrees/second (11). Nevertheless, if the clinician is concerned with the bilateral or reciprocal muscle group comparison of an athlete, then isokinetic dynamometry should be the modality of choice over isometric or isotonic measure. It should be kept in mind, however, that the reproducibility, or reliability, of isokinetic testing for a desired protocol should be sufficient enough so that measures for training or injury induced changes in muscle strength are not attributed to instrument or testing error.

With respect to the Biodex System 2 Isokinetic Dynamometer (Biodex Medical Inc., Shirley, NY), previous investigators have established reliability coefficients for peak torque and angular work (5,6). Feiring and coworkers (5) reported intraclass correlation coefficients (ICC) ranging from 0.82 to 0.98 for isokinetic peak torque and single repetition work at angular velocities of 60, 180, 240 and 300 degrees/second. Gross et al. (6) found ICC's ranging from 0.67 to 0.97 for non-windowed peak torque and angular work at 60 and 180 degrees/second. One of the functions of isokinetic dynamometry is its reported value as a measure of fatigue. Thorstensson and Karlsson (15) originally recommended the use of a fatigue index as an indicator of endurance capacity for a muscle group. Specifically, the decline in peak torque after 50 contractions was expressed as a percentage of the highest of the first 3 peak torques to the last 3 peak torques (15). One of the more widely used fatigue protocols in clinical practice is the measurement of the number of contractions performed until peak torque decreases to 50 % of its initial value (9). The Biodex System 2 Dynamometer currently proposes the use of a fatigue index in which the percent decline in work is measured as the work performed during the last one-third of the test to the work performed during the first one-third of the test. A similar measure performed on the

Cybex II Isokinetic Dynamometer yielded low test re-test reliability coefficients at angular velocities of 180 and 240 degrees/second (2). However, Burdett and Van Swearingen (2) found that work performed during the last 5 repetitions of a 25 repetition test was a clinically reliable measure for muscle endurance. Such findings not only necessitate the need for a better understanding of the reliability of various muscular endurance protocols, but they also indicate the importance for the precision of these measures. The ability to quantify reliable and relatively precise values for maximal strength and endurance, as measured through isokinetic dynamometry, would provide the sports medicine setting with a valuable tool for the evaluation of muscular capability and injury assessment. To date, test re-test reliability for the Biodex System 2 Dynamometer has yet to be established for a number of these isokinetic parameters.

The purpose of this study was to determine the reliability of the Biodex System 2 isokinetic Dynamometer for concentric quadricep and hamstring strength for the following variables: peak torque, peak torque/body weight, total work, work performed during the last one-third of a muscular endurance test, a work fatigue index and average power for the dominant and non-dominant lower limb at 60 and 180 degrees/second.

Materials and Methods

Subjects for this study consisted of 21 (10 males, 11 females: mean age = 21.91 ± 2.2 years, height = 169.23 ± 11.24 cm, weight = 70.28 ± 14.64 kg) college aged volunteers with no previous history of injury to the lower extremity. Prior to participation in this study, each subject provided informed consent approved through the Biomedical Institutional Review Board at the University of Pittsburgh.

Instrumentation

The Biodex System 2 Isokinetic Dynamometer was used for the assessment of reciprocal concentric quadricep and hamstring strength. Data for these variables were recorded and analyzed with the Biodex Advantage Software v.4.0 program (Biodex Medical Inc., Shirley, NY). Peak torque for isokinetic quadricep and hamstring strength was assessed as the highest single repetition value among all the contractions for a given set (1). A Fitron (Lumex Corp., Ronkonkoma, NY) lower extremity cycle ergometer was used for warm-up purposes. Prior to testing, all subjects completed the dynamic warm-up period on the Fitron lower extremity ergometer which consisted of cycling for 5 minutes at approximately 60 revolutions per minute followed immediately by quadriceps and hamstring stretching.

Isokinetic strength assessment

Subjects were placed in a comfortable upright seated position on the Biodex dynamometer chair and was secured using thigh, pelvic and torso straps in order to minimize extraneous body movements. The lateral femoral epicondyle was used as the bony landmark for matching the axis of rotation of the knee joint with the axis of rotation of the dynamometer resistance adapter. Once the subject was placed in a position that allowed for a comfortable and unrestricted motion for knee extension and flexion from a position of 90 degrees of flexion to terminal extension, the following measurements were taken: seat height, seat inclination, dynamometer head height, and resistance pad level. These measures were recorded and stored on the Biodex Advantage Software program in an attempt to identify and reproduce similar testing positions for each individual subject. Gravity correction was obtained by measuring the torque exerted on the dynamometer resistance adapter with the knee in a relaxed state at terminal extension. Values for the isokinetic variables measured were automatically adjusted for gravity by the Biodex Advantage Software v.4.0 (1). Although calibration of the Biodex dynamometer is recommended to be performed on a monthly basis by the manufacturer's service manual for both clinical and research use, the investigators in the present study conducted this procedure on a bi-weekly basis (1). During the testing procedure, the cushion setting on the control panel for the ends of the range of motion were set to their lowest (hard) setting in order to reduce the effect of limb deceleration on the reciprocal motion (14).

