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ANTERIOR CRUCIATE LIGAMENT INJURIES IN FOOTBALL

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Anterior cruciate ligament injuries in football

THESIS FOR A DOCTORAL DEGREE (PhD)

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To my parents

Aliud cūrā, omnia rēctē erunt

SAMMANFATTNING PÅ SVENSKA

Att spela fotboll medför att knät utsätts för stora påfrestningar vilket ibland leder till skador. En allvarlig och relativt vanlig knäskada är en ruptur av det främre korsbandet. Om korsbandet går av resulterar det initialt i smärta och svullnad. De symtomen går ofta tillbaka efter några veckor men efter som det främre korsbandet har dålig förmåga att läka så är det vanligt med bestående instabilitet i knät. För att återställa stabiliteten i knät är det mycket vanligt med en operation där man återskapar korsbandet. Speciellt för de som önskar att ägna sig åt att spela fotboll igen. Av de som opererats för en främre korsbandsskada i Sverige så har drygt 40% fått sin skada när de spelat fotboll.

I **studie I** undersöktes faktorer associerade med en återgång till fotboll efter en främre korsbandsrekonstruktion. Deltagarna tillfrågades om deras återgång till fotboll och knäsymptom under fysisk aktivitet. Data samlades in från Capio Artro Clinics lokala databas avseende kirurgisk information, enkäter, knästabilitet och muskelstyrka. Studien fann att kvinnligt kön, broskskada och knäsmärta under fysisk aktivitet var oberoende negativa faktorer för att återvända till fotbollen efter en rekonstruktion av korsbandet.

I **studie II** gjordes en 10 års uppföljning av fotbollsspelare från alla nivåer i svenska korsbandsregistret via ett frågeformulär. Syftet var att undersöka hur många spelare som återgick till fotbollen, vad som påverkade deras beslut och om det finns några skillnader i ytterligare främre korsbandsrupturer mellan de som återgick och de som inte gjorde det. 54% av fotbollsspelarna angav att spelade igen efter operationen. Av de som slutade efter operationen så angav två tredjedelar att den huvudsakliga orsaken till det var på grund av det opererade knät. Spelarna som återvände till fotbollen hade en betydligt högre risk att drabbas av en ny främre korsbandsskada.

I **studie III** undersöktes hur en främre korsbandsrekonstruktion påverkade unga fotbollstalangers möjlighet att spela på en elitnivå som vuxna. Alla fotbollsspelare som deltagit på de nationella elitlägren för 15 åringar under 6 säsonger följdes upp, data samlades in från Svenska fotbollförbundet och korsbandregistret. I studien framkom att totalt så hade 10% av alla spelarna genomgått en korsbandsoperation. De som opererats i åldern 15–19 hade en lika stor chans att spela på elitnivå vid 21 års ålder och var aktiva i samma utsträckning som de som inte opererats.

I **studie IV** gjordes en epidemiologisk undersökning av spelare som tillhandahållit information om fotbollsspecifika faktorer associerade med sin skada på korsbandsregistrets hemsida. Studien fann att ACL skador uppstod oftare under matcher än under träning. Knäkontrollsövningar utfördes av 31% av kvinnorna och 16% av männen och 40% av spelarna angav att de inte planerade att återgå till fotbollen. Spelare i lag som byter tränare och spelare som går till en högre division ådrog sig fler ACL skador.

ABSTRACT

Anterior cruciate ligament (ACL) injuries and football are clearly intertwined. ACL injuries are principally sustained when participating in pivoting activities and, as it is such a popular sport, football is consequently a major cause of these injuries. The flip side of this is of course that ACL injuries negatively affect the afflicted players' potential to play the game. It is this relationship the present thesis attempts to elucidate.

