Clinical Journal of Sport Medicine
7:11–16 © 1997 Lippincott-Raven Publishers, Philadelphia

Relation Between Open and Closed Kinematic Chain Assessment of Knee Strength and Functional Performance

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Abstract:
Objective: To assess the relationship between concentric isokinetic quadriceps and hamstring strength values with the single leg hop for distance test, a closed kinematic chain activity.
Design: Correlational study.
Setting: Neuromuscular Research Laboratory, University of Pittsburgh.
Participants: Subjects for this study consisted of 37 college-aged volunteers (21 men, 16 women: mean age = 22.76 ± 3.52 years, height = 169.90 ± 10.60 cm, weight = 69.31 ± 14.60 kg) with no previous history of injury to the lower extremity.
Intervention: Each subject performed three trials of a single leg hop for distance test for the dominant and nondominant limbs followed by isokinetic evaluation. Isokinetic strength was assessed with the Biodex System II Isokinetic Dynamometer (Biodex Medical Inc., Shirley, NY, U.S.A.) for the quadriceps and hamstrings at preset angular velocities of 60°/s (5 repetitions) and 180°/s (30 repetitions). Before testing, each subject completed a dynamic warm-up period that consisted of submaximal cycling at a fixed cadence of 60 revolutions/min followed subsequently by quadriceps and hamstring muscle stretching.
Main outcome measures: The distance hopped in centimeters was converted to a ratio of the distance hopped to the individual leg length measured from the anterior superior iliac spine to the medial malleolus. Isokinetic values were obtained for peak torque (Nm), peak torque/body weight (%), total work (Nm), and average power (W).
Main results: Low to moderate significant relationships were found to exist between the single leg hop for distance test and the isokinetic variables for the quadriceps and hamstrings of both limbs at each test velocity. Significant correlation coefficients ranged from $r = 0.33$ to $r = 0.69$ at 60°/s and $r = 0.33$ and $r = 0.67$ at 180°/s. Correlation coefficients were found to be statistically greater for the hamstrings than the quadriceps for total work and average power at 60°/s and for peak torque/body weight, total work, and average power at 180°/s ($p < 0.05$).
Conclusions: Concentric quadriceps and hamstring strength seem to demonstrate a significant contribution to the single leg hop for distance test; however, the hamstring muscles may play a more important role during the propulsive phase, thereby enabling subjects to jump further.
Key Words: Kinematic chain assessment—Knee strength—Performance, functional—Hamstring muscle—Quadriceps muscle.
Clin J Sport Med 1997;7(1):11–6.

The contribution of the knee musculature to successful athletic performance has been a highly emphasized component in many training programs. Furthermore, optimal strength of the quadriceps and hamstrings has been deemed necessary for the prevention and rehabilitation of activity-induced injuries to the knee. The ability to quantify measures of strength and functional performance of the knee have also been established with a high degree of reliability. Perhaps the most widely used and objective measure of knee strength has been the use of isokinetic dynamometry. This type of evaluation, however, leads one to question the usefulness and practicality of associating isokinetically obtained values of strength with functional tests of performance (2,6,12–14). It has been suggested, though, that a relationship exists between isokinetic knee strength and a single leg hop for distance test (3,17,25–27).

In an attempt to comprehend the outcomes of these conflicting studies, the biomechanical nature of isokinetic knee assessment and functional performance tests can best be explained by the concept of the kinematic chain. In its simplest sense, the kinematic chain is composed of rigid links that are interconnected by a series of pin joints (16,22). In the closed kinematic chain model of the lower extremity, motion at the knee joint will cause a corresponding and predictable motion at both the hip and ankle, whereas motion at any one joint is free to occur independently of the other joints in the open kinematic chain (16,22). By definition, therefore, an activity such as the single leg hop for distance test can be considered a closed kinematic chain movement, and isokinetic knee extension and flexion can be appropriately referred to as an open kinematic chain. As a result, muscle recruitment

Received April 8, 1996. Accepted July 23, 1996.
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and forces imparted on the joint will differ between these two forms of motion (18).

