# ECCENTRIC KINETIC CHAIN EXERCISE AS A CONSERVATIVE MEANS OF FUNCTIONALLY REHABILITATING CHRONIC ISOLATED POSTERIOR CRUCIATE LIGAMENT INSUFFICIENCY

by

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## Abstract

Chronic, isolated posterior cruciate ligament (PCL) insufficiency can present several complications including patellofemoral pain, difficulty with stair descent and sudden changes in direction. The purpose of the present study was to develop a home, eccentric kinetic chain exercise program that improves strength, function and symptomatology.

Thirteen, isolated posterior cruciate ligament (PCL) injured subjects and thirteen, healthy sedentary individuals were included in the study. The PCL group underwent 12 weeks of prescribed eccentric squat exercise. The healthy, sedentary group did not undergo exercise intervention. Both groups executed the Tegner Hop Test, Lysholm Knee Scale Score and Kinetic Communicator isokinetic testing. All tests were administered at 0, 6, and 12 weeks of the investigation. Four relationships were explored to analyze the effectiveness of the eccentric rehabilitation program and to define significant differences ($p < 0.05$) between healthy and PCL-injured subjects.

Subject X Treatment data analysis clearly indicated that there were significant increases in eccentric quadricep and hamstring torque over the twelve week period. Tegner Hop Test and Lysholm Knee Scale scores also increased significantly following the eccentric squat program. Quadricep, eccentric/concentric ratios (@ 60 & 120 degrees per second) increased significantly after twelve weeks of rehabilitation. Significant strength differences did not exist between either extremity in the PCL group at any time throughout the course of this study.

Prior to rehabilitation, there were no significant differences between eccentric and concentric torque values in the quadriceps, or hamstrings, of the PCL-injured group.

Following the eccentric squat program, the injured extremity, quadriceps did exhibit a significantly greater eccentric torque than concentric torque.

The PCL group was significantly weaker than the control group in quadriceps, eccentric torque (@60 & 120 degrees per second), at week 0. The 12-week program resulted in there being no significant differences between PCL and control groups in eccentric, quadriceps torque.

The results of this investigation strongly support the eccentric squat program as a viable means of functionally rehabilitating chronic PCL-insufficiency with eccentric kinetic chain exercise.

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# Chapter 1

## Introduction

As a major topic of sport orthopaedic research, the posterior cruciate ligament (PCL) has long stood in the "shadow" of its partner ligament, the anterior cruciate (ACL). The sport medicine community has focused on the ACL because of its frequent injury and many post-injury complications. However, the PCL is now regarded as a primary "static" stabilizer of the knee and its reported injury has increased. Better diagnostic testing and equipment have indicated that the ligament injury occurs more often than previously thought.

In order to clinically manage PCL-insufficiency, conservative treatment must aim at strengthening the musculature that surrounds, and acts upon, the knee joint. A pilot study has revealed the presence of eccentric weakness in the hamstrings and quadriceps of a group of "isolated" PCL-injured patients. Eccentric muscle action plays a vital role in those activities that require jumping, deceleration and/or any sudden changes in direction. Therefore, eccentric, thigh muscle strengthening should be a major component of any prescribed knee rehabilitation.

Because the quadriceps share a synergistic relationship with the PCL in maintaining anteroposterior (A-P) knee stability, their reconditioning following PCL injury is essential. However, the hamstring muscle group should not be overlooked because of their essential role as antagonist regulators of posteroanterior (P-A) translation of the tibia on the femur. Neglecting their conditioning, may predispose an athlete to ACL-injury.

Both muscle groups need to be employed in a rehabilitation program following "isolated" PCL-injury. The literature has advocated kinetic chain exercise as an optimal means of functionally rehabilitating the cruciate-deficient knee. Kinetic chain exercise reconditions the entire lower extremity kinetic chain rather than the knee in isolation. Also, posterior knee shear is limited, compressive forces on the articular cartilage are evenly distributed, and muscular coactivation of the antagonist muscle group is utilized during active knee extension/flexion.

The current study will help further identify strength deficits in the "isolated" PCL-injured patient. Also, a modified "eccentric squat" exercise protocol has been tested as an effective means of functionally restoring lower extremity kinematics.

**Purpose of the Investigation**

Based on the information provided by the literature, it was the purpose of the current study to develop a home, kinetic chain exercise program that concentrates on improving eccentric and concentric strength in the hamstring and quadricep muscle groups.

It is also the objective of the current study to test kinetic chain exercise as a means of improving the PCL-deficient knee functionally, isokinetically and subjectively. The goal of the exercise program will be to correct the strength imbalances so that torque ratios resemble those of a healthy knee.

Lastly, the study includes a "control" group of sedentary individuals so that the strength deficits found in the pilot study can be reconfirmed as being specific to the isolated PCL-injury.

## Significance of the Study

In the literature and clinical setting, there is a lack of raw data on, and recommendation for, "isolated" PCL-injury management. This study will reveal new information on the strength attributes of a sample of "isolated" PCL-injured patients and provide an innovative means of rehabilitation.

An objective of the current study is to develop a home exercise program that is both simple in nature and that requires little-to-no equipment. Patients need a home treatment protocol that can be continued after supervised physiotherapy sessions have been completed. Hopefully, the eccentric squat rehabilitation program will be feasible to the patient while producing a favorable functional result.

In the past, many authors have advocated the use of aggressive thigh muscle physiotherapy as a means of conservatively treating PCL-insuffiency. However, an effective method of rehabilitating the PCL-deficient knee with an emphasis on quadricep, eccentric muscle action has not yet been reported.

## Statement of the Problem

To determine if a kinetic chain (closed kinetic chain), home exercise program will significantly improve the PCL-deficient athlete functionally, subjectively and isokinetically. Also, to establish how a group of "isolated" PCL-injured subjects differ from a "healthy" control group prior to, and following, a kinetic chain exercise program.

## Delimitations

(1) Sample selection; male subjects between 18 to 35 years of age, a group of "isolated" PCL injured athletes (n=13) and a group of sedentary, healthy subjects (n=13).

(2) Using the Kinetic Communicator Testing device which tests an individual through a certain range of motion, isokinetically, while performing isolated knee extension/flexion.

(3) The use of the functional, Tegner Hop Test which is a controlled, predesigned one-legged hop test.

(4) The prescribed rehabilitation programme consisting of an exercise protocol designed for thirteen, individual PCL-injured subjects.

(5) The use of the Lysholm Knee Scoring Scale that records the patients perceived knee function and symptomatology.

## Limitations

(1) Inorder to ensure sample homogeneity, inclusion in the study must be limited to very specific criteria. However, this restricts what can be inferred about patients in other places who are female and different ages.

(2) Selecting a particular velocity and range of motion to examine the PCL-deficient knee limits what can be said about the knee as it functions in nature. Also, the execution of isolated knee extension/flexion rarely occurs in sport or activities of daily living.

(3) The functional, Tegner Hop Test is a controlled and elementary means of testing dynamic knee function. Because the test requires only basic kinematics over a predetermined course, it limits what can be inferred about how the knee will perform in sport.

(4) The proposed exercise program has been limited to one kinetic chain exercise. Each patient will start, and finish, at the same point of the programme and will follow the same progression. This characteristic limits how appropriate the treatment is for each patient. Each patient is an individual and their strengths and needs will differ.

(5) The use of the Lysholm Knee Scoring Scale provides valuable qualitative information regarding changes in perceived knee function and symptomatology. However, subjective information varies, considerably, and has been shown to not always correlate with dynamic knee function.

**Definition of Terms**

"isolated" PCL-injury: a partial, or complete rupture, of the posterior cruciate ligament that is not related to any other associated ligamentous, meniscal, and/or capsular damage.

eccentric muscle action: occurs when the muscle-tendon unit lengthens in the face of stress, producing so called negative work (34). Eccentric muscle action provides the muscle with its shock absorbancy, deceleration and "spring" characteristics.

concentric contraction: occurs when the muscle-tendon unit shortens in length resulting in positive work (34).

conservative treatment: treatment or injury management that does not involve surgery or invasive measures.

kinetic chain exercise ("closed kinetic chain"): exercise that involves having the peripheral joint (foot or hand) fixed to the primary source of resistance, i.e. leg press or squat (29).

isolated joint exercise ("open" kinetic chain): exercise that involves having the peripheral joint free, and the resistance is applied to another point along the kinetic chain, i.e. seated leg extension (29).

eccentric/concentric ratio: the quotient of a particular muscle group's eccentric, average peak torque divided by the concentric, average peak torque (31).

injured/noninjured ratio: the relative quotient between injured and noninjured extremities when comparing a particular muscle group and average peak torque.

hamstring/quadricep ratio: the relative quotient between the hamstrings and quadriceps of the same extremtity.

**Hypotheses**

It is hypothesized that the proposed kinetic chain, rehabilitation program will render the following results:

(1) Isokinetic eccentric torque will significantly increase in the quadriceps of both extremities, following the 12-week training regimen.

(2) The eccentric/concentric (E/C) ratio will increase, significantly.

(3) The injured/noninjured (N/I) ratio will equal, or exceed, 1.00.

(4) The hamstring/quadricep (H/Q) ratio will reach the level of 0.60, where it is considered "healthy".

(5) Tegner Hop Test scores will increase, significantly, following the 12-week eccentric squat program.

(6) Lysholm Knee Scale scores will improve, significantly.

It can also hypothesized that the proposed testing devices will establish that:

(1) Prior to training, the muscles of the injured and noninjured extremities of the isolated PCL-injured group will be significantly weaker than the corresponding extremities of the control group.

(2) Significant differences in muscle torque will not exist between PCL and control groups, following the 12-week exercise program.

# Chapter 2

# Review of Literature

## Anatomy, Function and Biomechanics

The posterior cruciate ligament (PCL) has been so named because of its distal insertion into the posterior tibia . Its semilunar origin is located on the lateral surface of the medial femoral condyle. From here, it courses inferiorly, posteriorly, and laterally to insert into the posterior capsule and tibial periostium (2,9,52,).

Several authors have suggested that the PCL is the strongest ligament of the knee (20,21,26). From its femoral to tibial attachment, the PCL averages 38mm in length and 13mm in width (2,4,14,17). Studies have indicated that the PCL consists of two portions; an anterolateral and posteromedial band that become taut at different degrees of knee flexion (2,9,14,26,52). Van Dommelen and Fowler (52) explained that the anterolateral band makes up the "bulk" of the ligament and that these fibers become taut as the knee enters full knee flexion. Conversely, the thin posteromedial band becomes taut in knee extension (52). Kannus et al. (26) describe the PCL as being a continuum of fascicles of which different portions become taut through the knee's full range of motion. Understanding the tension of the PCL at different points of knee flexion/extension will help to explain why certain mechanisms illicit injury.

A comprehensive review of PCL anatomy should include two other closely related ligaments; the anterior and posterior meniscofemoral ligaments. Although they are not always present, it is estimated that 70% of all knees have either one or the other (16,26).

The anterior meniscofemoral ligament is named the Ligament of Humphrey and courses from the PCL femoral origin to the posterior horn of the lateral meniscus (2,9,14,26,52). It is believed to be no thicker than one-third the diameter of the PCL (26). The ligament of Humphrey passes anterior to the PCL and is estimated as being present in 36% of all knees (16).

The thicker of the two meniscofemoral ligaments is the posterior, Ligament of Wrisberg (2,14,26,52). Kannus et al. (26) reported that this ligament can be up to half of the PCL diameter and that it is present in 35% of all knees. The ligament of Wrisberg courses posteriorly, in relation to the PCL, from the femoral attachment of the PCL to its distal insertion onto the posterolateral aspect of the lateral meniscus (2,14,26,52).

Many investigators have commented on the function of the PCL and believe that it represents 90-95% of the total anteroposterior restraint against posterior translation of the tibia on the femur of a flexed knee (2,6,9,14,26,52). It also functions, synergistically, with the anterior cruciate ligament to provide restraint against varus and valgus stress, as well as, external rotation (2,6,9,52). Furthermore, the PCL contributes to the "screwhome" mechanism of the knee by ensuring that the femoral condyles are appropriately fixed on the tibial plateau as the knee approaches extension (26,52).

The posterior cruciate ligament is said to be "intrasynovial" but "extraarticular" (2,9,26,52). This means that the ligament is enveloped in synovium but that it actually, in an anatomical sense, lies outside of the joint. It is through the synovial sheath that the PCL receives its vascular and nervous supply (2,26,52).

Arnoczky and Warren (2) best describe the vascular supply to the posterior cruciate ligament. The primary arterial contribution comes from the ligamentous branches of the middle genicular artery and, the medial and lateral branches of the inferior genicular artery (2). All three arteries are branches of the common popliteal artery. The arteries gain access to the ligament by passing through posterior capsule. Within the synovial sheath, the arteries form a network of periligamentous vessels (2). Connecting branches from the periligamentous vessels anastomose with a series of endoligamentous arteries that actually supply the substance of the PCL. The endoligamentous vessels lie parallel to the collagen fibers in a longitudinally-oriented manner (2).

Finally, the PCL receives sensory innervation from the posterior articular branch of the posterior tibial nerve (2,26,52). It courses through the posterior capsule where its fibers join, and run with, the periligamentous vessels (2).

**Mechanism of Injury**

Currently, it is estimated that 50% of all PCL injuries occur in motor vehicle accidents, 40% in athletics and 10% during activities of daily living (26). The literature also suggests that the incidence of this injury in athletics is increasing and that this can be attributed to better diagnostic testing, education and, hence, earlier recognition. Also, an increase in athletic participation and, subsequent, increased exposure to trauma may account for the injury's growing incidence.

One extremely important component of a patient history is a thorough description of the mechanism of injury. Along with an extensive knowledge of anatomy and biomechanics, understanding the mechanism of injury can help the practitioner arrive at an accurate diagnosis. The PCL literature has quite thoroughly presented the three most common mechanisms of PCL-injury. Others have been reported as individual case studies; all of which will be presented in this section.

Injury to the PCL, regardless of the mechanism, usually involves a high magnitude of force. The resulting PCL-injury will manifest itself as either an "isolated" tear, or a PCL tear with associated other ligamentous, meniscal or capsular damage (4,14,26).

The most common mechanism involves a direct anteroposterior (A-P) force to the anterior tibia of a knee in approximately 90 degrees of flexion (4,10,14,26,34,40,51). Commonly referred to as the "dashboard" injury, this direct trauma often results in an "isolated" PCL tear (4,14,26,40). A patient who has suffered this type of injury will often present with an abrasion over the tibial tubercle and/or anterior, proximal tibia (4,14,26,51).

In athletics, this mechanism occurs in football when a player has his/her foot planted and, subsequently, receives a tackle to the anterior tibia (4,26,49). Also, this injury can occur in soccer when a player misses a kick and strikes an opposing player in the anterior tibial region (4,26,40,49). Lastly, the injury frequently occurs in cycling when the rider falls from the bicycle, the pretibial region collides with the curb and the knee is flexed at 90 degrees.

Regardless of the exact source of trauma, the PCL is most commonly injured with the knee in approximately 90 degrees of flexion because the ligament is horizontally oriented and the knee joint is in its "loose-packed" position. In the "loose-packed" position, the knee loses its inherent osseous stability and the PCL is vulnerable to direct A-P tibial trauma (51). With the knee at 90 degrees of flexion, a direct A-P force to the anterior tibia will cause the tibial plateau to translate posteriorly and place the PCL under undue strain (51).

The two other common mechanisms by which the PCL is injured are knee hyperextension and hyperflexion (26). Hyperflexion will often occur when a person lands from a fall on a flexed knee (26). This injury has been reported as happening with the ankle in a dorsiflexed (14) and plantarflexed position (51). It is important to remember that the anterior, "bulk" portion of the PCL is taut in flexion (2,26). Its injury during hyperflexion is, then, easily understood. However, in extension the posterior fibers become taut and it has been reported that a PCL tear will occur at approximately 30 degrees of hyperextension (40,51). Commonly, this hyperextension will result in PCL damage as well as ACL disruption and/or other ligamentous injury (9).

Reports have also been given on two rather unique mechanisms seen in competitive sport (20,21,40). Hughston et al. (20,21) stated that rotational injuries with associated valgus/varus stress are common causes of PCL injury. The resulting injury, in this case, would most likely involve the PCL as well as some collateral and/or meniscal involvement (20,21).

In 1986, Stanish et al. reported on two cases found in competitive wrestling (40). Both athletes suffered an "isolated" PCL-injury that resulted from forced knee flexion with the tibia internally rotated . The authors emphasised that there are as many as five maneuvers, in wrestling, that employ forced knee flexion with internal tibial rotation (40).

Quite often the site of PCL lesion will be dictated by the mechanism involved. Kannus et al. (26) explained that midsubstance interstitial tears most oftenly occur following a fall on a flexed knee with either the ankle dorsi- or plantarflexed. Avulsion fractures commonly occur at either the femoral or tibial PCL attachments (26,50). A direct blow to the anterior tibia, driving the tibia posteriorily in relation to the femur, will frequently result in an avulsion fracture at the PCL tibial insertion or an "isolated" tear of the ligament. Hyperextension can lead to either a tibial or femoral avulsion (26). Hughston et al. reported that a femoral avulsion will result from a rotational injury involving a varus or valgus stress (20,21).

Lastly, it has been postulated that the site of lesion can also be influenced by the velocity of the trauma (26). Notably, that midsubstance tears frequently occur from high velocity trauma whereas avulsion fractures tend to result at lower speeds (26).

**Nonoperative Treatment**

A discussion of the treatment for PCL-insufficiency should begin with a description of those structures that actually provide the knee with stability. Kannus et al. (26) portrayed the knee as having both "static" and "dynamic" stabilizers. The static stabilizers include the main ligaments, menisci, articular cartilage and capsular ligament (2,26,51). Their repair relies on invasive surgical procedures including arthroscopy, replacement with augmentation and reconstruction (20,21,23).

The "dynamic" stabilizers are those muscles and tendons that act on the joint (2,26,52). Nonoperative, or conservative, treatment focusses on increasing the strength of the "dynamic" stabilizers inorder to increase stability and to compensate for an incompetent PCL (7,25,26,34,43,47).

Their are specific situations when the orthopaedic community agrees that the nonoperative approach is best and, others, when surgery is clearly indicated. The literature suggests that there are three instances when surgery (operative treatment) is indicated for the management of PCL-insufficiency (20,21,23,51). Injuries involving subluxed bony avulsions require open reduction with internal fixation (4,40,50,51). Secondly, PCL ruptures that have associated other ligamentous, meniscal and/or capsular damage result in a multitude of instabilities and, therefore, require surgical reconstruction or replacement (26,49,51). Lastly, in chronic cases of posterior instability associated with PCL-injury that fail to respond to aggressive physiotherapy, surgery should be suggested to the patient as an alternative form of management (43,45,47).

Nonoperative treatment is the treatment of choice when dealing with nondisplaced bony avulsions and, both, partial and complete "isolated" tears of the PCL (14,25,26). Tegner et al. have shown that chronic cases of PCL injury also respond favorably to conservative thigh muscle strengthening (43,45,47). The authors reported that 80% of their patients experienced considerable improvement, both functionally and subjectively, following a three month muscle training regimen (43,45,47). Cross and Powell (10) described a correlation between good quadricep tone (strength) and favorable functional result.

Several investigators have advocated the use of diligent exercise as a means of conservative treatment (7,10,14,24-26,28,43,45,47). With "isolated" tears and nondislaced avulsion fractures, the essential factor in increasing stability is to strengthen the quadriceps and hamstrings (3,7,26,38,39,55,56).

Inorder to understand the reason why quadricep strengthening is effective, it is important to realize that the quadriceps muscle group has an "anterior drawer" effect, on the tibia, between 0-70 degrees of knee flexion (3,38,39,55,56). The PCL and quadricep muscle group are, therefore, agonists and work synergistically to maintain the anteroposterior stability of the knee (3,38,39,55,56).

Several authors (7,10,14,24-26,28,40,43,45,47) have stated that vigorous quadricep strengthening, in the acute and chronic stages of PCL injury, can maximize the dynamic stability of the knee complex. Long-term studies have reported that an intense physiotherapy program involving thigh muscle strengthening will produce an asymptomatic knee and a good-to-excellent functional result (10,24-26,28,34,43,45). Investigators have agreed that muscle strengthening does not decrease the amount of anteroposterior (A-P) laxity (10,24,26,43,45). It does, however, result in a functionally "sound" knee and a rapid return to activity (26). In the literature, it is well established that there is no correlation between the degree of "static" laxity and eventual functional result following quadricep strengthening (10,24,26,43,45). A patient can present with a fairly high degree of A-P laxity (10+mm) and still be very active and asymptomatic (10,26).

The main goal in quadriceps conditioning is to attain, and maintain, at least 100% relative quadricep strength between the injured and noninjured extremities (26,34). Motivating patients to comply and maintain an on-going exercise program is the true challenge facing the sports medicine practitioner.

In 1981, Cain and Schwabb reported on an athlete who totally compensated for posterior knee instability through aggressive quadricep strengthening and maintenance (7). Through biomechanical analysis, electromyogram (EMG) and quantitative muscle testing, these investigators demonstrated how strong quadriceps counterbalance A-P knee laxity during gait (7).

