

**RETURN TO SPORTS ACTIVITY AND PARTICIPATION AFTER ANTERIOR
CRUCIATE LIGAMENT (ACL) RECONSTRUCTION**

by

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Return to pre-injury level of sports activity and participation (RPSP) is one of the main reasons for undergoing anterior cruciate ligament reconstruction (ACLR), however previous reports have demonstrated great variations in the rate of return to pre-injury level of sports, ranging from 31% to 92%. Factors that influence RPSP after ACLR are not well known.

The aims of this project were to: 1) conduct a cross-sectional survey study to determine RPSP (using a definition for RPSP that includes the type and frequency of sports participation and frequency of sports activities) of subjects that underwent ACLR 1 to 5 years prior to participation, 2) conduct a prospective observational study to determine RPSP 12 months after ACLR and 3) identify factors that influence RPSP after ACLR.

251 participants (mean age, 26.1 ± 9.9 years) completed the survey that determined return to sports rate at an average of 3.4 ± 1.3 years after ACLR. Using our definition, 122 (48.6%) participants RPSP.

Thirty-five subjects who were between 14 and 35 years of age who participated in competitive or recreational sports prior to suffering a complete unilateral ACL tear were enrolled in our prospective study. Factors related to impairment and performance of knee function and psychological readiness to return to sports were evaluated. Using our definition for RPSP, only 14 participants (40%) returned to sports 12 months after ACLR. Participants' mean age at the

time of surgery was 19.79 ± 4.64 years and 17 (48.6%) were females. The most common reasons for not RPS in both studies were fear of re-injury and lack of confidence in the knee.

Higher levels of psychological readiness for return to sports 3 and 6 months after ACLR predicted RPS 12 months after ACLR. Individuals that were able to hop 6 months after surgery were also more likely to RPS. Psychological factors need to be addressed during rehabilitation as early as 3 months after surgery to increase an individual's confidence and thus return to sports. Individuals should also be encouraged to start activities such as hopping as soon as they become physically ready do so in order to increase their likelihood to RPS 12-month after ACLR.

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PREFACE

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“Whoever fears Allah, Allah will find a way out for him (from every difficulty) and He will provide for him from sources that he could never have imagined.” [The Noble Quran 65:2-3]

1.0 INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction is one of the most common orthopaedic surgical procedures performed in the United States.¹ A primary goal after ACL reconstruction (ACL-R) and rehabilitation is for the patient to return to his/her prior level of activity and sports participation without symptoms, and prevent recurrent injury to the knee or injury to the contralateral knee. It is assumed that ACL reconstruction is successful in returning individuals to their prior level of sports activity and participation. However recent evidence indicates that is not the case. Return to pre-injury level of sports at approximately 1 year after ACL reconstruction ranges from 31% - 92%.²⁻⁶ A recent study by Ardern et al⁷ reported that at medium term follow-up (mean 39.6 ± 13.8 months) after ACL-R only 45% of patients had returned to their pre-injury level of sports participation. A meta-analysis⁸ involving 5770 subjects from 48 studies found poor rate of return to sport at 3.5 years after ACLR, with only 63% returning to their pre-injury level of sports participation, and 44% returning to competitive sports. An update of this meta-analysis, was expanded to include 7556 subjects from 69 studies, and demonstrated that 65% of individuals returned to their pre-injury level of sports activity; and 55% returned to competitive sports at an average follow-up of 3.3 years after ACLR.⁹ Some studies have indicated that physical, psychological and socio-economic factors may influence return to sports.^{4,5,7,10,11} A recent systematic review by Barber-Westin et al¹¹ has shown that there is no consensus on when to release patients to unrestricted sports activities. Additionally, they reported that there is a general lack of

objective assessment; and of 264 studies included in the review, only 1 study had used validated questionnaires to determine return to sports.

Individuals are expected to return to sports between 9 to 12 months after ACL reconstruction surgery,^{12,13} however there are no universally accepted guidelines for return to sports activity and participation after ACL reconstruction. Guidelines for return to sports that have been proposed include graft healing based on time from surgery, recovery of knee function as evidenced by range of motion and strength, performance-based measures of function (i.e. hop tests) and patient-reported outcomes.^{11,14,15} Enhanced understanding of variables influencing an individual's ability to return to pre-injury level of sports activity and participation after ACL reconstruction is still needed.

Therefore, the overall goals of this project were to: 1) conduct a survey to determine return to prior level of sports activity and participation in individuals that have undergone ACL reconstruction at the UPMC Center for Sports Medicine between 2006 and 2011, 2) conduct a prospective cohort study to determine return to pre-injury level of sports activity and participation 1 year after ACL reconstruction and 3) identify factors that influence knee function and sports activity and participation after ACL reconstruction.

Return to sports was evaluated using a comprehensive method of return to pre-injury level of sports activity and participation. This definition includes the type and frequency of sports participation and frequency of sports activities as defined by the Marx Activity Rating Scale. This comprehensive definition of successful return to sports requires individuals 1) to have returned to the same or more demanding type and frequency of sports participation, and 2) to have the same or better Marx Activity Rating Scale score as before injury. This definition is consistent

with the International Classification of Function and Disability (ICF) model of function and disability (and its definition of activity and participation).

1.1 SPECIFIC AIMS

1.1.1 Specific aim 1

To determine the prevalence of return to pre-injury level of sports activity and participation after ACL reconstruction.

1.1.2 Specific aim 2

To prospectively determine the incidence of return to pre-injury level of competitive and recreational sports activity and participation 12 months after ACL reconstruction.

1.1.3 Specific aim 3

To identify factors that influence return to pre-injury level of competitive and recreational sports activity and participation after ACL reconstruction.

2.0 BACKGROUNDS AND SIGNIFICANCE

2.1 EPIDEMIOLOGY OF ANTERIOR CRUCIATE LIGAMENT (ACL) RECONSTRUCTION

Anterior cruciate ligament ACL rupture is considered a very common knee injury with an annual incidence of 35 per 100,000 people^{16,17} and an estimated occurrence of more than 200,000 ACL injuries per year in the United States.¹⁸⁻²⁰ Up to 90% of individuals that suffer an ACL tear opt to undergo ACL reconstruction.²¹ Therefore, ACL reconstruction is one of the most common orthopaedic surgical procedures in the United States.¹ The major indications for ACL reconstruction and post-operative rehabilitation are to restore knee function, allow the individual to return to his/her prior level of sports activity and participation after ACL injury, and to prevent future development of osteoarthritis (OA). Osteoarthritis of the knee has been shown to be common after ACL injuries. A recent systematic review by Qiestad et al²² has shown that at a minimum 10-year follow-up, up to 13% of individuals with an isolated ACL injury have radiographic evidence of tibiofemoral OA and the prevalence of radiographic OA increases to between 21% and 48% when an individual with an ACL injury has a concomitant meniscus injury.

Anterior cruciate ligament reconstruction aims to restore mechanical stability and maximize function of the injured knee. Knee stability and function after ACL reconstruction are assessed

primarily in terms of impairment of knee structure and function and by activity limitations and participation restrictions of the individual. Impairment of knee function is most commonly assessed in terms of symptoms, effusion, range of motion, knee joint laxity, and quadriceps and hamstring muscle performance. Patient-reported and performance-based outcome measures are frequently used to assess activity limitations and participation restrictions.

2.2 RETURN TO SPORTS AFTER ACL RECONSTRUCTION

There is no consensus in the literature regarding the percentage of patients who return to sports participation after ACL reconstruction. It is assumed that ACL reconstruction is successful in returning individuals to their prior level of sports activity and participation. However recent evidence indicates that is not the case. The reported rate for return to sports after ACL reconstruction among studies varies and a wide range of values has been reported. The return to pre-injury level of sports at approximately 1 year after ACL reconstruction ranges from 31% - 92%.²⁻⁶ A meta-analysis involving 5770 subjects from 48 studies performed by Ardern et al⁸ has shown that at a mean follow-up of 41.5 months, 63% had returned to their pre-injury level of participation, and 44% had returned to competitive sport. In the same study the authors did an analysis by subgroups defined by the length of follow-up. They found that only 38% had returned to competitive sport at some point after 2 years follow-up compared with 65% who returned to competitive sports at less than 2 years follow-up. Ardern et al¹⁰ also found that only 33% of patients attempt return to pre-injury level of competitive sports 1 year after ACL reconstruction. An update of this meta-analysis, was expanded to include 7556 subjects from 69 studies, and demonstrated that 65% of individuals returned to their pre-injury level of sports activity; and 55% returned to competitive sports at an average follow-up of 3.3 years after ACLR.⁹

2.3 MEASURING RETURN TO SPORTS

Return to pre-injury level of activity and sports participation is an important indicator of successful ACL reconstruction. However, information about how to accurately measure return to sports after ACL-R, and whether or not return to pre-injury level of sports is successful are limited. Return to pre-injury level of sports measures have not been clearly described in the literature. One of the main problems in accurately estimating return to pre-injury level of sports after ACL reconstruction is the lack of a consensus of how return to pre-injury level of sports is operationally defined. Return to sports has been reported in terms of return to any sport²³⁻²⁵; return to pre-injury level of sports participation using a global question,²⁶⁻²⁸ return to pre-injury level of sports participation using patient-reported outcome measures such as Tegner scale^{2,29-31} and Marx Activity Level Score;³² return to preoperative level of sports;^{33,34} return to pre-injury level of sports participation based on type of sport;^{35,36} return to competitive or non-competitive sports based on pre-injury type and frequency of sports^{4,37,38} and return to the same number of hours of sports participation per year as before injury.³⁹ Although these terms seem to cover the broad spectrum of sports participation, an accurate definition for return to sports is still unclear.

A logical definition for return to sport is the return to pre-injury level of sports participation. However, this definition also needs to be clarified. A more comprehensive definition for return to pre-injury level of sport must include questions about return to the same sports activities (running, jumping, cutting and pivoting) as well as the same type and frequency of sports participation (football, soccer, basketball etc.) as before injury. To our knowledge, no study has ever used the combination of these questions (return to pre-injury sports activities and type and frequency of

sports participation) to determine return to pre-injury level of sports participation after ACL reconstruction.

The use of an accurate and more comprehensive definition for return to pre-injury level of sports has been recommended in the literature. Thomee et al⁴⁰ reviewed the literature and suggested that a detailed description of the type and level of activity, in addition to the time of return and duration of participation must accompany the use of term return to sports. Feller JA et al⁴¹ has also suggested that when return to pre-injury level of sports is measured, more clarification is needed to determine if individuals have returned to training or competition and, if they have returned to competition, whether they have returned to the same sport, level of competition and level of competency as before injury.

2.4 FACTORS THAT INFLUENCE RETURN TO SPORTS ACTIVITY AND PARTICIPATION

The ability to and timing of return to sports are very variable and depend on many factors. These factors include the demographic characteristics of the patient (i.e. age, gender, BMI, and smoking status); pre-injury level of activity; time from injury to surgery; surgical methods to reconstruct the ACL (i.e. graft type, anatomic or non-anatomic); the individual's physical status determined by parameters of knee function such as ROM, pain, effusion, and muscle strength, knee stability, knee kinematics after injury and surgery; individual's psychological status (i.e. fear of re-injury, fear of losing job with second injury); individual's environmental and social status (i.e. family and career obligations); and factors related to post-operative rehabilitation (i.e. rehabilitation protocols).

Determining when an individual should return to sports has been always a matter of debate after ACL reconstruction. It is unclear how fast or how late the patient can return to sports and still be considered to have a successful return to sport. A recent systematic review by Barber-Westin et al¹¹ has shown that there is no consensus on criteria for return to sports decisions and there are a lack of patient-reported and objective assessments that can be used to determine when to release an individual to unrestricted participation in sports activities. Barber-Westin et al¹¹ found that the time since ACL surgery was the only factor used to determine readiness for return to sport in 32% (84) of the studies that were included in a systematic review of the literature. Forty (15%) of the studies listed time from surgery along with subjective criteria such as “regained full functional stability” as factors to determine readiness for return to sport.

2.4.1 Influence of pre-injury level of sport on return to sports

Pre-injury level of sport is one of the major factors that may affect return to sports. Return to pre-injury level of activities and sports participation is always a patient's desire. Baseline activity level has been found to influence return to pre-injury level of sports 12 months after ACL reconstruction.^{6,42} Competitive athletes were more likely to return to pre-injury level of sports than recreational athletes 12 months after ACL reconstruction. Additionally, high pre-injury level of activity has been found to be the strongest predictor for return to sports 2 years after ACL reconstruction.⁴³ This suggests that athletes and people who play at a high level of sports participation may have a greater desire and motivation to return sports than non-athletic individuals.

2.4.2 Influence of time from injury to surgery on return to sports

Time from injury to surgery could be also a factor that influences return to sports. The study by Lentz et al⁴² reported that there was no significant difference in time from injury to surgery between patients who returned and did not return to sports after ACL reconstruction (70 days vs. 80 days, respectively). However, both groups had surgery within 2-3 months after injury which may have less influence on return to sports than if the time from injury to surgery was longer. The more time from injury to surgery the more potential weakness and atrophy the individual may develop because patients will limit their activities and function as a protecting mechanism. This factor needs to be explored more in future studies.

2.4.3 Influence of graft type on return to sports

Graft type has not been considered as a factor in the decision on when an individual should return sports, however some studies have shown that young and active individuals that undergo ACLR with allograft are at a higher risk of graft failure and second ACL injury than patients that undergo surgery with an autogenous bone patellar tendon bone (BPTB) graft.^{44,45} Another study by Borchers et al⁴⁶ found that individuals that underwent reconstruction with an allograft had an increased odds ratio (5.56) of ACL failure compared to those that underwent reconstruction with a 4-strand gracilis/semitendinosus autograft. These results raise the question of whether more time or more stringent criteria are needed before individuals that underwent surgery with an allograft are released to return to sport. A recent meta-analysis⁹ found differences in return to sports between hamstring and patellar tendon graft approximately 3.3 years after ACL reconstruction, however, the effect of graft type on return to sports was contradictory. Those with a patellar tendon graft

had greater odds of returning to pre-injury level of sports while those with a hamstring tendon graft had increased odds of returning to competitive sports participation. Therefore, the effect of graft type on return to sports will continue to be debated.

The graft after ACL reconstruction has been shown to go through several phases of healing and ligamentization including early graft healing, proliferation and remodeling, and maturation phases. However, the timeline for biological graft changes between animals and humans has been found to be substantially different.⁴⁷ In animals, the early graft-healing phase occurs from 0 to 4 weeks.⁴⁸ However, in humans it seems to be longer. The systematic review by Claes et al⁴⁷ has shown that the duration of the early graft healing phase in humans ranges from between 3 to 6 months. However, the start of the early graft-healing phase was different between the studies. Two studies reported that the early phase was between 0 to 3 months⁴⁹ and 0 to 5 months⁵⁰ after ACL reconstruction. On the other hand, two studies reported that early phase starts at 3 and 6 months and extends to 6 and 12 months, respectively.^{51,52} The early graft healing phase is characterized by increasing necrosis and hypocellularity. However, complete necrosis may not be seen in humans as it is in animals.⁵³ Hypervascularity of the graft has been noted in humans in the early phase of healing after surgery and vascularity has been found at least in the periphery of the graft at any given time point after ACL reconstruction.⁴⁷

The second phase of graft healing and ligamentization is the proliferation and remodeling phase. This phase is typically between 4-12 weeks in animals,⁴⁸ and last up to 7 months in humans.⁴⁷ However, the timeline for this phase also has been reported to vary between studies from 3 to 10 months⁴⁹ to 12 to 18 months⁵² after ACL reconstruction. The proliferation and remodeling phase is characterized by high levels of cellular activity and changes in the extracellular matrix that are accompanied by the lowest mechanical properties of the graft during

healing.⁴⁸ Immediately after surgery, strength of the graft is limited by the strength of graft fixation. Healing of the graft within the tunnels ranges from 6 weeks to 8-12 weeks for bone-to-bone fixation and soft tissue-to-bone fixation, respectively.⁵⁴ Although the ends of the grafts may heal to the bone tunnels by 6 to 12 weeks, the graft itself is likely still weak during this period.

The third phase of graft healing is the maturation phase. It involves the ongoing process of continuous remodeling of the healing graft toward the morphology and mechanical strength of the native cruciate ligaments⁴⁸ or to the time point from which no further changes are witnessed in the remodeled grafts.⁴⁷ There is no consensus in the literature on when this phase ends. Graft maturation has been observed as early as 3 months in animals and up to 36 months in humans.⁴⁷

Early return to sport has been associated with increased graft failure.⁵⁵ Exposing the knee to early and high forces may increase the risk of graft failure. Six to 9 months after surgery, when the graft is still undergoing maturation, the graft will be at increased risk of injury and starting strenuous sport activities during this time may jeopardize the graft. Van Eck et al⁵⁶ found an overall graft failure rate of 13% following anatomic ACL reconstruction with allograft and 50% of the re-ruptures occurred between 6 and 9 months after surgery.

2.4.4 Influence of anatomic or non-anatomic ACL reconstruction on return to sports

Another factor that needs to be considered in making return to sports decisions are the recent advances in anatomic methods to surgically reconstruct the ACL. Anatomic ACL reconstruction is defined as the functional restoration of the ACL to its native dimensions, collagen orientation, and insertion sites.⁵⁷ Anatomic ACL reconstruction may result in a more rapid return of range of motion, however the in situ forces in an anatomically placed graft are greater (comparable to the native ACL) than those in a non-anatomically placed graft (less force than the native ACL due to

non-anatomic position of the graft).⁵⁸ Araujo et al⁵⁹ found that at lower degrees (0 to 30°) of knee flexion, anatomic ACL reconstruction exposes the graft to higher loads than non-anatomic ACL reconstruction, which could increase the risk of failure in the early rehabilitation phase when the healing process is still not complete. As a result of this, rehabilitation and return to sport after anatomic ACL reconstruction may need to be progressed slower than after traditional, non-anatomic ACL reconstruction.¹⁴

2.4.5 Influence of individual's physical status on return to sports

Ongoing knee problems also influence return to sports after ACL reconstruction. Pain, swelling, limited ROM, knee effusion and muscle weakness of the ACL-reconstructed knee are a major factors that may delay or prevent individuals from returning to sports. Therefore, individuals should have no pain or swelling, full ROM compared to the contralateral knee and adequate muscle strength (quadriceps limb symmetry index LSI > 85% of the contralateral limb) as soon as possible to be safely released to return to sports.

