Eccentric and concentric isokinetic moment characteristics in the quadriceps and hamstrings of the chronic isolated posterior cruciate ligament injured knee

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Abstract

Objective—Functional strength deficits associated with chronic isolated posterior cruciate ligament (PCL) insufficiency have received limited attention in the literature. The purpose of this study was to determine the eccentric and concentric isokinetic moment characteristics of the quadriceps and hamstrings in a sample of patients with isolated PCL injury.

Methods—Eccentric and concentric mean average and average peak moments were measured for 17 patients with a history of conservatively treated isolated PCL injury using an isokinetic dynamometer. Quadriceps and hamstring isokinetic moments were recorded from 10° to 90° of knee flexion. Strength ratios were calculated and compared with those reported in the literature for healthy subjects.

Results—The hamstrings of the involved side (eccentric/concentric (E/C) ratio = 1.06) were significantly weaker ($p < 0.05$) eccentrically than those of the contralateral side (E/C ratio = 1.29). All hamstrings/quadriceps (H/Q) ratios were less than the universally accepted value of 0.60 and the eccentric H/Q ratio for the injured extremity was significantly lower than the non-injured ($p < 0.05$). In a bilateral comparison, the injured/non-injured (I/N) ratio was less than 1.00 for concentric quadriceps, eccentric quadriceps, and hamstring isokinetic moments. Calculation of the E/C ratio showed that, for the quadriceps, it was 1.08 on the injured side and 1.07 on the non-injured extremity.

Conclusions—Eccentric strengthening should be an integral part of functionally rehabilitating the quadriceps and hamstrings of athletes who suffer from the complications associated with chronic isolated PCL insufficiency.

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Keywords: posterior cruciate ligament; eccentric muscle action; concentric muscle contraction; strength ratios; quadriceps; hamstrings

Knowledge of the functional strength deficits in the chronic isolated posterior cruciate ligament (PCL) deficient athlete is essential to the appropriate prescription of a rehabilitation programme. The literature has reported on quadriceps concentric strength and, more

recently, on the eccentric/concentric (E/C) ratio present in the quadriceps of both PCL injured and healthy subjects. Healthy subjects are specifically those who have no prior history of any knee ligamentous, meniscal, or associated muscle injury. However, no study has investigated both hamstring and quadriceps muscle moments in the athlete with isolated PCL injury. No data are currently available on E/C or hamstring/quadriceps (H/Q) ratios in the injured and non-injured extremities of this group of patients.

Although literature reports of muscular strength ratios are limited, it appears that healthy subjects exhibit an E/C ratio of 1.25-1.30 in the quadriceps and 1.25-1.35 in the hamstrings.¹ Further research will help to clarify whether these healthy strength ratios are reasonable goals of rehabilitation. Also, it has yet to be reported whether there are strength ratios that are too high and that may subject the knee to potential injury. This, too, must be considered when designing an eccentric exercise protocol.

In the past, the emphasis of conservative treatment and rehabilitation of isolated PCL injury has been on diligent concentric and eccentric quadriceps strengthening. The aim of this programme is to strengthen the quadriceps sufficiently to compensate for the posterior sag that exists secondary to the deficient or absent PCL.

Emphasis has been placed on the quadriceps femoris muscle group because of the synergistic relation it shares with the PCL in maintaining anteroposterior knee stability. Today, trends in knee rehabilitation protocol tend to favour a functional approach that aims at improving total lower extremity kinematics, rather than the knee in isolation. A functional weight bearing mode of therapeutic exercise also facilitates the conditioning of the soleus/gastrocnemius complex which Tibone *et al*² have rendered important as secondary compensatory stabilisers of the PCL deficient knee.

The purpose of this investigation was to identify the eccentric and concentric strength deficits present in a sample of athletes with chronic isolated PCL injury. Once the strength deficits have been established, a subsequent study³ will be conducted to test kinetic chain exercise as a functional means of improving lower extremity kinematics following isolated PCL injury.

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Materials and methods

Seventeen conservatively treated isolated PCL injured male athletes between the ages of 18 and 35 years were included in the study. Conservative treatment at the acute stage of injury included physical therapy, closed kinetic chain eccentric quadriceps strengthening, and, in some cases, a functional knee brace. Inclusion in this study was based on a thorough review of each subject's history, mechanism of injury, and diagnosis. Diagnosis was made clinically and confirmed by the presence of a positive posterior sag and posterior drawer test. All participants had sustained the injury at least six months previously during a variety of athletic endeavours and had received primary care at the Allan McGavin Sports Medicine Centre.

