PATIENCE YOU MUST HAVE, MY YOUNG ATHLETE

Rehabilitation Specific Outcomes after Anterior Cruciate Ligament Reconstruction

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The beautiful thing about
learning is nobody can take it
away from you

— B. B. KING

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ABSTRACT

SUSANNE BEISCHER

Patience You Must Have, My Young Athlete

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To my family

An anterior cruciate ligament (ACL) injury is one of the most common knee-related injuries, usually occurring in younger individuals during sports participation. Moreover, almost 1 in 4 of younger athletes sustain a subsequent ACL injury once they return to sport (RTS). Few previous studies have, however, focused on outcomes in adolescent athletes (15-20 years of age) after a primary ACL reconstruction.

The overall aim of this thesis was to describe outcomes after a primary ACL reconstruction in terms of muscle function, RTS, concomitant injuries, subsequent ACL injury, psychological aspects and symptoms related to knee function in adolescent athletes, aged 15 to 20 years, and in adult athletes, aged 21 to 30 years.

This thesis comprises 5 studies, all based on data from a rehabilitation outcome register, Project ACL. The primary statistical methods used were comparative analyses between adolescents and adult athletes as well as uni- and multivariable analyses with different binary dependent outcomes. The results are presented under the following 4 topics: *symmetrical muscle function, return to sport, subsequent ACL injuries* and *self-reported knee function & psychological outcome.*

The first topic was evaluated in 2 prospective cohort studies (Studies I and IV). It was found that the majority of young athletes make an early return to knee-strenuous sport after a primary ACL reconstruction, without recovering their muscle function (Study I). In addition, athletes with more symmetrical knee-extension and knee-flexion strength, a more symmetrical hop performance and higher present self-efficacy after 4 months of rehabilitation had increased odds of achieving symmetrical muscle function 12 months after an ACL reconstruction (Study IV).

The second topic was evaluated in 1 prospective cohort study (Study I) and 1 case-control study (Study III). Study III combined data from Project ACL with surgical data from the Swedish National Knee Ligament Register. It was found that male sex, younger age, a higher preinjury level of physical activity and the absence of concomitant injuries to the medial collateral ligament and meniscus predicted RTS 12 months after ACL reconstruction. In addition, adolescent athletes had a higher RTS rate at 8 months, where as many as 50% had returned to knee-strenuous sport compared with 38% of the adult athletes (Study I).

The third topic was evaluated in 1 prospective cohort study (Study V). It was found that the time of RTS and the preinjury level of physical activity were associated with a subsequent ACL injury. Athletes who returned to sports before 9 months after an ACL reconstruction had a 7 times higher ACL reinjury rate compared with athletes who returned after 9 months.

Finally, the fourth topic was evaluated in 1 case-control study (Study II) which showed that adolescent athletes, especially females, perceived enhanced self-efficacy, had a higher RTS rate and were more motivated to reach their goals after the ACL reconstruction. In addition, athletes with symmetrical muscle function reported greater motivation and superior self-efficacy compared with athletes who had not recovered their muscle function 8 and 12 months after the ACL reconstruction. Regardless of age, athletes who had returned to sport had a stronger psychological profile.

Taken together, it appears to be important that young athletes receive information about not returning to sport before they are both physiologically and psychologically ready and that this may take longer than 12 months. Based on the findings in this thesis, the rehabilitation of young athletes, especially adolescent athletes, should be prolonged to more than 9 months, preferably to at least 12 months.

SAMMANFATTNING PÅ SVENSKA

SUSANNE BEISCHER

Patience You Must Have, My Young Athlete

En främre korsbandsskada är en av de vanligaste skadorna som drabbar knäleden och skadan drabbar främst unga idrottsaktiva. Ungefär en fjärdedel drabbas dessutom av en andra främre korsbandsskada efter återgång till idrott. Få tidigare studier har specifikt undersökt utfall hos idrottande ungdomar i åldern 15-20 år efter en primär främre korsbandsskada.

Huvudsyftet med denna avhandling var att beskriva utfall efter en främre korsbandsrekonstruktion avseende muskelfunktion, återgång till idrott, associerade skador, efterföljande främre korsbandsskada, psykologiska variabler samt symtom och knäfunktion hos idrottande ungdomar, 15-20 år, och vuxna, 21-30 år.

Denna avhandling innehåller fem studier, som alla baserats på Projekt Korsband, ett rehabiliteringsregister. Huvudsakligen användes jämförande analyser mellan ungdomar och vuxna samt uni- och multivariabla analyser med olika binära beroende utfall. Resultaten av avhandlingen presenteras utifrån följande fyra teman; *symmetrisk muskelfunktion, återgång till idrott, efterföljande främre korsbandsskada* samt *patient-rapporterad knäfunktion & psykologiska utfall.*

Det första temat undersöktes i två prospektiva kohortstudier (Studie I och IV). Vi fann att majoriteten av unga idrottare, 15 till 30 år gamla, återgick till knäkrävande idrott tidigt och utan att muskelfunktion var återställd (Studie I). Vidare visades att idrottare med mer symmetrisk styrka i knäextension och knäflexion, en mer symmetrisk hoppförmåga, samt högre tilltro till sin förmåga tidigt efter en främre korsbandsrekonstruktion hade högre odds att återställa sin muskelfunktion, mätt med ett batteri av fem muskelfunktionstester vid 12 månader (Studie V).

Det andra temat undersöktes i en prospektiv kohortstudie (Studie I) och en fall-kontroll studie (Studie III). I den senare kombinerades data från Projekt Korsband med data från Svenska Korsbandsregistret. Fynden var att manligt kön, yngre ålder, en högre preoperativ fysisk aktivitetsnivå samt avsaknaden av associerade skador på mediala kollateralligamentet samt mediala eller laterala menisken predikterade återgång till idrott vid 12 månader efter en främre korsbandsrekonstruktion. Dessutom hade en högre andel, 50 %, av ungdomarna återgått till knäkrävande idrott vid 8 månader, jämfört med 38 % för de vuxna idrottarna (Studie I).

Det tredje temat, undersöktes i en prospektiv kohortstudie (Studie V). Tid för återgång till idrott såväl som preoperativ fysisk aktivitetsnivå visades vara associerade med en efterföljande främre korsbandsskada. De idrottare som återgick till idrott innan 9 månader efter en främre korsbandsrekonstruktion hade 7 gånger så hög risk att drabbas av en efterföljande främre korsbandsskada jämfört med de idrottare som återgick efter 9 månader.

Det fjärde temat, undersöktes i en fall-kontrollstudie (Studie II) som visade att ungdomsidrottare, speciellt de kvinnliga, upplevde högre knärelaterad tilltro till sin förmåga, hade återgått till idrott i högre grad samt var mer motiverade att nå sina mål efter en främre korsbandsoperation. Vidare visades att idrottare med symmetrisk muskelfunktion rapporterade högre motivation och högre knärelaterad tilltro till sin förmåga jämfört med de idrottare som inte återställt sin muskelfunktion. Oavsett ålder uppvisade de idrottare som återgått till idrott en starkare psykologisk profil.

Sammantaget tycks det vara av stor vikt att yngre idrottare informeras om att inte återgå till idrott förrän de är tillräcklig återställda, såväl fysiskt som psykiskt, och att detta kan ta längre tid än 12 månader. Baserat på resultaten av denna avhandling rekommenderas att rehabiliteringen av yngre idrottare, speciellt av ungdomar, bör pågå mer än 9 månader, helst i minst 12 månader.

LIST OF PAPERS

SUSANNE BEISCHER

Patience You Must Have, My Young Athlete

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. Young athletes return too early to knee-strenuous sport, without acceptable knee function after anterior cruciate ligament reconstruction
Beischer S, Hamrin Senorski E, Thomeé C, Samuelsson K, Thomeé R
Knee Surgery Sports Traumatology Arthroscopy, 2018;26(7):1966-1974

II. How is psychological outcome related to knee function and return to sport in adolescent athletes after ACL reconstruction?
Beischer S, Hamrin Senorski E, Thomeé C, Samuelsson K, Thomeé R
American Journal of Sports Medicine (accepted manuscript)

III. Low 1-year return to sport rate after anterior cruciate ligament reconstruction regardless of patient and surgical factors – A prospective cohort study on 272 patients
Hamrin Senorski E, Svantesson E, Beischer S, Thomeé C, Thomeé R, Karlsson J, Samuelsson K
American Journal of Sports Medicine, 2018;46(7):1551-1558

IV. Knee strength, hop performance and self-efficacy at 4 months are associated with symmetrical knee muscle function in young athletes 1 year after an anterior cruciate ligament reconstruction
Beischer S, Hamrin Senorski E, Thomeé C, Samuelsson K, Thomeé R
BMJ Open Sport & Exercise Medicine, 2019;5:e000504. doi: 10.1136/bmjsem-2018-000504

V. 86% reduced risk for subsequent ACL injury in young athletes who return to knee-strenuous sport later than 9 months after ACL reconstruction
Beischer S, Gustavsson L, Hamrin Senorski E, Karlsson J, Thomeé C, Samuelsson K, Thomeé R
Submitted to the Journal of Orthopaedic & Sports Physical Therapy

OTHER PAPERS BY THE AUTHOR NOT INCLUDED IN THE THESIS

VI. Return to knee-strenuous sport after anterior cruciate ligament reconstruction: a report from a rehabilitation outcome registry of patient characteristics
Hamrin Senorski E, Samuelsson K, Thomee C, Beischer S, Karlsson J, Thomee R
Knee Surgery Sports Traumatology Arthroscopy, 2017;25(5):1364-1374

VII. Factors affecting the achievement of a patient acceptable symptom state 1 year after ACL reconstruction - A cohort study on 343 patients from two registries
Hamrin Senorski E, Svantesson E, Beischer S, Grassi A, Krupic F, Thomeé R, Samuelsson K
Orthopaedic Journal of Sports Medicine, 2018;6(4):2325967118764317

LIST OF ABBREVIATIONS

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Patience You Must Have, My Young Athlete

ACL	Anterior Cruciate Ligament
ACL-RSI	Anterior Cruciate Ligament Return to Sport after Injury
AM	Anteromedial
BMI	Body Mass Index
HR	Hazard Ratio
CI	Confidence Interval
HT	Hamstring Tendon
ICC	Intraclass Correlation Coefficient
ICF	International Classification of Functioning, Disability and Health
KOOS	Knee injury and Osteoarthritis Outcome Score
LSI	Limb Symmetry Index
K-SES	The original version of the Knee Self-Efficacy Scale
K-SES$_{short}$	The shorter version of the Knee Self-Efficacy Scale
MDC	Minimal Detectable Change
MIC	Minimal Important Change
Nm	Newton meter
OA	Osteoarthritis
OCEBM	Oxford Centre for Evidence Based Medicine
OR	Odds Ratio
PL	Posterolateral
PROs	Patient-Reported Outcomes
ROC	Receiver Operating Characteristics
SD	Standard Deviation
SEM	Standard Error of Measurement
SNKLR	Swedish National Knee Ligament Register
Tegner	Tegner Activity Scale
RTS	Return to Sport

DEFINITIONS

SUSANNE BEISCHER

Patience You Must Have, My Young Athlete

ACL reconstruction	Reconstruction of the native ACL using a graft
Adolescent athletes	Athletes aged 15 to 20 years
Adult athletes	Athletes aged 21 to 30 years
Allograft	Tissue from a donor of the same species as the recipient but not genetically identical
Autograft	Tissue from one point to another of the same individual's body
Bias	Systematic error
Body mass index (BMI)	Weight (kg)/height $(m)^2$
Confounder	A distortion that modifies an association between an exposure and an outcome because a factor is independently associated with the exposure and the outcome
Contralateral	Belonging to or occurring on the opposite side of the body
Face validity	Subjective judgement by experts in the field that items appear to assess the desired qualities[226]
Incidence	The number of new cases of a condition or injury that develop during a specific period of time, such as a year
Intraclass coefficient (ICC)	Reliability coefficient. Reflects the test's/PROs' ability to differentiate between patients
Ipsilateral	Belonging to or occurring on the same side of the body
LSI	Limb Symmetry Index. The LSI is defined as the ratio of the results of the injured and the uninjured limb expressed as a percentage (injured/uninjured x 100)
Minimal detectable change (MDC)	A measurement of the variation in a scale due to measurement error. A change in the score can only be considered to represent a real change if it is larger than the MDC[226]
Minimal important change (MIC)	The smallest change in a score needed for the effect to be considered clinically relevant[226]
Multivariable variable model	A statistical model in which there are multiple independent variables. This type of statistical model can be used to assess the relationship between a number of variables

Muscle function	Knee strength and hop performance
Non-parametric statistics	A statistical method where the data are not required to fit a normal distribution
Null hypothesis	The assumption that no differences exist between populations
Odds	The ratio of the probability of an event occurring in a group with a given exposure to the probability of the event not occurring in the same group
Odds ratio	The ratio of the odds in a group to the odds in another group
Overfitting	The production of an analysis that corresponds too closely or exactly to a particular set of data and may therefore fail to fit additional data or predict future observations reliably
Parametric statistics	A statistical method that relies on the assumption of normal distribution
Predictor	A variable associated with an increased risk/chance of an outcome
P value	The level of statistical significance, i.e. the probability of finding the observed, or more extreme, results when the null hypothesis of a study question is true
Return to sport	Participating in knee-strenuous sport, defined as returning to a Tegner Activity Scale of ≥ 6
Sensitivity	True positive rate = the level at which a test is able correctly to detect a condition (e.g. an ACL injury) in patients who actually have the condition [226]
Specificity	True negative rate = the level at which a test is able correctly to rule out a condition [226]
Symmetrical muscle function	Achieving an LSI of at least 90% in 5 tests of muscle function (2 strength tests and 3 single-leg-hop tests)
Statistical power	The probability of making a type II error
Standard error of measurement (SEM)	Quantifies the precision of individual scores within the subject. $SEM = SD \times \sqrt{(1-R)}$ where SD is the standard deviation of test scores and R is the reliability of the test
Survival analysis	Studies the risk and time to an event
Type I error	Incorrect rejection of a true null hypothesis
Type II error	Failure to reject a false null hypothesis
Univariable model	A statistical model in which there is only one independent variable

1.

INTRODUCTION

SUSANNE BEISCHER

Patience you must have, my young athlete

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I'm going back to the start

— *COLDPLAY, "THE SCIENTIST"*

1.1 ANATOMY

The knee joint is the largest joint in the human body and consists of 2 parts, the tibiofemoral and the patellofemoral joints. Hereinafter, *knee joint* will be used to refer to the tibiofemoral joint, which consists of the thigh bone, the femur, and the shin bone, the tibia. The knee joint is classified as a modified hinge joint, which primarily permits flexion and extension. Limited rotatory movement can also occur when the knee is flexed.

The articulating surfaces of the femur and tibia are covered with hyaline cartilage, which protects the bones as they move *(Figure 1)*. The primary role of the cartilage is to transmit and distribute load and, together with the synovial fluid, provide near friction-free and smooth articulation. [39]

As the joint socket of the knee joint is almost flat, the stability of the joint needs to be ensured by the surrounding tissues, primary by the menisci, the surrounding muscles and tendons and the knee ligaments.

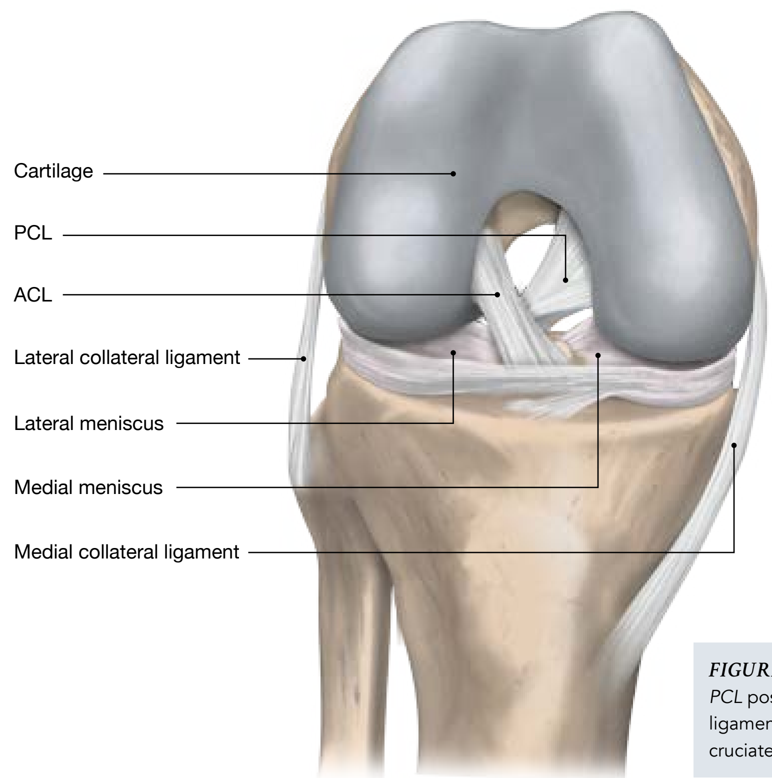

FIGURE 1 The knee joint. *PCL* posterior cruciate ligament, *ACL* anterior cruciate ligament.

1.1.1 Menisci

The menisci are crescent shaped and located between the femoral condyles and attached to the tibial plateau *(Figure 1)*. The medial meniscus, together with the lateral meniscus, covers approximately 70% of the tibial plateau. Their main functions are to distribute load, facilitate movement and contribute to joint stability.[219] The menisci adapt in shape and size and distribute forces across the knee joint during weight-bearing. As the menisci are made of fibrous cartilage, they act as soft elastic shock absorbers. In addition, as the menisci are also wedge shaped and accommodate to the end of the femur, they contribute to the stability of the knee joint.[220]

1.1.2 Muscles around the knee joint

Together with the menisci and the knee ligaments, the surrounding muscles and tendons are important for the functional stability of the knee joint. The most important muscle groups are the quadriceps and hamstrings in the anterior and posterior thigh. The quadriceps muscle is the largest extensor of the knee joint and produces an anterior translatory force on the tibia, in relation to the femur, when contracting. The hamstring muscles are the primary flexors of the knee joint and counteract the anterior translatory force produced by the quadriceps.

1.1.3 Ligaments of the knee joint

The 4 main stabilizing ligaments of the knee joint are the 2 collateral ligaments, the *medial collateral ligament (MCL)* and the *lateral collateral ligament (LCL)*, and the 2 cruciate ligaments, the *posterior cruciate ligament (PCL)* and the *anterior cruciate ligament (ACL) (Figure 1)*.

The MCL consists of 2 parts, the *superficial MCL* and the *deep MCL*, [139] and provides medial stability to the knee joint by preventing excessive medial opening. The MCL attaches proximally to the medial femoral epicondyle. The superficial part of the MCL has 2 distinct tibial attachments as it blends into the semimembranosus tendon and also attaches to the posteromedial crest of the tibia.[48,139] The deep medial aspect of the MCL consists of the meniscofemoral and the meniscotibial ligament, both of which attach to the medial meniscus. [48] An injury to the MCL usually occurs during valgus stress when the knee is partially flexed, as seen in *Figure 2*. This injury is common in young athletes [54,202] and can be either isolated or occur in combination with injuries to other structures of the knee.

The LCL provides lateral stability to the knee joint by preventing excessive lateral opening. This strong ligament originates from the lateral femoral condyle and inserts to the head of the fibula. Unlike the MCL, the LCL has no attachment to the nearby meniscus. An injury to the LCL is less common than an injury to the MCL. [139,248] An LCL injury has been reported to account for about 1% of all knee injuries compared with about 8% for MCL injury. [151]

The cruciate ligaments, the ACL and the PCL, derive their name from their crossed arrangement. The ligaments are named anterior and posterior according to their attachment to the tibia. The cruciate ligaments are the primary passive stabilizers of the knee joint, providing both translatory and rotatory stability. The ACL restricts the tibia from moving forward in relation to the femur, i.e. anterior translation, and provides nearly 90% of the passive stability during anterior translation. The PCL acts in the opposite direction, resisting the forward sliding of the femur in relation to the tibia.

The ACL originates from the medial side of the lateral femoral condyle and inserts on the medial tibia. The ACL is formed by 2 bundles, the anteromedial (AM) bundle and the posterolateral (PL) bundle. The bundles are named according to their tibial insertion. [76,186,224] As the AM bundle inserts anteriorly and medially on the tibia, it primarily restricts the anterior translation of the tibia, while the PL bundle restricts tibial rotation. [224] When the knee is extended, the PL bundle becomes tight and the AM bundle is moderately relaxed. [186] During knee flexion, the AM bundle tightens and the PL bundle loosens up.[271]

1.2 ACL INJURY

1.2.1 Injury mechanism

A rupture of the ACL primarily occurs in younger athletes during sports participation. Nearly three-quarters of all ACL injuries are classified as non-contact injuries, meaning that the injury occurs with minimal or no contact with another individual. [33,131] The injury most commonly occurs during a cutting maneuver *(Figure 2)*, or during a sharp deceleration or in a single-legged landing maneuver. [127,131,178,250] The mechanism of an ACL injury has been described as a forceful and sudden valgus collapse with the knee close to full extension, combined with external or internal rotation of the tibia *(Figure 3)*. [127,178] This description of the ACL injury mechanism is supported by the fact that the peak strain in the ACL occurs with the knee flexed between 0° and 30°. [29] The fact that valgus loading is a key factor in the ACL injury mechanism has been repeatedly confirmed in previous research.[104-106,131] From the point of the initial foot contact, the ACL is found to rupture within 40 milliseconds. [127]

FIGURE 2 Illustration of a cutting maneuver which, together with a single-legged landing, is the most common situation that causes an anterior cruciate ligament injury. The injury occurs within the first 40 milliseconds after the initial foot contact.

Koga et al. [127] formulated the following hypothesis regarding the mechanism of a non-contact ACL injury.

1) When a valgus load is applied to the knee joint, the MCL becomes tauter and a lateral compression of the knee joint occurs.

2) In combination with the anterior force caused by the contraction of the quadriceps, the load on the knee causes a displacement of the femur in relation to the tibia, where the lateral femoral condyle shifts posteriorly and the tibia translates anteriorly and rotates internally, resulting in an ACL rupture *(Figure 3, left)*.

3) After an ACL rupture, the primary restraint to anterior translation of the tibia is gone, which causes the posterior displacement of the medial femoral condyle, resulting in the external rotation of the tibia *(Figure 3, right)*. This external rotation may be aggravated by the typical movement pattern in which the foot rotates externally relative to the trunk.

FIGURE 3 The anterior cruciate ligament ruptures when the tibia translates anteriorly and rotates internally and the lateral femur condyle shifts posteriorly (left). After the rupture, the medial femoral condyle shifts laterally, resulting in the external rotation of the tibia, which may be aggravated by the typical movement pattern in which the foot rotates externally relative to the trunk (right).

1.2.2 *Incidence*

The annual incidence of ACL injury in Sweden has been estimated at 80/100,000 inhabitants, which represents about 8,000 injuries a year. [169] National ACL injury or reconstruction incidence rates at population levels are available for several countries, particularly in Scandinavia and Australia. [161] The annual incidences of primary ACL reconstruction are similar across these countries, with about 30-40 per 100,000 inhabitants. [161] However, the incidence varies by age,[47,84,169] patient sex [30,82,160,169,193] and the type and level of physical activity.[30,160] For instance, the highest incidence is seen in younger athletes participating in high-risk sports, such as soccer, basketball and floorball. [69,82,192,216] In Sweden, male patients aged 21 to 30 years are reported to have the highest incidence; 225/100,000 inhabitants. [169] On the other hand, female patients sustain an ACL injury at a younger age compared with male patients; most commonly between the ages of 11 to 20 years. [169,216] One explanation for this finding can be that females are more exposed to injury risk situations at a younger age compared with male patients.

It is well established that women run a higher risk of sustaining a primary ACL injury compared with men. [30,82,160,193] A systematic review and meta-analysis [160] of 58 studies of athletes participating in organized sports reported that 1 in 29 female athletes and 1 in 50 male athletes sustain an ACL injury in a period that spans from 1 season to 25 years. The relative risk of ACL injury was found to be 1.5 times higher in females compared with male athletes. The higher risk seen in females is probably multifactorial; however, the reasons for this are not yet fully understood. Hormonal factors [25,107,273] and knee valgus moments [104,106,131] are factors that have been found to explain the difference in risk between females and males.

1.2.3 *Concomitant injuries*

An isolated ACL injury is thought to appear in 12-40% of all ACL injuries. [135,179,243] Knowledge regarding the way concomitant injuries influence outcome after an ACL reconstruction is limited. With respect to the association between concomitant injuries and regaining symmetrical muscle function, conflicting results have been reported. [97,132] Krych et al. [132] reported that cartilage damage, classified as 1 or less on the Outerbridge chondral knee lesion classification, i.e. softening and swelling of cartilage,[38] was associated with achieving symmetrical muscle function in strength and hop tests at 6 months after an ACL reconstruction compared with having cartilage damage of 2 or more, i.e. fragmentation and fissuring of the surface or the subchondral bone. In contrast, Hamrin Senorski et al. [97] did not find any association between concomitant injuries and the likelihood of regaining symmetrical muscle function 12 months after an ACL reconstruction. Moreover, Lepley et al. [143] showed that patients who undergo meniscectomy or meniscal repair at the time of the ACL reconstruction did not differ with respect to strength in knee extension at the time of return to sport (RTS) compared with patients with an isolated ACL reconstruction. However, the studies by Hamrin Senorski et al. [97] and Lepley et al. [143] included a limited number of patients, which might explain why no associations were found. Even though there appear to be conflicting results regarding the association between concomitant injuries and short-term outcome in terms of muscle function, concomitant knee injuries are reported to have a negative influence on achieving acceptable patient-reported knee function 12 months after an ACL reconstruction[96] and an increased risk of impaired knee function in the long term, i.e. more than 10 years after the ACL reconstruction.[173]

1.2.4 *Clinical presentation*

A patient who has sustained an ACL injury often describes an audible “pop” or a feeling that “something was going out and then going back” and that it was impossible to continue the activity. Occasionally, pain and effusion limit further activity, but sometimes swelling is only minimal or delayed. Moreover, a description of a feeling of instability or lack of confidence in the knee when trying to resume the activity is common.

An ACL injury can be confirmed by clinical testing and/or magnetic resonance imaging. [36] Three commonly applied tests in clinical practice to diagnose an ACL injury are the anterior drawer, the Lachman and the pivot shift tests.[26] Because the ACL is the primary restraint to anterior movement of the tibia, an injury to the ACL often results in anterior laxity, which can be tested with the anterior drawer and Lachman tests. The anterior drawer test shows good sensitivity and specificity in chronic conditions but not in acute conditions.[26] In contrast, the Lachman test is reported to be the most valid test for diagnosing ACL ruptures, both in acute as well as in chronic conditions, in clinical practice and during anesthesia.[26,252] However, the pivot shift test is reported to have the highest specificity but limited sensitivity, especially in awake patients. [26] In contrast to the anterior drawer and Lachman tests, the pivot shift test assesses combined rotatory translational knee laxity [26,162] and is regarded as the best indicator of a patient’s perceived instability, as the test is able to provoke the feeling of an episode of “giving way”.

