Strength does not influence knee function in the ACL-deficient knee but is a correlate of knee function in the and ACL-reconstructed knee

Erik Hohmann
FRCS, FRCS (Tr&Orth), MD, PhD
Musculoskeletal Research Unit, Central Queensland University, Rockhampton, Australia
Medical School, University of Queensland
Email: ehohmann@optusnet.com.au

Adam Bryant
PhD
Centre for Health, Exercise and Sports Medicine, Faculty of Medicine, The University of Melbourne, Australia
Email: albryant@unimelb.edu.au

Kevin Tetsworth
MD, FRACS
Department of Orthopaedic Surgery, Royal Brisbane Hospital, Herston, Australia
CONROD Professor of Orthopaedic Trauma Surgery, Division of Surgery, University of Queensland Medical School, Herston QLD 4029, Butterfield Street, Australia
Email: kevin_tetsworth@health.qld.gov.au

Corresponding Author:
Erik Hohmann
Musculoskeletal Research Unit, CQ University
PO Box 4045
Rockhampton QLD 4700
Australia
ehohmann@optusnet.com.au
Tel : +61 7 4920 6536

Abstract

Purpose

Knee function, whether anterior cruciate ligament (ACL)-deficient or ACL-reconstructed, is related to many conditions, and no single biomechanical variable can be used to definitively assess knee performance. The purpose of this study was to investigate the relationship between extension and flexion muscle strength and knee function in patients prior and following ACL reconstruction.

Methods:

44 ACL-deficient patients with a mean age of 26.6 years were tested between 3-6 months following an acute injury and 2 years following ACL reconstruction. All reconstructed patients underwent surgical reconstruction within six months of ACL injury using bone-patellar tendon and interference screws. The Cincinnati Knee Rating System was used to assess knee function. Muscle strength was assessed with the Biodex™ Dynamometer. Isokinetic concentric and eccentric flexion and extension peak torque (Nm/kg) was tested at three different speeds: 60 deg/sec, 120 deg/sec and 180 deg/sec. Isometric strength was tested in 30 and 60 degrees of knee flexion. Both the involved and non-involved legs were tested to calculate symmetry indices.

Results:

The mean Cincinnati score in the ACL-deficient patient was 62.0±14.5 (range 36-84) and increased to 89.3±9.5 (range 61-100) in the ACL-reconstructed patient. Significant relationships between knee function and muscle strength in the ACL-deficient group were observed for knee symmetry indices (r=0.38-0.50, p=0.0001-0.05). In the ACL-reconstructed group significant relationships between knee functionality were observed for isometric and isokinetic peak torque of the involved limb (r=0.46-0.71, p=0.0001-0.007).

Conclusion

The findings of this study suggest that neither extension nor flexion peak torque were correlates of knee function in the ACL-deficient knee. However, leg symmetry indices were correlated to knee function. In the ACL-reconstructed knee, knee symmetry indices were not related to knee function but extension and flexion isokinetic concentric and isometric peak torque were.

Key Words:

Anterior cruciate ligament deficient; muscle strength; knee functionality; anterior cruciate ligament reconstruction; bone patellar tendon

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INTRODUCTION

In those anterior cruciate ligament-deficient (ACLD) patients with higher levels of function it appears that compensatory adaptations initiated at a subconscious level act to limit the potential for excessive anterior tibial translation (ATT) that could occur in the absence of the ACL [3,35]. As the quadriceps and hamstring muscles apply counter-opposed forces to the tibia, it is acknowledged that these muscles may be recruited to stabilize the ACL-deficient knee during dynamic weight-bearing activities [33]. For example, neurophysiological responses that protect the integrity of the ACL-deficient knee can inhibit quadriceps activity and may also contribute to hamstring facilitation, thereby leading to negligible atrophy and weakness of the hamstrings relative to the quadriceps [34].

Surgical reconstruction of the ACL successfully restores long-term static stability of the knee in more than 90% of patients [24]. Despite these documented favourable outcomes, quadriceps and hamstring muscle strength deficits have been reported in the anterior cruciate ligament reconstructed (ACLR) knee by numerous authors [1,9,17,21] DeJong, et al. [9] demonstrated a quadriceps strength deficit of 20% one year following surgery. In fact, strength deficits as great as 10% persist seven to nine years after surgery [9,17].

