

Ability of closed and open kinetic chain tests of muscular strength to assess functional performance

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The purpose of this study was to investigate the ability of closed and open kinetic chain tests of muscular strength to assess functional performance. Sixteen healthy male subjects, with a mean (\pm SD) age, body mass and height of 27 ± 5 years, 78 ± 9 kg and 183 ± 9 cm, respectively, volunteered to participate in the study. In the closed kinetic chain test (involving muscles working across multiple joints), the subjects performed a 3 repetition maximum (3 RM) barbell squat. The open kinetic chain test (involving muscles working across a single joint) consisted of a concentric isokinetic knee extension at an angular velocity of $60^\circ/\text{s}$, and was performed using a Kinetic Communicator II

dynamometer. The test of functional performance (vertical jump) was performed with the subject standing erect, quickly performing a countermovement jump for maximal height. Moderately strong significant ($P<0.05$) correlations between the test of functional performance and the closed and open kinetic chain tests of muscular strength were noted, $r=0.51$ and $r=0.57$, respectively. It is suggested that the effect of training or rehabilitation interventions should not be based exclusively on tests of muscular strength. Rather, various forms of dynamometry including functional performance tests could be recommended.

Today, resistance exercise training plays a vital role in most athletic and rehabilitation programs. Except for sports like weight lifting, power lifting, and bodybuilding where the sole purpose is to enhance muscular strength and power, it is also believed among sports coaches and physical therapists that resistance training will result in improvements in functional performance such as jumping, throwing or running.

Tests of muscular function are commonly performed to assess functional performance, both in the sporting and the rehabilitation fields (Abernethy et al. 1995). However, the relationship between tests of muscular function and functional performance is still not clear. Yet, tests of strength and power are often used to monitor training-induced changes in performance or the effectiveness of rehabilitation. For example, Østerås et al. (1998) used a rehabilitation protocol following surgery of the anterior cruciate ligament (ACL) where they recommended quadriceps muscle torque force corresponding to 85% of the muscle strength, compared with the non-operated limb, before no restrictions needed be taken in sport and work activities. Recent studies, however, indicate a relatively low relationship between tests of muscle function and dynamic performance, both in healthy subjects (Murphy & Wilson 1997, Wilson et al. 1997) as well as in subjects with ACL-reconstruction (Pfeif-

er & Banzer 1999). Pincivero et al. (1997) studied the relationship between concentric isokinetic quadriceps and hamstring strength values with the single hop for distance, a functional activity. It was concluded that only low to moderate significant relationships existed between the single hop for distance and the knee strength tests.

Currently, isometric, isokinetic and isotonic dynamometry are used to assess muscular function. Each form has its drawbacks, the main argument against isometric assessment being that isometric tests bear little resemblance to the dynamic nature of most sporting activities (Ashley & Weiss 1994). The perceived disadvantage of isokinetic assessment is the absence of acceleration and stretch-shortening cycle, and that single-joint, isolated assessment often is used, which again bears little resemblance to functional performance (Augustsson et al. 1998). Those against isotonic assessment tend to emphasize poor reliability and objectivity due to intersubject, intertrial and interlaboratory variations (Abernethy et al. 1995). Regardless of which of the three modes of dynamometry is employed, assessment can be performed using either closed or open kinetic chain movement.

A barbell squat is a free weight, closed kinetic chain exercise, involving muscles working across

multiple joints. Athletes, using resistance training, often include a barbell squat program to improve lower extremity strength. Several studies have used a barbell squat test to determine the effect of various training and rehabilitation interventions (Wilson et al. 1997, Hickson et al. 1994). Isokinetic or isotonic testing and training such as knee extension/flexion, using muscles working across only single joints in an open kinetic chain, are also commonly used to evaluate and improve lower extremity strength (Thomeé et al. 1995, Fry et al. 1991).

In recent years, the importance of using closed kinetic chain evaluation (Greenberger & Paterno 1995) and rehabilitation (Beynon et al. 1997) has been stressed, due to the belief that closed as opposed to open kinetic chain movement is more closely related to function. Moreover, several authors suggest that some types of open kinetic chain exercise are associated with greater anterior-posterior shear forces (Bynum et al. 1995, Yack et al. 1993) and patellofemoral compression forces (Bynum et al. 1995) compared to other types of closed kinetic chain exercise. However, few studies have compared the ability of closed and open kinetic chain tests of muscular strength to assess functional performance. Thus, the purpose of this study was to assess the relationship between a closed kinetic chain test of lower extremity strength and an open kinetic chain test of knee extensor strength with a test of functional performance.