Adequate muscle strength that is required before returning individuals to sports is still a source of discussion and debate. Quadriceps weakness is a primary impairment following ACL reconstruction.⁶⁰ Quadriceps weakness has also been found to be related to poor functional outcomes after ACL reconstruction.⁶¹⁻⁶⁴ Schmitt et al found that a quadriceps strength deficit of greater than 15% when compared to the contralateral limb negatively affects function and performance.⁶⁰ Furthermore, it has been suggested that poor muscle function (i.e. poor hop, leg-raise) might predict the future development of knee OA.⁶⁵⁻⁶⁷ Additionally neuromuscular function (i.e. neuromuscular control, voluntary quadriceps activation) may be important to prevent knee OA.⁶⁸⁻⁷⁰

Criteria for return to sports that have often been stated include mean limb symmetry index for knee extensor and flexor peak torque greater than 80%, limb mean symmetry index of 90% for the hop test; ≤ 5 mm side-to-side difference in anterior tibial translation, and a normal or nearly normal IKDC score. However, the meta-analysis by Ardern et al⁸ has shown that even if these criteria were met only 63% of patients returned to their pre-injury level of sports and only 56% returned to competitive sports after ACL reconstruction.

Thomee et al⁴⁰ recommended the use of a “battery of tests” to detect deficits in strength and functional performance, which may more accurately determine an individual’s readiness for return to sports. The use of a single strength or functional performance test such as a test to assess knee extensor strength or the single-leg hop test may not be sensitive enough to detect deficits in strength and functional performance. A battery of tests, including three different tests for lower extremity muscle strength (leg extension, leg flexion and leg press) and three different hop tests (vertical jump, hop for distance and side hop) was shown to be a valid method and to have a greater ability compared with any single test to discriminate between the injured and non-injured side in individuals after ACL injury and after ACL-R.^{71,72} They found that individuals achieved an average LSI of $\geq 90\%$ at 24 months on each individual test. However, when a test battery was used the success rate (an LSI of $\geq 90\%$ in all three tests) at 24 months for the muscle power test battery was 48% and 44% for the hop tests battery.⁷³ The use of a battery of tests seems to have some promise to determine readiness for return to sports; however more studies are needed to support the use of a test battery.

2.4.6 Influence of individual's psychological, environmental and social status on return to sports

Psychological and social factors may also influence an individual's decision to return to sports. Several studies have shown that fear of re-injury was the major and most common reason cited by individuals for not returning to sports or for returning to a lower level of sports participation after ACL reconstruction.^{8,26,27,42,74,75} Other psychological and social factors such as fear of job loss with re-injury,⁸ lack of confidence of the reconstructed knee,⁴² frustration because of longer than expected recovery,⁷⁵ and family commitment or life style changes⁸ have been reported in the literature. Fear of re-injury could be related to the individual's physical and functional status. An individual might be fearful of another injury to his knee if he/she has instability, limited joint motion or weakness. Individuals with frequent episodes of giving way, limited range of motion, or muscle weakness may have lack of confidence in their knees and therefore, fear of having another injury. To my knowledge no study has determined the relationship between an individual's fear of re-injury with their physical and functional examination, and further studies are needed to explore this relationship.

Self-efficacy beliefs and internal health locus of control could be also factors that affect return of knee function and thus return to sports. Perceived self-efficacy is defined as one's judgment of his/her potential ability to perform a task.⁷⁶ An internal health locus of control refers to the one's belief that his/her outcome is under the control and directly related to his/her own behaviors.⁷⁷ Perceived self-efficacy and internal locus of control have been shown to be associated with patient-reported outcomes such as SF-36, IKDC-SKF, KOOS, KOS-ADL and KOS-SAS scales after ACL reconstruction.⁷⁷⁻⁸¹ Higher perceived self-efficacy and internal locus of control have been found to be associated with better knee function and quality of life.^{77,79-81} The influence

of perceived self-efficacy and internal locus of control on return to sports is unknown and studies that evaluate their effect are still needed.

2.4.7 Influence of individual's characteristics on return to sports

Patient age and gender have been also discussed in the literature as factors that may affect return to sport after ACL reconstruction. An individual's desire to return to sports may be influenced by his/her age. Return to sports has been reported to be less frequent in older individuals (≥ 25 years of age) compared to younger individuals after ACL reconstruction.⁷ The reasons for this may be that older individuals have different priorities (i.e. work or family commitments) and lack of motivation for returning to sports compared to young individuals.⁴¹ There is no consensus in the literature regarding the effect of gender on return to sports. Earlier return to sports has been reported for males compared to females.^{10,82} However, Kvist et al²⁶ has found no gender differences between individuals that returned versus did not return to their pre-injury level of sports. In addition, Shelbourne et al⁸³ has found no gender difference in mean activity levels at up to 5 years follow-up after ACL reconstruction. Arden et al⁷ found that men and women have similar rates of return to sports and return to pre-injury levels of sports. A recent study by Brophy et al⁸⁴ reported that there was no difference between males and females in the time to return to play at long term follow-up of 7.2 ± 0.9 years, however age and gender were found to be predictors for return to sports at approximately 12 months follow-up. At 12 months, males were more likely to return to sports than females, and older individuals (≥ 30 year-old) were less likely to return to sports than younger individuals. Dunn et al⁴³ found that gender (being female), higher BMI, and smoking in the six months prior to surgery were associated with a lower rate of return to sport at 2-year follow-up after ACL reconstruction.

2.4.8 Influence of rehabilitation on return to sports

Rehabilitation after ACL reconstruction could be also a factor that influences return to sports. Rehabilitation after ACL reconstruction has evolved over the past 20 years. The evolution in rehabilitation after ACL reconstruction is in part due to the advances in surgical procedures that address ACL injuries. However, despite the advances in surgery and rehabilitation, the optimal rehabilitation program is still debatable and depends on the surgical procedure to reconstruct the ACL, concomitant surgical procedures that were performed, the individual's prior level of activity and fitness, response to surgery and rehabilitation and desired activity level following surgery. Studies examining the effects of rehabilitation have evaluated the effects of accelerated vs. non-accelerated rehabilitation,⁸⁵ early start vs. delayed rehabilitation,^{86,87} home vs. supervised rehabilitation programs,⁸⁸⁻⁹⁰ the use of brace or not,⁹¹⁻⁹³ and the use of closed kinetic chain (CKC) vs. open kinetic chain (OKC) exercises^{94,95} on an individual's impairment (i.e. ROM, laxity, pain) and functional and activity limitations (i.e. IKDC Subjective Knee Form, hop). However, to our knowledge only one study has compared the effect of different rehabilitation protocols such as (CKC) vs. (OKC) exercises on return to pre-injury of sports and reported an earlier return to sports with combined CKC and OKC exercises.⁹⁶ Therefore, more studies are needed to determine the effect of different rehabilitation protocols on return to pre-injury level of sports.

2.4.9 Objective criteria to determine timing of return to sports

Barber-Westin in her systematic review¹⁵ has reviewed the objective criteria used to determine when individuals should return to sports and found that return to sports decisions after ACL reconstruction are commonly based on 3 objective criteria. The most common objective criterion

used to determine return to sports was assessment of lower extremity isokinetic muscle strength, which was reported in 18 out of 21 studies that were reviewed, followed by lower limb symmetry (7 out of 21 studies) and knee examination parameters (6 out of 21 studies). The systematic review indicated that the suggested criteria for return to sports were: 1) quadriceps and hamstring strength 80 to 90% of the contralateral leg; 2) limb symmetry index during the single-leg hop for distance greater than or equal to 90% and 3) full ROM and no effusion of the knee. No recommendations considered the ratio of hamstring to quadriceps torque.

2.5 IMPAIRMENT MEASURES OF KNEE FUNCTION AND STRUCTURE, PERFORMANCE-BASED MEASURES OF ACTIVITY, AND PATIENT-REPORTED MEASURES OF SYMPTOMS, ACTIVITY LIMITATIONS AND PARTICIPATION RESTRICTION

The individual's impairment of knee structure and function, functional performance, pre-injury level of activity, and psychological status are the major factors that influence return to sport after ACL reconstruction. Reliable and valid measures for these factors must be used to more precisely assess return to sports. The following section will discuss the most commonly used measures for impairment of knee function and structure, performance-based measures of activity, and patient-reported measures of symptoms, activity limitations and participation restrictions.

2.5.1 Measuring impairment of knee function

Swelling, limited ROM, increased knee laxity, and weakness of quadriceps and hamstring muscles are the major impairments of knee function. Swelling of the knee is most commonly assessed by using the modified stroke test. The test is graded on a 5-point scale (none, trace, 1+, 2+, and 3+).⁹⁷ The modified stroke test has been found to have a very good inter-rater reliability ($k = 0.75$).⁹⁷ Passive and active ROM of the knee is most often measured with a standard goniometer. Intra- and inter-tester reliability coefficients for goniometric measurement of passive knee extension are .98 and .86 respectively and for passive knee flexion they are .99 and .90 respectively.⁹⁸

Laxity of the knee can be measured manually or by using a knee arthrometer. Manual examination of knee laxity after ACL injury and surgery most often includes the Lachman and pivot shift tests. A recent meta-analysis⁹⁹ of the Lachman and pivot shift tests revealed the Lachman test has high sensitivity (.85) and specificity (.94) and the pivot shift has high specificity (.98), but low sensitivity (.24) for ACL insufficiency. The KT-1000 arthrometer is the most common instrument that is used to measure the side-to-side difference in anterior tibial translation of the knee. It is commonly used to quantify anterior tibial translation at 25 degrees of flexion with a 134N anterior and maximum manual load. Intra-rater reliability for the KT arthrometer side to side difference has been found to be high (ICC=.90 to .99), with standard errors of measurement ranging from .30 to .64 mm.¹⁰⁰

Quadriceps and hamstring performance are commonly measured by isokinetic testing at various velocities including 60, 120, 180, 240, and 300- degrees per second,¹⁰¹⁻¹⁰⁶ or by isometric testing using a dynamometer.^{107,108} Isokinetic strength testing has been shown to be a reliable method of quadriceps strength testing (ICC = 0.81-0.97)¹⁰⁹ and sensitive to strength changes in the

first 2 years following ACL reconstruction.¹¹⁰ Use of an isokinetic dynamometer is considered the gold standard for measuring muscle performance. However, isokinetic testing might require more time, practice, and warm up than isometric testing. In addition, early after ACL reconstruction the healing graft needs to be protected and thus only limited range is allowed. Therefore, the use of isometric testing is preferred especially for early testing (4 months) after ACL reconstruction. A maximum voluntary isometric torque test using an isokinetic dynamometer has been shown to be a valid and reliable method of quadriceps strength testing^{60,108,111} with intra-tester reliability and inter-tester reliability ICCs of 0.97 and 0.82, respectively.¹¹¹

In the situations where isokinetic dynamometry is not available, a hand-held dynamometer could be a reasonable alternative for isometric testing of quadriceps and hamstring performance, provided the examiner takes appropriate steps to adequately stabilize the patient and provide resistance. Use of a hand-held dynamometer to measure isometric quadriceps strength has been shown to be strongly associated with isokinetic testing, which is considered the gold standard (r from 0.72- 0.99).¹¹²⁻¹¹⁴ The use of a hand-held dynamometer for isometric testing of the knee flexors after ACL-R has been found to have a good inter-tester reliability (ICC = 0.89).¹¹⁵ For testing strength of the knee extensors, inter-tester reliability when using a hand-held dynamometer has been found to have ICCs ranging from 0.76-0.94 for a variety of knee conditions.¹¹⁶

2.5.2 Performance-based measures of knee function

Performance-based measures of function are also important outcome measures after ACLR. According to International Classification of Functioning and Disability (ICF) model of disablement, these measures are considered measures of activity limitation. Hop tests are the most common performance-based measures of activity that are used to measure functional performance

after ACL injury and surgery. Hop tests include the single hop for distance, straight triple hop for distance, triple crossover hop for distance, and 6-m timed hop. The hop test indices and the overall limb symmetry index have been shown to have high levels of test re-test reliability (ICC from .82 to .93), with standard error of measurement ranging from 3.04% to 5.5%) in a sample of subjects after ACL reconstruction.¹¹⁷

The step-down test is useful to evaluate an individual's quality of movement that is thought to be an indicator of neuromuscular control for the trunk and lower extremity. The step-down test has been found to be a valid and reliable measure (Cohen's Kappa= .67) that is able to recognize altered movement patterns in patients with patellofemoral pain syndrome (PFPS).¹¹⁸ Another useful measure is the Star Excursion Balance Test that has been found to be a good measure of deficits in dynamic postural control for a variety of lower extremity injuries including ACL injury.^{119,120} The modified SEBT is a reasonable alternative test to simplify and reduce the time necessary to perform SEBT test. The reliability estimates for the SEBT test have been found to be strong (ICC from 0.81 to 0.93).^{121,122} The intratester reliability for the modified SEBT test has been also found to be good to excellent (ICC 0.81 to 0.96).¹²³ The single-leg vertical jump is also an important measure for dynamic postural stability that mainly provides information about muscle power during jumping and landing tasks. The ICCs for single-leg vertical jump were found to be strong and range from (0.88-0.97).¹⁰⁹

2.5.3 Patient-reported measures of symptoms, activity limitations and participation restrictions

Patient-reported outcome measures are also used to measure the individual's perception of the effect of ACL injury on his/her symptoms, activity and participation. Use of patient-reported

outcome measures has become more common and important for several reasons, including ease of administration and relevance to the individual and health care providers. Many patient-reported outcome measures have been established and used; however only a few measures have been sufficiently validated to measure outcome after ACL injury and surgery.

Patient-reported outcomes are typically classified as general health or specific patient-reported outcome measures. General health measures evaluate health-related quality of life including aspects of physical, social and mental function. Specific patient-reported outcome measures can be disease-or region-specific. Disease-specific measures are designed to evaluate specific diagnostic groups or patient populations and region-specific measures are designed to evaluate specific body regions such as the knee.¹²⁴

General health measures such as SF-36 have not been shown to be a good measure for patients with ACL Injury. Moller et al¹²⁵ found no differences in general health based on the subscales of the SF-36 between patients and age-gender matched control group after ACL reconstruction. In addition, the SF-36 has not been found to be associated with objective measures of knee laxity (eg, Lachman test, pivot shift, instrumented laxity) after ACL injury, although it was able to detect improvement in these patients.¹²⁶ Therefore, the SF-36 may be limited in its ability to detect clinically relevant functional limitations in patients after ACL injury and surgery.

The use of specific patient-reported outcome measures for knee injuries has been commonly preferred and utilized in the literature for patients after ACL injury and surgery. There are many specific patient-reported outcome measures that have been developed to assess the effects of injury to the knee including ACL injuries. The most common valid and reliable patient-reported outcome measures that have been developed to assess the effects of ACL injury include the International Knee Documentation Committee Subjective Knee Form (IKDC-SKF), Knee Injury and

Osteoarthritis Outcome Score (KOOS), Lysholm Knee Score, and Knee Outcome Survey (KOS). The Tegner Sports Activity Scale and the Marx Activity Level Scale are the most common instruments that have been used to assess an individual's level of sports activity. Kinesiophobia or fear of re-injury is most commonly measured by Tampa scale for kinesiophobia. In addition, the ACL Return to Sport after Injury (ACL-RSI) scale has been recently developed to measure the psychological impact of returning to sport after ACL reconstruction. The Knee Self-Efficacy Scale (K-SES) and the Internal Health Locus of Control (HLOC) component of multidimensional HLOC Scale are valid and reliable measures for self-efficacy beliefs and internal health locus of control, respectively.