Several investigators (24,26,43,45) have reported on the favorable functional result gained through intense thigh muscle conditioning. Although the hamstring muscle group has an antagonist relationship with the PCL, it too must be strengthened later in PCL rehabilitation (3,26,38,39). Optimal knee function depends on muscle strength balance between the hamstring and quadricep muscle groups ($H/Q > 0.60$), the injured and noninjured extremities and, between the concentric and eccentric strength of individual muscle groups (3,15,26,34,38,39).

Diligent, ongoing muscle strengthening appears to be the treatment of choice for those who wish a "speedy" recovery from either an "isolated" PCL injury or a nondisplaced avulsion fracture (14,26). Along with the auspicious subjective and functional results, there are other factors which favor the nonoperative approach (26).

For the most part, surgery is more costly and involves a higher degree of risk. Consistent and predictable results have not yet been established in treating PCL insufficiency. At present, there is insufficient evidence to suggest that surgical treatment is any more effective, than nonoperative, in managing "isolated" tears or nondisplaced avulsions (26).

The deleterious effects of surgery, and the required length of immobilization, are a major "set-back" to the athlete or physical laborer who relies on fitness for their livelihood. Conservative treatment has a much shorter immobilization period and, thus, return to pre-injury status can occur much faster. Operative treatment is essential when dealing with multiple instabilities and/or subluxed avulsions (20,21,21). In the event that primary nonoperative management renders a poor functional result, most orthopods advocate secondary surgical intervention (26,43,45,47).

The method of nonoperative treatment for "isolated" PCL tears was first established in the early 1920's. Today, the basic principles remain the same, except the methodology has advanced due to research and technology. Following an acute "isolated" PCL tear, a recommended 2-3 week, immobilization period in a rehabilitation knee brace has been recommended (10,14,25,26,34).

The duration of 2-3 weeks allows for the essential physiologic processes healing to occur. Early fibroblast invasion and proliferation to the injured PCL occurs within this time frame (25).

Exercise that maintains quadricep and hamstring tone can begin within the first three days of the injury (25,26). Isometric exercise maintains the thigh musculature without moving the joint and, thus, does not jeopardize the healing collagen fibers (25). Also, active quadricep, concentric strengthening commences immediately in the form of straight or bent leg raises (25,26).

Concentric hamstring exercises do not begin until 2-3 weeks, post-injury (26,38,55,56). Because the hamstrings act as antagonists to the healing PCL, their exercise should be avoided until the ligament has had sufficient time to heal (25). Once sufficiently healed, exercise helps in promoting the proper orientation of collagen. As the knee returns to its full range of motion, eccentric hamstring muscle conditioning can be employed (26).

The primary goal of muscle rehabilitation, in the PCL-injured patient, is to achieve a level of strength balance between the extremities (injured/ noninjured > 1.00), the agonist-antagonist muscle groups (hamstrings/quadricep > 0.60) and within the same muscle group (eccentric/concentric > 1.30) (3,26,34,37,38,39). More specifically, the quadricep strength of the injured leg should equal, or exceed, that of the noninjured leg in all respects (34). This level of strength balance will allow for the quadriceps to compensate for straight posterior laxity and to ensure for more efficient knee mechanics (7,34). The literaure has reported that strength imbalance may lead to chronic complications such as clinical chondromalacia patella (10), patellofemoral pain (10,12,21,49), tricompartmental osteoarthritis (10), instability and giving-away (1,9,10), and difficulty with stair descent (7,9,10,12) and sudden changes in direction (1).

**Functional Rehabilitation and Kinetic Chain Exercise**

Although the literature stresses the importance of quadricep strengthening in PCL rehabilitation, diligent hamstring conditioning must also be included in a manner that functionally restores lower extremity kinematics (22,31,32,33,47). This can be achieved through a functional rehabilitation program that utilizes kinetic chain exercise ("closed" kinetic chain) (33).

Current trends in knee rehabilitation favor a functional approach which focuses on the restoration of joint motion, strength, proprioception, agility, and confidence (31,32). The goal of such a program is for the patient/athlete to attain that level of function he/she desires (31). Therefore, the training regimen should be both patient- and injury-specific (31,33).

Functional rehabilitation begins with the restoration of full, joint range of motion (ROM) and, then, muscular strength and endurance (31,32). It is during these initial steps that muscular imbalances need to be addressed. Following sufficient strength and endurance training, proprioception and agility exercises can be employed to enhance the joint's neurovascular, neurosensory and kinesthetic function (31,32). These rehabilitation steps need to proceed, sequentially, and in a reasonable progression so that the patient may gain enough confidence to carry out those tasks he/she wishes to perform (32). Also, failure to follow this regimen may lead to a reinjury or a "plateauing" in performance (32).

The rehabilitation program needs to follow in a progressive manner that does not illicit pain, effusion and/or tendinitis (31,32). Progression from simple to more complex tasks must be based on patient performance rather than on time factors (31). Functional gains will not occur in the face of pain or swelling so it is essential that training errors be avoided (31,32).

"Specificity of training" is the basis on which the functional program is designed and this is accomplished by incorporating activities in the protocol that resemble those performed in the patient's sport and/or vocation (3,31,32,33,38,39). Kinetic chain exercise ("closed" kinetic chain) provides a functional rehabilitation program with the high level of specificity, necessary (33).

Kinetic chain exercise has been recommended as a method of functional cruciate rehabilitation that utilizes the lower extremity kinetic chain concept (33,47). During lower extremity kinetic chain exercise, the peripheral joint (ankle/foot) meets the resistance and is fixed (33). Both the squat and leg extension press are movements that are specific to walking, running, jumping and climbing activities (31-33).

Along with the level of specificity that kinetic chain exercise provides, it also helps to facilitate the neural adaptation necessary for the restoration of muscular reflex and coordination, balance and proprioception (31-33).

Traditional rehabilitation methods have employed "isolated" knee movements because it was felt that they limited the degree of stress placed on the injured ligamentous structures (33). However, "isolated" joint movement, or "open" kinetic chain activity, involves one joint and does not utilize the lower extremity kinetic chain concept (33). Kicking, is the only activity in sport that functionally requires "isolated" knee extension.

The benefits of a functional program involving kinetic chain exercise to the lower extremity, as a whole, have been presented. However, there are other significant features that affect the cruciate-deficient knee, directly, that need to be mentioned.

During lower extremity kinetic chain exercise, the applied load is axially-oriented. Conversely, "isolated" knee extension illicits an applied force that is directed perpendicular to the tibia (33). The difference in the direction of applied force has an effect on knee shear which involves the anteroposterior (A-P) translation of the tibia on the femur. When dealing with an injured posterior cruciate ligament, posterior knee shear must be minimized so that the incompetent cruciate ligament, secondary capsular restraints, reconstruction, or repair, are not put under undue strain (33). Kinetic chain exercise limits A-P translation because weight bearing produces an axially-oriented force through the distal tibia (33).

Also, kinetic chain exercise is the only method of exercise that reproduces the concurrent shift (40), or muscular coactivation (3,38,39), of the antagonist muscle group as a regulator of A-P translation during active knee extension and flexion. The concept of muscular coactivation involves the submaximal contraction of the antagonist during activity inorder to regulate the A-P drawer effect the agonist has on the tibiofemoral joint during active flexion and extension (3,38,39). This unique feature of kinetic chain exercise, along with it's axially-oriented force, make it the best method of rehabilitation to limit posterior knee shear and, thus, strain to the deficient posterior cruciate (33).

Lastly, muscular coactivation also effects the compressive forces on the articular surface of the tibiofemoral joint (3). During kinetic chain exercise, muscular coactivation ensures that compressive forces are distributed evenly along the articular surface of the knee. However, in the absence of the antagonist regulatory effect, there is a focal stress point along the articular surface that endures the load (3). Repetitive stress to this focal point may lead to the deterioration of the articular cartilage, early tissue damage and eventual osteoarthritis (3).

Herein, we see the importance of rehabilitating the patient in a functional manner that utilizes kinetic chain exercise. This method will reproduce those mechanisms necessary for the restoration of knee kinematics and will limit the amount of strain placed on the incompetent posterior cruciate ligament.

**Functional Deficits Associated With PCL-Insuffiency**

Very few authors have commented on the functional deficits associated with PCL-insufficiency. Tibone et al, (48) investigated several aspects of gait during walking, fast walking and stairclimbing. Their comparison of an "untreated" (conservatively managed) group to a reconstructed group revealed several pertinent observations (48).

During fast cadence walking, Tibone et al. (48) observed that "untreated" PCL patients exhibited, significantly, less knee extension during midstance of gait. Avoidance of full knee extension was explained as a defense mechanism to limit the amount of stress placed on the secondary restraints (posterior capsule) which would be greater in full extension versus slight knee flexion (48).

Of special interest to the current study, is the finding that the "untreated" PCL patients exhibited quadricep weakness on the involved side (48). Tibone et al. attributed this quadricep weakness to the decreased mechanical advantage of the extensor mechanism that exists with the posterior sag of the tibia (48). The resulting posterior subluxing of the tibia on the femur decreases the moment arm of the knee extensor mechanism and, therefore, the quadricep strength is weakened.

Lastly, myoelectric studies (EMG) revealed that the gastrocnemius-soleus complex appears to fire early inorder to help compensate for the incompetent PCL and weakened extensor mechanism (48).

**Eccentric/Concentric Strength Relationships in Healthy Subjects**

The recognition of strength deficiency in the PCL-injured patient and, subsequent, design of a rehabilitation program depends on an understanding of what has been reported in healthy subjects. Several authors (18,35,53,54) have reported on the eccentric/concentric strength relationships present in healthy individuals.

Westing et al. (53) reported on the eccentric/concentric reltionship in the quadriceps femoris muscle group. These authors reported that eccentric torque was significantly greater ($p<0.05$) than the concentric torque at all testing velocities. They also found that this difference in relative torque increased with increasing isokinetic testing velocity (53). Similarly, Perkins et al. (35) found that eccentric torque was significantly greater than concentric torque in hamstrings and quadriceps. Male athltetes and moderately active individuals (35) were tested at three testing velocities; 90, 135 and 180 degrees per second. Lastly, Griffin et al. (18) measured knee extensor and flexor muscle groups in males and females. They, too, found that both muscle groups were significantly stronger ($p<0.05$) eccentrically than concentrically for both sexes.

**Report on "Isolated" PCL Pilot Study**

Prior to the current investigation, a pilot study of eighteen "isolated" PCL-injured athletes was performed. This study examined the eccentric, and concentric, torque relationships within, and between, the thigh muscle groups of PCL- deficient patients. The sample consisted of eighteen males, between the ages of eighteen and thirty-five years of age. All patients were at least six months post-injury and received conservative treatment for an "isolated" tear of the posterior cruciate ligament (PCL) in the acute stage of injury.

The Kinetic Communicator (KINCOM) was used to measure mean average and average peak isokinetic torque. All of the athletes were measured for eccentric and concentric thigh muscle torque. Quadricep and hamstring muscle groups were tested on both the injured and noninjured extremities. The test was an isokinetic test (@ 50 degrees/second) and measured torque between 10-90 degrees of knee flexion.

This study helped to identify the strength deficits present in a sample of "isolated" PCL-deficient athletes. The investigators explored three strength relationships; 1) eccentric/concentric ratio within an individual muscle group, 2) eccentric and concentric strength between the same muscle group of the injured and noninjured extremity, and 3) the hamstring/quadricep ratio between the injured and noninjured sides.

Shirakura et al. (37) have recently reported on the eccentric/concentric ratio in the quadriceps of the uninjured leg of an "isolated" PCL-injured group and of a control group of healthy knees. They revealed that this ratio is almost exactly the same in both groups and that in males it was 1.30 (37). They did not, however, provide the eccentric/concentric ratio for the quadriceps of the injured extremity. Several investigators (18,35,53,54) have reported on the eccentric/concentric relationship in the quadriceps (18,35,53,54) and hamstring (18,35) muscle groups. These authors described that, in both genders, quadricep and hamstring eccentric torque was significantly greater than the corresponding concentric torque.

Information is limited on the clear definition of an eccentric strength deficiency. For the purpose of the pilot study, an eccentric defiency was defined as an eccentric/concentric ratio < 1.10. This definition was used to identify strength deficiency in both the hamstring and quadricep muscle groups. Parolie and Bergfeld (34) suggested that the goal of knee rehabilitation should be to attain and maintain an injured/noninjured ratio of 1.00, or greater. This optimal ratio applies to the relative eccentric and concentric strength between the cruciate-deficient extremity and noninjured side. Ghena et al. (15) have reported that a hamstring/quadricep ratio of 0.60, or greater, is universally accepted as "healthy". Although these "optimal" ratios are not necessarily conclusive, they did provide the investigator with some guideline as to what could be considered "unhealthy".

It was on the basis of this study's findings that the kinetic chain rehabilitation program has been designed. When examining the three relationships mentioned above, the following pertinent information was observed:

1. Patients exhibited eccentric weakness in the quadriceps of both extremities; injured and noninjured. Eccentric torque was not significantly greater than concentric torque in the quadriceps of either extremity (Table PS.1.).

2. The hamstrings of the injured extremity were significantly weaker ($p<0.05$), eccentrically, than those of the noninjured extremity (Table PS.1).

3. There was a significant difference ($p<0.05$), in eccentric hamstring/quadricep (H/Q) ratio, when comparing the injured to noninjured extremities (Table PS.2.).

4. Although not significantly different, the quadriceps of the injured extremity were weaker both eccentrically, and concentrically, when compared to the noninjured side. Also, the hamstrings were eccentrically weaker on the injured side. This is important because the goal of knee rehabilitation is to have the relative strength 10% greater on the injured side inorder to compensate for the incompetent ligament (Table PS.1).

**Table of Means PS.1.**
**Pilot Study: Isolated PCL-Injured Isokinetic Torque**

Quadriceps & Hamstrings @ 50 degrees per second

| EXTREMITY | MUSCLE GROUP/ACTION | ISOKINETIC TORQUE | |
|---|---|---|---|
| Injured | Quadriceps/Eccentric | Avg. Peak | 182.1 Nm |
| | | Mean Avg. | 152.7 Nm |
| | Quadriceps/Concentric | Avg. Peak | 168.9 Nm |
| | | Mean Avg. | 137.7 Nm |
| | Hamstrings/Eccentric | Avg. Peak | 89.2 Nm |
| | | Mean Avg. | 74.4 Nm |
| | Hamstrings/Concentric | Avg. Peak | 84.0 Nm |
| | | Mean Avg. | 73.6 Nm |
| Noninjured | Quadriceps/Eccentric | Avg. Peak | 186.2 Nm |
| | | Mean Avg. | 156.5 Nm |
| | Quadriceps/Concentric | Avg. Peak | 174.2 Nm |
| | | Mean Avg. | 142.1 Nm |
| | Hamstrings/Eccentric | Avg. Peak | 103.9 Nm |
| | | Mean Avg. | 89.4 Nm |
| | Hamstrings/Concentric | Avg. Peak | 80.7 Nm |
| | | Mean Avg. | 72.6 Nm |

Avg.= average, Nm= Newton meters, PCL= posterior cruciate ligament.

**Table of Means PS.2.**
**Pilot Study: Peak Isokinetic Torque Ratios**

Isolated PCL Group Strength Ratios @ 50 degrees per second

| STRENGTH RELATIONSHIP | MODALITY | RATIO |
|---|---|---|
| Eccentric/Concentric | Quadriceps/Injured | 1.08 |
| | Quadriceps/Noninjured | 1.07 |
| | Hamstrings/Injured | 1.06 |
| | Hamstrings/Noninjured | 1.29 |
| Injured/Noninjured | Quadriceps/Eccentric | 0.98 |
| | Quadriceps/Concentric | 0.97 |
| | Hamstrings/Eccentric | 0.86 |
| | Hamstrings/Concentric | 1.04 |
| Hamstring/Quadriceps | Injured/Eccentric | 0.49 |
| | Injured/Concentric | 0.50 |
| | Noninjured/Eccentric | 0.56 |
| | Noninjured/Concentric | 0.46 |

Injured= injured extremity, Noninjured= noninjured extremity, PCL= posterior cruciate ligament.

# Chapter 3

# Methodology

## Sample Description

The current study included a treatment group of isolated PCL-injured patients (n=13) and a control group of healthy, sedentary individuals (n=13). Isolated PCL-injured patients underwent a 12-week, eccentric squat program and were compared to the nontreatment, control group at 0, 6, and 12 weeks of the program. Inclusion in the study was based on certain criteria that were strictly adhered to. Isolated PCL-injured patients had all received primary care at the Allan McGavin Sports Medicine Centre. Acceptance into the study was based on a thorough review of each patient's file, diagnosis, history and mechanism of injury.

Subjects in the treatment group had all received conservative treatment for an isolated, PCL injury. Diagnosis of the injury was made clinically and confirmed by the presence of both a positive posterior sag and posterior drawer test. Accepting only isolated cases eliminated any possibility of the multiplanar instability that is associated with multiple ligamentous injury. All subjects were at least six months post injury and had been treated nonoperatively at the acute stage of injury.

The treatment group underwent 12 weeks of eccentric, kinetic chain exercise and were tested for strength, performance and subjectively at 0, 6 and 12 weeks. The control group of healthy individuals did not do the eccentric ptogram or any other form of lower extremity strengthening during the course of this study. They, too, underwent the exact same testing procedures at 0, 6 and 12 weeks.

## The Rehabilitation Program

Subjects in the treatment group were placed on a twelve week, home exercise program. In an effort to ensure compliance to the program, the exercise protocol was simple and required little-to-no equipment for execution. The program was both challenging and progressive so as to stimulate participant interest and motivation.

The prescribed exercise focused on restoring lower extremity kinematics, thigh muscle strength (hamstrings and quadriceps), and facilitated muscular coactivation of the antagonist during active knee extension/flexion. In terms of muscle strength and endurance, the exercise involved both eccentric and concentric muscle action of the quadriceps and hamstring muscle groups. Athough the focus of this study was on thigh muscle strength, this program also conditioned the gastrocnemius-soleus complex that Tibone et al. (48) have rendered important as compensatory stabilizers in the PCL-deficient knee.

The exercise design was a modified eccentric squat protocol where the participant executed two-legged squats (11) for the first six weeks and, then, gradually introduced single-leg squats over the later six weeks. The initial six weeks of two-legged, eccentric squat exercises were modelled after the program currently used at the Allan McGavin Sports Medicine Centre.

The eccentric program progressed daily, in repetitions, and resistance increased, weekly. The exercises were executed seven days a week, for a total of twelve weeks. Prior to and following each exercise session, the participant was advised to stretch the involved musculature and to ice each knee for twenty to thirty minutes.

## Exercise Protocol

### Daily Progression

Day#1 3X8 reps

Day#2 3X10 reps

Day#3 3X12 reps

Day#4 3X14 reps

Day#5 3X16 reps

Day#6 3X18 reps

Day#7 3X20 reps

### Weekly Progression

Week #1 slow drop two-legged, eccentric squats

Week #2 fast drop two-legged, eccentric squats

Week #3 ... with 2kg/hand

Week #4 ... with 4kg/hand

Week #5 ... with 6kg/hand

Week #6 ... with 8kg/hand

Week #7 2 sets of two-legged, eccentric squat with 8kg/hand; 1 set one-legged squat per leg, fast drop.

Week #8 2 sets of two-legged, eccentric squat with 8kg/hand; 1 set one-legged squat per leg, 2kg in hand.

Week #9 2 sets of two-legged, eccentric squat with 8kg/hand; 1 set one-legged squat per leg, 4kg in hand.

Week #10 1 set of two-legged, eccentric squat with 8kg/hand; 2 sets one-legged squat per leg, 4kg in hand.

Week #11 1 set of two-legged, eccentric squat with 8kg/hand; 2 sets one-legged squat per leg, 6kg in hand.

Week #12 1 set of two-legged, eccentric squat with 8kg/hand; 2 sets one-legged squat per leg, 8kg on hand.

**Description of Execution**

For the first six weeks, the PCL subjects performed only two-legged, eccentric squats. The starting position for this exercise had the participant in a standing position, hands by side. The feet were positioned shoulder-width apart and the exercise was initiated by unlocking the knees.

Flexion occurs at the knee and hip to the point were the patient is comfortable. From this position, the patient slowly returns to standing upright by actively extending the knee and hip. The exercise is continually repeated for the prescribed amount of repetitions. Resistance is introduced, incrementally, by the introduction of handheld weights.

During weeks 7-12, the number of two-legged squats was slowly decreased and the one-legged squat was introduced. The one-legged squat involves exercising only one extremity, at a time, and resistance is increased by the introduction of handheld weights.

The starting position for this exercise involves standing on one leg with the nonexercising leg lifted from the ground, beside (@ 90 degrees of knee flexion). The patella was positioned over the second toe with knee in full extension. The patient ensures balance by maintaining a light touch on a nearby counter or railing.

From this position, the patient quickly drops into a comfortable squat. The individual then slowly returns to the upright position by actively extending the knee and hip. The exercise is continually repeated for the prescribed number of repetitions.

**Parameters Measured and The Rationale For Their Selection**

The Kinetic Communicator (KINCOM) was used to measure the average peak isokinetic torque of the thigh muscles about the knee. The hamstring and quadricep muscle groups were tested for both eccentric and concentric torque. The use of the KINCON as a testing device provided the eccentric and concentric raw data pertinent to monitoring strength gains and relationships.

The Tegner Hop Test (46) was used to examine changes in knee functional performance before, during and after the rehabilitation. The use of this performance test has been advocated by Fonsesca et al. (13) and tested for validity by that same group. Finally, the Lysholm Knee Scale Score (44) was used to monitor subjective information regarding the patient's symptomatology and perceived knee function before, during and after the exercise program.