Method

Subjects

Sixteen male subjects, healthy and generally physically active with asymptomatic back, hip and knee function, volunteered to participate in the study. Their mean (\pm SD) age, body mass and height were 27 ± 5 years, 78 ± 9 kg and 183 ± 9 cm, respectively. Nine subjects had previous experience of the barbell squat exercise and of general weight training. The subjects' physical activity level was registered on a scale of 1–8 points, where 1 represented no physical activity and 8 represented engagement in competitive sports, as described by Engström (1980). The median physical activity level score was 6 in the subject group and the interquartile range was 2.75. The study was approved by the Ethics Committee of the Faculty of Medicine, Göteborg University, Sweden.

Testing procedures

Subjects were instructed and acquainted with the testing procedures orally and in writing prior to testing.

In the closed kinetic chain test, subjects performed a barbell squat 3 repetition maximum (3 RM): three consecutive repetitions of lowering the maximum weight possible until the thighs were parallel to the floor, and then raised to an erect position, with an Olympic barbell on the shoulders. The 3 RM for each subject was determined by the ability to complete 3 repetitions while maintaining correct depth and technique of the squat. The weight lifted was incremented by 2.5–10 kg until failure. Two minutes' rest was allowed between trials. A board (2 cm thick) elevating the heels of the subject, thus facilitating

a squatting position, as well as a tightly worn weight-belt supporting the trunk were mandatory. The subject was instructed to keep the back upright with the feet at approximately 20° of external rotation, shoulder width apart. One testleader, positioned at the side of the subject, monitored that correct depth and technique of the squat was maintained. The other testleader spotted the subject from behind, hands placed around the waist of the subject during the lift in case of failure, using strong verbal commands and encouragement. A mirror, placed 2 m in front of the subject, enabled visual feedback. Prior to testing the subject performed a warm-up of 10 min of ergometer cycling and two submaximal sets of 15 repetitions of barbell squat. A safety squat rack (Squat Rack BL 101920, Competition Line, Borås, Sweden) and an Olympic 20 kg barbell with free-weight plates and collars (Casall, Norrköping, Sweden) were used. The barbell squat 3 RM test and the concentric isokinetic knee extension test were separated by 24–72 h.

The open kinetic chain test (concentric isokinetic knee extension) was performed using a Kinetic Communicator II dynamometer (Chattanooga Group, Inc., P.O. Box 489, Hixson, TN 37343, USA). After 10 min of ergometer cycling at 50 W resistance, the subject was positioned with a hip angle of 75° of flexion in the test chair. The axis of the knee joint was aligned with the axis of the Kin-Com dynamometer resistance arm and the lower leg shin pad was secured at approximately 10 cm proximal to the lateral malleolus. The trunk, hip and thigh were strapped down to ensure proper positioning and stabilization. After 5–6 submaximal concentric knee extensions of the right leg at an angular velocity of $60^\circ/\text{s}$, the subject performed 3 maximal trials from 90° to 5° knee angle (0° being full knee extension). The highest peak torque value was documented. One minute of rest was allowed between each trial. One subject tested his left leg because of discomfort. A research physical therapist conducted the dynamometer tests.

The test of functional performance (vertical jump) test was performed with the subject standing erect on a platform, quickly performing a countermovement jump for maximal height. A measuring tape, secured at a tightly worn belt placed around the subject's waist, was pulled through a loop in the platform when the subject performed a vertical jump and the height was documented, as described by Thomeé et al. (1995). Vertical jump height was defined as the highest value among 4 trials. The test was supervised by the testleaders, instructing and monitoring the subjects during all the trials. The vertical jump test followed directly after the concentric isokinetic knee extension test.

Statistical analysis

To examine the relation between the values of the closed and open kinetic chain tests of muscular strength with the test of functional performance, Pearson product-moment correlation coefficients were determined. Relationship differences between the closed and open kinetic chain tests of muscular strength variables were then computed using two-tailed *t* test for testing differences between two dependent correlation coefficients (Guilford & Fruchter 1973). The significance was considered at the α level of $P < 0.05$.