Establishing a relationship between isokinetic knee strength values and the single leg hop for distance test would help to identify the contribution between quadriceps and hamstring force output to functional performance. Because previous studies focused mainly on peak torque values solely for the quadriceps muscles, an examination of the hamstring muscles as well as other strength variables such as total work and average power may further delineate the role of the knee to a single leg hop for distance. This focus is of particular interest for purposes of performance and rehabilitation assessment. The use of the single leg hop for distance test in the evaluation of the anterior cruciate ligament–injured patient, for instance, has been adopted by some as a reliable and objective measure of knee function (17,25–27), whereas others have refuted this relationship (2,6,12–14). Moreover, Robertson and Fleming (20) found that the knee played a very minor role as an energy generator during the propulsion phase of the standing long jump. These inconsistent results not only question the validity of the single leg hop for distance test as an objective evaluation of knee function, but they also lead the researcher and clinician to investigate the role of the hamstring muscles in horizontal jumping ability.

According to the closed kinematic chain principle, the single leg hop for distance test is not an isolated assessment of knee function, because corresponding motion occurs at both the ankle and hip (16,22). During knee extension in the closed kinematic chain position, the hamstrings and quadriceps muscles undergo a concurrent shift in which the hamstrings contract concentrically at the hip and eccentrically at the knee, whereas the quadriceps contract concentrically at the knee and eccentrically at the hip (18,22). The ability of the muscles to shorten, thereby producing force with a resultant joint torque, provides a more clear comprehension of the propulsive characteristics of the single leg standing long jump.

The purpose of this study was to (a) examine the relation between concentric isokinetic quadriceps and hamstring strength values with a closed kinematic chain activity, the single leg hop for distance test, and (b) determine differences in this relationship between isokinetic strength of the quadriceps and hamstring muscles.

MATERIALS AND METHODS

Subjects for this study consisted of 37 college-aged volunteers (21 men, 16 women: mean age = 22.76 ± 3.52 years, height = 169.90 ± 10.60 cm, weight = 69.31 ± 14.60 kg) with no previous history of injury to the lower extremity. Before participation in this study, each subject provided informed consent approved through the Biomedical Institutional Review Board at the University of Pittsburgh. To reduce the possible effects of fatigue, each subject performed the single leg hop test for distance before the isokinetic evaluation. Subjects were provided a 5-min rest period after the single leg hop for distance test. All subjects reported subjective feelings of full recovery after this rest interval. The order of limb testing for the hop and the isokinetic test was randomly selected. Before testing, each subject completed a dynamic warm-up period that consisted of cycling on a Fitron (Lumex Corp., Ronkonkoma, NY, U.S.A.) bicycle for 5 min at 60 revolutions/min followed by quadriceps and hamstring stretching. Subjects were instructed to cycle at an effort level that they perceived to be a light to moderate intensity. Each subject then performed the single leg hop for distance test within 1–2 min subsequent to the warm-up period.

Closed kinematic chain assessment

Closed kinematic chain assessment of knee functional performance was assessed by a single leg hop for distance test (4,5,27,28). A tape measure marked in centimeters was placed across the floor to determine the distance jumped. Subjects were instructed to stand on one leg and to position their toes to the zero mark on the tape, with their arms by their sides. Subjects were then instructed to hop forward as far as possible and to land on the same leg. To simulate a functional test, subjects were allowed to swing their arms forward as they jumped. In addition, subjects were instructed to wear running shoes that they felt accustomed to for two reasons: (a) to improve the comfort of the test so that each subject might exert as maximal an effort as possible, and (b) to increase the safety and reduce the possibility of injury to the foot or lower leg that may be incurred from the landing phase of the jump. The distance from the zero mark to their heel was recorded for three trials and then averaged. Each subject was given two to three practice trials before the test. To determine the relative distance jumped, the absolute average distance of the three trials was divided by the subject's leg length measured from the anterior superior iliac spine to their medial malleolus. This corrected relative value was then used for statistical analysis.