The choice of graft appears to have an influence on strength recovery after surgery [1,2,20]. Keays et al. [20] followed 62 patients for six years after ACL reconstruction. In patients who received hamstring tendon grafts extension symmetry indices increased from 0.91 pre- to 1.02 and in patients who received bone-patella tendon graft increased from 0.86 pre- to 0.94 six years post-surgery. Flexion strength in the patella group decreased from 1.01 pre- to 0.98 post-surgery and decreased in the hamstring group from 0.99 pre- to 0.97 post-surgery.

Aglietti et al. [2] assessed 120 patients one year post ACL-reconstruction. He observed an extensor strength deficit of 10% in patients with patella tendon and 4% in patients with hamstring tendons.

Several authors [17,19,37] have reported that full restoration of muscle strength is associated with better outcomes, although other studies [11,20,27] have shown no correlation between quadriceps strength and outcomes. However the above studies either use non-validated measures or scores which do not primarily measure function; the results of these studies have therefore to be interpreted with caution.

The purpose of this study was, therefore, to investigate the relationship between muscle strength and knee functiony measured by the Cincinnati Knee Rating System in a cohort of ACL-deficient who underwent arthroscopic assisted ACL-reconstruction with bone-patella tendon. We hypothesized that the ACL-deficient subjects would rely on strength in the absence of static stability, and they would exhibit a relationship between muscle strength and knee function (H_1). We further hypothesized strength would be less important in ACL-reconstructed subjects, and they would not exhibit a relationship between muscle strength and knee functionality (H_2).

METHODS

Subjects:

Volunteers were recruited within four weeks of their acute injury if they met the inclusion criteria. Ethical clearance was obtained from both the Human Ethics Research Review Panel of the University and the Regional Health District. All participants were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

The following inclusion criteria were applied: isolated ACL injury; age between 18 and 50 years; surgical reconstruction between three and within six months of injury; and no history of surgery or trauma to the contra-lateral lower extremity. Subjects were excluded if there was evidence of injuries to the meniscus, medial and lateral collateral ligaments, posterior cruciate ligament, articular cartilage or ipsilateral lower extremity joints demonstrated by MR imaging; radiographic or arthroscopic evidence of bony avulsion of the anterior cruciate ligament from the tibial eminence; significant side to side differences in varus/valgus instability during the initial clinical examination and/or under anaesthesia; reported intra- and postoperative complications such as infection, stiffness, arthrofibrosis, recurrent trauma or hypertrophic scar formation resulting in limited range of movement; any additional operations following the initial procedure; and, patients who had combined procedures for realignment (such as high tibial osteotomies or distal femoral osteotomies) in combination with anterior cruciate ligament reconstruction.

Surgical Procedure and Rehabilitation

All patients underwent surgical reconstruction by a single fellowship trained experienced knee surgeon using an arthroscopic assisted ACL-reconstruction utilizing the central third of the patellar tendon and interference screws as described previously [14]. Post-operatively, the extremity was placed into a ROM brace for six weeks. Immediate weight-bearing as tolerated by the patient was instituted from day one post-surgery, and a previously described accelerated rehabilitation protocol was initiated for all patients [15].

Outcome measures

Cincinnati Scoring System

The Cincinnati Knee Rating System was employed as an independently validated outcome instrument; prior studies have demonstrated it is a sensitive tool to measure both subjective and objective knee function [4,6,13]. This outcome instrument is more specific and applicable to ACL injured patients, as it includes familiar and widely employed functional components. The Cincinnati Knee Rating System consists of 13 scales, and all 13 scales were used in this study [4]. Using the Cincinnati Knee Rating System criteria, the treating surgeon performed both the clinical examination and assessed the requisite radiographs.

The following scales were assessed by an independent examiner: subjective assessment, activity level, instability level using a KT 2000, and functional testing. The Cincinnati Knee Rating System incorporates three hopping tests (single-leg-hop, timed-hop for distance and vertical-jump) into the overall scoring to better qualify knee function. Functional testing was conducted at the University's Human Performance Laboratory on a cemented non-slip surface. Subjects were asked to perform each of the hopping tests until three valid attempts were recorded. Each testing session was conducted with the non-involved leg first, followed by the involved extremity, with results averaged over the three attempts.