**Measurement Technique and Protocol**

The Kinetic Communicator (KINCOM) is a hydraulically powered, computer controlled exercise testing device,. It was used to measure and record the isokinetic eccentric and concentric torque of the quadriceps and hamstrings.

Each individual received a five-minute, stairclimbing warm-up and ample time to stretch the involved musculature. Following the warm-up, the patient received instruction and practice trials to familiarize himself with the resistance that the KINCOM provides. Each subject received four submaximal repetitions of each exercise prior to each maximal test.

Once the patient was confident and familiar with the KINCOM, they were asked to perform four maximal repetitions at a constant velocity of 60 and 120 degrees per second (deg/sec). Average peak torque was recorded between 10 and 90 degrees of knee flexion. Four maximal tests were performed at each velocity; quadriceps (injured and noninjured extremities), hamstrings (injured and noninjured extremities). The control group performed the exact same testing on both left and right extremities.

During the testing session, the patient was seated with the pelvis and exercising thigh securely strapped to the bench. The mechanical axis of rotation was aligned with lateral femoral condyle and the load cell was placed, distally, 3/4 the length of the fibula. All data was collected and stored on floppy disc. Subjects were tested, isokinetically, at pretreatment (0 weeks), midtreatment (6 weeks), and at postreatment (12 weeks).

Prior to each KINCOM session, the patient was asked to complete the Lysholm Knee Scale Score. This particular knee score has bee recommended as an effective means of monitoring a patient's subjective comments concerning perceived knee function and symptomatology (44).

Lastly, each patient performed the Tegner Hop Test prior to each KINCOM testing session. The subject was asked to perform three, one-legged hops with each leg. Each hop began with the individual standing, statically, on one leg with the middle of the jumping-leg foot on the starting line. The nonjumping leg was held at 90 degrees, beside, and legs were tested alternately to prevent fatigue.

**Experimental Design and Analysis of Data**

Average peak isokinetic torque values collected by the KINCOM were statistically analyzed using 1X3 and 2X3 repeated measures analysis of variance (RMANOVA). The BMDP.2V program was used to perform this analysis and Tukey's HSD testing was used for all post hoc comparisons.

1X3 RMANOVA with repeated measures on the second factor (subject X testing time) was used to monitor significant changes in each dependent variable over the 12 week treatment protocol. Dependent variables included average peak torque values and ratios for each of the testing modalities. One-way, Tukey's HSD testing was used for all post hoc comparisons.

2X3 RMANOVA with repeated measures on the second factor was used to examine significant differences between injured and noninjured extremities in the PCL group, eccentric and concentric muscle action in the muscles of the PCL group, and between the PCL and control groups. Dependent variables included isokinetic torque values, strength ratios, Tegner Hop Test and Lysholm scores. Two-way, Tukey HSD testing was used for all post hoc comparisons on between-subjects factors, within-subject factors and their interaction. Significance was accepted at the $p<0.05$ level for all statistical analysis.

# Chapter 4

# Results and Discussion

## Results

### A. Subjects X Treatment

Statistical analysis clearly indicated significant increases in quadriceps, eccentric torque for both injured and noninjured extremities over the 12-week, eccentric squat program (Table A.1.). Significant increases ($p < 0.05$) in strength were present at both isokinetic velocities (60 & 120 degrees per second). Tukey's HSD testing revealed that, in some instances, significant increases occurred in the first six weeks, not in the later six weeks, but remained significant for the 12-week program, overall.

At 60 degrees per second (deg/sec), quadriceps eccentric torque values for both extremities increased significantly between weeks 1-6 and weeks 1-12. However, there was no significant increase between weeks 7-12 (Table A.1.). At 120 degrees per second, significant increases in eccentric strength occurred between weeks 1-6 and weeks 7-12, in the injured extremity. The noninjured extremity also increased significantly over the 12-week program (Table A.1.).

Quadriceps, concentric torque increased significantly ($p < 0.05$) in the noninjured (@ 60 deg/sec) and injured extremities (@ 120 deg/sec). Tukey's HSD testing indicated that significant increases occurred between weeks 1-6 and 1-12 for the noninjured extremity (@ 60 deg/sec). The injured extremity increased significantly in quadriceps, concentric strength over weeks 1-12 (@120 deg/sec).

**Table of Means A.1.**
**Subjects vs. Treatment: Quadriceps Muscle Group**

| MODALITY | TIME | AVERAGE PEAK TORQUE +/- S.D. |
|---|---|---|
| INJQUADECC @ 60 deg/sec | 0wks | 167.54 +/- 52.00 |
| | 6wks | 187.69 +/- 67.10* |
| | 12wks | 198.92 +/- 63.70*** |
| NONQUADECC @ 60 deg/sec | 0wks | 164.15 +/- 55.66 |
| | 6wks | 183.31 +/- 53.08* |
| | 12wks | 194.23 +/- 53.39*** |
| INJQUADECC @ 120 deg/sec | 0wks | 158.31 +/- 60.91 |
| | 6wks | 185.15 +/- 57.34* |
| | 12wks | 213.15 +/- 69.56**,*** |
| NONQUADECC @ 120 deg/sec | 0wks | 169.31 +/- 58.46 |
| | 6wks | 181.77 +/- 61.06 |
| | 12wks | 193.46 +/- 40.59*** |
| INJQUADCON @ 60 deg/sec | 0wks | 177.15 +/- 46.82 |
| | 6wks | 183.46 +/- 49.51 |
| | 12wks | 187.46 +/- 51.41 |
| NONQUADCON @ 60 deg/sec | 0wks | 167.15 +/- 54.58 |
| | 6 wks | 185.62 +/- 55.18* |
| | 12wks | 186.00 +/- 52.34*** |
| INJQUADCON @ 120 deg/sec | 0wks | 151.85 +/- 41.61 |
| | 6wks | 159.46 +/- 41.70 |
| | 12wks | 171.15 +/- 48.76*** |
| NONQUADCON @ 120 deg/sec | 0wks | 153.15 +/- 40.06 |
| | 6wks | 158.38 +/- 50.76 |
| | 12wks | 165.00 +/- 43.04 |

*= $p<0.05$ (@ 0-6 weeks), **= $p<0.05$ (@ 7-12 weeks), ***= $p<0.05$ (@ 0-12 weeks)

INJ= injured, NON= noninjured, ECC= eccentric, CON= concentric, HAMS= hamstrings, deg/sec= degrees per second, wks= weeks.

**Table of Means A.2.**
**Subjects vs. Treatment: Hamstrings Muscle Group**

| MODALITY | TIME | AVERAGE PEAK TORQUE +/- S.D. |
|---|---|---|
| INJHAMSECC @ 60 deg/sec | 0wks | 95.08 +/- 29.17 |
| | 6wks | 105.69 +/- 33.89 |
| | 12wks | 106.15 +/- 29.80 |
| NONHAMSECC @ 60 deg/sec | 0wks | 97.92 +/- 29.19 |
| | 6wks | 109.92 +/- 30.30 |
| | 12wks | 114.69 +/- 32.32 |
| INJHAMSECC @ 120 deg/sec | 0wks | 95.23 +/- 41.44 |
| | 6wks | 106.54 +/- 38.87 |
| | 12wks | 111.69 +/- 29.46 |
| NONHAMSECC @ 120 deg/sec | 0wks | 103.62 +/- 31.07 |
| | 6wks | 110.00 +/- 32.74 |
| | 12wks | 116.69 +/- 28.48 |
| INJHAMSCON @ 60 deg/sec | 0wks | 88.23 +/- 26.92 |
| | 6wks | 98.46 +/- 28.60 |
| | 12wks | 98.85 +/- 29.30 |
| NONHAMSCON @ 60 deg/sec | 0wks | 86.08 +/- 23.86 |
| | 6 wks | 100.69 +/- 27.03 |
| | 12wks | 99.62 +/- 24.09 |
| INJHAMSCON @ 120 deg/sec | 0wks | 80.31 +/- 30.06 |
| | 6wks | 89.69 +/- 30.05 |
| | 12wks | 93.38 +/- 33.17 |
| NONHAMSCON @ 120 deg/sec | 0wks | 80.00 +/- 26.10 |
| | 6wks | 86.00 +/- 26.70 |
| | 12wks | 92.65 +/- 26.86 |

*= $p<0.05$ (@ 0-6 weeks), **= $p<0.05$ (@ 7-12 weeks), ***= $p<0.05$ (@ 0-12 weeks)

INJ= injured, NON= noninjured, ECC= eccentric, CON= concentric, HAMS= hamstrings, deg/sec= degrees per second, wks= weeks.

**Table of Means A.3.**
**Subjects vs. Treatment: Eccentric/Concentric Strength Ratios**

| MODALITY | TIME | AVERAGE PEAK TORQUE +/- S.D. |
|---|---|---|
| QUADINJ E/C @ 60 deg/sec | 0wks | 0.96 +/- 0.22 |
| | 6wks | 1.02 +/- 0.18 |
| | 12wks | 1.06 +/- 0.19*** |
| QUADNON E/C @ 60 deg/sec | 0wks | 0.99 +/- 0.18 |
| | 6wks | 1.00 +/- 0.16 |
| | 12wks | 1.08 +/- 0.24 |
| QUADINJ E/C @ 120 deg/sec | 0wks | 1.03 +/- 0.24 |
| | 6wks | 1.17 +/- 0.23 |
| | 12wks | 1.25 +/- 0.22*** |
| QUADNON E/C @ 120 deg/sec | 0wks | 1.11 +/- 0.21 |
| | 6wks | 1.18 +/- 0.25 |
| | 12wks | 1.20 +/- 0.25 |
| HAMSINJ E/C @ 60 deg/sec | 0wks | 1.09 +/- 0.21 |
| | 6wks | 1.12 +/- 0.21 |
| | 12wks | 1.09 +/- 0.13 |
| HAMSNON E/C @ 60 deg/sec | 0wks | 1.14 +/- 0.14 |
| | 6wks | 1.10 +/- 0.16 |
| | 12wks | 1.14 +/- 0.16 |
| HAMSINJ E/C @ 120 deg/sec | 0wks | 1.18 +/- 0.19 |
| | 6wks | 1.19 +/- 0.19 |
| | 12wks | 1.27 +/- 0.32 |
| HAMSNON E/C @ 120 deg/sec | 0wks | 1.24 +/- 0.21 |
| | 6wks | 1.32 +/- 0.14 |
| | 12wks | 1.34 +/- 0.21 |

*= p<0.05 (@ 0-6 weeks), **= p<0.05 (@ 7-12 weeks), ***= p<0.05 (@ 0-12 weeks)

INJ= injured, NON= noninjured, E/C= eccentric/concentric ratio, HAMS= hamstrings, QUAD= quadriceps, deg/sec= degrees per seocond, wks= weeks.

**Table of Means A.4.**
**Subjects vs. Treatment: Hamstring/Quadricep Strength Ratios**

| MODALITY | TIME | AVERAGE PEAK TORQUE RATIO +/- S.D. |
|---|---|---|
| INJECC H/Q @ 60 deg/sec | 0wks | 0.58 +/- 0.11 |
| | 6wks | 0.57 +/- 0.11 |
| | 12wks | 0.55 +/- 0.12 |
| NONECC H/Q @ 60 deg/sec | 0wks | 0.61 +/- 0.10 |
| | 6wks | 0.61 +/- 0.14 |
| | 12wks | 0.60 +/- 0.15 |
| INJECC H/Q @ 120 deg/sec | 0wks | 0.60 +/- 0.17 |
| | 6wks | 0.58 +/- 0.12 |
| | 12wks | 0.55 +/- 0.16 |
| NONECC H/Q @ 120 deg/sec | 0wks | 0.63 +/- 0.12 |
| | 6wks | 0.62 +/- 0.12 |
| | 12wks | 0.61 +/- 0.11 |
| INJCON H/Q @ 60 deg/sec | 0wks | 0.51 +/- 0.11 |
| | 6wks | 0.54 +/- 0.09 |
| | 12wks | 0.53 +/- 0.09 |
| NONCON H/Q @ 60 deg/sec | 0wks | 0.53 +/- 0.10 |
| | 6wks | 0.55 +/- 0.12 |
| | 12wks | 0.55 +/- 0.12 |
| INJCON H/Q @ 120 deg/sec | 0wks | 0.52 +/- 0.15 |
| | 6wks | 0.56 +/- 0.09 |
| | 12wks | 0.54 +/- 0.13 |
| NONCON H/Q @ 120 deg/sec | 0wks | 0.53 +/- 0.15 |
| | 6wks | 0.56 +/- 0.11 |
| | 12wks | 0.57 +/- 0.17 |

*= $p<0.05$ (@ 0-6 weeks), **= $p<0.05$ (@ 7-12 weeks), ***= $p<0.05$ (@ 0-12 weeks)

INJ= injured, NON= noninjured, H/Q= hamstring/quadricep ratio, NON= noninjured, INJ= injured, deg/sec= degrees per second, wks= weeks.

**Table of Means A.5.**
**Subjects vs. Treatment: Hop Test & Lysholm Knee Score Scale**

| TEST | TIME | MEAN SCORE +/- S.D. |
|---|---|---|
| Injured-side Hop Test | 0wks | 187.50 +/- 18.68cm |
| | 6wks | 199.63 +/- 18.32cm * |
| | 12wks | 203.88 +/- 20.46cm *** |
| Noninjured-side Hop Test | 0wks | 193.25 +/- 16.51cm |
| | 6wks | 203.38 +/- 19.76cm * |
| | 12wks | 207.75 +/- 16.84cm *** |
| Lysholm Knee Score | 0wks | 80.08 +/- 11.83 |
| | 6wks | 91.23 +/- 4.64* |
| | 12wks | 92.00 +/- 10.58*** |

*= $p<0.05$ (@ 0-6 weeks), **= $p<0.05$ (@ 7-12 weeks), ***= $p<0.05$ (@ 0-12 weeks)

wks= weeks, cm= centimeters, S.D.= standard deviation.

The injured extremity gained significant increases in hamstring, eccentric strength at both testing velocities (Table A.2.) At 60 degrees per second, significant increases in eccentric strength occurred between weeks 1-6 and 1-12. At 120 degrees per second, eccentric strength increases occurred between weeks 1-12 of training. The noninjured extremity recorded significant gains between weeks 1-12 (@ 60 degrees per second).

Both extremities increased significantly in hamstring, concentric strength at both testing velocities. At 60 degrees per second, significant increases occurred between weeks 1-6 and weeks 1-12. However, at 120 degrees per second, significance occurred between weeks 1-12.

Eccentric/concentric strength ratios did not increase significantly in the treatment group except in the injured extremity, quadriceps (Table A.3.). At both testing velocities, significant increases occurred following 12 weeks of eccentric squat rehabilitation. Hamstring/quadricep ratios did not change as a result of the exercise intervention (Table A.4.).

The treatment group of isolated PCL-injured subjects did significantly improve in functional and subjective tests. Tegner Hop Test scores increased significantly ($p<0.05$) in both extremities following weeks 1-6 and weeks 1-12 (Table A.5.). Lysholm Knee Scale scores also improved significantly after weeks 1-6 and weeks 1-12 (Table A.5.).

## B. Injured versus Noninjured Extremity Comparison

There were no significant differences between injured and noninjured extremities prior to, during or following the exercise treatment program (Table B.1. - B.9.). Quadriceps and hamstring torque values at both velocities did not differ significantly, nor did

eccentric/concentric or hamstring/quadricep ratios. Hop Test scores did not differ between extremities at the three testing sessions.

## C. Eccentric versus Concentric Torque Comparison

At 60 degrees per second, there were no significant differences in eccentric and concentric torque in either muscle group, or in either extremity (Table C.1.). Significant differences did not appear prior to the treatment program at the 120 degrees per second velocity, either. However, between weeks 1-6 and weeks 1-12, the injured extremity, quadriceps did exhibit significantly greater eccentric torque than concentric torque (Table C.2.).

## D. Treatment Group versus Control Group Comparison

At 60 degrees per second (deg/sec), the injured extremity of the PCL group significantly differed from the control extremity in quadriceps eccentric and concentric strength prior to rehabilitation (Table D.1.). Following the exercise program, the PCL-injured extremity did not differ from the healthy, control group in any regard. At week 0, the PCL-noninjured extremity was significantly weaker than the control group in eccentric, quadriceps torque. However, following the 12-week exercise regimen, they

**Table of Means B.1.**
**PCL Treatment Group: Injured vs. Noninjured Extremity**

QUADRICEP MUSCLE GROUP @ 60 degrees per second

| TIME | MODALITY | AVERAGE PEAK TORQUE (Nm) | | |
|---|---|---|---|---|
| | | INJURED EXTREMITY | NONINJURED EXTREMITY | |
| 0wks | QUADECC | 167.54 +/- 52.00 | 164.15 +/- 55.66 | NS |
| | QUADCON | 177.15 +/- 46.82 | 167.15 +/- 54.58 | NS |
| 6wks | QUADECC | 187.69 +/- 67.10 | 183.31 +/- 53.08 | NS |
| | QUADCON | 183.46 +/- 49.51 | 185.62 +/- 55.18 | NS |
| 12wks | QUADECC | 198.92 +/- 63.70 | 194.23 +/- 53.39 | NS |
| | QUADCON | 187.46 +/- 51.41 | 186.60 +/- 52.34 | NS |

NS= not significant= p>0.05
QUAD= quadriceps, ECC= eccentric, CON= concentric, wks= weeks, Nm= Newton meters

**Table of Means B.2.**
**PCL Treatment Group: Injured vs. Noninjured Extremity**

QUADRICEP MUSCLE GROUP @ 120 degrees per second

| TIME | MODALITY | AVERAGE PEAK TORQUE (Nm) | | |
|---|---|---|---|---|
| | | INJURED EXTREMITY | NONINJURED EXTREMITY | |
| 0wks | QUADECC | 158.31 +/- 60.91 | 169.31 +/- 58.46 | NS |
| | QUADCON | 151.85 +/- 41.61 | 153.15 +/- 40.06 | NS |
| 6wks | QUADECC | 185.15 +/- 57.34 | 181.77 +/- 61.06 | NS |
| | QUADCON | 159.46 +/- 69.70 | 158.38 +/- 50.76 | NS |
| 12wks | QUADECC | 213.15 +/- 69.56 | 193.46 +/- 40.59 | NS |
| | QUADCON | 171.15 +/- 48.76 | 165.00 +/- 43.04 | NS |

NS= not significant= p>0.05
QUAD= quadriceps, ECC= eccentric, CON= concentric, wks= weeks, Nm= Newton meters

**Table of Means B.3.**
**PCL Treatment Group: Injured vs. Noninjured Extremity**

HAMSTRING MUSCLE GROUP @ 60 degrees per second

| TIME | MODALITY | AVERAGE PEAK TORQUE (Nm) | | |
|---|---|---|---|---|
| | | INJURED EXTREMITY | NONINJURED EXTREMITY | |
| 0wks | HAMECC | 95.08 +/- 29.17 | 97.92 +/- 29.19 | NS |
| | HAMCON | 88.23 +/- 26.92 | 86.08 +/- 23.86 | NS |
| 6wks | HAMECC | 105.69 +/- 33.89 | 109.92 +/- 30.30 | NS |
| | HAMCON | 98.46 +/- 28.60 | 100.69 +/- 27.03 | NS |
| 12wks | HAMECC | 106.15 +/- 29.80 | 114.69 +/- 32.32 | NS |
| | HAMCON | 98.85 +/- 29.30 | 99.62 +/- 24.09 | NS |

NS= not significant= p>0.05
HAM= quadriceps, ECC= eccentric, CON= concentric, wks= weeks, Nm= Newton meters

**Table of Means B.4.**
**PCL Treatment Group: Injured vs. Noninjured Extremity**

HAMSTRING MUSCLE GROUP @ 120 degrees per second

| TIME | MODALITY | AVERAGE PEAK TORQUE (Nm) INJURED EXTREMITY | NONINJURED EXTREMITY | |
|---|---|---|---|---|
| 0wks | HAMECC | 95.23 +/- 41.44 | 103.62 +/- 31.07 | NS |
| | HAMCON | 80.31 +/- 30.06 | 80.00 +/- 26.10 | NS |
| 6wks | HAMECC | 106.54 +/- 38.87 | 110.00 +/- 32.74 | NS |
| | HAMCON | 89.69 +/- 30.04 | 86.00 +/- 26.70 | NS |
| 12wks | HAMECC | 111.69 +/- 29.46 | 116.69 +/- 28.48 | NS |
| | HAMCON | 93.38 +/- 33.17 | 91.92 +/- 26.86 | NS |

NS= not significant= p>0.05
HAM= quadriceps, ECC= eccentric, CON= concentric, wks= weeks, Nm= Newton meters

**Table of Means B.5.**
**PCL Treatment Group: Injured vs. Noninjured Extremity**

QUADRICEP MUSCLE GROUP E/C STRENGTH RATIOS

| TIME | MODALITY | ECCENTRIC/CONCENTRIC RATIO +/- S.D. INJURED EXTREMITY | NONINJURED EXTREMITY | |
|---|---|---|---|---|
| 0wks | QD @ 60 dg/s | 0.96 +/- 0.22 | 0.99 +/- 0.18 | NS |
| | QD @ 120 dg/s | 1.03 +/- 0.24 | 1.11 +/- 0.21 | NS |
| 6wks | QD @ 60 dg/s | 1.02 +/- 0.18 | 1.00 +/- 0.16 | NS |
| | QD @ 120 dg/s | 1.17 +/- 0.23 | 1.18 +/- 0.25 | NS |
| 12wks | QD @ 60 dg/s | 1.06 +/- 0.19 | 1.08 +/- 0.24 | NS |
| | QD @ 120 dg/s | 1.25 +/- 0.22 | 1.20 +/- 0.25 | NS |

NS= not significant= p>0.05
QD= quadriceps, E/C= eccentric/concentric, dg/s= degrees per second, wks= weeks, S.D.= standard deviation.