Reciprocal concentric isokinetic knee extension and flexion was assessed at 2 angular velocities of movement: 60 degrees/second and 180 degrees/second. The assessment of muscular endurance was identified as the 180 degrees/second test for this study. Testing at each velocity consisted of 5 submaximal followed by 2–3 maximal repetitions for warm-up purposes. Five maximal repetitions were then performed at 60 degrees/second. Once both limbs were tested, each subject was given a brief period of volitional recovery and then performed 30 maximal repetitions at 180 degrees/second. Values for peak torque, peak torque/body weight, total work and average power were computed for the quadriceps and hamstrings at 60 degrees/second in addition to work performed during the last one third of the test and work fatigue for the 180 degree/second test. The work fatigue index is defined as the work performed during the last one third of the endurance test (last 10 repetitions) to the work performed during the first one third of the endurance test (first 10 repetitions) and was expressed as a percentage decline in work performed. Each subject performed the 60 degrees/second followed by the 180 degrees/second test. The assessment of muscular endurance was identified as the 180 degree/second test for this study. Testing at each velocity consisted of 5 submaximal followed by 2 - 3 maximal repetitions for warm-up purposes. Five maximal repetitions were then performed at 60 degrees/second. Once both limbs were tested, each subject was given a brief period of volitional recovery and then performed 30 maximal repetitions at 180 degrees/second. Values for peak torque, peak torque/body weight, total work and average power were computed for the quadriceps and hamstrings at 60 degrees/second in addition to work performed during the last one third of the test and work fatigue for the 180 degree/second test. The work fatigue index is defined as the work performed during the last one third of the endurance test (last 10 repetitions) to the work performed during the first one third of the endurance test (first 10 repetitions) and was expressed as a percentage decline in work performed. Each subject performed the 60 degree/second test prior to the 180 degree/second test in an attempt to remove the effect of fatigue that may have occurred during the muscle endurance test. During the testing procedure, each subject was required to fold their arms across their chest and were given verbal encouragement as well as visual feedback from the Bio-dex monitor in an attempt to achieve a maximal effort level as demonstrated previously (7). All testing procedures as well as verbal encouragement were given by the same inves-

Table 1 Intraclass correlation coefficients (2, 1) ± SEM (%) for concentric isokinetic strength of the quadriceps and hamstrings of the dominant and non-dominant limb at 60 degrees/second (* indicates ICC coefficients below the acceptable r ≥ 0.80).

	Dominant		Non-Dominant	
	Quadriceps	Hamstrings	Quadriceps	Hamstrings
Peak torque (Nm.)	0.97 ± 4.8	0.97 ± 4.9		
Peak torque/ body weight (%)	0.86 ± 5.1	0.92 ± 5.3	0.76 ± 7.5*	0.87 ± 7.3
Total work (Nm.)	0.89 ± 8.9	0.95 ± 7.4	0.88 ± 9.6	0.90 ± 11.6
Average power (Watts)	0.92 ± 2.0	0.95 ± 7.1	0.93 ± 6.9	0.95 ± 7.1

Table 2 Intraclass correlation coefficients (2, 1) ± SEM (%) for concentric isokinetic strength of the quadriceps and hamstrings of the dominant and non-dominant limb at 180 Degrees/second (* indicates ICC below the acceptable r ≥ 0.80).