An overall knee functional rating was calculated for all subjects, based on summing the points awarded for their symptoms, their ability to perform daily and sports activities, and single-leg functional testing. The score for each subject was summed and the overall total was then normalized to a score out of 100.

Muscle strength

Muscle strength was assessed using a Biodex™ Isokinetic Dynamometer (BIODEX™ , Shirley, New York). Isokinetic concentric and eccentric strength, for both the hamstring and quadriceps muscles, was tested at two different speeds: 120 deg/sec and 180 deg/sec. Isometric strength was tested in 30 and 60 degrees of knee flexion. Both the involved and non-involved leg was tested, and leg symmetry indices were calculated. Each subject performed one set of five maximal extension and flexion repetitions at the nominated speeds. Peak torque (Nm/kg) generated by both the quadriceps and hamstring muscles of the involved and non-involved limbs were corrected for bodyweight, and a mean calculated from the three best trials for each test speed and test mode. For isometric tests, the highest force generated (Nm/kg) during the two knee extension and flexion trials was recorded for subsequent analysis.

Testing protocol

ACL-deficient subjects were referred to a physiotherapist for treatment including anti-inflammatory measures, ROM exercises, maintenance of quadriceps strength and proprioceptive exercises. Subjects were tested at a minimum of three months following injury and only after the knee effusion had resolved, full range of motion returned, and good subjective quadriceps control was achieved. The ACL-reconstructed patients was tested at a mean time following ACLR surgery of 24.2 months (range 23-28). The testing session began with a standardized warm-up consisting of five minutes of cycling at a power output of 100W on a Monark™ Friction-Braked Cycle Ergometer. This was followed by the hopping tests as recommended by Barber, et al. [4], and then completion of the Cincinnati questionnaires and a clinical examination. The session was concluded with the assessment of muscle strength, with a five-minute break between isometric, isokinetic, and eccentric testing to avoid fatigue related errors.

Statistical Analysis

The study was powered to designed to provide the number of cases required to achieve a statistically significant (p=0.05, power 0.8) correlation of $r \geq 0.50$ between muscle strength and knee function as measured by the Cincinnati Score. The sample size calculation based on these parameters indicated that 32 patients per group were needed. Means and standard deviations were calculated for the dependent variables. Pearson's product moment correlation coefficients were used to establish the strength of the relationships between muscle strength and knee function. Critical r-values (two tailed) were calculated, and a level of significance of $p < 0.05$ was selected in all analyses. Peak torque differences between the involved and non-involved extremity were analyzed using a two-tailed paired student t-test. All analyses were conducted using Systat (version 13; Systat, Chicago, IL). The coefficient of correlation "r" was interpreted according to Cohen [8] in the following fashion: 0.0 – 0.3 weak, 0.31–0.5 moderate, >0.51 strong.

RESULTS

Forty-four ACL-deficient subjects with a mean age of 26.6 years were included. There were 33 males with a mean age of 26.4 (16-49) years, and 11 females with a mean age of 27 (17-38) years.

The mean Cincinnati score in the ACL-deficient subjects was 62.0±14.5 (range 36-84). The mean Cincinnati score in the ACL-reconstructed subject measured 89.3±9.5 (range 61-100). Tables 1 and 2 summarize the results of all muscle strength tests. Significant relationships between muscle strength and knee function in the ACL-deficient group were mainly observed for knee symmetry indices (Table 3). In the ACL-reconstructed group, significant relationships were observed between peak torque of the involved limb and knee function (Table 4).

DISCUSSION

The principal findings of this study were that peak torque values in the ACL-deficient knee are not a predictor of knee function. However, symmetry indices in ACL-deficient subjects are strongly correlated with knee function. Paradoxically, in the ACL-reconstructed knee this relationship reverses and symmetry indices are not related to knee function; instead, isokinetic concentric and isometric peak torque values are correlated with knee function.