In **Study I,** factors associated with a return to football after ACL reconstruction were examined in football players. The participants were asked about their return to football and knee symptoms during physical activity. Data were collected from Capio Artro Clinics local database regarding surgical information, patient-reported outcome measurements (PROMs), knee laxity and muscle strength. In the study, female gender, cartilage injury and knee pain during physical activity were found to be independent negative factors for returning to football after ACL reconstruction.

In **Study II,** a 10-year follow-up of football players from all levels in the Swedish National Knee Ligament Registry (SNKLR) was performed using a questionnaire to investigate how many players returned to play, what influenced their decision and whether there were any differences in additional ACL injuries (graft failure and/or contralateral ACL injury) between those who returned to play and those who did not. Fifty-four per cent of the football players returned to play after ACL reconstruction and, in two-thirds of those who did not return, the reason was knee related. Players who returned to football ran a significantly higher risk of sustaining further ACL injury.

In **Study III,** the effect of an ACL reconstruction for teenage football talents on their potential to continue as football players and become elite players at senior level was investigated. All players from the NEC (national elite camps) over six seasons were followed and data were collected from the SNKLR and the Swedish FA. As no significant differences were found between the ACL-reconstructed and uninjured players, it appears that ACL-reconstructive surgery in talented youth football players offers them the opportunity to

become elite players as seniors and permits an activity level on a par with that of their uninjured peers.

In **Study IV,** an epidemiological survey was made of players who, on the website of the SNKLR, provided information on football-specific factors associated with their ACL injury. The study found that ACL injuries were more frequently sustained during games, 66%, than during practice, 25%. Knee control exercises to warm up were used by 31% of the female players and 16% of the males. Forty per cent of the players reported that they did not plan on returning to football. Teams changing coaches and players moving to a higher division appear to run an increased risk of ACL injury.

LIST OF SCIENTIFIC PAPERS

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

I. **Factors associated with returning to football after anterior cruciate ligament reconstruction**
Alexander Sandon, Suzanne Werner & Magnus Forssblad.
Knee Surgery Sports Traumatolgy and Arthroscopy. 2015 Sep;23(9):2514-21.

II. **High Risk of Further Anterior Cruciate Ligament Injury in a 10-Year Follow-up Study of Anterior Cruciate Ligament-Reconstructed Soccer Players in the Swedish National Knee Ligament Registry**
Alexander Sandon, Björn Engström & Magnus Forssblad.
Artroscopy. 2020 Jan;36(1):189-195.

III. **Can Talented Youth Soccer Players Who Have Undergone Anterior Cruciate Ligament Reconstruction Reach the Elite Level?**
Alexander Sandon, Tor Söderström, Andreas Stenling, Magnus Forssblad.
Am J Sports Med. 2021 Feb;49(2):384-390.

IV. **Increased occurrence of ACL injuries for football players in teams changing coach and for players going to a higher division**
Alexander Sandon, Werner Krutsch, Volker Alt, Magnus Forssblad.
Knee Surgery Sports Traumatology and Arthroscopy. 2021 May 13. doi: 10.1007/s00167-021-06604-w. Online ahead of print

LIST OF ABBREVIATIONS

ACL	Anterior cruciate ligament
ACLR	Anterior cruciate ligament reconstruction
ALL	Anterolateral ligament
BPTB	Bone-patella tendon-bone
DB	Double bundle
EQ-5D	Euro Quality of Life-5 Dimensions questionnaire
FIFA	Fédération Internationale de Football Association
FOGIS	Swedish Football Association's administrative IT system
KOOS	Knee injury and Osteoartritis Outcome Score
LCL	Lateral collateral ligament
M	Mean
MCL	Medial collateral ligament
MRI	Magnetic resonance imaging
MLS	Major league soccer
n.s	Not significant
NEC	Swedish national elite camp
OR	Odds ratio
PCL	Posterior cruciate ligament
PROM	Patient-reported outcome measurement
RCT	Randomised control study
SB	Single bundle
SD	Standard deviation
SNKLR	The Swedish National Knee Ligament Registry
UEFA	Union of European Football Associations

