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Isokinetic and functional parameters in patients following reconstruction of the anterior cruciate ligament

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Abstract. Both isokinetic testing and functional tests are commonly used to evaluate patients following reconstruction of the anterior cruciate ligament (ACLR). To determine the relationship of scores on an isokinetic test to scores on a variety of lower extremity functional tests ten healthy subjects and eleven ACLR patients at least six months after surgery performed knee isokinetic test at 60 and 180 deg/sec and three functional tests: leg vertical jump, single hop, and triple cross-over hop for distance. Correlation coefficients of isokinetic peak torque to body weight and functional testing were not significant at the $P < 0.05$ level in patients or control subjects, whi1e ratio of involved to uninvolved knee quadriceps isokinetics peak torque and Limb Symmetry Index (LSI) of functional test were significant at the $P < 0.05$ level ($r = 0.54$ to 0.97). These results indicate a significant relationship between the LSI of various functional tests and side-to-side ratio of isokinetic testing just in ACLR patients.

Keywords: ACL-reconstruction, isokinetic strength, hop test, limb symmetry index

1. Introduction

The anterior cruciate ligament (ACL) is one of the most commonly injured knee ligaments [9,15]. Disruption of this ligament may lead to an unstable joint with functional impairment [9]. To return successfully to the same activity level after injury, early surgical stabilization is often recommended. One of the most commonly used reconstruction procedures is the arthroscopic patellar tendon autograft, utilizing the central one third of the patella tendon to reconstruct the ACL.

Traditional evaluation following anterior cruciate ligament reconstruction has focused on physical characteristics and measurement of knee stability such as strength, laxity and range of motion. Despite the surgical achievement of ligamentous stability, some patients still experience permanent weakness of the thigh muscle, functional deficits, and a decline in sports activity after ACL reconstruction with patellar tendon autograft [20,28,34,41].

Open kinetic chain evaluation has been used as the primary tool to assess patient strength, readiness to proceed to a higher functional level, and return to sports. Reliance on such criteria has been refuted based on the lack of a strong relationship between the result of these measurements and the patient's perception of knee function or readiness to return to sport. Closed kinetic chain activities have been developed for patients as an alternative to evaluate strength and to determine suitability to progress to higher functional level [9,14, 15]. Hop test was designed to assess both strength and confidence in the involved leg [16]. Various one-legged tests have been established and validated [5,19,29] as indicators for return to a functional level and patient's perception of knee function.

Although hop test score are sometimes believed to reflect lower extremity muscular strength conflicting views exist [3–7,12,19,26,29–33,35,36,38,39,43].

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Some authors indicated moderate correlation between isokinetic torque and functional testing [4,19,30,39] whereas others have reported minimal or no correlation [3,12,26,38]. The discrepancies in results may be derived from differences in methodology, subject populations, testing methods, equipment, and pathologic conditions.

New utilities in isokinetic dynamometry including eccentric mode, gravity correction and dump setting may help in identifying a better relationship between the isokinetic strength of knee and performance on hop tests. The purpose of this study was therefore to assess the relationship of isokinetic strength of the quadriceps and hamstring muscles to performance scores obtained from three hop tests at least 6 months after ACL reconstruction surgery.

2. Methods

2.1. Subjects

Eleven amateur level athletes (mean age $= 30 \pm 8$ years, height 176 ± 7 cm and body weight $= 83 \pm 18$ Kg) at least 6 months following unilateral ACL-reconstruction (ACLR) surgery participated in the study. They were all submitted to intra-articular reconstruction of the anterior cruciate ligament with patellar tendon graft (7L, 4R) by the same surgical team. All patients were rehabilitated using a modified version of the accelerated protocol described by Shelbourne [37] (Table 1). All patients signed an informed consent. Individuals with contralateral injury were excluded. Ten age- and activity-matched healthy subject participated in this study as control subjects.

2.2. Isokinetic muscle testing

Quadriceps and hamstrings muscle performance were determined using a Biodex System 3 isokinetic dynamometer. The dynamometer was calibrated prior to the testing session according to procedures prescribed by the manufacturer. Both the involved and uninvolved knees were tested using stabilization with the patient lying supine for quadriceps and prone for hamstrings testing.

