Relationship Between Closed-Linear-Kinetic- and Open-Kinetic-Chain Isokinetic Strength and Lower Extremity Functional Performance

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Context: Isokinetic strength and functional performance are used to assess recovery after rehabilitation. It is not known whether low-speed closed-linear-kinetic isokinetic muscle strength correlates with functional performance.

Objective: To investigate the relationship between linear closed (CKC) and open (OKC) concentric isokinetic strength of the dominant lower-limb extensors and functional performance.

Design: Correlational analysis.

Setting: University laboratory.

Participants: Thirty uninjured men and women (age = 20.9 ± 2.4 years).

Main Outcome Measures: Peak CKC and OKC isokinetic strength and best score from a shuttle run for time, single-leg vertical jump, and single-leg hop for distance.

Results: Neither lower-limb CKC nor OKC isokinetic strength measured at low speeds correlated highly with performance on the functional tasks of jumping, hopping, and speed/agility.

Conclusions: Although the basis of both closed and open isokinetic strength must be appreciated, they should not be the only determinants of functional performance.

Key Words: strength measurements, functional testing, isokinetic testing


The knee musculature is important for successful performance in sports and is the site of many sport-related injuries. For these reasons, it has been the focus of testing and rehabilitation studies. Isokinetic dynamometry provides an accurate, reliable, and objective method of measuring lower extremity muscle strength using either open-kinetic-chain (OKC) or closed-kinetic-chain (CKC) exercise. OKC isokinetic evaluation of the knee extensors and flexors has traditionally been used to measure strength and to establish a patient’s readiness to return to sports participation. Studies

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examining the relationship between OKC knee-extensor isokinetic strength and functional performance have found significant positive correlations,\textsuperscript{12-16} as well as low or no correlation.\textsuperscript{17,18}

Isokinetic CKC exercise is also performed for lower extremity strength assessment and rehabilitation. In general, CKC exercise is described as more specific, more functional, and safer than OKC exercise. Because CKC exercise appears to replicate functional tasks, muscle-strength assessment in the closed chain might be a better predictor of functional performance than open-chain strength assessment is.\textsuperscript{4,19} Most of the isokinetic studies that have investigated CKC strength used a modified isokinetic dynamometer that provides movement through an angular arc of motion.\textsuperscript{20,21} Recently another mode of isokinetic dynamometry has become available that provides accommodating resistance in a linear fashion with distal fixation to create the closed-chain environment.\textsuperscript{6,8} In reviewing the literature, we could only identify 1 study that reported comparing linear closed-chain lower extremity isokinetic strength and functional performance.\textsuperscript{22} In that study, isokinetic leg-press strength was evaluated at 76.2 cm/s and correlated significantly ($R = .665$ to .757) with 2 unilateral performance tests: the single-leg hop for distance and the single-leg vertical jump.

The results of studies that evaluated the effectiveness of hopping, jumping, and cutting-type tests in determining lower extremity functional limitations in anterior-cruciate-ligament-deficient knees have been adopted by some as a reliable and objective measure of knee function,\textsuperscript{14,16} whereas other studies have not established this relationship.\textsuperscript{3,17,23} Moreover, even if functional testing is an important part of the information needed to determine an athlete’s status, the reliability of only a few of these tests has been established. The single-leg hop for distance appears to be very consistent in determining functional stability, with ICCs as high as .99 reported.\textsuperscript{24} Although functional testing cannot provide the sophisticated analysis of limb function that can be obtained from gait and forceplate studies, hop-and-jump testing appears to be useful as a general screening assessment that can be performed in a clinical setting.\textsuperscript{14}