1.3 TREATMENT OF ACL INJURY

There are 2 primary treatment options after an ACL injury; (1) rehabilitation, or (2) rehabilitation in combination with an ACL reconstruction. It is, however, not known whether either is the optimal treatment for an ACL injury.[87] It is likely that ACL reconstruction is the best option for some individuals but not for others. The aim of both treatment options is to reduce perceived joint instability and to improve overall knee function. However, there are several areas of disagreement in terms of the best treatment of patients with an ACL injury. They are, for instance, related to the optimal timing of the ACL reconstruction, reconstruction versus no reconstruction, surgical techniques and the benefit of different rehabilitation programs.

To date, only 1 randomized controlled trial (RCT) [70,71] has been published comparing a group of patients with an ACL injury who underwent rehabilitation alone with a group who underwent rehabilitation in combination with early ACL reconstruction. The group who underwent rehabilitation alone had the option of late reconstruction. In this RCT, young active patients (18-35 years of age) were included. The primary outcome was the change in patient-reported knee function from baseline to 2 and 5 years after the ACL injury or the ACL reconstruction.[70,71] No differences between the 2 groups were found at either of the 2 follow-ups. However, as many as 51% of the patients in the group who underwent rehabilitation alone opted for late ACL reconstruction. Moreover, the patients who underwent an early reconstruction had a higher frequency of small meniscal tears at baseline. The meniscal tears in patients who were assigned to rehabilitation plus early ACL reconstruction were more likely to be left untreated. These limitations need to be considered when interpreting the results.

1.3.1 ACL reconstruction

The primary indication for an ACL reconstruction is the patient's perceived instability of his/her knee. The aim of the ACL reconstruction is therefore to restore stability, in order to prevent the knee from future instability, and to protect the knee from subsequent knee-related injuries, e.g. injuries to the meniscus or the cartilage, and reduce the risk of future osteoarthritis. It is well known that ACL reconstruction reduces anteroposterior and rotational knee laxity.[70] However, it is not known whether an ACL reconstruction leads to an enhanced outcome in terms of overall knee function, a reduced number of subsequent intra-articular injuries or a reduced incidence of osteoarthritis.

In Sweden, it is estimated that approximately 50% of patients with an ACL injury are treated with an ACL reconstruction. [69] Regardless of the reconstruction rate, the total rate of ACL reconstructions per 100,000 population has increased during the last few decades, especially in younger athletes. [47,221,274] The average age of a patient undergoing an ACL reconstruction is 27 years; 25 years for females and 28 years for males. [69] Moreover, 42% of patients who undergo an ACL reconstruction in Sweden are females. [192] Irrespective of patients' sex, it appears that the highest incidence of ACL reconstruction occurs in adolescents,[47,103,160,169,192,225] with a significant peak at the age of 17 years.[47]

An ACL reconstruction is normally performed using arthroscopic surgery. There are 3 primary graft choices for ACL reconstruction; the hamstring tendon (HT) autograft, the bone-patella bone-tendon (BPTP) autograft and an allograft. In Sweden, HT grafts are the most common graft choice, [214] where about 90% of all the patients who undergo an ACL reconstruction receive this graft. [4,84,97] In the European countries, HT autografts together with BPTP autografts dominate as the primary graft choices; 92-99% of the patients receive these grafts. [192] *Figure 4* shows the harvesting of HT and BPTB grafts. The BPTB graft involves the central third of the patellar tendon and the HT graft includes both semitendinosus and gracilis hamstring tendons. *Figure 5* shows a reconstructed ACL.

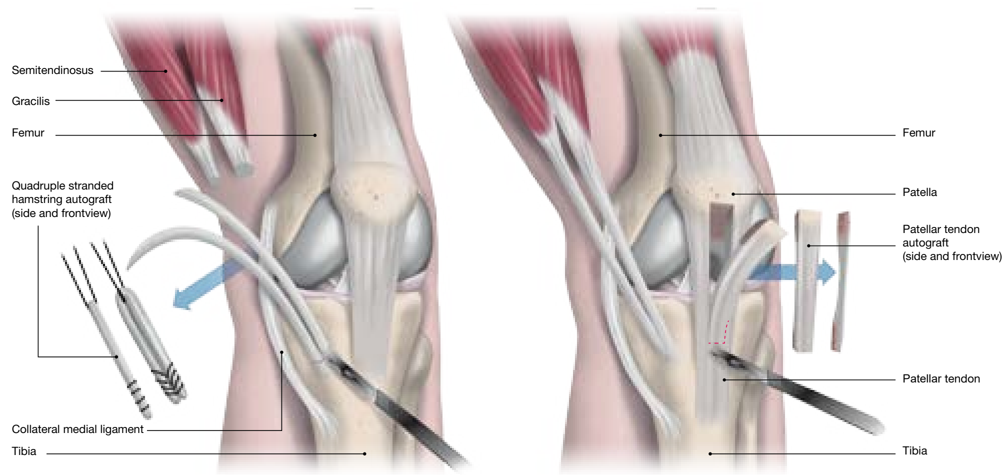

FIGURE 4 Harvesting grafts. Hamstring tendon autograft (left) and bone-patella tendon-bone graft (right).

There is no consensus on which autograft is superior with respect to the re-rupture rate[53,58,74,75,185] and no or only minor differences with respect to long-term functional outcome have been shown between HT and BPTB grafts. [31,157] The primary advantage of the BPTB graft is the bone plugs at each end, providing good conditions for the fixation and ingrowth of the graft.[215] On the other hand, pain when kneeling, anterior knee pain and knee-extension weakness [215,243] are commonly reported problems. A quadruple HT autograft is reported to be stronger and stiffer than a BPTB graft.[170] However, patients receiving HT autografts are reported with reduced end-range knee-flexion strength and a change in the muscle-tendon properties of the hamstring muscles. [128,129] In the United States, allografts are a common graft choice, together with HT grafts. [192] The main indications for an allograft are ACL revision, multiple ligament reconstruction and athletes with a low tolerance of leg muscle deficits. [125] Even though the choice of graft should be individualized, it depends on the surgeon's competency and familiarity with the different techniques.

FIGURE 5 The knee joint with a reconstructed anterior cruciate ligament.

1.3.2 Rehabilitation

Regardless of whether or not a patient chooses to undergo an ACL reconstruction as part of his/her treatment, a long period (up to a year, sometimes longer) of rehabilitation is essential. Since the injury to the ACL is often associated with a variety of different aspects that need to be considered, the rehabilitation needs to be individualized. The physical therapist thus needs to consider aspects such as the presence of concomitant injuries, graft choice, patient adherence to the rehabilitation, psychological status, the patient's goal for rehabilitation, the demands of the activities the patient wishes to resume and how much time the patient is prepared to spend on rehabilitation.

Immediately after an ACL injury, rehabilitation is started to reduce knee joint effusion, restore range of motion and improve knee-extension strength. [51,88,148] If the patient opts for an ACL reconstruction, a preoperative protocol comprising progressive rehabilitation for at least 5 weeks before the ACL reconstruction is recommended. [88,198] Preoperative rehabilitation, with the goal of regaining at least 80-90%[51,88] of knee-extension strength in the injured leg compared with the uninjured leg, before ACL reconstruction, has been found to be associated with an improved postoperative outcome. [51,52,88]

Traditionally, the rehabilitation after an ACL reconstruction has been divided into phases with different goals and content. The description of rehabilitation phases, as illustrated in *Table 1*, is influenced by the work of Thomeé & Kvist [240] and Herrington et al.[102] However, there is no consensus presented in the literature on how rehabilitation after an ACL reconstruction should be designed. [254]

The *initial rehabilitation phase*, **Phase 1**, is characterized by postoperative care and the early implementation of treatment with low-load exercises. The main purpose of this phase is to reduce and control effusion, improve ROM and activate the muscles around the knee. The initial phase corresponds to the inflammatory healing phase. Because inflammation has been found to contribute to further cartilage damage after an ACL injury, [145] inflammation needs to be resolved before further progression to the next phase can take place.

The phase for *tolerance training*, **Phase 2**, starts with continued low-load exercises, such as bilateral weight-bearing activities that gradually progress until the knee tolerates full unilateral weight-bearing activities. During **Phase 3**, *specific hard training* exercises are initiated. This means that the patient progresses from bilateral load activities to full unilateral load activities in multidirectional planes, alongside a progressive and relatively heavy period of training with very high intensity exercises at the end of the phase.

The last phase, **Phase 4**, is characterized by multidirectional running and landing tasks, which are aligned to the needs of the sport the patient wants to return to. This phase, which can be regarded as the most difficult and demanding, aims to restore the unique characteristics of all damaged tissue to withstand the often very intense loads during sports. A recent appealing consensus statement regarding RTS emphasizes that the RTS phase starts from the day of injury, which can be an important concept to promote to the patient. [8]

TABLE 1 Rehabilitation following ACL reconstruction

Progression phase	Rehabilitation phase	Goal	Healing phase	Example of exercises
Postoperative	**Phase 1** Initial	Control pain, reduce effusion, improve ROM	Inflammation	ROM exercises, calf rises, hip abduction/extension, gait training, isometric hamstring/quadriceps
Bilateral loading	**Phase 2** Tolerance training	No effusion, full extension, unrestricted walking, good balance and control	Repair	Mini squats and lunges, leg press, leg extension (isometric/dynamic), bridges, Nordic hamstring (isometric then supported/unsupported dynamic), single-leg calf rises, balance exercises, bilateral hop exercises
Unilateral loading	**Phase 3** Specific hard training	Full ROM, return to running, knee strength ≥ 90% of the uninjured leg, restricted agility drills	Remodeling	Running drills (forwards/sideways/backwards/sprinting), loaded squats and lunges, deadlifts, Nordic hamstrings, progressive unilateral hop exercises, agility drills (changing directions, kicking)
Sport-specific loading	**Phase 4** Return to sports	Return to sports	Maturity	Progressive RTS (restricted training, unrestricted training, match play, competitive match play)

ROM Range of Motion
RTS Return to Sport

Even though success means different things to different people, RTS is often equivalent to success from a patient's perspective. [62] However, a clinician might define success after ACL injury/reconstruction as the prevention of new or subsequent injuries.[8] With regard to the convincing findings relating to primary ACL injury prevention,[18,163,164,187,247] it is surprising that postoperative rehabilitation protocols seldom include recommendations on knee-specific training once the rehabilitation is ended. White et al. [262] designed a rehabilitation protocol with the aim of preventing future injuries. Only 2.5% of the patients who underwent rehabilitation according to their protocol sustained a subsequent ACL injury, i.e. a graft rupture or a contralateral ACL injury, within 2 years of the ACL reconstruction.[19] The reinjury rate in this study is lower than the reinjury rate in a general ACL population (6%) and much lower than the reinjury rate of up to 30% in young patients. [5-7,45,135,217,243,256,266] In the light of the high risk of a subsequent ACL injury, especially in younger patients, there is, therefore, a need for future research on secondary prevention.

It is usually suggested that the progression of an exercise or progression to the next phase of the rehabilitation protocol should be guided by the fulfillment of certain criteria. [102,194,240] By monitoring pain and effusion of the knee joint, decisions on the progression of exercises can be supported, as pain and effusion relate to the tolerance of the load placed on the knee. An increased knee circumference at the patella of > 1 cm [122] and pain that increases from day to day, as measured with a 10-point numeric rating scale, [130,238] are indications that the joint load has been too high. Patients who experience increased pain, effusion and/or deficits of range of motion should undergo treatment to resolve these impairments before further progression of the rehabilitation takes place.

Regaining symmetrical muscle function and enhancing neuromuscular control are 2 cornerstones of rehabilitation. Several positive associations have been reported by patients when symmetrical muscle function and adequate neuromuscular control have been regained. For instance, more symmetrical knee-extension strength is associated with improved self-reported knee function, enhanced hop performance and landing quality. [51,218 115] Moreover, more symmetrical knee-extension strength lowers the risk of a new knee-related injury. [91 200] Enhanced neuromuscular control can be achieved by training exercises for muscle strength, coordination and proprioceptive ability and this has been associated with improved knee function, knee joint position sense, knee joint stability, muscle strength, hop performance and function during activities of daily living. [199,275] However, the choice and level of exercises vary a great deal between different patients throughout the rehabilitation. The most important recommendations are that the exercises need to progress successively and be varied.[32]

Figure 6 gives an example of how an exercise can progress throughout the rehabilitation and gradually help to enhance the patient's capacity to regain symmetrical muscle function.

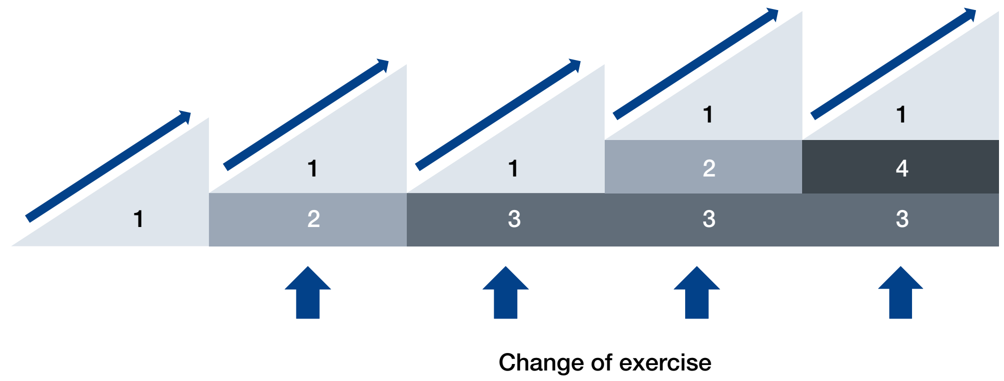

FIGURE 6 Illustration of the progression of an exercise (1) during rehabilitation in order to achieve, for example, symmetrical muscle function. The current figure is a modified version from Blanchard et al.'s 1 illustration of a theoretical model for exercise progression as a continuum. For example, in a squat exercise, the patient can start by performing mini-squats (1) within the first weeks after the anterior cruciate ligament reconstruction. The starting squat exercise can then progress by increasing the ROM, duration, speed and number of repetitions et cetera. In the next stage, the squats can be performed with an external load (2) and the repetitions, speed and ROM could initially be reduced. The load is then eliminated and another stimulus, for instance, performing the exercise on one leg (3), is introduced. After that, this exercise is loaded again (2). In the next phase, the single-leg squat is progressed to be performed on a balance board, for example (4).
ROM Range of Motion

To facilitate planning, to set realistic expectations and to strengthen a patient's self-efficacy the physical therapist should carefully inform the patient of all the details of the rehabilitation program. Even though information directed at the patient is essential throughout the entire rehabilitation, this is especially important during the initial phase *(Table 1)*. A higher level of self-efficacy and the use of positive strategies to cope with the injury and complete the rehabilitation will increase the patient's motivation, diligence and compliance with the rehabilitation. [240]

1.4 OUTCOMES AFTER AN ACL INJURY

There is no consensus on what is regarded as a satisfactory outcome after an ACL reconstruction. The International Classification of Functioning, Disability and Health (ICF), which was introduced in 2001, is a biopsychosocial model classifying health components of functioning and disability. The ICF comprises sections on *Functioning and Disability* and *Contextual factors (Figure 7)*. Functioning is further divided into 3 components; body functions and structures, activity and participation. By measuring several components of the ICF, clinicians treating patients after an ACL reconstruction can obtain a more comprehensive summary of the patient's health.[40,180,269]

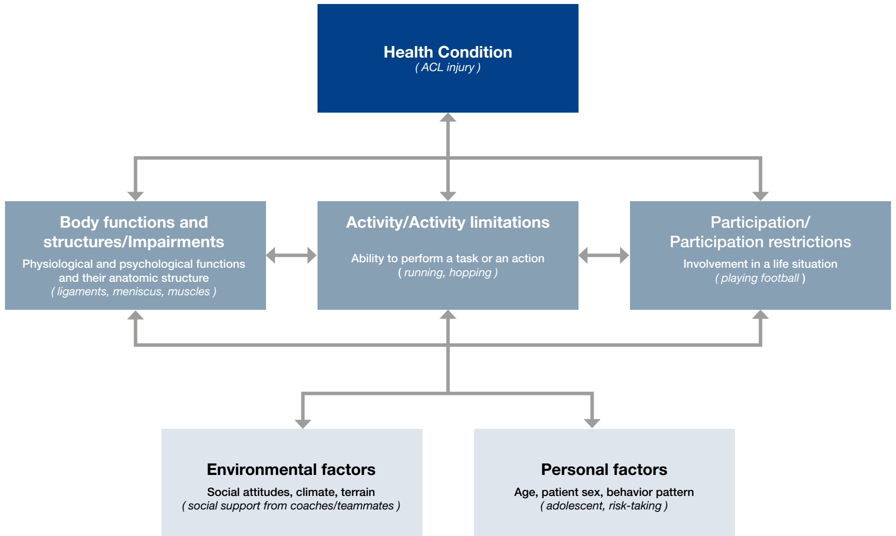

FIGURE 7 International Classification of Functioning, Disability and Health with examples in parentheses for a patient with an anterior cruciate ligament injury.

1.4.1 Short-term results

Short-term results are generally outcomes evaluated 1 to 5 years after an event, which, in this thesis, refers to an ACL reconstruction. All short-term outcomes reported in this thesis relate to 12 months after ACL reconstruction and they are all related to the *Functioning* section or the Personal factors component of the section *Contextual factors* of the ICF *(Figure 7)*. Outcomes relevant to patients who have undergone ACL reconstruction include the results of tests of muscle function, joint laxity and biomechanics, as well as the results from patient-reported outcomes (PROs). These tests can be used to describe the patient's perception of the severity of their injury and monitor progress during rehabilitation.

Knee function

Patient-reported outcomes are useful tools when it comes to obtaining information on the patients' perceptions of treatment outcome and they are often used to evaluate changes in knee function after an ACL reconstruction.[37,149] Two of the most commonly used PROs with respect to knee function are the Knee injury Osteoarthritis Outcome

Score (KOOS) and the International Knee Documentation Committee Subjective Knee Form (IKDC).[253,261]

Patients with an ACL injury, regardless of treatment choice, report inferior knee function compared with knee-healthy individuals.[182] [113,135] Enhanced knee function has been reported to be associated with a higher rate of RTS,[60,93] passing RTS criteria, [146] patient satisfaction[9] and superior hop performance. [3,67,196] Moreover, younger age and male sex are found to predict an enhanced level of knee function after an ACL reconstruction. [2,23,95,96] However, it is not known whether there is any discrepancy in subjective knee function between patients of different ages who have already returned to sport.

QUESTION

Is there a difference in self-reported knee function between adolescent and adult athletes who have returned to sport?

Regaining symmetrical muscle function

The main functional impairments after an ACL reconstruction are considered to be deficits in knee-extension strength and reduced neuromuscular control, both belonging to the component of body function/structures in the ICF. [269] Regaining symmetrical muscle function is regarded as an important goal during rehabilitation, as more symmetrical muscle function is associated with a higher rate of RTS [13,166] and a lower risk of subsequent injuries. [91,137] However, many patients demonstrate muscle strength deficits in the injured leg compared with the uninjured leg and compared with healthy matched controls, 9 to 12 months after ACL surgery. [51,140,241] In addition, the majority of patients are reported not to regain symmetrical muscle function 6 to 12 months after an ACL reconstruction. [81,91,101,241,245] However, it is not known how many adolescent athletes regain symmetrical muscle function and if the proportion differ between different age-groups.

QUESTIONS

How many adolescent athletes that have returned to sport have achieved symmetrical muscle function?

Is there a difference between adolescent and adult athletes in terms of the proportion of athletes that meet RTS criteria?

Knee-extension strength has been reported to have a large impact on knee function. For instance, knee extension asymmetry at the time of RTS is associated with changes in knee joint biomechanics, [117,181] poorer self-reported function [51,148,267] and poorer physical function and performance. [142] Patients who RTS are more likely to have a higher knee-extension peak torque-body weight ratio compared with patients who do not RTS. [93,141] A larger proportion of young athletes, who meet the criteria for symmetrical knee strength at the time of RTS, are reported to maintain the same level of sports participation over the year following the RTS, compared with those who do not meet the criteria.[245] Finally, the importance of regaining symmetrical muscle function is also illustrated by the findings that a more symmetrical hop performance pre- and postoperatively is reported to be associated with superior patient-reported knee function 12 months after ACL reconstruction. [89,147]

The limb symmetry index (LSI) is the most frequently reported criterion for assessing whether strength and hop performance are classified as normal or abnormal after an ACL injury or reconstruction. [8,149,239,241] The LSI is defined as the ratio of the results on the injured side and the uninjured side expressed as a percentage. An LSI of > 90% is commonly regarded as a sufficient level for both muscle strength and hop performance. [22,37,91,137,149,239]

Many factors could contribute to symmetrical muscle function. For instance, patients who, at an early stage, have fewer symptoms, fewer impairments and more symmetrical muscle function may be better off when it comes to recovering symmetrical muscle function 12 months after the ACL reconstruction. [51,118,146,148,267] Because an association between self-efficacy and symmetrical hop performance has been reported in patients after an ACL reconstruction, [236] psychological outcomes appears also to be important variables to consider when attempting to find predictors of symmetrical muscle function.

Younger age has been identified as a predictor of an excellent muscle-function outcome 6 months after an ACL reconstruction.[132] Recently, Toole et al. [245] reported that only 14% of young athletes that were cleared for RTS met their RTS criteria, including an LSI of > 90% in both hop and strength tests. This is worrying and presents a major challenge that needs to be resolved, as patients younger than 20 years of age who are involved in knee-strenuous sport at their primary ACL injury constitute a high-risk group in terms of sustaining a subsequent ACL injury. It would therefore be of clinical value if modifiable predictors could be identified for symmetrical muscle function, especially for young athletes.

QUESTION

Can early outcomes predict the achievement of symmetrical muscle function 1 year after ACL reconstruction?

1.4.2 *Psychological factors*

Historically, evaluations after an ACL reconstruction have focused on objective physical outcomes. However, despite normal or nearly normal knee function, as measured with a PRO and 2 hop tests, only 55% of the general ACL population are reported to return to a competitive level of sports after an ACL reconstruction. [13,14] The discrepancy between RTS rate and physical status can possibly explain the increased interest in the association between psychological factors and physical outcomes. Negative psychological responses, such as anxiety, depression and loss of athletic identity, [72,190] as well as positive responses, such as high motivation, high confidence, high self-efficacy and low fear of reinjury, [12,229,236] have been described in patients after an ACL injury.

To better understand psychological aspects that might affect both the rehabilitation and RTS, several theoretic models have been developed. In 1998, Wiese-Bjornstal presented the biopsychosocial framework with respect to psychological response to sports injury. [265] According to this framework *(Figure 8)*, outcomes after an injury are influenced by patient emotions, thoughts and behavior, e.g. actions and efforts. [264]

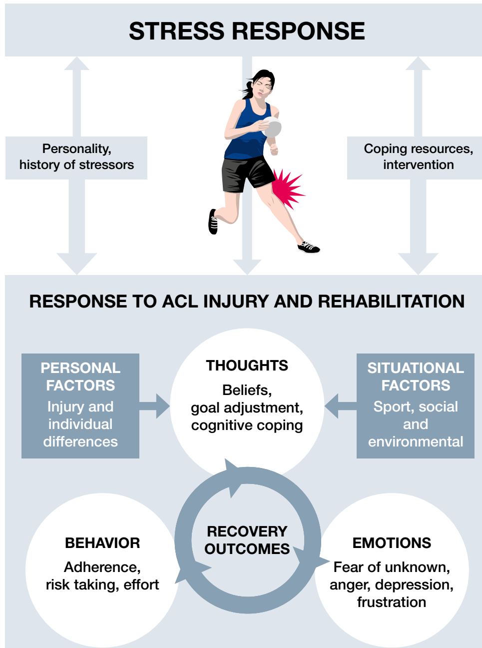

FIGURE 8. A modified version of the Integrated model of response to sports injury, originally described by Wiese-Bjornstal et al. [265]

For many patients, the ultimate goal after an ACL reconstruction is to RTS. According to the framework by Wiese-Bjornstal et al. [265] *(Figure 8)*, RTS corresponds to *recovery outcome*. Patients who succeed in returning to sport after an ACL reconstruction have been characterized by lower levels of fear of reinjury, [134,208,244] higher self-efficacy of knee function, [94,236] greater motivation to RTS [12,59,78,191] and higher levels of psychological readiness to RTS. [10,14,259] Moreover, in a meta-analysis, Ivarsson et al. [120] reported that low levels of negative psychological responses, such as anxiety and fear, and high compliance with rehabilitation were predictors of a successful RTS after sports injuries, including acute ACL injuries. Together, these 2 predictors explained 36% of the variance in RTS, [123] indicating the importance of addressing psychological factors in the rehabilitation after an ACL reconstruction.

Psychological readiness to RTS

The construct of *psychological readiness to RTS* includes emotions, risk appraisal and confidence in performance, [255] where confidence is suggested to be the key component. [189] Greater psychological readiness to RTS can be described as a combination of the athlete experiencing high confidence levels and low levels of fear and anxiety with respect to reinjury and underperforming. [68,77] The importance of psychological readiness to RTS has been highlighted by Ardern et al., [14] showing that psychological readiness before and early after an ACL reconstruction was associated with returning to the preinjury level of sports at 12 months. Higher levels of psychological readiness appear to be associated with male sex, younger age, a shorter time between injury and surgery, a higher frequency of preinjury sports participation, greater limb symmetry and higher patient-reported knee function. [259,272]

The interesting question is, however, whether psychological readiness to RTS plays the same important role in adolescents as in older athletes. In a recent study, McPherson et al.[153] reported that younger (<20 years) patients who sustained a subsequent ACL injury had lower psychological readiness to RTS compared with patients who did not sustain a subsequent ACL injury. This pattern was not found in older patients. However, this was the first study to compare younger and older athletes with respect to psychological readiness, especially with respect to subsequent ACL injuries. More studies are therefore needed to confirm this result. Moreover, injured patients, as a group, were in another study by McPherson et al. [154] reported to demonstrate less improvement in psychological readiness as compared with uninjured athletes. Both these studies[154] [153] confirm the importance of attaining and maintaining a strong psychological profile during rehabilitation, as well as in the RTS phase of rehabilitation.

Self-efficacy

The theory of self-efficacy was originally formulated by Bandura in 1977. [20] According to Bandura's theory, self-efficacy is defined as a person's confidence in his/her perceived ability to perform tasks despite pain or discomfort. The level of self-efficacy is considered to be influenced by one's initiative for action, level of effort and resilience to setbacks, as well as previous experience of failure and success, including one's own and by observing others. [20]

Higher levels of self-efficacy have repeatedly been reported as a predictor of enhanced outcome in patients with acquired diseases or impairments. [27,73,150,155,203,242] With respect to the knee, the association between self-efficacy and outcomes has been reported for patients with knee osteoarthritis,[27,35,150] total joint arthroplasty[251,270] meniscectomy [57] and ACL injury. [9,66,235,236]

In 2006, Thomeé et al. [233] developed a new instrument to measure self-efficacy in patients after an ACL injury or reconstruction. Knee-related self-efficacy was found to be a predictor of outcome, with respect to function in sport and recreational activities, quality of life, frequency of physical activity and acceptable hop performance, 1 year after an ACL reconstruction. [236]

Patient-reported symptoms and functions, as well as a patient's locus of control, have been found to explain 40% of a patient's level of self-efficacy. [234] In contrast to psychological readiness to RTS, patient sex, age and level of physical activity appear not to be associated with the level of self-efficacy 12 months after ACL reconstruction. [234]

Because psychological responses appear to be associated with a range of rehabilitation outcomes, clinicians need to consider the influence of an injured athlete's thoughts, feelings and actions on the rehabilitation.[68] One interesting question is whether the higher odds of RTS reported in younger patients can be explained by differences in psychological response between age groups.[13] However, specific knowledge with respect to psychological response in adolescent athletes is lacking.