Muscle weakness and its possible association with function in the ACL-deficient knee is well recognized in the literature [9,10,28,30,31,37,39]. DeJong, et al. [9] reported that in patients with leg symmetry indices (LSI) below 85, there was a direct correlation between those who performed poorly during functional tests and a weak quadriceps on isokinetic testing. This supports the findings of other authors, who have demonstrated that ACL-deficient patients cope best when they have no significant quadriceps deficit [31,34,40]. It is, therefore, not surprising that there is a demonstrable relationship between strength and functional hopping assessment. However, a recent study by Hurd, et al. [16] refutes such a relationship, and instead demonstrated quadriceps strength had no significant impact on dynamic knee stability or hop performance.

We note that our results corroborate the findings of Hurd, et al. [16]. Although absolute strength is not an indicator of function, leg symmetry indices are indeed correlated in the ACL-deficient knee. It appears that objective strength deficits in the involved limb do not significantly influence the subject's perception of knee function. We believe these findings in the ACL-deficient group are more likely related to factors such as neuromuscular control and neurocognitive function [12,18,36]. Arthrogenic inhibition of the involved and uninvolved limb, downregulation, and altered patterns of muscle activation may all act together to minimize anterior tibial translation during dynamic tasks [7,38].

In the ACL-reconstructed knee, a correlation between leg symmetry indices and functional outcome was no longer observed. The results of this study instead identified a significant relationship between knee function and both isometric and isokinetic muscle strength; no relationships was observed for eccentric strength. Surgical restoration of static stability would, therefore, appear to result in less reliance on reflex inhibition, and the emphasis in rehabilitation should then be to build muscle strength in order to return to the previous level of sporting activity. This assumption is already supported by several prior studies [25,26,29]. Muaidi, et al. [26] found knee rotation proprioception was reduced in ACL-deficient patients, and this deficit improved three to six months after surgical reconstruction. Mir, et al. [25] could find no evidence of impaired joint position sense when comparing subjects following ACL reconstruction to a healthy uninjured control group. Finally, Risberg, et al. [29] demonstrated a significantly improved Cincinnati score in patients who underwent a neuromuscular training program versus a traditional strength program after ACL reconstruction. Most activities of daily living and athletic activities include an element of eccentric muscle action, especially during loading of the extremity with the foot fixed on the ground. One possible explanation for the lack of correlation with eccentric muscle strength could be related to the focus of most rehabilitation programs on concentric strength during the first 12 month following surgery. Athletic activities normally require more eccentric contractions during dynamic tasks such as acceleration, deceleration and jump landings. However, most standard rehabilitation protocols only allow these activities twelve months after surgery, in order to protect the graft from excessive loading.

In both the ACL-deficient and ACL-reconstructed patients hamstring strength, surprisingly, was not an important correlate with knee function. Various authors have previously suggested it is important to strengthen the hamstrings, to potentially reduce anterior tibial translation and unload the ACL during rehabilitation [24,41]. Ageberg, et al. [1] observed lower hamstring to quadriceps strength ratios after ACL reconstruction using hamstring tendon grafts, and concluded it may have a negative effect on dynamic knee joint stability. Blackburn, et al. [5] suggested hamstring stiffness results in a more stable knee; they postulate the hamstrings ability to resist lengthening, rather than any force production, may contribute to knee stability. It could therefore be argued that muscle strength needs to reach a certain threshold for subjects to have the perception of a functional knee. Provided ACL-deficient patients have strength values exceeding this proposed threshold, a correlation between strength and function would not be observed.

It would appear that neuromuscular adaptations occur in order to have symmetrical lower extremities that act together and behave similarly. The more successful these adaptations are, the better knee function is perceived, and this perhaps explains the demonstrated relationship between symmetry indices and knee function. However, if the functional demands increase, the strength threshold must up regulate in order to cope with the increase in activity. As long as this threshold in strength is not achieved a correlation between knee function and strength values would be observed. This assumption is supported by the fact that, despite a documented muscle weakness of up to 20% following ACL reconstruction, subjective and objective functional deficits are not observed in many studies [9,17,19,33]. In these instances the strength values have almost certainly reached the necessary threshold, enabling the subjects to perform their desired activities with no further need to gain additional strength.