Concentric and eccentric peak torques were recorded after gravity correction at 60°/s (3 repetitions) and 180°/s (5 repetitions). Warm-up consisted of stationary bicycling with no resistance for five minutes.

Patients were instructed to perform five submaximal repetitions of knee flexion and extension at the two test velocities in order to become familiar with the testing apparatus. After one minute of rest, maximal strength measurements were collected for both speeds, with 1 min rest between velocities. The range of motion was 10° to 90° of knee flexion (0° was defined as full extension).

2.3. Functional assessment

One legged single hop, triple cross-over hop for distance and vertical jump were performed using both the involved and sound legs but with the normal leg first. The distance hopped was measured in centimeter and all tests were performed three times. The maximum of the three values was accepted. Limb symmetry index (LSI) that expresses the ratio of distance recorded from the test of involved limb to the test of uninvolved limb as a percentage (involved/uninvolved $\times$ 100 $=$ LSI) was calculated for indicating performance asymmetry [1,9, 15].

2.4. IKDC-subjective score

All patients filled in the International Knee Document Committee Subjective Knee Evaluation Form (IKDCSKEF) in order to record their self-assessment. Maximum score was 100 [14].

2.5. Statistical analysis

For each test velocity the peak torque to body weight ratio for concentric and eccentric muscle activity was used in data analysis. Paired T-test was used to compare the involved and ACLR knee. Pearson's correlation coefficients were used to examine the relationships between the functional test score and isokinetic torque (value of each limb and Limb Symmetry Index). Statistical significance was set at $p < 0.05$.

3. Results

The IKDCSKEF score was significantly ($p < 0.00$) lower in patients (78.5 ± 12.5) than in control subjects (94.3 ± 8.9). Functional tests scores were also lower significantly in involved than uninvolved knee of ACLR subjects ($P < 0.00$). Limb Symmetry Index (LSI) in the functional tests was lower in patient than control subjects but a significant difference was

Table 1
Accelerated rehabilitation program for ACL-reconstruction

Day 1 Rigid knee immobilizer in full extension for walking, weight bearing as tolerated
2–3 days Passive range of motion (ROM) 0 to 90 (emphasis on full extension)
2–4 days Discharge from hospital.
7–10 days ROM terminal extension, prone hangs if patient has not achieved full extension, wall slides, heel slide active-assisted flexion, strengthening-knee,
2–3 weeks ROM (0 to 110), step-ups, leg press, quarter squats, stationary bicycling,
6–8 weeks ROM, strength evaluation, lateral shuffles, cariocas, light jogging, jumping rope, agility drills, weightroom activities, stationary bicycling and swimming
10 weeks Full ROM; increased agility workouts, sport-specific activities
16 weeks Increased agility workouts
4–6 months Return to full sports participation

indicated only for the single hop LSI. Quadriceps peak torque in the reconstructed knee was lower than the normal knee. Consequently, the hamstring to quadriceps muscle strength ratios (H/Q ratios) was much higher for the involved than the uninvolved leg (Table 2).

No significant correlation was revealed between the functional test scores and IKDCSKEF score or isokinetic torques (both modes and both speeds) in patient or control subjects. Simple and functional H/Q ratios in both speeds were not significantly correlated with functional test in patient or control subjects. The LSI in the functional tests was significantly correlated with the IKDCSKEF score in patients as well as with the side-to-side ratio of the isokinetic quadriceps torque which was measured at both velocities (Table 3). Such relations were not found in control subjects.

4. Discussion

The results indicate that ACLR subjects produced significantly more extensor torque with the uninvolved knee than with the reconstructed knee. Several studies have demonstrated that after injury and reconstruction of the ACL bringing quadriceps back to normal strength is difficult and often not achieved [2,10,17,18,20,28, 34].

Diminished quadriceps strength is not due to harvesting of the patellar tendon [27], instead it is suggested that lack of afferents from ACL to gamma loop is the mechanism which underlying the reduction of voluntary activation of quadriceps often observed in patient with ACLR [25,42]. There was however a negligible deficit of hamstring strength and hence the H/Q ratio was higher in the involved knee.