Isokinetic strength assessment

Isokinetic strength was assessed with the Biodex System 2 Isokinetic Dynamometer (Biodex Medical Inc., Shirley, NY, U.S.A.). Subjects were placed in a comfortable upright seated position on the Biodex dynamometer chair and were secured using thigh, pelvic, and torso straps 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° 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 in the Biodex Advantage Software program v.4.0 (Biodex Medical Inc.) to standardize the testing position 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). Calibration of the Biodex dynamometer was performed according to the specifications outlined by the manufacturer's service manual (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 to reduce the effect of limb deceleration on the reciprocal motion (24).

Reciprocal concentric isokinetic knee extension and flexion was assessed at two angular velocities of movement: 60° and 180°/s. Testing at each velocity consisted of five submaximal followed by two to three maximal repetitions for warm-up purposes. Five maximal repetitions were then performed at 60°/s when each subject indicated his or her state of preparation. Once both limbs were tested, each subject was given a brief period of volitional recovery and then performed 30 maximal repetitions at 180°/s. Values for peak torque, peak torque/body weight, total work, and average power were computed for the quadriceps and hamstrings at both angular velocities. Each subject performed the 60°/s test before the 180°/s test in an attempt to remove the effect of fatigue that may have occurred during the latter test velocity. The duration of the rest period between the 60 and 180°/s tests was ~2 min long. Because the duration of the 60°/s test was 14–16 s, the calculated work:rest time ratio was 1:7 to 1:8. During the testing procedure, subjects were required to fold their arms across their chests and were given verbal encouragement as well as visual feedback from the Biodex monitor in an attempt to achieve a maximal effort level as demonstrated previously (11). All testing procedures as well as verbal encouragement were provided by the same investigator for all subjects. Limb dominance was determined for each subject by identifying the leg with which he or she would preferably kick a ball, and the order of limb testing was randomized.

Previous studies have demonstrated high intraclass correlation (ICC) coefficients for isokinetic testing at these two angular velocities using the Biodex Isokinetic Dynamometer (8,10). As part of reliability testing for this study, 21 subjects from this sample were randomly selected to perform an identical isokinetic test 1 week after the initial assessment to establish test–retest reliability (7,21). ICC values obtained from these subjects yielded coefficients for the following isokinetic parameters at 60 and 180°/s: peak torque (r = 0.93–r = 0.97), peak torque/body weight (r = 0.76–r = 0.92), total work (r = 0.88–r = 0.95), and average power (r = 0.89–r = 0.95) (19).

Statistical analysis

To examine the relation between the corrected values for the single leg hop for distance test and isokinetic peak torque, peak torque/body weight, total work, and average power, Pearson product-moment correlation coefficients were determined. Relationship differences between the quadriceps and hamstring isokinetic strength variables were then computed using the t test for testing differences between two dependent correlation coefficients with a preset α level of $p < 0.05$ (9).

RESULTS

Relation between isokinetic and hop tests

Low to moderate, yet statistically significant, relationships were found to exist between isokinetic peak torque, peak torque/body weight, total work, and average power and the single leg hop for distance test for the quadriceps and hamstring muscles of both limbs at each velocity. Significant correlation coefficients ranged from $r = 0.33$ to $r = 0.69$ at 60°/s (Table 1) and r = 0.33–r = 0.67 at 180°/s (Table 2).

Quadriceps and hamstring relationship differences

When comparing the correlation coefficients between the isokinetic variables and the single leg hop for distance test, it was found that the relationships were statistically greater for the hamstring muscles than the quadriceps for total work and average power at 60°/s and peak torque/body weight, total work, and average power at 180°/s for the dominant limb (Table 3). It was also shown that the relationship was greater for the hamstrings than the quadriceps in the nondominant limb for total work and average power at 180°/s.