Moreover, prior studies that aimed to compare psychological response between different groups of patients with an ACL injury have controlled for the level of muscle function by assessing the patients using different hop tests. [14,138,259] The rationale for this is that a patient's behavior, cognition and emotions are thought to be influenced by their functional outcome. [264] These previous studies used 2 hop tests to control for muscle function recovery, with a cut-off level of an LSI of ≥ 85%. However, Thomeé et al.[241] reported that, when using more demanding criteria for successful muscle function, using batteries of tests or increasing the acceptable LSI level from > 90% to > 95% or > 100%, the success rate, i.e. the rate of patients achieving a given cut-off value for symmetry, decreased. The association between the recovery of muscle function and psychological outcome therefore requires further evaluation.

QUESTIONS

Is there a difference in psychological outcome between younger athletes who have and have not returned to sport?

Is there a difference in psychological outcome between adolescent and adult athletes after a primary ACL reconstruction?

Is there a difference in psychological outcome between younger athletes who have and have not recovered their muscle function?

1.4.3 *Return to sport*

The definition of RTS and thereby the reported RTS rate vary across studies. [13,94] However, success means different things to different people and expectations of the overall condition of the knee joint are high 12 months after an ACL reconstruction, [8,62] especially in patients who are younger, highly active and without previous knee surgery. [62] More than 90% of the patients expect to RTS within 12 months after the ACL reconstruction.[62] In contrast, only 55% of patients in a general ACL population have been reported to return to competitive sports participation 12 months after ACL reconstruction. [13] Factors that are positively associated with RTS are younger age, male sex, being an elite athlete and having a more positive psychological profile. [13,14,59,119] Moreover, a more symmetrical muscle function are described as a positive predictor of RTS. [13,166] Even though most ACL injuries are not isolated [135,179,243] few previous studies have accounted for concomitant injuries with respect to a patient's ability to RTS after an ACL reconstruction.

QUESTIONS

Is there a difference between adolescent and adult athletes in the proportion of athletes returning to a knee-strenuous sport?

How do concomitant injuries influence the rate of RTS?

The length of time for ACL-reconstructed athletes to RTS varies. Most patients who do not succeed in participating in sports 12 months after ACL reconstruction are reported to return to some form of sport within 2 years after the reconstruction.[15] In spite of this, only 2 in 5 patients were active at their preinjury level of sport 2 years after ACL reconstruction. In contrast, in men's professional soccer and in patients younger than 18 years of age, almost all RTS after ACL reconstruction.[45,249] The reasons for this might be greater motivation, faster recovery of muscle function and stronger psychological profile. However, few previous studies have compared potentially explanatory variables between adolescent and adult athletes.

A decision to RTS is seldom a straightforward decision. In most cases, the patient and the clinician share the same goal – to make a safe and timely RTS. However, what "timely" means has not been defined and differs between rehabilitation protocols, patients and clinicians (as well as between other stakeholders, such as coaches, parents and managers). Moreover, patient age, level of sport and incitement, e.g. amateur versus professional player, will influence the RTS decision. It is, however, important to recognize that patients who RTS earlier run an increased risk of a subsequent knee-related injury, as confirmed in recent studies. [45,91] These findings stress that the current evidence needs to be better implemented in daily clinical work and carefully considered in the RTS decision.

Over time, the pendulum has swung from time-based toward an objective criterion-based RTS decision. In spite of this, there is to date no consensus in the literature on how best to determine when a patient can RTS after ACL reconstruction. [8,22,37,258] Recently, Burgi et al. [37] published a study with the aim of describing the criteria used to clear athletes to RTS after a primary ACL reconstruction. As many as 67% of the studies published before September 2017 failed to report any RTS criteria. Moreover, 42% of the included studies gave postoperative time as the sole criterion, 41% included some kind of strength measurement and 13% included at least one hop test as criteria. Using an LSI of ≥ 80% as a cut-off value for knee strength was just as common as using ≥ 90% (22% each). With respect to hop tests, the most common cut-off value was an LSI of ≥ 90%. Taken together, the recent compilation by Burgi et al. [37] further highlights the need for valid RTS criteria, as well as implementing these findings into research and clinical rehabilitation guidelines.

1.4.4 *Subsequent ACL injury*

One devastating complication after a primary ACL reconstruction is sustaining a subsequent ACL injury, i.e. a graft rupture or an injury to the contralateral ACL. In a study by Schilaty et al. [217] the overall incidence of a subsequent ACL injury was reported to be approximately 6% in patients older than 16 years of age (mean age 28.1 years). From that study, 67% of the subsequent ACL injuries were contralateral and the highest incidence of a subsequent ACL injury was seen in female athletes, 17-25 years of age, who returned to a competitive level of sport. [217] The fact that younger patients are a high-risk group has been repeatedly reported in the scientific literature. [5-7,45,135,217,243,256,266] A recent systematic review and meta-analysis reported that almost 1 in 4 patients, aged 25 or younger, who returned to high-risk sport will sustain a subsequent ACL injury after the primary ACL reconstruction. [266]

As young patients are more prone to return to their preinjury sport, [13,257] it is important to consider risk factors in an RTS decision. A higher preinjury physical activity level [7,61,124,222,266] and a premature RTS have been found to be other important risk factors for a subsequent ACL injury.[45,91] Grindem et al. [43] reported that the rate of knee-related reinjuries, such as injury to the meniscus, cartilage and the collateral ligaments, decreased by 51% for every month the RTS was delayed. This is in line with another study which reported an association between an early RTS and a subsequent ACL injury in athletes younger than 18 years of age. [45]

In addition, achieving symmetrical muscle function before RTS [91,116,137] and returning to high-risk sports [91,124,213,222,228] are regarded as other important factors to consider when attempting to reduce the reinjury risk after a primary ACL reconstruction. Recently, Grindem et al. [91] and Kyritsis et al. [137] published interesting results. Kyritsis et al. [137] found that patients failing to meet their RTS criteria, including achieving symmetrical knee-extension strength and hop performance, prior to RTS ran a 4 times higher risk of a subsequent ACL injury. Grindem et al. [91] reported that patients with more symmetrical knee-extension strength (isokinetic concentric), measured seated at 60°/s with 5 maximum effort repetitions, ran a significantly lower risk of a knee-related reinjury. [91] However, the studies by Grindem et al. [91] and Kyritsis et al. [137] have some limitations which must be considered. For instance, the study by Grindem et al. [91] only comprised 74 patients with a mean age of 24.3 years and a total of 26 knee-related reinjuries. These reinjuries included injuries to the menisci, the cartilage, the graft or the contralateral ACL. A total of 8 ACL graft ruptures and 2 contralateral ACL injuries were identified. The question of whether the results of reduced risk of knee-related knee injuries are only applicable to subsequent ACL injuries is therefore justified. Moreover, Kyritsis et al. [137] based their conclusions on 22 graft ruptures in 158 male professional athletes with a mean age of 21 years. It is thus unclear how these results can be generalized to an overall ACL population.

Taken together, younger athletes who return to knee-strenuous sport run a significantly higher risk of sustaining a subsequent ACL injury. Moreover, the time between reconstruction and RTS and achieving symmetrical muscle function prior to RTS appear to be critical factors to consider in the RTS decision.

QUESTION

Are time to RTS and symmetrical muscle function associated with subsequent ACL injuries in young athletes?

1.4.5 *Long-term outcomes*

Osteoarthritis (OA) is a condition characterized by structural and functional changes in all tissues of the joint. Knee OA, together with OA of the hip, are the leading causes of pain and disability in older adults.[42] Common symptoms include swelling, reduced range of motion, pain, impaired function and a lower level of physical activity.

Patients undergoing ACL reconstruction expect the knee joint to be normal or nearly normal after the reconstruction and 98% expect no or only a slightly increased risk of OA.[62] In contrast, patients who have sustained an ACL injury run a remarkably high risk of developing knee OA. [174,243,263] As early as 10 years after the ACL reconstruction, approximately 50% have radiographic signs of OA with associated reported pain and functional impairment. [174] This means that patients who sustain their ACL injury in adolescence might show radiographic signs of OA at an age of 30 years. The discrepancies between patient expectations and the reality regarding OA emphasize the need for appropriate patient information early after the ACL reconstruction. [198]

An ACL injury combined with an injury to the medial meniscus or to the MCL,[136, 193] as well as higher BMI, are well-documented risk factors for the development of OA. [276] Patients who are stronger and have symmetrical muscle function run a decreased risk of deterioration in knee-related symptoms and functions as time passes. [43,177] Recently, Oiestad et al. [176] reported that patients who returned to a pivoting sport after an ACL reconstruction demonstrated lower odds of knee OA and better patient-reported ADL function compared with patients who had not returned to a pivoting sport, on condition that they had not sustained a meniscal injury. [176] These findings further reinforce the importance of helping and encouraging the patient to regain symmetrical muscle function, setting realistic expectations/goals and providing information about risk factors. [198]

In addition to the elevated risk of OA, individuals with an ACL injury run an approximately 4 times higher risk of being overweight/obese 3-10 years after the injury compared with healthy matched individuals. [65,263] This fact, combined with the symptoms of OA, such as pain, impaired knee function and lower levels of physical activity, might predispose patients with an ACL deficit to non-communicable diseases.[28] Nevertheless, failure to RTS, a higher BMI, sustaining a subsequent ACL injury and severe radiographic OA are all associated with reduced quality of life in patients with an ACL injury. [63,64]

Patients with an ACL injury demonstrate impaired knee-related quality of life 5 to 23 years after the injury compared with a healthy population. [53] An ACL injury may therefore result in the risk of reduced knee function and quality of life for many years, sometimes for life, especially in those who suffer a subsequent ACL injury. [63]

1.5 EVALUATION

To help patients reach their goals and prevent future injuries and impairments, clinicians need to understand and evaluate factors that contribute to a successful outcome, such as RTS. As described in chapter 1.3.2, the rehabilitation after ACL reconstruction nowadays is often criterion based. In order to provide feedback to the clinician and the patient and to evaluate goals of progression, repeated evaluation is considered necessary during the entire rehabilitation. [90] Importantly, an outcome measurement needs to be reliable, valid and have acceptable responsiveness. Reliability refers to “the degree to which the measurement instrument is free from measurement error” and validity has been defined as “the degree to which a measurement instrument measures the construct(s) it purports to measure”. [159] Responsiveness is defined as “the ability of an instrument to detect change over time in the construct to be measured”. [159]

Traditionally, objective measurements of strength and hop performance have been used to guide clinicians in the RTS decision. However, other types of test, such as clinical examination (range of motion, thigh circumference, effusion measurements, tests of ligament laxity), quality of motion, agility tests, biomechanical tests and PROs have been described in the literature.[37] It is recommended that decisions relating to RTS should be based on the results of a battery of muscle function tests, [8,239] together with the results of assessments of patients’ psychological response.[8]

Even though no consensus exists on how best to determine whether a patient can RTS, [81,91,137,168] the battery of tests should cover several levels of the ICF, as described on page 33. The LSI, defined as the result for the injured leg divided by the result for the uninjured leg, is the most frequently reported method for assessing whether strength and hop performance are sufficient. [37,149,239]

1.5.1 Measurement of muscle function

Assessments of knee strength can be performed using several different types of test. In this thesis, isometric and isokinetic tests were used. These tests have been criticized for a lack of functional relevance to sporting and training situations. However, isokinetic tests are still regarded as the ‘gold standard’ for measuring muscle strength and are convenient, reliable measurements, which supports their use as an appropriate method of assessment after ACL reconstruction.[246] However, there is no standardized isokinetic strength protocol following ACL reconstruction. In 2015, Undheim et al. [246] systematically reviewed isokinetic-strength-evaluation protocols that had been published and used for patients after an ACL reconstruction. Based on their results, they aimed to propose a standard protocol to enable consistency of testing and accurate comparison in future research. The suggested protocol included 5 repetitions of concentric knee extension and flexion at 60°/s. However, no protocol for isokinetic-strength evaluation has been validated as a useful predictor of successful RTS. In this thesis, isokinetic and isometric strength tests were used to assess knee strength based on a protocol reported by Neeter et al. [168]

Several hop tests have been described in the literature and they are usually used to assess strength, power, quality of movement and functional performance. Commonly used hop tests are the *single hop for distance*, [80,92,209] the *triple hop for distance*, [80,209] the *crossover hop for distance*, [209] the *6-m hop for time*, [209] the *side hop*[80,92] and the *vertical hop*. [92,110] In this thesis, the battery of hop tests, originally described by Gustavsson et al., [74] includes the *single leg hop for distance*, the *side hop* and the *vertical hop*.

1.5.2 Patient-reported outcomes (PROs)

The use of PROs has increased in the field of sports medicine, both in daily clinical work and in research, during the last decade. Two of the most commonly used PROs with respect to knee function are the KOOS and the Knee Documentation Committee Subjective Knee Form (IKDC).[253,261]

Psychological readiness to RTS and self-efficacy are 2 of the most commonly assessed psychological aspects in patients after an ACL injury or reconstruction. [9,94,208,223,233,259] The ACL Return to Sport after Injury (ACL-RSI) scale (Appendix) and the Knee Self-Efficacy Scale (K-SES) (Appendix) are both reliable and validated PROs [233,255] developed to assess psychological readiness to RTS and knee-related self-efficacy in patients who have sustained an ACL injury. However, few batteries of tests that are commonly used to determine when RTS can be recommended in research include these PROs.

Patient-reported outcomes, such as the Tegner Activity Scale (Tegner) (Appendix) [230] and the Marx score, [152] are commonly used in research to define whether a patient has returned to sport.

2.

RATIONALE FOR THIS THESIS

SUSANNE BEISCHER

Patience you must have, my young athlete

"

All you have to decide is what to do with the time that is given to you

— J.R.R. TOLKIEN

The rationale for this thesis is to improve our knowledge of the outcome in young athletes after a primary ACL reconstruction. Athletes younger than 25 years of age are of particular interest, as they run a 4 times higher risk of suffering a subsequent ACL injury compared with a general population with an ACL injury. In individuals younger than 20 years of age, a reinjury rate of over 30% has been reported. Moreover, young athletes have a higher RTS rate compared with older athletes, which may partly explain the high reinjury risk reported in young athletes.

Factors that explain the discrepancies in the RTS rate between younger and older patients have not previously been studied. An individual's psychological response to an injury, surgery and rehabilitation appears to influence the RTS rate. In adult athletes, a more positive psychological response prior to an ACL reconstruction and early in the rehabilitation process is associated with a higher RTS rate. For instance, patients who RTS have been described as having higher self-efficacy of knee function, greater motivation to RTS and higher levels of psychological readiness to RTS. However, it is not known whether this relationship is valid for adolescent athletes. Moreover, evaluations of self-efficacy, motivation and psychological readiness are rarely included in the batteries of tests used to complement the decision-making process for RTS. Furthermore, no studies have been found evaluating the association between recovery of muscle function and psychological outcome when it comes to RTS, especially in adolescent athletes.

One important goal of the rehabilitation after an ACL reconstruction is to regain symmetrical muscle function. However, previous studies have repeatedly reported that the majority of individuals do not achieve this goal. Specific knowledge relating to modifiable rehabilitation-specific factors that predict symmetrical muscle function in young athletes is, however, lacking. Moreover, the proportion of young athletes that actually achieve symmetrical muscle function prior to their RTS is not known.

There is no consensus on which RTS criteria should be used when determining when patients can safely RTS after an ACL reconstruction. [37,258] A safe RTS can be defined as a minimal risk of a reinjury or a subsequent associated injury in the short term and a reduced risk of osteoarthritis in the long term. In 2016, 2 studies reported that patients not meeting specific RTS criteria might run an increased risk of a subsequent knee-related injury and graft failure. In addition, one of the studies stated that, for every month the patient delayed his/her RTS, the risk of a knee-related reinjury decreased significantly. It is, however, unknown if the reduced risk of a knee-related injury is applicable to a reduced risk of a subsequent ACL injury in young athletes.

At the beginning of 2019, almost 20,000 publications related to the term "anterior cruciate ligament" were found in the PubMed database. Despite the large number of publications, it can be argued that the vast majority of previous studies have not been large enough to manage the heterogeneity of individuals after an ACL reconstruction. With respect to the high reinjury risk in younger athletes, clinical guidelines and specific RTS criteria for this young age group might be needed. However, these guidelines and criteria cannot be developed on the basis of the current scientific literature. The reasons for this include the fact that most of the previous literature included individuals of different ages and different preinjury levels of sport.

To obtain specific knowledge of young athletes who have undergone an ACL reconstruction, large amounts of data are needed. This approach means that different sub-groups, for example based on patient sex, age, concomitant injuries and preinjury level of sport, can be created. This thesis was therefore based on data from a rehabilitation-specific register, Project ACL, which utilizes a web-based platform for regular assessments with validated PROs and tests of muscle function. At the beginning of 2019, the register contained more than 2,000 individuals with an ACL injury, data from almost 6,000 muscle function test occasions and 40,000 completed PROs. Using data from Project ACL enabled us to handle large amounts of data from which subgroups of about 150-400 patients were created and investigated.

To summarize, younger athletes have a higher RTS rate, but the rate of a subsequent ACL injury is also high in this population. One interesting question is whether the higher RTS rate in younger athletes is associated with a faster recovery of muscle function and/or a stronger psychological profile. Finally, is there an association between a subsequent ACL injury, an early RTS and asymmetrical muscle function prior to RTS in younger athletes?

3.

AIMS

SUSANNE BEISCHER

Patience you must have, my young athlete

”

To boldly go where no man has gone before

— JEAN-LUC PICARD, STAR TREK

The overall aim of this thesis was to describe the outcome after a primary ACL reconstruction in terms of RTS, muscle function, psychological outcome, symptoms, concomitant injuries, subsequent ACL injury and knee function in adolescent athletes, aged 15 to 20 years, and adult athletes, aged 21 to 30 years.

SPECIFIC AIMS

Study I

The aim was to evaluate the return to knee-strenuous sport rate, muscle function and subjective knee function among adolescent patients (15– 20 years of age) and adult patients (21–30 years of age) 8 and 12 months, respectively, after ACL reconstruction.

Study II

The aim was to investigate psychological readiness to return to sport, knee-related self-efficacy and motivation in adolescent (15-20 years old) and adult athletes (21-30 years old) after ACL reconstruction. A further aim was to compare athletes (15-30 years old) who had recovered their muscle function and returned to sport with athletes that had not.

Study III

The aim was to study whether patient characteristics, concomitant injuries, and graft choice at primary ACL reconstruction can predict RTS 1 year after surgery.

Study IV

The aim was to investigate whether patient demographics, short-term PROs and muscle function are able to predict the achievement of symmetrical muscle function in 5 tests of muscle function in young athletes 1 year after ACL reconstruction.

Study V

The aim was to investigate the association between sustaining a subsequent ACL injury and 1) time to RTS and 2) symmetrical muscle function at the time of RTS in young athletes after primary ACL reconstruction.

4.

METHODS

SUSANNE BEISCHER

Patience you must have, my young athlete

4.1 EVIDENCE-BASED MEDICINE

Evidence-based medicine was originally defined as "the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients".[212] In 2000, this definition was updated to "a systematic approach to clinical problem-solving which allows the integration of the best available research evidence with clinical expertise and patient values". [211] In 2000, the Oxford Centre of Evidence Based Medicine (OCEBM) presented a classification system called "Levels of evidence" *(Table 2)* to make the process of finding appropriate evidence more practical and facilitate the interpretation of the results of the evidence. In 2011, the "Levels of evidence" was updated. [112,172] This classification system categorizes the evidence based on considerations of study design, risk of bias, reliability and the consistency of the results, for example. The OCEBM levels of evidence are a hierarchy of the likely best evidence designed in such way that it can be used as a short cut for busy clinicians, researchers, or patients. [111]

TABLE 2 Levels of Evidence according to Oxford Centre Evidence Based Medicine 2011[172]

1a	Systematic review of RCTs (with level of evidence I)
1b	Individual RCT
2a	Systematic review of RCTs (level of evidence II) or cohort studies
2b	Individual RCT (level of evidence II) or cohort study
3a	Systematic review of case-control studies
3b	Individual case-control study
4	Case series or poor-quality cohort studies and case-control studies
5	Expert opinion without explicit critical appraisal

RCT Randomised Controlled Trial

Study designs

The quality, the reliability and the clinical value of a scientific study are influenced by its design. [204] According to the OCEBM,[171] a study can be classified as either analytic or non-analytic. A non-analytic study, also called a descriptive study, aims to describe what is happening in a population, e.g. the prevalence or the incidence in a specific patient population. Case reports, case series, qualitative studies and cross-sectional studies are all defined as non-analytic studies.

The aim of an analytic study is to quantify the relationship between 2 variables, i.e. the effect on an outcome of an intervention or an exposure. An analytic study comprises one intervention or an exposed group that is compared with one or more groups. Analytic studies can be classified as an observational study, meaning that the researcher is not involved or is able to manipulate the study, or an experimental study, meaning that the researcher plays an active role.[111]

In experimental studies, e.g. an RCT, the included patients are divided into 2 or more groups to receive an intervention or exposure. The patients are then followed up under controlled conditions. This type of study, particularly if it is randomized and blinded, has more potential to control for biases, e.g. systematic errors that can occur in scientific studies, compared with other study designs. RCTs are regarded as the gold standard to determine the efficacy of a treatment or an intervention, [207] even though this type of study has been criticized for not representing usual care. [227]

4.1.1 *Observational study*

In an observational study, the exposure (an intervention or a risk factor) and the outcomes (e.g. a disease) are observed as they occur. Depending on the direction (prospective or retrospective design) and timing of assessments of the exposure and the outcome, the study design is classified as a *cross-sectional study,* a *case-control study*, or a *cohort study*. However, one study can comprise several design elements. For instance, baseline measurements in a cohort study can be used as a cross-sectional study.

In a *cross-sectional study,* the outcome and the exposure are assessed at one particular time. A cross-sectional study can provide information on the association between variables. However, no conclusion with respect to causality can be drawn.

A *case-control study* is designed to determine whether an outcome of interest, e.g. a disease or a condition, is associated with a specific exposure. Individuals who have the condition of interest, e.g. a disease, are compared with a suitable group of individuals without the condition with respect to an exposure.[144] As a result of its design, a case-control study is always retrospective, as it starts with the outcome.

A *cohort study* is a controlled prospective observational study designed to assess the association between exposures and outcomes. An exposed and an unexposed group of individuals are followed until a follow-up of assessments of outcomes is performed and outcomes are compared. Data are collected at baseline and at pre-defined follow-ups. As a result of its design, a cohort study is classified as a prospective study, as it starts with the exposure.

A cohort study based on register data is a specific cohort study design. Even though the study starts after data have been obtained, this type of study is not a retrospective study and should not be associated with recall bias, as the data have been collected prospectively. [55,56] Register-based studies offer advantages with respect to the generalizability of the results, identifying incidences, understanding practices and determining the long-term effects of different types of exposure/intervention. [227] However, observational studies have limitations such as individual variation and confounding factors. For example,

variation can exist in biological responses, in previous treatments, in activity levels and in types of activity and variations in lifestyles.

This thesis includes studies that were designed as prospective cohort studies (Studies I, IV, V) and case-control studies (Study II and III).

4.2 PROJECT ACL

This doctoral thesis is based on data from a rehabilitation outcome register, Project ACL. The data collection for the register started in September 2014 after more than 10 years of clinical experience of testing and evaluating patients with an ACL injury. The concept of Project ACL is to include a large number of patients with an ACL injury, irrespective of their age, sex, time from injury, or choice of treatment. At present, more than 2,000 patients have been included in the project and almost 6,000 muscle function tests and about 40,000 PROs have been completed.

The register consists of 2 parts: a battery of validated PROs and a battery of muscle-function tests for lower extremity muscle strength and hop performance. The patients included in Project ACL are regularly assessed according to a predefined schedule of follow-ups after their primary ACL injury or after their reconstructive surgery. The follow-ups are performed at 10 weeks, 4, 8, 12, 18 and 24 months and thereafter yearly up to 5 years. The plan thereafter is to assess the patient every 5 years after injury or ACL reconstruction.

After every assessment, the results are registered in the Project ACL database and a personal report for the patient is automatically generated and is available online to the patient. In addition, every patient has the opportunity to make his/her personal report available to the responsible orthopedic surgeon and/or physical therapist. Moreover, mean statistics from all test results in Project ACL are automatically updated and are available online (www.projektkorsband.se) to support the interpretation of muscle function and PROs results. Participation in Project ACL is voluntary for patients, physical therapists and surgeons.

In Project ACL, approximately 85% of the included patients have been treated with ACL reconstruction and rehabilitation in combination. About 60% of all the included patients were between 15 and 30 years of age at their primary ACL reconstruction. The most common sports in which the patients in this age group were involved prior to their primary ACL injury were football (soccer) (40%), handball (16%), floorball (8%) and basketball (3%).

To date, about 25% of all the included patients are adolescents, 15-20 years of age. One in 4 of these patients is registered with more than one ACL injury compared with 16% in the 21- to 30-year age group and 6% in patients older than 30 years of age.

4.3 SWEDISH NATIONAL KNEE LIGAMENT REGISTER (SNKLR)

The Swedish National Knee Ligament Register (SNKLR)[232] is a nationwide database which was established at the beginning of January 2005. The register is 1 of 3 Scandinavian ACL registries aiming to improve treatment outcomes through feedback to health care. In addition, the register aims to detect procedures and devices that cause early failure and to identify factors associated with good and poor outcomes.

The SNKLR gathers information on patients with ACL injuries and associated knee surgery. Patient data and surgical treatment data are registered on a web-based protocol. [55] The protocol consists of one surgeon-reported section and one patient-reported section. The surgeon reports information on the type of activity performed at the time of the injury, the time from injury to reconstruction, graft selection and surgical fixation techniques. In addition, information regarding previous surgery on the injured knee, the contralateral knee and all concomitant injuries is registered. If treatment of any concomitant injury is performed, this is also registered. Patients are regularly followed up with PROs preoperatively, 1, 2, 5 and 10 years after ACL surgery/reconstruction. [56] However, no clinical follow-ups are performed. Continuous registration regarding associated knee surgery, i.e. revision surgery or contralateral ACL reconstruction, is performed. Participation in the SNKLR is voluntary for patients and surgeons.

More than 90% of all ACL reconstruction performed in Sweden are registered in the SNKLR and the response rate of the PROs is about 50-70%. [55] The SNKLR was used in Study III.

4.4 SUBJECTS

At total of 729 unique patients were included in the 5 studies and 41 of these patients were included in all the studies. Moreover, 87 patients were included in Studies I-IV and 159 patients were included in both Study II and Study IV. *Table 3* shows the patient demographics of the included athletes presented in this thesis stratified by each study. All the included patients had undergone a primary ACL reconstruction and, prior to their injury, they were regarded as athletes, defined as being involved in knee-strenuous sport, i.e. a preinjury Tegner score of ≥ 6.