Since strength does not always correlate significantly with physical performance, authors recommend utilizing both functional testing and isokinetic dynamometry. Functional tests in addition to muscular strength also assess neuromuscular control, speed of muscle contraction, lower extremity power, joint function and joint range of motion [9,15].

We did not find any significant correlation between functional testing scores and knee isokinetic torque to body weight or IKDCSKEF score. Several studies have assessed the relationship between results of isokinetic tests and functional tests [9,15,16]. Some authors concluded that low correlations were evident between isokinetic testing and various functional tests [3, 7,12,26,29,31,38]. In contrast, several authors have concluded that positive correlation between isokinetic and functional test do exist [2,4–6,19,23,24,30,32,33, 35,36,39,40,43]. This study describes a moderate to strong correlations between the quadriceps side-to-side strength ratio and the LSI of functional tests with only a trend between hamstring side-to side strength ratio and function in ACLR patients. IKDCSKEF score also had a significant relationship with quadriceps side-to-side strength ratio.

Keays et al. reported similar relationship between side-to-side ratio of concentric torque and LSI of functional testing ($r = 0.655$ to 0.744 and $P < 0.00$) in 31 ACLR subjects [24]. They measured isokinetic torque in lower velocity (60 and 120°/Sec), sitting position and concentric mod. Our results indicate higher correlations between isokinetic torque and functional test indices (up to $r = 0.97$). This could be due to the test position, higher velocity (60 and 180°/Sec), and eccentric mode of contraction which seems to be more similar to real functional states and also recommended by others [8,14,23].

There was no significant correlation between Hecc/Qconc ratio and functional testing scores in ACLR or control subjects. Dvir et al. described this ratio for the first time and referred it as a ‘dynamic control ratio’ [13]. Gibson et al. found that despite the strength losses which are particularly evident in quadriceps muscle in chronic ACL deficient subjects the Hecc/Qcon

Table 2
Mean values (standard deviation) of knee isokinetic torque/body weight ratio (Newton meter/kilogram) and H/Q ratio of ACL-reconstructed patients (both in percent). P-value of T-test for bilateral comparison are presented (Q = quadriceps, H = hamstring, con = concentric and ecc = eccentric)

Variable	Speed	Reconstructed knee	Normal knee	T-test (P-value)
Qcon	60°/s	188.4% (45.4%)	244.1% (45.2%)	0.01
	180°/s	150.5% (46.4%)	196.5% (45%)	0.02
Qecc	60°/s	229.9% (71.7%)	303.1% (55.2%)	0.00
	180°/s	213.6% (74.4%)	292.5% (63.4%)	0.01
Hcon	60°/s	108.3% (25%)	112.7% (24.9%)	0.4
	180°/s	89.1% (22%)	88.1% (25.7%)	0.86
Hecc	60°/s	97.9% (33.9%)	103.7% (26.2%)	0.4
	180°/s	104.1% (27.6%)	97.8% (26.2%)	0.44
Hcon/Qcon	60°/s	59.4% (15.7%)	46.7% (9.5%)	0.02
	180°/s	61.8% (16.6%)	45.7% (11.2%)	0.04
Hecc/Qecc	60°/s	44.1% (14.1%)	34.4% (7.8%)	0.02
	180°/s	52.4% (18.3%)	33.9% (8.2%)	0.02
Hecc/Qcon	60°/s	52.8% (16.6%)	42.6% (9.3%)	0.051
	180°/s	72.6% (23.2%)	50.8% (11.7%)	0.048
Hcon/Qecc	60°/s	50.3% (16.2%)	37.7% (8.7%)	0.01
	180°/s	45% (15%)	30.5% (8.5%)	0.01

Table 3
Pearson correlation coefficient (significance level) between Limb Symmetry Index (LSI) of three functional tests with IKDCSKEF score and side-to-side ratio of quadriceps isokinetic torque (Q = quadriceps, con = concentric and ecc = eccentric)