**Table of Means B.6.**
**PCL Treatment Group: Injured vs. Noninjured Extremity**

HAMSTRING MUSCLE GROUP E/C STRENGTH RATIOS

| TIME | MODALITY | ECCENTRIC/CONCENTRIC RATIO +/- S.D. | | |
|---|---|---|---|---|
| | | INJURED EXTREMITY | NONINJURED EXTREMITY | |
| 0wks | HM @ 60 dg/s | 1.09 +/- 0.21 | 1.14 +/- 0.14 | NS |
| | HM @ 120 dg/s | 1.18 +/- 0.19 | 1.24 +/- 0.21 | NS |
| 6wks | HM @ 60 dg/s | 1.12 +/- 0.21 | 1.10 +/- 0.16 | NS |
| | HM @ 120 dg/s | 1.19 +/- 0.19 | 1.32 +/- 0.14 | NS |
| 12wks | HM @ 60 dg/s | 1.09 +/- 0.13 | 1.14 +/- 0.16 | NS |
| | HM @ 120 dg/s | 1.27 +/- 0.32 | 1.34 +/- 0.21 | NS |

NS= not significant= p>0.05
HM= hamstrings, E/C= eccentric/concentric, dg/s= degrees per second, wks= weeks, S.D.= standard deviation.

**Table of Means B.7.**
**PCL Treatment Group: Injured vs. Noninjured Extremity**

ECCENTRIC HAMSTRING/QUADRICEP STRENGTH RATIOS

| TIME | MODALITY | HAMSTRING/QUADRICEP RATIO +/- S.D. | | |
|---|---|---|---|---|
| | | INJURED EXTREMITY | NONINJURED EXTREMITY | |
| 0wks | EC @ 60 dg/s | 0.58 +/- 0.11 | 0.61 +/- 0.10 | NS |
| | EC @ 120 dg/s | 0.60 +/- 0.17 | 0.63 +/- 0.12 | NS |
| 6wks | EC @ 60 dg/s | 0.57 +/- 0.11 | 0.61 +/- 0.14 | NS |
| | EC @ 120 dg/s | 0.58 +/- 0.12 | 0.62 +/- 0.12 | NS |
| 12wks | EC @ 60 dg/s | 0.55 +/- 0.12 | 0.60 +/- 0.15 | NS |
| | EC @ 120 dg/s | 0.55 +/- 0.16 | 0.61 +/- 0.11 | NS |

NS= not significant= $p>0.05$
EC= eccentric, dg/s= degrees per second, wks= weeks, S.D.= standard deviation.

**Table of Means B.8.**
**PCL Treatment Group: Injured vs. Noninjured Extremity**

CONCENTRIC HAMSTRING/QUADRICEP STRENGTH RATIOS

| TIME | MODALITY | HAMSTRING/QUADRICEP RATIO +/- S.D. INJURED EXTREMITY | NONINJURED EXTREMITY | |
|---|---|---|---|---|
| 0wks | CO @ 60 dg/s | 0.51 +/- 0.11 | 0.53 +/- 0.10 | NS |
| | CO @ 120 dg/s | 0.52 +/- 0.15 | 0.53 +/- 0.15 | NS |
| 6wks | CO @ 60 dg/s | 0.54 +/- 0.09 | 0.55 +/- 0.12 | NS |
| | CO @ 120 dg/s | 0.56 +/- 0.09 | 0.56 +/- 0.11 | NS |
| 12wks | CO @ 60 dg/s | 0.53 +/- 0.09 | 0.55 +/- 0.12 | NS |
| | CO @ 120 dg/s | 0.54 +/- 0.13 | 0.57 +/- 0.17 | NS |

NS= not significant= $p>0.05$
CO=concentric, dg/s= degrees per second, wk=weeks, S.D.= standard deviation.

**Table of Means B.9.**
**PCL Treatment Group: Injured vs. Noninjured Extremity**

HOP TEST

| TIME | HOP TEST SCORE in CENTIMETERS +/- S.D. | | |
|---|---|---|---|
| | INJURED EXTREMITY | NONINJURED EXTREMITY | |
| 0wks | 187.50 +/- 18.68 cm | 193.25 +/- 16.51 cm | NS |
| 6wks | 199.63 +/- 18.32 cm | 203.38 +/- 19.76 cm | NS |
| 12wks | 203.88 +/- 20.46 cm | 207.75 +/- 16.84 cm | NS |

NS= not significant= p>0.05
wk=weeks, S.D.= standard deviation, cm= centimeters.

**Table of Means C.1.**
**Eccentric vs. Concentric Muscle Action**

Eccentric vs. Concentric Muscle Action @ 60 degrees per second

| TIME | MODALITY | AVERAGE PEAK TORQUE (Nm) ECCENTRIC TORQUE | CONCENTRIC TORQUE | |
|---|---|---|---|---|
| 0wks | QDIN | 167.54 +/- 52.00 | 177.15 +/- 46.82 | NS |
| | QDNO | 164.15 +/- 55.66 | 167.15 +/- 54.58 | NS |
| | HMIN | 95.08 +/- 29.17 | 88.23 +/- 26.92 | NS |
| | HMNO | 97.92 +/- 29.19 | 86.08 +/- 23.86 | NS |
| 6wks | QDIN | 187.69 +/- 67.10 | 183.46 +/- 49.51 | NS |
| | QDNO | 183.31 +/- 53.08 | 185.62 +/- 55.38 | NS |
| | HMIN | 105.69 +/- 33.89 | 98.46 +/- 28.60 | NS |
| | HMNO | 109.92 +/- 30.30 | 100.69 +/- 27.03 | NS |
| 12wks | QDIN | 198.92 +/- 63.70 | 187.46 +/- 51.41 | NS |
| | QDNO | 194.23 +/- 53.39 | 186.00 +/- 52.34 | NS |
| | HMIN | 106.15 +/- 29.80 | 98.85 +/- 29.30 | NS |
| | HMNO | 114.69 +/- 32.32 | 99.62 +/- 24.09 | NS |

S= significant= p<0.05, NS= not significant= p>0.05.
QD= quadriceps, wks= weeks, Nm= Newton meters, NO= noninjured extremity, IN= injured extremity, HM= hamstrings.

**Table of Means C.2.**
**Eccentric vs. Concentric Muscle Action**

Eccentric vs. Concentric Muscle Action @120 degrees per second

| TIME | MODALITY | AVERAGE PEAK TORQUE (Nm) | | |
|---|---|---|---|---|
| | | ECCENTRIC TORQUE | CONCENTRIC TORQUE | |
| 0wks | QDIN | 158.31 +/- 60.91 | 151.85 +/- 41.61 | NS |
| | QDNO | 169.31 +/- 58.46 | 153.15 +/- 40.06 | NS |
| | HMIN | 95.23 +/- 41.44 | 80.31 +/- 30.06 | NS |
| | HMNO | 103.62 +/- 31.07 | 80.00 +/- 26.10 | NS |
| 6wks | QDIN | 185.15 +/- 57.34 | 159.46 +/- 41.70 | S |
| | QDNO | 181.77 +/- 61.06 | 158.38 +/- 50.76 | NS |
| | HMIN | 106.54 +/- 38.87 | 89.69 +/- 30.05 | NS |
| | HMNO | 110.00 +/- 32.74 | 86.00 +/- 26.69 | NS |
| 12wks | QDIN | 213.15 +/- 69.56 | 171.15 +/- 48.76 | S |
| | QDNO | 193.46 +/- 40.59 | 165.00 +/- 43.04 | NS |
| | HMIN | 111.69 +/- 29.46 | 93.38 +/- 33.17 | NS |
| | HMNO | 116.69 +/- 28.48 | 91.92 +/- 26.86 | NS |

S= significant= $p<0.05$, NS= not significant= $p>0.05$.
QD= quadriceps, wks= weeks, Nm= Newton meters, NO= noninjured extremity, IN= injured extremity, HM= hamstrings.

**Table of Means D.1.**
**Treatment vs. Control Group**

QUADRICEP MUSCLE GROUP @ 60 degrees per second

| TIME | MODALITY | AVERAGE PEAK TORQUE (Nm) | | |
|---|---|---|---|---|
| | | TREATMENT GROUP | CONTROL GROUP | |
| 0wks | QDINEC | 167.54 +/- 52.00 | 208.62 +/- 39.50 | S |
| | QDNOEC | 164.15 +/- 55.66 | 205.38 +/- 51.77 | S |
| | QDINCO | 177.15 +/- 46.82 | 194.62 +/- 44.89 | S |
| | QDINCO | 167.15 +/- 54.58 | 181.38 +/- 44.08 | NS |
| 6wks | QDINEC | 187.69 +/- 67.10 | 216.77 +/- 59.24 | S |
| | QDNOEC | 183.31 +/- 53.08 | 197.92 +/- 54.31 | NS |
| | QDINCO | 183.46 +/- 49.51 | 187.62 +/- 43.09 | NS |
| | QDNOCO | 185.62 +/- 55.18 | 177.38 +/- 41.53 | NS |
| 12wks | QDINEC | 198.92 +/- 63.70 | 199.54 +/- 53.23 | NS |
| | QDNOEC | 194.23 +/- 53.39 | 191.54 +/- 52.11 | NS |
| | QDINCO | 187.46 +/- 51.41 | 172.69 +/- 43.33 | NS |
| | QDNOCO | 186.00 +/- 52.34 | 167.07 +/- 45.16 | S |

S= significant= $p<0.05$, NS= not significant= $p>0.05$.
QD= quadriceps, EC= eccentric, CO= concentric, wks= weeks, Nm= Newton meters, NO= noninjured extremity, IN= injured extremity.

did not significantly differ. The PCL-noninjured extremity did not differ, significantly, to the control in quadriceps, concentric torque prior to exercise intervention. Nevertheless, at week 12, the PCL-noninjured extremity did significantly exceed the control in concentric, quadriceps torque.

At 120 degrees per second, only the PCL-injured extremity differed from the healthy control in quadriceps eccentric and concentric strength (Table D.2.). They differed prior to treatment but did not after 6 and 12 weeks of rehabilitation.

The hamstring muscle group of the PCL treatment group did not significantly differ from the control group in any regard prior to, during or following eccentric squat rehabilitation (Tables D.3. & D.4.). There were no significant differences between PCL and control groups in eccentric/concentric or quadricep/hamstring ratios during the course of this study (Table D.5. to D.8.).

Hop Test scores did not statistically differ between treatment and control groups at any of the three testing times. However, the PCL group did increase their scores, significantly, between weeks 1-6 and weeks 1-12 (Table D.9.). The subjective, Lysholm Knee Scale scores revealed that, prior to the rehabilitation program, the PCL group did score significantly less than the control group. However, at week 12, the two groups did not differ in scores and the PCL group did improve significantly following the program (Table D.9.).

**Table of Means D.2.**
**Treatment vs. Control Group**

QUADRICEP MUSCLE GROUP @ 120 degrees per second

| TIME | MODALITY | AVERAGE PEAK TORQUE (Nm) | | |
|---|---|---|---|---|
| | | TREATMENT GROUP | CONTROL GROUP | |
| 0wks | QDINEC | 158.31 +/- 60.91 | 202.92 +/- 53.86 | S |
| | QDNOEC | 169.31 +/- 58.46 | 191.00 +/- 46.82 | NS |
| | QDINCO | 151.85 +/- 41.61 | 166.85 +/- 31.46 | S |
| | QDNOCO | 153.15 +/- 40.06 | 166.85 +/- 32.58 | NS |
| 6wks | QDINEC | 185.15 +/- 57.34 | 212.54 +/- 56.15 | NS |
| | QDNOEC | 181.77 +/- 61.06 | 192.62 +/- 45.20 | NS |
| | QDINCO | 159.46 +/- 41.70 | 171.62 +/- 36.15 | NS |
| | QDNOCO | 158.38 +/- 50.76 | 162.69 +/- 34.22 | NS |
| 12wks | QDINEC | 213.15 +/- 69.56 | 202.23 +/- 46.33 | NS |
| | QDNOEC | 193.46 +/- 40.59 | 198.69 +/- 47.73 | NS |
| | QDINCO | 171.15 +/- 48.76 | 165.62 +/- 39.40 | NS |
| | QDNOCO | 165.00 +/- 43.04 | 159.00 +/- 39.77 | NS |

S= significant= $p<0.05$, NS= not significant= $p>0.05$.
QD= quadriceps, EC= eccentric, CO= concentric, wks= weeks, Nm= Newton meters, NO= noninjured extremity, IN= injured extremity.

**Table of Means D.3.**
**Treatment vs. Control Group**

HAMSTRING MUSCLE GROUP @ 60 degrees per second

| TIME | MODALITY | AVERAGE PEAK TORQUE (Nm) TREATMENT GROUP | CONTROL GROUP | |
|---|---|---|---|---|
| 0wks | HMINEC | 95.08 +/- 29.17 | 121.77 +/- 26.76 | NS |
| | HMNOEC | 97.92 +/- 29.19 | 122.00 +/- 39.30 | NS |
| | HMINCO | 88.23 +/- 26.92 | 101.38 +/- 23.82 | NS |
| | HMNOCO | 86.08 +/- 23.86 | 100.08 +/- 30.17 | NS |
| 6wks | HMINEC | 105.69 +/- 33.89 | 130.38 +/- 38.22 | NS |
| | HMNOEC | 109.92 +/- 30.30 | 124.62 +/- 30.56 | NS |
| | HMINCO | 98.46 +/- 28.60 | 103.77 +/- 27.49 | NS |
| | HMNOCO | 100.69 +/- 27.03 | 102.69 +/- 21.90 | NS |
| 12wks | HMINEC | 106.15 +/- 29.80 | 115.23 +/- 30.52 | NS |
| | HMNOEC | 114.69 +/- 32.32 | 115.62 +/- 33.39 | NS |
| | HMINCO | 98.85 +/- 29.30 | 100.46 +/- 26.77 | NS |
| | HMNOCO | 99.62 +/- 24.09 | 96.54 +/- 26.26 | NS |

S= significant= p<0.05, NS= not significant= p>0.05.
HM= hamstrings, EC= eccentric, CO= concentric, wks= weeks, Nm= Newton meters, NO= noninjured extremity, IN= injured extremity.

**Table of Means D.4.**
**Treatment vs. Control Group**

HAMSTRING MUSCLE GROUP @ 120 degrees per second

| TIME | MODALITY | AVERAGE PEAK TORQUE (Nm) | | |
|---|---|---|---|---|
| | | TREATMENT GROUP | CONTROL GROUP | |
| 0wks | HMINEC | 95.23 +/- 41.44 | 119.15 +/- 36.09 | NS |
| | HMNOEC | 103.62 +/- 31.07 | 112.69 +/- 37.88 | NS |
| | HMINCO | 80.31 +/- 30.06 | 94.31 +/- 24.98 | NS |
| | HMNOCO | 80.00 +/- 26.10 | 92.23 +/- 26.10 | NS |
| 6wks | HMINEC | 106.53 +/- 38.87 | 135.46 +/- 39.88 | NS |
| | HMNOEC | 110.00 +/- 32.74 | 130.15 +/- 41.44 | NS |
| | HMINCO | 89.69 +/- 30.05 | 106.85 +/- 34.70 | NS |
| | HMNOCO | 86.00 +/- 26.70 | 103.07 +/- 29.65 | NS |
| 12wks | HMINEC | 111.69 +/- 29.46 | 128.31 +/- 33.56 | NS |
| | HMNOEC | 116.69 +/- 28.48 | 132.00 +/- 37.85 | NS |
| | HMINCO | 93.38 +/- 33.17 | 100.31 +/- 25.42 | NS |
| | HMNOCO | 91.92 +/- 26.86 | 101.08 +/- 29.12 | NS |

S= significant= $p<0.05$, NS= not significant= $p>0.05$.
HM= hamstrings, EC= eccentric, CO= concentric, wks= weeks, Nm= Newton meters, NO= noninjured extremity, IN= injured extremity.

**Table of Means D.5.**
**Treatment vs. Control Group**

ECCENTRIC/CONCENTRIC STRENGTH RATIOS @ 60 degrees per second

| TIME | MODALITY | E/C RATIO TREATMENT GROUP | CONTROL GROUP | |
|---|---|---|---|---|
| 0wks | QDIN E/C | 0.95 +/- 0.22 | 1.09 +/- 0.17 | NS |
| | QDNO E/C | 0.98 +/- 0.18 | 1.16 +/- 0.29 | NS |
| | HMIN E/C | 1.09 +/- 0.21 | 1.22 +/- 0.15 | NS |
| | HMNO E/C | 1.14 +/- 0.14 | 1.22 +/- 0.12 | NS |
| 6wks | QDIN E/C | 1.02 +/- 0.18 | 1.10 +/- 0.12 | NS |
| | QDNO E/C | 1.00 +/- 0.16 | 1.11 +/- 0.15 | NS |
| | HMIN E/C | 1.12 +/- 0.21 | 1.26 +/- 0.20 | NS |
| | HMNO E/C | 1.10 +/- 0.16 | 1.21 +/- 0.13 | NS |
| 12wks | QDIN E/C | 1.06 +/- 0.19 | 1.15 +/- 0.15 | NS |
| | QDNO E/C | 1.08 +/- 0.24 | 1.16 +/- 0.14 | NS |
| | HMIN E/C | 1.09 +/- 0.13 | 1.16 +/- 0.20 | NS |
| | HMNO E/C | 1.14 +/- 0.16 | 1.20 +/- 0.16 | NS |

S= significant= $p<0.05$, NS= not significant= $p>0.05$.
HM= hamstrings, QD= quadrioceps, E/C= eccentric/concentric, Nm= Newton meters, NO= noninjured extremity, IN= injured extremity, wks= weeks.

**Table of Means D.6.**
**Treatment vs. Control Group**

ECCENTRIC/CONCENTRIC STRENGTH RATIOS @ 120 degrees per second

| TIME | MODALITY | E/C RATIO TREATMENT GROUP | CONTROL GROUP | |
|---|---|---|---|---|
| 0wks | QDIN E/C | 1.03 +/- 0.24 | 1.21 +/- 0.23 | NS |
| | QDNO E/C | 1.11 +/- 0.21 | 1.16 +/- 0.22 | NS |
| | HMIN E/C | 1.18 +/- 0.19 | 1.28 +/- 0.25 | NS |
| | HMNO E/C | 1.36 +/- 0.37 | 1.24 +/- 0.21 | NS |
| 6wks | QDIN E/C | 1.17 +/- 0.23 | 1.23 +/- 0.11 | NS |
| | QDNO E/C | 1.18 +/- 0.25 | 1.20 +/- 0.22 | NS |
| | HMIN E/C | 1.19 +/- 0.19 | 1.29 +/- 0.16 | NS |
| | HMNO E/C | 1.30 +/- 0.16 | 1.32 +/- 0.14 | NS |
| 12wks | QDIN E/C | 1.25 +/- 0.22 | 1.24 +/- 0.15 | NS |
| | QDNO E/C | 1.20 +/- 0.25 | 1.29 +/- 0.17 | NS |
| | HMIN E/C | 1.27 +/- 0.32 | 1.29 +/- 0.18 | NS |
| | HMNO E/C | 1.30 +/- 0.22 | 1.34 +/- 0.21 | NS |

S= significant= $p<0.05$, NS= not significant= $p>0.05$.
HM= hamstrings, QD= quadrioceps, E/C= eccentric/concentric, Nm= Newton meters, NO= noninjured extremity, IN= injured extremity, wks= weeks.

**Table of Means D.7.**
**Treatment vs. Control Group**

HAMSTRING/QUADRICEP STRENGTH RATIOS @ 60 degrees per second

| TIME | MODALITY | H/Q RATIO TREATMENT GROUP | CONTROL GROUP | |
|---|---|---|---|---|
| 0wks | INEC H/Q | 0.58 +/- 0.11 | 0.58 +/- 0.06 | NS |
| | NOEC H/Q | 0.61 +/- 0.10 | 0.60 +/- 0.16 | NS |
| | INCO H/Q | 0.51 +/- 0.11 | 0.53 +/- 0.09 | NS |
| | NOCO H/Q | 0.53 +/- 0.10 | 0.56 +/- 0.15 | NS |
| 6wks | INEC H/Q | 0.58 +/- 0.11 | 0.63 +/- 0.12 | NS |
| | NOEC H/Q | 0.61 +/- 0.14 | 0.64 +/- 0.11 | NS |
| | INCO H/Q | 0.54 +/- 0.09 | 0.56 +/- 0.10 | NS |
| | NOCO H/Q | 0.55 +/- 0.12 | 0.59 +/- 0.10 | NS |
| 12wks | INEC H/Q | 0.55 +/- 0.12 | 0.60 +/- 0.14 | NS |
| | NOEC H/Q | 0.60 +/- 0.15 | 0.61 +/- 0.09 | NS |
| | INCO H/Q | 0.53 +/- 0.09 | 0.59 +/- 0.11 | NS |
| | NOCO H/Q | 0.55 +/- 0.12 | 0.59 +/- 0.09 | NS |

S= significant= $p<0.05$, NS= not significant= $p>0.05$.
H/Q=hamstrings/quadricep,Nm= Newton meters, NO= noninjured extremity, IN= injured extremity, wks= weeks, EC=eccentric, CO=concentric.