	Dominant		Non-Dominant	
	Quadriceps	Hamstrings	Quadriceps	Hamstrings
Peak torque (Nm.)	0.96 ± 5.6	0.96 ± 6.1	0.95 ± 6.2	0.96 ± 6.4
Peak torque/ body weight (%)	0.82 ± 6.1	0.90 ± 6.1	0.85 ± 6.1	0.89 ± 6.2
Total work (Nm.)	0.88 ± 9.6	0.95 ± 7.4	0.90 ± 8.5	0.91 ± 9.0
Work last third (Nm.)	0.84 ± 10.8	0.91 ± 9.9	0.88 ± 8.7	0.85 ± 9.9
Work fatigue index (%)	0.62 ± 12.3*	0.52 ± 20.8*	0.74 ± 9.8*	0.84 ± 11.0
Average power (Watts)	0.89 ± 9.5	0.95 ± 7.6	0.93 ± 7.5	0.93 ± 8.1

tigator for all subjects. Limb dominance was determined for each subject by identifying the leg in which the subject would preferably kick a ball and the order of limb testing was randomized. Each subject performed the identical testing procedure on two separate sessions that were separated by 1 week. Subjects were also tested at similar times of the day in order to reduce the effect of diurnal variation influences.

Statistical analysis

To establish test re-test reliability, intraclass correlation coefficients (ICC) (2, 1) were calculated for the variables obtained at each respective velocity (4, 13). ICC's were accepted as clinically meaningful if values were equal to or greater than r ≥ 0.80 (3). In order to determine the precision of measurement for the isokinetic variables in this study the standard error of measurement (SEM) values were calculated and expressed as a percentage of the mean for each of the test re-test isokinetic variables. The interpretation of the SEM values as a percentage was conducted in order to present the findings in a clinically applicable manner for future reference (4).

Results

Reliability coefficients

ICC's (2, 1) for the quadriceps and hamstrings muscles of the dominant and non-dominant legs at 60 degrees/second are presented in Table 1. From this study sample, test re-test reliability coefficients were above r ≥ 0.80 for quadriceps and hamstring peak torque (r = 0.93 to r = 0.97), total work (r = 0.88 to r = 0.95), and average power (r = 0.92 to r = 0.95). ICC values for peak torque/body weight measures were also found to be highly reliable (r = 0.86 to r = 0.92) except for the non-dominant quadriceps (r = 0.76).

ICC values for the 180 degree/second muscular endurance test are displayed in Table 2. These values followed a similar pattern for those observed at 60 degrees/second. Reliability coefficients were found to be highly reliable for peak torque (r = 0.95 to r = 0.96), peak torque/body weight (r = 0.82 to r = 0.90), total work (r = 0.88 to r = 0.95), work performed during the last one third of the test (r = 0.84 to r = 0.91) and average power (r = 0.89 to r = 0.95). With the exception of the non-dominant hamstrings (r = 0.84), test re-test ICC values for the work fatigue index were lower (r = 0.52 to r = 0.74) than the r ≥ 0.80 standard established for this study.

Precision of measurement

The standard error of measurement (SEM) values for quadriceps and hamstring strength of the dominant and non-dominant limb at 60 degrees/second is presented in Table 1. The results indicate relatively low to moderate SEM measures for peak torque (4.8 % to 7.6 %), peak torque/body weight (5.1 % to 7.5 %), total work (7.4 % to 11.6 %) and average power (2.0 % to 7.1 %).

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SEM values for quadriceps and hamstring strength of the dominant and non-dominant limb at 180 degrees/second are presented in Table 2. For ICC values accepted as clinically meaningful (ie – r ≥ 0.80), low to moderate SEM values were also found to exist for peak torque (5.6 % to 6.4 %), peak torque/body weight (6.1 % to 6.2 %), total work (7.4 % to 9.6 %, work performed during the last one third of the test (8.7 % to 10.8 %) and average power (7.5 % to 9.5 %). SEM values for the work fatigue index ranged from 9.8 % to 20.8 %.

Discussion

The major findings of this study indicated that the most frequently used isokinetic variables to describe muscle function, peak torque, peak torque/body weight, total work and average power, were found to be highly reliable at both testing velocities. These results appear to be in general agreement with those reported previously for the Biodex System 2 Isokinetic Dynamometer (5, 6). Feiring et al. (5) found high test re-test coefficients for peak torque and single repetition work at 60 and 180 degrees/second that ranged from r = 0.93 to 0.98. However, Gross et al. (6) found relatively higher reliability values using windowed data as opposed to raw values. Although it has been recommended that windowed data be utilized in clinical practice to obtain better reliability or consistency of testing, the results from the present study determined that the use of raw data yielded ICC's that were higher than the standard (r ≥ 0.80) established for this clinical significance. Based on these results, therefore, the use of non-windowed data in the assessment of isokinetic strength should provide a reliable measure of muscle function throughout the full range of motion. The ability of reproducing the testing protocol with respect to calibration, gravity correction and patient set-up should be deemed the most important components for improving the reliability of a test (16).