The Kinetic Communicator (KinCom; Med Ex Diagnostics, Coquitlam, British Columbia, Canada) is the isokinetic dynamometer that was used to collect mean average and average peak isokinetic moments. Eccentric and concentric isokinetic measurements were collected for quadriceps and hamstrings between 10° and 90° of knee flexion. Four continuous maximal effort repetitions were executed for each test at a constant velocity of 50°/s.

Before each testing session, each patient was provided ample time for a five minute stair climbing warm up and to stretch the involved musculature. Each patient executed five equal intensity submaximal effort practice repetitions to familiarise himself with the resistance that the isokinetic dynamometer provides. After the warm up and each practice trial, the subject was asked to perform four continuous maximal effort repetitions for each of the four muscle group tests: injured and non-injured extremity quadriceps, injured and non-injured side hamstrings.

During each practice and testing session, the subject was seated, with the pelvis and exercising thigh securely strapped to the bench. The mechanical axis of rotation was aligned with the lateral femoral condyle, and the load cell was positioned distally at three quarters the length of the fibula. All isokinetic measurements were gravity corrected as described in the isokinetic dynamometer operations manual. Mean average and average peak isokinetic moments were recorded and stored on computer disc.

The data were collected and organised so that three strength relations could be analysed: (a) eccentric/concentric between ipsilateral quadriceps and hamstrings; (b) injured/non-injured between contralateral quadriceps and hamstrings in eccentric and modes; (c) ipsilateral hamstring/quadriceps ratios in eccentric and concentric modes. One-tailed dependent t tests were used to determine significant discrepancies in strength (moment). Alpha was set at 0.05 for all statistical analysis.

Results

Average peak and mean average moment values were calculated and arranged in three strength ratios: (a) E/C; (b) H/Q; (c) injured/non-injured side (I/N) (tables 1 and 2). Calculated ratios were then compared with those in

Table 1 Average peak and mean average isokinetic torque

Extremity/muscle group/muscle action	Average peak torque (N.m)	Mean average torque (N.m)
IQE	182.2 (78.8)	152.7 (63.7)
IHE	89.2 (33.0)	74.4 (26.4)
NQE	186.2 (74.9)	156.5 (61.7)
NHE	103.9 (40.9)	89.4 (35.5)
IQC	168.9 (72.3)	137.7 (35.5)
IHC	84.0 (32.9)	69.0 (26.2)
NQC	174.2 (63.4)	142.1 (47.7)
NHC	80.6 (31.8)	67.6 (25.2)

Results are expressed as mean (SD). I, injured; N, non-injured; Q, quadriceps; H, hamstrings; E, eccentric; C, concentric.

Table 2 Isokinetic strength ratios. Average peak isokinetic torque

Extremity/ muscle action and/or muscle group	Strength ratio	Significance
IQ E/C	1.08	NS
NQ E/C	1.07	
IH E/C	1.06	
NH E/C	1.29	p<0.05
IE H/Q	0.47	
NE H/Q	0.56	
IC H/Q	0.5	NS
NC H/Q	0.46	
QE I/N	0.98	
QC I/N	0.97	NS
HE I/N	0.86	
HC I/N	1.04	p<0.05

I, injured; N, non-injured; Q, quadriceps; H, hamstrings; E, eccentric; C, concentric.

the literature reported for healthy subjects. There was no significant difference between the calculated E/C ratio for the injured (1.08) and non-injured extremities (1.07). These findings are quite different from those reported in the literature for healthy uninjured knees.⁴

The H/Q ratio has received the greatest attention in the literature. Results from this investigation indicate that all H/Q ratios for eccentric and concentric moments were less than the 0.60 level reported as being "universally accepted" by the rehabilitation community.⁵ The non-injured extremity exhibited a significantly lower eccentric H/Q ratio than the injured extremity (p<0.05). Concentrically, there were no significant differences between extremities (table 2).