TABLE 3 Table of included athletes presented in this thesis

	Study I	Study II	Study III	Study IV	Study V
Total (n)	270 (8m) 203 (12m)	384 (8m) 271 (12m)	272	237	159
Female (%)	51 (8m) 52 (12m)	50 (8m) 52 (12m)	51	59	64
Mean age + SD (y)	22.0 ± 4.3 (8m) 22.0 ± 4.3 (12m)	22.1 ± 4.5 (8m) 22.2 ± 4.6 (12m)	26.0 ± 9.5	21.5 ± 4.2	21.5 ± 4.4
Level of physical activity pre-injury [a]	9 [6-10] (8 & 12m)[b]	9 [6-10] (8 & 12m)[b]	8 [7-9][c]	9 [6-10][b]	9 [6-10][b]

SD standard deviation,
m month
y years
[a] As measured by the Tegner Activity Scale
[b] Reported as the median [min-max]
[c] Reported as the median [Q1-Q3]

4.5 EVALUATION

4.5.1 *Test of knee strength and hop performance*

Since the start of Project ACL, 2 methods of muscle-strength assessment have been used. Initially, isometric tests of knee extension and flexion were performed using a David F200 DMS-EVE and a David F300 DMS-EVE (David Health Solutions Ltd, 2013, Finland) and contributed to about 9-35% of the results in Studies I, II, IV and V. In December 2015, the isometric tests were replaced by isokinetic concentric strength tests of knee extension and knee flexion using a Biodex System 4 (Biodex Medical Systems, Shirley, New York). In addition, the patients included in Project ACL are assessed with a battery of 3 single-leg-hop tests, at the 4-month follow-up at the earliest. [92]

To perform the strength tests, the patient should have no pain or effusion. In addition, patients should have performed single-leg exercises as part of their rehabilitation for at least 2 to 3 weeks before the tests with a moderate load and without perceiving new or increased symptoms. To perform the hop tests, the patients should tolerate high-load single-leg exercises and perform them regularly, as well as having good control of their trunk, hip and knee in single-leg exercises, e.g. a lunge. In addition, they should have practiced single-leg maximum hop tests with their responsible physical therapist. At the time of follow-up, the test leader asks the patient questions according to a strict health declaration in order to ensure that the patient is able and well prepared to perform the tests.

The results of each test in the battery of muscle-function tests were presented as the LSI and achieving an LSI of ≥ 90% in all five tests of muscle function was defined as *achieving symmetrical muscle function.*[24]

4.5.1.1 *Strength of knee extension and knee flexion*

The assessments of muscle function are performed according to a standardized protocol consisting of a 10-minute warm-up on an exercise bike, followed by a warm-up procedure and familiarization with sub-maximum practice trials in the corresponding strength-test device *(Table 4)*. Both the isometric and the isokinetic tests were performed unilaterally, starting with the injured leg first. For the isometric tests, the patients are instructed to extend/flex their knee with maximum effort for 2 to 4 seconds *(Figure 9)*. For the isokinetic test, the patients are instructed to extend/flex their knee with maximum effort and as fast as possible from 90° of flexion to a maximum extended knee and back to 90° of flexion. The patient performs 3 to 5 maximum isometric/isokinetic trials with 40 seconds' rest in between. Verbal encouragement from the test leader is allowed. The highest peak torque (Newton meter, Nm) for extension and flexion for each leg was documented and used for further analysis.

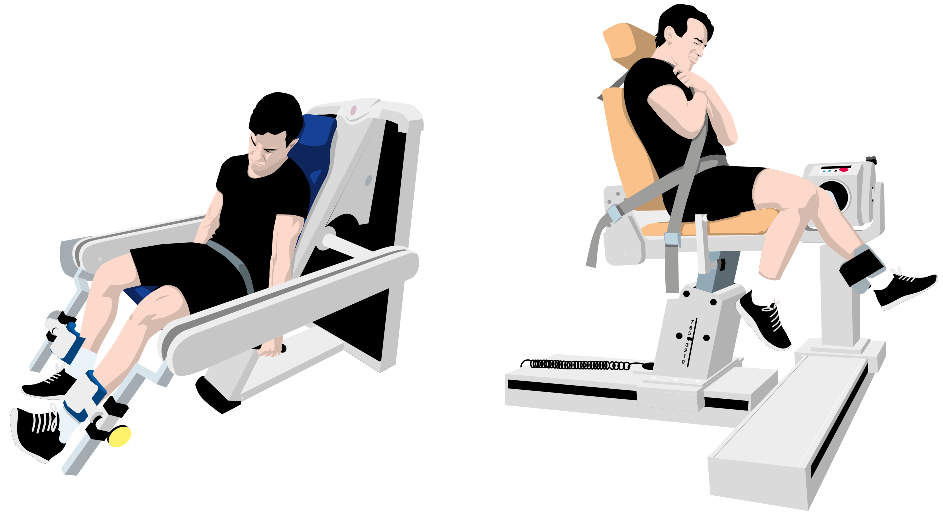

FIGURE 9 Isometric (left) and isokinetic (right) strength test.

TABLE 4 Tests of muscle function

	Knee angles (°)	Number of practice trials (% of 1RM)	Number of maximum repetitions	Rest between repetitions (s)
Knee extension				
Isometric[a]	60	3 (70, 80, 90% of 1RM)	3-5	40
Isokinetic[b]	0-90	1-2 (90% of 1RM)		
Knee flexion				
Isometric[c]	30	3 (70, 80, 90% of 1RM)	3-5	40
Isokinetic[b]	0-90	1-2 (90% of 1RM)		
Single-leg vertical hop[d]	-	2	3	20-30
Single-leg hop for distance	-	2	3	20-30
Single-leg side hop[e]	-	10	1	360

RM Repetition Maximum
s seconds
[a] Measured with David F200 DMS-EVE (David Health Solutions Ltd, 2013, Finland)
[b] Measured with Biodex System 4 (Biodex Medical Systems, Shirley, New York, USA) at 90°/s
[c] Measured with David F300 DMS-EVE (David Health Solutions Ltd, 2013, Finland)
[d] Measured with Muscle lab, Ergotest Technology, Oslo, Norway
[e] As many hops as possible in 30 seconds over 2 lines, 40 centimeters apart

4.5.1.2 Single-leg-hop tests

After strength testing, the included athletes are assessed with 3 hop tests in the following order; single-leg vertical hop; single-leg hop for distance; and single-leg side hop *(Figure 10)*. For detailed information about the number of practice trials and maximum trials per hop test, see *Table 4*.

The injured leg is always tested first, followed by the uninjured leg. Verbal encouragement from the test leader is allowed.

4.5.1.3 Single-leg vertical hop

The single-leg vertical hop test *(Figure 10, left)* is performed as a counter-movement jump and starts with the patient standing on 1 leg with his/her hands behind his/her back. The patient is asked to do a quick knee bend and then jump as high as possible. In this thesis, the Muscle Lab (Ergotest Technology, Oslo, Norway) was used to register the height (cm) of the hop by recording flight time. The system then converted the flight time into jump height in centimeters.

The unilateral vertical hop is reported to have an interclass correlation coefficient (ICC) of 0.97 and a standard error of measurement (SEM) of 0.6 cm. [92]

4.5.1.4 Single-leg hop for distance

The single-leg-hop test *(Figure 10, middle)* starts with the patient standing on one leg, with his/her hands behind his/her back. The patient is instructed to hop as far as possible and perform a controlled, balanced landing. This means keeping the landing foot in place (i.e. no extra hops are allowed) until 2–3 seconds have passed. Failure to perform a controlled landing results in a disqualified test. This single-leg-hop test for distance has been shown to have high test-retest reliability with ICCs of 0.92-0.95[92,195,209], an SEM of 3.5-4.6 cm [195,209,241] and a minimal detectable change MDC of ± 8.1 cm.[195]

4.5.1.5 Single-leg side hop

The test starts with patient standing on 1 leg with his/her hands behind his/her back *(Figure 10, right)*. The patient is instructed to perform as many hops as possible over 2 lines, 40 cm apart, during 30 seconds. The number of successful hops performed, without touching the lines, is documented. Three minutes of rest are given between trials for the injured and for the uninjured leg. The side-hop test has high test-retest reliability with an ICC of 0.93 and an SEM of 3.2 number of hops. [92]

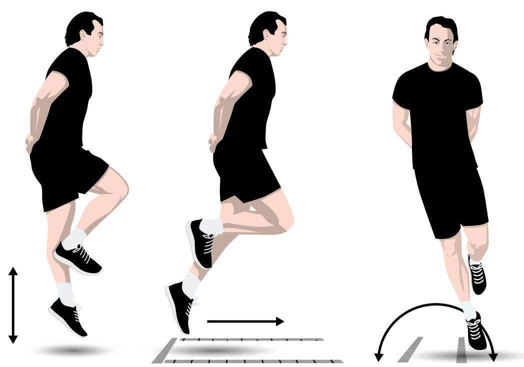

FIGURE 10 Hop tests: single-leg vertical hop (left), single-leg hop for distance (middle) and single-leg side hop (right).

4.5.2 *Patient-reported outcomes (PROs)*

Patient-reported outcomes were used in all 5 studies *(Table 5)*.

4.5.2.1 *Tegner Activity Scale (Tegner)*

The *Tegner* [230] (Appendix) was used in all 5 studies to assess both preinjury and present levels of physical activity and to determine whether or not the patient had returned to sport. The reported preinjury level of physical activity was used as an inclusion criterion in all 5 studies.

The Tegner is graded from 1 to 10, with 1 representing the least strenuous knee activity and 10 representing the most strenuous knee activity, such as rugby and international soccer. The Tegner was used to identify the preinjury physical activity level of ≥ 6, which, in this thesis, is defined as participation in knee-strenuous sport.[94]

The Tegner has been reported to have acceptable test-retest reliability with an ICC of 0.8 for patients with an ACL injury or reconstruction. [233]

4.5.2.2 *Knee injury Osteoarthritis Outcome Score (KOOS)*

The Knee injury and Osteoarthritis Outcome Score [206] was used to assess patients' opinions of their knee and associated problems (Appendix). The KOOS comprises 42 items in 5 subscales; pain (9 items), other symptoms (7 items), activities of daily living (17 items), function in sport and recreation (5 items) and knee-related quality of life (4 items). Each subscale is scored independently from 0 (worst) to 100 (best) by dividing the mean score for each subscale by 4 and then multiplying the result by 100. Additionally, the $KOOS_4$ can be calculated and is an average score of 4 subscales, where the dimension of function throughout daily living is excluded to minimize the risk of a ceiling effect. The reason for this is that young, active patients rarely have difficulty with activities of daily living, such as putting on socks/stockings. [70] The KOOS has been reported to have acceptable test-retest reliability, with an ICC ranging from 0.85 to 0.93 for each subscale for patients with an ACL injury or after an ACL reconstruction. [206]

The MDC in the KOOS for patients with a knee injury ranges from 5 to 12 points for each subscale. [41] The minimal important change MIC, defined as the smallest change in score needed for the effect to be considered clinically relevant, has been reported to be 12.1 for the KOOS subscales function in sport and recreation and 18.3 points for the subscale knee-related quality of life. [114]

4.5.2.3 *Knee Self-Efficacy Scale (K-SES)*

To assess perceived knee-related self-efficacy, a shorter version of the original K-SES [233] was used. The original version is divided into 2 subscales; *present self-efficacy*, including 18 items, and *future self-efficacy*, including 4 items. Patients rate each item on an 11-point Likert scale, ranging from 0 = *not at all certain* to 10 = *very certain.* A mean score of 7 or more on present self-efficacy subscale has been used as an indicator of an acceptable level of self-efficacy. [236] In Study II, the cut-off value of 7 was therefore used to report the rate of athletes achieving this level or higher, together with reporting the median score for each of the 2 sub-scales.

Good validity and acceptable test-retest reliability (ICC = 0.75) have been reported for the original version of the K-SES for patients with an ACL injury or ACL reconstruction in individuals aged 16 to 60 years. [233]

After considering suggestions from patients with an ACL injury/reconstruction and several colleagues with many years' clinical experience of patients with an ACL injury/reconstruction, together with an item analysis, 4 items were omitted and 3 questions were somewhat rephrased.

Evaluation of measurement properties of the short version of Knee Self-efficacy Scale

The reliability, structure and validity of the shorter version of the K-SES ($K\text{-}SES_{short}$) (Appendix) were assessed according to the "COSMIN checklist for evaluating methodological quality". [158] A test-retest reliability analysis was performed on a cohort of patients with ACL reconstruction from 2010 (unpublished data) and resulted in an ICC of 0.92 for the $K\text{-}SES_{short}$ subscale *present* as well as for the $K\text{-}SES_{short}$ subscale *future*. Test-retest data were collected for 32 patients (50% females, mean age 28.9 ± 10.3, min-max 16-50 years) with an average of 10 days between test and retest. To be included in the test–retest evaluation, the patients' condition had to be regarded as clinically stable during this period. All patients had undergone ACL reconstruction and completed the test-retest between 4 and 12 months after reconstruction.

For a further test of reliability, structure and validity, data on the results of PROs (KOOS, ACL-RSI scale, Tegner, Physical Activity Scale[85,233] and the $K\text{-}SES_{short}$) were extracted from Project ACL in May 2018. Eleven follow-ups were used in the analysis; 10 weeks, 4, 8, 12 and 18 months after ACL injury, pre ACL reconstruction (within 6 weeks prior to reconstruction) and 10 weeks, 4, 8, 12 and 18 months after ACL reconstruction. Patient demographics for included patients at each follow-up are shown in *Table 5.* Internal consistency is the degree of interrelatedness between items[159] and it was deemed good if Cronbach's alpha was between 0.70 and 0.95 for the subscales.[231] The $K\text{-}SES_{short}$ showed very good homogeneity at all 11 follow-ups. Cronbach's α ranged from 0.93 to 0.97 for the $K\text{-}SES_{short}$ subscale *present* and from 0.78 to 0.92 for the $K\text{-}SES_{short}$ subscale *future (Table 5)*.

Construct validity includes structural validity, hypotheses testing and cross-cultural validity and is defined as the degree to which the scores of a PRO are consistent with à priori hypotheses, based on the assumption that the instrument validly measures the construct that is going to be measured.[159] To assess the structural validity, a maximum likelihood factor analysis using Harris Kaiser's rotation method was applied to the $K\text{-}SES_{short}$. A cut-off value of ≥ 0.4 was used for the rotated factor loadings. At all 11 follow-ups, the factor analysis produced the same 2 factors of importance with an eigenvalue set at > 1, as the original version of K-SES *(Table 6)*. Factor 1 was related to how the patients perceived their present physical performance/function, while factor 2 was related to how the patients perceived their future physical performance/prognosis for their knee.

TABLE 5 Patient demographics and Chronbachs α for the K-SES$_{short}$ at 11 follow-ups for patients with an ACL injury and after ACL reconstruction

						Chronbachs α	
						K-SES$_{short}$	K-SES$_{short}$
Follow-ups	n	Age	Female (%)	Weight	Height	present	future
10 weeks after ACL injury	101	44.5 (12;63)	77	72.6 (15.4)	172.3 (10.8)	0,958	0,853
4 months after ACL injury	114	42.0 (12;63)	73	73.5 (15.9)	171.8 (13.8)	0,951	0,859
8 months after ACL injury	114	43 (12;65)	70	73.0 (14.9)	172.8 (10.7)	0,962	0,873
12 months after ACL injury	102	46 (19;69)	67	74.2 (14.7)	173.2 (10.3)	0,956	0,874
18 months after ACL injury	77	45 (11;69)	64	74.3 (14.8)	173.8 (10.8)	0,967	0,924
Preoperative[a]	288	27 (13;61)	76	72.0 (14.6)	172.9 (9.3)	0,948	0,828
10 weeks after ACL reconstruction	909	25 (11;65)	68	72.4 (13.6)	173 .6 (9.3)	0,933	0,779
4 months after ACL reconstruction	925	25 (11;65)	68	72.6 (13.6)	173.8 (9.5)	0,934	0,810
8 months after ACL reconstruction	875	26 (14;65)	63	72.7 (13.3)	174.0 (9.6)	0,942	0,812
12 months after ACL reconstruction	713	25 (14;65)	62	72.4 (13.0)	173.8 (9.4)	0,950	0,830
18 months after ACL reconstruction	437	27 (15;65)	56	72.2 (12.5)	173.8 (9.3)	0,945	0,843

Age is presented as median (min;max) and weight and height as mean (standard deviation)
[a] follow-up performed within 6 weeks before ACL reconstruction
K-SES$_{short}$ The shorter version of Knee Self-Efficacy Scale

TABLE 6 Example of a rotated component matrix from the 8 month-follow up after ACL reconstruction

	Factor	
	1	2
Item 1	0,779	0,177
Item 2	0,766	0,247
Item 3	0,795	0,231
Item 4	0,764	0,191
Item 5	0,718	0,166
Item 6	0,761	0,131
Item 7	0,622	0,166
Item 8	0,653	0,149
Item 9	0,730	0,256
Item 10	0,760	0,200
Item 11	0,548	0,326
Item 12	0,767	0,252
Item 13	0,770	0,266
Item 14	0,704	0,336
Item 15	0,272	0,877
Item 16	0,232	0,850
Item 17	0,179	0,567
Item 18	0,116	0,571

Extraction method: Maximum likelihood.
Rotation method: Varimax with Kaiser normalization.

Hypothesis testing was performed using Spearman's correlation coefficient for non-parametric data, comparing the scores from the K-SES$_{short}$ with the KOOS subscales of *sport and recreation* and *QoL*, the ACL-RSI and the Tegner. Six predefined hypotheses were developed by the authors. These hypotheses, ordered in level of importance, are presented in *Table 7*. Because the K-SES, the ACL-RSI and the KOOS were developed for similar patient groups and measure essentially the same constructs, we expected that, from follow-ups between 4 and 18 months after injury and between 4 and 18 months after the ACL reconstruction, high correlations (Spearman r>0.50) on average between both the subscales *present* and the *future* of the K-SES$_{short}$ and the average score on the subscales of *sport and recreation* and *QoL* of the KOOS, the total score of the ACL-RSI and the present physical activity level measured with the Tegner would be found *(Table 7)*.

All 6 hypotheses regarding the relationships between scores on the K-SES$_{short}$ and scores on other knee-specific PROs were confirmed at all follow-ups *(Table 7)*. At the follow-up at 4 months after injury and 2 and 4 months after ACL reconstruction, some correlations were between 0.4 and 0.5. This was somewhat expected and can be explained by the heterogeneity in the ACL reconstructed population early after surgery in terms of symptoms and function and psychological readiness to RTS.

4.5.2.4 Anterior Cruciate Ligament Return to Sport after Injury (ACL-RSI) scale

The Swedish version of the ACL-RSI scale [255] [136] was used to assess psychological readiness to return to sports participation. The ACL-RSI scale measures 3 types of response with 12 items believed to be associated with the resumption of sport after an injury: emotions (5 items), confidence in performance (5 items) and risk appraisal (2 items). Patients are asked to rate each item on a 10-point Likert scale that ranged from, for instance, *extremely likely* to *not likely at all.* [136] Higher scores reflect a more positive psychological response. The Swedish version of the ACL-RSI scale is reported to be valid, internally consistent and reliable (ICC = 0.89) for patients aged 18-45 years after an ACL reconstruction. [136]

In previous studies, the ACL-RSI scale has been reported as the mean total score, mean score, or as a score transformed to a 0-100 scale; (total score x 100)/120. Patients achieving a total score higher than 56 on the ACL-RSI scale have been found to have higher odds of returning to their preinjury level of sport, compared with patients reporting < 56 points. [14] In Study II, the cut-off value of 56 was used as an outcome by determining the rate of athletes achieving this level of psychological readiness, while also reporting the median total score of the ACL-RSI scale.

4.5.2.5 Motivation and goal-setting

In Study II, the questions *"How important is it for you to achieve your goal for rehabilitation?", "How likely do you think it is that you will achieve your goal for rehabilitation?"* and *"How motivated are you to achieve your goal for rehabilitation?"* were used to assess patients' motivation and goal-setting. The questions are graded from 1 = not at all important/likely/motivated to 5 = extremely important/likely/motivated. The questions have been developed for Project ACL by the research group. First, the scientific literature with respect to the topic was reviewed. To ensure face validity, [226] three physical therapists, all with experience of patients with an ACL injury, then took part in the development of the questions.

TABLE 7 Predefined hypotheses used in tests of construct validity ordered in level of importance for the short version of the K-SES

Hypotheses	Spearman's correlation
Patients with a high present Tegner would score high on the subscale of present self-efficacy of the K-SES$_{short}$	0.4 - 0.7
Patients who scored high on the subscale of sport and recreation on the KOOS would score high on the subscale of present self-efficacy of the K-SES$_{short}$	0.6 – 0.8
Patients who scored high on the subscale of quality of life on the KOOS would score high on the subscale of present self-efficacy of the K-SES$_{short}$	0.5 - 0.8
Patients who scored low on the subscales of pain and symptoms of the KOOS would score low on the subscale of present self-efficacy of the K-SES$_{short}$	0.4 - 0.8
Patients who scored high on the ACL-RSI scale[a] would score high on the subscale of present self-efficacy of the K-SES$_{short}$	0.4 - 0.7
Patients who scored high on the ACL-RSI scale[a] would score high on the subscale of future self-efficacy of the K-SES$_{short}$	0.5 - 0.8

ACL-RSI Anterior Cruciate Ligament Return to Sport after Injury scale
K-SES The original version of Knee Self-Efficacy Scale
K-SES$_{short}$ The shorter version of the Knee Self-Efficacy Scale
KOOS Knee injury Osteoarthritis Outcome Score
[a] measured at 8-, 12- and 18-month follow-ups

TABLE 8 Patient-reported outcomes used in Studies I-V

	Study I	Study II	Study III	Study IV	Study V
Tegner Activity Scale (Tegner)	x	x	x	x	x
Knee injury Osteoarthritis Outcome Score (KOOS)	x			x	
The shorter version of the Knee Self-Efficacy Scale (K-SES$_{short}$)		x		x	
Anterior Cruciate Ligament Return to Sport after Injury (ACL-RSI scale) scale		x			
Motivation and goal-setting questions		x			

4.6 STUDY I

Study design: Prospective, observational register study, level of evidence; 2b

Patients and methods

Patients with a unilateral ACL injury who had undergone ACL reconstruction, aged 15 to 30 years at the primary ACL reconstruction, were included. A further inclusion criterion was a preinjury self-reported physical activity level on the Tegner [230] of ≥ 6. Patients who met these inclusion criteria and had undergone a reconstruction between September 2013 and July 2016 were eligible for inclusion.

Patient demographic data *(Table 9)* and cross-sectional data from 5 tests of muscle function (2 strength tests and 3 hop tests), from the KOOS and the Tegner, performed at 8 and 12 months after a primary ACL reconstruction, were extracted from Project ACL.

Outcome

The rate of return to knee-strenuous sport, i.e. returning to a Tegner level of 6 or higher, [94] and the proportions of patients achieving an LSI of ≥ 90% in all 5 tests of muscle function and KOOS subjective knee function scores were compared between the adolescent athletes (15-20 years of age) and adult athletes (21-30 years of age) at both follow-ups.

TABLE 9 Patient demographics for included patients at 8 and 12 months after anterior cruciate ligament reconstruction in Study I

	8 months						12 months					
	All included patients (n = 270)			Returned to knee-strenuous sport (Tegner Activity Score ≥6) (n = 114)			All included patients (n = 203)			Returned to knee-strenuous sport (Tegner Activity Score ≥6) (n = 136)		
	Age 15-20 years (n = 102)	Age 21-30 years (n = 168)	p value	Age 15-20 years (n = 51)	Age 21-30 years (n = 63)	p value	Age 15-20 years (n = 76)	Age 21-30 years (n = 127)	p value	Age 15-20 years (n = 56)	Age 21-30 years (n = 80)	p value
Age at reconstruction (years) mean ± SD	17.4 ± 1.3	24.9 ± 2.6	n.a.	17.2 ± 1.2	24.5 ± 2.7	n.a.	17.3 ± 1.2	24.8 ± 2.8	n.a.	17.2 ± 1.2	24.3 ± 2.6	n.a.
Height (cm)	173 ± 10	177 ± 9	0.008	172 ± 10	179 ± 8	0.010	170 ± 22	177 ± 9	0.004	171 ± 25	178 ± 9	0.002
Weight (kg)	70 ± 11	76 ± 13[a]	0.002	72 ± 11	79 ± 13[a]	0.001	71 ± 11[b]	75 ± 11	0.005	71 ± 10[b]	77 ± 11	0.002
Pre-injury physical activity level[c]	8.7 ± 0.9 9 [6–10]	8.2 ± 1.2 8 [6–10]	0.001	8.9 ± 0.9 9 [7–10]	8.8 ± 1.0 9 [6–10]	n.s.	8.7 ± 0.9 9 [7–10]	8.3 ± 1.2 8 [6–10]	0.001	8.7± 0.9 9 [7–10]	8.7 ± 1.0 9 [6–10]	n.s.
Female, n (%)	69 (67)	70 (42)	<0.001	30 (59)	19 (30)	0.002	52 (68)	51 (40)	<0.001	36 (64)	27 (34)	<0.001

For categorical variables, n (%) is presented.
For continuous variables, the mean ± SD is presented. Pre-injury physical activity level is presented as mean ± SD and with median [min–max].
For comparisons between groups, chi-square test was used for dichotomous variables, the Mann-Whitney U test for ordered categorical variables and the independent t-test for continuous variables.
$p \leq 0.05$ indicates statistical significance.
[a] missing data for 1 patient
[b] missing data for 2 patients
[c] as measured with the Tegner, score range: 0-10
n.a. not applicable
n.s. not significant

4.7 STUDY II

Study design: Case-control study, level of evidence; 3b

Patients and methods

Athletes with a unilateral ACL injury who had undergone ACL reconstruction between March 2014 and August 2017 and were aged 15-30 years at the reconstruction were eligible for inclusion. A further inclusion criterion was a preinjury level of physical activity on the Tegner [230] of ≥ 6.

Patient demographic data and cross-sectional data from the 8-month and 12-month follow-ups, including the results from the 5 tests of muscle function, the Tegner, the K-SES$_{short}$, the ACL-RSI scale and from 3 single questions, were extracted from Project ACL. These outcomes were compared between adolescents (15-20 years old) and adults (21-30 years old), as well as between athletes who had and had not achieved symmetrical muscle function. *Table 10* shows patient demographics at the 8- and 12-month follow-ups respectively.

Outcome

The ACL-RSI scale was used to assess the athletes' psychological readiness to RTS[136] and the K-SES$_{short}$ was used to assess present and future self-efficacy of knee function. Psychological readiness to RTS was analysed by comparing the total score of the ACL-RSI scale and the proportion of athletes achieving a total score of 56 or higher respectively. Scores from the subscales of *present* and *future* K-SES$_{short}$ were compared between age groups as well as the proportion of athletes achieving a score of 7 or higher on the K-SES$_{short}$ subscale *present.* Motivation and goal-setting were assessed using 3 individual questions described on page 64. The results of muscle function tests were presented as the LSI. Achieving an LSI of ≥ 90% in 5 tests of muscle function was defined as achieving symmetrical muscle function. This variable was used to group the included athletes into those that had and those that had not achieved symmetrical muscle function.