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1 THE KNEE

1.1 KNEE ANATOMY

The knee joint is one of the main joints involved in ambulation and has several planes of motion: flexion/extension, internal/external rotation, varus/valgus angulation, anterior/posterior translation, medial/lateral translation and cephalad/caudad translation [148]. The knee joint is a gliding hinge joint, and the kinematics of the knee are rolling, gliding and rotation. The purpose of the joint is to provide motion by allowing the bones, the femur, tibia and patella, to move in relation to each other, while bearing the load caused by gravity and movement [68]. The joint needs to balance motion and stability and this is done through interaction by the involved bones, cartilage surface, ligaments, menisci, joint capsule and muscles [68]. Although the joint has several planes of motion, the primary one is flexion and extension, which is achieved by the large muscle groups at the front and the back of the thigh. The quadriceps muscles in the front provide force in extension and active flexion is performed by the hamstring muscles at the back of the thigh. Normal range of motion in this plane is 0-135 degrees of flexion, but a few degrees of hyperextension are common [50]. The stability of the knee is assisted by four major ligaments, namely the medial collateral ligament (MCL), lateral collateral ligament (LCL), anterior cruciate ligament (ACL) and the posterior cruciate ligaments (PCL). Excess anterior/posterior movement is limited by the cruciate ligaments, which vary in tension and length throughout the range of motion due to their asymmetric attachment sites [68]. The PCL prevents the posterior translation of the tibia relative to the femur and the ACL instead prevents anterior translation. The medial compartment of the knee is stabilised by the MCL with assistance from the PCL, the capsule and the medial meniscus. The medial side is more stable and allows less rotation than the lateral side. The lateral side has no distinct ligament connecting the femur and tibia. Stability in the lateral compartment is obtained by the LCL in conjunction with the popliteus and biceps tendons, as well as the iliotibial band and lateral capsule, including the anterolateral ligament (ALL) [70]. As in other joints, the rolling and gliding function of the knee is facilitated by the smooth cartilage surface lining the articular bones. The cartilage also performs the function of a shock absorber. The incongruent shape of the femoral condyles and the tibial plateau is compensated for by the medial and lateral menisci adapting to movements in the joint. The menisci attach along the capsule in the periphery and have anterior and posterior roots anchoring them to the tibial plateau [70].

1.1 ANATOMY AND FUNCTION OF THE ANTERIOR CRUCIATE LIGAMENT

The ACL stretches from the posteromedial part of the lateral femoral condyle in an oblique fashion down to the tibia and attaches between the intercondylar eminences. Ways of describing the ACL have been the subject of debate. A great deal of the previous literature describes two bundles, the anteromedial bundle and the posterolateral bundle, named after their relative attachments on the tibia [68]. Smigielski, on the other hand, describes the ACL as having a ribbon-like structure from its femoral attachment to the midsubstance without any distinct bundles [153]. He suggests that the bundle-like appearance of the ligament is caused by the twisting of the flat, ribbon-like structure in flexion [153]. Others have instead described the ACL as a collection of continuous fibres that fan out and are taut to a varying extent during the range of motion [7].

Two landmarks that are used to identify the ACL's attachment on the femoral side are the lateral intercondylar ridge (also referred to as the resident's ridge) and the lateral bifurcate ridge (also referred to as the cruciate ridge) [154]. On the tibial side, the ACL has an oval or C shape that varies between individuals and an insertion between the medial tibial eminence and the anterior root of the lateral meniscus [45]. The ACL is an intra-articular ligament with a synovial membrane. It receives its blood supply from the middle genicular artery and is innervated by the tibial nerve [7]. The primary function of the ACL is to prevent the anterior translation of the tibia and, secondarily, it prevents the internal rotation of the tibia and valgus angulation of the knee [118]. A rupture to the ACL might lead to varying degrees of instability and the knee giving way or buckling, especially in more strenuous situations like pivoting sports.