The critical variable for developing strength (maximal torque), at least in the context of isokinetics, is the amount of torque developed during muscle contraction.\textsuperscript{25} Because greater strength gains have been reported to occur at slower exercise velocities, it might be important to know whether strength measured at a low speed using isokinetic linear CKC movement shows a strong correlation with functional performance.\textsuperscript{25-28} Understanding whether CKC muscle force produced at a low isokinetic speed shows a relationship to functional activity could help in developing evaluation-based protocols. Therefore, the purpose of this study was to compare the relationships between low-speed open and linear closed-chain isokinetic strength and 3 performance tests: the single-leg hop for distance, the single-leg vertical jump, and the speed/agility run.
Methods

Subjects

Thirty (age = 20.9 ± 2.4 years, weight = 68.50 ± 15.3 kg, height = 170.25 ±9.1 cm) uninjured men (n = 15) and women (n = 15) participated. None of the subjects had a previous history of injury to the lower limb. They were asked to refrain from vigorous exercise during the experimental period. The study was approved by the institutional review board at the University of South Alabama, and all subjects read and signed an informed consent form before participating.

Procedures

One week before testing, each subject participated in a familiarization session and observed and practiced the isokinetic and functional tests. Each subject kicked a ball to determine leg dominance; the leg used to kick the ball was chosen as the dominant limb. Testing was performed on 3 days, with 1 week between testing sessions. Knee-extension contractions were performed on the first testing day, the seated leg-press contractions on the second testing day, and the functional tests on the third testing day. One examiner performed all measurements for each particular test.

Isokinetic Testing

Isokinetic knee-extension testing of the dominant leg was performed using the LIDO Active dynamometer (Loredan Biomedical, Sacramento, Calif). Each subject was seated with the back reclined at approximately 100° and the dynamometer shaft aligned with the lateral knee-joint line. The ipsilateral thigh was secured with a bolster and 2 large Velcro® straps secured the pelvis and torso. Arms were held at the sides, with the hands grasping seat handles. The lever-arm pad was positioned to place the inferior rim immediately superior to the medial malleolus.

Maximal knee-extension contractions were performed through a 90° ROM (90° to 0° of flexion) at a speed of 60°/s. Testing consisted of each subject performing 6 submaximal and 3 near-maximal repetitions for a warm-up followed by a 60-s rest. The subject then performed 5 maximal contractions in knee extension, with the reciprocal movement of knee flexion performed submaximally so that hamstring fatigue did not interfere with performing the knee-extension contractions. All subjects were verbally encouraged to extend the knee through the range of motion as hard and as fast as possible.

Isokinetic seated leg-press testing of the dominant lower extremity was conducted using the Closed Chain Rider System (Mettler Electronics, Anaheim, Calif). The Closed Chain Rider mechanism consists of 2 rail extensions that contain channels for the movement of rubber-wheeled rollers attached
to leg-coupling devices (Figure 1). When engaged, the leg couplers are linked to a closed chain that is supported on 2 sprockets at either end of the extrusions. The closed chain is coupled to a motor that is used as a brake to provide accommodating resistance during exercise. The braking action is regulated by computer software. Testing was performed with the back reclined at approximately 100°. Seat straps were placed across the pelvis and chest to secure the subject. The feet were placed into the foot pedals and secured. Both feet were moved to approximate the maximum exercise range with 1 leg extended while the opposite flexed. The foot couplers were then locked to the chain. During the test session, the subject grasped the handles located on either side of the seat for maximum stability.

The seated leg-press warm-up protocol was identical to the knee-extension warm-up protocol, except that leg-press movements were performed. The testing protocol consisted of performing 5 maximal-effort repetitions of alternating leg-press movements at a speed of 25 cm/s (10 in/s). Subjects were instructed and verbally encouraged to perform each leg-press movement as fast and forcibly as possible. Reliability of measuring force at 25 cm/s for this system has been reported to be high ($R = .86$).

**Functional Testing**

The subjects performed 3 function tests: a single-leg hop for distance, a single-leg vertical jump, and a 25.5-m shuttle run. A warm-up immediately preceded each test, after which the subject performed 3 consecutive trials, with the best score used for data analysis.