TABLE 10 Baseline demographics at 8 and 12 months after anterior cruciate ligament reconstruction for included patients in Study II

	8 months			12 months		
	Age 15-20 (n=174)	Age 21-30 (n=210)	p value	Age 15-20 (n=123)	Age 21-30 (n=148)	p value
Females, n (%)	110 (63%)	82 (39%)	<0.001	80 (65%)	62 (42%)	<0.001
Height (cm)	173.6 (9.7) (155; 201)	176.8 (9.5) (150; 200)	<0.001	173.4 (9.3) (155; 197)	175.9 (9.7) (150; 200)	0.023
Weight (kg)	69.0 (11.8) (50; 115)	76.0 (12.2) (49; 118)	<0.001	69.4 (10.5) (50; 104)	74.7 (12.5) (49; 102)	<0.001
BMI (kg/m2)	22.8 (2.8) (18; 39)	24.2 (2.4) (18; 32)	<0.001	23.0 (2.5) (18; 39)	24.0 (2.5) (18; 32)	<0.001
Age at surgery	17.8 (1.6) (15.1; 20.9)	25.7 (2.7) (21.0; 31.0)		17.9 (1.7) (15.1; 21.0)	25.9 (2.6) (21.0; 30.9)	
Time to ACL reconstruction (months)	6.5 (8.6) (0.0; 56.6)	10.5 (16.5) (0.2; 133.1)	0.0038	5.5 (6.8) (0.0; 55.9)	9.6 (15.7) (0.8; 133.1)	0.0065
Tegner$_{pre-injury}$						
6	3 (2%)	20 (10%)		1 (1%)	18 (12%)	
7	10 (6%)	51 (24%)		5 (4%)	33 (22%)	
8	58 (33%)	40 (19%)	<0.001	50 (41%)	34 (23%)	<0.001
9	60 (35%)	73 (35%)		43 (35%)	50 (34%)	
10	43 (25%)	26 (12%)		24 (20%)	13 (9%)	
Returned to sport	86 (49%)	73 (35%)	<0.001	90 (73%)	86 (58%)	<0.001

For categorical variables, n (%) is presented.
For continuous variables, the mean (SD) and (min; max) are presented.
For comparisons between groups, Fisher's exact test (lowest one-sided p value multiplied by 2) was used for dichotomous variables. The Mantel-Haenszel chi-square test was used for ordered categorical variables and the Mann-Whitney U test was used for continuous variables.
BMI Body Mass Index
Tegner Tegner Activity Scale

4.8 STUDY III

Study design: Case-control study, level of evidence; 3b

Patients and methods

This study was based on data from Project ACL and the SNKLR. Patients who had patient-reported data in Project ACL from the 1-year follow-up were eligible for inclusion. Additional intraoperative and surgical information was extracted from the SNKLR, including data reported on concomitant injuries and graft choice. Only patients who had undergone a primary ACL reconstruction and had undergone no previous knee surgery were regarded as eligible. Patients were excluded if they had an early postoperative infection, registered in Project ACL or in the SNKLR. Patient demographics are presented in *Table 11*.

Outcome

The Tegner [230] was the primary outcome and was used to determine RTS. Patients who reported a Tegner of ≥ 6 at the 1-year follow-up were classified as having achieved RTS and this was used as the dependent outcome in the regression model.

TABLE 11 Baseline demographics and drop-out analysis for included and excluded patients in Study III

	Included (n=272)	Excluded (n=170)	p value
Patient sex			
Female	138 (50.7%)	82 (48.2%)	0.68
Age at primary ACL injury	25.0 (9.2)	25.3 (9.2)	0.77
Age at primary ACL reconstruction	26.0 (9.5)	26.2 (9.6)	0.89
Height (cm)	174.7 (9.6)	175.7 (9.8)	0.24
Weight (kg)	72.6 (12.0)	75.0 (15.1)	0.23
BMI (kg/m2)	23.8 (2.9)	24.1 (3.3)	0.52
Graft choice			
Hamstring tendon	234 (86.0%)	91 (91.0%)	0.43
Patellar tendon	34 (12.5%)	9 (9.0%)	
Other	4 (1.5%)	0 (0.0%)	
Concomitant injuries			
Medial meniscus	60 (22.1%)	24 (23.5%)	0.86
Lateral meniscus	77 (28.3%)	35 (34.3%)	0.32
Cartilage	65 (23.9%)	27 (26.5%)	0.70
Medial collateral ligament	12 (4.4%)	7 (6.9%)	0.47
Lateral collateral ligament	1 (0.4%)	1 (0.4%)	0.94
Meniscus (medial or lateral)	122 (44.9%)	53 (52.0%)	0.27
Tegner Activity Scale pre-injury (0-10)	8.0 (7.0; 9.0)	8.0 (7.0; 9.0)	0.27

For categorical variables, n (%) is presented.
For continuous variables, the mean (SD) is presented.
For ordered categorical variables, median (Q1; Q3) is presented.
For comparisons between groups, Fisher's exact test (lowest one-sided p value multiplied by 2) was used for dichotomous variables and the Mann-Whitney U-test was used for continuous variables.
Q Quartile

4.9 STUDY IV

Study design: Prospective cohort study, level of evidence 2b

Patients and methods

Patients with a unilateral ACL injury who had undergone ACL reconstruction, aged 15 to 30 years at the primary reconstruction, were included. A further inclusion criterion was a preinjury self-reported Tegner physical activity level of ≥ 6. [230] Patients who met these inclusion criteria and had undergone a reconstruction between September 2013 and April 2017 were eligible for inclusion. Baseline demographics and the drop-out analysis for included and excluded patients are shown in *Table 12*.

Data from the 4-month and the 12-months follow up, including results from 5 tests of muscle function in addition to demographic data, information regarding graft type used at the reconstruction and results from PROs including the Tegner [230], $KOOS_4$ [206] and $K\text{-}SES_{short}$, [233] were extracted from Project ACL.

Demographic data included age at the primary reconstruction, patient sex, height, weight, BMI and preinjury level of sport. Demographic data, graft type and results from the PROs and tests of muscle function were used as independent variables. The results of muscle function tests were presented as the LSI, defined as the ratio between the results for the injured side and the non-injured side expressed as a percentage.

Outcome

Achieving an LSI of ≥ 90% in all 5 tests of muscle function was defined as achieving symmetrical muscle function and was used as the dependent variable. [239]

TABLE 12 Baseline demographics and drop-out analysis for included and excluded patients in Study IV

	Included (n=237)	Excluded (n=153)	p value
Patient sex			
Female	139 (58.6%)	97 (63.4%)	0.41
Height (cm)	174.0 (150.0; 200.0)	175.0 (155.0; 197.0)	0.21
Weight (kg)	70.0 (45.0; 102.0)	72.0 (49.0; 118.0)	0.091
BMI (kg/m^2)	23.1 (18.5; 35.4)	23.9 (17.9; 38.7)	0.099
Age at primary ACL reconstruction	21.5 (4.2)	22.1 (4.4)	0.18
Pre-injury physical activity level			
6	13 (6%)	9 (6%)	
7	33 (14%)	25 (16%)	
8	71 (30%)	45 (29%)	0.45
9	82 (35%)	54 (35%)	
10	38 (16%)	20 (13%)	
Graft choice			
Hamstring	190 (86.0%)	95 (83.3%)	
Patella	27 (12.2%)	15 (13.2%)	0.67
Allograft	3 (1.4%)	2 (1.8%)	
Other graft	1 (0.5%)	1 (0.9%)	

For categorical variables, n (%) is presented.
Patient's height, weight and BMI are presented as the median (min; max).
Patient's age at primary ACL reconstruction is presented as the mean (SD).
For comparisons between groups, Fisher's exact test (lowest one-sided p value multiplied by 2) was used for dichotomous variables, the chi-square test was used for non-ordered categorical variables and the Mann-Whitney U-test was used for continuous variables.
[a] as measured with the Tegner Activity Scale
BMI Body Mass Index

4.10 STUDY V

Study design: Prospective cohort study, level of evidence; 2b

Patients and methods

Athletes who had undergone a primary ACL reconstruction between March 2013 and December 2017 and were aged between 15 and 30 years at their primary ACL reconstruction were included. A further inclusion criterion was a preinjury self-reported physical activity level on the Tegner of ≥ 6. Patients were excluded if they had > 2 ACL injuries or if any complication occurred during the muscle function tests that was considered to have influenced the results, e.g. muscle strain or knee pain. Moreover, athletes were excluded from further analyses if they had not responded to a study-specific questionnaire *(Table 13)* or had not performed tests of muscle function close to the RTS.

TABLE 13 Project-specific questionnaire regarding return to sport used in Study V

1.	*"Since your primary ACL reconstruction, have you reached any of these levels of physical activity?" (yes/no)*
1a.	*(If yes) "Please specify when you returned to at least level 6" (month/year)*
Examples of Tegner Activity level 6-10	
10	Soccer – national or international level, American football, wrestling, figure skating
9	Soccer, ice hockey, mogul skiing
8	Basketball, handball, floorball, long jump
7	Badminton, high jump, tennis, downhill skiing, volleyball
6	Baseball, hurdling, orienteering, snowboarding

To determine time to RTS, defined as having returned to at least level 6 of the Tegner,[230] an online questionnaire *(Table 13)* was sent to patients registered in Project ACL, who had performed tests of muscle function at the 8-, 12- or the 18-month follow-up.

To assess the association between a subsequent ACL injury and symmetrical muscle function prior to the return to knee-strenuous sport, data from strength and hop tests were extracted from the follow-up closest to the RTS.

Patient demographics for included athletes stratified by athletes with and without a subsequent ACL injury are presented in *Table 14*.

Outcome

The primary outcome was a subsequent ACL injury after the primary anterior cruciate ligament reconstruction. Data regarding the number of ACL injuries were extracted from Project ACL.

TABLE 14 Baseline demographics stratified by athletes with and without a subsequent anterior cruciate ligament injury in Study V

	Subsequent ACL injury (n=18)	No subsequent ACL injury (n=141)	p values
Patient sex			
Female	13 (72%)	89 (63%)	0.63
Height (cm)	171.2 (8.3)	174.7 (9.5)	0.13
Weight (kg)	67.2 (8.5)	71.2 (12.5)	0.21
Tegner pre-injury			0.029
6	0 (0.0%)	6 (4.3%)	
7	2 (11.1%)	18 (12.8%)	
8	3 (16.7%)	43 (30.5%)	
9	5 (27.8%)	51 (36.2%)	
10	8 (44.4%)	23 (16.3%)	
Graft choice			0.099
Hamstring	13 (72.2%)	120 (87.0%)	
Patella	4 (22.2%)	17 (12.3%)	
Quadriceps	1 (5.6%)	0 (0%)	
Allograft	0 (0%)	1 (0.7%)	
Age at index ACL reconstruction (years)	20.3 (3.4)	21.7 (4.5)	0.21
Time from ACL injury to reconstruction (months)	4.3 (4.8)	6.4 (8.1)	0.041
Time of follow up	11.1 (10.0) 7.6 (0.4;28.4)	19.4 (11.1) 16.5 (2.5;46.5)	n.a.

For categorical variables, n (%) is presented.
For continuous variables, mean (SD) is presented.
Time of follow up is presented with mean (SD), median (min; max).
For comparison between groups Fisher´s exact test (lowest 1-sided p value multiplied by 2) was used for dichotomous variables, the Mantel-Haenszel chi Square test was used for ordered categorical variables and the Mann-Whitney U-test was used for continuous variables.
Tegner Tegner Activity Scale
SD Standard Deviation
n.a not applicable

5.

STATISTICAL METHODS

SUSANNE BEISCHER

Patience you must have, my young athlete

In Study I, statistical analysis was performed using the statistical package for the social sciences (SPSS) (version 22, 2013; SPSS Inc., Chicago, IL, USA). In Studies II-V, the statistical analysis was performed using the statistical analysis system (SAS) (SAS/STAT, version 14.2, 2016; SAS Institute Inc., Cary, North Carolina, USA).

All significance tests were 2-sided and conducted at the 5% significance level.

STUDY I

To describe patient demographics and outcomes, the mean and standard deviation (SD) were used for continuous variables. Categorical outcome variables were presented with frequencies and percentages and ordered categorical outcome variables were reported with the median, interquartile range and minimum and maximum.

The variables were compared between age groups using the chi-square test for non-ordered categorical variables, the Mann-Whitney U test for ordered categorical variables and the independent t-test for continuous variables.

A power analysis based on the results of a previous study [241] suggested that 36 persons per group were needed for a power of 80% to detect a significant difference in knee extension strength, presented as the LSI, between groups, with a variance of 10%.

STUDY II

To describe the patient sample and the outcome, continuous variables were summarized with the mean, SD and minimum and maximum. Categorical outcome variables were presented with frequencies and percentages. Non-parametric outcomes were reported with the median, interquartile range and minimum and maximum. Data on patient demographics were compared using Fisher's exact test (lowest one-sided p value multiplied by 2) for dichotomous variables, the Mantel-Haenszel chi-square test for ordered categorical variables and the Mann-Whitney U test for continuous variables in comparative analyses between included and excluded athletes.

For between-group comparisons, i.e. between age groups, between athletes that had or had not returned to sport and between athletes who had and had not recovered their muscle function, Fisher's exact test (lowest one-sided p value multiplied by 2) was used for dichotomous variables and the Mann-Whitney U test was used for continuous variables.

STUDY III

To describe patient demographics and outcomes, counts and proportions were used for categorical variables. Continuous variables were reported as the mean and SD and median with the first and third quartiles. Comparisons between included and excluded patients were performed with Fisher's exact test (lowest one-sided p value multiplied by 2) for dichotomous variables and the Mann-Whitney U test for continuous variables. In order to analyze the association between predictors and return to knee-strenuous sport, a binary logistic regression was performed. Return to sport was defined as reporting level ≥ 6 on the Tegner at the 12-month follow-up and was used as a dependent variable. The presence of concomitant injuries was dichotomously (yes/no) used as an independent variable in the regression analyses. The analysis of graft choice was only based on patients who received a HT or patellar tendon autograft, owing to the small number of patients receiving other grafts. Patient demographics of sex, age (per 10 years), weight at reconstruction, height and preinjury level of physical activity (as measured with the Tegner) were included as independent variables.

With the aim of trying to find the best predictive model for RTS 12 months after ACL reconstruction, a stepwise multivariable logistic model was used. Variables with $p < 0.20$ in the univariable analysis were entered into the stepwise analyses. The results of the logistic regression models were presented with odds ratios (OR), 95% confidence intervals and p values. For all the regression models used, the area under the receiver operating characteristics (ROC) curve was given as a measurement of goodness of fit, using limits of 0.90-1 = excellent, 0.80-0.90 = good, 0.70-0.80 = fair, 0.60-0.70 = poor and 0.50-0.60 = fail. [156]

STUDY IV

To describe the patient sample and outcomes, categorical variables were summarized with frequencies and percentages. Continuous variables were reported with the mean and SD and the median with minimum and maximum values. These variables were compared between groups using Fisher's exact test (lowest one-sided p value multiplied by 2) for dichotomous variables, the Mantel-Haenszel chi-square test for ordered categorical variables, the chi-square test for non-ordered categorical variables and the Mann-Whitney U test for continuous variables.

The primary outcome was the achievement of symmetrical muscle function 12 months after ACL reconstruction. To analyse the association between independent variables and the primary outcome, a binary logistic regression was performed.

To predict the achievement of symmetrical muscle function at 12 months, a forward stepwise multivariable logistic model including all independent variables was used. A secondary model, excluding the 3 hop tests, was also performed. In this secondary analysis, knee extension symmetry was entered first, based on previous publications.[12, 16-21] Variables which had a p value of < 0.20 in the univariable analyses were entered into the 2 stepwise regression models, where the variable with the highest area under the ROC curve was entered first.

The OR, i.e. the ratio between the odds of an increase in the predictor, 95% CIs and p values, was used to present the results of the logistic regression models. The area under the ROC curve was given as a measurement of goodness of fit, using limits of 0.90-1 = excellent, 0.80-0.90 = good, 0.70-0.80 = fair, 0.60-0.70 = poor and 0.50-0.60 = fail. [156]

STUDY V

Descriptive statistics for patient demographics and outcomes were reported as the count and proportions for categorical variables. Continuous variables were reported with the mean, SD and minimum and maximum.

The demographics were compared between included and excluded athletes using Fisher ́s exact test (lowest one-sided p value multiplied by 2) for dichotomous variables, the Mantel-Haenszel chi-square exact test for ordered categorical variables and the Mann-Whitney U test for continuous variables.

In order to analyze the association between the primary outcome of a subsequent ACL injury and the independent variables *time to RTS, symmetrical muscle function prior to RTS* and specific patient demographics, a Cox proportional hazards regression model was used for categorical and continuous variables. Time 0 was defined as the first month of participation in sports equal to knee-strenuous sport, i.e. Tegner ≥ 6. Hazard ratios (HR) were calculated for descriptive purposes. Multiple survival analysis was performed with stepwise Cox proportional hazards regression. Only variables that affected survival time in the univariable tests ($p < 0.1$) were included as possible risk factors in the multivariable analysis. Generalized R^2 was calculated for both the univariable and the multivariable analysis in order to compare the models.

6.

ETHICS

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All the included patients were given written information about the study and participation in Project ACL is voluntary for patients. Informed consent was obtained for all patients and the rights of subjects are fully protected. Ethical approval was obtained from the Regional Ethical Review Board in Gothenburg, Sweden (registration numbers: 265-13, T023-17).

7.

RESULTS AND SUMMARIES OF STUDIES

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7.1 STUDY I

Background

Athletes younger than 25 years of age constitute a high-risk group in terms of a sustaining subsequent ACL injury. [266] An early RTS [45,91] and not achieving symmetrical muscle function prior to RTS [91,137,183] are identified as risk factors for a subsequent ACL injury. However, it is not known how many young athletes, 15-30 years of age, achieve symmetrical muscle function prior to RTS.

Aim

The aim of this study was to evaluate the return to knee-strenuous sport rate, muscle function and subjective knee function among adolescent patients (15– 20 years of age) and adult patients (21–30 years of age) 8 and 12 months, respectively, after ACL reconstruction.

Results

Of the athletes included at the 8-month follow-up, 42% (114/270) reported that they had returned to knee-strenuous sport. The corresponding proportion at 12 months was 67% (136/203). Moreover, adolescent athletes had a higher RTS rate at 8 months compared with the adult athletes (50% versus 38%, $p = 0.044$). No differences in the RTS rate between the age groups were seen at 12 months.

In all, 29% of both the adolescent (13/45) and the adult athletes (14/49), who had returned to knee-strenuous sport, achieved symmetrical muscle function with an LSI ≥ 90% in all 5 tests of muscle function at 8 months after ACL reconstruction. At the 12-month follow-up, 20% of the adolescent athletes (8/40) and 28% of the adult athletes (17/60) ($p = 0.346$) achieved symmetrical muscle function. No difference in the proportion of athletes who achieved symmetrical muscle function or in the mean LSI was seen between adolescent and adult athletes at any of the follow-ups *(Table 15)*. Moreover, no difference in patient-reported knee-function was seen between age groups at any follow-up.

Conclusion

The majority of young athletes make an early return to knee-strenuous sport after a primary ACL reconstruction, without recovering their muscle function. To set realistic expectations, clinicians are recommended to ensure that young athletes receive information about not to return before muscle function is recovered and that this may take longer time than 12 months.

TABLE 15 Results from tests of muscle function, including the proportion (%) of athletes achieving symmetrical muscle function with a Limb Symmetry Index of (≥ 90%) at 8 and 12 months in athletes who had returned to knee-strenuous sport

	8 months			12 months		
	Age 15-20 years	Age 21-30 years	p value	Age 15-20 years	Age 21-30 years	p value
	(n = 45)	(n = 50)		(n = 40)	(n = 60)	
Knee extension	94 ± 9	94 ± 12	n.s.	98 ± 9	97 ± 11	n.s.
	80	72		83	83	
Knee flexion	100 ± 10	100 ± 14	n.s.	99 ± 10	99 ± 14	n.s.
	84	80		80	78	
Vertical hop	88 ± 10[a]	88 ± 15[b]	n.s.	92 ± 14[a]	90 ± 12[b]	n.s.
	46	54		50	50	
Hop for distance	96 ± 8[b]	95 ± 10[a]	n.s.	97 ± 7[a]	96 ± 7[b]	n.s.
	81	80		78	83	
Side hop	99 ± 15[c]	93 ± 15[d]	n.s.	101 ± 17[d]	97 ± 12[d]	n.s.
	78	72		78	75	

For categorical variables, n (%) is presented.
For continuous variables, the mean (SD) is presented.
Statistically significant difference between groups at a p value of < 0.05 using an independent t-test.
[a] Missing value for 1 patient
[b] Missing value for 2 patients
[c] Missing value for 4 patients
[d] Missing values for 3 patients
n.s. not significant.

7.2 STUDY II

Background

Adult patients who return to their preinjury level of sport after an ACL reconstruction have been characterized by a more positive psychological response. However, less is known about the association between the recovery of muscle function and psychological outcome when it comes to determining RTS, especially in young athletes.

Aim

The aim was to investigate psychological readiness to return to sport, knee-related self-efficacy and motivation in adolescent (15-20 years old) and adult athletes (21-30 years old) after ACL reconstruction. A further aim was to compare athletes (15-30 years old) who had recovered their muscle function and returned to sport with athletes that had not.

Results

Patient sex was evenly distributed in the athletes included at both follow-ups; 50% (192/384) versus 52% (141/271) females at 8 and 12 months. At both follow-ups, the adolescent athletes (15-20 years old) comprised more females than males (8 months, 63% versus 39%, p<0.001; 12 months, 65% versus 42%, p = 0.002) and had a higher RTS rate at both follow-ups (8 months, 49% versus 35%, p<0.001; 12 months, 73% versus 58%, p<0.001) compared with the adult athletes.

In all, 22% and 23% of the athletes had recovered their muscle function at the 8- and 12-month follow-up respectively. Athletes who had recovered their muscle function had a higher RTS rate compared with athletes who had not (8 months, 58% versus 29%, p = 0.0021; 12 months, 84% versus 44%, p = 0.0098).

Psychological outcome

The adolescents reported significantly higher levels of present (8 months, Δ = 0.3, p = 0.0062; 12 months, Δ = 0.4, p = 0.041) and future knee-related self-efficacy (8 months, Δ = 0.5, p = 0.0010; 12 months, Δ = 0.7, p = 0.042) 8 and 12 months postoperatively *(Table 16)*.

TABLE 16 Knee-related self-efficacy and psychological readiness to return to sport at 8 months and 12 months after anterior cruciate ligament reconstruction stratified by age groups (Study II)

	8 months			12 months		
	Age 15-20 (n=174)	Age 21-30 (n=210)	p value	Age 15-20 (n=123)	Age 21-30 (n=148)	p value
Present K-SES$_{short}$	8.4 (2.8; 10.0)	8.1 (0.0; 10.0)	0.0062	9.0 (5.0; 10.0)	8.6 (1.8; 10.0)	0.041
Future K-SES$_{short}$	8.0 (1.5; 10.0)	7.5 (1.3; 10.0)	0.0010	8.0 (0.8; 10.0)	7.3 (0.0; 10.0)	0.042
Present K-SES$_{short}$ ≥7	149 (86%)	148 (71%)	<0.001	105 (85%)	123 (83%)	0.74
ACL-RSI	58.3 (17.5; 99.2)[a]	55.0 (10.0; 99.2)[b]	0.14	63.8 (13.3; 100.0)[c]	58.3 (10.0; 100.0)[d]	0.28
ACL-RSI > 56	62 (53%)	65 (44%)	0.18	52 (62%)	60 (53%)	0.28

For categorical variables, n (%) is presented.
For continuous variables, the median (min; max) is presented.
For comparisons between groups, Fisher's exact test (lowest one-sided p value multiplied by 2) was used for dichotomous variables and the Mann-Whitney U test was used for continuous variables.
ACL-RSI Anterior Cruciate Ligament Return to Sport Index Scale
Present K-SES$_{short}$ subscale of present self-efficacy of the short version of the Knee Self-Efficacy Scale
Future K-SES$_{short}$ subscale of future self-efficacy of the short version of the Knee Self-Efficacy Scale
[a] Missing values for 56 patients
[b] Missing values for 61 patients
[c] Missing values for 39 patients
[d] Missing values for 35 patients

Athletes who had recovered their muscle function were more motivated to achieve their goal compared with athletes who had not recovered their muscle function ($p<0.001$) and they reported higher levels of present self-efficacy at both follow-ups (8 months, $\Delta = 0.5$, $p = 0.0016$; 12 months, $\Delta = 0.7$, $p < 0.001$). No differences in the other psychological outcomes were found between the age groups or between athletes who had and had not recovered their muscle function. With respect to RTS, both adolescent and adult athletes who had returned to sport reported higher levels on the K-SES$_{short}$ and the ACL-RSI scale at both follow-ups *(Table 17)*.

Because the adolescents comprised significantly more females than males at both follow-ups (8 months, $p < 0.001$; 12 months, $p < 0.001$), sub-group analyses of the psychological outcomes stratified by patient sex were carried out. These analyses resulted in similar findings between the age groups for females but not for males.

Conclusion

Adolescent athletes, especially females, perceived enhanced self-efficacy, had a higher RTS rate and were more motivated to realize their goals 8 and 12 months after ACL reconstruction. Regardless of age, athletes who had returned to sport and athletes with symmetrical muscle function had a stronger psychological profile.

TABLE 17. Knee-related self-efficacy and psychological readiness to return to sport at 8 months and 12 months after anterior cruciate ligament reconstruction stratified by age groups

	8 months			12 months		
	Not returned to sport (n=225)	Returned to sport (n=159)	p value	Not returned to sport (n=95)	Returned to sport (n=176)	p value
Age 15-20	n=88	n=86		n=33	n=90	
Present K-SES$_{short}$	7.9 (2.8; 9.9)	9.0 (5.9; 10.0)	<0.0001	7.6 (3.1; 9.8)	8.6 (5.8; 10.0)	<0.0001
	n=88	n=86		n=28	n=79	
Future K-SES$_{short}$	7.7 (1.5; 10.0)	8.7 (4.3; 10.0)	<0.0001	7.0 (1.8; 9.5)	8.3 (1.5; 10.0)	0.0030
	n=88	n=86		n=28	n=79	
Present K-SES$_{short}$ ≥7	67 (76.1%)	82 (95.3%)	0.0005	16 (57.1%)	72 (91.1%)	0.0004
ACL-RSI	51.3 (17.5; 89.2)	68.8 (35.0; 99.2)	0.0002	39.2 (17.5; 85.0)	59.2 (17.5; 91.7)	0.0049
	n=68	n=50		n=15	n=46	
ACL-RSI > 56	29 (42.6%)	33 (66.0%)	0.020	3 (20.0%)	25 (54.3%)	0.040
Age 21-30	n=137	n=73		n=62	n=86	
Present K-SES$_{short}$	7.6 (0.0; 9.6)	8.9 (5.4; 10.0)	<0.0001	7.1 (1.4; 9.6)	8.4 (4.6; 10.0)	<0.0001
	n=137	n=73		n=57	n=78	
Future K-SES$_{short}$	7.3 (1.3; 10.0)	8.0 (3.8; 10.0)	0.0054	6.8 (1.3; 10.0)	8.0 (3.5; 10.0)	0.0009
	n=137	n=73		n=57	n=78	
Present K-SES$_{short}$ ≥7	83 (60.6%)	65 (89.0%)	<0.0001	30 (52.6%)	66 (84.6%)	0.0001
ACL-RSI	47.9 (10.0; 99.2)	60.0 (28.3; 98.3)	<0.0001	50.0 (10.0; 95.8)	59.6 (29.2; 99.2)	0.023
	n = 96	n = 53		n=41	n=48	
ACL-RSI > 56	32 (33.3%)	33 (62.3%)	0.0012	14 (34.1%)	29 (60.4%)	0.0042

For categorical variables, n (%) is presented.
For continuous variables, the median (min; max) is presented.
For comparisons between groups, Fisher's exact test (lowest one-sided p value multiplied by 2) was used for dichotomous variables and the Mantel-Haenszel chi-square test was used for ordered categorical variables.
Present K-SES$_{short}$ subscale of present self-efficacy of the short version of the Knee Self-Efficacy Scale
Future K-SES$_{short}$ subscale of future self-efficacy of the short version of the Knee Self-Efficacy Scale

7.3 STUDY III

Background

Ruptures of the ACL commonly occur with concomitant injuries to other structures in the knee, such as collateral ligaments, meniscus, bone and articular cartilage. However, few studies have studied how concomitant injuries affect the short-term likelihood of a return to a knee-strenuous sport after ACL reconstruction.