		LSI of Vertical Jump	LSI of Cross-over Hop	LSI of Single Hop
IKDCSKEF Score	Patient	**0.70** (**0.02**)	**0.78** (**0.01**)	0.60 (0.07)
	Control	−0.01 (0.97)	0.25 (0.48)	0.18 (0.61)
Side-to-side ratio of	Patient	**0.66** (**0.03**)	**0.93** (**0.00**)	**0.85** (**0.00**)
Qconc 60 deg/sec	Control	0.52 (0.13)	0.53 (0.12)	0.21 (0.56)
Side-to-side ratio of	Patient	**0.72** (**0.01**)	**0.76** (**0.02**)	**0.54** (**0.09**)
Qecc 60 deg/sec	Control	−0.04 (0.92)	0.48 (0.16)	−0.06 (0.86)
Side-to-side ratio of	Patient	**0.60** (**0.049**)	**0.83** (**0.01**)	**0.64** (**0.03**)
Qconc 180 deg/sec	Control	0.75 (0.01)	0.28 (0.44)	0.14 (0.69)
Side-to-side ratio of	Patient	**0.72** (**0.01**)	**0.97** (**0.00**)	0.59 (0.07)
Qecc 180 deg/sec	Control	0.57 (0.09)	0.25 (0.49)	0.30 (0.40)

ratio was not changed [17]. They concluded from the findings that muscular co-ordination strategies may have been altered to maintain normal limb activity. However there was no significant correlation between Hecc/Qcon ratio and hop tests score or IKDCSKEF, so the present results do not support Gibson's hypothesis in ACLR subjects. Hamstring/quadriceps ratio itself is a rather crude parameter and the current isokinetic criterion is the side-to-side strength ratio [13]. The relationship between eccentric hamstring and concentric quadriceps strength is important, but as Coombs and Garbutt have argued "although the functional H/Q ratios account for the role of the antagonist in knee joint stabilization at specific joint angles, they do not account for the hamstring-quadriceps relationship throughout the entire ROM" [11]. It seems that analysis of the functional H/Q ratios over the entire ROM and study of the hamstring co-activation during knee extension by EMG may help to address functional joint stability in these patients.

Isokinetic testing should be used for testing lower extremity strength, while functional tests should be used to determine performance levels. Good relation between LSI of functional testing and side-to-side ratio of isokinetic dynamometry results show that each of these tools may be used for assessing ACLR subjects. However when an isokinetic dynamometer is not available LSI of functional tests can be used to evaluate quadriceps strength deficiency.

References

[1] E. Ageberg, Consequences after a ligament injury on neuromuscular function and relevance to rehabilitation using to anterior cruciate ligament, *J Electromyogr Kinesiol* **12** (2002), 205–212.