Results

The mean (\pm SD) barbell squat 3 RM strength, concentric isokinetic knee extension torque and vertical jump height were 101 ± 18 kg, 241 ± 65 Nm and 54 ± 7 cm, respectively.

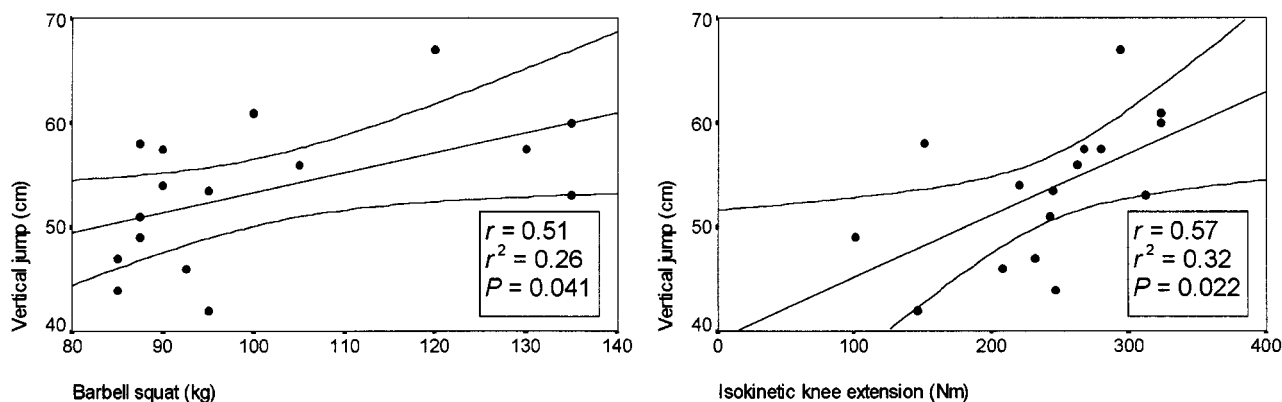


Fig. 1. Correlation between the closed kinetic chain test (3 RM barbell squat) and the open kinetic chain test (concentric isokinetic knee extension), respectively, and the test of functional performance (vertical jump) in healthy male subjects ($n=16$) with 95% confidence interval.

Relation between muscular strength and functional performance tests

Moderately strong significant ($P<0.05$) correlations between the test of functional performance and the closed and open kinetic chain tests of muscular strength were noted, $r=0.51$ and $r=0.57$, respectively. Fig. 1 illustrates the correlations between closed and open kinetic chain test scores and the test of functional performance. There was also a moderately strong significant ($P<0.01$) correlation between the closed and the open kinetic chain test of muscular strength, $r=0.64$.

Closed and open kinetic chain relationship differences

When comparing the coefficients of correlation ($r=0.51$ and $r=0.57$) between the tests of muscular strength and functional performance, it was found that this relationship was not significantly different ($t=0.70$, $P>0.05$).

Discussion

We investigated the ability of closed and open kinetic chain tests of muscular strength to assess functional performance. Moderately strong significant ($P<0.05$) correlations were noted between the test of functional performance and the closed and open kinetic chain tests of muscular strength, $r=0.51$ and $r=0.57$, respectively. A correlation of $r=0.64$ ($P<0.01$) was obtained between the closed and the open kinetic chain test of muscular strength.

The fact that the closed and open kinetic chain tests of muscular strength did not differ in regard to their ability to predict performance probably reflects that the quadriceps muscle is important in vertical jumping and that, furthermore, individual quadriceps

muscle strength correlates with gluteus maximus muscle and triceps surae muscle strength.

In a recent study by Blackburn & Morrissey (1998), open kinetic chain knee extensor strength demonstrated startlingly low correlation with vertical jump ($r=0.01$) and standing long jump ($r=0.07$) performance, whereas Petschnig et al. (1998), who studied the relationship between an isokinetic quadriceps strength test and four different functional performance tests in healthy subjects and patients with surgery of the ACL, reported moderately strong correlation coefficients (between $r=0.45$ and $r=0.55$). In a review (Abernethy et al. 1995) of articles where correlations between muscular strength tests and functional performance were investigated, relationships typically ranged between $r=0.50$ and $r=0.93$.