In a bilateral comparison of specific types of muscle group action, the injured extremity was weaker in all modalities except hamstring concentric strength; all I/N ratios were less than 1.00 (table 2). The injured side significantly differed from the contralateral side in eccentric hamstring strength (p<0.05) (table 2). When mean average moment was examined, the outcomes were very similar to those calculated using average peak moments (table 1).

Discussion

Isolated PCL injuries occur much less often than other knee ligamentous and meniscal damage.⁶ There has been little documentation in the literature on specific isokinetic strength characteristics in subjects with chronic isolated PCL insufficiency or on how best to manage this group with a therapeutic exercise programme. It has been widely recommended that isolated PCL injury be treated with aggressive physiotherapy. However, the question that still

remains is what mode of exercise will best rehabilitate this patient population.

The quadriceps femoris muscle group has received most of the attention in PCL rehabilitation.^{6,7} Its synergistic relation to the PCL in maintaining anteroposterior knee stability has made it the centre of interest and the focus of PCL rehabilitation.⁶⁻¹⁰ The aim of rehabilitation has been to strengthen the quadriceps sufficiently so that the extensor mechanism is better able to compensate for the incompetent PCL and the additional stress placed on the patellofemoral joint.^{6,7} This protocol has primarily involved only isometric and concentric quadriceps muscle action.

However, if knee function is considered as a complex synergistic balance of osseous, soft tissue, and musculotendinous variables, the approach to knee rehabilitation must be holistic. Baratta *et al*⁸ and Solomonow *et al*^{9,10} have reported extensively on the importance of muscular co-activation and its relevance to knee ligament rehabilitation. They report on the submaximal contraction of the antagonist during active knee extension/flexion and stress the importance of including both the hamstrings and quadriceps in a knee rehabilitation programme regardless of the specific ligament injured.

This study examined both muscle groups because functionally they work eccentrically and concentrically in a synchronous manner. It was important to determine both eccentric and concentric moment values for these muscle groups, which act as primary stabilisers of the knee.

As a topic of sport medicine research, the importance and relevance of strength ratios is still in its infancy. Very little has been reported on healthy knee mechanics, let alone isolated PCL injury. Shirakura *et al*⁴ reported on a group of PCL injured and non-injured healthy subjects. They reported a quadriceps E/C ratio of 1.29 in the non-injured extremity of the PCL injured patients and 1.30 in the control group with healthy knees. Griffin *et al*¹ and others¹¹ have reported that the eccentric moments are significantly greater than the concentric torque in both quadriceps and hamstrings. These investigators all used the KinCom and similar testing parameters to those in this study.

The present investigation found a quadriceps E/C ratio of 1.08 in the injured extremity and 1.07 on the contralateral side. This suggests that, in comparison with the subjects studied by Shirakura *et al*,⁴ the present subjects were weak eccentrically in the quadriceps of both extremities. Furthermore, Griffin *et al*¹ and others¹¹ have reported that the eccentric moment was significantly greater than concentric moment for both quadriceps and hamstrings at all isokinetic velocities. In contrast, our subjects did not differ significantly, with quadriceps eccentric moment greater than concentric moment.

Why then do we see eccentric weakness in the quadriceps of the injured and non-injured extremities? The answer can only be speculative but perhaps bipedal deceleratory activity is

avoided after injury resulting in diminished eccentric strength in the musculature involved. Many subjects described a reluctance to perform such activities as stair descent, sudden changes in direction, and jumping. Chronic instability secondary to PCL laxity may affect confidence to do such tasks and therefore lead to a bilateral eccentric strength deficiency.

There have been no previous reports on the E/C ratio in the hamstring muscle group of patients with isolated PCL injury. This study showed an E/C ratio of 1.29 in the hamstrings on the non-injured extremity. In comparison, the E/C ratio for the hamstrings on the injured side was significantly less at 1.06 ($p < 0.05$).

The H/Q ratio has received the greatest amount of attention in the literature. Ghena *et al*⁵ reported that an H/Q ratio of 0.60 or greater has been universally accepted in the rehabilitation community. A major concern with an H/Q ratio less than 0.60 has been that this imbalance may increase the potential for eventual anterior cruciate ligament injury. Ghena *et al*⁵ reported an eccentric H/Q ratio of 0.646 and concentric H/Q ratio of 0.553 in healthy subjects. These values were recorded at a constant velocity of 60°/s. All of our eccentric and concentric H/Q ratios were recorded at 50°/s and were less than the 0.60 level. A comparison of injured and non-injured sides showed that there was a significant difference between eccentric H/Q ratios ($p < 0.05$).