**Table of Means D.8.**
**Treatment vs. Control Group**

HAMSTRING/QUADRICEP STRENGTH RATIOS @ 120 degrees per second

| TIME | MODALITY | H/Q RATIO TREATMENT GROUP | CONTROL GROUP | |
|---|---|---|---|---|
| 0wks | INEC H/Q | 0.60 +/- 0.17 | 0.58 +/- 0.12 | NS |
| | NOEC H/Q | 0.63 +/- 0.12 | 0.60 +/- 0.11 | NS |
| | INCO H/Q | 0.52 +/- 0.15 | 0.56 +/- 0.10 | NS |
| | NOCO H/Q | 0.53 +/- 0.10 | 0.55 +/- 0.15 | NS |
| 6wks | INEC H/Q | 0.58 +/- 0.12 | 0.64 +/- 0.08 | NS |
| | NOEC H/Q | 0.62 +/- 0.12 | 0.70 +/- 0.11 | NS |
| | INCO H/Q | 0.56 +/- 0.09 | 0.61 +/- 0.10 | NS |
| | NOCO H/Q | 0.56 +/- 0.11 | 0.63 +/- 0.12 | NS |
| 12wks | INEC H/Q | 0.55 +/- 0.16 | 0.64 +/- 0.13 | NS |
| | NOEC H/Q | 0.61 +/- 0.11 | 0.68 +/- 0.14 | NS |
| | INCO H/Q | 0.54 +/- 0.13 | 0.61 +/- 0.12 | NS |
| | NOCO H/Q | 0.57 +/- 0.17 | 0.62 +/- 0.09 | NS |

S= significant= $p<0.05$, NS= not significant= $p>0.05$.
H/Q=hamstrings/quadricep, Nm= Newton meters, NO= noninjured extremity, IN= injured extremity, wks= weeks, EC=eccentric, CO=concentric.

**Table of Means D.9.**
**Treatment vs. Control Group**

HOP TEST & LYSHOLM KNEE SCORE SCALE

| TIME | MODALITY | TREATMENT GROUP | CONTROL GROUP | |
|---|---|---|---|---|
| 0wks | INJ HOP | 187.50 +/- 18.68cm | 206.63 +/- 16.00cm | NS |
| | NON HOP | 193.25 +/- 16.51cm | 208.63 +/- 18.42cm | NS |
| | LYSHOLM | 80.80 +/- 11.83 | 96.15 +/- 7.50 | S |
| 6wks | INJ HOP | 199.63 +/- 18.32 | 214.50 +/- 14.54 | NS |
| | NON HOP | 203.36 +/- 19.76 | 215.63 +/- 12.88 | NS |
| | LYSHOLM | 91.23 +/- 4.64 | 96.62 +/- 7.51 | S |
| 12wks | INJ HOP | 203.88 +/- 20.46 | 214.13 +/- 16.48 | NS |
| | NON HOP | 207.75 +/- 16.84 | 217.63 +/- 9.90 | NS |
| | LYSHOLM | 92.00 +/- 10.58 | 96.92 +/- 6.63 | NS |

S= significant= $p<0.05$, NS= not significant= $p>0.05$.
INJ=injured extremity, NON= noninjured extremity, cm= centimeters, wks= weeks.

**Discussion**

Chronic posterior cruciate ligament (PCL) insufficiency can present several subjective and functional complications. The literature reports on several including patellofemoral pain (9,10,12,21,49), clinical chondromalacia patella (10), tricompartmental osteoarthritis (10), difficulty with stair descent (7,9,10,12) and sudden changes in direction (1), instability and episodes of giving-away (1,9). Inorder to effectively manage these complications, the sports medicine practitioner must, first, identify why they might be associated with chronic, PCL-insufficiency.

Pilot study results, and pretreatment measures in the present study, clearly indicate the presence of eccentric weakness in the quadriceps of both the injured and noninjured extremities of isolated PCL-injured subjects. This observation is supported by the literature findings that in the quadriceps of healthy individuals, eccentric torque was significantly greater than concentric torque at all reported isokinetic testing velocities (18,35,53,54). In the pilot study, and at week 0 of the present study, the quadriceps of the PCL subjects were not significantly stronger in eccentric torque than concentric for either extremity. The presence of quadriceps, eccentric weakness became the basis for the development of a home exercise program and provided insight into why some of the post-injury complications may exist.

Prior to the initiation of the current study, it was the intent of the primary investigators to identify the strength deficits associated with chronic, isolated PCL-injury and, then, to design an appropriate home exercise program. A literature review and interviews with local physiotherapists clearly indicated that quadriceps eccentric strengthening should be the focus of such a home program but that a holistic approach need be taken to improve total lower extremity kinematics.

Functional rehabilitation with eccentric kinetic chain exercise was chosen as the most appropriate means of acheiving these rehabilitation goals. Several authors (3,29,31-33,38,39,47) have advocated kinetic chain exercise because it minimizes anteroposterior tibiofemoral shear forces (29,33) and ensures even distribution of compressive forcess on the articular cartilage (3). Baratta et al.(3) and Solomonow et al. (38,39) recommend kinetic chain exercise because it reproduces concurrent shift, or muscular coactivation, of the antagonist muscle group as a regulator of anteroposterior (A-P) translation during active knee extension and flexion.

Lastly, quadriceps eccentric kinetic chain exercise is also very "specific" to the injury and its chronic complications. As many authors have stressed (3,31-33,38-39) specificity is the key to designing an appropriate exercise rehabilitation program.

The eccentric drop squat program currently employed at the Allan McGavin Sports Medicine Centre was modified and extended from 6 to 12 weeks in duration. It was the intent of the investigators to develop a program that was performed, daily, and that progressed in difficulty, both daily and weekly. Also, inorder to maximize patient compliance, the program was designed to be fundamentally easy to execute, inexpensive and require little time.

The study included two groups of male subjects; isolated PCL-injured (n=13) and healthy, sedentary individuals (n=13). Both groups were tested isokinetically, functionally and subjectively over a 12-week period. Tests were conducted at 0, 6, and 12 weeks to monitor changes in eccentric and concentric strength, knee function and participant subjectivity. The PCL treatment group consisted of patients who had been diagnosed at the Allan McGavin Sports Medicine Center with isolated PCL injuries.

The nontreatment, control group was employed to both monitor the effects of the treatment and to establish the strength characteristics of healthy individuals. The control group had no history of any knee injury and were not involved in a lower extremity strengthening program during the course of the investigation.

The results of the present investigation have been organized to analyze four distinct relationships; PCL subjects versus treatment, injured versus noninjured extremities in the PCL group, eccentric versus concentric torque characteristics, and PCL versus control group. The remaining discussion will report on the significant findings within each of these comparison categories. All significant findings were determined using one-way and two-way RMANOVA and post hoc comparisons using Tukey's HSD testing. Alpha has been set at $p < 0.05$ for all statistical analysis.

Subjects X treatment analysis was performed using 1X3 RMANOVA with repeated measures on the second factor. Post hoc testing enabled the investigators to determine whether changes in dependent variables occurred in between weeks 1-6, weeks 7-12 or, overall, between weeks 1-12. Only significant findings will be included in the discussion.

At 60 and 120 degrees per second (deg/sec), significant increases in eccentric, quadricep torque occurred over the twelve week treatment in both extremities of the PCL-injured group (Figure A.1., Table A.1.). Significant increases in strength occurred in the first six weeks in the injured extremity (@ 60 and 120 deg/sec) and in the noninjured extremity (@ 60 deg/sec). The injured extremity also increased ($p < 0.05$) between weeks 7-12 (@120 deg/sec). The results strongly indicate that the eccentric squat program was successful in strengthening the quadriceps, eccentrically, and that the injured extremity appeared to respond more favorably at the higher, more

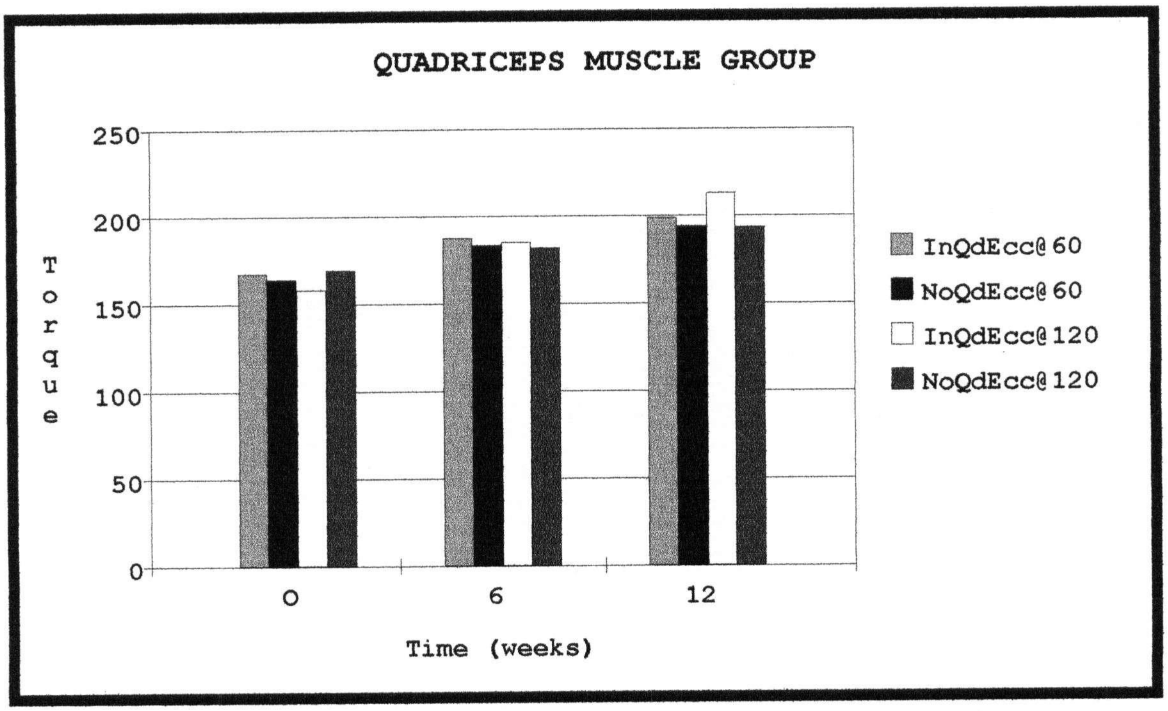


Figure A.1.
Subjects vs. Treatment (Quadriceps, Eccentric Torque)

functional, isokinetic velocity of 120 degrees per second. Increases in concentric, quadriceps torque were not as marked as the eccentric but did occur over the twelve week period in the noninjured extremity (@60 deg/sec) and in the injured extremity (@120 deg/sec)(Figure A.2., Table A.1.).

Interestingly enough, the hamstrings of both extremities in the PCL group increased significantly in both eccentric and concentric torque over the twelve week training program (Figures A.3. & A.4., Table A.2.).

Only the injured extremity of the PCL group had significant increases in quadricep, eccentric/concentric ratios, at 60 and 120 degrees per second (Figure A.5., Table A.3.). The hamstring, eccentric/concentric ratios did not significantly increase during or following the 12-week exercise program (Table A.3.). Eccentric and concentric, hamstring/quadricep ratios also went unchanged over the rehabilitation period (Table A.4.). This can be attributed to the observation that both quadriceps and hamstring did increase significantly in torque as a result of the treatment.

Tegner Hop Test and Lysholm Knee Scale scores responded favorably to the eccentric squat program (Figures A.6. & A.7., Table A.5.). The functional, Hop Test distance scores increased significantly for both extremities in the PCL group. Distances increased significantly between weeks 1-6 and 1-12, but not between weeks 7-12 (Table A.5.). This may indicate that the two-legged squat exercise, that is executed primarily during the first six weeks, has a greater effect on hopping distance.

Similarly, the Lysholm scores increased significantly between weeks 1-6 and weeks 1-12. This subjective questionnaire showed marked improvement in the PCL group's

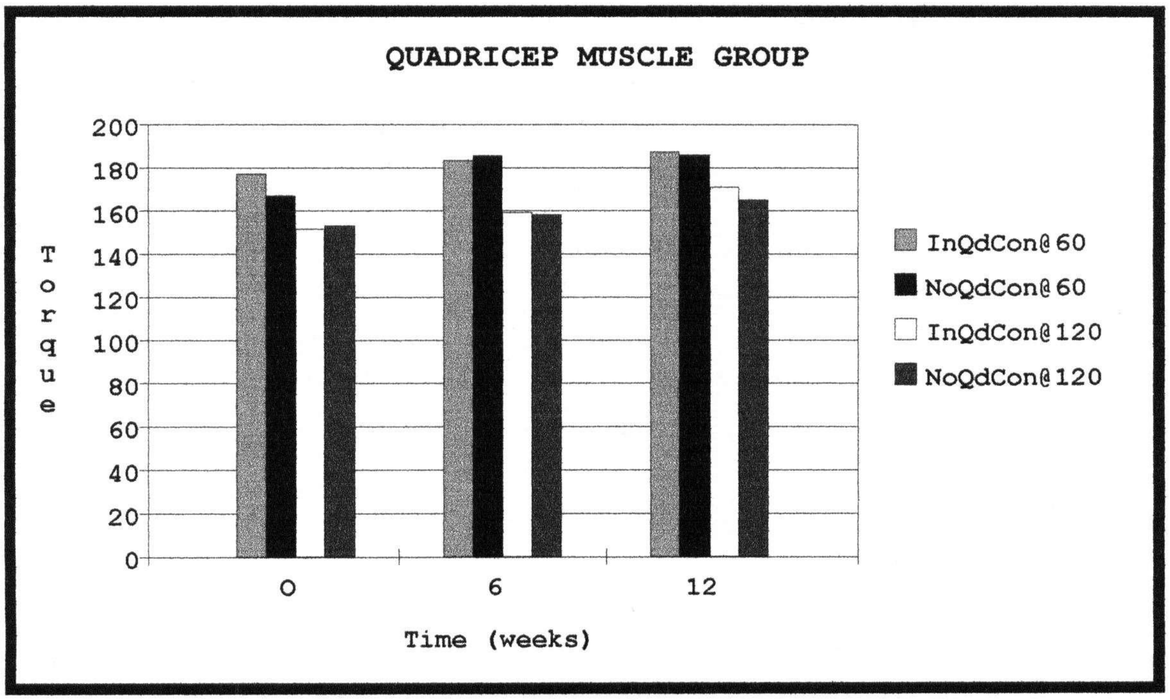


Figure A.2.
Subjects vs. Treatment (Quadriceps, Concentric Torque)

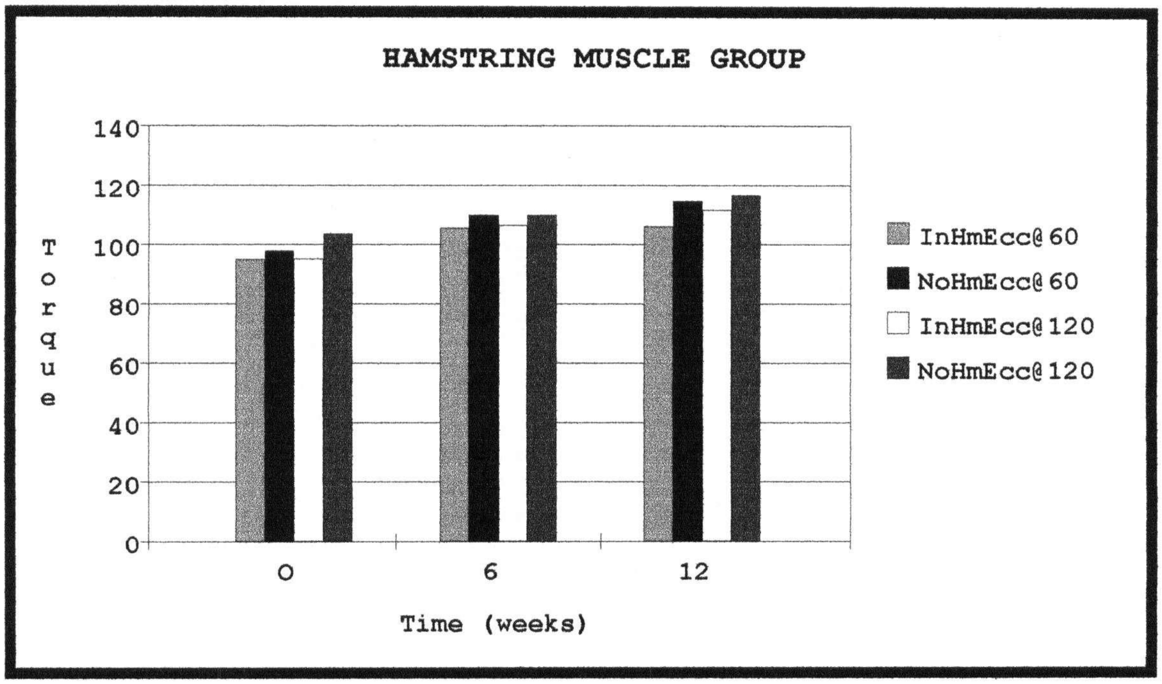


Figure A.3.
Subjects vs. Treatment (Hamstring, Eccentric Torque)

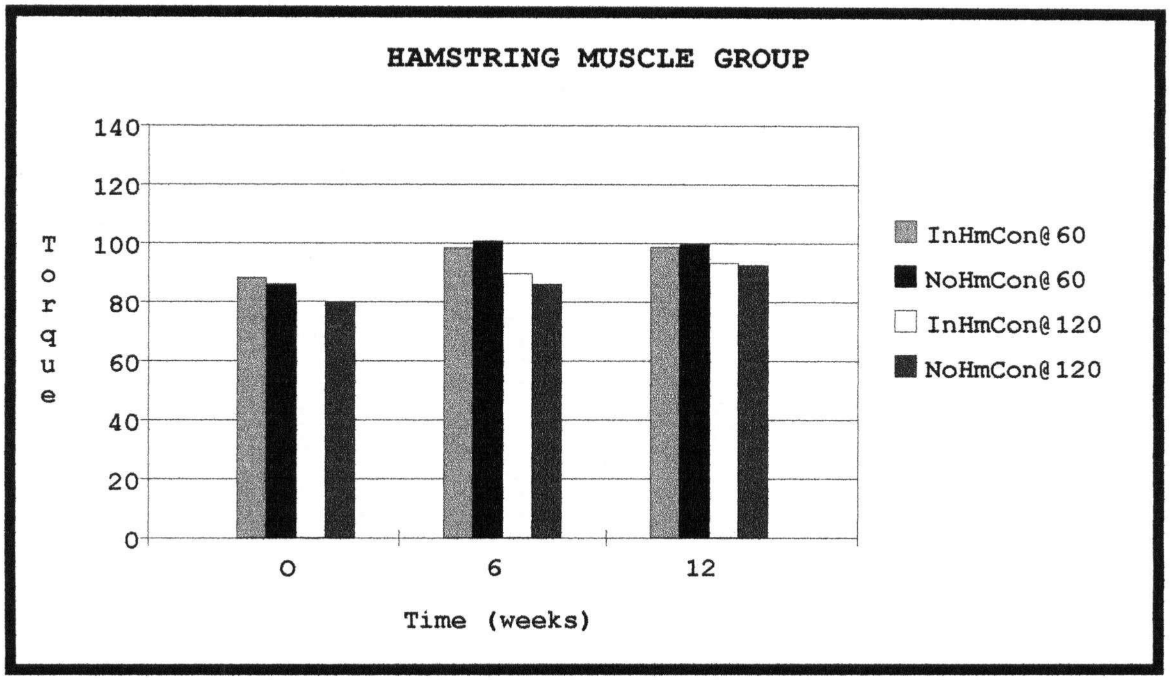


Figure A.4.
Subjects vs. Treatment (Hamstring, Concentric Torque)