1.2 HISTORY OF THE ANTERIOR CRUCIATE LIGAMENT

The Greek physician Claudius Galen practising in the Roman Empire was the first to describe the ACL's function in supporting stability and preventing abnormal movement in the knee. Prior to this, the cruciate ligaments were thought to be part of the nervous system. The first mention of cruciate ligament anatomy was found in ancient Egyptian scrolls (3000 BC). The first mechanical studies of the ACL were performed by the German Weber brothers in 1836. They describe the roll and glide mechanism of the knee and an abnormal anterior sagittal

movement of the tibia following the transection of the ACL. Cadaveric studies by Bonnet in 1945 advanced the knowledge of the mechanism of knee ligament injuries and the first recorded description of an ACL rupture was made by Stark in 1850. The technique for the commonly used Lachman test used for diagnosing an ACL rupture was first described by the Greek Noulis in 1875 [26].

1.3 TREATMENT AND SURGICAL TECHNIQUES FOR ACL RECONSTRUCTION

The first reported ACL repair was performed by Mayo-Robson and reported on by Battle in 1900. Since then, several surgical techniques have been tested and developed. Initially, attempts were made to suture the ligament. Back in 1916, Jones reported that stitching the ligament was futile and this was subsequently corroborated some 60 years later by Feagin and Curl, who published a long-term follow-up of young adults with ACL repairs [26, 44]. After that, the trend shifted towards reconstruction, which is the dominant treatment option today, although repair with augmentation has again attracted attention in the last few years [134]. The first ACL reconstructions (ACLR) were performed with a fascia lata graft. In the 1930s, the use of a hamstring graft was introduced by Galeazzi and Macey [26]. The hamstring graft remains popular for ACLR and was used in nearly 90% of the cases in Sweden in 2020, according to the annual report from the Swedish National Knee Ligament Registry (SNKLR). Earlier, a combination of a double-bundle semitendinosus and a double-bundle gracilis tendon was used, but today most surgeons use a quadruple-bundle semitendinosus graft with the benefit of keeping the gracilis function intact. The semitendinosus tendon is harvested via a cut over the pes anserinus and dissection down to the tendon. The tendon is then harvested with a special tool called a stripper that is placed around the tendons and slid up in the thigh to release the tendon at the tendomuscular junction. The second most popular graft today in Sweden is the bone-patella tendon-bone (BPTB) graft. This technique was first introduced in the 1960s by Jones [75]. The middle third of the patellar tendon is harvested through an incision from the distal part of the patella down to the tuberositas tibia. The tendon is incised in the fibre direction and bone blocks from the patella and tibia are cut out with a saw or a bone chisel and mallet. The third choice for ACLR is the quadriceps graft that has gained popularity in recent years. It can be used as a free tendon graft or with a bone block on one side. The harvesting technique is similar to the BPTB graft harvest but on the proximal side of the patella. In the 1970s and 1980s, attempts were made to reconstruct the ACL with

synthetic grafts, but they had poor outcomes and a high rate of complications and, as a result, they are not used nowadays [26]. Another option is to use an allograft, a graft from another person. This has the benefit of no harvest-site morbidity, but it is far more difficult in terms of logistics and regulations and is not commonly used in Sweden. The first ACLRs were all performed with open surgery, but, with the advances in technology, the ACLR has become a surgery performed almost exclusively arthroscopically which started in Sweden 1989. This shift in technique was also driven by changes in the surgical approach from an extra-articular to an intra-articular reconstruction [100]. Tiny incisions are made anteromedially and anterolaterally on each side of the patellar tendon for the arthroscope (camera) and instruments and the inside of the knee is visualised on a screen. To place the chosen graft for the new ACL, holes are drilled in the tibia and femur. For a period, double-bundle (DB) ACLRs were popular, with the idea that they would better mimic the native ACL and its two bundles and provide better kinematics [96]. DB means that two separate tunnels are drilled in both the tibia and femur for two individual grafts. This technique is technically more challenging for the surgeon and has not shown superior results. For this reason, it has lost popularity [33]. Instead, the single-bundle (SB) technique is used, meaning that only one tunnel is placed on the tibial and femoral side. On the tibial side, a drill guide is used for the placement of the tunnel. On the femoral side, the three main methods for placing and drilling the tunnel are transtibial, anteromedial and rear entry. Modern ACL surgery aims at placing the graft anatomically, meaning as closely as possible to the direction and location of the native ACL [22].