Several investigators¹²⁻¹⁵ have reported significant concentric weakness when comparing injured with non-injured side quadriceps in PCL injured patients. Keller *et al*¹⁶ reported that there was no quadriceps weakness in their patient sample. Our results are very similar to those reported by Keller *et al*.¹⁶ Tegner *et al*^{14,17} and Parolie *et al*¹⁸ have suggested that it should be the goal of rehabilitation to attain and maintain an I/N ratio greater than 1.00. The aim is to strengthen the quadriceps sufficiently to compensate for the incompetent PCL and subsequent anteroposterior instability. When hamstring muscle groups were compared, the injured side was found to be significantly weaker eccentrically than the contralateral side ($p < 0.05$).

We found eccentric strength deficiency in the quadriceps of both extremities and the hamstrings of the injured extremity. Most of our sample informally described difficulty with stair descent, activities involving sudden changes in direction, and squatting. These all involve deceleration and eccentric muscle action. On the basis of our findings, we conclude that eccentric strengthening should be incorporated into quadriceps and hamstring conditioning programmes designed to manage chronic isolated PCL insufficiency.

In the past, knee rehabilitation has focused on exercising the knee in isolation with open kinetic chain exercise. Current trends in knee rehabilitation seem to favour a functional approach that aims to improve lower extremity kinematics rather than the knee in isolation.

This study shows strength discrepancies present in a sample of athletes with chronic isolated PCL insufficiency. It has led to a sub-

sequent investigation that confirms these strength deficiencies and tests closed kinetic exercise as a functional means of managing chronic isolated PCL insufficiency.

CONCLUSIONS

From this investigation we conclude the following: (a) This sample of patients suffering from chronic isolated PCL insufficiency exhibit eccentric weakness of the hamstrings of the injured side compared with the non-injured side. (b) Eccentric and concentric H/Q ratios for both extremities were less than the 0.60 level described by Ghena *et al.*⁵ A significant difference was present in the eccentric H/Q ratio between injured and non-injured extremities ($p < 0.05$). (c) In a bilateral comparison, the eccentric and concentric quadriceps I/N ratios were less than 1.00. The hamstrings on the injured side were significantly weaker in eccentric strength than those on the non-injured side. (d) Although somewhat inconclusive, we believe that the quadriceps E/C ratios found in this study are insufficient when compared with those reported in the literature as healthy. Further research is warranted to determine whether quadriceps eccentric weakness is associated with symptomatic chronic isolated PCL injury. A subsequent study³ has confirmed this speculation and helps to explain the symptomatic complaints in this patient sample and how they may best be managed with eccentric kinetic chain exercise.

Contributors: C L M conducted this research as part of a Master of Science (Human Kinetics) degree program, at the University of British Columbia. He was involved in formulating the primary research hypothesis, discussion core ideas, study design, patient file review and recruitment, data collection, conducted the data analysis, wrote the current paper, and has presented this research at the Canadian Academy of Sports Medicine. Through the School of Human Kinetics and the Allan McGavin Sports Medicine Centre, C L M worked with J E T (Graduate Committee Chair), D B C, and W R. J E T was involved in overseeing the entire study and advised the primary author (C L M) on all aspects of the research. D B C and W R were involved in discussing core ideas, proofreading, and helping to edit the manuscript before submission. C L M wrote the

manuscript and carried out all revisions. Other contributors include Dr Donna MacIntyre and Mr Jim Govett, who helped in KinCom training, Mr Alex McKechnie and Mr Richard Healy for direct input by discussing core ideas relevant to the rehabilitation of the cruciate deficient knee.

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Take home message

Patients who suffer isolated PCL injury often return in the chronic stage reporting anterior knee pain and episodes of instability, giving way, and difficulty with stair descent and sudden changes in direction. In the past, rehabilitation in the acute stage has primarily focused on quadriceps rehabilitation with concentric exercise. In order to develop a kinetic chain exercise programme for functional rehabilitation of the knee, the strength deficits present must first be identified and all musculature that surrounds the knee considered. Quadriceps and hamstring eccentric weakness may be present in patients suffering chronic isolated PCL insufficiency.