Aim

The aim was to study whether patient characteristics, concomitant injuries, and graft choice at primary ACL reconstruction can predict RTS 1 year after surgery.

Results

In all, 272 (51%) females met the final inclusion criteria. In the multivariable analyses, increased odds of RTS were found in male patients (OR, 2.58; 95% CI, 1.43-4.65; P = 0.0016) and in patients with a higher preoperative level of physical activity (OR, 1.45; 95% CI, 1.13-1.87; P = 0.0038). Moreover, younger age at the time of reconstruction was favorable for an RTS (OR, 2.32; 95% CI, 1.59-3.33; P < 0.0001). In addition, patients who did not have an MCL injury had higher odds of RTS (OR, 7.61; 95% CI, 1.42-40.87; P = 0.018), as well as patients with no meniscal injury (lateral or medial) (OR, 1.92; 95% CI, 1.10-3.36; P = 0.023). The area under the ROC curve for a multivariable model to predict RTS had a fair goodness of fit (0.78; 95% CI, 0.72-0.83) *(Figure 11).*

Conclusion

Patients of male sex, a younger age, a higher preinjury level of physical activity, and with no reported concomitant injury to the MCL or the meniscus had higher odds of returning to knee-strenuous sport 1 year after an ACL reconstruction. To set proper expectations, it is important to inform patients with concomitant injuries at the time of ACL reconstruction that RTS may not be possible during the first year after surgery.

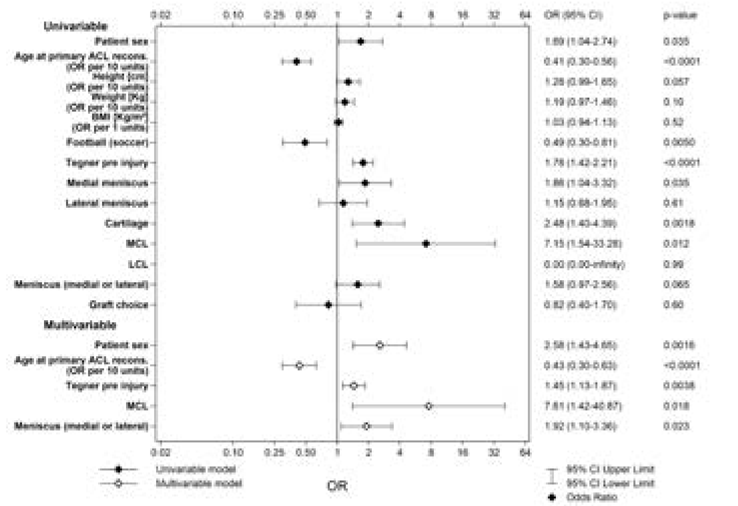

FIGURE 11 Logistic regression models, odds ratios (ORs) and 95% confidence intervals (CIs) for return to sport. An OR of > 1 indicates a result favoring the absence of concomitant injury. For age at index ACL reconstruction, an OR of > 1 indicates a result favoring older age. For graft choice, an OR of < 1 indicates a result favoring a hamstring tendon autograft, while an OR of > 1 favors a patellar tendon autograft.
BMI Body Mass Index
MCL Medial Collateral Ligament
LCL Lateral Collateral Ligament.

7.4 STUDY IV

Background

Recovering symmetrical muscle function is one of the main goals of rehabilitation after ACL reconstruction. A more symmetrical muscle function has been associated with a higher RTS rate and a lower reinjury risk. It would therefore be of clinical value to find modifiable factors early in the rehabilitation period that can predict the recovery of symmetrical muscle function prior to RTS.

Aim

The aim was to investigate whether patient demographics, short-term PROs and muscle function are able to predict the achievement of symmetrical muscle function in 5 tests of muscle function in young athletes 1 year after ACL reconstruction.

Results

Of the 237 athletes, 62 (26%) had achieved symmetrical muscle function 12 months after ACL reconstruction. None of the patient demographics could predict the achievement of symmetrical muscle function 12 months after ACL reconstruction. Increased odds of symmetrical muscle function 12 months after ACL reconstruction were found in athletes with higher present self-efficacy at 4 months; OR = 1.28 ([95% CI; 1.04-1.58], p = 0.020). Moreover, an increase in the OR was found in athletes with more symmetrical knee-extension strength, OR = 1.73 ([95% CI; 1.28-2.34], p = 0.0004), and knee-flexor strength, OR = 1.39 ([95% CI; 1.07-1.81], p = 0.015). With respect to hop tests, athletes with a more symmetrical hop performance in the vertical hop, OR = 1.77 ([95% CI; 1.27-2.45], p = 0.0006), the single-leg hop for distance, OR = 1.98 ([95% CI; 1.24-3.17], p = 0.0043), and the side hop, OR = 1.64 ([95% CI; 1.15-2.33], p = 0.0059) had increased odds of achieving symmetrical muscle function 12 months postoperatively *(Figure 12)*.

No predictive multivariable model could be created because of data missing from hop tests and the limited number of patients who had achieved the dependent outcome of symmetrical muscle function. Moreover, when excluding athletes with missing data (hop tests, n = 105) from the 3 hop tests at 4 months, a total of 166 athletes were included in the second multivariable model. No combinations of variables were significant when performing the multivariable model.

Conclusion

Symmetrical knee-extension and knee-flexion strength, a more symmetrical hop performance and higher present self-efficacy at an early stage all increased the odds of achieving symmetrical muscle function in young athletes one year after ACL reconstruction.

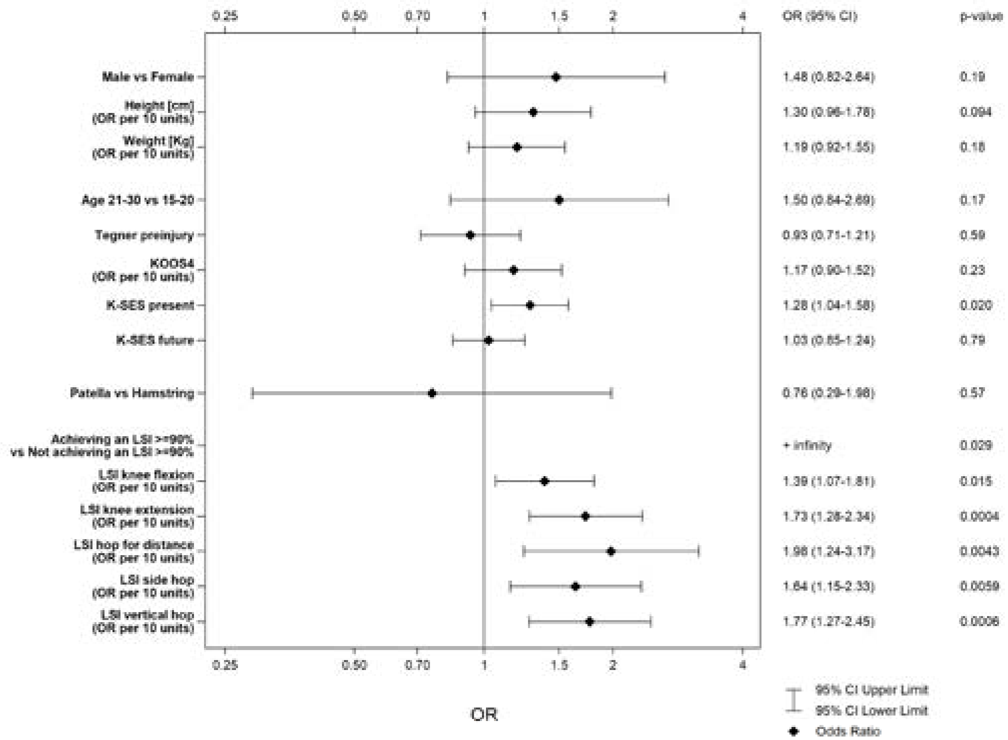

FIGURE 12 Univariable logistic regression models, odds ratios (ORs) and 95% confidence Intervals (CIs) for muscle function recovery, defined as achieving a Limb Symmetry Index of ≥ 90% in 5 tests of muscle function 12 months after an ACL reconstruction. For patient sex an OR of > 1 indicates a result favoring males. For age at primary anterior cruciate ligament reconstruction, an OR of > 1 favors the older age group (21-30 years old). For graft choice, an OR of > 1 indicates a result favoring patellar tendon autografts.
KOOS4 average score on the Knee injury Osteoarthritis Outcome Score (4 dimensions)
K-SES$_{present}$ present Knee Self-Efficacy Scale
K-SES$_{future}$ future Knee Self-Efficacy Scale
LSI Limb Symmetry Index
Tegner pre-injury Tegner Activity Scale prior to the injury

7.5 STUDY V

Background

Almost 1 in 4 patients aged 25 years or younger who return to high-risk sport will sustain a subsequent ACL injury after their primary ACL reconstruction. Recent studies have highlighted the importance of delaying RTS and achieving symmetrical muscle function prior to RTS in order to reduce the risk of a subsequent knee injury. However, it is unknown whether these variables are valid for young non-professional athletes.

Aim

The aim was to investigate the association between sustaining a subsequent ACL injury and 1) *time to RTS* and 2) *symmetrical muscle function at the time of RTS* in young athletes after primary ACL reconstruction

Results

In all, 159 (64% females) met the final inclusion criteria. A total of 18 (11%) athletes sustained a subsequent ACL injury, of which 10 were graft ruptures and 8 were contralateral ACL injuries. In the univariable analysis, increased odds of a subsequent ACL injury were found in athletes with a higher level of preinjury physical activity, HR = 2.1 [95% CI; (1.22-3.56), p = 0.0069].

A 23% risk reduction for a subsequent ACL injury was found for every month RTS was delayed, HR = 0.77 [95% CI; (0.62-0.95), p = 0.016]. Moreover, the risk of a subsequent ACL injury was reduced by 85% by delaying the return to knee-strenuous sport activities to more than 9 months. *Figure 13* shows that the rate of a subsequent ACL injury was more than 7 times higher in athletes who returned to sport before 9 months compared with athletes who returned to sport after 9 months. No effect of achieving symmetrical muscle function (p = 0.68) or extension symmetry (p = 0.61) was found on the risk of a subsequent ACL injury.

In the multivariable analysis, using a Cox proportional hazards regression model, an earlier time to RTS, HR = 0.14 [95% CI; (0.05-0.37), p < 0.0001], and higher level of preinjury physical activity, HR = 2.21 [95% CI; (1.26 -3.87), p = 0.0056], were associated with sustaining a subsequent ACL injury.

Conclusion

Returning to knee-strenuous sport earlier than 9 months after ACL reconstruction entails a markedly increased risk of sustaining a new ACL injury compared with waiting 9 months or more. Athletes who participated in high-risk pivoting sport were twice as likely to sustain a new ACL injury.

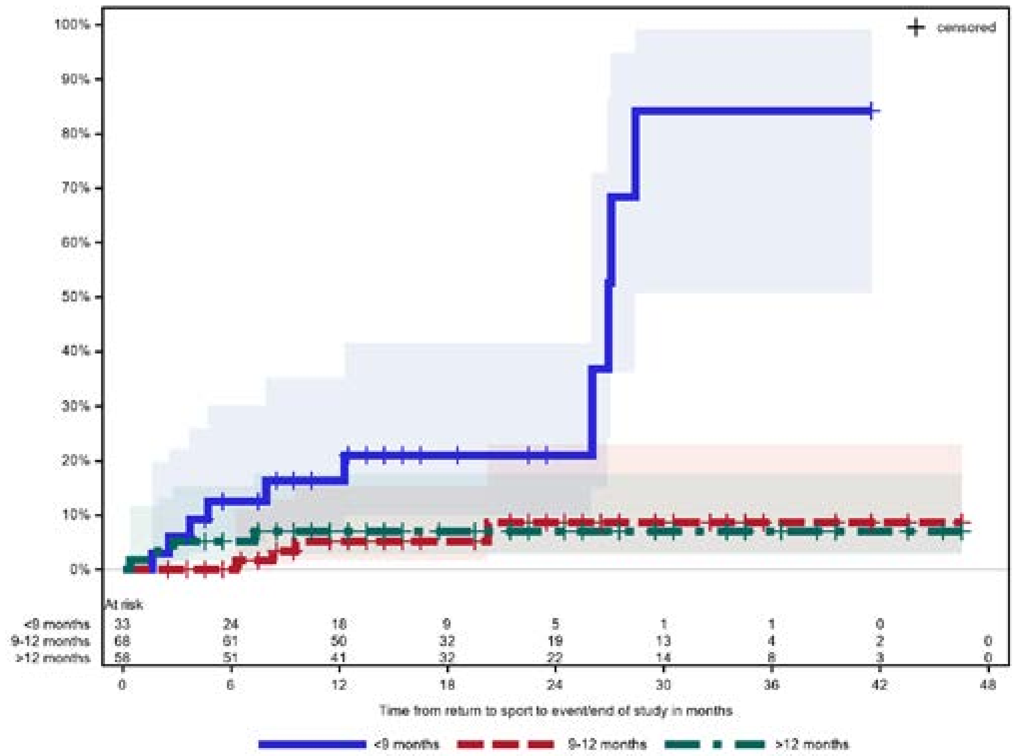

FIGURE 13 Kaplan-Meier curve showing the failure rate (rate of a subsequent ACL injury) in athletes after ACL reconstruction who returned to sport prior to 9 months, between 9-12 months, and after 12 months.

7.6 SUMMARY OF RESULTS

SYMMETRICAL MUSCLE FUNCTION

- Regardless of age, the majority (>70%) of the athletes returned to knee-strenuous sport without achieving symmetrical muscle function at 8 and 12 months after ACL reconstruction (Study I)
- More symmetrical knee strength and hop performance and higher present self-efficacy at 4 months were associated with achieving symmetrical muscle function 12 months after ACL reconstruction (Study IV)

RETURN TO SPORT

- Male sex, younger age, a higher preinjury level of physical activity and the absence of concomitant injuries to the medial collateral ligament and meniscus were found to predict RTS 12 months after ACL reconstruction (Study III)
- At 8 months, 50% of the adolescent athletes had returned to knee-strenuous sport compared with 38% of the adult athletes (Study I)

SUBSEQUENT ACL INJURY

- An early RTS was identified as a risk factor of a subsequent ACL injury. The risk of a subsequent ACL injury was reduced by 86% by delaying the return to knee-strenuous sport to more than 9 months (Study V)
- Symmetrical muscle function close to RTS was not associated with a subsequent ACL injury (Study V)
- A higher preinjury level of physical activity was found to increase the risk of a subsequent ACL injury (Study V)

PSYCHOLOGICAL OUTCOME AND SELF-REPORTED KNEE FUNCTION

- Adolescent athletes, especially females, perceived enhanced self-efficacy, had a higher RTS rate and were more motivated to reach their goals 8 and 12 months after ACL reconstruction (Study II)
- Athletes with symmetrical muscle function reported greater motivation and superior self-efficacy compared with athletes who had not recovered their knee function 8 and 12 months after ACL reconstruction (Study II)
- Younger athletes who returned to sport reported higher levels of self-efficacy and psychological readiness to RTS (Study II)
- No difference in self-reported knee function was found between adolescent and adult athletes 8 and 12 months after ACL reconstruction (Study I)

8.

DISCUSSION

SUSANNE BEISCHER

Patience you must have, my young athlete

"

The more I see the less I know for sure

— *JOHN LENNON*

The overall aim of this thesis was to describe the outcome after a primary ACL reconstruction in terms of RTS, muscle function, psychological outcome, symptoms, concomitant injuries, subsequent ACL injury and knee function in adolescent athletes, aged 15 to 20 years, and adult athletes, aged 21 to 30 years.

The results will be discussed in relation to the following topics: *symmetrical muscle function, return to sport, subsequent ACL injuries* and *self-reported knee function & psychological outcome.*

Symmetrical muscle function

The goal of achieving symmetrical muscle function is important for patients with an ACL injury, because symmetrical muscle function is associated with enhanced outcome, such as improved self-reported knee function,[51] improved hop performance [115,218] and a lower risk of subsequent knee injuries. [91,137] However, knowledge is limited when it comes to the proportion of adolescent athletes that achieve symmetrical muscle function before RTS, as well as the factors that predict symmetrical muscle function in young athletes.

In Study I, there was no difference in the proportion of athletes recovering symmetrical muscle function between adolescent and adult athletes who had returned to sport at 8 or 12 months after ACL reconstruction (8 months: 29% versus 29%; 12 months: 20% versus 24%; n.s.). Recently, Toole et al. [245] reported that only 14% of young athletes, who were cleared for unrestricted sports participation by their surgeon and treating rehabilitation specialist, actually met their study-specific RTS criteria, including an LSI of > 90% in hop and strength tests. Even though the rate of achieving symmetrical muscle function was 2 times higher in Study I compared with the study by Toole et al., [245] the results clearly demonstrate that too few patients regain what can be considered a minimum level of muscle function prior to RTS. Moreover, the results indicate that surgeons and physical therapists do not use a battery of tests to make well-founded decisions on RTS.

In accordance with previous studies, [81,91,101,241,245,260] the LSIs from the tests of muscle function in Study I and V, were ≥ 90% on average for each of the 5 muscle functions tests (Studies I and V). However, the majority of the included athletes did not regain symmetrical muscle function in all 5 tests before they returned to sport. This is worrying and emphasizes the importance of using results from a battery of tests for RTS decisions and not merely the results from a single test of muscle function. [8,239]

In this thesis, we used validated assessments for the physical therapist to use when planning rehabilitation, as well as enhancing patient motivation. Despite these strong and stringent methods, only 1 in 3 to 4 patients achieved symmetrical muscle function 8 or 12 months after ACL reconstruction. The results in the general ACL injured population are not known, but it is worrying that they may be worse. Grindem et al. [88] reported that specialized care is associated with superior outcome in patients with an ACL injury compared with a general ACL population. Therefore, it can be assumed that the regular assessment of athletes used in this thesis resulted in some benefits, e.g. providing the athletes and their responsible physical therapists with valuable information about the progress of the rehabilitation and guided them in the rehabilitation and thereby increasing the athletes' possibility to regain symmetrical muscle function.

The proportion of athletes regaining symmetrical muscle function varied between 20 and 29% in Studies I, II, IV and V. Because an association between a higher RTS rate and symmetrical muscle function has been described, [13,166] it was somewhat surprising that the athletes included in Studies I and V did not have a higher rate of regaining symmetrical muscle function compared with the athletes included in Studies II and IV. Studies I and V comprised athletes that had all returned to knee-strenuous sport compared with Studies II and IV, which included athletes who both had and had not returned to sport. The fact that only 1 in 3 to 4 athletes achieves symmetrical muscle function represents a major challenge for all physical therapists treating patients after an ACL reconstruction. In the last few years, several expert opinions and editorials have been published highlighting the need to implement current evidence into the rehabilitation after an ACL reconstruction [86,90,198] and, with respect to this, recent studies indicate that patients are being discharged too early to RTS or that they receive rehabilitation with inadequate content. [49,50] Ebert et al. [49] reported that fewer than 30% of the patients received supervised rehabilitation of more than 6 months and only about 5% received rehabilitation that followed evidence-based guidelines,[254] i.e. ≥ 9-12 months of rehabilitation, comprising agility and landing exercises, as well as a structured RTS. Moreover, an association between rehabilitation and the LSIs for each test of muscle function was reported, [49] indicating that supervised rehabilitation is important in order to regain symmetrical muscle function and be able to safely RTS. The findings reported by Ebert et al. [49] are alarming and suggest a need for action with respect to implementing current knowledge into the rehabilitation of athletes, especially in high-risk groups such as adolescent athletes. In addition, with respect to the findings in Study I, it can be strongly recommended that patients should be informed at the beginning of their rehabilitation that, in many cases, regaining symmetrical muscle function will take longer than 12 months.

Recent studies have reported an association between symmetrical muscle function and a lower risk of subsequent knee injuries. [91,137] Interestingly, Study IV found 6 modifiable predictors of symmetrical muscle function that are of clinical value, especially in young athletes who are regarded as a high-risk group with respect to a subsequent ACL injury. [5-7,45,135,217,243,256,266] The finding of an association between early strong self-efficacy and regaining symmetrical muscle function (Study IV) is in line with previous studies that have reported self-efficacy as a predictor of enhanced outcome in patients with other knee-related impairments. [27,35,150,251,270] [9,57,66,235,236]

According to the *Integrated model of response to sport injury* (page 37), it can be assumed that athletes with high self-efficacy (*thoughts*) in Study IV were more motivated to set more difficult goals and participate in and be more compliant with the rehabilitation (*behavior).* These athletes would therefore have greater potential to achieve symmetrical muscle function *(rehabilitation outcome)* compared with athletes with low self-efficacy. In addition, a higher proportion of the patients included in Study II who had recovered their muscle function achieved the acceptable cut-off value of 7 units on the K-SES$_{short}$, as well as higher levels of present self-efficacy, which further strengthens the hypothesis that there is a positive association between enhanced psychological response and symmetrical muscle function. However, the results for self-efficacy in Study IV must be interpreted with caution, as the area under the ROC curve was 0.60, indicating that the predictive capacity of this model was poor. [156]

An individual's level of self-efficacy is considered to be influenced by his/her level of effort and resilience to setbacks, among other things, [20,21] and is believed to be enhanced by master experience, social modeling and verbal persuasion, as well as the patient's emotional and physiological response, [21] which implies opportunities to strengthen one's level of self-efficacy. This topic will be further discussed on page 103.

Early predictors of enhanced outcome are valuable, as they can provide the physical therapist with valuable information and improve his/her understanding of the patients, as well as planning the rehabilitation. The finding that more symmetrical muscle strength, as well as hop performance 4 months after the ACL reconstruction, were associated with symmetrical muscle function at 12 months (Study IV) is in accordance with previous studies. [99,166] [147] However, symmetrical hop performance as early as 4 months after an ACL reconstruction must be regarded as uncommon. In Study IV, 40% of the athletes were able to perform hop tests as early as 4 months after the ACL reconstruction. This finding provides important information to clinicians as well as to patients in order to set realistic expectations during rehabilitation. These findings also highlight the fact that not all patients have a knee that tolerates hopping as early as 4 months after the ACL reconstruction. Reasons for not being able to hop might be the presence of concomitant injuries, insufficient knee strength, fear of reinjury and low self-efficacy.

An important finding relating to symmetrical muscle function in this thesis is that almost 40% of athletes that had an LSI of 80% or higher in knee-extension strength at the 4-month follow-up regained symmetrical muscle function at 12 months, compared with fewer than 10% of the athletes that had an LSI lower than 80%. This finding further indicates that it might be important to regain symmetrical knee-extension strength early in the rehabilitation period in order to enhance the short-term results after an ACL reconstruction. [51,118,148,267] [115,117,181,218] It therefore seems reasonable to help and encourage patients who demonstrate knee-extension strength lower than an LSI of 80% at an early stage through acceleration and the optimization of strength during the entire rehabilitation process.

In Study IV, no multivariable model could be created when using patient demographics, knee-extension and flexion strength and PROs (KOOS$_4$ and K-SES$_{short}$) as independent variables. This might indicate that factors other than the aspects of muscle function and self-efficacy that were investigated in this study affect the achievement of symmetrical muscle function across a battery of tests in young athletes 12 months after ACL reconstruction. Other factors might be concomitant injuries, motivation, compliance with the rehabilitation and personality. However, there was no information on the presence of concomitant injuries in Study IV. Because conflicting findings are reported in terms of the influence of concomitant injuries on symmetrical muscle function, [97,132,143] future studies are recommended to control for concomitant injuries when assessing potential predictors of symmetrical muscle function.

Finally, in order to avoid misleading results when comparing the results of different studies with each other, it is necessary that the methods used to assess, muscle strength, for example, are similar/equal. However, there is a lack of consensus in terms of the optimal strength methods to be used, as well as the appropriate criteria for releasing patients to unrestricted sports activities after an ACL reconstruction.[22,37,246] For example, the results of isokinetic tests may be affected by aspects of the isokinetic protocol, e.g. angular velocity, range of motion, number of repetitions, contraction mode and gravity correction. In Studies I, II, IV and V, an isokinetic test protocol including 3 to 5 repetitions of concentric knee extension and flexion at 90°s^{-1} was used. In a study by Undheim et al., [246] a protocol consisting of concentric/concentric mode of contraction, an angular velocity of 60°s^{-1}, 3-5 repetitions, range of motion of 0-90° and the use of gravity correction was recommended. Even though the protocol used in this thesis is slightly different it should be remembered that there is no standardized isokinetic strength evaluation protocol following ACL reconstruction and that the recommendations of Undheim et al. [246] were based on what has most frequently been reported in the literature. [246] The reason for choosing an angular velocity of 90°s^{-1} in this thesis was that patients included in Project ACL are evaluated as early as 10 weeks after their injury or ACL reconstruction, which is a time point at which the tolerance of higher loads can be limited. With respect to the force-velocity curve, 90°s^{-1} was therefore chosen, since angular velocity of 60°s^{-1}, for example, would have resulted in higher loads on the knee joint.

TAKE-HOME MESSAGES

Only approximately 25% of athletes regain symmetrical muscle function 12 months after an ACL reconstruction.

Fewer than 30% of adolescent athletes that return to sport 8 or 12 months after an ACL reconstruction regain symmetrical muscle function prior to their RTS.

No differences were found between adolescent and adult athletes in terms of the proportion of athletes that met RTS criteria 8 or 12 months after the ACL reconstruction.

Young athletes with more symmetrical knee-extension and knee-flexion strength, a more symmetrical hop performance and higher present self-efficacy, early after ACL reconstruction, have increased odds of achieving symmetrical muscle function 12 months after ACL reconstruction.

Return to sport

In a systematic review and meta-analysis, Ardern et al. [13] reported that just over 50% of patients who had undergone ACL reconstruction returned to competitive sport and two-thirds returned to their previous sport. More than 90% of the patients expect to return to their previous sport 12 months after the ACL reconstruction [62] and an RTS after 12 months might therefore be perceived as a failure. In Studies I-III, the RTS rate at 12 months varied between 57% and 67%. It is important to note that, in this thesis, RTS was defined as a self-reported Tegner level of 6 or higher, which might be different from a return to previous sport. Hamrin Senorski et al. [94] compared the definition used in this thesis with a narrower definition of RTS; return to preinjury Tegner ± 1 but over 6. The rationale for this was that the narrower definition could exclude patients who actually do return successfully to a knee-strenuous sport. In agreement with the literature,[16] the use of a return to Tegner 6 or higher resulted in an increase in the RTS rate. Regardless of which definition is used and with respect to the patients' expectations, it is important to inform all patients with an ACL injury that RTS after an ACL reconstruction may take longer than 12 months.