Östenberg et al. (1998) recently reported low correlations between isokinetic knee extensor strength and functional tests in healthy female soccer players and recommended not using functional performance and isokinetic testing interchangeably. Murphy & Wilson (1997) went even further, suggesting the effectiveness of training or rehabilitation programs should be based on changes in performance rather than tests of muscular function. However, the restoring of muscle size and strength is a cornerstone in rehabilitation, and therefore tests of muscular function must be considered essential. In a recent study (Pfeifer & Banzer 1999), pronounced strength deficits over a long period of time after surgery on the ACL was noted. Likewise, Carter & Edinger (1999) were intrigued to find only half of the competitive athletes in their study had achieved 80% or greater leg strength of the ACL-operated leg by six months after surgery, as it is now customary to allow return to full activities at that time, with some authors advocating return to sports as early as four months after the procedure

(De Carlo et al. 1999, Howell & Taylor 1996). Carter & Edinger (1999) concluded that athletes theoretically may return to sports four to six months postoperatively, but that frequently leg strength is not adequate at that time to do so without running the risk of reinjuring the knee. This is supported by Johnston et al. (1998), who investigated the effect of lower extremity muscular fatigue on motor control performance. It was concluded that fatigued individuals are at increased risk of injury because of loss of balance and that preconditioning may prevent injury.

Both closed and open kinetic chain testing could under certain circumstances be considered as having low validity. As a diagnostic test, a closed kinetic chain movement, involving several groups of muscles working across multiple joints, is unable to determine to what extent a particular muscle is activated. Conversely, the open kinetic chain test, because of its more "non-functional" nature, is able to isolate a specific muscle and thereby detect dysfunction. Thus, the purpose of assessment should determine which mode of dynamometry be used: to identify specific deficiencies or problem areas, open kinetic chain testing would be preferred, whereas a closed kinetic chain test may be better suited for assessing functional performance.

Despite several studies (Beynnon et al. 1997, Yack et al. 1993) concerning safety issues of closed and open kinetic chain exercises in ACL rehabilitation, and although some authors have advocated the sole use of closed kinetic chain exercises (Bynum et al. 1995, Shelbourne & Nitz 1992), it is concluded that both types of exercises can be performed in ways that do not place excessive strain on the ACL (Fitzgerald 1997). Escamilla et al. (1998), comparing knee joint biomechanics while performing closed and open kinetic chain weight training at a 12 RM load, reported that peak ACL tension forces in open kinetic chain exercise were only 0.2 times bodyweight, and non-existent in closed kinetic chain exercise. Factors such as joint compressive forces (e.g. axial loading) and joint geometry probably play integral roles in knee joint stability during closed kinetic chain exercise (Isear et al. 1997), whereas significant coactivation of the antagonists during maximal knee flexion/extension, indicating an inhibitory mechanism which prevents overloading of the joint and contributes to joint stabilization (Kellis & Baltzopoulos 1998), would ex-

plain the low ACL tension forces during open kinetic chain exercise.

There are some methodological issues to be addressed. The sample size in the present study was moderate, but for our purposes we believed it was adequate. No definitive answers regarding the exact correlation between tests of muscular strength and functional performance could be achieved from the present study. Our results are nevertheless of importance due to the scarcity of data in the literature on the ability of closed and open kinetic chain tests of muscular strength to assess functional performance.

More research is needed to further improve protocols and dynamometry employed in the assessment of training or rehabilitation interventions. A challenge for future research could be to develop tests sensitive and specific enough to discriminate relevant muscular and functional deficits or compensations following, for example, ACL-reconstruction. We believe a testing procedure that combined muscular strength with functional performance parameters would enhance the diagnostic spectrum and provide a more comprehensive assessment. For example, functional performance ought to be tested under both fatigued and nonfatigued conditions. This presumably would improve the possibilities to evaluate and compare muscular function of the healthy and injured leg.

In conclusion, the moderate correlations between tests of muscular strength and the vertical jump test indicate that the results of strength measurements cannot be used to adequately assess functional performance. Consequently, it is suggested that the effect of training or rehabilitation interventions should not be based exclusively on tests of muscular strength. Rather, various forms of dynamometry including functional performance tests could be recommended.

Key words: barbell squat; isokinetic knee extension; vertical jump; multi- versus isolated-joint testing; rehabilitation.

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