The IKDC-SKF is an 18-item measure of symptoms, function and sports activities for individuals with a variety of knee conditions, including ACL injuries.¹²⁷ It has been found to have good evidence for validity, reliability, and responsiveness.¹²⁷⁻¹²⁹ Normative data in a representative sample of the US population has been also determined.¹³⁰ Test re-test reliability was high (ICC .94) with a standard error of measurement of 4.6.¹²⁷ The IKDC Subjective Knee Form is related to concurrent measures of physical function ($r=.47$ to $.66$) but not emotional function ($r=.16$ to $.26$).¹²⁷

The KOOS is a knee specific patient-reported outcome measure that is widely used in studies evaluating the outcome of ACL reconstruction. The KOOS consists of 42 items that result in 5 scores including pain, other symptoms, activities of daily living (ADL), sports and recreation and knee-related quality of life.¹³¹ Psychometric testing of the KOOS reveals acceptable levels of test re-test reliability (ICCs range from $.75$ for the activities of daily living scale to $.93$ for the other symptoms scale), validity and responsiveness.¹³¹

The Lysholm knee scale is a measure that was developed for follow-up evaluation of knee ligament surgery, with an emphasis on symptoms of instability and pain.¹³² It consists of eight

items (limp, support, stair climbing, squatting, instability, locking and catching, pain, swelling).^{132,133} The Lysholm knee scale is one of the most widely used measures for knee ligament surgery.¹³⁴ However, its validity, sensitivity, and reliability have been questioned.^{135,136}

The Knee Outcome Survey (KOS) is a patient-reported measure that evaluates symptoms and functional limitations commonly experienced by individuals who have a variety of pathological disorders of the knee, including ligamentous and meniscal injuries, patellofemoral pain, and osteoarthritis.¹³⁷ It consists of two separate scales: the Activities of Daily Living Scale and the Sports Activity Scale. The Activities of Daily Living Scale includes 14 items related to symptoms and functional limitations experienced during activities of daily living, while the Sports Activity Scale consists of 10 items related to symptoms and functional limitations experienced during sports activities. The Activities of Daily Living Scale has been found to be valid, reliable, and responsive measure. Test re-test reliability was high (ICC .97) with a standard error of measurement of 3.2.¹³⁷ The Sports Activity Scale (SAS) consists of 10 items that assess symptoms and functional limitations during a variety of sports activities such as running, jumping and landing, stopping and starting, and cutting and pivoting. Symptoms are graded according to the restriction the symptom imposes during sports activities, and functional limitations are graded in terms of the difficulty or limitation experienced in performing specific sports-related activities.¹³⁸ The SAS has a high degree of internal consistency and demonstrates hypothesized relationships to other measures of function during sports and activities of daily living.^{138,139}

The Tegner Activity scale is a very commonly used measure of an individual's activity level. It consists of single item that has a 11-level response scale that ranges from 0-10, where zero represents an individual on sick leave or disability pension due to the knee problem and a score of 10 represents competitive sports at a national or international elite soccer level.¹³³ The test re-test

reliability for Tenger Activity Scale was acceptable (ICC .82) with a standard error of measurement of 0.64 and minimum detectable change of 1.¹⁴⁰ However, one criticism of the scale is that it relates activity level to specific sports (i.e. soccer) rather than to the frequency of participating in the sports. Also, level nine for example (competitive sports—soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball) covers multiple levels of competition and sports. Therefore, people might return to the same sport but with a lower level in terms of frequency of sports participation or to different sports and maintain the same Tegner rating score.

The Marx Activity Level Score is a short non-sport specific activity rating scale that evaluates an individual's perception of the frequency of performing specific sports activities including running, cutting, decelerating, and pivoting activities.¹⁴¹ It has been found to have a good validity and reliability. Test re-test reliability was high (ICC .97).¹⁴¹

The Tampa scale for kinesiophobia (TSK) is a scale that aims to quantify fear of re-injury due to movement and physical activity. It was originally designed for patients with musculoskeletal pain and consists of 17 statements on an individual's perception of their experience of injury and physical activity.¹⁴² Each statement is provided with a four point Likert scale. The sum of the statements results in a score that ranges from 0 to 51, with a higher score indicating more fear. This scale has been found to have acceptable validity and reliability (Cronbach's alpha = 0.81),¹⁴³ however it was tested on patients with chronic musculoskeletal pain that may differ substantially on clinical presentation when compared with patients having ACL reconstruction.

The ACL-RSI scale is a 12-item scale that measures the association between three types of psychological responses (emotions, confidence in performance, and risk appraisal) with

resumption of sport following athletic injury.³⁸ ACL-RSI has demonstrated evidence of reliability and validity, (Cronbach's alpha = 0.92).³⁸

The Knee Self-Efficacy Scale (K-SES) is a 22-item scale that measures one's judgment of his/her potential ability to perform a task.⁷⁶ The scale is divided into 4 sections, three of them asking about the current certainty of being able to perform the task, despite knee pain/discomfort (daily activities (seven items), sports and leisure activities (five items), and knee functions tasks (six items)). The last section is knee function in the future (four items), in which the patients report how certain they feel about their future capabilities. K-SES has demonstrated good reliability and validity for measuring perceived self-efficacy after ACL reconstruction (ICC = 0.75 and Cronbach's alpha = 0.94).⁷⁸

The Multidimensional Health Locus of Control (MHLOC) Scale, Form C is an 18-item condition specific scale that aims to measure one's beliefs about where the control over his/her health comes from and determined by what factors.¹⁴⁴ The internal health component of the MHLOC scale consists of 6 items that mainly address to what degree one perceives that his/her outcome is under the control and directly related to his/her own behaviors. The internal component of MHLOC has been found to have acceptable test re-test reliability ($r = .66$ to $.88$)¹⁴⁴ and validity.^{81,144}

3.0 RETURN TO PRE-INJURY LEVEL OF SPORTS ACTIVITY AND PARTICIPATION AFTER ANTERIOR CRUCIATE LIGAMENT (ACL) RECONSTRUCTION

Background: Return to sports is a primary goal for anterior cruciate ligament (ACL) reconstruction. Recent studies indicate that return to prior level of sports participation is less than optimal.

Purpose: The purpose of this study was to: (1) evaluate return to pre-injury level of sports activity and participation (RPSP) after ACL reconstruction (using a comprehensive definition for return to pre-injury level of sports that includes the type and frequency of sports participation and frequency of sports activities as defined by the Marx Activity Rating Scale); and (2) determine the reasons for not being able to return to pre-injury level of sports.

Study Design: Cross-Sectional Study, Level of evidence, 2b.

Methods: Participants who were 1 to 5 years post ACL reconstruction completed a survey to determine their pre-and post-surgery sports activity levels, knee injury history, and reasons for not returning to prior level of sports participation. The International Knee Documentation Committee Subjective Knee Form (IKDC-SKF) was used to compare symptoms and function between patients

who did and did not achieve the criteria for return pre-injury level of sports activity and participation.

Results: Two hundred fifty one participants (mean age, 26.1±9.9 years) completed the survey at an average of 3.4±1.3 years after ACL reconstruction. One-hundred twenty-two (48.6%) met our criteria for return to pre-injury level of sports activity and participation. Participants who met the criteria for RPSP were younger (23.6±9.3 years) than those who did not (28.5±9.8 years, $p < 0.001$), with no gender differences (48.9% of women vs. 48.2% of men). Participants that met criteria for RPSP had fewer symptoms and better function (based on the IKDC-SKF) than those who did not (86.3±10.7 vs. 79.8±13, $p < 0.001$). Of those who did not return to pre-injury level of sports activity and participation; 51.2% reported that they did not return because of fear of re-injury, 33.3% lacked confidence in their knee, 30.2% reported ongoing problems with their knee, 23.3% reported work or family obligations, and 9.3% were no longer eligible to participate in sports.

Conclusion: Return to pre-injury level of sports activity and participation after ACL reconstruction is low and consistent with recent reports. Less than 50% of participants returned to pre-injury level of sports participation using our criteria for return to sports. Fear of re-injury, lack of confidence, and ongoing knee problems are the major reasons for not returning to prior sports. These issues need to be addressed in order to improve the return to sports rate after ACL reconstruction.

Keywords: Knee, Anterior cruciate ligament, ACL, Surgery, Return to sport

3.1 INTRODUCTION

Anterior cruciate ligament reconstruction (ACLR) is one of the most common orthopaedic surgical procedures performed in the United States.¹ A primary goal after ACLR and rehabilitation is for the individual to return to his/her prior level of activity and sports participation without symptoms, and to prevent recurrent injury to the ipsilateral or contralateral knee. Recent evidence indicates that return to pre-injury level of sports approximately one year after ACL reconstruction varies considerably, ranging from 33% to 92%.²⁻⁵ A recent study⁷ reported that at medium term follow-up 2 to 4.5 years after ACLR, only 45% of individuals had returned to their pre-injury level of sports participation. A meta-analysis⁸ involving 5770 subjects from 48 studies found poor rate of return to sport at 3.5 years after ACLR, with only 63% returning to their pre-injury level of sports participation, and 44% returning to competitive sports. An update of this meta-analysis, was expanded to include 7556 subjects from 69 studies, and demonstrated that 65% of individuals returned to their pre-injury level of sports activity; and 55% returned to competitive sports at an average follow-up of 3.3 years after ACLR.⁹

A substantial problem in accurately estimating the rate of return to sports after ACLR is the lack of consensus on how to define return to pre-injury level of sports activity and participation (RPSP). Return to sports has been defined in terms of return to any sport²³⁻²⁵; or using a single global question,²⁶⁻²⁸ such as “Did you return to your pre-injury level of sports?”. Return to sports

has been also reported in terms of return to pre-injury level of sports using patient-reported outcome measures such as the Tegner scale^{2,29-31} or Marx Activity Rating Scale,³² return to pre-injury level of sports participation based on type of sport^{35,36} or based on pre-injury type and frequency of sports,^{4,37,38} and return to the same number of hours of sports participation per year as before injury.³⁹ Although these definitions seem to cover the broad spectrum of sports participation, an accurate comprehensive definition for return to pre-injury level of sports participation is still unclear. For an individual to be considered as having returned to their pre-injury level of sports activity and participation (RPSP), it can be argued that the individual should return to the same type of sports with the same frequency while putting the same amount of stress on his/her knee as before injury. This definition of returning to the pre-injury level of sports activity and participation provides a more comprehensive definition of return to sports, which is consistent with the International Classification of Function and Disability (ICF) model of function and disability. In this model, activity is defined as execution of task or action by individual and participation is defined as involvement in life situations. Using these definitions, sports activity was defined in our study in terms of that ability to run, cut, decelerate and pivot as measured by the Marx Activity Rating Scale.¹⁴¹ Similarly, participation in sports was defined in terms of the type and frequency of sports participation

Structure and function of the knee as well as contextual factors may influence the rate of return to pre-injury level of sports participation. Individuals may return to their pre-injury level of sports participation but after a short period of time they may re-injure their reconstructed knee, which may be considered successful return to sports but failed ACLR. Patients may successfully return to their pre-injury level of sports participation after ACLR but may not maintain their sports participation for reasons that are not related to their primary surgery such as another injury (i.e.

car accident, fall, etc), or life style changes (i.e. finished school or college and no longer being eligible to participate in sport in which they were injured, marriage and family commitment, pregnancy, etc), or because of aging.

The two purposes of this study were: 1) to evaluate return to pre-injury level of sports participation after ACL reconstruction using a definition for return to pre-injury level of sports that considered the type and frequency of sports participation as well as frequency of sports activities as defined by the Marx Activity Rating Scale; and 2) to determine the reasons why an individual did not return to his/her pre-injury level of sports activity and participation.

3.2 MATERIALS AND METHODS

3.2.1 Subjects

A medical records review for the dates between 1/1/2007 and 4/30/2011 was performed to identify all eligible research subjects between 14 and 50 years of age at the time of primary unilateral ACL reconstruction performed by a surgeon affiliated with our institution. Clinical and operative notes were reviewed. Patients who had prior knee injury or surgery to either knee were not eligible to participate in the study. This study was approved by our Institutional Review Board using an expedited review process.

3.2.2 Procedures

Invitation letters along with the questionnaires and informed consent forms were sent to potential subjects using a three-phase mailing procedure followed by postcard reminders and phone calls to maximize response rate. The questionnaire inquired about subjects' pre- and post-surgical levels of sports activity and participation. Subjects were asked to report their level of sports participation before injury as well as the most demanding level of sports participation after surgery (Appendix A & B). Subjects were also asked to report the frequency of running, cutting, decelerating and pivoting as measured by Marx Activity Rating Scale as well as symptoms, knee injury history and reasons for not being able to return to sports if applicable. The International Knee Documentation Committee Subjective Knee Form (IKDC-SKF)¹²⁷ was also used to compare symptoms and function between patients who did and did not return to pre-injury level of sports participation.

Reasons for not returning to pre-injury level of sports participation included ongoing problems with knee, fear of re-injury, lack of confidence in the knee, expired eligibility for sports participation, work or family obligations, and space for a free response if additional reasons prevented the return to pre-injury level of sports participation. The questionnaire was pilot tested to evaluate the burden of the survey on patients as well as to integrate patients' comments and suggestions, and to clarify any potentially uncertain questions cited by patients before final administration.

3.2.3 Return to sports outcome

Return to pre-injury level of sports participation was operationally defined as returning to the same or more demanding type of sports participation (strenuous sports activities, moderate sports

activities, light sports activities, or no sports), at the same or greater frequency (4 to 7 times per week, 1 to 3 times per week, 1 to 3 times per month, or less than one time per month) with the same or better Marx Activity Rating score as before injury. For this study we considered the individual's best reported level of sports participation after ACL reconstruction.

3.2.4 Data analysis

Descriptive statistics including frequency counts and percentages were calculated and summarized for all nominal variables. Measures of central tendency (means, medians) and dispersion (standard deviations, inter-quartile ranges) were calculated for all continuous variables. The prevalence estimate for return to prior level of sports participation was determined by dividing the number who returned at their best following surgery to their pre-injury level of sports using our definition of return to pre-injury level of sports by the total number of participants. A 95% confidence interval around the estimate was also created. Independent t-tests and chi-square tests were used to compare the differences in the IKDC SKF as well as return to sports by age subgroups for those that met versus did not meet the definition for RPSAP.

For all inferential statistical analyses, an alpha level of $p < 0.05$ was considered statistically significant. All statistical analyses were performed using IBM SPSS Version 21.0 (SPSS Inc. Chicago, IL).

3.3 RESULTS

Based on a review of medical records, we identified 797 individuals who were potentially eligible to participate in our study (Figure 1). The investigators were unable to locate 303 individuals who could not be contacted via mailing or telephone (mailing returned to sender, wrong address, number out of service, etc.). We were able to establish contact with the remaining 494 eligible subjects. However, 198 did not respond despite 3 mailings, a postcard reminder and 2 phone messages. Of the individuals that responded to our invitation to participate in the study, 29 refused to participate in the study and 6 returned the questionnaires without a signed informed consent form. Two individuals were determined to be deceased. Completed questionnaires and signed informed consent forms were received from the remaining 259 subjects. After a second review of the medical records, eight subjects were deemed ineligible and excluded from the analysis. This included two individuals that had a previous contralateral ACL reconstruction, one who had an injury of both knees and five who were ineligible based upon age at the time of surgery. The remaining 251 participants were included in our study, which is equal to a response rate of 51.6% (251/486).

Of those who agreed to participate in our study, there were 139 (55.4 %) females and the average length of follow-up was 3.4 ± 1.3 years. The mean age at the time of surgery was 26.1 ± 9.9 years and the median time from injury to surgery was approximately 2 months.

The subjects who did not respond to our invitation were younger (21.1 ± 8.3) than those who did respond (26.1 ± 9.9 , $p < .001$) with a higher percentage of males (60%), ($p < .001$). No other differences were found between responders, non-responders, and those who refused to participate in the study. A summary of demographics for those who did and did not completed the questionnaire as well as refusals is presented in Table 1.1.

3.3.1 Return to pre-injury level of sports

Based on our operational definition for RPSP, 122 (48.6%; 95% CI, 42.4%-54.8%) individuals returned to their pre-injury level of sports activity and participation after ACL reconstruction. Individuals who returned to their pre-injury level of sports participation were younger (23.6 ± 9.3 years) than those who did not (28.5 ± 9.8 years, $p < 0.001$), with no gender differences (48.9% women; 48.2% men). Sixty-nine percent (54/78) of high school aged (14-18 years) individuals met the criteria for RPSP compared to only 47% (26/55) of college aged (19-23 years) individuals and 36% (42/118) of those older than college age (≥ 24 years), $p < 0.001$ (Table 2.1). The post-hoc comparisons for the differences in return to pre-injury level of sports participation by age group showed that there was significant differences between high school aged individuals vs. college aged and older than college age individuals, ($p = 0.012$ and $p < 0.001$; respectively). There was no significant difference between college aged individuals and those who were older than college age in return to pre-injury level of sports activity and participation; ($p = .144$).

Of the 129 participants who did not return to pre-injury level of sports, 51.2% reported that they did not return because of fear of re-injury, 33.3% lacked confidence in the knee, 30.2% were due to ongoing problems with their knee, 23.3% were due to work or family obligations, 9.3% were no longer eligible for participation in sports, and 17.8% were due to other reasons such as age, pregnancy, unspecified pain, limited time for sports participation, and other health problems. Reasons for not returning to pre-injury level of sports participation are summarized in Table 3.1.

The rates of re-injury of the ipsilateral knee and injury to the contra-lateral knee are presented in Table 4.1. Of those who met our RPSP criteria, eight (14.8%) high-school aged and 4 (15.4%) college-aged participants had a re-injury that required revision ACLR.

3.3.2 Patient reported function

Individuals who returned to their pre-injury level of sports participation had fewer symptoms and better function based on the IKDC-SKF than those who did not return to sports (86.3 ± 10.7 vs. 79.8 ± 13 , $p < 0.001$). After standardizing the IKDC-SKF scores to an age- and gender-matched normal population,¹³⁰ there continued to be a significant difference in the IKDC-SKF scores between those who did ($z = -.80$) and did not return to pre-injury level of sports participation ($z = -1.46$) ($p < .001$), however both groups had lower scores compared to an age- and gender-matched normal population.

3.4 DISCUSSION

The purpose of this study was to determine the rate of return to pre-injury level of sports activity and participation in the medium term (3.4 Years) after ACL reconstruction using a definition that considered the type and frequency of sports participation, as well as the frequency of sports activities as defined by the Marx Activity Rating Scale. This definition is consistent with the ICF model of functioning and disability. Asking individuals specific questions about type and frequency of sports participation and frequency of sports activities such as cutting and pivoting will guide them to be more specific and precise in reporting their actual sports activity and participation level. Comparing sports participation after surgery to the pre-injury level of sports participation will provide a better judgment about an individual's actual return to pre-injury level of sports participation compared to just asking the individual a global question such as "Did you return to your pre-injury level of sports?" When presented with this type of global questions,

individuals might only think about whether they returned to their previous type of sports and how many times they play their sports without considering how much stress they put over their knees (sports activities, i.e. running, cutting, pivoting, decelerating) during sports participation. The lack of clarity with these types of global questions could over-estimate an individual's return to his/her pre-injury level of sports participation. In addition, answering a general question may be biased by an individual's satisfaction with his/her surgery and his/her overall function. Asking separate questions about the type and frequency of sports participation and frequency of sports activities before and after surgery will yield the most accurate determination of whether individuals actually returned to their pre-injury level of sports participation.