[2] M.S. Anderade, M. Cohen, I.C. Picarro and A.C. Silva, Knee performance after anterior cruciate ligament reconstruction, *Isokinetics and Exercise Science* **10** (2002), 81–86.
[3] M.A. Anderson, J.H. Gieck, D. Perrin, A. Weltman, R. Rutt and C. Denegar, The relationship among isometric, isotonic, and isokinetic concentric and eccentric quadriceps and hamstring force and three component of athletic performance, *JOSPT* **14**(3) (1991), 114–120.
[4] J. Augustsson and R. Thomee, Ability of closed and open kinetic chain tests of muscular strength to assess functional performance, *Scandinavian Journal of Medicine and Science in Sports* **10**(3) (2000), 164–168.
[5] S.D. Barber, F.R. Noyes, R.E. Mangine, J.W. McCloskey and W. Hartman, Quantitative assessment of functional limitations in normal and anterior cruciate ligament-deficient knees, *Clin Orthop Relat Res* **255** (1990), 204–214.
[6] S.D. Barber, F.R. Noyes, R. Mangine and M. DeMaio, Rehabilitation after ACL reconstruction: function testing, *Orthopedics* **15**(8) (1992), 969–974.
[7] J.R. Blackburn and M.C. Morrissey, Relationship between open and closed kinetic chain strength of the lower limb and jumping performance, *JOSPT* **27**(6) (1998), 430–435.
[8] L.E. Brown, *Isokinetics in Human Performance*, Human Kinetics, USA, 2000.
[9] J.J. Callaghan, A.G. Rosenberg, H.E. Rubash, P.T. Simonian and T.L. Wickewicz, *The Adult Knee*, Lippincott Williams & Wilkins, USA, 2003.
[10] C. Cardone, Z. Menegassi and R. Emygdio, Isokinetic assessment of muscle strength following anterior cruciate ligament reconstruction, *Isokinetics and Exercise Science* **12** (2004), 173–177.
[11] R. Coombs and G. Garbutt, Developments in the use of the hamstring/quadriceps ratio for the assessment of muscle balance, *Journal of Sports Science and Medicine* **1** (2002), 56–62.
[12] A. Delitto, J.J. Irrgang, C.D. Harner and F.H. Fu, Relationship of isokinetic quadriceps peak torque and work to one legged hop and vertical jump in ACL reconstructed subjects, *Phys Ther* **73**(6) (1993), S85.
[13] Z. Dvir, G. Eger, N. Halperin and A. Shklar, Thigh muscles activity and ACL insufficiency, *Clinical Biomechanics* **4** (1989), 87–91.
[14] Z. Dvir, *Isokinetics Muscle Testing, Interpretation and Clinical Applications*, (2nd ed.), Churchill Livingstone, 2004.
[15] T.S. Ellenbecker, *Knee Ligament Rehabilitation*, Churchill Livingstone, USA, 2000.
[16] G.K. Fitzgerald, S.M. Lephart, J.H. Hwang and M.R.S. Wainner, Hop tests as predictors of dynamic knee stability, *JSOPT* **31** (2001), 588–597.
[17] A.St.C. Gibson, M.I. Lambert, J.J. Durandt, N. Scales and T.D. Noakes, Quadriceps and hamstring peak torque ratio changes in person with chronic anterior cruciate ligament deficiency, *JOSPT* **30**(7) (2000), 418–427.
[18] A. Gokeler, T. Schmalz, E. Knopf, J. Freiwald and S. Blumentritt, The relationship between isokinetic quadriceps strength and laxity on gait analysis parameters in anterior cruciate ligament reconstructed knees, *Knee Surg Sports Traumatol Arthrosc* **11** (2003), 372–378.
[19] H.B. Greenberger and M.V. Paterno, Relationship of knee extensor strength and hopping test performance in the assessment of lower extremity function, *JOSPT* **22**(5) (1995), 202–206.
[20] T. Hess, J. Duchow, S. Roland and D. Kohn, Single- versus two-incision technique in anterior cruciate ligament replacement: Influence on postoperative muscle function, *American Journal of Sports Medicine* **30**(1) (2002), 27–31.
[21] J.J. Irrgang, A.F. Andersen, A.L. Boland, C.D. Harner, M. Kurosaka, P. Neyret, J.C. Richmond and D. Shelborne, Development and validation of the international knee documentation committee subjective knee form, *Am J Sports Med* **29**(5) (2001), 600–613.
[22] S. Jaric, Role of body size in the relation between muscle strength and movement performance, *Exerc Sport Sci Rev* **31** (2003), 8–12.
[23] T. Jarvela, P. Kannus, K. Latvala and M. Jarvinen, Simple measurement in assessing muscle performance after an anterior cruciate ligament reconstruction, *Int J Sports Med* **23** (2002), 196–201.
[24] S.L. Keays, J.E. Bullock-Saxton, P. Newcombe and A.C. Keays, The relationship between knee strength and functional stability befor and after anterior cruciate ligament reconstruction, *J Orth Res* **21** (2003), 231–237.
[25] Y. Konishi, T. Fukubayashi and D. Takeshita, Mechanism of quadriceps femoris muscle weakness in patients with anterior cruciate ligament reconstruction, *Scand J Med Sci Sports* **12** (2002), 371–375.
[26] J.E. Kovaleski, R.J. Heitman, D.P.S. Andrew, L.R. Gurchiek and A.W. Pearsall IV, Relationship between closed-linear-kinetic- and open-kinetic-chain isokinetic strength and lower extremity functional performance, *Journal of Sport Rehabilitation* **10**(3) (2001), 196–204.
[27] S.M. Lephart, M.S. Kocher, C.D. Harner and F.H. Fu, Quadriceps strength and functional capacity after anterior cruciate ligament reconstruction. Patellar tendon autograft versus allograft, *Am J Sports Med* **21**(5) (1993), 738–743.
[28] C.G. Mattacola, D.M. Perrin, B.M. Gansneder, J.H. Gieck, E.N. Saliba and F.C. McCue, Strength, functional outcome, and postural stability after anterior cruciate ligament reconstruction, *J Atheletic Training* **37** (2002), 262–268.
[29] F.R. Noyes, S.D. Barber and R.E. Mangine, Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture, *Am J Sports Med* **19**(5) (1991), 513–518.
[30] J. Nyland, D.N. Caborn, J. Rothbauer, Y. Kocabey and J. Couch, Two-year outcomes following ACL reconstruction with allograft tibialis anterior tendons: a retrospective study, *Knee Surg Sports Traumatol Arthrosc* **11**(4) (2003), 212–218.
[31] A. Ostenberg, E. Roos, C. Ekdahl and H. Roos, Isokinetic knee extensor strength and functional performance in healthy female soccer players, *Scandinavian Journal of Medicine and Science in Sports* **8** (1998), 257–264.
[32] R. Petschnig, R. Baron and M. Albrecht, The relationship between isokinetic quadriceps strength test and hop tests for distance and one-legged vertical jump test following anterior cruciate ligament reconstruction, *JOSPT* **28**(1) (1998), 23–31.
[33] D.M. Pincivero, S.M. Lephart and R.G. Karunakara, Relation between open and closed kinematic chain assessment of knee strength and functional performance, *Clin J Sport Med* **7**(1) (1997), 11–16.
[34] D.M. Pincivero, B.M. Heller and S.I. Hou, The effects of ACL injury on quadriceps and hamstring torque, work and power, *Journal of Sports Sciences* **20**(9) (2002), 689–696.
[35] M.D. Ross, J.J. Irrgang, C.R. Denegar, C.M. McCloy and E.T. Unangst, The relationship between participation restrictions and selected clinical measures following anterior cruciate ligament reconstruction, *Knee Surg Sports Traumatol Arthrosc* **10**(1) (2002), 10–19.