1.4 REGISTRIES AND THE EVALUATION OF KNEE FUNCTION

1.4.1 The Swedish National Knee Ligament Registry

The Swedish National Knee Ligament Registry was established in 2005, alongside similar registries in Denmark and Norway, as a nationwide database for prospective data collection relating to ACL surgeries. The registry contains information provided by the surgeon and the patient. The surgeon enters all the surgical procedures on the knee, graft type and diameter, fixation method, surgical technique, associated injuries and any surgical treatment of meniscal or cartilage injuries, as well as the aetiology and date of injury. Patients are asked to fill out two patient-reported outcome measurements (PROMs), the Knee injury and Osteoarthritis Outcome Score (KOOS) and the Euro Quality of Life-5 Dimensions

questionnaire (EQ-5D), preoperatively and then at one, two, five and 10 years postoperatively. The SNKLR covers more than 90% of all ACL reconstructions performed in Sweden and has a 50% to 70% response rate for the PROMs [36]. Although the response rate is not as high as expected, a non-response analysis has been performed showing the validity of the PROMs in the registry [114]. In the first year of the registry, a total of 2,105 reconstructions were recorded. Since then, the number of registered surgeries has doubled to over 4,000 in recent years (Table 1).

Table 1 Number of ACL reconstructions registered annually in the SNKLR 2005-2020.

Year	*Total*	*Primary*	*Revision*
2005	2105	1997	108
2006	2643	2511	132
2007	2937	2766	171
2008	3190	2994	196
2009	3266	3078	188
2010	3584	3355	229
2011	3559	3339	220
2012	4308	4012	296
2013	3770	3483	287
2014	3711	3443	268
2015	3808	3523	285
2016	3924	3622	302
2017	4220	3883	337
2018	4176	3840	336
2019	4440	4065	375
2020	4001	3685	316

Since the inception of the SNKLR, the hamstring autograft has been the predominant graft choice in primary ACLR, rising in popularity to being used in more than 90% of the cases in the first part of the last decade. In the last few years, the quadriceps tendon has been introduced as an alternative and the patellar graft has experienced a resurgence in popularity (Figure 1). The graft choice for football players follows the same trend (Figure 2). The patellar graft is the most commonly used for ACL revisions. The quadriceps tendon has gained in popularity in revisions and is now used more often than hamstring grafts (Figure 3).