Our operational definition for return to pre-injury level of sports participation required individuals to have returned to the same or more demanding type and frequency of sports participation and the same or better Marx Activity Rating Scale score as before injury to be considered to have successfully returned to their pre-injury level of sports participation. Using this definition, 48.6% of participants had returned to their pre-injury level of sports participation after surgery at an average of 3.4 ± 1.3 years after ACL reconstruction. The prevalence of return to pre-injury level of sports participation in this study is low, but is consistent with recent reports. A recent meta-analysis⁹ has shown that at a mean follow-up of 3.3 years, only 65% of patients had returned to their pre-injury level of sports participation. An explanation for the difference between these results and the meta-analysis likely lies in the disparity in the definition of return to pre-injury level of sports participation between studies included in the meta-analysis compared to the comprehensive criteria used to define successful return to pre-injury sport participation in our study. In another study, Arden et al⁷ evaluated return to pre-injury level of sports at 2 to 7 years

after ACL reconstruction, reporting that 45% of patients had returned to their pre-injury level of sports participation at an average 3.3 ± 1.15 years after ACL reconstruction.

The rate of RPSP was not different between male/female. Approximately half of the men (48.2%) and women (48.9%) returned to their pre-injury level of sports participation. Several studies have found the same results in term of gender differences and return to sports.^{7,26,83} However, males may return to sports earlier than females.^{10,82} A recent study by Brophy et al⁸⁴ reported that there was no difference between males and females in return to play at long term follow-up of 7.2 ± 0.9 years, however age and gender were found to be predictors for return to play at approximately 12 months follow-up. At 12 months, males were more likely to return to sports than females, and older individuals (≥ 30 year-old) were less likely to return to sports than younger individuals.

We found that individuals in the high-school and college-age ranges returned to their pre-injury levels of sport participation more frequently than those over the age of 24 years. Younger individuals may have more desire to return to sports for reasons such as getting scholarship for college or motivation to go back to their sports and help their teams. Also they may have more eligibility to play their prior sports compared individuals older than 24 who have typically completed eligibility for participation in college sports. On the other hand, older than college-age individuals may not return to their pre-injury level of sports participation because of work or family obligations, as well as life style changes such as finishing college, no longer eligible to participate in formal sports, marriage and pregnancy, etc. Other reasons that may prevent people from returning to their prior sports include sustaining another injury that is not related to their primary surgery such as injury to another joint (i.e. ankle), car accident, fall, etc. These results are similar to those reported by others.⁷

Reasons for not returning to pre-injury level of sports participation have been explored in this study by asking individuals to cite all reasons for not returning to sports. The most common cited reasons were fear of re-injury (51%), lack of confidence (33%) and ongoing problems with the knee (30%), which are similar to previous reports.^{7,42,145} Several studies have shown that fear of re-injury was the major and most common reason cited by individuals for not returning to sports or for returning to a lower level of sports participation after ACL reconstruction.^{8,26,27,42,74,75} Fear of re-injury and lack of confidence are potentially modifiable and should be given more attention by physicians, physical therapists, athletic trainers, and families in order to improve return to pre-injury level of sports outcomes. Evaluating psychological status during rehabilitation may help identify those with high fear and low confidence.⁹ Discussing the possible reasons and solutions for this fear of RPSP; educate about the realistic time to return to specific activities; and regularly evaluating physical status and performance might help decrease fear and increase confidence. Additionally, participation in a rehabilitation and return to sports program that progressively and systematically exposes the individual to activities that place higher demands on the knee, may allow individuals to develop strategies to safely and more confidently perform the activities, thus reducing the individual's level of fear and improving the chances of return to sports.

An important outcome to be considered when evaluating return to sports is re-injury of the ipsilateral knee and new injury to the contra-lateral knee. Our results showed that a total of 21 (8.2%) participants (18 injured during sports participation) had another ACL injury to their ipsilateral knee that required surgery, and 15 (5.9%) had contralateral ACL surgery (12 injured during sports participation). Of those who had ipsilateral ACL surgery, 13 (61.9%) returned to their pre-injury level of sports participation based on our criteria. Of those who had contralateral ACL surgery, only 6 (40%) met our criteria for return to sports. Our subgroup analysis showed

that 52.4% (11/21) of those who had another ipsilateral injury were high-school or younger individuals (1 individual injured before he/she returned to sports), and 38.1% (8/21) were in the college-aged range (2 individuals injured before they returned to sports). On the other hand, 60% (9/15) of those who had contralateral ACL injury were high-school or younger individuals (3 individual injured before they returned to sports), compared to only 13.3% (2/15) and 26.7% (4/15) who were college-aged and older than college age, respectively.

Our results show that young active individuals (less than 18 years-old) had more ipsilateral and contralateral ACL injuries than older individuals. These results are similar to recent reports that found there was a high percentage of ipsi- and contralateral ACL injuries among young active individuals within two years from the time they were cleared to return to sports after ACL reconstruction.^{146,147} The greater rate of re-injury is likely associated with the greater return to sport rates in young athletes.

Contralateral ACL injuries were relatively high and existed across all ages, consistent with recent reports.¹⁴⁸ Individuals might put more stress on the contralateral knee to avoid stressing the reconstructed knee, resulting in an increased risk of injury to the contralateral knee. Alternatively, rehabilitation/recovery of strength and neuromuscular control of the reconstructed knee might be inadequate, resulting in increased stress on the contralateral knee. Therefore, it may be necessary to completely rehabilitate the surgical knee and give additional attention to the contralateral limb during rehabilitation to prevent these injuries.

A strength of our study is that we used strict criteria to define return to pre-injury level of sports participation. To meet the criteria for return to pre-injury level of sports participation, individuals had to return to the same or more demanding type and frequency of sports participation

with the same or better Marx Activity Rating Scale score as before injury. Adopting these standardized criteria to define return to pre-injury levels of sports participation will provide a better estimate of the true return to sports rate and will help to ensure the ability to compare results among future studies.

Our study has some limitations that need to be acknowledged. The nature of survey studies can always be affected by recall bias. However, this was an important start for future prospective studies using the same criteria for defining return to sports. Non-responders to our study invitation were younger and more likely to be males than those that responded. Since younger individuals in our sample and previous reports^{7,42} were more likely to return to prior sports, missing data from younger individuals could affect the prevalence of return to sports and result in an under-estimation of the true overall return to sports rate.

In the future, prospective studies using comprehensive criteria for defining return to sports are necessary to more accurately determine the incidence of return to sports as well as the factors that are associated with return to sports. In these prospective studies, the pre-injury level of sports participation should be determined immediately after injury and return to sports activities, including return to running and agility, jumping, pivoting and cutting activities and return to participation in practice and competition should be documented. Additionally, factors that are likely to be associated with return to sports, such as concomitant meniscus or cartilage injuries, additional injuries or surgeries to ipsilateral or contralateral knee, strength, balance, and neuromuscular control, fear of re-injury and confidence of return to pre-injury level of sports participation should be also measured.

3.5 CONCLUSION

Return to pre-injury level of sports activity and participation after ACL reconstruction in this study was low (48.6%) and was consistent with other recent reports. A greater percentage (69%) of high-school-age participants returned to prior sports compared to (47%) college-aged participants and only 36% of participants older than college-age. However, high-school and college-age participants were more susceptible to re-injury of the ACL reconstructed knee as well as injury of the contra-lateral knee that required surgery. Fear of re-injury, lack of confidence, and ongoing knee problems played the greatest role in preventing return to pre-injury level of sports. These issues should be addressed by performing more precise anatomic ACL reconstruction and during post-operative rehabilitation to improve return to sports after ACL injury and reconstruction; and to improve pre-operative counseling for expectations of surgery.

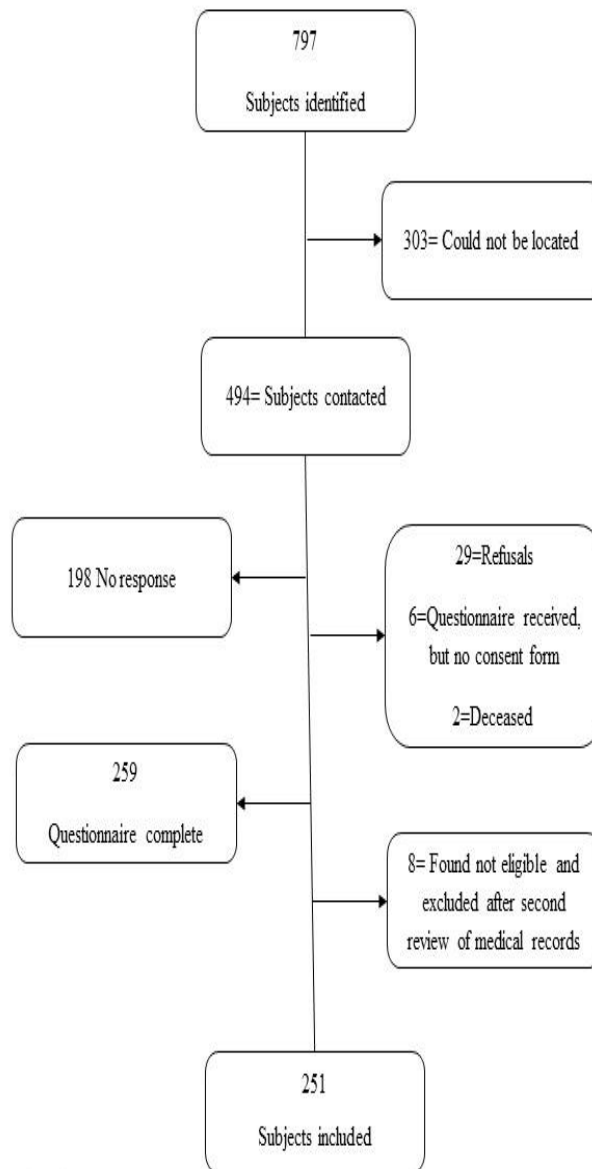


Figure 1. Flow diagram of subjects' recruitment process

Table 1.1: Demographics for Those Who Did and Did Not Respond to the Questionnaire

	Non- Responders* n=206	Responders n=251	Refused n=29	p-value
Age the Time of Surgery†	21.1 ± 8.3	26.1 ± 9.9	27.6 ± 11.5	p< .001
Females n, %	83 (40.3%)	139 (55.4%)	17 (58.6%)	p< .001
Length of Follow-Up†	2.9 ± 1.1	3.4 ± 1.3	3.1 ± 1.1	p= .269

*Non-responder group includes contacted by telephone without returning the survey, returned questionnaire without consent and deceased.
† Indicates values are presented as mean ± standard deviation

Table 2.1: Return to Pre-Injury Level of Sports Activity and Participation After ACLR By Age Subgroups.

Age at The Time of Surgery	Comprehensive RPSP	Total
	Yes	
≤ 18 Y.o	54 (69.3%)	78
19 – 23 Y.o	26 (47.3%)	55
≥ 24 Y.o	42 (35.6%)	118
Total	122 (48.6%)	251

Table 3.1: Reasons For Not Returning to Pre-Injury Level of Sports Activity and Participation After ACLR

Age at The Time of Surgery	≤ 18 Y.o n, (%)	19-23 Y.o n, (%)	≥ 24 Y.o n, (%)	Total n, (%)
Fear of Re-Injury*	12 (9.3%)	21 (16.3%)	33 (25.6%)	66 (51.2%)
Lacked Confidence in The Knee*	9 (7%)	16 (12.4%)	18 (13.9%)	43 (33.3%)
Ongoing Knee Problems*	8 (6.2%)	14 (10.8%)	17 (13.2%)	39 (30.2%)
Work or Family Obligations*	4 (3.1%)	2 (1.6%)	24 (18.6%)	30 (23.3%)
No Longer Eligible*	3 (2.3%)	5 (3.9%)	4 (3.1%)	12 (9.3%)
Other Reasons*	5 (3.9%)	5 (3.9%)	13 (10%)	23 (17.8%)

* Not mutually exclusive

Table 4.1: Rates of Re-Injury (ACL Revision) for Ipsilateral Knee and The Contralateral ACL Surgery and Their Return to Sports Status After Primary ACLR

Age at The Time of Surgery		ACL Revision (21)	Contralateral ACL Surgery (15)
14-18 yrs.	Returned	54	8 (14.8%)
	Did Not Return	24	4 (7.4%)
19-23 yrs.	Returned	26	3 (12.5%)
	Did Not Return	29	5 (20.1%)
≥ 24 yrs.	Returned	26	4 (15.4%)
	Did Not Return	29	4 (13.8%)
Total	Returned	42	2 (6.9%)
	Did Not Return	76	2 (4.8%)
		122	1 (1.3%)
		129	2 (2.6%)
		122	6 (4.9%)
		129	8 (6.2%)
			9 (7%)

4.0 RETURN TO PRE-INJURY LEVEL OF SPORTS ACTIVITY AND PARTICIPATION AFTER PRIMARY ANTERIOR CRUCIATE LIGAMENT (ACL) RECONSTRUCTION: A PROSPECTIVE COHORT STUDY

Background: Return to pre-injury level of sports activity and participation is one of the main reasons for undergoing anterior cruciate ligament reconstruction (ACLR) in young active individuals. Recently, a meta-analysis reported low rates (65%) of return to pre-injury level of sports and return to competitive sports (55%) after ACLR. However, there was no consensus in the definition of return to pre-injury level of sports between the studies included in this meta-analysis which may over or under-estimate the true rate of return to sports.

Purpose: The purpose of this study was to (1) determine the incident rate of return to pre-injury level of sports activity and participation 12-months after ACLR using a comprehensive definition for return to pre-injury level of sports activity and participation that includes the type and frequency of sports participation and frequency of sports activities as defined by the Marx Activity Scale; (2) determine the reasons for not returning to pre-injury level of sports activity and participation.

Study Design: Prospective Cohort Study, Level of evidence, 1b.

Methods: Individuals between 14 and 35 years of age who participated in competitive or recreational strenuous or moderate sports prior to suffering a complete unilateral ACL tear, and

elected to undergo ACLR with autograft were eligible to participate in the study. Subjects were prospectively followed for 12 months after surgery to determine return to pre-injury level of sports activity and participation. Competitive sports were defined as participation in strenuous or moderate sports activities 4-7 times per week and a minimum total Marx Activity Scale score of 12 and recreational sports were defined as participation in strenuous or moderate sports activities 1 to 3 times per week with a minimum total Marx Activity Scale score of 8.

Results: Fifty-seven participants enrolled in the study of which 35 have reached the 12-month follow-up time point. The mean age at the time of surgery for those with complete follow-up was 19.79 ± 4.64 years and 17 (48.6%) were females. Thirty (85.7%) subjects were playing at the competitive sports level before injury with no differences in sex (53.3% female vs 46.7% male). Using our definition for return to pre-injury level of sports activity and participation, 14 (40%) participants returned to their pre-injury level of sports activity and participation 12 months after ACL reconstruction with a higher return to sports rate in males (50%) than females (29.4%), however this difference was not statistically significant. Of those who returned to prior level of sports activity and participation, 13 (92.9%) returned to competitive sports and 1 (7.1%) returned to recreational sports participation. Lack of confidence in the knee (38.1%) and fear of re-injury (33.3%) were the most common reasons for not returning to the prior level of sports activity and participation.

Conclusion: Using standardized criteria for defining return to pre-injury level of sports activity and participation, return to sports at 12 months is low (40%) and consistent with recent reports, however it may provide an accurate estimate of the true rate of return to sports. Similar to other reports, fear of re-injury and lack of confidence in the knee are the major reasons for not returning

to pre-injury level of sports activity and participation. These results support the importance of addressing these issues to improve return to sports after ACLR.

Keywords: Knee, Anterior cruciate ligament, ACL, Surgery, Return to sport

4.1 INTRODUCTION

Anterior cruciate ligament (ACL) injuries are very common in the United States¹⁷ and many other countries.¹⁴⁹⁻¹⁵¹ The estimate of ACL surgeries in the US population has significantly increased from 32.94 to 43.48 per 100,000 person-years between 1994 and 2006.¹⁵² This is equal to an estimate of 138,000 ACL surgeries in 2014. The increase in the number of ACL reconstructions over this time period may be due to the increase in sports participation in the young population¹⁵² as well as the continuous participation in sports throughout the year without time off, which has been hypothesized to increase the risk of ACL injury and thus surgery particularly in young athletes.

Although return to sports activity and participation is one of the main reasons for undergoing ACL reconstruction especially in young active individuals, recent evidence has demonstrated that return to sports after ACL reconstruction is low with only 65% having returned to pre-injury level of sports and 55% returned to competitive sports at an average of 3.3 years after surgery.⁹ Depending on surgical and rehabilitation protocols, clearance for return to sports after ACL reconstruction may take place between 6 to 9 months after surgery^{56,153} and a large proportion of athletes are expected to return to pre-injury level of sports activity and participation within 1 year after ACL surgery. However, recent studies show that return to prior level of sports 12 months

after ACL reconstruction varies greatly, ranging from 31% to 92%.²⁻⁶ One of the possible explanations for the variability in the rate of return to pre-injury level of sports is the inconsistency in the definition of return to pre-injury level of sports. Some people determine return to pre-injury sports by asking individuals a single global question such as “Have you returned to your pre-injury level of activity”^{26,154} while others use patient-reported scales such as the Tegner Activity Scale.²⁹ The lack of consensus in how return to pre-injury level of sports participation is defined may lead over- or -under estimation of the true rate of return to sports.