[36] Sachs, D.M. Daniel, M.L. Stone and R.F. Garfein, Patellofemural problems after anterior cruciate ligament reconstruction, *Am J Sports Med* **17** (1989), 760–765.
[37] K.D. Shelbourne and P. Nitz, Accelerated rehabilitation after anterior cruciate ligament reconstruction, *Am J Sports Med* **18** (1990), 292–299.
[38] M. Swarup, J.J. Irrgang and S. Lephart, Relationship of isokinetic quadriceps peak torque and work to one-legged hop and vertical jump, *Phys Ther* **88** (1992), S72.
[39] M. Tomioka, T.M. Owings and M.D. Grabiner, Lower extremity strength and coordination are independent contributors to maximum vertical jump height, *Journal of Applied Biomechanics* **17**(3) (2001), 181–187.
[40] A. Tsiokanos, E. Kellis, A. Jamurtas and S. Kellis, The relationship between jumping performance and isokinetic strength of hip and knee extensors and ankle plantar flexors, *Isokinetics and Exercise Science* **10** (2002), 107–115.
[41] Y. Urabe, M. Ochi and K. Onari, Changes in isokinetic muscle strength of the lower extremity in recreational athletes with anterior cruciate ligament reconstruction, *Journal of Sport Rehabilitation* **11**(4) (2002), 252–267.
[42] D. Urbach, W. Nebelung, R. Becker and F. Awiszus, Effect of reconstruction of the anterior cruciate ligament on the voluntary activation of quadriceps femoris, *J Bone Joint Surg[Br]* **83-B** (2001), 1104–1110.
[43] K.E. Wilk, W.T. Romaniello, S.M. Soscia, C.A. Arrigo and J.R. Andrews, The relationship between subjective knee score, isokinetic testing and functional testing in act-reconstructed knee, *JOSPT* **20** (1994), 60–73.