This study has limitations. We used strict inclusion and exclusion criteria to reduce the potential bias introduced by other intra-articular pathology. Fewer patients fulfill these criteria, and our results cannot be generalized to subjects who have additional meniscal or cartilage injuries. The smaller sample size also increases the chance of a type II error. However, an a-priori sample size determination and the calculation of the critical r-value was performed in order to minimize type II error. For this project surgical reconstruction was performed using bone-patellar tendon-bone grafts. It has been demonstrated that the choice of graft influences recovery of muscle strength, and the results may therefore be different with hamstring tendon grafts [19,32]. However, Lautamies, et al. [23] could not demonstrate a clinically significant functional difference between hamstring and patellar tendon grafts, despite reporting differences in the strength of the quadriceps and hamstring muscles.

Conclusion

The findings of this study suggest that neither extension nor flexion peak torque were correlates of knee function in the ACL-deficient knee. However, leg symmetry indices were correlated to knee function. In the ACL-reconstructed knee, knee symmetry indices were not related to knee function but extension and flexion isokinetic concentric and isometric peak torque were.

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Table 1: Results of all strength tests (in Newton) for the ACL-deficient group

	involved	non involved	symmetry index
isomet 30 ext	95.3+43.4 (15-206)	136.9+52.5 (55-207)	70.9.9+21.4 (22-100)
isomet 30 flex	71.5+30.1 (21-130)	100.7+32.3 (51-162)	71.4+19.9 (14-100)
isomet ext 60	142.7+68.2 (30-321)	206.8+80.6 (78-341)	70.3+21.5 (15-100)
isomet flex 60	66.2+31.8 (10-161)	89.9+30.9 (46-174)	73.4+22.1 (13-98)
isokin ext 60	139.4+77.4 (30-269)	228.5+78.7 (52-345)	61.7+25.7 (15-99)
isokin flex 60	60.6+36.9 (8-183)	87.2+35.3 (15-108)	68.5+26.3 (12-100)
isokin ext 120	125.8+65.4 (25-273)	191.5+58 (79-312)	65.4+25.7 (19-100)
isokin flex 120	60.6+31.2 (12-149)	87.2+32.9 (19-193)	68.5+26.9 (13-100)
isokin ext 180	112+54.6 (19-234)	167.4+51.1 (25-249)	66.9+24 (22-97)
isokin flex 180	56.6+33.5 (7-142)	82.2+37.5 (22-197)	65.6+23.8 (26-99)
ecc ext 60	154.2+62.9 (40-311)	201.4+50 (105-349)	74.7+19.1 (29-100)
ecc flex 60	92.7+47.4 (17-186)	134.8+47.5 (38-295)	67.4+25.1 (12-99)
ecc ext 120	159+63.1 (33-289)	209.8+57.5 (97-310)	73.5+19.9 (15-96)
ecc flex 120	93.7+43.3 (7-212)	136.2+45.6 (22-277)	68.3+21.8 (16-97)
ecc ext 180	157.8+58.9 (32-257)	208.9+57.5 (138-358)	75.5+19.4 (14-100)
ecc flex 180	93.2+39.2 (25-174)	137.1+41.2 (62-270)	68.8+23.3 (17-99)

*isomet: isometric; isokin: isokinetic concentric; ecc: isokinetic eccentric; ext: extension; flex: flexion

Table 2: Results of all strength tests (in Newton) for the ACL-reconstructed group

	involved	non involved	symmetry index
isomet 30 ext	117.2+60.1 (55-204)	146.9+60.9 (84-317)	78.5+13.7 (54-98)
isomet 30 flex	75.7+29.5 (40-148)	88.3+36.6 (51-196)	85.9+7.7 (77-97)
isomet ext 60	139.3+75.4 (64-361)	205.9+88.4 (119-488)	67.9+18.1 (43-94)
isomet flex 60	64.2+26.5 (33-140)	80.9+36.7 (49-180)	81+12.8 (61-100)
isokin ext 60	135.2+56.6 (61-259)	214.7+55.9 (125-286)	62.2+17.5 (42-98)
isokin flex 60	79+36 (17-136)	97.8+37.7 (44-152)	78.6+14.5 (52-100)
isokin ext 120	138.2+51.2 (67-216)	198.4+55.1 (110-274)	68.9+12.2 (51-87)
isokin flex 120	75.4+37.5 (21-135)	87.8+36.8 (20-145)	81.5+18 (30-100)
isokin ext 180	122.2+53 (35-202)	163.8+64.5 (51-246)	73.7+13.6 (52-96)
isokin flex 180	66.7+35.9 (11-124)	79.5+37.4 (12-135)_	81.4+12.8 (46-96)
ecc ext 60	144.2+52 (69-251)	175.6+52.5 (113-257)	81.5+14.1 (37-100)
ecc flex 60	100.2+42.1 (43-190)	125.8+55.9 (50-252)	81.3+9.5 (65-100)
ecc ext 120	145.9+48 (68-243)	167+51.2 (94-253)	86.7+9.4 (60-97)
ecc flex 120	124.9+41.4 (42-186)	124.9+57.2 (46-252)	77.1+14 (51-100)
ecc ext 180	154.5+50.6 (70-265)	175.4+51.6 (80-289)	87.9+12.1 (56-100)
ecc flex 180	99.2+37.5 (24-165)	122.6+47.3 (48-250)	81+14 (52-100)