The low percentage of return to pre-injury level of sports 12 months after ACL reconstruction in some studies suggests that individuals may take longer than 12 months to return to pre-injury level of sports. A recent study¹⁵⁵ showed that 41% of those who did not return to their pre-injury level of sports at 1 year had returned to pre-injury level of sports 2 years after ACL reconstruction. The overall of return to pre-injury level of sports increased from 31% at 1 year to 60% at 2 years after ACL reconstruction. Despite the fact that people might be physically and functionally ready to return to sports, they may not return to sports because of fear of re-injury^{74,75} and sometime for reasons such as work and family obligations or life style changes. Using standardized criteria to define return to pre-injury levels of sports participation is important and will help comparing and combining results among future studies as well as accurately identifying the reasons for not returning to sports.

The aims of this study were to: (1) determine the incident rate of return to pre-injury level of sports activity and participation 12 months after ACL reconstruction using a comprehensive definition that includes the type and frequency of sports participation and frequency of sports activities as defined by the Marx Activity Rating Scale; and (2) determine the reasons for not returning to pre-injury level of sports activity and participation.

4.2 MATERIALS AND METHODS

4.2.1 Subjects

Participants were recruited between October 2013 and December 2014. The study was approved by our Institutional Review Board using a full board review process and informed consent to participate in the study was obtained from all subjects, and parents or legal guardians if needed.

All individuals who 1) were between 14 and 35 years of age; 2) had a complete ACL tear to previously uninjured knee; 3) were scheduled for ACL reconstruction within 12 months of injury; 4) participating in competitive or recreational strenuous and moderate sports prior to injury and desired to return to that level of sports; 5) underwent ACL reconstruction with autograft hamstring, patellar tendon or quadriceps tendon performed by the surgeons at our institution 6) and were willing to continue participation in the study and return for all scheduled follow-up visits, even if he/she moved from the region were eligible for participation in this prospective study. Subjects were not eligible to participate in the study if they 1) had prior surgery to the ipsilateral or contralateral knee 2) had prior knee injury to the injured knee that resulted in symptoms and limited sports participation for more than three months 3) had a current or prior injury to the contralateral knee that resulted in symptoms and limited sports participation for more than three months. Individuals with concomitant ligament injury that did not require surgery, those with meniscus tear, treated with meniscectomy or repair as well as those with cartilage lesions were eligible for participation in this study to explore the effects of ligament, meniscus, and cartilage injury on return of knee function and sports activity and participation.

4.2.2 Procedures

Subjects were recruited prior to surgery and prospectively followed for 12 months. After the informed consent was obtained, participants were asked to complete a series of questionnaires before undergoing surgery that assessed demographic characteristics and sports activity and participation. Also, the individual's surgical findings at the time of surgery were documented using standardized forms.

Sports activity level and participation prior to injury was determined immediately at the time of first clinical visit by asking participants to report their highest level of sports activity and participation before injury including the type of sports activity (strenuous sports, moderate sports, light sports, or no sports) and frequency of sports participation (4 to 7 times per week, 1 to 3 times per week, 1 to 3 times per month, or less than one time per month) as well as the frequency of running, cutting, pivoting, and decelerating as measured by Marx Activity Rating Scale,¹⁴¹ (Appendix C & D). Marx Activity Scale items were summed to create score that ranges from 0 to 16.

Twelve months after the surgery subjects were asked to report their current type and frequency of sports participation as well as the frequency of running, cutting, pivoting, and decelerating. Subjects were also asked to answer a single global question "Have you returned to your pre-injury level of sports in terms of the type, frequency, and intensity of sports that you did before injury?" to determine the agreement between these two methods of determining return to sports. Competitive sports participation was defined as participation in strenuous sports activities that involve jumping, cutting, and hard pivoting (i.e. football, soccer, basketball, volleyball and gymnastics) or moderate sports activities that involve running, twisting and turning (i.e. tennis,

racquetball, handball, ice hockey, field hockey, skiing, and wrestling) for 4-7 times per week with a minimum total Marx Activity Scale score of 12. Recreational sports participation was defined as participation in strenuous or moderate sports activities at least 1 time per week and with a minimum total Marx Activity Rating Scale score of 8.

4.2.3 Main outcome measure

The main outcome in this study was return to pre-injury level of sports activity and participation 12 months after ACL reconstruction using a new method for determining return to sports. Participants were deemed to have returned to their pre-injury level of sports if they returned to the same type and frequency of sports with at least the same Marx Activity Rating Scale score as before injury. Reasons for not returning to pre-injury level of sports activity and participation were also determined and included not ready/not cleared by the physician, ongoing problems with knee, lack of confidence in the knee, fear of re-injury, no longer eligible to participate in prior sports, work or family obligations, and a blank space for any additional reasons prevented return to pre-injury level of sports.

4.2.4 Secondary outcome measure

Return to pre-injury level of sports participation 12 months after ACL reconstruction was also determined based on global question “Have you returned to your pre-injury level of sports in terms of the type, frequency, and intensity of sports that you did before injury?”

4.2.5 Data analysis

Descriptive statistics including frequency counts and percentages were calculated for all nominal variables such as baseline activity level, gender, and graft type as well as reasons for not returning to sports. Measures of central tendency (means, medians) and dispersion (standard deviations) were also calculated and summarized for all continuous variables. The incidence rate and the associated 95% confidence interval for return to pre-injury level of sports activity and participation 12 months after ACL reconstruction were calculated. Independent t-tests, chi-square tests, and Fisher's exact tests were also used to compare the differences in baseline demographic characteristics and surgical findings and procedures between those who did and did not return to pre-injury level of sports activity and participation as appropriate.

Data analyses were performed using IBM SPSS Version 22.0 (SPSS Inc. Chicago, IL) and an alpha level of $p < 0.05$ was considered statistically significant for all inferential statistical analyses.

4.3 RESULTS

Over 200 ACL injured individuals were screened for our study eligibility of which 68 met our study initial eligibility criteria and provided informed consent. Eleven subjects were withdrawn because of exclusion criteria that were discovered after consent was obtained (i.e. prior ACL injury discovered upon further review of medical records, partial ACL tear determined at time of arthroscopy, reconstruction was performed with allograft). The remaining 57 subjects participated in this study, of which 35 have reached the 12-month follow-up time point (100% follow-up of all

possible subjects). Follow-up for the remaining 22 subjects is ongoing and will be continued through 2 years. Subject recruitment and follow-up are summarized in Figure 2. A comparison between those who did and did not complete the 12-month follow-up was performed and indicated that there were no systematic biases with respect to age, body mass index (BMI), activity level and surgical findings and procedures (Table 1.2). However, those with complete follow-up consisted of a higher proportion of individuals that participated in competitive sports.

The mean age at the time of surgery for the group with complete follow-up was 19.79 ± 4.64 years and 17 (48.6%) were female. Time from injury to surgery was 1.95 ± 1.5 months and 30 (85.7%) subjects were playing competitive sports level before injury with no differences in competitive sports participation between sexes (53.3% female vs. 46.7% male). The most common sports played prior to injury were basketball (12 subjects), football, (8 subjects), soccer (5 subjects), volleyball (2 subjects), and lacrosse (2 subjects).

Return to pre-injury level of sports activity and participation 12 months after ACL reconstruction in our cohort was 40% (95% CI, 25.6%-56.4%). Of those who played competitive sports prior to the surgery, 13 (43.3%) athletes returned to their pre-injury level of sports compared to only 1 (20%) athlete of those who played recreational sports. There were no differences in all baseline demographic characteristics and surgical findings between those who did and did not return to pre-injury level of sports activity and participation (Table 2.2).

Based on the global question of return to sports, 21 (60%) subjects reported that they returned to their pre-injury level of sports of which 7 (33.3%) subjects overestimated their return to pre-injury level of sports activity and participation and were found to have not returned to the pre-injury level of sports participation based on the comprehensive criteria. None of other subjects has underestimated his/her return to sports. The agreement between the two definitions is presented

in Table 3.2. Subjects with conflicting results on return to sports were asked to clarify if there was a true reduction in their level of sports participation and the reasons for that reduction. The 7 subjects declared that they were playing sports at lower level compared to before surgery for a variety of reasons (“began working two jobs”, “scared of re-tearing my ACL in the same knee” “play at different position, because better suited somewhere else”, “not playing for the college”, “not cleared by my physician” “not enough time and energy to play previous sports given that I’m training for marathon”, “didn't like coach, so playing different sport”).

The reasons that individuals did not return to their pre-injury level of sports are summarized in Table 4.2. Eight subjects (38.1%) reported that they did not return to prior level of sports participation because they lacked confidence in their knees and 7 subjects (33.3%) because of fear of re-injury. Seven subjects (33.3%) did not return because they were not ready or not cleared by their physician and 5 subjects (23.8%) because of other reasons (“Lack of time”, “had a meniscus surgery”, “didn’t go back to my school”, “not enough time and energy to play previous sports given that I’m training for marathon”, “didn't like coach, so playing different sport”).

4.4 DISCUSSION

Using a new method for defining return to pre-injury level of sports activity and participation, we found that 40% of competitive and recreational athletes returned to pre-injury level of sports activity and participation 12 months after surgery. These results are consistent with recent evidence that indicates that return to pre-injury level of sports after ACL reconstruction is less than optimal,⁹ however the current study used a standardized method for defining return to pre-injury

level of sports that may provide a more accurate estimate of the true rate of return to sports. Using a global question of return to sports, almost 20% of subjects overestimated their return to pre-injury level of sports activity and participation indicating that by answering a single question of return to sports, individuals may perceive themselves as being able to return the same level of sports participation as before injury but in reality they did not. This also supports the importance of using standardized criteria for determining return to sports.

The majority of participants in this study were young athletes and before surgery expressed a desire to return to their prior level of sports participation. Therefore, study participants were expected to return to prior level of sports activity and participation within 12 months after surgery. However, return to pre-injury level of sports activity and participation 12 months was less than 50%. This supports the notation that people may take longer than 12 months to return to pre-injury level of sports.¹⁵⁵

Consistent with recent reports,⁶ there was no difference in return to pre-injury level of sports activity and participation 12 months after ACL reconstruction between sexes (42.9% female vs. 57.1% male). Return to pre-injury level of sports was higher in competitive sports athletes (43.3%) compared to recreational sports athletes (20%), however because of the available sample size, this difference was not significant. A recent study showed that competitive athletes returned to pre-injury level of sports more commonly than recreational athletes 12 months after ACL surgery.⁶ Return to competitive sports participation in the current study was also higher in males (57.1%) than in females (31.3%), but this difference was not significant due to the limited sample size. Other studies with larger sample sizes have found similar results with higher return to pre-injury level of competitive sports in male athletes than females 12 months after ACL reconstruction.^{10,84} Some studies suggested that females may have less motivation than males to

resume their prior sports.^{156,157} Also, females may experience re-injury or injury to the contralateral knee more often than males.¹⁴⁶ However, it is still unclear why female competitive athletes return to pre-injury level of sports less frequently than males.

Prior studies have demonstrated that older individuals (≥ 30 years-old) are less likely return to pre-injury level of sports 12 months after ACL surgery.⁸⁴ However in our study, there was no difference in age between those who returned (19.06 ± 4.24 years) compared to those that did not return (20.28 ± 4.94 years) to pre-injury level of sports activity and participation. This in part may be explained by the fact that we restricted participation in this study to individuals between 14 and 35 years of age. Therefore, the majority of participants in current study were young individuals.

We were not able to find a significant association between graft type and return to pre-injury level of sports activity and participation 12 months after surgery. Although a patellar tendon graft was more commonly used in those that returned to their prior level of sports within 12 months, we were unable to demonstrate that this relationship was significant because of the limited distribution of graft types that were used in this study. Only 26% of subjects in current study underwent reconstruction using a patellar tendon graft. The effect of graft choice on return to sports is still debated.⁹

The current study results showed no differences in return to pre-injury level of sports activity and participation 12 months after surgery between those who had a concomitant meniscus or ligament injury versus those with isolated ACL injury. Previous evidence²² showed that at longer period of follow-up (>10 years), individuals with concomitant meniscus injury had a higher percentage of radiographic OA (21% to 48%) compared to 13% in individuals with an isolated ACL injury. The increase in OA rate could be associated with more functional limitations and thus lower rate of return to sports activities. The effect of concomitant meniscus injury and surgery as

well as ligament injuries on return to sports may require a longer period of follow-up. In addition, the effect of concomitant meniscus or cartilage injuries on maintaining the level of sports activity and participation are still unclear and needs further investigation.

Participants who did not return to pre-injury level of sports participation were asked to cite all reasons for not returning to prior sports participation. Similar to other reports,^{7,42,145} the most common reasons for not returning to pre-injury levels of sports activity and participation 12 months after surgery were lack of confidence in the knee (38.1%) and fear of re-injury (33.3%). These findings support the growing evidence that emphasize the need to address fear of re-injury and lack of confidence to improve return to sports after ACL reconstruction.^{6,154} This can be achieved during rehabilitation through evaluating and identifying those with high fear of re-injury and less confidence and addressing the possible causes for this fear.⁹ Additionally, educating individuals about the expected time to return to specific activities; regularly evaluating their physical status and performance, as well as enrolling them in a return to sports program that progressively and systematically exposes the individual to activities that place higher demands on the knee might help decrease their fear and increase their readiness to return to sports.

Approximately 33% of those who did not return to sports in current study reported that they did not return because they were not ready or not cleared by their physicians. This supports the suggestion that following ACL reconstruction individuals may require more than 12 months to return to their prior level of sports participation. Despite the fact that our study was restricted to young individuals that expressed the desire to return to sports, 24% did not return to their pre-injury level of sports participation because of life style changes or changes in the desire of resuming sports at the same level. This suggests that maybe there is a natural reduction in sports participation due to age and life style changes that could be expected even without ACL injury.

A strength of current study is that it used a standardized procedure to define return to pre-injury level of sports activity and participation. Pre-injury activity level was determined immediately prior to the surgery and subjects were followed prospectively for 12 months to accurately determine their 12-month return to sports status. To accurately estimate the rate of return to pre-injury level of sports, we included young active individuals that expressed a desire for return to pre-injury level of sports. The current study also is one of few studies that evaluated the differences in patient characteristics and surgical findings and procedures between those who returned versus did not return to pre-injury level of sports.

A limitation of our study is that the follow-up time for 12 months is generally considered a short period after ACL reconstruction, however the purpose of this study was to determine return to pre-injury level of sports that is assumed to be achieved during the first 12 months after ACL reconstruction. Additionally the participants' rehabilitation programs were not standardized and subjects were permitted to receive their rehabilitation according to their convenience. This may have influenced the return to sports rate. However, this study is a prospective observational study that is more representative to clinical situations and practices. Furthermore, the percentage of competitive athletes was higher in the group with complete versus incomplete follow-up. Since competitive athletes were more likely to return to pre-injury level of sports, this may affect the current findings and result in an over-estimation of the overall return to sports rate.

To validate our standardized method for determining return to pre-injury level of sports activity and participation as well as to support its accuracy more prospective studies that evaluate return to pre-injury level of sports using the same method are needed. Future studies should also evaluate return to pre-injury level of sports at longer follow-up times to determine return to sports for those who did not return to sports at shorter follow-up time point (i.e. 12 months) as well as to

determine if athletes maintain their level of sports participation over time. Reasons for not maintaining sports activity level should be also explored.

4.5 CONCLUSION

Return to pre-injury level of sports activity and participation 12 months after ACL reconstruction is low (40%) and consistent with recent reports, however using a standardized criteria for defining return to pre-injury level of sports may provide a more accurate estimate of the true rate of return to sports. As previously reported by other studies, fear of re-injury and lack of confidence are the major reasons for not returning to pre-injury level of sports activity and participation. As such, addressing psychological factors during rehabilitation may be as important as other factors to improve return to sports.

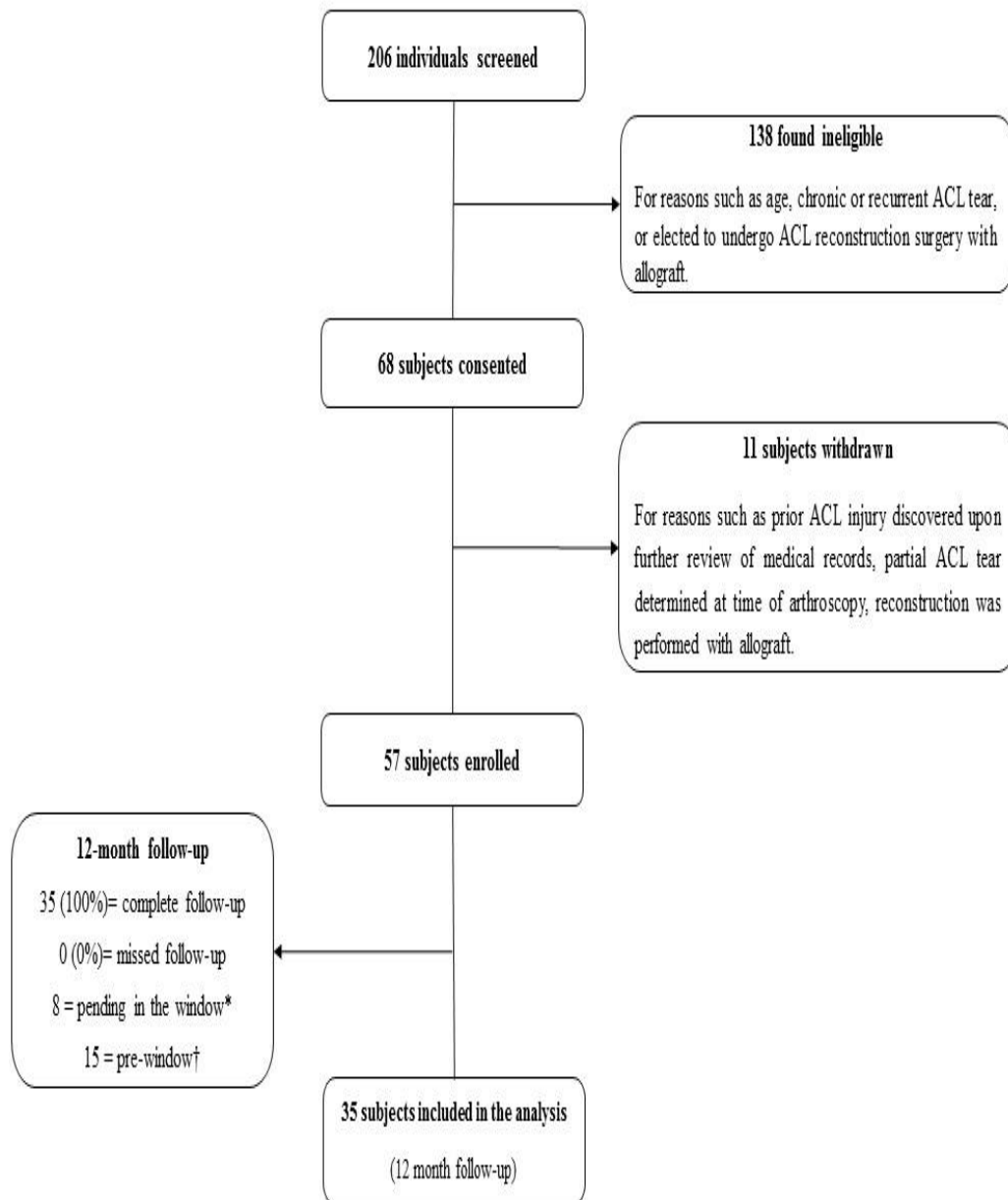


Figure 2. Flow diagram of subjects' recruitment and follow-ups

* Subject's evaluation session is due but it's still within the window of follow-up (10 to 14 mos)

† Pre-window means that subject did not reach follow-up time point.