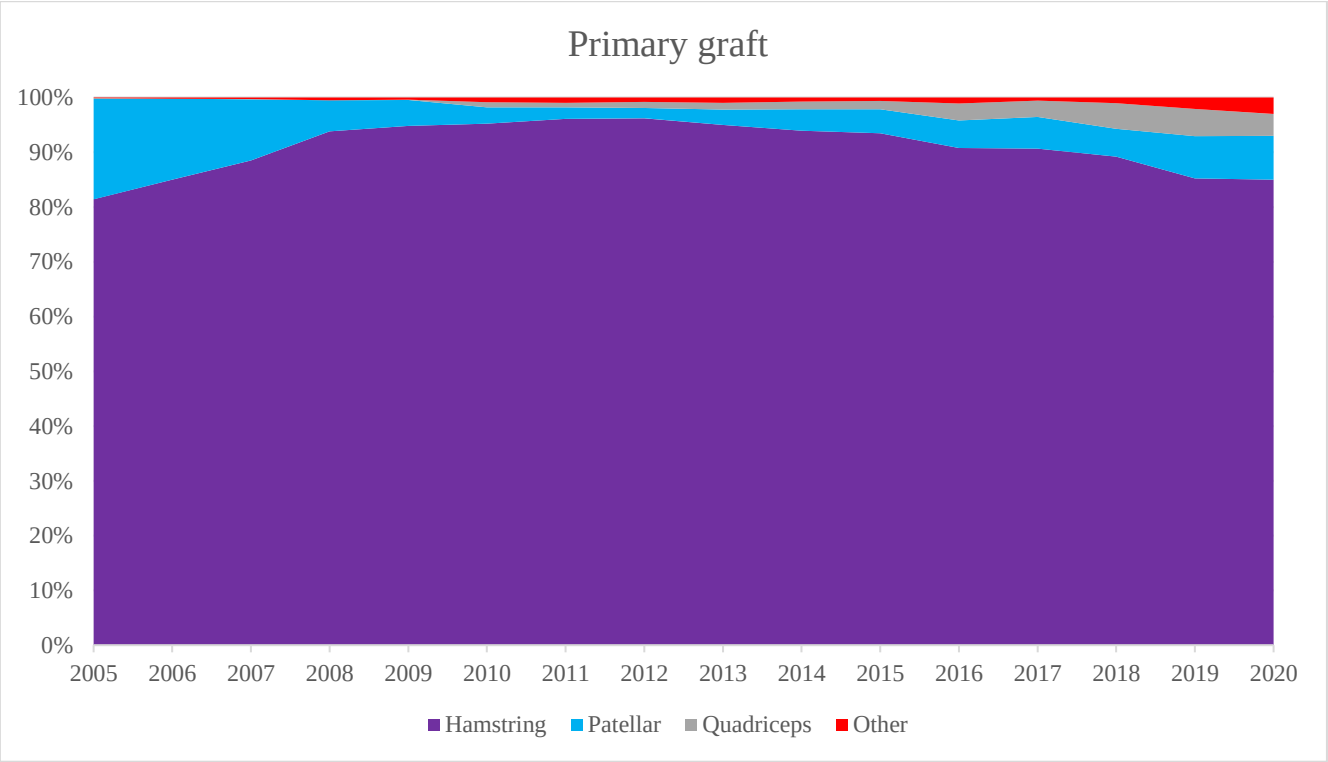

Figure 1. Frequency of grafts used for primary ACL reconstruction per year from the SNKLR.