In accordance with previous studies, [11,13,78] male sex and having a higher preinjury level of sports participation were positive predictors of RTS (Study III). The finding that males have a higher RTS rate is also confirmed by the results in Study I, where 64% of the adolescent male athletes had returned to sport 8 months after the ACL reconstruction compared with 43% of the female adolescent athletes. Moreover, an important and novel finding in Study III was that athletes with a concomitant meniscal injury and MCL injury had decreased odds of RTS. For instance, the absence of an MCL injury resulted in a 7-fold increase in favorable odds of RTS 12 months after ACL reconstruction. The higher odds can, at least in part, be explained by the fact that only a small number of athletes had an MCL injury (n = 18), which brings uncertainty to the analyses. However, it can be assumed that athletes with both an ACL and MCL injury can experience instability of the knee joint, which may affect their ability or the time to RTS. In other words, the findings in Studies I-III indicate that at least 40% of the athletes appear to need more than 12 months before they are able to return to knee-strenuous sports, especially if a concomitant injury is present at the time of injury/reconstruction. It seems clear that it is time for us to reconsider our recommendations and expectations for the time required to RTS after ACL reconstruction.

Like previous studies,[11,13] the results of Studies I-III indicate that younger age is a positive predictor of RTS. In Studies I and II, the adolescent athletes, 15-20 years old, had a 12-14 percentage points higher RTS rate at the 8-month follow-up compared with the adult athletes, 21-30 years old. At the 12-month follow-up, no difference in RTS rate was found between the age groups in Study I (74% versus 63%). In contrast, in Study II, a significant difference was found at 12 months, where 73% of the adolescent athletes and 58% of the adult athletes had returned to sport. An explanation of the differences in RTS rate between these 2 studies could be that Study II comprised over 30% more athletes compared with Study I, indicating a type II-error. Moreover, the finding that younger age was a positive predictor of RTS at 12 months (Study III) further strengthens the conclusion that there is a difference in RTS rates between the age groups. This finding represents important knowledge for all clinicians during rehabilitation, since adolescent athletes run an increased risk of a subsequent ACL injury once they RTS. [266] In addition, as the time to RTS was associated with a higher risk of a subsequent ACL injury in Study V, clinicians are strongly recommended to prolong the rehabilitation for adolescent athletes, even if they present acceptable psychological and physiological outcomes earlier than 9 months.

TAKE-HOME MESSAGES

Adolescent athletes make an earlier RTS compared with adult athletes.

The absence of concomitant injuries to the medial collateral ligament and meniscus were positive predictors of RTS 12 months after ACL reconstruction.

Subsequent ACL injuries

If RTS is equated with success, a subsequent ACL injury, i.e. a graft rupture or an injury to the contralateral ACL, must be regarded as treatment failure. Since young athletes are found to be more prone to RTS, it is important to consider risk factors before making decisions on RTS.

In accordance with previous studies, [45,91] an association between time to RTS and subsequent ACL injuries was found in Study V. Athletes who returned to sport earlier than 9 months after ACL reconstruction had a more than 7 times higher risk of sustaining a subsequent ACL injury compared with athletes who returned to sport after 9 months. Alternatively expressed, the risk of a subsequent ACL injury was reduced by 86% by delaying the return to knee-strenuous sport activities to more than 9 months. Based on these findings, the recommendation to prolong rehabilitation to more than 9 months, especially in adolescent athletes, appears justified.

In spite of this, more than 50% of the adolescent athletes in Studies I and II made an RTS within 9 months after the ACL reconstruction. In Study V almost two-thirds of the athletes returned to knee-strenuous sport between 7 and 11 months. As the time to RTS is a modifiable factor, we need to understand why athletes make an early RTS. It is somewhat surprising that as many as two-thirds of the athletes had returned to sport when only 24% of the athletes in Study V met the RTS criteria. Worryingly, the explanation of an early RTS is most probably related to the athlete, as well as to the responsible physical therapist and/or orthopedic surgeon, who may not have used results from a battery of tests to make well-founded RTS decisions. For instance, an individual's personality and behavior appear to explain differences in RTS rate to a large extent. Tjong et al. [244] reported that patients who had returned to sport perceived themselves as being self-motivated, competitive and self-aware. In contrast, patients who did not RTS perceived themselves as cautious, having a relaxed life outlook, being procrastinators or lacking self-confidence. [244] It can therefore be assumed that patients who RTS are more prone to take risks compared with athletes not returning to sport. In addition, the adolescent period of life is known as a period that entails increased risks in general [197,205] and this might partly explain why this age group has a higher RTS rate and accordingly a higher subsequent ACL injury risk. However, knowledge related to individuals' personality and behavior with respect to time to RTS and subsequent ACL injury is limited and needs further evaluation.

The optimal timing of RTS is not known, which is reflected in a study that aimed to investigate views and practices of Australian therapists on rehabilitation and RTS after ACL reconstruction.[50] In all, about 20% and just over 50% of the therapists were willing to discharge patients for sport at 6-9 and 9-12 months respectively and about 25% preferred 12-18 months after ACL reconstruction.[50] Based on knowledge of the biological and functional recovery of the knee, Nagelli and Hewett [165] suggested that the RTS should be delayed until 2 years after an ACL reconstruction in order to lower the rate of a subsequent ACL injury in young athletes. This suggestion might be accurate; however, previous studies have clearly demonstrated that a long period of rehabilitation after ACL reconstruction is mentally and emotional challenging. [46,100] For instance, Heijne et al. [100] reported that patients perceived the rehabilitation period as being much longer than they had imagined before the ACL reconstruction. Feelings of frustration and loss of confidence in the rehabilitation process were commonly reported when the expected time of RTS was not reached. [100] Lack of patience appears to be a reasonable explanation of why adolescent athletes RTS too early after an ACL reconstruction, which underlines the importance of setting and modifying expectations and goals during the entire rehabilitation.

The use of only a time criterion to determine unrestricted sports participation is not enough.[8,37] Since an objective criterion-based RTS decision is recommended, [8,239,254] the athletes in this thesis were evaluated using a battery of muscle function tests, including both knee-strength and hop tests. In the light of the results of Study I and previous work by Toole et al. ,[245] where adolescent athletes were found to RTS without achieving symmetrical muscle function, we wanted to investigate the association between symmetrical muscle function close to RTS and a subsequent ACL injury. However, no association between symmetrical muscle function and a subsequent ACL injury was found in Study V which is in accordance with a recent publish study.[116] In contrast, Kyritsis et al. [137] reported a 4-fold higher risk of a subsequent ACL injury in patients who did not meet their RTS criteria prior to RTS. The apparent differences between Study V and the study by Kyritsis et al. [137] can be attributed to the fact that the latter only included male elite athletes and the use of different batteries of muscle function tests. Another explanation could be that only 18 athletes in Study V had sustained a subsequent ACL injury and a small proportion, about 25%, of all the included athletes regained symmetrical muscle function, resulting in a fairly small population.

In accordance with the findings in Study V, Grindem et al. [91] did not find a difference in reinjury rate between patients who met their specific RTS criteria and patients who did not. However, in contrast to the results in Study V, Grindem et al. [91] reported that more symmetrical knee-extension strength was associated with a reduction in the risk of a knee-related reinjury. [91] The discrepancies in results in terms of knee-extension symmetry between these studies include the fact that the athletes in Study V were approximately 3 years younger and had, at group level, regained an LSI of ≥ 90% in knee-extension strength. In the study by Grindem et al., [91] the corresponding LSI was 75% in patients who had sustained a knee-related reinjury, e.g. an injury to the meniscus, cartilage or the collateral ligaments. The higher LSI seen in the athletes in Study V might have been protective of a subsequent ACL injury.

Despite the fact that no association was found between symmetrical muscle function and a subsequent ACL injury in this thesis, clinicians are strongly recommended to help and encourage patients to regain symmetrical muscle function after an ACL reconstruction. The reason for this recommendation is that more symmetrical muscle function has been reported to be associated with enhanced short- and long-term outcomes. [43,115,117,177,218] The findings in Study II, where athletes with symmetrical muscle function reported a stronger psychological profile and had a higher RTS, further strengthen this recommendation. In addition, as promising results with respect to secondary prevention have been reported, [19,262] all patients should be encouraged to continue to perform specific prevention, including strength, hop and neuromuscular exercises, regularly as part of their training once they finish their rehabilitation.

The total rate of a subsequent ACL injury of 11% for younger athletes in Study V was lower than the 23-36% rate that has been reported in the literature. [45,256,266] One explanation could be that the athletes in Project ACL were repeatedly assessed with tests of muscle function and PROs, which might have provided the athletes and their responsible physical therapists with valuable information about the progress of the rehabilitation and guided them in the RTS decision. An enhanced outcome after an ACL reconstruction is believed to be achieved by following structured and progressive pre- and postoperative rehabilitation programs, [88,198] combined with clear goal-setting, detailed patient information and consistently measuring the progress of rehabilitation.[86,90,184,198]

TAKE-HOME MESSAGES

Athletes who RTS early and have a high pre-injury level of physical activity run a high risk of sustaining a subsequent ACL injury.

The risk of a subsequent ACL injury was reduced by 86% by delaying the return to knee-strenuous sport activities to more than 9 months.

Self-reported knee function and psychological outcome

Study I was the first study that compared self-reported knee function between adolescent and adult athletes who had undergone ACL reconstruction. There was no difference in symptoms, knee function or quality of life, as measured with the KOOS, between the adolescent and adult athletes 8 and 12 months after the ACL reconstruction. At group level, all the included athletes reached what has been described as a level of recovery[23,182] 12 months after ACL reconstruction for all the KOOS subscales except for the knee-related quality of life subscale. The athletes included in Study I reported more than 20 points lower scores at both the 8- and the 12-month follow-ups compared with the scores regarded as an acceptable level on the quality of life subscale.[23] An acceptable level is defined as the lower threshold for the 95% CI of 18- to 34-year-old males based on a published Swedish reference population. [182] The finding of lower levels of quality of life might indicate a negative psychological response to the injury, the reconstruction, or the rehabilitation in these athletes. Even though no previous study has investigated the psychological response in adolescent patients, adults with a lower level of self-efficacy prior to the ACL reconstruction have been described as reporting lower levels of quality of life at 12 months. [236] In addition, lower levels of quality of life have been reported to be associated with failure to RTS, a higher BMI, greater fear of reinjury, sustaining a subsequent ACL injury and severe radiographic OA. [63,64,83,134] Therefore, in Study II, we aimed to investigate the psychological response in both adolescent and adult athletes.

The finding of higher self-efficacy and psychological readiness to RTS in athletes (15-30 years of age) who had returned to sport compared with athletes who had not returned to sport in Study II confirms previous findings reported in older patients. [10,12,14,59,78,94,134,191,208,236,244,259] Irrespective of whether the athletes were adolescent or adult, patients who had returned to sport reported higher levels of psychological readiness to RTS and stronger self-efficacy, which implies that the relationship between RTS and a more positive psychological response seems true in adolescent athletes. However, as the outcome (psychological response) and exposure (RTS) were assessed at the same time, no causal conclusion can be drawn.

To date, one previous study[237] has investigated the effect of strengthening a patient's level of self-efficacy during the rehabilitation in order to enhance outcome after an ACL reconstruction. Thomeé et al. [237] presented a clinical model based on the assumption that an individual's level of self-efficacy is influenced by his/her level of effort, persistence, resilience to setbacks, master experience, social modeling and verbal persuasion, as well as by his/her emotional and physiological response. [20] [21] The model has 4 stages, *understanding, maturity, persistence* and *coping,* and comprises elements of giving information, challenging, increasing variety and complexity, evaluating and giving feedback and giving support and encouragement. [237] The model is intended to be implemented during rehabilitation with the aim of guiding physical therapists gradually to enhance patients' knee-related self-efficacy after an ACL reconstruction. The model was evaluated in an RCT, which included 24 patients with an acute ACL injury randomized to 1 intervention and 1 control group, each comprising 12 patients. No effect of the model on patient-reported knee function was found, however, and this could be explained by the fact that the study was underpowered. Larger RCTs are therefore needed to further investigate this topic.

The finding of higher levels of self-efficacy in adolescents is novel. [235] However, since an association between self-efficacy and RTS was found in both adolescent and adult athletes (Study II), we cannot exclude the possibility that the difference in self-efficacy between age groups is explained by the higher RTS rate found in the adolescent athletes. Moreover, as symmetrical muscle function appears to be associated with self-efficacy (Study II), the differences in self-efficacy could also be explained by differences in the proportions of athletes who had achieved symmetrical muscle function. Since a small number of athletes had regained symmetrical muscle function, a comparative analysis between age groups stratified by symmetrical muscle function (yes/no) would have been underpowered and was therefore not performed. However, the findings in Study I indicate that there is no difference between adolescent and adult athletes in regaining symmetrical muscle function 8 and 12 months after an ACL reconstruction. Nevertheless, the findings of differences in self-efficacy between the age groups should be interpreted with some caution, as the differences were small and no information in terms of the MIC in the K-SES$_{short}$ is available.

According to the *Integrated model of response to sport injury* (page 37), a patient's functional outcome, e.g. muscle function, has a considerable influence on behavior, cognition and affective status after ACL reconstruction. [264] In Study II, we compared psychological readiness to RTS, self-efficacy and motivation between athletes who had and had not regained symmetrical muscle function. Previous findings,[236] as well as the result from Study IV, where an association between self-efficacy and regaining symmetrical muscle function was found, strengthen the finding in Study II of greater self-efficacy in athletes who had regained symmetrical muscle function. However, as with the association between the psychological outcome and RTS, we are unable to determine whether athletes regain symmetrical muscle function because of higher levels of self-efficacy or whether symmetrical muscle function causes higher levels of self-efficacy. Nevertheless, as symmetrical muscle function appears to be associated with a stronger psychological profile and a higher RTS rate, it is advisable to encourage all athletes to regain their muscle function before RTS.

In the light of this, it can be assumed that athletes with high self-efficacy will be more motivated to and will RTS regardless of whether or not they are physically and/or psychologically ready. Interestingly, besides higher levels of self-efficacy, the adolescent athletes reported greater motivation to realize their goal, a finding that not was seen in the adult athletes. This finding supports the idea that greater motivation to RTS is an important contributory factor to RTS [59,191] and may explain why adolescent athletes have a higher RTS rate (Studies I-III). Moreover, athletes who RTS before 9 months were found to run a substantially higher risk of a subsequent ACL injury (Study V) and it is not known whether the level of motivation and self-efficacy could contribute to a subsequent ACL injury. Recently, it was reported in a study by McPherson et al.[153] that younger (<20 years) patients who sustained a subsequent ACL injury had less psychological readiness to RTS before they returned to sport compared with patients who did not sustain a subsequent ACL injury. [153] However, this was the first study including a psychological outcome as an explanatory variable for a subsequent ACL injury and this topic therefore needs further investigation.

In contrast to self-efficacy, no difference in psychological readiness to RTS, as measured with the ACL-RSI scale, was found between age groups or between athletes who had and had not recovered their muscle function. However, despite the fact that 49% of the adolescent athletes had returned to sport 8 months after ACL reconstruction, only about two-thirds reached the cut-off of > 56 points, which has been associated with higher odds of returning to the preinjury level of sport, compared with patients reporting < 56 points. [14] Based on the study by McPherson et al., [153] a cut-off value of 76.7 points at 12 months after the ACL reconstruction was found to identify younger patients who sustained a second ACL injury, with 90% sensitivity. In the light of this finding, the cut-off value of 56, used in Study II, can be regarded as low. In Study II, the median value of the ACL-RSI varied between 55.0 and 63.8 points at the 8- and 12-month follow-ups. In patients who had regained symmetrical muscle function, 74% reached the cut-off of > 56 and the median of the ACL-RSI was 74.2. All the findings with respect to the ACL-RSI scale imply that the majority of the included athletes in Study II, irrespective of age, were not psychologically ready to RTS. Even though no differences in psychological readiness to RTS were found between athletes who had and had not achieved symmetrical muscle function, athletes with symmetrical muscle function reported the highest score on both the K-SES$_{short}$ and the ACL-RSI scale. Reasons why no differences between groups were significant may include the small number of athletes who had recovered their muscle function and had completed the ACL-RSI scale at 8 and 12 months after ACL reconstruction (8 months, n=44; 12 months, n=35). This topic therefore needs to be further evaluated in future studies.

TAKE-HOME MESSAGES

Adolescent athletes, especially females, perceived enhanced self-efficacy, had a higher RTS rate and were more motivated to realize their goals 8 and 12 months after ACL reconstruction (Study II).

Athletes with symmetrical muscle function reported greater motivation and superior self-efficacy compared with athletes who had not recovered their muscle function 8 and 12 months after ACL reconstruction (Study II).

Younger athletes who returned to sport reported higher levels of self-efficacy and psychological readiness to RTS (Study II).

No difference in symptoms, knee function and quality of life, was found between adolescent and adult athletes 8 and 12 months after ACL reconstruction (Study I).

9.

STRENGTHS AND LIMITATIONS

SUSANNE BEISCHER

Patience you must have, my young athlete

This thesis includes cohort studies based on register data. As a result, conclusions on causality cannot be drawn. In order to prove causality, it is necessary to perform an interventional study and control for bias.

Since this thesis was based on data from the rehabilitation register, Project ACL, there was no control of either the rehabilitation program or the RTS criteria used to clear the athletes to RTS. In other words, the rehabilitation each athlete received was individualized by his/her responsible physical therapist.

It is important to realize that this thesis only covers a limited number of possible outcomes after an ACL reconstruction. With respect to the ICF (page 33), the included outcomes cover both parts, i.e. *Functioning* and *Contextual factors*. However, several other outcomes, such as ligament laxity, quality of motion, speed and biomechanical outcomes, are described in the literature but were not included in this thesis. Another outcome, often not included in the rehabilitation of patients with an ACL injury, which probably requires more attention in future studies, is endurance, e.g. maximum oxygen uptake capacity. Moreover, no outcomes related to the ICF component of *Environmental factors*, i.e. circumstances in which the individual lives, such as support and relationships, attitudes and natural environment, were not included in this thesis.

This thesis did not cover long-term outcomes, which often refer to evaluations more than 10 years after an event. An important question to answer is: does a successful short-term result really matter if the athletes suffer from OA and/or reduced quality of life 10 years after the ACL reconstruction? To date, only a few studies[174,175,268] have specifically investigated OA and quality of life in athletes who underwent an ACL reconstruction before the age of 30. Moreover, this thesis did not include athletes treated with rehabilitation alone. Not including non-reconstructed athletes means that no comparisons can be made between non-reconstructed and reconstructed athletes. Since only 1 previous RCT study has compared ACL reconstruction in combination with rehabilitation with rehabilitation alone, there is a real need for more RCTs of this kind in the future.

Tests of muscle function

Several different tests to assess patients' knee strength have been described in previous studies.[1,81,121,126,210,246] Isokinetic muscle strength tests, which are regarded as the gold standard,[246] evaluate muscle strength during constant velocity compared with isometric tests in which no movement occurs. With respect to the force-velocity curve, an isometric test will therefore result in higher measured muscle forces compared with an isokinetic test.[34,44,98,126]

One limitation of this thesis is that between 9% and 35% of the athletes in Studies I, II, IV and V were assessed with isometric strength tests, while the other 65% to 91% were assessed with concentric isokinetic tests. Only using results from the isokinetic tests would have resulted in underpowered studies. We therefore decided to include athletes who had all been assessed with isometric tests, from the first 1.5 years of Project ACL. As a result, no absolute value for each test could be used in the statistical analysis and the results were therefore presented as the LSI. With respect to previous studies demonstrating a high to moderate correlation between isometric and isokinetic tests of knee extension, [98,126] it can be assumed that the use of results from the isometric and isokinetic tests had no or only a minor influence on the conclusion drawn in Studies I, II, IV and V. Furthermore, the test protocol used in Project ACL for assessing isometric and isokinetic tests was not equal to the protocols used in the studies comparing the results of isometric tests with the results of isokinetic tests, which might somewhat limit our assumption that there are no differences in LSI between the test methods. In addition, Knezevic et al. [126] reported somewhat lower correlations when comparing LSIs in relation to absolute values. This finding indicates one of the limitation of LSIs, which will be discussed further below.

Limb Symmetry Index

In a recently published study, [260] the use of the LSI in RTS decisions was questioned, as LSIs appear to overestimate knee function after ACL reconstruction and might not be sensitive enough to predict a subsequent ACL injury. Furthermore, lower absolute levels of muscle function in the uninvolved leg might conceal an abnormal muscle function, since the LSI is calculated as a ratio between the injured and the uninjured leg. For instance, Hiemstra et al.[109] reported that deficits in strength are common in both legs after ACL reconstruction. [108,241] The LSI may therefore not be the best clinical benchmark to use. [79,109]

The limitation with LSIs can be easily understood when illustrated theoretically in the following way. Imagine a patient who, in a follow-up, in the single-leg hop for distance, jumps 111 cm on the injured leg and 118 cm on the uninjured leg. These results will give an LSI of 94%, which would be equal to “meeting the criteria” in most RTS protocols. However, if the test is repeated the day after and the patient still performs a hop within the methodological error of approximately 4 cm [195,209,241] and now jumps 107 cm on the injured leg and 122 cm on the uninjured leg, he or she will achieve an LSI of 88%, which would have been regarded as “not meeting the criteria” in this thesis. This theoretical illustration reflects that a small change in absolute values can have a large effect on the LSI and, secondly, affect whether the patient is considered to have met or not met the RTS criteria. It is therefore always important to consider the methodological error in an RTS decision or when the results of repeated measurements are interpreted and compared with one another. In addition, since the LSI is only a ratio, a patient that jumps 80 cm on the injured leg and 82 cm on the uninjured leg, representing an LSI of 98%, will be defined as meeting this criterion, compared with a patient

jumping 160 cm on the injured leg and 180 on the uninjured leg (LSI = 89%). The question is whether the patient who jumps 80 cm will be better off compared with the patient who jumps 160 cm.

In a perfect world, individual preinjury reference values for all patients would provide valuable information in order to set rehabilitation goals and enable comparisons with the uninjured leg. Several studies have reported normative values,[44,167,201] but even if age, sex, and sports-matched normative values for knee-muscle strength in a healthy population might provide a better understanding of normal variation and the interpretation of muscle function results than LSIs, it will still be necessary that studies use the same method. Moreover, quadriceps strength, in absolute values, normalized to body mass, has been reported to be a stronger predictor of high self-reported function compared with the LSI of knee-extension strength in patients after an ACL reconstruction. [133,188] For instance, patients with a quadriceps strength normalized to body mass at 3.1 $Nmkg^{-1}$, as measured with an isometric test at 90° of knee flexion, were found to have more than 8 times higher odds of reporting high self-reported knee function more than 6 months after ACL reconstruction. [188] This finding suggests that achieving 3.1 $Nmkg^{-1}$ might be a more important clinical benchmark for knee-extension strength compared with an LSI of ≥ 90%. However, it is important to remember that no corresponding cut-off value has been reported for concentric isokinetic tests.

9.1 STUDY-RELATED LIMITATIONS

Study I

The main limitation of this study includes the definition of RTS. The Tegner score only reflects how knee strenuous the sports in which the patients participated are. Data relating to exposure, i.e. the frequency of participation, or whether the participation in sport was modified or equal to unrestricted training/competition, were not available. In addition to the limitation of using the Tegner, as well as the 2 tests of muscle strength, the adolescent athletes comprised more women than men compared with the adult athletes. Subgroup analyses stratified by age group were therefore performed. However, no differences between the sexes in any of the outcomes were found. The uneven distribution of patients’ sex in the different age groups was therefore assumed not to limit the opportunity to draw conclusions. However, the number of athletes who performed the battery of tests was somewhat low and these sub-analyses might therefore be underpowered.

Study II

The methodological limitations of Study II included the differences in patient demographics between the adolescent and the adult athletes at both the 8- and the 12-month follow-ups. However, demographic differences are not unexpected between adolescents and adults. In spite of this, further studies are required to investigate whether the differences in demographics between adolescents and adults are able to explain differences in psychological outcome. Moreover, the athletes excluded at the 12-month follow-up had a slightly higher physical activity level compared with the included athletes. This finding may have a minor effect on the generalizability of the conclusion drawn from the 12-month follow-up. A post-hoc sample size analysis with 80% power revealed that 45 athletes per group were needed to detect a significant difference in the ACL-RSI scale of 12 units. Future studies with larger populations are therefore needed. Even though a large population was included, only about one-fifth of the athletes had recovered their muscle function at the follow-ups. This fact, together with the missing data for the ACL-RSI scale, may have resulted in too small a number of athletes being included in the analyses of psychological readiness. Moreover, considering all the sub-analyses that were performed in Study II, the risk of false positives and negative outcomes cannot be excluded.

Another limitation of Study II can be that a shorter version of the K-SES was used. Even though the shorter version shows the same, or even better, measurement properties, including reliability, structure and validity, these data are so far unpublished. Compared with the original version of the K-SES, the shorter version included patients from the age of 11 implying that the K-SES_{short} is also valid for individuals younger than 16 years of age. Finally, the Swedish version of the ACL-RSI has not been evaluated for measurement properties for individuals younger than 18 years of age. [136] Since patients as young as 15 years were included in the present study, some of the items within this questionnaire may have been too difficult for the adolescents to comprehend. However, Webster et al. [259] used the ACL-RSI scale in individuals as young as 14 years of age and no reports of any problems when using the questionnaire in this population were made.

Study III

The limitations of Study III include the fact that the reference group in the univariable analyses comprised all the included athletes who did not have the concomitant injury of interest. As a result, the analyses may be biased, as the reference group may have included athletes with other concomitant injuries. For instance, in the univariable analysis of the association of meniscal injuries with RTS, the reference group, i.e. athletes without meniscal injuries, may have included patients with a concomitant cartilage injury who might have similar, equal, or even larger limitations. As a result, the results for the reference group might be misleading and might have resulted in an underestimation of the association with an additional injury. Moreover, no account was taken of the potential differences in localization and the severity or the potential differences in the surgical and rehabilitation treatment of the injury of interest and this could potentially bias the results. Finally, for some of the predictors, only a small number of athletes were represented in some variables, e.g. LCL injury (n=1) and PT autografts (n=34), which may have limited the ability to draw conclusions, with regard to concomitant injuries and their association with RTS.

Study IV

The most important limitation of Study IV, apart from the methods for assessing and reporting the results of the muscle function tests, included the fact that only a minority of the athletes who performed the tests of muscle function were able to perform all 3 hop tests at the 4-month follow-up and this resulted in an overly small population and, as a result, a multivariable model could not be created. Moreover, as in Study II, a shorter version of the K-SES was used. Since the results of measurement properties, in this shorter version, have not until now been known to others than our research group, the possibility to interpret the results can be limited.

Study V

The methodological limitations of Study V included the fact that only about 50% of the athletes who responded to the study-specific questionnaire had attended a follow-up of muscle function close to RTS, resulting in 159 athletes, with 18 subsequent ACL injuries, which can be considered as a minimum of events in a multivariable model. Moreover, as data relating to the time to RTS were collected retrospectively, there is a risk of recall bias. Like Study I, data relating to exposure were lacking, i.e. the frequency of participation, or whether the athlete participated in modified or unrestricted training/competition. However, no consensus on how to define RTS exists and the definition varies across studies. [13,94] Future studies are therefore recommended to include exposure of the definition of RTS. Finally, the present study did not account for other factors that might further explain the risk of a subsequent ACL injury, such as differences in rehabilitation protocols, surgical techniques of ACL reconstruction, the treatment of concomitant injuries, contextual and social factors, or psychological factors.