Table 1.2: Demographics Characteristics and Surgical Findings and Procedures For Those Who Did and Did Not Complete 12-Month Follow-Up After ACL Reconstruction

	Complete Follow-Up (12 mos.) n=35	Incomplete Follow-Up (12 mos.)* n=22	p-value
Age The Time of Surgery†	19.8 ± 4.6	20.1 ± 4.6	.689
Females n, %	17 (48.6%)	13 (59.1%)	.439
BMI†	24.0 ± 5.6	23.7 ± 2.3	.827
Time From Injury to Surgery, Months†	1.98 ± 1.6	1.46 ± 1.0	.164
Competitive n, %	30 (85.7%)	14 (63.6%)	.053
Graft Type n, %			.987
Hamstring Tendon	23 (65.7%)	14 (63.6%)	
Patellar Tendon	9 (25.7%)	6 (27.3%)	
Quadriceps Tendon	3 (8.6%)	2 (9.1%)	
Medial Meniscus Tear n, %	9 (25.7%)	5 (22.7%)	.799
Medial Meniscus Treatment n, %			.496
Tear Left In Situ	1 (2.9%)	2 (9.1%)	
Repair	6 (17.1%)	3 (13.6%)	
Meniscectomy	2 (5.7%)	0	
Lateral Meniscus Tear n, %	16 (45.7%)	8 (36.4%)	.486
Lateral Meniscus Treatment n, %			.499
Tear Left In Situ	5 (14.3%)	3 (13.6%)	
Repair	8 (22.9%)	3 (13.6%)	
Meniscectomy	3 (8.6%)	2 (9.1%)	
Concomitant Ligament Injury n, %	4 (11.4%)	2 (9.1%)	.780
Concomitant Cartilage Injury n, %	5 (14.3%)	0	.145

*Incomplete follow-up group includes those who did not reach 12-month follow-up window at the time of analysis.

† Indicates values are presented as mean ± standard deviation

Table 2.2: Demographics Characteristics and Surgical Findings and Procedures For Those Who Did and Did Not Return to Pre-Injury Level of Sports Activity and participation 12 Months After ACLR

	Returned n=14	Did Not Return n=21	p-value
Age The Time of Surgery†	19.06 ± 4.2	20.28 ± 4.9	.455
Females n, %	5 (35.7%)	12 (57.1%)	.214
Time From Injury to Surgery, Months†	1.72 ± 1.7	2.15 ± 1.50	.433
BMI†	23.97 ± 4.0	24.07 ± 6.8	.960
Competitive n, %	13 (92.9%)	17 (80.1%)	.324
Graft Type n, %			.542
Hamstring Tendon	8 (57.1%)	15 (71.4%)	
Patellar Tendon	5 (35.7%)	4 (19.1%)	
Quadriceps Tendon	1 (7.2%)	2 (9.5%)	
Medial Meniscus Tear n, %	3 (21.4%)	6 (28.6%)	.636
Medial Meniscus Treatment n, %			.552
Tear Left In Situ	0	1	
Repair	3 (21.4%)	3 (14.3%)	
Meniscectomy	0	2	
Lateral Meniscus Tear n, %	9 (64.3%)	7 (33.3%)	.072
Lateral Meniscus Treatment n, %			.866
Tear Left In Situ	3 (21.4%)	2 (9.5%)	
Repair	4 (28.6%)	4 (19.1%)	
Meniscectomy	2 (14.3%)	1 (4.8%)	
Concomitant Ligament Injury n, %	2 (14.3%)	2 (9.5%)	1.000
Concomitant Cartilage Injury n, %	2 (14.3%)	3 (14.3%)	1.000

† Indicates values are presented as mean ± standard deviation

Table 3.2: Agreement Between The Comprehensive† and Global‡ Methods of Defining Return to Pre-Injury Level of Sports Activity and Participation

	Comprehensive Return to Sport		Total
	Yes n= 14	No n= 21	
Global Return to Sports			
Yes	14 (100%)	7 (33.3%)	21
No	0	14 (66.7%)	14

† Return to sports based on the type and frequency of sports participation and frequency of sports activities as defined by the Marx Activity Rating Scale.

‡ Return to based on global question “Have you returned to your pre-injury level of sports in terms of the type, frequency, and intensity of sports that you did before injury?”

Table 4.2: Reasons For Not Returning to Pre-Injury Level of Sports Activity and Participation 12 Months After ACLR

Reason*	Total (n=21)
Lack Confidence in the Knee	8 (38.1%)
Fear of Re-Injury	7 (33.3%)
Not Ready/Not Cleared by Physician	7 (33.3%)
Ongoing Knee Problems	2 (9.5%)
Work or Family Obligations	2 (9.5%)
No Longer Eligible	1 (4.8%)
Other Reasons	5 (23.8%)

*Not mutually exclusive

5.0 PREDICTORS OF RETURN TO PRE-INJURY LEVEL OF SPORTS ACTIVITY AND PARTICIPATION AFTER PRIMARY ANTERIOR CRUCIATE LIGAMENT (ACL) RECONSTRUCTION: A PROSPECTIVE COHORT STUDY

Background: Return to pre-injury level of sports after anterior cruciate ligament reconstruction (ACLR) is less than optimal. Factors that predict return to pre-injury level of sports activity and participation after ACLR are not well known.

Purpose: The purpose of this study was to identify factors that influence return to pre-injury level of sports activity and participation 12 months following primary ACLR.

Study Design: Prospective Cohort Study, level of evidence, 1b

Methods: Competitive and recreational athletes who were between 14 to 35 years of age and underwent primary unilateral ACLR with autograft hamstring, patellar, or quadriceps tendon were assessed pre-operatively and at 3, 6 and 12 months after surgery. The primary outcome was return to pre-injury level of sports activity and participation 12 months after ACLR. The primary predictors of interest included the quadriceps limb symmetry index (LSI), lateral step down, Y-balance, and single-leg hop and vertical jump tests, and psychological readiness for return to sports as measured by the ACL Return to Sport after Injury (ACL-RSI) scale. Factors related to subject characteristics (age, time from injury to surgery, gender, and baseline activity level), as well as details related to injury and surgery (concomitant injury to other ligaments, menisci and cartilage; and graft type) were also evaluated.

Results: A total of 57 subjects participated in the study, of which 35 participants (48.6% females) have completed the 12 months follow-up and were included in the analysis. The mean age at the time of surgery was 19.8 ± 4.64 years and 85.7% subjects were playing competitive sports before injury. None of the baseline variables including subject characteristics, details of injury and surgery, or baseline ACL-RSI scale were predictive of return to sports at 12 months. Three months after surgery, only the ACL-RSI scale was a predictor for return to pre-injury level of sports activity and participation. Those who returned to their pre-injury level of sports had significantly higher levels of psychological readiness to return to sports than those who did not (79.2 ± 15.8 vs. 51.2 ± 24.4 , $p = .009$). At six months, only the ability to hop and jump ($p = .003$) as well as the ACL-RSI scale ($p = .038$) were predictors for return to pre-injury level of sports activity and participation 12 months after surgery. Sixty nine percent of those who returned to sports were able to hop and jump at 6 months compared to 6.7% of those that did not return.

Conclusion: Greater psychological readiness for return to sports 3 and 6 months after surgery and the ability to hop and jump 6 months after surgery predicted return to pre-injury level of sports activity and participation 12 months after ACLR. Following ACL reconstruction, an individual's psychological readiness and confidence to return to sports needs to be addressed during rehabilitation as early as 3 months after surgery in order to improve return to sports by 12 months after surgery. Also, individuals should be encouraged to start hopping and jumping as soon as they become physically ready to perform these activities to increase their likelihood to return to sports 12 months after ACLR.

Keywords: Knee, Anterior cruciate ligament, ACL, Surgery, Predictors, Return to sport

5.1 INTRODUCTION

Return to pre-injury level of sports activity and participation after ACL reconstruction is a desire and always of concern among young active individuals.¹⁵⁸ ACL reconstruction is expected to lead to successful return to an individual's pre-injury level of sports activity and participation. However, recent evidence indicates that return to pre-injury level of sports is less than optimal with at least 1 in every 2 individuals not returning to his/her pre-injury level of sports participation by 12 months after ACL surgery.^{4,6,10} Individuals are expected to return to sports between 9 to 12 months after ACL reconstruction surgery,^{12,13} but there are no universally accepted guidelines for return to sports activity and participation after ACL reconstruction. Guidelines for return to sports that have been proposed include graft healing based on time from surgery, recovery of knee function as evidenced by range of motion and strength, performance-based measures of function (i.e. hop tests) and patient-reported outcomes.^{11,14,15} Quadriceps strength and hop tests are the most commonly used criteria for determining an individual's readiness to return to sports.^{107,159,160} Also, they have been found to be associated with knee function.^{40,110,139,161,162} However, the ability of these frequently used measures to predict return to pre-injury level of sports activity and participation after ACL reconstruction is unknown.

Psychological responses after ACL reconstruction have been extensively studied and showed a strong association with return to sports.^{6,9,154,163} Recent evidence has suggested that psychological factors may influence return to sports and are worthy of more attention.^{4,153,164} There

has been an emphasis on evaluating the differences in knee impairment measures (i.e. quadriceps strength), performance-based measures (i.e. hop tests), and patient-reported measures of knee function between those who did versus did not return to sports at time of clearance for return to sports or at longer follow-ups.^{9,154,159} However, the importance of evaluating these factors earlier during rehabilitation and their influence on return to sports has not been well studied. Age, gender, and graft type have been found to be associated with return to sports approximately 3.3 years after ACL reconstruction.⁹ However, except for baseline activity level (competitive athletes) recent studies found no influence of age, gender, time from injury to surgery, graft type (autograft vs. allograft) and concomitant meniscus, cartilage, or ligament injury on rate of return to pre-injury level of sports 12 months after ACL reconstruction.^{6,42} Therefore, enhanced understanding of variables influencing an individual's ability to return to pre-injury level of sports activity and participation 12 months after ACL reconstruction is still needed.

The purpose of this study was to identify factors that influence return to pre-injury level of sports activity and participation 12 months after primary ACL reconstruction. To our knowledge, this is the first study that examined the predictive ability of knee impairment measures (quadriceps strength) and performance-based (i.e. hop tests) measures of knee function to predict return to pre-injury level of sports activity and participation 12 months after ACL reconstruction.

5.2 MATERIALS AND METHODS

5.2.1 Subjects

All competitive and recreational athletes with a complete acute ACL tear who were between 14 and 35 years of age and underwent unilateral primary ACL reconstruction surgery with autograft hamstring, patellar or quadriceps tendon were eligible for participation in our study. Individuals were not eligible to participate in the study if they had prior surgery to the ipsilateral or contralateral knee. Individuals with concomitant ligament injury that did not require surgery, those with a meniscus tear, those treated with meniscectomy or repair as well as those with cartilage lesions were eligible for participation in this study to explore the effects of ligament, meniscus, and cartilage injury on return to sports activity and participation. This study was ethically approved by our Institutional Review Board, and written informed consent was obtained from all eligible subjects, and parent, or legal guardian as necessary for minors.

5.2.2 Procedures

Single-bundle (33 subjects) and double-bundle (2 subjects) arthroscopic ACL reconstructions, were performed by 4 surgeons affiliated with our institution. Subjects were assessed pre-operatively and postoperatively at 3, 6, and 12 months (Figure 3). Participants completed questionnaires before undergoing surgery that assessed demographic characteristics and sports activity and participation. Concomitant ligament, meniscus, and cartilage injury were documented at the time of surgery using standardized forms.

5.2.3 Primary outcome measure

The primary outcome measure was return to pre-injury level of sports activity and participation 12 months after ACL reconstruction. Determination of the level of sports activity and participation was based on the type of sports activity (strenuous, moderate, light, or no sports) and frequency of sports participation (4 to 7 times per week, 1 to 3 times per week, 1 to 3 times per month, or less than one time per month) as well as the frequency of running, cutting, pivoting, and decelerating as measured by Marx Activity Rating Scale.¹⁴¹ Marx Activity Scale items were summed to create score that ranges from 0 to 16. Pre-injury sports activity and participation was determined immediately after enrollment in the study. Subjects were deemed to have returned to their pre-injury level of sports activity and participation 12 months after surgery if they returned to the same type and frequency of sports with at least the same Marx Activity Rating Scale score as before injury. Competitive sports participation was defined as participation in strenuous sports activities that involved jumping, cutting, and hard pivoting (i.e. football, soccer, basketball, volleyball and gymnastics) or moderate sports activities that involved running, twisting and turning (i.e. tennis, racquetball, handball, ice hockey, field hockey, skiing, and wrestling) 4 to 7 times per week with a minimum total Marx Activity Scale score of 12. Recreational sports participation was defined as participation in strenuous or moderate sports activities at least 1 time per week and with a minimum total Marx Activity Scale score of 8.

5.2.4 Primary predictor variables

The ACL-RSI scale was administered prior to and 3, and 6 months after surgery. The ACL-RSI scale³⁸ is a 12-item scale that measures the association between three types of psychological

responses (emotions, confidence in performance, and risk appraisal) related to resumption of sports following athletic injury.³⁸

Quadriceps strength was measured 3 and 6 months after surgery by performing a maximum voluntary isometric torque test using an isokinetic dynamometer (Biodex System III; Biodex Medical Systems, Shirley NY). The peak isometric torque during each maximal effort trial was recorded and the average of the 3 trials was used in data analysis. The isometric strength limb symmetry index (LSI) of the involved leg was expressed as a percentage of the non-involved leg (maximal voluntary isometric quadriceps torque of the involved side divided by maximal voluntary isometric torque of the non-involved side multiplied by 100). A maximum voluntary isometric torque test using an isokinetic dynamometer has been shown to be a reliable and valid method of quadriceps strength testing^{60,108,111} with intra- and inter-tester reliability ICCs of 0.97 and 0.82, respectively.¹¹¹

The lateral step-down test as described by Piva et al¹¹⁸ was assessed 3 and 6 months after surgery. The step-down test evaluates an individual's quality of movement and is thought to be an indicator of neuromuscular control for the trunk and lower extremity.¹¹⁸ The step-down test has been found to be a valid and reliable measure (Cohen's Kappa= .67) that is able to recognize altered movement patterns in patients with patellofemoral pain syndrome (PFPS).¹¹⁸ Subjects were asked to stand in single limb support on the ACL reconstructed extremity with his/her hands on the waist, with the knee straight and foot close to the edge of a 20 cm high step. The subject then bends the knee of the stance leg until the contralateral leg gently contacts the floor and then re-extends the knee to the starting position. During the movement the examiner faced the subject and scored the test based on 5 criteria. One point was added to the total score if: 1) the subject used an arm strategy in an attempt to recover his/her balance; 2) the trunk leaned to any side; 3) the pelvis

rotated or elevated on one side compared with the other; 4) the knee deviated medially and the tibial tuberosity crossed an imaginary vertical line over the second toe, or 5) if he/she was unable to maintain unilateral steady balance. Two points were added to total score if the knee deviated medially and the tibial tuberosity crossed an imaginary vertical line over the medial border of the foot. A total score of 0 or 1 was classified as good movement quality; a total score of 2 or 3 was classified as medium quality and a total score greater than or equal to 4 was classified as poor movement quality.