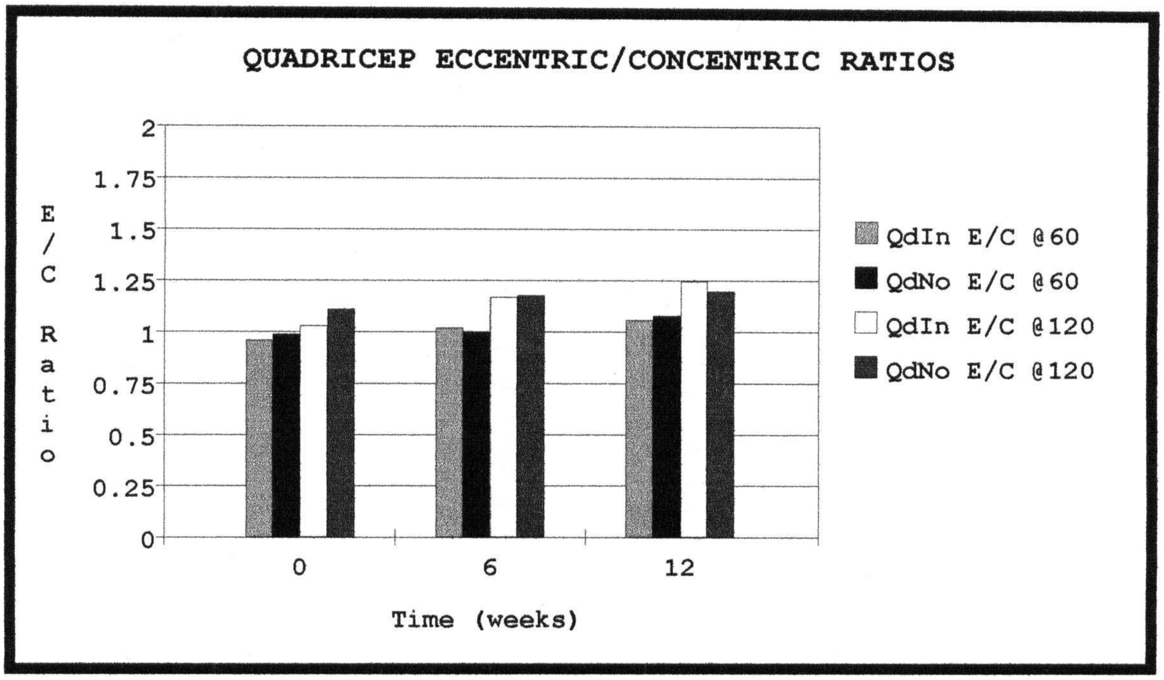


Figure A.5.
Subjects vs. Treatment (Quadriceps, Eccentric/Concentric Ratio)

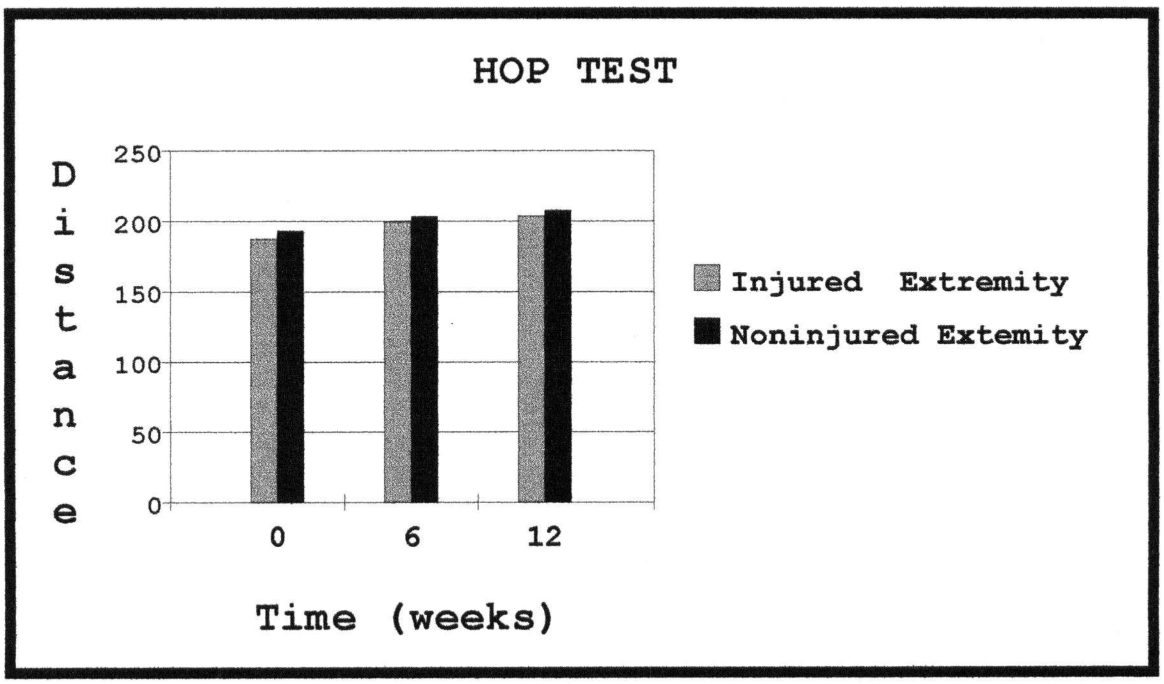


Figure A.6.
Subjects vs. Treatment (Tegner Hop Test Scores)

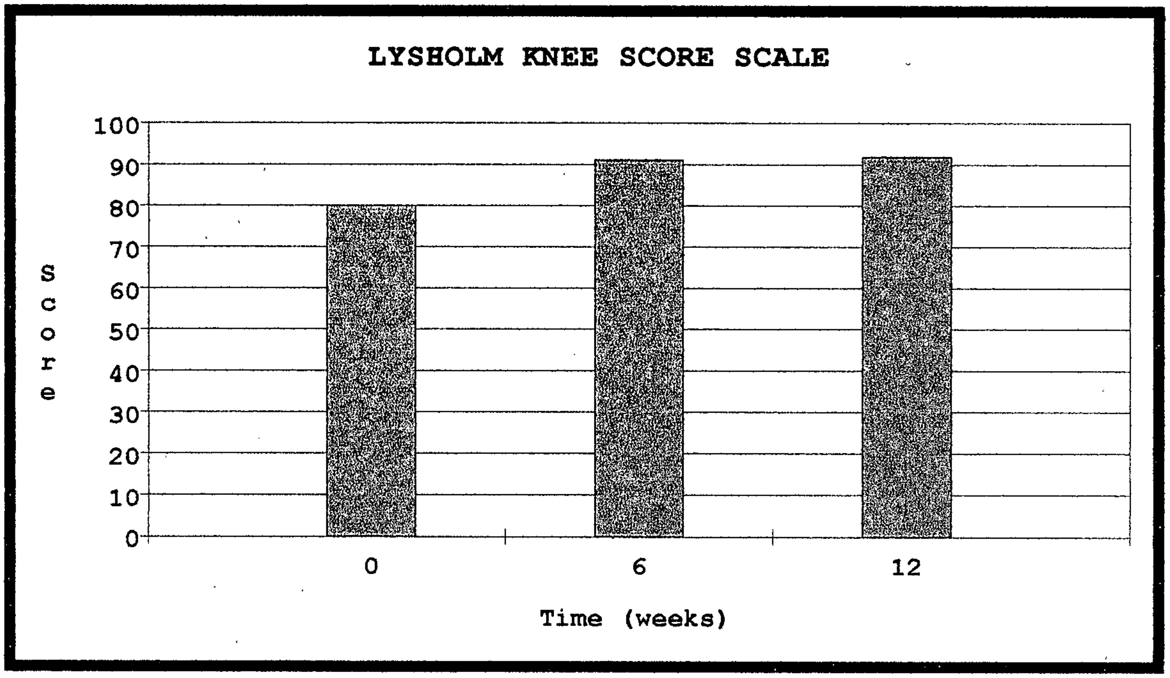


Figure A.7.
Subjects vs. Treatment
Lysholm Knee Scale Scores

perceived knee function and symptomatology following the eccentric exercise rehabilitation (Figure A.7., Table A.5.).

An interesting discovery of the pilot study was the recognition that injured and noninjured extremities did not differ, significantly, in quadriceps strength. In the past, the contralateral side has often been used as a control in comparison with the injured side. Based on the pilot study discovery, it became important to reconfirm these findings in the current study. The 2X3 RMANOVA with repeated measures on the second factor was used to analyze the relationship between injured and noninjured extremities in the PCL treatment group. Post hoc comparisons were done using a two-way, Tukey's HSD test and alpha was maintained at $p < 0.05$.

At 60 and 120 degrees per second (deg/sec), there were no significant differences between extremities in quadriceps eccentric and concentric torque, at any point of the treatment program (Figures B.1. & B.2., Tables B.1. & B.2.). This is an important finding because it reconfirms the pilot study findings which reported no significant differences between the injured and contralateral extremities.

Similarly, extremities did not differ in quadriceps, concentric torque at either testing velocities (Figures B.3. & B.4., Tables B.1 & B.2.). This finding supports the Keller et al. (27) report which did not find any difference between injured and noninjured extremities in quadricep strength. However, later in the discussion differences between PCL-injured and healthy subjects will show that, possibly, the noninjured-side is not the optimal limb to choose as a "healthy" control when analyzing injured-side strength deficiency. The hamstring muscle group (Tables B.3. & B.4.) also presented similar characteristics.

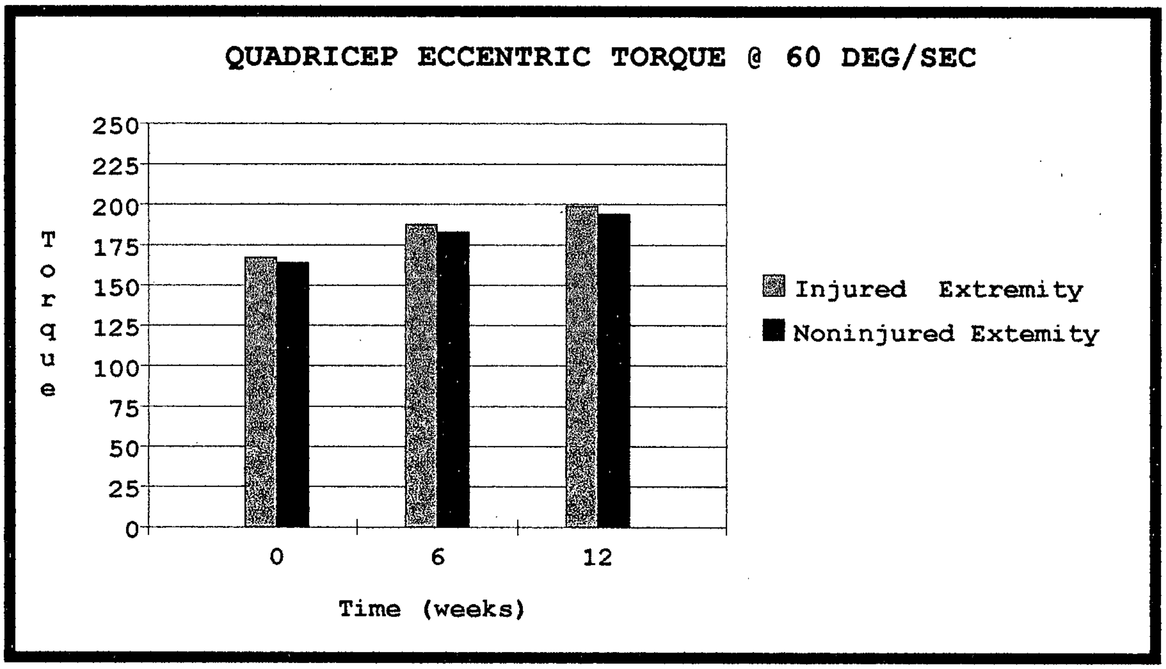


Figure B.1.
Injured vs. Noninjured Extremity
Quadriceps, Eccentric Torque @ 60 degrees per second

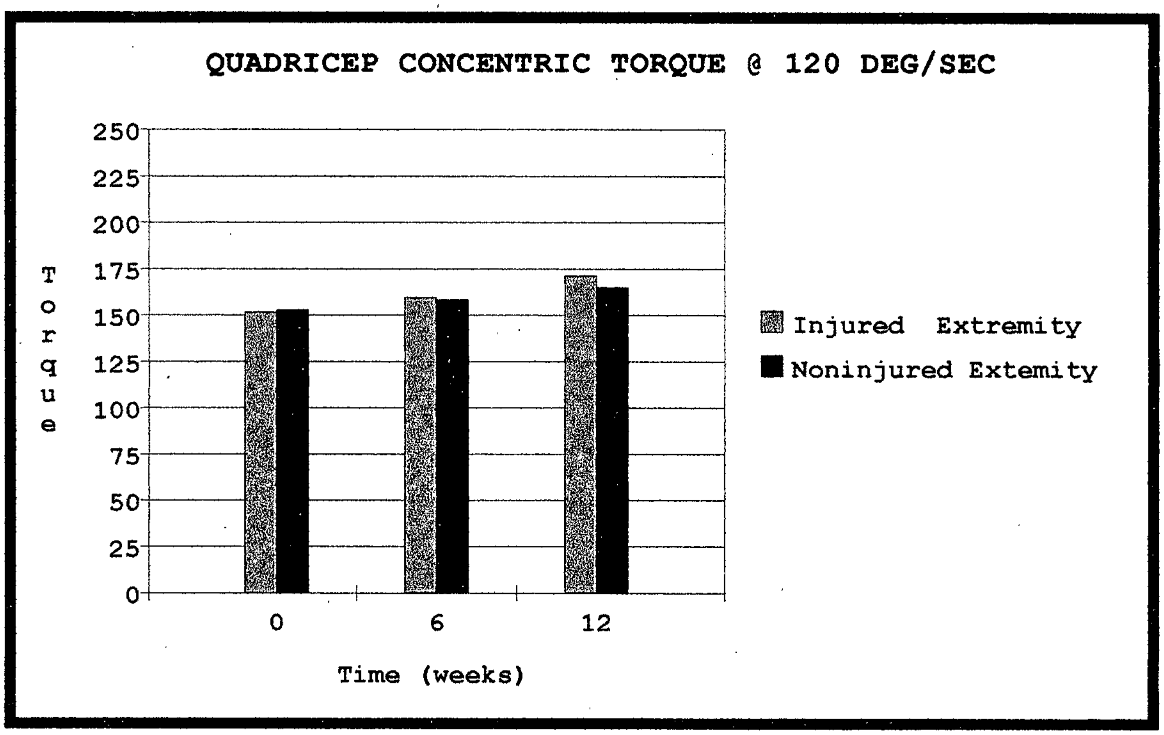


Figure B.2.
Injured vs. Noninjured Extremity
Quadriceps, Concentric Torque @ 120 degrees per second

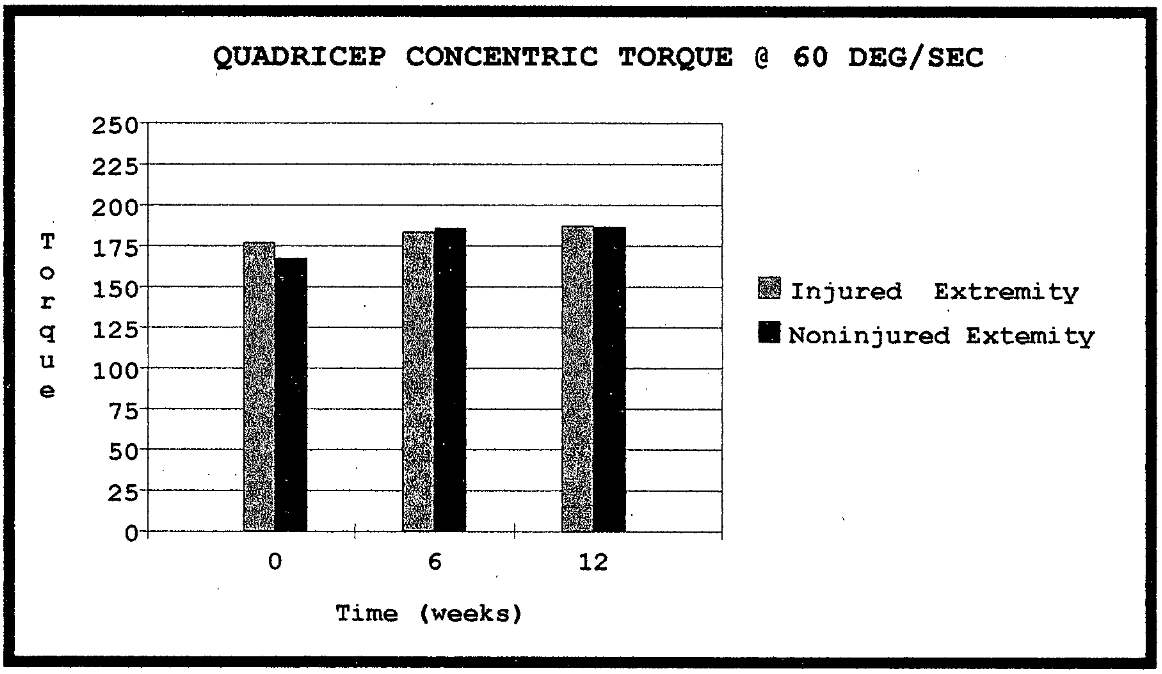


Figure B.3.
Injured vs. Noninjured Extremity
Quadriceps, Concentric Torque @ 60 degrees per second

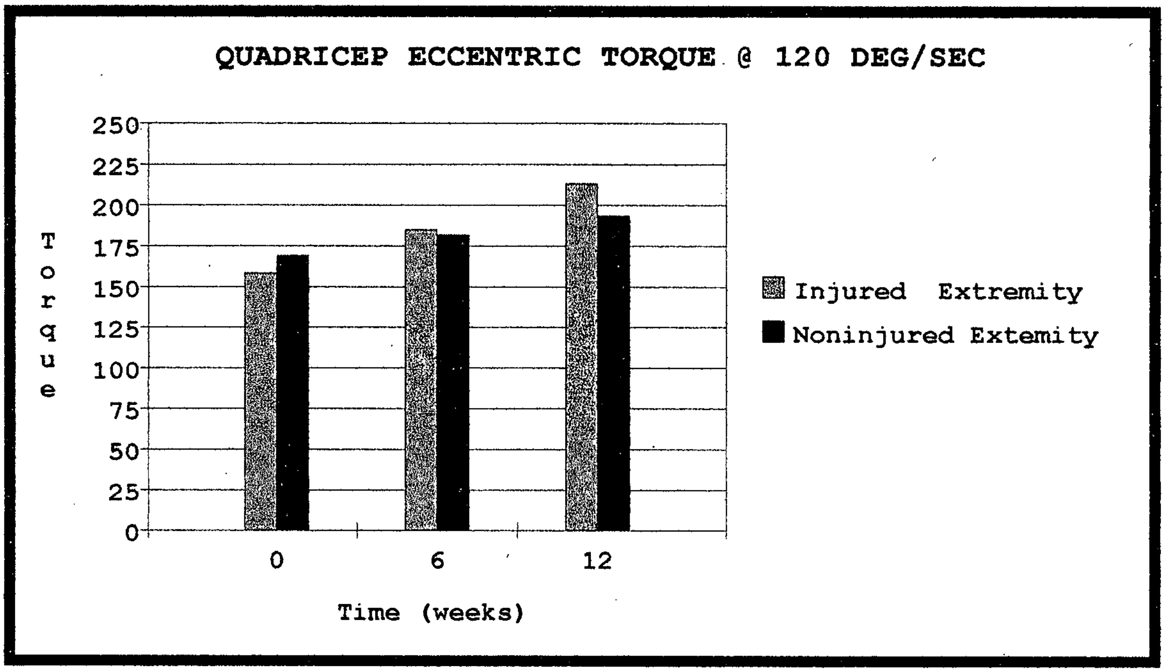


Figure B.4.
Injured vs. Noninjured Extremity
Quadriceps, Eccentric Torque @ 120 degrees per second

As one might predict from the preceding discussion, there were also no significant differences found between extremities in quadriceps, eccentric/concentric ratios (Figures B.5. & B.6., Table B.5.). Similarly, eccentric hamstring/quadriceps ratios (Figure B.7. & B.8., Table B.7.) and Tegner Hop Test scores (Figure B.9., Table B.9.) did not differ, either.

The preceding discussion of the injured/noninjured comparison in the isolated PCL-injured group raises some interesting questions for future knee research. One can only contemplate why eccentric weakness might be present in both extremities of this group rather than only on the injured-side. Perhaps, an avoidance of deceleration-type activity, post-injury, could lead to an eventual strength deficit in the chronic stage of the injury. Most deceleration activities are bipedal and it is reasonable, therefore, to predict that long-term eccentric strength deficits could occur secondary to PCL injury. This hypothesis may further be strengthened when, later, eccentric strength will be compared between the PCL group and the healthy, control group.

The pilot study revealed eccentric, quadriceps weakness and this finding has been supported by literature reports on healthy subjects (18,35,53,54). These investigators have reported that in the quadriceps and hamstrings of healthy individuals the eccentric torque significantly exceeded the concentric torque at all reported isokinetic velocities. There were no significant differences between eccentric and concentric torque in the quadricep muscle groups observed in the pilot study of isolated PCL-injured subjects. It was because of these findings that we concluded that the quadriceps of this sample were weak, eccentrically. The literature has also reported that an eccentric/concentric ratio of 1.25 to 1.30 was present in the quadriceps of healthy subjects (18,35,37,53,54). This could, possibly, be the ideal level to strive for in rehabilitation.