*isomet: isometric; isokin: isokinetic concentric; ecc: isokinetic eccentric; ext: extension; flex: flexion

Table 3: Relationships between knee functionality and muscle strength for the ACL-deficient group

	involved		non involved		symmetry index	
	p	r	r	p	r	p
isomet 30 ext	0.35	ns	0.02	ns	***0.5***	***0.002***
isomet 30 flex	***0.33***	***0.03***	0.03	ns	***0.46***	***0.001***
isomet ext 60	0.21	ns	-0.004	ns	***0.43***	***0.009***
isomet flex 60	0.16	ns	0.07	ns	0.26	0.002
isokin ext 60	0.42	ns	0.11	ns	0.51	ns
isokin flex 60	0.19	ns	0.05	ns	0.26	ns
isokin ext 120	0.37	ns	0.09	ns	0.47	ns
isokin flex 120	***0.37***	***0.06***	0.19	0.003	***0.43***	***0.03***
isokin ext 180	0.45	ns	0.22	ns	***0.46***	***0.05***
isokin flex 180	0.3	ns	0.12	0.0004	0.43	ns
ecc ext 60	0.35	ns	0.07	ns	0.54	ns
ecc flex 60	0.21	ns	-0.01	ns	0.32	ns
ecc ext 120	0.38	ns	0.1	ns	***0.46***	***0.0001***
ecc flex 120	0.32	ns	0.15	ns	***0.31***	***0.03***
ecc ext 180	0.36	ns	0.12	ns	0.41	ns
ecc flex 180	0.28	ns	-0.06	ns	***0.38***	***0.04***

*significant relationships above the critical r-value of 0.304 are highlighted displayed in bold and italics

Table 4: Relationships between knee functionality and muscle strength for the ACL-reconstructed group

	ACL-reconstructed					
	involved		non involved		symmetry index	
	r	p	r	p	r	p
isomet 30 ext	***0.46***	***0.007***	0.33	ns	***0.66***	***0.02***
isomet 30 flex	*0.39*	*ns*	0.39	ns	-0.12	ns
isomet ext 60	***0.46***	***0.001***	0.3	ns	0.51	ns
isomet flex 60	***0.46***	***0.0005***	0.48	ns	-0.04	ns
isokin ext 60	***0.57***	***0.0001***	0.49	ns	0.47	ns
isokin flex 60	0.7	ns	0.65	ns	0.51	ns
isokin ext 120	***0.65***	***0.0003***	0.58	n	0.5	ns
isokin flex 120	0.76	ns	0.71	ns	0.62	ns
isokin ext 180	***0.71***	***0.005***	0.61	ns	0.4	0.0002
isokin flex 180	***0.71***	***0.005***	0.72	ns	0.4	ns
ecc ext 60	0.25	ns	0.28	ns	0.11	ns
ecc flex 60	0.37	ns	0.28	0.0009	0.25	0.05
ecc ext 120	0.38	ns	0.29	ns	0.36	ns
ecc flex 120	0.39	ns	0.36	0.001	0.29	0.02
ecc ext 180	0.5	ns	0.41	ns	0.35	ns
ecc flex 180	0.54	ns	0.24	0.0005	0.45	ns

*significant relationships above the critical r-value of 0.404 are highlighted displayed in bold and italics