The modified star excursion balance test (Y-balance test) as described by Gribble et al¹¹⁹ was also evaluated 3 and 6 months after surgery. Subjects performed the test in three directions (anterior, posteromedial, and posterolateral). Each subject performed 4 practice trials reaching in each of the three directions followed by 3 trials.¹⁶⁵ The Y-balance test composite score for each limb was calculated by dividing the sum of the maximum reach in the three directions for that limb divided by three times limb length, and then multiplied by 100. The side-to-side differences (non-involved minus involved limb) were used for analysis. The star excursion balance test has been found to be a good measure for dynamic postural control deficits in lower extremity injuries including ACL injury.^{119,120}

Hop tests, as described by Noyes et al¹⁶⁶ were evaluated 6 months after surgery. The tests included the: 1) single hop for distance; 2) straight triple hop for distance; 3) triple cross-over hop for distance in which the subject crosses over a 15 cm wide strip with each successive hop and 4) timed hop in which the subject hops 6 m as fast as possible. For each test, the results for the involved leg were expressed as a percentage of the non-involved leg and the average of the 4 hops was calculated to represent the overall limb symmetry index (LSI). The hop test indices and the overall limb symmetry index have been shown to have high levels of test re-test reliability (ICC

from .82 to .93), with standard error of measurement ranging from 3.04% to 5.5% in a sample of subjects after ACL reconstruction.¹¹⁷

Single-leg vertical jump as modified and described by Brosky et al¹⁰⁹ was evaluated 6 months after surgery by using the Vertec unit (Sports Imports, Inc., Columbus, OH). Standing baseline reach was subtracted from the total vertical jump height to obtain the height jumped. The vertical jump index was calculated as the vertical jump distance on the involved limb divided by the vertical jump distance on the noninvolved limb multiplied by 100. The ICCs for single-leg vertical jump were found to be strong and ranged from 0.88-0.97.¹⁰⁹

5.2.5 Secondary predictor variables

Subject characteristics were evaluated including: age at time of surgery, gender, body mass index (BMI), time from injury to surgery, and pre-injury activity level, and surgical findings and procedures (concomitant injury to other ligaments, menisci and cartilage; and graft type). ACL re-injury and injury to the ipsilateral or contralateral knee were evaluated as additional predictors for return to sports.

5.2.6 Data analysis

Descriptive statistics were calculated and summarized for all variables. This included frequency counts and percentages for nominal variables and measures of central tendency (means, medians) and dispersion (standard deviations, ranges) for continuous variables. Independent t-tests, chi-square tests, and Fisher's exact tests were used to evaluate the differences in primary and secondary variables between those who did and did not return to pre-injury level of sports activity and participation as appropriate. Univariate logistic regression analyses were performed for the

baseline, 3 and 6 month primary and secondary variables to identify factors that predicted return to pre-injury level of sports activity and participation 12 months after ACLR. Multivariate logistic regression analysis was not performed due to the limited sample size. An alpha level of $p < 0.05$ was considered statistically significant. All statistical analyses were performed using IBM SPSS Version 22.0 (SPSS Inc. Chicago, IL).

5.3 RESULTS

A total of 57 subjects participated in the study of which 35 participants (48.6% females) completed 12 months follow-up and were included in this analysis. The mean age at the time of surgery was 19.8 ± 4.64 years and 30 subjects (85.7%) were playing competitive sports before injury with no gender differences in competitive sports participation (53.3% female vs. 46.7% male). Twelve months after surgery, 14 subjects (40%) returned to their pre-injury level of sports activity and participation. Of those who played competitive sports prior to the surgery, 13 (43.3%) athletes returned to their pre-injury level of sports compared to only 1 (20%) of those athletes who played recreational sports. No additional injuries were documented before return to pre-injury level of sports activity and participation.

Data for the ACL-RSI scale 3 and 6 months after surgery were available for 30 subjects (85.7%), (13 returned vs. 17 did not return to sports). Complete data regarding strength and functional measures were available for 28 subjects (80%), (13 returned vs. 15 did not return to sports). None of the baseline variables including subject characteristics (i.e. age, and baseline activity level), graft type, as well as concomitant ligament, meniscus or cartilage injury were predictive of return to sports activity and participation 12 months after ACLR (Table 1.3). The

baseline scores on ACL-RSI scale were also not different between those who returned (43.5 ± 29.5) versus did not return to sports (55.4 ± 27.8), ($p = .255$).

The 3-month prediction models (Table 2.3) demonstrated that the ACL-RSI scale was the only predictor for return to pre-injury level of sports activity and participation (OR, 1.08; 95% CI, 1.02-1.14). Those who returned to their pre-injury level of sports had significantly higher levels of psychological readiness to return to sports than those who did not (79.2 ± 15.8 vs. 51.2 ± 24.4 , $p = .009$). The 6-month prediction models showed that those who were cleared and able to hop and jump had higher odds of return to sports compared to those who were not (OR, 33.8; 95% CI, 3.3-351.1). Sixty nine percent of those who returned to sports were able to hop and jump 6 months after ACL reconstruction surgery compared to only 6.7% of those who did not return ($p = .003$). Six month psychological readiness to return to sports as measured by ACL-RSI scale ($p = .038$) was also predictive of return to pre-injury level of sports activity and participation 12 months after surgery (OR, 1.05; 95% CI, 1.003-1.1). Those who returned to sports had higher levels of psychological readiness for return to sports than those who did not (76.1 ± 17.5 vs. 60.4 ± 16.7 , $p = .038$). None of the other 6-month variables were predictive for return to sports status 12 months after ACL reconstruction. However the lateral step down test showed a trend toward significance, with almost 69% of those who returned to their prior level of sports participation having good quality of movement compared to only 33% for those that did not return to sports, $p = .064$. The summary of the 6 months univariate logistic regression models is presented in Table 3.3. We used the receiver operating characteristics (ROC) curve to determine the best ACL-RSI cutoff score that has the highest discriminative capability at 3 and 6 months after surgery. Our results showed that an ACL-RSI score of 68 points (area under ROC curve = .84, 95% CI, 0.70-0.98) had the highest discriminative ability 3 months after surgery with sensitivity of 77% and specificity of

77%. At 6 months after surgery, an ACL-RSI score of 60 points (area under ROC curve = .73, 95% CI, 0.55-0.91) had the highest discriminative ability with sensitivity of 73% and specificity of 57%.

5.4 DISCUSSION

The current study evaluated the ability of commonly used impairment and performance-based measures of knee function, as well as psychological readiness to predict return to pre-injury level of sports activity and participation 12 months after ACL reconstruction. Additionally, baseline demographics and surgical findings and procedures were explored to evaluate their potential influence on return to sports. The majority of subjects in our study were young athletes that expressed a desire to return to their pre-injury level of sports, however return to pre-injury level of sports activity and participation 12 months after primary ACL reconstruction was only 40%. This supports the importance of identifying factors that influence return to sports.

Consistent with other reports,^{6,42} our study results showed no differences in baseline demographics including age, gender, BMI, and time from injury to surgery as well as concomitant meniscus, ligament, or cartilage injury between those who returned versus did not return to pre-injury level of sports activity and participation 12 months after ACL reconstruction. This is in contrast to other studies that have found that at longer follow-up (>3 years), older age, females, and having a cartilage injury were associated with the inability to return to pre-injury level of sports.^{9,167,168} Our findings and previous reports^{4,23} suggest that these factors may not have an important influence on return to sports at shorter follow-up (12 months).

Return to pre-injury level of sports activity and participation was not predicted by baseline activity level in current study compared to others.^{4,23} This in part could be explained by the higher percentage of competitive athletes (85.7%) in our study. Also, competitive sports athletes in current study returned to their pre-injury level of sports more than recreational sports athletes (43.3% vs. 20%), however because of the available sample size, this difference was not statistically significant.

Graft type was not a predictor for return to pre-injury level of sports activity and participation in our study. A recent meta-analysis⁹ found differences in return to sports between hamstring and patellar tendon graft approximately 3.3 years after ACL reconstruction, however, the effect of graft type on return to sports was contradictory. Those with a patellar tendon graft had greater odds of returning to pre-injury level of sports, while those with a hamstring tendon graft had an increased odds of returning to competitive sports participation. Therefore, the effect of graft type on return to sports will continue to be debated.

The baseline scores on ACL-RSI scale in our study were not different between those who returned (43.5 ± 29.5) versus did not return to sports (55.4 ± 27.8). However, a recent study by Ardern et al⁶ found significant differences in baseline ACL-RSI scores between those who did and did not return to sports (mean difference = 8 points) suggesting that our study may be underpowered to show significant difference (mean difference = 12 points). Similar to recent evidence,⁶ the ACL-RSI scale scores 3 and 6 months after ACL reconstruction predicted return to pre-injury level of sports activity and participation 12 months after surgery. These findings, also the lack of differences in impairment-based (quadriceps strength) and most of the performance-based measures of knee function between those that returned versus did not return to sports

supports the growing evidence that psychological factors are important factors that influence return to sports and need to be addressed.^{6,75}

Using the ROC curve, our results indicate that an individual who score less than 68 and 60 points at 3 and 6 months after surgery respectively, may have less likelihood of return to pre-injury level of sports 12 months after ACL reconstruction. These findings may help clinicians not only to use ACL-RSI scale as predictor but also as clinical detector of those who may less likely return to sports 12 months after ACL reconstruction because of psychological factors.

Participation in a rehabilitation program that is specifically designed for individuals with high fear of re-injury and lower levels of psychological readiness to return to sports that progressively and systematically exposes the individual to high-demand activities, may allow individuals to develop strategies to more confidently perform the activities, consequently reducing the individual's level of fear and increasing the likelihoods of return to sports. Additionally, fear of re-injury after ACL reconstruction may be in particular similar to the fear avoidance beliefs experienced by individuals with low back pain (LBP). Therefore, some of the cognitive behavior approach to treat individuals with LBP¹⁶⁹⁻¹⁷¹ might be appropriate to treat individuals with high fear of re-injury and lower levels of psychological readiness after ACL reconstruction.

An individual's ability to perform the single-leg hop and vertical jump tests were evaluated 6 months after ACL reconstruction. While there was only 1 subject cleared to hop and jump that did not return to sports 12 months after surgery, the comparison of the hop and vertical jump tests LSI between those who returned versus did not return to sports was inappropriate due to violation of statistical assumptions. We found that the ability to hop and jump significantly predicted (OR, 33.8) 12 months return to pre-injury level of sports activity and participation.

Perhaps the ability to hop and jump 6 months after surgery may be an indication of an individual's physical readiness to perform these tasks. However, the ability to hop and jump may be influenced by other factors such as fear of performing high demand activities, as well as the surgeon's protocol. Therefore, encouraging individuals to perform hopping and jumping as soon as they are physically able to do so and by systematically exposing an individual's knee to high-demands activities may help them return to their pre-injury level of sports by 12 months after surgery. A previous report has demonstrated that earlier initiation (5 months) of vigorous activities were not different from late initiation (9 months) in terms of return to activity level or risk of re-injury.⁸² However, appropriate and sufficient time for graft healing as well as the absence of impaired knee function should be considered before starting forceful activities.^{14,47,56}

Individuals who returned versus did not return to sports in our study demonstrated differences in performance of the lateral step down test 6 months after surgery, despite there being no differences in quadriceps muscles performance. However, because of the available sample size, these differences were not statistically significant. This suggests that athletes may have adequate muscular strength but lack neuromuscular control of the trunk and lower extremity, resulting in altered movement patterns during a lateral step down task. Consistent with these findings, a recent study by Bell et al¹⁷² showed differences in landing mechanics between individuals that have undergone ACLR who were cleared to return to sports versus healthy controls. Following ACL reconstruction, individuals had more lateral trunk deviation and worse landing mechanics compared to healthy individuals. The effect of altered movement patterns and neuromuscular control on return to sports is worthy of further investigations.

The strength of our study is that we prospectively evaluated the influence of multiple factors (impairment and performance measures of knee function, as well as psychological factors)

on return to pre-injury level of sports that are most commonly evaluated in the literature at the time of clearing individuals to return to sports or after returning to sports. We prospectively determined the ability of these factors 3 and 6 months after surgery to predict return to pre-injury level of sports activity and participation 12 months after ACL reconstruction. Taking into consideration the multifactorial nature of returning to sports, we also evaluated the influence of demographic factors and surgical findings and procedures on return to pre-injury level of sports activity and participation. Additionally, to control for the potential influence of age or lack of interest on return to sports, we only included young active individuals that expressed a desire to return to their pre-injury level of sports activity and participation.

The current study has some limitations that need to be acknowledged. The small sample size in our study may have influenced the generalizability of study findings. In addition, the study was underpowered to detect significant differences in some variables such as lateral step-down test although these differences may be clinically meaningful. Also, only 40% in our study returned to pre-injury level of sports activity and participation 12 months after ACL reconstruction, suggesting that a 12-month follow-up period may be too early to evaluate return to pre-injury level of sports since individuals may require more than 12 months to return to pre-injury level of sports. However, a large proportion of our study participants were young active athletes that were expected to return to their pre-injury level of sports within 12 months after ACL reconstruction.

Our study findings are consistent with other recent reports.^{6,9,154,163} that have demonstrated a strong association between psychological readiness and return to sports. Future studies that develop and evaluate psychological intervention programs for those with high fear and lower levels of readiness to return to sports are needed. Future studies should also prospectively evaluate factors

that influence return to pre-injury level of sports at longer follow-up times, as well as determine factors that result in reduced sports participation over time.

The poor movement quality during the lateral step down test 6 months after surgery in those who did not return to sports along with the few differences in performance-based measures and no differences in muscular strength between those who did vs. did not return to sports may indicate that future studies should examine the lack of neuromuscular control and altered movement patterns during performance of the tasks and activities (i.e. hop and jump) and their influences on return to sports.

5.5 CONCLUSION

Higher levels of psychological readiness for return to sports 3 and 6 months after ACL reconstruction predicted return to pre-injury level of sports activity and participation 12 months after ACL reconstruction. Individuals that were able to hop and jump 6 months after surgery were also more likely to return to pre-injury level of sports activity and participation. Psychological factors need to be addressed during rehabilitation as early as 3 months after surgery to increase an individual's confidence and thus return to sports. Individuals should also be encouraged to start activities such as hopping and jumping as soon as they become physically ready do so in order to increase their likelihood to return to competitive and recreational sports 12 months after ACL reconstruction.

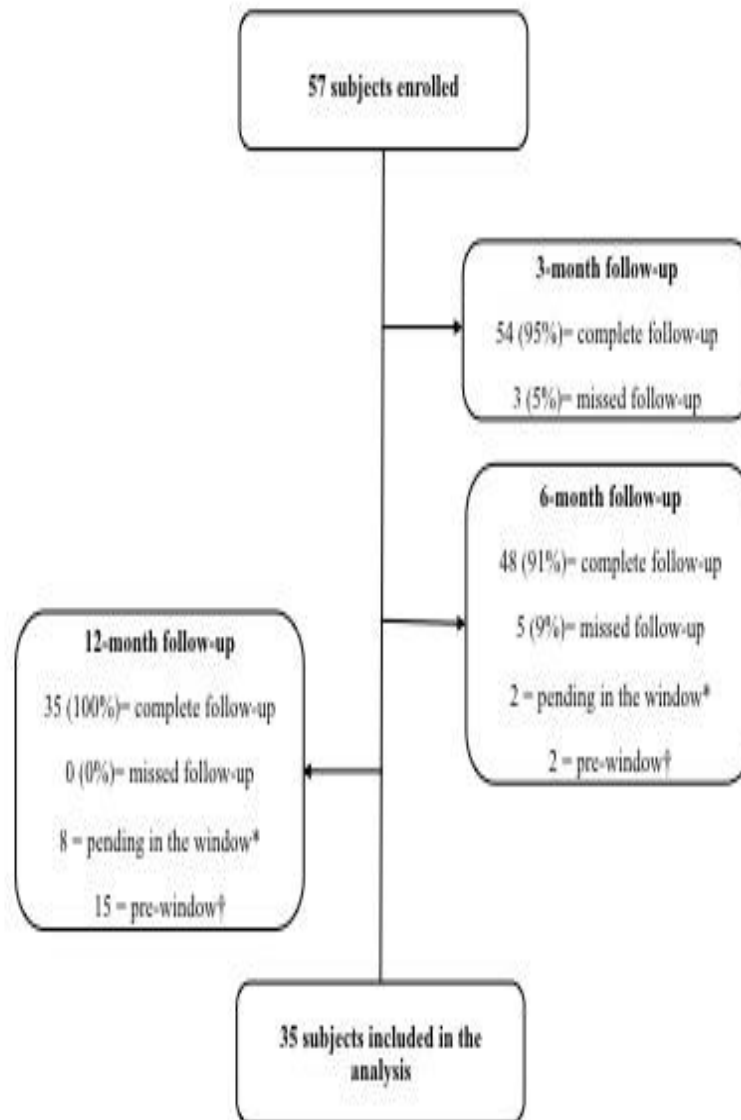


Figure 3. Flow diagram of subjects' recruitment and follow-up times

* Subject's evaluation session is due and but it's still within the window of follow-up (5-7 months, for 6 months follow-up and 10-14 months, for 12 months)

† Pre-window means that subject did not reach follow-up time point

Table 1.3: Demographics and Surgical Findings and Procedures for Those Who Did and Did Not Return to Pre-Injury Level of Sports Activity and Participation 12 Months after ACLR

	Returned n=14	Did Not Return n=21	p-value
Age the Time of Surgery†	19.06 ± 4.2	20.28 ± 4.9	.455
Females n, %	5 (35.7%)	12 (57.1%)	.214
Time from Injury to Surgery, Months†	1.72 ± 1.7	2.15 ± 1.5	.433
BMI†	23.97 ± 4.0	24.07 ± 6.8	.960
Competitive n, %	13 (92.9%)	17 (80.1%)	.324
Graft Type n, %			.542
Hamstring Tendon	8 (57.1%)	15 (71.4%)	
Patellar Tendon	5 (35.7%)	4 (19.1%)	
Quadriceps Tendon	1 (7.2%)	2 (9.5%)	
Medial Meniscus Tear n, %	3 (21.4%)	6 (28.6%)	.636
Lateral Meniscus Tear n, %	9 (64.3%)	7 (33.3%)	.072
Concomitant Ligament Injury n, %	2 (14.3%)	2 (9.5%)	1.000
Concomitant Cartilage Injury n, %	2 (14.3%)	3 (14.3%)	1.000

† Indicates values are presented as mean ± standard deviation

Table 2.3: Univariate Logistic Regression Model of 3-Month Predictors of Return to Pre-Injury Level of Sports 12 Months after ACLR