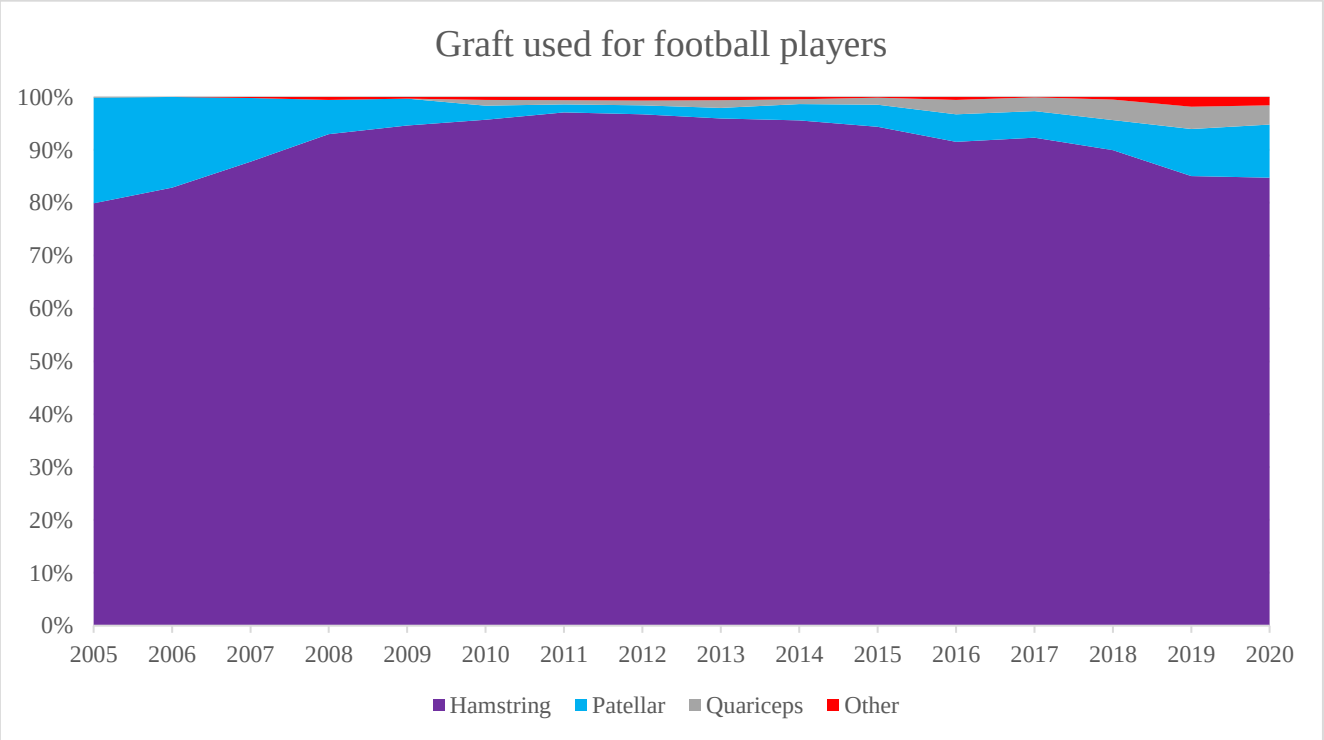

Figure 2. Frequency of grafts used for primary ACL reconstruction in football players per year from the SNKLR.