**Single-Leg Hop.** A tape measure marked in centimeters was placed across the floor to determine the distance jumped. The distance from the zero
mark to the subject’s heel was recorded in centimeters. Subjects stood on
the dominant leg with toes on the zero mark, held their hands behind their
back to prevent generating momentum, and hopped as far as possible from
a squatting position, landing on the same foot. Each subject was required
to “stick” the landing. If displacement of the foot occurred, the trial was
not counted and was repeated.

Single-Leg Vertical Jump. Vertical jump height was measured using the
Vertec (Sports Imports, Columbus, Ohio). Each subject stood on the domi-
nant leg and extended the ipsilateral hand overhead as far as possible with-
out overreaching. The maximal reach height was measured and recorded.
The subject was instructed to place the nondominant arm behind his or
her back. The subject then jumped vertically with maximum effort from a
squatting position with a knee angle of 90°, measured with a goniometer.
The total vertical-jump score was calculated as the standing-height score
subtracted from the jumping-height score.

Speed/Agility Run. The shuttle-run test was performed on a 6.1-m course,
with 3 changes in direction. Each subject ran 6.1 m, touched a line on the
floor with one foot, reversed direction, then returned to the start, touched
the line, and repeated the process. The elapsed time was measured using
a handheld stopwatch and recorded.

Statistical Analyses
Dominant-leg knee-extension peak torque (N · m), seated leg-press peak
force (N), and the best score from each of the functional tests were used
for analysis. Pearson product-moment correlation coefficients were com-
puted to determine relationships between the functional-test scores and
open- and closed-chain isokinetic strength. An alpha level of .05 was used
to determine the significance level. Means and standard deviations were
calculated for all variables.

Results
Table 1 shows the means and standard deviations obtained for each of the
variables. Isokinetic leg-press-strength scores were significant but moder-
ately correlated with the single-leg hop ($R = .448, P = .013$) and shuttle-run
time ($R = -.494, P = .006$). The vertical jump did not correlate significantly
($R = .260, P = .166$). Isokinetic knee-extension strength demonstrated
slightly higher correlations with the single-leg hop ($R = .623, P = .0001$)
and shuttle-run time ($R = -.510, P = .004$) but not with the vertical jump ($R = .327, P = .078$).

Discussion
Previous studies have not compared isokinetic leg-press strength measured
at a low testing speed with functional performance. Our results showed low to moderate, yet statistically significant, relationships between knee-extension and leg-press muscle force and the performance of the single-leg hop and agility run. Our findings, in general, concur with those of many previous studies that examined knee-extension muscle-force production and performance of a functional task. Pincivero\textsuperscript{15} found low to moderate correlations ($R = .33$ to $ .67$) between OKC quadriceps and hamstring isokinetic strength and the single-leg hop for distance in volunteers with no previous history of injury to the lower extremity. Low to moderate correlations ($R = .01$ to $ .55$) were also reported by Petsching\textsuperscript{29} between OKC isokinetic quadriceps strength and the single- and triple-leg hops for distance and vertical jump height in subjects after anterior-cruciate-ligament reconstruction. Likewise, Lephart\textsuperscript{23} reported low correlations ($R = .32$ to $ .42$) between OKC isokinetically tested quadriceps and hamstring muscle strength and the shuttle run, a cocontraction semicircular maneuver, and a carioca maneuver using anterior-cruciate-ligament-insufficient athletes. In contrast, other authors\textsuperscript{18,30,31} reported higher correlation ($R = .78$ to $ .85$) between OKC isokinetic strength of the knee extensors and functional performance in uninjured college students and skiing and high-jump athletes. These authors used moderate to high speeds ($120^\circ$/s to $240^\circ$/s) to isokinetically measure muscle strength, which could explain the higher correlation coefficients they found.