10.

CONCLUSIONS

SUSANNE BEISCHER

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SYMMETRICAL MUSCLE FUNCTION

- The majority of young athletes make an early return to knee-strenuous sport after a primary ACL reconstruction, without recovering their muscle function.
- In order to set realistic expectations and goals, clinicians are recommended to ensure that young athletes receive information about not returning before muscle function has been recovered and that this may take longer than 12 months.
- Symmetrical knee-extension and knee-flexion strength, a more symmetrical hop performance and higher present self-efficacy at an early stage all increased the odds of achieving symmetrical muscle function in young athletes 1 year after ACL reconstruction.

RETURN TO SPORT

- Patients of male sex, a younger age, a higher preinjury level of physical activity, and with no reported concomitant injury to the MCL or the meniscus had higher odds of returning to knee-strenuous sport 12 months after an ACL reconstruction.
- To set proper expectations, it is important to inform patients with concomitant injuries at the time of ACL reconstruction that RTS may not be possible during the first year after surgery.

SUBSEQUENT ACL INJURIES

- Returning to sport earlier than 9 months after an ACL reconstruction entails a markedly increa-sed risk of sustaining a new ACL injury compared with waiting more than 9 months.
- Athletes who participated in high-risk pivoting sport were twice as likely to sustain a new ACL injury.

PSYCHOLOGICAL OUTCOME

- Regardless of age, athletes who had returned to sport and athletes with a symmetrical muscle function had a stronger psychological profile.
- Adolescent athletes, especially females, perceived enhanced self-efficacy, had a higher RTS rate and were more motivated to realize their goals after ACL reconstruction.

REHABILITATION RECOMMENDATIONS FOR YOUNG ATHLETES BASED ON PREVIOUS RESEARCH

- Perform regular assessments of muscle function and psychological outcome [86,90,254]
- Set realistic goals and expectations during the entire rehabilitation [86,90]
- Base an RTS decision on the results of a battery of muscle function tests and psychological patient-reported outcomes (e.g. the ACL-RSI scale or the K-SES) and not merely on a single test [8,239,254]
- Encourage patients to continue performing specific prevention exercises regularly as part of their training once they finish their rehabilitation [17,19]

FURTHER REHABILITATION RECOMMENDATIONS FOR YOUNG ATHLETES BASED ON THIS THESIS

- Inform all athletes that, in many cases, regaining symmetrical muscle function across a battery of tests, as well as regaining an acceptable level of psychological outcome, will take longer than 12 months after an ACL reconstruction
- Focus on optimizing knee-extension strength during the entire rehabilitation process and especially in athletes who have a strength deficit of more than 20% in knee extension early after ACL reconstruction
- Prolong the rehabilitation period to more than 9 months and preferably to more than 12 months, especially for adolescent athletes, even if they present an acceptable psychological and physiological outcome at an early stage
- Implement current knowledge of rehabilitation after an ACL reconstruction into clinical practice, especially in high-risk groups such as adolescent athletes

11.

FUTURE PERSPECTIVES

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”

You should always take the best from the past, leave the worst back there and go forward into the future

— BOB DYLAN

Despite the large number of publications related to outcomes after an ACL reconstruction, several questions remain to be answered. This thesis provides novel knowledge with regard to adolescent athletes. In spite of this, we do not fully understand why as many as a quarter of adolescents sustain a subsequent ACL injury within the first years after their RTS. In order to develop evidence-based rehabilitation guidelines and RTS criteria for patients after an ACL reconstruction, there is a need to find and better understand the outcome measurements that will provide the most accurate and adequate information. These outcomes should ideally cover every component of an ACL injury, from symptoms, muscle function and RTS to personal and environmental factors. Further investigation of these components could help researchers to reach consensus about test protocols and RTS criteria.

To enhance the planning and content of the rehabilitation protocol, there is a need for a better understanding of how physiological outcome, such as symptoms and muscle function, and psychological outcome, such as self-efficacy and psychological readiness to RTS, change during the first year after an ACL reconstruction. The finding in this thesis that athletes did not achieve symmetrical muscle function to a greater extent at 12 months compared with athletes at 8 months indicates that knee strength and hop performance between 8 and 12 months do not improve sufficiently. If this finding is confirmed in future studies, the question is still why? Are we providing rehabilitation programs with insufficient content? Or is this lack of improvement in strength and/or hop performance a result of the fact that the frequency of high-load strength-training sessions are reduced in favor of the introduction of more low-load sport-specific exercises, such as cutting and jumping, and gradual sports participation? Nevertheless, future studies are needed to focus on a comparison between different rehabilitation protocols with the aim of delineating evidence-based guidelines after an ACL reconstruction, especially in adolescent athletes.

This thesis was the first to investigate psychological outcomes in adolescent athletes in relation to RTS and muscle function recovery. Recently, an association between psychological readiness and a subsequent ACL injury was reported, indicating that the search for answers explaining the high rate of subsequent ACL injuries in adolescents may need to be more widespread. It appears to be important to continue the novel example of inter-professional research that was presented in Study III, as well as in recent studies by Hamrin Senorski et al., [96,97] for example. Professions, other than orthopedic surgeons and physical therapists, such as sport psychologists, physiologists and social scientists, might all be able to contribute.

In the rehabilitation register, Project ACL, 86% of patients with an ACL injury undergo an ACL reconstruction in combination with rehabilitation. In Sweden, the corresponding proportion is roughly estimated to be 50%, indicating that the selection of treatment varies within different clinics, facilities, regions, hospitals and so on. We therefore need better criteria to determine whether a patient should be treated with an ACL reconstruction and rehabilitation or with rehabilitation alone. To date, our knowledge of who will and who will not benefit from each treatment is limited. To improve our understanding of both treatment options, there is a need to investigate outcomes related to muscle function, RTS, psychological factors, osteoarthritis and quality of life, for example.

Moreover, studies with a sufficient number, 400-500, of patients, thereby providing greater power, are required to produce reliable results about rare events, such as a subsequent ACL injury and muscle function recovery, to confirm the findings in this thesis and further investigate predictors and whether there are differences between age groups and sexes, for example. The findings could then be used to understand whether adolescents and adults need different rehabilitation protocols and criteria.

Even if the answers to all our questions for future research could be found, the major challenge of implementing the knowledge into clinical practice still remains. This thesis has provided new rehabilitation recommendations after ACL reconstruction for adolescent athletes. If this knowledge only stays within the covers of this book and is not spread to the sports medicine and sports communities, it will be worthless. The best way of implementing new knowledge into clinical practice is a challenge for future work. Although many questions remain to be answered, I truly believe that we can all learn from the current evidence and already today take the first steps towards more evidence-based practice.

12.

ACKNOWLEDGEMENT

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”

We are only as strong as we are united, as weak as we are divided

— *J.K. ROWLING*

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Unit of Physiotherapy, Institute of Neuroscience and Physiology, The Sahlgrenska Academy

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The Virdhall/Anderson family

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Sara & Per-Henrik Beischer

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Gun & Ingvar Pettersson

My beloved parents. I am deeply grateful to you for always being here, for me and my family, through ups and downs. Without your support I would neither have managed everyday life nor finished this thesis. Mother, special thanks for your phone calls, supporting words and all the help with the kids. And thank you, father, for finding small practical projects for me when "too much writing has been a weariness of my flesh". I am going to continue to write, so just give me a call whenever you need help moving a pile or something like that!

Oda

The apple of my eye and beloved daughter. Your courage and all your struggles inspire. With your super powers, you will be able to become and do exactly what you dream of. Oda, if I can, then you can. Thank you for all the walks we have taken and will take, for sharing your "spot-on" thoughts and reflections and because you are you. "You are not alone." Love you the most!

Frank

My treasure and beloved son. Thanks for all the hugs, your boundless love and your wise reasoning. You have a will of steel. Use it and you will reach your goals! Looking forward to continuing to play music and chess with you, build LEGO and chop lots of firewood. This summer, let's go for a hike, just you and me! Love you to the moon and back!

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13.

APPENDICES

SUSANNE BEISCHER

Patience you must have, my young athlete

GÖTEBORGS UNIVERSITET

Sahlgrenska Universitetssjukhuset

SVENSKA KORSBANDSREGISTRET

PROJEKT KORSBAND

Tegner - Fysisk aktivitet

Före skada

Klicka på den **högsta** nivå när det gäller ansträngning/påfrestning på ditt knä,
som du ansåg dig vara på i samband med arbete, motionsidrott eller aktiv idrott **före din knäskada**.

Finns inte din idrott eller ditt arbete med på skalan så försök värdera och likställ det emot något av alternativen.

Motionsidrott – idrott "bara för skojs skull" **Aktiv idrott** – Regelbunden tävling och träning

10	**Aktiv idrott**	Akrobatik, Am fotboll, Brottning, Fotboll på högsta elitnivå, Konståkning, Rugby
9	**Motionsidrott**	Akrobatik, Am fotboll, Brottning, Konståkning, Rugby
	Aktiv idrott	Fotboll, Ishockey, Puckelpist
8	**Motionsidrott**	Puckelpist
	Aktiv idrott	Backhoppning, Basketboll, Budo, Handboll, Innebandy, Längdhopp, Squash, Trestegshopp
7	**Motionsidrott**	Backhoppning, Basketboll, Budo, Fotboll, Handboll, Innebandy, Ishockey, Längdhopp, Squash, Tresteg
	Aktiv idrott	Badminton, Höjdhopp, Stavhopp, Tennis, Utförsåkning, Volleyball
6	**Motionsidrott**	Badminton, Höjdhopp, Ishockey, Stavhopp, Tennis, Utförsåkning, Volleyball
	Aktiv idrott	Bandy, Baseball, Hinderlöpning, Häcklöpning, Orientering, Telemark skiing, Snowboard
5	**Arbete**	Tung verkstad, Brandman, Militär, Skogsarbetare
	Motionsidrott	Bandy, Baseball, Orientering, Telemark, Snowboard
	Aktiv idrott	Boxning, Brännboll, Diskus, Fallskärmshopp, Fäktning, Gymping, Kulstötning, Längdskidor, Motorcross, Motionsspårlöpning, Slägga, Speedway, Spjut, Tyngdlyftning, Vattenskidor
4	**Arbete**	Bonde, Polis, Hamnarbetare, Plåtslagare, Murare, Byggarbetare
	Motionsidrott	Boxning, Brännboll, Diskus, Fäktning, Gymping, Kulstötning, Längdskidor, Motorcross, Motionsspårlöpning, Slägga, Speedway, Spjut, Tyngdlyftning, Vattenskidor
	Aktiv idrott	Bordtennis, Dans, Löpning på plant underlag, Vattenpolo, Windsurfing
3	**Arbete**	Jägmästare, Lätt verkstadsarbete, Lastbilschaufför, Målare, Trädgårdsarbetare, Renhållningsarbetare, Skådespelare, Snickare, Sotare, Städerska, Vägarbetare
	Skogspromenader	
	Motionsidrott	Bordtennis, Dans, Löpning på plant underlag, Vattenpolo, Windsurfing
	Aktiv idrott	Bodybuilding, Bowling, Curling, Cykel, Golf , Segling, Simning, Ridning
2	**Arbete**	Affärsbiträde, Bilreparatör, Biträde, Förskollärare, Militär, Nattvakt, Servitör, Sjuksköterska
	Gång på ojämt underlag	
	Motionsidrott	Bodybuilding, Bowling, Curling, Cykel, Golf, Segling, Simning, Ridning
1	**Arbete**	Busschaufför, Flygare, Frisör, Kock, Kontor, Läkare, Lärare, Sekreterare
	Gång på plant underlag	
	Idrott	Bridge, Bågskytte, Kanot, Schack, Skytte

Nästa

Ser formuläret konstigt ut? tryck här För en enklare version.

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PROJEKT KORSBAND

Tegner - Fysisk aktivitet

Just nu

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som du anser dig vara på i samband med arbete, motionsidrott eller aktiv idrott **just nu**.

Finns inte din idrott eller ditt arbete med på skalan så försök värdera och likställ det emot något av alternativen.

Motionsidrott – idrott "bara för skojs skull" **Aktiv idrott** – Regelbunden tävling och träning

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	Motionsidrott	Boxning, Brännboll, Diskus, Fäktning, Gymping, Kulstötning, Längdskidor, Motorcross, Motionsspårlöpning, Slägga, Speedway, Spjut, Tyngdlyftning, Vattenskidor
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	Skogspromenader	
	Motionsidrott	Bordtennis, Dans, Löpning på plant underlag, Vattenpolo, Windsurfing
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	Gång på ojämt underlag	
	Motionsidrott	Bodybuilding, Bowling, Curling, Cykel, Golf, Segling, Simning, Ridning
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	Gång på plant underlag	
	Idrott	Bridge, Bågskytte, Kanot, Schack, Skytte

Nästa

Ser formuläret konstigt ut? tryck här För en enklare version.

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PROJEKT KORSBAND

K-SES - Tilltro till din förmåga - A & B

Om formuläret ser konstigt ut så tryck här för en simplare version.

Frågeformulär om:

hur säker du är på din förmåga att klara av olika aktiviteter **just nu**
och
hur säker du känner dig på hur ditt knä skall fungera **i framtiden**

Vi vill ta reda ***på hur säker du är på din förmåga*** att ***just nu*** klara av:
A. Vissa dagliga aktiviteter
B. Vissa fritids-, motions- och idrottsaktiviteter
C. Vissa fysiska aktiviteter
Vi vill också ta reda på hur säker du känner dig ***just nu*** på hur ditt knä skall fungera i framtiden.
D. Din knäfunktion i framtiden

Du skall endast svara på ***din upplevelse*** av ***hur säker du är på din förmåga att*** klara av de olika aktiviteterna och inte på hur bra du faktiskt klarar av det.

A. Dagliga aktiviteter

Markera rutan för den siffra som bäst beskriver ***hur säker du är på din förmåga*** att kunna utföra aktiviteten ***just nu*** oavsett smärta/besvär.

Hur säker är du på att:	**0 = inte alls säker**									**10 = mycket säker**	
gå i skogen	0	1	2	3	4	5	6	7	8	9	10
gå nedför backar/trappor	0	1	2	3	4	5	6	7	8	9	10
springa för att hinna med tex en buss	0	1	2	3	4	5	6	7	8	9	10
arbeta i trädgården	0	1	2	3	4	5	6	7	8	9	10
städa	0	1	2	3	4	5	6	7	8	9	10

B. Fritids-, motions- och idrottsaktiviteter

Markera rutan för den siffra som bäst beskriver ***hur säker du är på din förmåga*** att kunna utföra aktiviteten ***just nu*** oavsett smärta/besvär.

Hur säker är du på att:	**0 = inte alls säker**									**10 = mycket säker**	
cykla längre sträckor	0	1	2	3	4	5	6	7	8	9	10
åka längdskidor	0	1	2	3	4	5	6	7	8	9	10
simma	0	1	2	3	4	5	6	7	8	9	10
dansa	0	1	2	3	4	5	6	7	8	9	10
fjällvandra	0	1	2	3	4	5	6	7	8	9	10

Nästa

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PROJEKT KORSBAND

K-SES - Tilltro till din förmåga - C & D

Om formuläret ser konstigt ut så tryck här för en simplare version.

Du skall endast svara på ***din upplevelse*** av ***hur säker du är på din förmåga att*** klara av de olika aktiviteterna och inte på hur bra du faktiskt klarar av det.

C. Fysiska aktiviteter

Markera rutan för den siffra som bäst beskriver ***hur säker du är på din förmåga*** att kunna utföra aktiviteten ***just nu*** oavsett smärta/besvär.

Hur säker är du på att:	**0 = inte alls säker**									**10 = mycket säker**
att sitta på huk	0	1	2	3	4	5	6	7	8	9	10
att hoppa i sidled från ett ben till det andra	0	1	2	3	4	5	6	7	8	9	10
att göra enbenshopp på det skadade benet	0	1	2	3	4	5	6	7	8	9	10
att göra snabba vändningar	0	1	2	3	4	5	6	7	8	9	10

D. Din knäfunktion i framtiden

Markera rutan för den siffra som bäst beskriver just nu ***hur säker du är på din förmåga*** i framtiden.

Hur säker är du på att:	**0 = inte alls säker**										**10 = mycket säker**
du blir bra i ditt knä	0	1	2	3	4	5	6	7	8	9	10
du skall kunna återgå till den fysiska aktivitetsnivå du hade före skadan?	0	1	2	3	4	5	6	7	8	9	10
du inte får nya skador i ditt knä?	0	1	2	3	4	5	6	7	8	9	10
ditt knä blir bättre än före operation (för dig som är opererad)	0	1	2	3	4	5	6	7	8	9	10

Tillbaka

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PROJEKT KORSBAND

KOOS - Knee injury and Osteoarthritis Outcome Score

Symptom & Stelhet

Om formuläret ser konstigt ut så tryck här för en simplare version.

INSTRUKTIONER:
Detta formulär innehåller frågor om hur Du ser på ditt knä.
Informationen ska hjälpa till att följa hur Du mår och fungerar i ditt dagliga liv.

Besvara frågorna genom att kryssa för det alternativ Du tycker stämmer bäst in på dig (ett alternativ för varje fråga). Om Du är osäker, kryssa ändå för det alternativ som känns riktigast.

Symptom
Tänk på de symptom Du haft från ditt knä under den senaste veckan när Du besvarar dessa frågor.

Har knät varit svullet?	Aldrig	Sällan	Ibland	Ofta	Alltid
Har Du känt att det maler i knät eller hör Du klickande eller andra ljud från knät?	Aldrig	Sällan	Ibland	Ofta	Alltid
Har knät hakat upp sig eller låst sig?	Aldrig	Sällan	Ibland	Ofta	Alltid
Har Du kunnat sträcka knät helt?	Alltid	Ofta	Ibland	Sällan	Aldrig
Har Du kunnat böja knät helt?	Alltid	Ofta	Ibland	Sällan	Aldrig

Stelhet
Följande frågor rör ledstelhet. Ledstelhet innebär svårighet att komma igång eller ökat motstånd då Du böjer eller sträcker i knät. Markera graden av ledstelhet Du har upplevt i ditt knä den senaste veckan.

Hur stelt har ditt knä varit när Du just har vaknat på morgonen?	Inte alls	Något	Måttligt	Mycket	Extremt
Hur stelt har ditt knä varit efter att Du har suttit eller legat och vilat senare under dagen?	Inte alls	Något	Måttligt	Mycket	Extremt

Nästa

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SVENSKA KORSBANDSREGISTRET

PROJEKT KORSBAND

KOOS - Knee injury and Osteoarthritis Outcome Score

Smärta

Om formuläret ser konstigt ut så tryck här för en simplare version.

INSTRUKTIONER:
Detta formulär innehåller frågor om hur Du ser på ditt knä.
Informationen ska hjälpa till att följa hur Du mår och fungerar i ditt dagliga liv.

Besvara frågorna genom att kryssa för det alternativ Du tycker stämmer bäst in på dig (ett alternativ för varje fråga). Om Du är osäker, kryssa ändå för det alternativ som känns riktigast.

Hur ofta har Du ont i knät?	Aldrig	Varje månad	Varje vecka	Varje dag	Alltid

Vilken grad av smärta har Du känt i ditt knä den **senaste veckan** under följande aktiviteter?

Snurra/vrida på belastat knä	Ingen	Lätt	Måttlig	Svår	Mycket svår
Sträcka knät helt	Ingen	Lätt	Måttlig	Svår	Mycket svår
Böja knät helt	Ingen	Lätt	Måttlig	Svår	Mycket svår
Gå på jämnt underlag	Ingen	Lätt	Måttlig	Svår	Mycket svår
Gå upp eller ner för trappor	Ingen	Lätt	Måttligt	Svår	Mycket svår
Under natten i sängläge (smärta som stör sömnen)	Ingen	Lätt	Måttligt	Svår	Mycket svår
Sittande eller liggande	Ingen	Lätt	Måttligt	Svår	Mycket svår
Stående	Ingen	Lätt	Måttligt	Svår	Mycket svår

Tillbaka Nästa

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SVENSKA KORSBANDSREGISTRET

PROJEKT KORSBAND

KOOS - Knee injury and Osteoarthritis Outcome Score

Funktion

Om formuläret ser konstigt ut så tryck här för en simplare version.

INSTRUKTIONER:
Detta formulär innehåller frågor om hur Du ser på ditt knä.
Informationen ska hjälpa till att följa hur Du mår och fungerar i ditt dagliga liv.

Besvara frågorna genom att kryssa för det alternativ Du tycker stämmer bäst in på dig (ett alternativ för varje fråga). Om Du är osäker, kryssa ändå för det alternativ som känns riktigast.

Funktion, dagliga livet
Följande frågor rör Din fysiska förmåga. Ange graden av svårighet Du upplevt den senaste veckan vid följande aktiviteter på grund av dina knäbesvär.

Gå nerför trappor	Ingen	Lätt	Måttlig	Svår	Mycket svår
Gå uppför trappor	Ingen	Lätt	Måttlig	Svår	Mycket svår
Resa dig upp från sittande	Ingen	Lätt	Måttlig	Svår	Mycket svår

Ange graden av **svårighet** Du upplevt med varje aktivitet den **senaste veckan**.

Stå stilla	Ingen	Lätt	Måttlig	Svår	Mycket svår
Böja Dig, t ex för att plocka upp ett föremål från golvet	Ingen	Lätt	Måttlig	Svår	Mycket svår
Gå på jämnt underlag	Ingen	Lätt	Måttligt	Svår	Mycket svår
Stiga i/ur bil	Ingen	Lätt	Måttligt	Svår	Mycket svår
Handla/göra inköp	Ingen	Lätt	Måttligt	Svår	Mycket svår
Ta på strumpor	Ingen	Lätt	Måttligt	Svår	Mycket svår
Stiga ur sängen	Ingen	Lätt	Måttligt	Svår	Mycket svår
Ta av strumpor	Ingen	Lätt	Måttligt	Svår	Mycket svår
Ligga i sängen (vända dig, hålla knät i samma läge under lång tid)	Ingen	Lätt	Måttligt	Svår	Mycket svår
Stiga i och ur badkar/dusch	Ingen	Lätt	Måttligt	Svår	Mycket svår
Sitta	Ingen	Lätt	Måttligt	Svår	Mycket svår
Sätta dig och resa dig från toalettstol	Ingen	Lätt	Måttligt	Svår	Mycket svår
Utföra tungt hushållsarbete (snöskottning, golvtvätt, dammsugning etc)	Ingen	Lätt	Måttligt	Svår	Mycket svår
Utföra lätt hushållsarbete (matlagning, damning etc)	Ingen	Lätt	Måttligt	Svår	Mycket svår

Tillbaka Nästa

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PROJEKT KORSBAND

KOOS - Knee injury and Osteoarthritis Outcome Score

Funktion

Om formuläret ser konstigt ut så tryck här för en simplare version.

INSTRUKTIONER:
Detta formulär innehåller frågor om hur Du ser på ditt knä.
Informationen ska hjälpa till att följa hur Du mår och fungerar i ditt dagliga liv.

Besvara frågorna genom att kryssa för det alternativ Du tycker stämmer bäst in på dig (ett alternativ för varje fråga). Om Du är osäker, kryssa ändå för det alternativ som känns riktigast.

Funktion, fritid och idrott
Följande frågor rör Din fysiska förmåga. **Ange graden av svårighet Du upplevt den senaste veckan vid följande aktiviteter på grund av dina knäbesvär.**

Sitta på huk	Ingen	Lätt	Måttlig	Stor	Mycket stor
Springa	Ingen	Lätt	Måttlig	Stor	Mycket stor
Hoppa	Ingen	Lätt	Måttlig	Stor	Mycket stor
Vrida/snurra på belastat knä	Ingen	Lätt	Måttlig	Stor	Mycket stor
Ligga på knä	Ingen	Lätt	Måttlig	Stor	Mycket stor

Livskvalité

Hur ofta gör sig Ditt knä påmint?	Aldrig	Varje månad	Varje vecka	Varje dag	Alltid
Har Du förändrat Ditt sätt att leva för att undvika att påfresta knät?	Inte alls	Något	Måttligt	I stor utsträckning	Totalt
I hur stor utsträckning kan Du lita på Ditt knä?	Helt och hållet	I stor utsträckning	Måttligt	Till viss del	Inte alls
Hur stora problem har Du med knät generellt sett?	Inga	Små	Måttligt	Stora	Mycket stora

Tillbaka

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PROJEKT KORSBAND

Återgång till idrott efter främre korsbandsskada

Instruktioner: Vänligen svara på följande frågor med tanke på den huvudsakliga idrottsaktivitet du utövade innan skadan. Besvara varje fråga genom att markera med ett kryss i den ruta som beskriver, hur du upplever situationen just nu i relation till de två ytterligheterna.

Är du säker på att du kan utöva din idrottsaktivitet på samma nivå som tidigare?

Inte alls säker	1	2	3	4	5	6	7	8	9	10	Helt säker

Tror du det är sannolikt att du skadar ditt knä igen genom att delta i din idrottsaktivitet?

Extremt sannolikt	1	2	3	4	5	6	7	8	9	10	Inte alls sannolikt

Är du orolig för att utöva din idrottsaktivitet?

Extremt orolig	1	2	3	4	5	6	7	8	9	10	Inte alls orolig

Är du säker på att ditt knä inte kommer att ge vika vid utövandet av din idrottsaktivitet?

Inte alls säker	1	2	3	4	5	6	7	8	9	10	Helt säker

Är du säker på att du kan utöva din idrottsaktivitet utan att bekymra dig för ditt knä?

Inte alls säker	1	2	3	4	5	6	7	8	9	10	Helt säker

Upplever du att det är frustrerande att behöva ta hänsyn till ditt knä med avseende på din idrottsaktivitet?

Extremt frustrerande	1	2	3	4	5	6	7	8	9	10	Inte alls frustrerande

Är du rädd för att skada ditt knä igen vid utövandet av din idrottsaktivitet?

Extremt rädd	1	2	3	4	5	6	7	8	9	10	Inte alls rädd

Är du säker på att ditt knä klarar att bibehålla kontroll under belastning?

Inte alls säker	1	2	3	4	5	6	7	8	9	10	Helt säker

Är du rädd att du, av en olyckshändelse, skadar ditt knä vid utövandet av din idrottsaktivitet?

Extremt rädd	1	2	3	4	5	6	7	8	9	10	Inte alls rädd

Har tankar på att vara tvungen att genomgå operation och rehabilitering igen, hindrat dig från att utöva din idrottsaktivitet?

Alltid	1	2	3	4	5	6	7	8	9	10	Aldrig

Är du säker på din förmåga att kunna prestera bra i din idrottsaktivitet?

Inte alls säker	1	2	3	4	5	6	7	8	9	10	Helt säker

Känner du dig avspänd inför att utöva din idrottsaktivitet?

Inte alls avspänd	1	2	3	4	5	6	7	8	9	10	Helt avspänd

Ser formuläret konstigt ut? tryck här! För en enklare version.

14.

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Patience you must have, my young athlete

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15.

STUDIES I-V

SUSANNE BEISCHER

Patience you must have, my young athlete