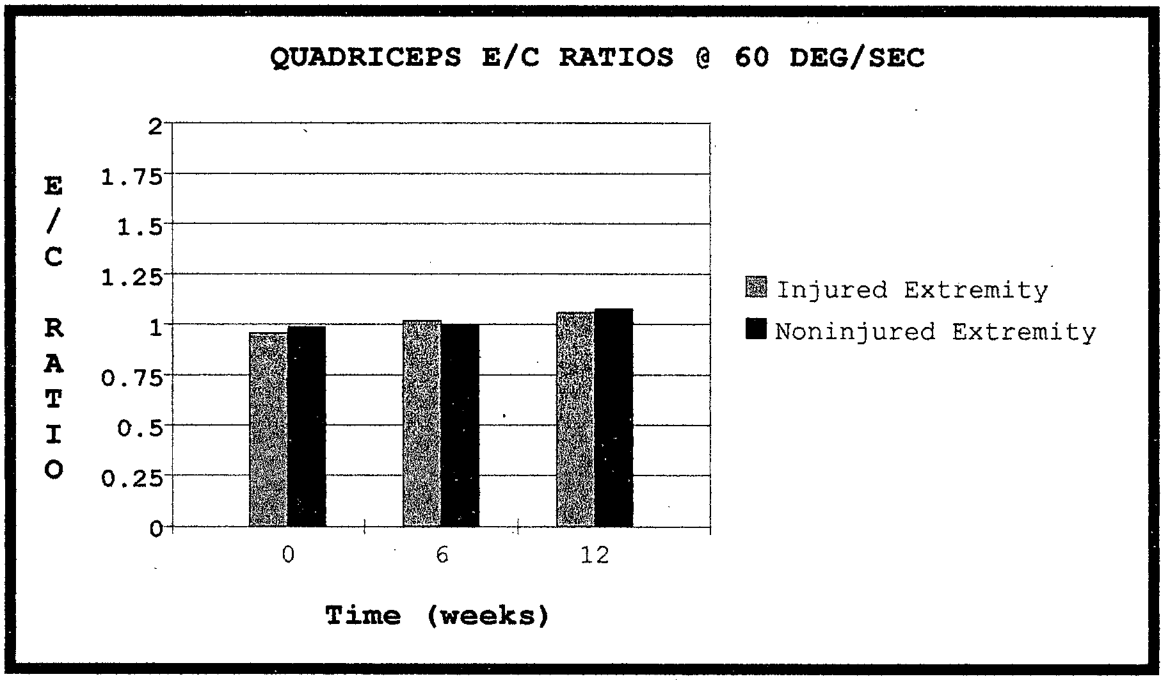


Figure B.5.
Injured vs. Noninjured Extremity
Quadriceps, Eccentric/Concentric Ratio @ 60 degrees per second

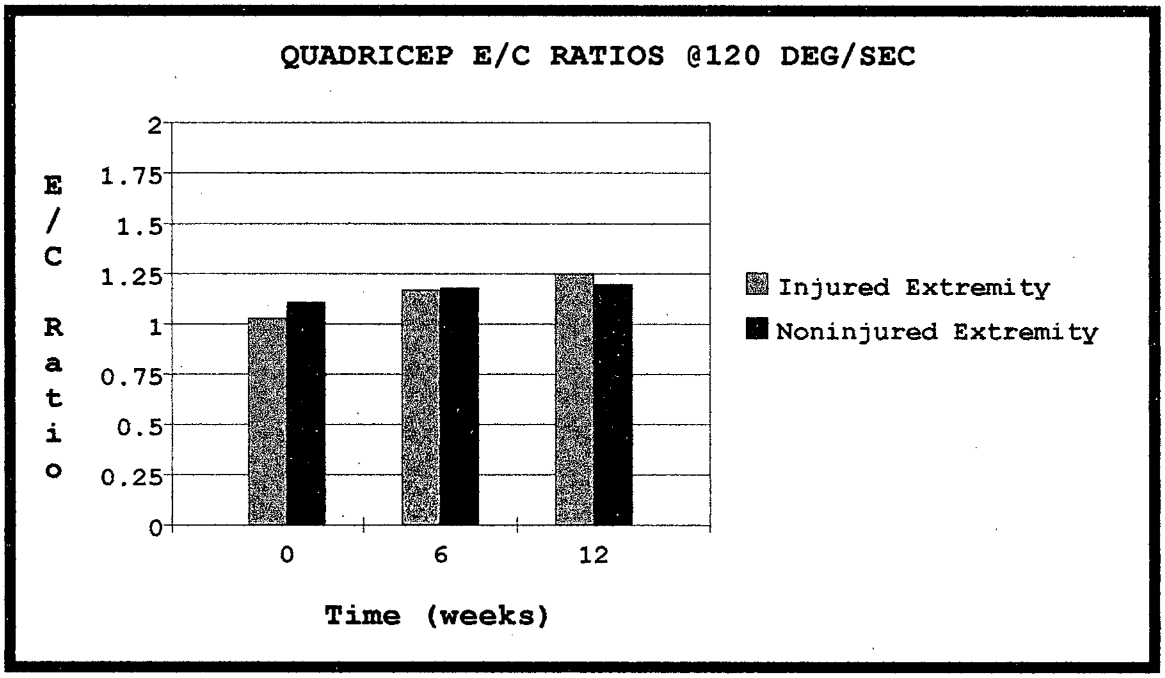


Figure B.6.
Injured vs. Noninjured Extremity
Quadriceps, Eccentric/Concentric Ratio @ 120 degrees per second

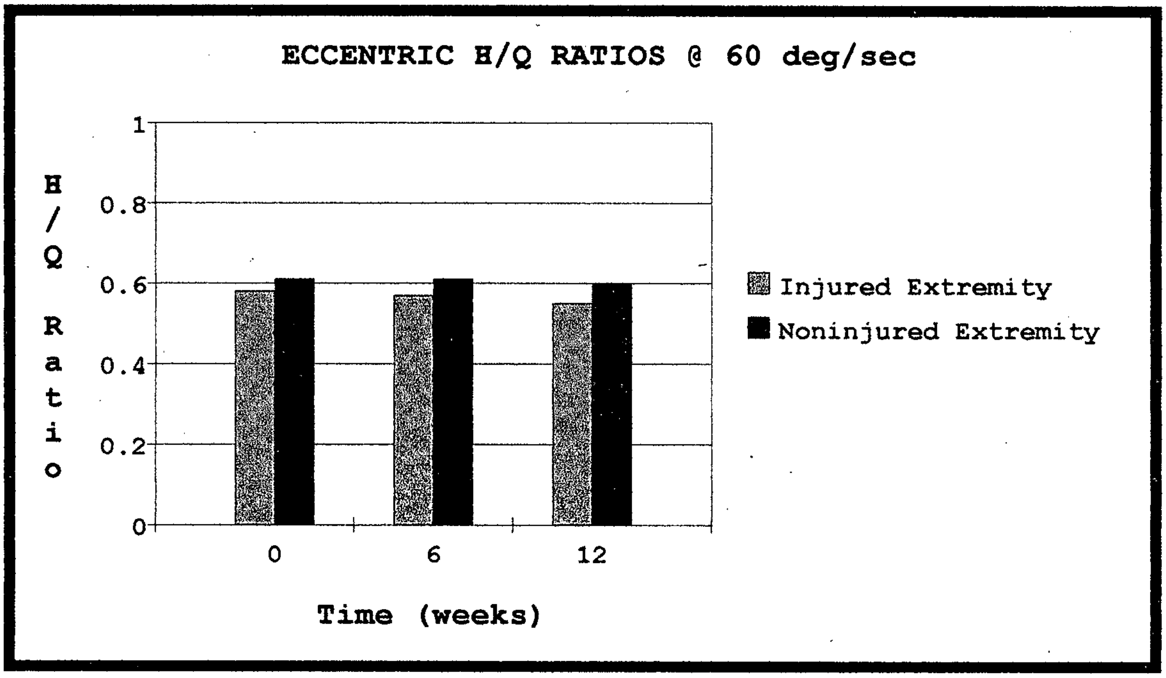


Figure B.7.
Injured vs. Noninjured Extremity
Eccentric, Hamstring/Quadriceps Ratio @ 60 degrees per second

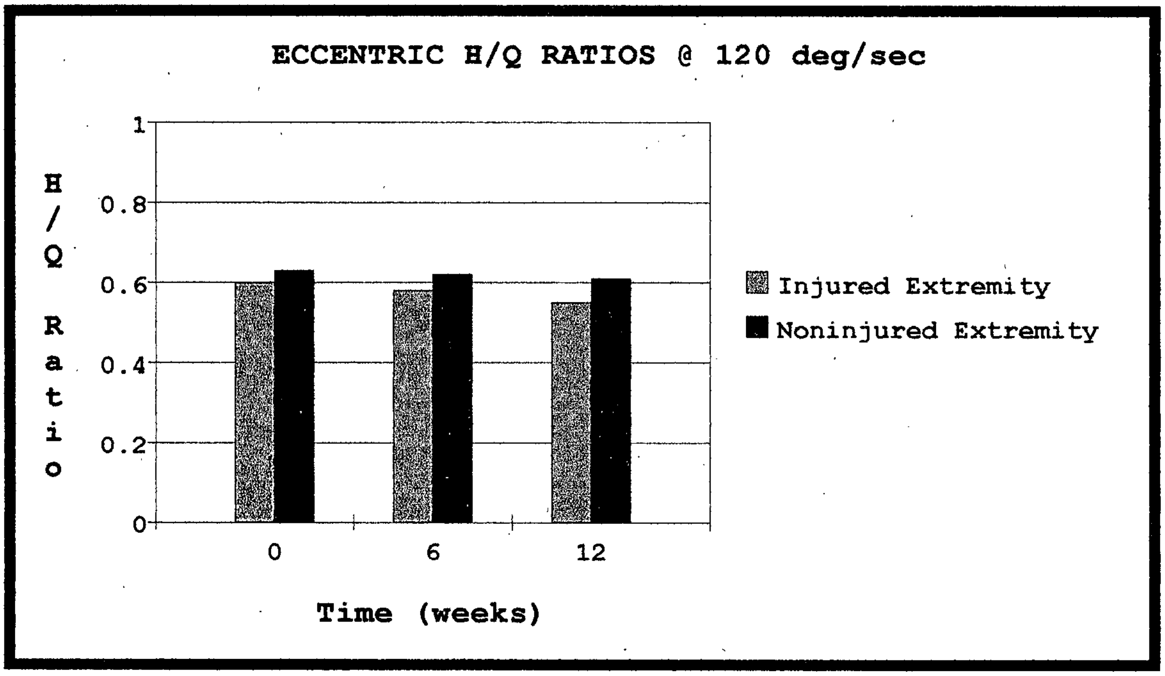


Figure B.8.
Injured vs. Noninjured Extremity
Eccentric, Hamstring/Quadriceps Ratio @ 120 degrees per second

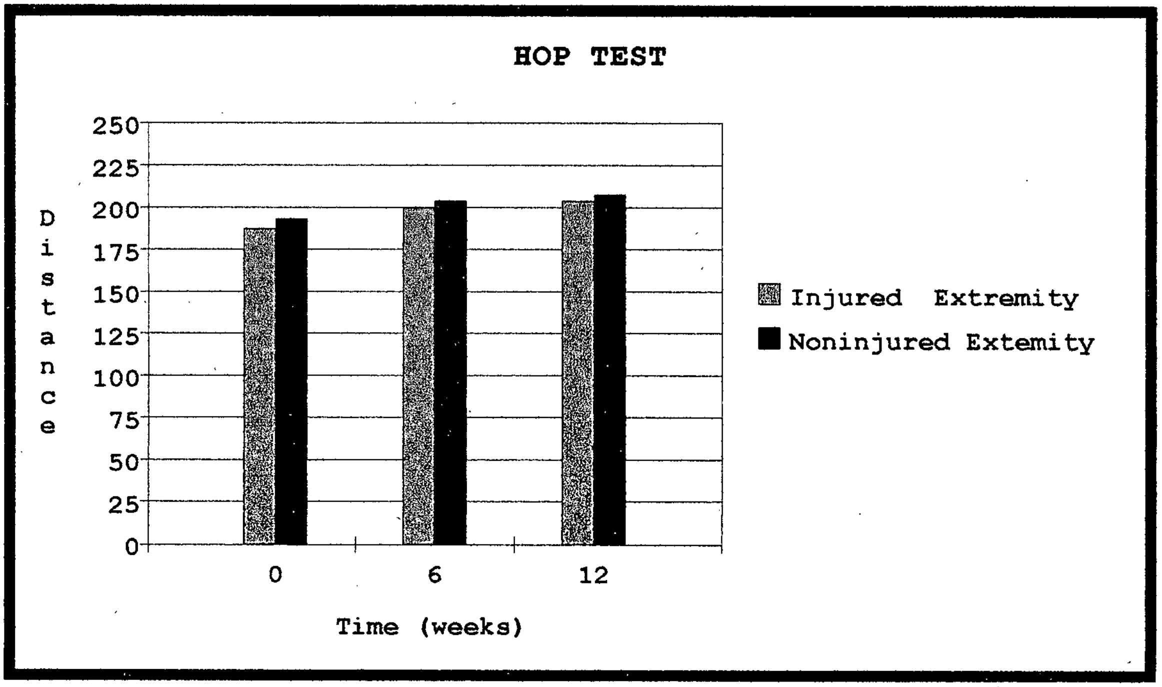


Figure B.9.
Injured vs. Noninjured Extremity
Tegner Hop Test Score

The present investigation also analyzed the eccentric/concentric relationship in a similar sample but also measured the effect of an eccentric squat program over the 12-week course. At 60 degrees per second, quadriceps eccentric torque did not differ from the concentric torque prior to, during, or following the rehabilitation program. However, with careful examination, the data (Figure C.1., Table C.1.) clearly indicates that prior to treatment, the concentric torque of the injured extremity was approximately 10 Newton meters (Nm) greater than the eccentric torque. Following the eccentric program, the eccentric torque exceeded the concentric torque by approximately 11 Nm. This pattern of strength gain, although not significant, is certainly noteworthy and represents a favorable improvement in the quadriceps of the injured extremity.

At 120 degrees per second, the eccentric torque of the injured extremity was not significantly greater than the concentric torque at the start of treatment (Figure C.2., Table C.2.). However, following 6 weeks and 12 weeks of exercise, the eccentric torque was significantly greater than the concentric torque. This illustrates that the eccentric squat program resulted in an increase of eccentric, quadriceps strength that better resembles that which has been reported in the literature as healthy (18,35,53,54). This is a significant finding that supports the effectiveness of the eccentric squat program as an optimal means of returning quadriceps, eccentric torque to healthy levels.

The final section of this discussion will compare the isolated PCL-injured group (treatment) to the healthy, sedentary control group (nontreatment). Prior to statisical analysis, each PCL subject was paired with a healthy, control subject. Subjects were paired on the basis of body habitus and age. The injured extremity of the PCL group was compared to the corresponding extremity of the control group (i.e. left-side, PCL-injured was paired with control, left extremity).

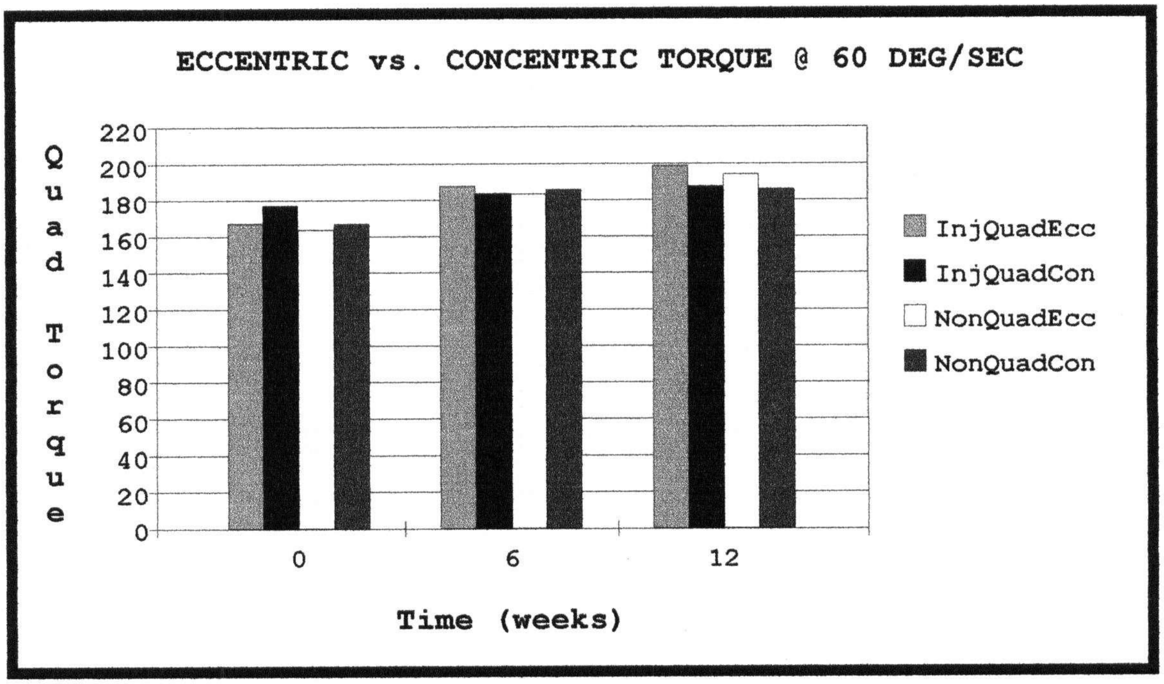


Figure C.1.
Eccentric vs. Concentric Torque @ 60 degrees per second

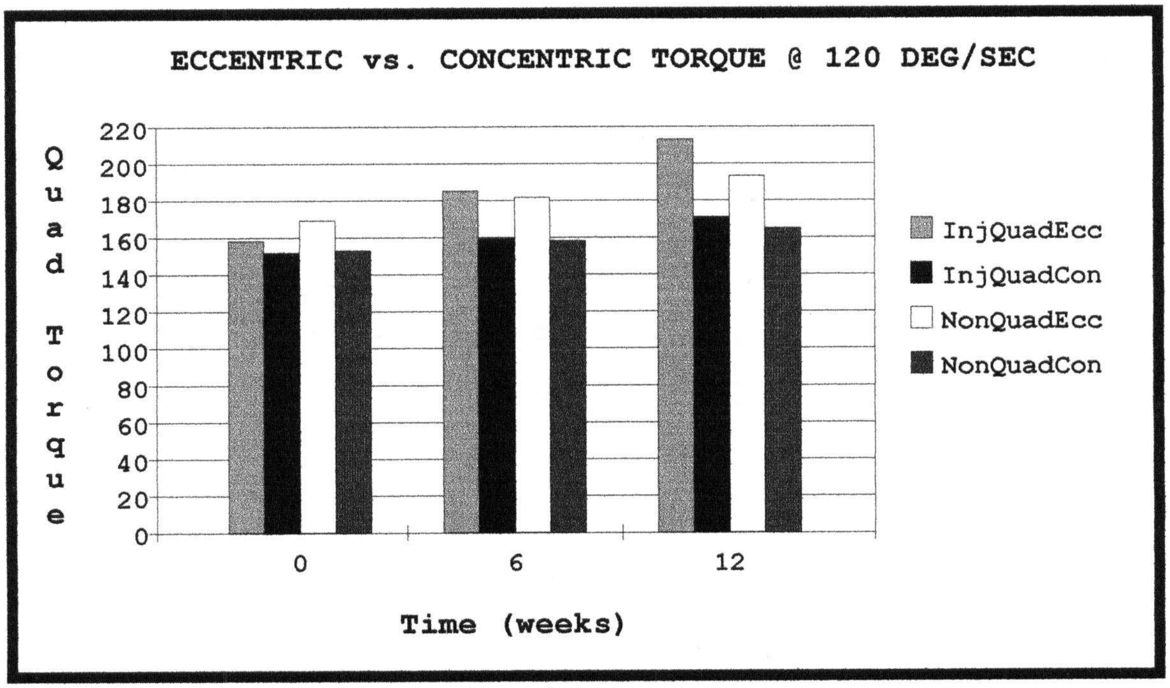


Figure C.2.
Eccentric vs. Concentric Torque @ 120 degrees per second

At 0 weeks, the PCL-injured group was significantly weaker than the control group in quadriceps, eccentric torque (@60 deg/sec)(Figure D.1., Table D.1.). Both the injured and noninjured-side quadriceps were weaker ($p<0.05$) than the corresponding extremities of the control group. The injured-side, quadriceps were also significantly weaker than the control group in concentric torque.

Following 6 weeks of treatment, only the injured-side, quadriceps still remained significantly weaker than the control in eccentric torque. At the completion of the eccentric program, there were no differences between the two groups in either eccentric or concentric torque. This, again, illustrates that the eccentric squat program was effective in restoring the strength of the PCL group to healthy measures.

Similarly at 120 degrees per second, prior to treatment the injured-side of the PCL group was significantly weaker than the control in both concentric and eccentric torque (Figure D.2., Table D.2.). Following exercise intervention, this discrepancy had resolved and the injured-side, quadriceps were stronger than the control extremity, although not significantly.

There were no significant differences between the PCL and control groups in hamstring, eccentric and concentric torque (Tables D.3. & D.4.), eccentric/concentric ratios (Figures D.3 & D.4.), hamstring/quadricep ratios (Tables D.7 & D.8.), and in Tegner Hop Test results (Figure D.5.).

Lastly, the subjective Lysholm Knee Scale was used to monitor improvements in perceived knee function and symptomatology. Prior to exercise therapy, Lysholm scores were significantly lower for the PCL group than the control group (Figure D.6.,

Table D.9.). At the completion of the prescribed exercise program, Lysholm scores did not differ, significantly. The areas which most notably improved on the Lysholm Knee Scale Score were under the categories of pain and instability.