We had hypothesized that CKC rather than OKC isokinetic strength would correlate more highly with functional performance because of greater joint-proprioceptive input, the linear range of motion used, and alternating leg and multijoint movements. The muscle force measured in the CKC leg-press movement was presumed to be task specific to the single-leg-hop, vertical-jump, and shuttle-run tests because of the combined ankle-, knee-, and hip-extensor forces being measured. In contrast, the open-chain test only measured knee-extensor strength. A study that examined the kinetics of broad jumping reported the contribution of the hip, knee, and ankle joints to be 46\%, 4\%, and 50\%, respectively.\textsuperscript{32} On the other hand, Van Soest

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
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<tbody>
<tr>
<td>Vertical jump (cm)</td>
<td>37.34 ± 13.7</td>
</tr>
<tr>
<td>Single-leg hop (cm)</td>
<td>164.59 ± 31.7</td>
</tr>
<tr>
<td>Shuttle run (s)</td>
<td>7.58 ± 1.1</td>
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<tr>
<td>CCK peak force (N)</td>
<td>976.93 ± 207.1</td>
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<tr>
<td>OKC peak torque (N · m)</td>
<td>217.80 ± 72.9</td>
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*CKC indicates closed kinetic chain, and OKC, open kinetic chain.
et al\textsuperscript{33} reported the contributions of the hip, knee, and ankle joints during the 1-legged vertical jump to be 34\%, 24\%, and 42\%, respectively. It might be that if a combined strength score for the ankle, knee, and hip extensors were used, a higher correlation would exist for the OKC muscle-force measurements.\textsuperscript{34}

Numerous biomechanical and neuromuscular variables (eg, balance, coordination, speed, reaction time, flexibility) in addition to strength are involved in successful functional-task performance.\textsuperscript{4,20} Therefore, muscle force might account for only a portion of the variance found. This would account for the low to moderate correlations we observed between isokinetic strength and functional performance. It might be that in low-speed isokinetic movement, task specificity is not as much a factor as it is in higher-speed movement. A recent study reported significant correlations for isokinetic knee extension at 180°/s ($R = .65$ and .76) and for an isokinetic leg-press movement at 76.2 cm/s ($R = .67$ and .76) with the single-leg hop and vertical jump.\textsuperscript{22} In our study, the closed-chain multijoint and alternating leg-press movements performed at 25 cm/s and the open-chain knee-extension movement performed at 60°/s might not have been performed quickly enough to allow a differentiation between these 2 isokinetic testing modes when predicting functional performance. This finding supports specificity of velocity when assessing open- and closed-chain isokinetic strength and showed the stronger relationship between isokinetic strength assessed at faster speeds to jumping and hopping.

In contrast to the higher correlations observed between isokinetic strength and the single-leg hop and vertical-jump tests, Negrete and Brophy\textsuperscript{22} found a poor relationship between OKC ($R = –.17$) and CKC ($R = –.12$) isokinetic strength and speed/agility-run time. Our results only showed moderate correlations between open ($R = –.51$) and closed ($R = –.49$) isokinetic strength and speed/agility. These findings suggest that neither low- nor high-speed isokinetic strength measured in either the CKC or OKC position correlates substantially to speed/agility-type activities and underscore the necessity for further research in defining more clearly the association of isokinetic-strength measures with the abilities to sprint and change direction. The results of the present study generally concur with the findings of other studies that OKC and CKC isokinetic strength measured at low speeds do not correlate highly with functional tasks.

The value of both open- and closed-chain assessment of isokinetic strength, particularly when individuals are healthy and highly trained, must be appreciated. Isokinetic assessment provides standardization for measuring and reporting change in function, provides important information about muscle-performance capabilities (eg, force–velocity relationships, concentric–eccentric relationships), and gives clinicians an opportunity to maximize functional outcomes when deficiencies in test results are observed in subgroups of individuals matched for age, sex, and performance expectations. Because this study involved healthy subjects with no injury to the lower extremity, the data from this study should not be extrapolated to
postinjury or surgical patients. Future studies should investigate the relationships between isokinetic strength and functional performance using athletes and patients with orthopedic lower extremity injury in order to determine readiness for return to normal activity.

**References**