	Returned to Sports n=12	Did Not Return to Sports n=16	OR (95%CI)	p-value
ACL-RSI Scale†	79.2 ± 15.8	51.2 ± 24.4	1.08 (1.02, 1.14)	.009*
Quadriceps Peak Torque LSI†	77.7 ± 14.8	69.9 ± 16.7	1.04 (.97, 1.10)	.276
Y-Excursion Balance Test Side-Side Difference†	6.9 ± 7.9	5.1 ± 4.5	1.05 (.92, 1.20)	.467
Lateral Step Down Test n,%				
Good Movement Quality	2 (16.7%)	3 (18.7%)	4.00 (.25, 63.95)	.327
Medium Movement Quality	9 (75%)	7 (43.8%)	7.71 (.75, 79.77)	.087
Poor Movement Quality‡	1 (8.3%)	6 (37.5%)		

*P <.05. † Indicates reference group
‡ Indicates values are presented as mean ± standard deviation. ACL-RSI- Anterior Cruciate Ligament-Return to Sport after Injury scale. LSI- Limb Symmetry Index. OR- Odds Ratio

Table 3.3: Univariate Logistic Regression Model of 6-Month Predictors of Return to Pre-Injury Level of Sports 12 Months after ACLR

	Returned to Sports n=13	Did Not Return to Sports n=15	OR (95%CI)	p-value
ACL-RSI scale†	76.1 ± 17.5	60.4 ± 16.7	1.05 (1.003 to 1.1)	.038*
Quadriceps Peak Torque LSI†	82.3 ± 16.8	79.0 ± 11.3	1.02 (.96 to 1.08)	.598
Y-Excursion Balance Test Side-Side Difference†	3.2 ± 3.5	1.7 ± 2.8	1.11 (.87 to 1.43)	.399
Lateral Step Down Test n,%			4.5 (.91 to 22.15)	.064
Good Movement Quality	9 (69.2%)	5 (33.3%)		
Medium Movement Quality‡	4 (30.8%)	10 (66.7%)		
Poor Movement Quality	0	0		
Able to Perform Hop and Vertical Jump Tests n,%	9 (69.2%)	1 (6.7%)	33.8 (3.3 to 351.1)	.003*

*P <.05. † Indicates reference group
‡ Indicates values are presented as mean ± standard deviation. ACL-RSI- Anterior Cruciate Ligament-Return to Sport after Injury scale. LSI- Limb Symmetry Index. OR- Odds Ratio

6.0 GENERAL DISCUSSION AND FUTURE DIRECTION

Return to pre-injury level of sports activity and participation is one of the main reasons for undergoing ACL reconstruction especially in young active individuals, however previous reports have demonstrated great variations in the rate of return to pre-injury level of sports, ranging from 31% to 92%.²⁻⁶ The limited conclusive results about the rate of return to sports after ACL reconstruction and the lack of consensus on how studies defined return to pre-injury level of sports participation generated the need for higher level of evidence studies that used a standardized definition for return to pre-injury level of sports activity and participation. In our studies we determined return to pre-injury level of sports activity and participation using a comprehensive definition that considered the type and frequency of sports participation, as well as the frequency of sports activities as defined by the Marx Activity Rating Scale. This definition is consistent with the International Classification of Function and Disability (ICF) model of function and disability (and its definition of activity and participation).

Using our comprehensive method for defining return to sports, return to pre-injury level of sports activity and participation was less than optimal in both the cross-section survey (48%) and prospective observational cohort (40%) studies. However, when return to sports in our prospective study was compared with the most commonly used method for determining return to sports (answering a single global question of return to sports) almost 20% of the subjects enrolled in our study over-estimated their return to sports supporting the importance of using standardized and

universal criteria to define return to pre-injury levels of sports participation. The standardized definition will enable more valid comparison and combination of results among future studies to better estimate the true return to sports rate as well as to accurately identify the reasons for not returning to sports.

Reasons for not returning to pre-injury level of sports participation have been explored in both studies. The most common reasons for not returning to pre-injury level of sports activity and participation were lack of confidence in the knee and fear of re-injury, which are similar to previous reports.^{8,26,74} Fear of re-injury and lack of confidence are potentially modifiable and should be given more attention by physicians, physical therapists, athletic trainers, patients and their families to improve return to pre-injury level of sports outcomes. Evaluating psychological status during rehabilitation may help identify those with high fear and low confidence.⁹ Discussing the possible reasons and solutions for this fear of return to sports; education about realistic timeframe for return to specific activities; and regularly evaluating physical status and performance might help decrease this fear and increase confidence. Additionally, participation in a rehabilitation and return to sports program that progressively and systematically exposes the individual to activities that place higher demands on the knee, may allow individuals to develop strategies to safely and more confidently perform the activities, thus reducing the individual's level of fear and improving their chances of return to sports.

Approximately 33% of those who did not return to sports in the prospective study reported that they did not return because they were not ready and not cleared by their physicians. This supports the suggestion that following ACL reconstruction individuals may require more than 12 months to return to their prior level of sports participation.

In our survey study, we have determined the predictors for return to pre-injury level of sports activity and participation by extracting information related to the subject characteristics (age at time of surgery, time from injury to surgery, gender), injury variables (concomitant injuries to other ligaments, menisci, cartilage; mechanism of injury), and surgical variables (Lachman and pivot-shift tests under anesthesia, graft source, femoral drilling technique, reconstructive technique) from the subject's medical record as well as from a questionnaire that was completed by individuals that agreed to participate in the study. Our results demonstrated that age at the time of injury and baseline activity level (competitive vs. recreational) were the only predictors for return to sports, which are similar to other reports. Older-age individuals (≥ 24 years-old) and those who played recreational sports prior to their injury were less likely to return to sports suggesting that older individuals and recreational athletes may have less desire to return to sports than young and competitive athletes. Additionally, reduced return to sports by older individuals may be related to life-style changes and family obligations in comparison to younger individuals.

In our prospective study, we evaluated the ability of commonly used impairment and performance-based measures of knee function (quadriceps limb symmetry index (LSI), lateral step down, Y-balance, and single-leg hop and vertical jump tests) as well as psychological readiness as measured by ACL-RSI scale to predict return to pre-injury level of sports activity and participation 12 months after ACL reconstruction. Additionally, baseline demographics and surgical findings and procedures were explored to evaluate their potential influence on return to sports. Our results showed that none of the baseline demographics and surgical findings and procedures including age at the time of surgery and baseline activity level that were been found in the retrospective survey study to be predictors for return to sports predicted return to pre-injury level of sports activity and participation 12 months after ACL surgery in our prospective cohort study. This may be explained

by the fact that we restricted participation in prospective study to individuals between 14 and 35 years of age and there were higher percentage of competitive athletes (85.7%) among those who completed 12-month follow-up. Also, despite the observation that competitive sports athletes in the prospective study returned to their pre-injury level of sports more than recreational sports athletes (43.3% vs. 20%), this difference was not significant because of the available sample size.

Regarding predictors for return to pre-injury level of sports, the ACL-RSI scale scores 3 and 6 months after ACL reconstruction predicted return to pre-injury level of sports activity and participation 12 months after surgery. These findings as well as the lack of differences in impairment-based (quadriceps strength) and most of the performance-based measures of knee function between those that returned versus did not return to sports supports the growing evidence that psychological factors are important factors that influence return to sports and need to be addressed.^{6,75} Future studies that develop and evaluate intervention programs for those with high fear to improve readiness to return to sports are needed. Future studies should also prospectively evaluate factors that influence return to pre-injury level of sports at longer follow-up times as well as determine factors that results in reduced sports participation over time. Fear of re-injury after ACL reconstruction may be in particular similar to fear avoidance believes experienced by individuals with low back pain (LBP). Therefore, some of the cognitive behavior approach to treat individuals with LBP¹⁶⁹⁻¹⁷¹ might be appropriate to treat individuals with high fear of re-injury and lower levels of psychological readiness after ACL reconstruction. In addition, individuals that were able to hop and jump 6 months after surgery were also more likely to return to pre-injury level of sports activity and participation. Perhaps the ability to hop and jump 6 months after surgery may be an indication of an individual's physical readiness to perform these tasks. However, the ability to hop and jump may be influenced by other factors such as fear of performing high demand

activities, as well as the surgeon's protocol. Therefore, encouraging individuals to perform hopping and jumping as soon as they become physically ready as well as systematically exposing an individual's knee to high-demands activities that help him/her to become ready to perform these activities may enable them to return to their pre-injury level of sports within 12 months after surgery.

None of other variables were predictive of return to sports 12 months after ACL reconstruction. However, the lateral step down test 6 months after surgery showed a trend toward significant prediction of return to sports. The poor movement quality during the lateral step down test 6 months after surgery in those who did not return to sports along with the few differences in performance-based measures and no differences in muscular strength between those who did vs. did not return to sports may indicate that future studies should examine the lack of neuromuscular control and altered movement patterns during the performance of tasks and activities (i.e. hop and jump) and their influences on return to sports.

To validate our standardized method for determining return to pre-injury level of sports activity and participation as well as to support its accuracy, more prospective studies that evaluate return to pre-injury level of sports using the same method are needed. Future studies should also evaluate return to pre-injury level of sports at longer follow-up times to determine return to sports for those who did not return to sports at shorter follow-up time points (i.e. 12 months) as well as to determine if athletes maintain their level of sports participation over time. Reasons for not maintaining sports activity level should be also explored.

6.1 LIMITATIONS

There are several limitations in our studies that need to be acknowledged. The first study was survey study that by nature can be affected by recall bias. However, this was an important start for future prospective studies using our criteria for defining return to sports. The non-responders to our study invitation were younger and more likely to be males than those that responded. Since younger individuals in our sample and previous reports were more likely to return to prior sports, missing data from younger individuals could affect the prevalence of return to sports and result in an under-estimation of the true overall return to sports rate.

A limitation of our prospective cohort study is that the follow-up time for 12 months is generally considered a short follow-up after ACL reconstruction. Only 40% in our study had returned to pre-injury level of sports activity and participation 12 months after ACL reconstruction suggesting that 12 months follow-up may be too early to evaluate return to pre-injury level of sports. The participants' rehabilitation programs were not standardized and subjects were permitted to receive their rehabilitation according to their convenience. This may have influenced the return to sports rate. The percentage of competitive athletes was higher in the group with complete versus incomplete follow-up. Since competitive athletes were more likely to return to pre-injury level of sports, this may affect the current findings and result in an over-estimation of the overall return to sports rate. The small sample size in our study may have influenced the generalizability of study findings. Also, multivariate logistic regression analysis was not

performed due to the limited sample size. Additionally, the study was underpowered to detect significant differences in some variables although these differences may be clinically meaningful.

6.2 CONCLUSION

Return to pre-injury level of sports activity and participation after ACL reconstruction was low in both studies but was consistent with other recent reports, however using standardized criteria for defining return to pre-injury level of sports may provide a more accurate estimate of the true rate of return to sports. Using a global question of return to sports, almost 20% of subjects overestimated their return to pre-injury level of sports activity and participation. This indicates that a response to a single question related to return to sports may result in individuals perceiving themselves to be able to return the same level of sports participation as before injury when in reality they have not.

As previously reported by other studies, fear of re-injury and lack of confidence played the greatest role in preventing return to pre-injury level of sports activity and participation. These issues should be addressed by performing more precise anatomic ACL reconstruction and during post-operative rehabilitation to improve return to sports after ACL injury and reconstruction.

Higher levels of psychological readiness for return to sports 3 and 6 months predicted return to pre-injury level of sports activity and participation 12 months after ACL reconstruction. Individuals that were able to hop and jump 6 months after surgery were also more likely to return to pre-injury level of sports activity and participation. Psychological factors need to be addressed

during rehabilitation as early as 3 months after surgery to increase an individual's confidence and thus return to sports. Also, individuals should be encouraged to start activities such as hopping and jumping as soon as they become physically ready to do so in order to increase their likelihood to return to sports 12 months after ACL reconstruction

APPENDIX A

BEFORE ACL INJURY

Please indicate in the spaces below the level of activity that you participated in **BEFORE YOUR INJURY**.

Prior to your knee injury, what type of sports activity did you participate in? Please indicate the **highest level** that describes the type of sports that you participated in prior to your knee injury.

- Strenuous sports activities** involve jumping, cutting, and hard pivoting (examples include football, soccer, basketball, volleyball and gymnastics)
- Moderate sports activities** involve running, twisting and turning (examples include tennis, racquetball, handball, ice hockey, field hockey, skiing, and wrestling)
- Light sports activities** do not involve running, twisting, and turning (examples include cycling, swimming and golf)
- No sports**

If you did **not** participate in any sports **prior to your knee injury**, please check one of the following:

- I performed activities of daily living without problems
- I had moderate problems with activities of daily living
- I had severe problems with activities of daily living/ on crutches/ full disability

Prior to your knee injury, how often did you participate in the sport activity that you indicated above?

- 4 to 7 times per week
- 1 to 3 times per week
- 1 to 3 times per month
- Less than one time per month

Marx Activity Rating Scale

Please indicate how often you performed each activity in your healthiest and most active state, **BEFORE YOUR INJURY.**

	Less than one time in a month	One time in a month	One time in a week	2 or 3 times in a week	4 or more times in a week
Running: running while playing a sport or jogging	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cutting: changing directions while running	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Decelerating: coming to a quick stop while running	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Pivoting: turning your body with your foot planted while playing a sport. For example, skiing, skating, kicking, throwing, hitting a ball (golf, tennis, squash)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

APPENDIX B

BEST AFTER SURGERY

Please indicate in the spaces below the HIGHEST/BEST level of activity that you were able to participate in **AFTER SURGERY**.

After surgery, what type of sports activity did you participate in? Please indicate the **highest level** that describes the type of sports that you participated in **after** surgery.

- Strenuous sports activities** involve jumping, cutting, and hard pivoting (examples include football, soccer, basketball, volleyball and gymnastics)
- Moderate sports activities** involve running, twisting and turning (examples include tennis, racquetball, handball, ice hockey, field hockey, skiing, and wrestling)
- Light sports activities** do not involve running, twisting, and turning (examples include cycling, swimming and golf)
- No sports**

If you did **not** participate in any sports **after** surgery, please check one of the following:

- I performed activities of daily living without problems
- I had moderate problems with activities of daily living
- I had severe problems with activities of daily living/ on crutches/ full disability

After surgery, how often did you participate in the sports activity that you indicated above?

- 4 to 7 times per week
- 1 to 3 times per week
- 1 to 3 times per month
- Less than one time per month

Marx Activity Rating Scale

Please indicate how often you performed each activity in your healthiest and most active state after surgery.

	Did not perform	Less than one time in a month	One time in a month	One time in a week	2 or 3 times in a week	4 or more times in a week
Running: running while playing a sport or jogging	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cutting: changing directions while running	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Decelerating: coming to a quick stop while running	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Pivoting: turning your body with your foot planted while playing a sport. For example, skiing, skating, kicking, throwing, hitting a ball (golf, tennis, squash)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

APPENDIX C (Baseline)

BEFORE ACL INJURY

Please indicate in the spaces below the level of activity that you participated in **BEFORE YOUR INJURY**.

Prior to your knee injury, what type of sports activity did you participate in? Please indicate the **highest level** that describes the type of sports that you participated in prior to your knee injury.

- Strenuous sports activities** involve jumping, cutting, and hard pivoting (examples include football, soccer, basketball, volleyball and gymnastics)
- Moderate sports activities** involve running, twisting and turning (examples include tennis, racquetball, handball, ice hockey, field hockey, skiing, and wrestling)
- Light sports activities** do not involve running, twisting, and turning (examples include cycling, swimming and golf)
- No sports**

If you did **not** participate in any sports **prior to your knee injury**, please check one of the following:

- I performed activities of daily living without problems
- I had moderate problems with activities of daily living
- I had severe problems with activities of daily living/ on crutches/ full disability

Prior to your knee injury, how often did you participate in the sport activity that you indicated above?

- 4 to 7 times per week
- 1 to 3 times per week
- 1 to 3 times per month
- Less than one time per month

Marx Activity Rating Scale

Please indicate how often you performed each activity in your healthiest and most active state, **in the 12 months prior to your injury.**

	Less than one time in a month	One time in a month	One time in a week	2 or 3 times in a week	4 or more times in a week
Running: running while playing a sport or jogging	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cutting: changing directions while running	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Decelerating: coming to a quick stop while running	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Pivoting: turning your body with your foot planted while playing a sport. For example, skiing, skating, kicking, throwing, hitting a ball (golf, tennis, squash)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

APPENDIX D (12 months post-surgery)

CURRENT STATUS

Please indicate in the spaces below the level of activity that you are able to participate in **CURRENTLY**.

What type of sports do you **currently** participate in? Please indicate the **highest level** that currently describes the type of sports that you **currently** participate in.

- Strenuous sports activities** involve jumping, cutting, and hard pivoting (examples include football, soccer, basketball, volleyball and gymnastics)
- Moderate sports activities** involve running, twisting and turning (examples include tennis, racquetball, handball, ice hockey, field hockey, skiing, and wrestling)
- Light sports activities** do not involve running, twisting, and turning (examples include cycling, swimming and golf)
- No sports**

If you do **not** participate in any sports **currently**, please check one of the following:

- I performed activities of daily living without problems
- I had moderate problems with activities of daily living
- I had severe problems with activities of daily living/ on crutches/ full disability

How often do you **currently** participate in the sports activity that you indicated above?

- 4 to 7 times per week
- 1 to 3 times per week
- 1 to 3 times per month
- Less than one time per month

Marx Activity Rating Scale

Please indicate how often you performed each activity in your healthiest and most active state, in the last 3 months.

	Less than one time in a month	One time in a month	One time in a week	2 or 3 times in a week	4 or more times in a week
Running: running while playing a sport or jogging	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cutting: changing directions while running	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Decelerating: coming to a quick stop while running	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Pivoting: turning your body with your foot planted while playing a sport. For example, skiing, skating, kicking, throwing, hitting a ball (golf, tennis, squash)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

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