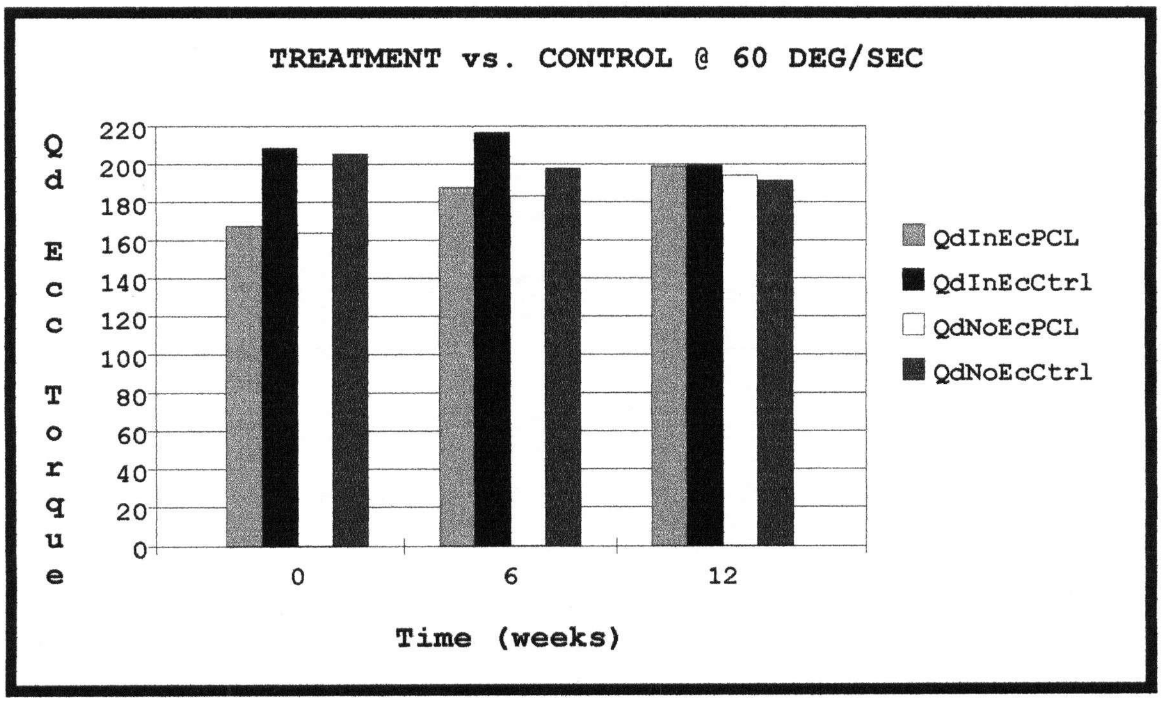


Figure D.1.
Treatment vs. Control Group
Quadriceps, Eccentric Torque @ 60 degrees per second

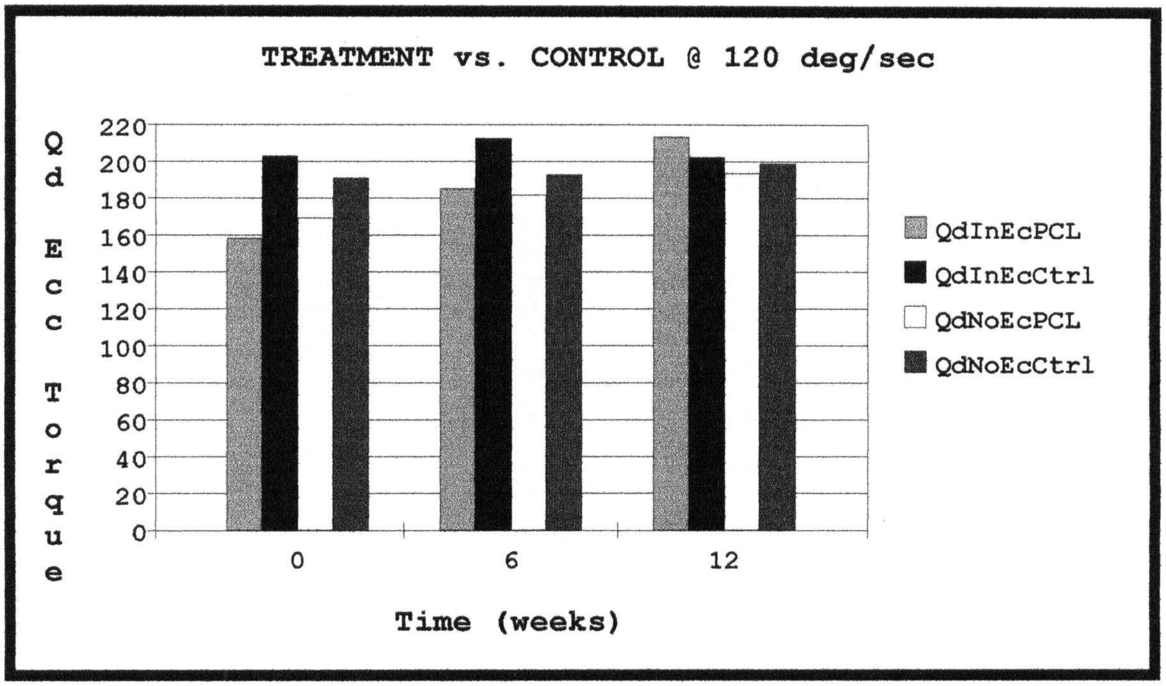


Figure D.2.
Treatment vs. Control Group
Quadriceps, Eccentric Torque @ 120 degrees per second

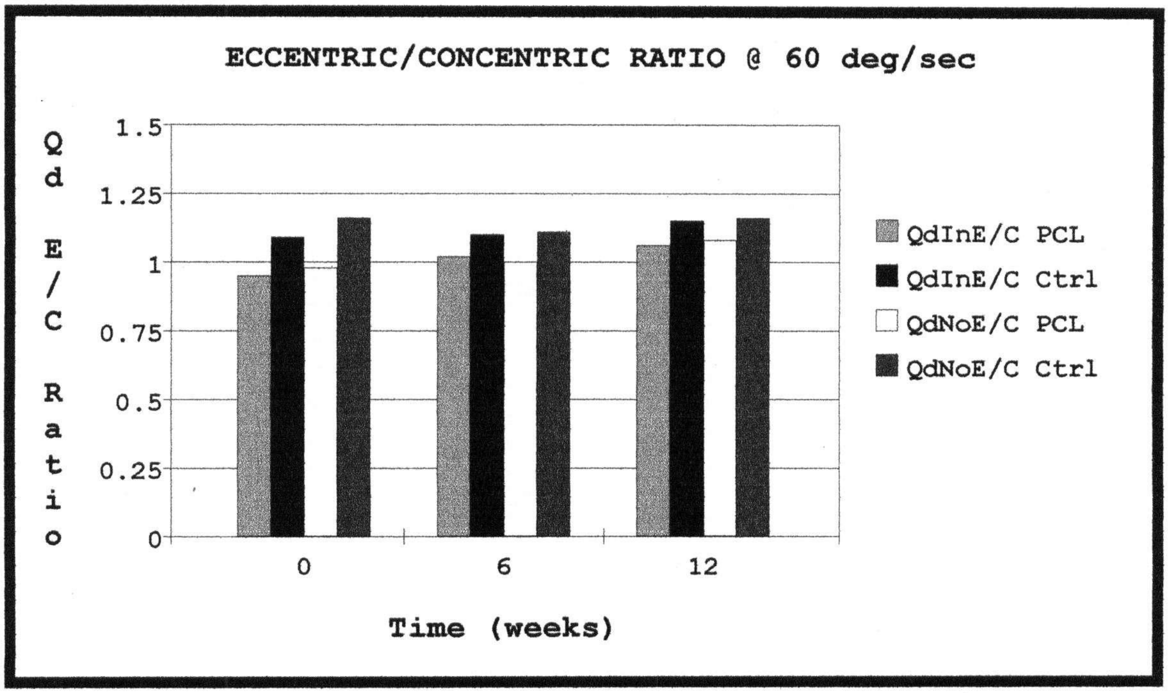


Figure D.3.
Treatment vs. Control Group
Quadriceps, Eccentric/Concentric Ratio @ 60 degrees per second

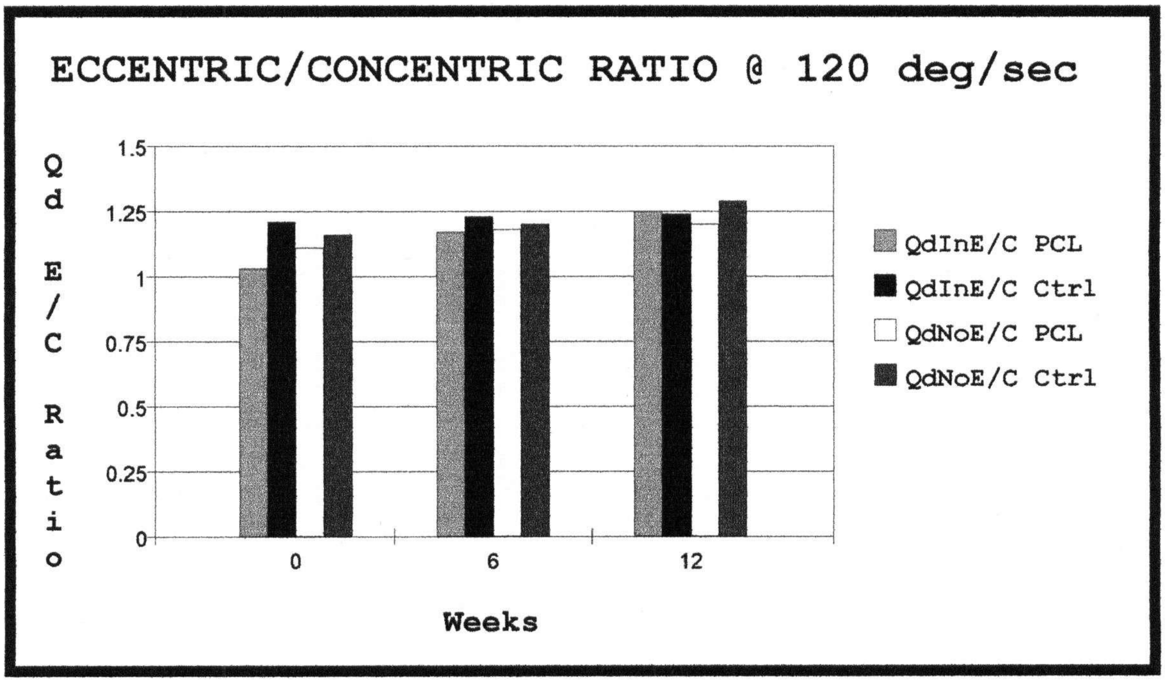


Figure D.4.
Treatment vs. Control Group
Quadriceps, Eccentric/Concentric Ratio @ 120 degrees per second

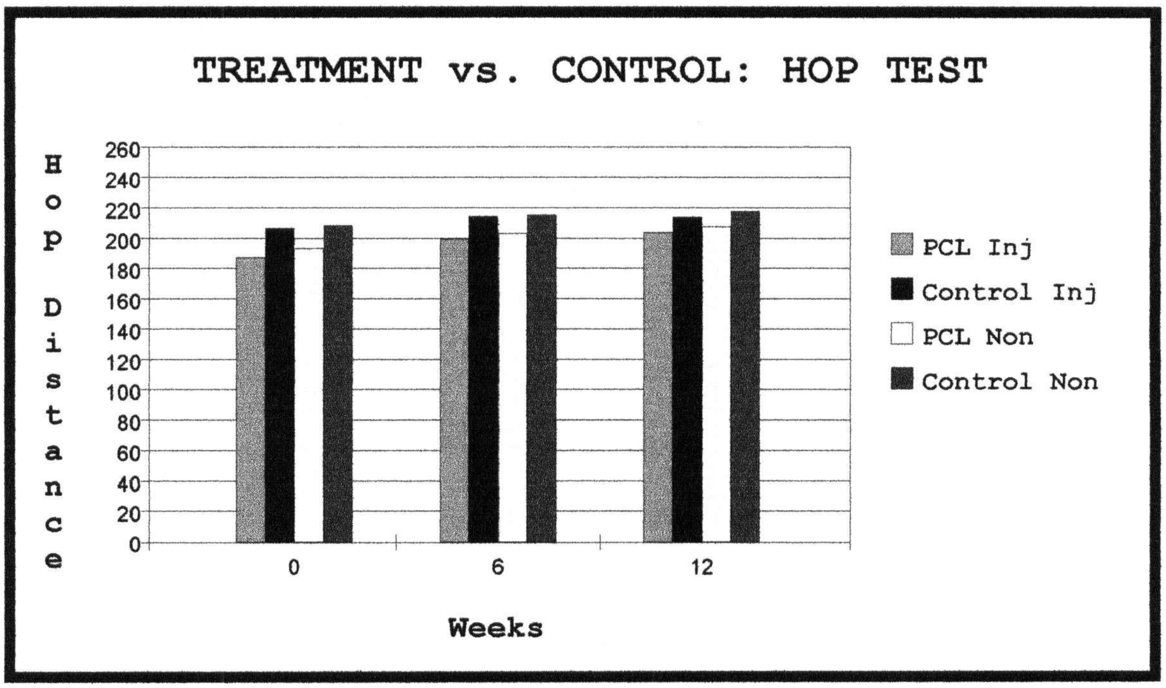


Figure D.5.
Treatment vs. Control Group
Tegner Hop Test

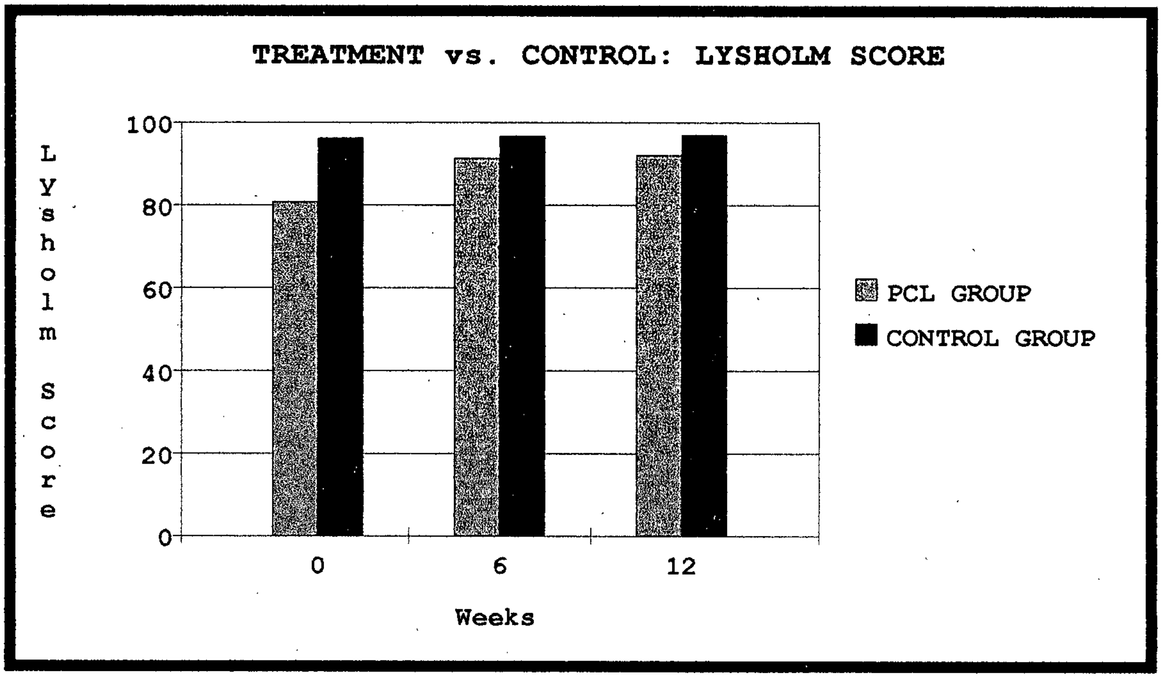


Figure D.6.
Treatment vs. Control Group
Lysholm Knee Scale Scores

# Chapter 5

## Summary, Conclusions & Recommendations

The main purpose of this study was to develop a home, eccentric kinetic chain exercise program that concentrated on improving eccentric and concentric strength in the hamstring and quadriceps muscle groups of a sample of isolated PCL-injured subjects. It was also the intent of the investigators to test kinetic chain exercise as a means of improving the chronic PCL-deficient knee functionally, isokinetically, and subjectively. The goal of the exercise program was to correct strength imbalances so that absolute and ratio values better resembled those of the healthy knee. Lastly, the study included a control group of healthy, sedentary individuals so that pilot study findings of eccentric, quadriceps strength weakness could be reconfirmed in the isolated PCL-injured sample.

Twenty-six males between the ages of 18 and 35 years of age were tested using the Kinetic Communicator (KINCOM), Tegner Hop Test and Lysholm Knee Scale. Thirteen ($n=13$) of the subjects were isolated PCL-injured subjects and they were placed on a 12-week, modified eccentric squat program. A nontreatment, control group ($n=13$) of healthy, sedentary individuals underwent the exact testing, at the same time intervals, but did not perform the prescribed exercise. Individuals in the control group had no prior history of any knee ligamentous, meniscal or capsular injury.

Results indicated that the eccentric squat program significantly increased eccentric and concentric quadriceps torque in both the injured and noninjured extremities of the treatment group. Scores in the Tegner Hop Test and Lysholm Knee Scale also increased ($p<0.05$) over the 12-week exercise rehabilitation. Significant concentric strength gains occurred in the hamstrings of both injured and noninjured extremities. Quadriceps concentric torque also significantly increased during some testing modalities, but not all. The injured extremity, quadriceps eccentric/concentric ratio increased significantly following treatment (@60 & 120 deg/sec). Injured and noninjured extremities of the PCL group did not differ in any regard prior to, during, or following the eccentric squat program.

Comparison of the eccentric/concentric relationship in both extremities of the PCL group further supported that, prior to exercise intervention, both extrmities were weak in quadriceps, eccentric strength. Following the 12-week treatment (@120 deg/sec), eccentric torque was significantly greater than concentric torque in the quadriceps of the PCL-injured extremity. this observation supports that the exercise program was successful in returning the PCL-injured extremity to healthy eccentric quadriceps strength as has been reported in the literature.

Further comparison of the PCL-injured group and control group revealed significantly lower eccentric strength in the quadriceps of the PCL group, prior to training. At the completion of the exercise intervention, the discrepancies had resolved and there no significant differences in strength between groups. Lysholm Knee scale scores were significantly lower in the PCL group prior to the 12-week exercise program. However, at week 12, there was no significant difference between the PCL and control groups.

## Conclusions

Reflecting back to the hypotheses set forth prior to the execution of this research, the following assumptions are supported:

1. The prescribed eccentric squat program did result in significant increases in quadriceps, eccentric torque in both extremities of the PCL treatment group, in Tegner Hop Test scores and in Lysholm Knee Scale scores.

2. The prescribed exercise intervention did not result in significant increases in quadriceps, eccentric/concentric ratio (with the exception of the injured extremity, quadriceps in the PCL group (@120 deg/sec). Eccentric, hamstring/quadricep ratios did not reach the 0.60 level that the literature has advocated.

3. Injured/noninjured ratios did exceed the 1.00 level for all quadriceps, eccentric and concentric torque, following exercise treatment.

4. The current study also indicated that the injured and noninjured extremities of the PCL group were significantly weaker than the control group in eccentric, quadriceps strength, prior to exercise intervention.

5. Following treatment, the PCL group did not differ from the control group in eccentric, quadriceps torque.

**Recommendations**

The current study findings strongly support that the eccentric squat program is an effective means of functionally rehabilitating chronic, isolated PCL-insufficiency. The exercise intervention significantly increased quadriceps, eccentric strength and resulted in strength values/ratios that are comparable to those found in healthy individuals.

Although literature reports on muscular strength ratios are limited, it appears that healthy individuals exhibit an E/C ratio of 1.25-1.30 in the quadriceps and 1.25-1.35 in the hamstrings. Further research will help to clarify whether these healthy, strength ratios are reasonable as goals of rehabilitation. Also, it has not yet been reported whether or not there are E/C ratios which are too high and that may subject the knee to injury. This, too, must be considered when designing an eccentric exercise protocol.

Clinicians should understand that this program is not being suggested as a means of total knee rehabilitation, in the acute stage of injury. This program is, however, being recommended as a home exercise program for the patient suffering from the chronic complications associated with isolated PCL-injury. The eccentric squat program is both specific to the involved anatomy and the chronic complications associated with the injury. It is an easy-to-execute and inexpensive means of improving the isolated PCL-deficient knee; subjectively, functionally and isokinetically.

Statistical analysis has indicated that certain attributes improve more markedly over the first six weeks of the program when the individual only performs two-legged, eccentric squats. If the goal of rehabilitation is primarily to increase quadriceps, eccentric strength, and to improve the knee functionally and subjectively, the clinician may only want to execute the initial six weeks of the exercise program. However, if the goal is to also improve the hamstring muscle group and increase E/C ratios, then the exercise should include the entire twelve weeks. In both cases, a maintenance program should be included and it is suggested that the final day's regimen be continued, 3-4 times per week.

It may be advantageous to conduct a follow-up study to determine if this program, alone, results in a desirable, permanent level of strength and the role that a maintenance program plays in sustaining an optimal strength level.

The use of healthy, nontreatment control group is recommended for future research if the objective is to identify specific characteristics in an injured group and/or to monitor strength gains that result from exercise intervention. Using the noninjured extremity as a healthy control may not be advantageous when investigating the attributes of an injured extremity. The current study suggests that, possibly, both extremities can suffer strength deficiency following injury.

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