TABLE 1. *Pearson product-moment correlation coefficients for the relation between isokinetic quadriceps and hamstring strength values at 60°/s and the single leg hop for distance test*

	Dominant		Nondominant	
	Quadriceps	Hamstrings	Quadriceps	Hamstrings
Peak torque (Nm)	0.39^{a}	0.55^{b}	0.49^{c}	0.58^{b}
Peak torque/body weight (%)	0.46^{c}	0.65^{b}	0.55^{b}	0.69^{b}
Total work (Nm)	0.32	0.56^{b}	0.44^{c}	0.55^{b}
Average power (W)	0.33^{a}	0.57^{b}	0.44^{c}	0.56^{b}

[a] $p < 0.05$.
[b] $p < 0.001$.
[c] $p < 0.01$.

TABLE 2. *Pearson product-moment correlation coefficients for the relation between isokinetic quadriceps and hamstring strength values at 180°/s and the single leg hop for distance test*

	Dominant		Nondominant	
	Quadriceps	Hamstrings	Quadriceps	Hamstrings
Peak torque (Nm)	0.42[a]	0.55[b]	0.51[b]	0.55[b]
Peak torque/body weight (%)	0.49[c]	0.61[b]	0.51[b]	0.67[b]
Total work (Nm)	0.33[a]	0.51[c]	0.40[a]	0.54[b]
Average power (W)	0.37[a]	0.53[b]	0.42[c]	0.58[b]

[a] $p < 0.05$.
[b] $p < 0.001$.
[c] $p < 0.01$.

DISCUSSION

The results from this study indicate that low to moderate, yet statistically significant relationships exist between isokinetic quadriceps and hamstring strength values and the single leg hop for distance test in noninjured subjects. These findings seem to be in agreement with those of others, who also found statistically significant relationships between these two variables. Moderate to high Pearson product-moment correlation coefficients ($r = 0.56$–$r = 0.89$) were found by Swarup et al. (23) between isokinetic peak torque and work for the quadriceps muscles and the one legged hop for distance. Significant positive relationships were also found by Wiklander and Lysholm (26), Tegner et al. (25), Barber et al. (3), and Noyes et al. (17). Most recently, Wilk et al. (27) documented a moderate positive correlation ($r = 0.62$) between quadriceps peak torque at 180°/s and the single leg hop for distance test. Although these previous studies included the use of different testing devices (Kincom and Cybex Isokinetic Dynamometers) as well as subjects with a history of knee disease, these moderate relationships seem to be quite consistent. It should be noted, however, that the majority of these studies focused mainly on isokinetic peak torque and work values when relationships were established. The present study demonstrated significant correlations for quadriceps and hamstring average power ($r = 0.33$–$r = 0.58$) and peak torque/body weight ($r = 0.46$–$r = 0.69$). The relatively higher correlations observed for the peak torque/body weight variables seem to suggest that an individual's relative strength scores may be a better indicator of functional performance as demonstrated by a single leg hop. Because the distance in which each subject was able to jump was corrected for by individual leg length, greater emphasis should be placed on relative performance measures when evaluating knee function in the clinical setting. In addition, it has been stated that the use of reciprocal muscle testing, as used in this study, allows for the stretch–shortening cycle to occur in conjunction with antagonistic muscle activity acting in an eccentric fashion during the agonist movement (27). This close approximation of lower extremity strength testing to functional performance may provide a partial explanation regarding these relationships.

Conversely, however, it should be kept in mind that significantly stronger relationships than those demonstrated in this study as well as others may not be observed because of the nature of these two forms of testing. Isokinetic strength testing allows for the isolation of the quadriceps and hamstring muscles, thereby concomitantly producing larger shear forces (15,18). Decreases in joint shear resulting from higher compressive forces is a major characteristic of the closed kinematic chain position (15,18). These moderate, yet consistent, relationships should not be expected to be higher due to the increased recruitment of biarticulate muscles during the single leg hop test.