The accuracy to which these protocols are reproducible is also a critical factor as determined by the standard error of measurement (4). Although high reliability coefficients have been previously reported for isokinetic strength, SEM values have lacked attention in the literature. The SEM values in this study were expressed as a percentage in order to allow clinical usage of these measures be to more applicable. As demonstrated by these results, re-test values for quadriceps and hamstrings peak torque, peak torque/body weight, total work and average power can be approximated by 5%-10% to the initial test. It should therefore, seem appropriate to attribute isokinetic strength changes to training or injury should they exceed the SEM values outlined in Tables 1 and 2 for 60 and 180 degrees/second, respectively.

The importance of establishing not only the magnitude of force output but also the ability to maintain this output over a prolonged duration can provide a valuable measurement for the assessment of muscle fatigue. However, the results from the present study do not support the use of the work fatigue index as a reliable isokinetic variable for muscular endurance. With the exception of the non-dominant hamstring muscles, reliability coefficients for this measure ranged from r = 0.52 to r = 0.74 which is below the clinically acceptable r ≥ 0.80 set for this study. In addition, high SEM values were also found for this variable (9.8% to 20.8%) indicating that substantial changes must be measured by this parameter in order to detect training or injury effects. Although the work fatigue index for the non-dominant hamstrings were found to be clinically reliable (r = 0.84), the standard error of measurement appeared to be high (11%). These findings are in accordance with Burdett and Van Swearingen (2) who found low ICC values for the calculated work fatigue index during a similar endurance protocol on the Cybex II Dynamometer. Since the calculated fatigue index is a measure of the quotient between the work performed during the first 10 repetitions and the last 10 repetitions, errors of measurement incurred during these two separate bouts may have been compounded in the final value, as explained by Burdett and Van Swearingen (2). In addition, a methodological learning effect may have likely occurred on the part of the subjects in which higher work values could have been attained during the first 10 repetitions of the endurance test on Day 2. An improved ability to recruit a greater number of higher threshold motor units may have resulted in a much earlier depletion of readily available adenosine triphosphate (ATP) as well as rapid energy supplying substrates (creatine phosphate) which would correspond to a greater decline in torque production (10, 15).

Conversely, however, Burdett and VanSwearingen found that the work performed during the last 5 repetitions of a 25 repetition test at 180 degrees/second was a clinically reliable measure for the quadriceps muscles (r = 0.95) but not for the hamstrings (r = 0.75) (2). The present study revealed somewhat similar results with respect to the quadriceps (r = 0.84) dominant and r = 0.88 non-dominant) but also showed clinically reliable values for the hamstrings (r = 0.85 non-dominant and r = 0.91 dominant). The discrepancy between the findings of the present study with that of Burdett and Van Swearingen (2) are most likely attributed to differences in testing protocol (25 repetitions vs 30 repetitions) and the equipment utilized (Cybex II vs Biodex System 2) in which intermachine reliability coefficients for raw data have been demonstrated to be low (6). The selection of the endurance protocol in the present study was based on the notion of producing a maximal localized muscular test for a period of 30 seconds. This reciprocal quadriceps and hamstring evaluation was designed in order to assess the capacity and contribution of the readily available adenosine triphosphate (ATP) and the creatine phosphate energy system to torque production (10). This assumption, however, does not take into account the contribution of the anaerobic glycolytic pathway for ATP re-synthesis and should, therefore, warrant further investigation.

Conclusion

Training induced changes in muscular strength and torque production can be measured objectively with the use of isokinetic dynamometry which has been shown to be a highly reliable measurement tool in this study as well as others that have utilized a similar protocol on the Biodex dynamometer (2, 5, 6). The results from the present investigation support previous findings for quadriceps and hamstring concentric peak torque, peak torque/body weight, total work and average power at 60 and 180 degrees/second with respect to test re-test reliability. However, the applicability of previous findings to clinical practice is limited with respect to the precision of these measures. In addition, the use of the work performed during the last one-third of a 30 repetition fatigue protocol at 180 degrees/second proved to be a reliable measure and should be considered as the isokinetic parameter to observe for examining training induced changes in muscular endurance. The work fatigue index, on the other hand, has not been found to be a reliable isokinetic measure as demonstrated in this study. The evaluation of a training program or the effects of musculoskeletal injury on strength should also take into consideration the SEM values presented in Tables 1 and 2 when utilzing similar test protocols to those in this study. Examining changes in muscle strength beyond the magnitude of error as presented can therefore be attributed to other factors such as training or injury. The establishment and documentation of reliability and SEM values allows the clinician to utilize isokinetic dynamometry with more confidence and with much more valid results.

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