The ability of an individual to jump a given distance is dependent mainly on the propulsive forces generated at takeoff. It has long been assumed that strong quadriceps muscles are necessary for optimal functional performance. The results from the present investigation, however, demonstrate statistically higher correlations for the isokinetic hamstring variables than for the quadriceps

TABLE 3. *Significant Pearson product-moment correlation coefficient differences ($p < 0.05$) between the quadriceps and hamstring isokinetic strength values at 60 and 180°/s for the dominant and nondominant limbs*

Variable	Difference	t value
Total work 60°/s—dominant leg	Hamstrings > quadriceps	3.52
Average power 60°/s—dominant leg	Hamstrings > quadriceps	3.30
Peak torque/body weight 180°/s—dominant leg	Hamstrings > quadriceps	8.95
Total work 180°/s—dominant leg	Hamstrings > quadriceps	2.68
Average power 180°/s—dominant leg	Hamstrings > quadriceps	2.43
Total work 180°/s—nondominant leg	Hamstrings > quadriceps	2.02
Average power 180°/s—nondominant leg	Hamstrings > quadriceps	2.71

(Table 3). It seems that the ability to generate higher concentric hamstring torque is better representative of single leg hop performance than the quadriceps. An early study conducted by Robertson and Fleming (20) found that the hip and ankle muscles were the primary energy generators to the standing long jump, whereas the knee contributed only 3.9%. Although extensor moments were observed at the knee, ankle, and hip joints during this action, the muscles of the knee were generally found to act as net energy absorbers (20). A greater ability to maximally recruit the hamstring muscles to generate higher levels of hip extensor torque seems to be a valid necessity for this functional performance test.

The significance of hamstring contributions to knee joint stability has been the focus of numerous investigations and clinical trials. Reflex hamstring contraction has been suggested to play a key role in dynamic knee stabilization through a reduction in anterior tibial displacement, thereby decreasing stress on the anterior cruciate ligament (ACL) (15,18). Previously, Wilk et al. (27) observed no significant correlations between isokinetic hamstring strength and the single leg hop for distance in subjects who had undergone ACL surgical reconstruction. The stronger relationships for hamstring strength, as depicted in the present study, seem to suggest that muscular strength of the knee flexors may enhance functional performance. The conflicting results between the present study and those of Wilk et al. (27) indicate that articular retensioning of ligamentous structures after reconstructive ACL surgery may play a major role in knee joint stabilization. Therefore, neuromuscular activation patterns of the hamstring muscles between the ACL reconstructed and noninjured subjects may have been different. Furthermore, the present study did not address the issue regarding previous lower extremity training activities, whereas the ACL reconstructed subjects observed by Wilk et al. (27) may have displayed adaptations characteristic of specific rehabilitation protocols subsequent to surgery. These conflicting results, however, necessitate the need for further investigation concerning the role of the hamstring muscles in dynamic knee function.

CONCLUSIONS

Propulsive power during ballistic movements is a vital component to successful performance. Activities such as the single leg hop for distance have been used extensively as an objective indicator of knee and quadriceps function. Although the results from the present investigation found statistically significant relationships between isokinetic quadriceps strength and the single leg hop for distance, the large contribution that is often assumed to occur from these muscles may be questioned. The present investigation supports the notion that the hamstring muscles may play a more important role during a single leg hop than previously thought. Because the hamstring muscles have been previously reported to act as a dynamic knee stabilizer, the results from this study support an increased use of hamstring activation exercises in knee rehabilitation programs. Based on the fact that these findings seem to be contrary to others, as cited, further investigation into the role of hamstring activation patterns is necessary to assist clinicians in gaining a clearer understanding of the contributory role of these muscles to functional performance.

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