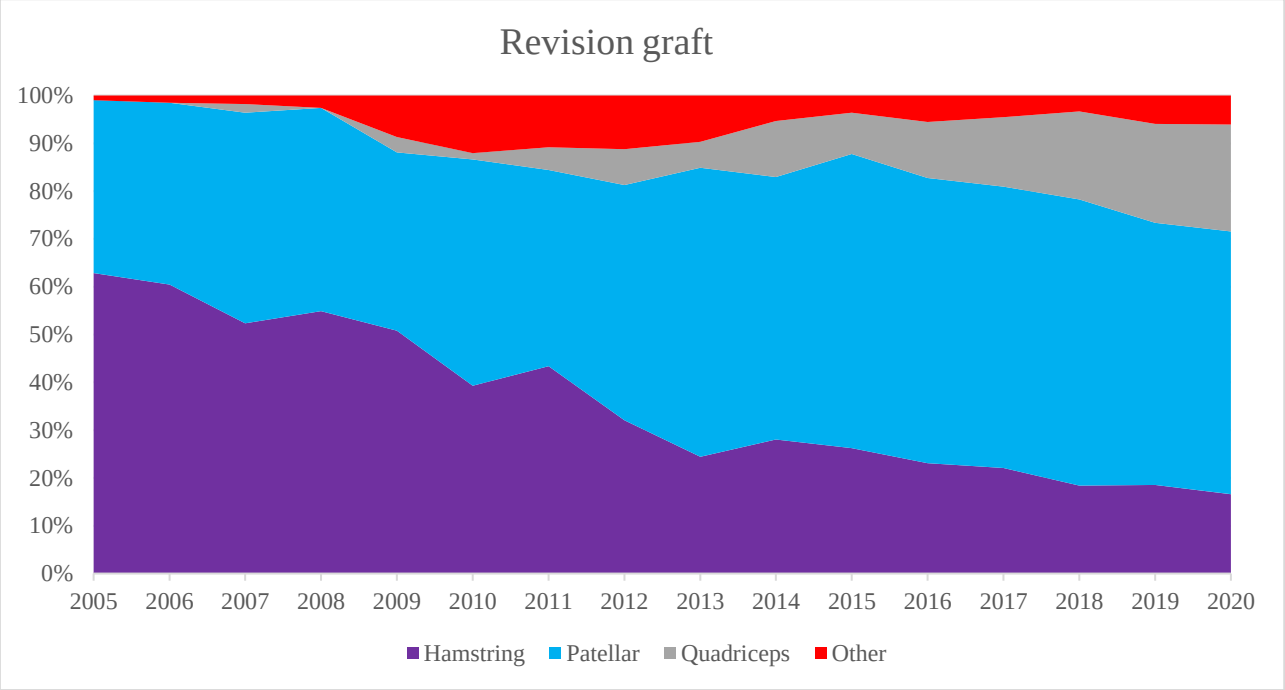

Figure 1. Frequency of grafts used for revision ACL reconstruction per year from the SNKLR.

1.4.2 Knee injury and Osteoarthritis Outcome Score

The Knee injury and Osteoarthritis Outcome Score (KOOS) was developed in 1995 to assess the outcome in patients with ACL injuries and osteoarthritis. It consists of five subscales: Symptoms, Pain, Activity of Daily Life (ADL), Sport and recreational function and Knee-related Quality of Life (QoL). Each subscale has several questions, to which the patient gives a score on a five-point scale. For each subscale, the results are transformed to 0-100, where 100 represents no knee problems [115].

1.4.3 EQ-5D

The EQ-5D was developed in 1987 and is a two-part questionnaire where the respondents describe their current health state. The first part includes five questions on mobility, self-care, usual activities, pain/discomfort and anxiety/depression. Each question has a three-level scale ranging from “no problems” to “extreme/severe problems”. An index value from 0 (worst) to 1 (best) is then calculated from the responses. The second page of the questionnaire includes a visual analogue scale (VAS) where the respondents grade their current state of health on a scale from 0-100, where 0 is the worst imaginable health state and 100 the best imaginable health state [112].

1.4.4 Lysholm knee scoring scale

The Lysholm knee scoring scale was introduced in 1982 and modified in 1985. Initially introduced as a physician-administered questionnaire, it has been validated over time and is primarily used as a PROM. It is used for following up ACLR patients and examines knee function in daily living but not in sports. Eight factors are rated to produce an overall score on a point scale of 0 to 100. An overall score is then given as “excellent” for 95 to 100 points; “good” for 84 to 94 points, “fair” for 65 to 83 points, or “poor” for fewer than 65 points [94].

1.4.5 Tegner activity scale

The Tegner activity scale was first described in 1985 and was initially designed for administration after ACL injuries. The Tegner activity scale is a one-item score that grades activity based on work and sports activities on a scale of 0 to 10. Zero represents disability because of knee problems and 10 represents playing football at national or international level [130].

1.4.6 KT-1000

In the 1980s, the KT-1000 knee arthrometer was developed by the MED Metric Corp to measure the anterior translation of the tibia while keeping the femur in a fixed position. The device is placed at the anterior of the patient’s knee and held in place by straps. The device needs to be calibrated by the examiner and a lever is then pulled with auditory feedback on the force applied. The translation is then calculated as the relative motions of pads on the patella and on the tibia. The result is meant to be an objective measurement of knee laxity pre- and postoperatively [25]. The result is, however, user dependent and studies have shown that it is not reliable as a continuous variable for comparisons between groups [6].

1.5 THE HISTORY OF FOOTBALL

The modern birth of football as we know it took place in England when it split from rugby and the Football Association was formed in 1863. When outlining the first set of rules, handling the ball was forbidden for everyone except the goalkeeper. Prior to this, a variety of football-like games had been played across England, dating all the way back to the eighth century AD. These games have been described as "mob football", with vague rules, considerable use of violence and with no limits on the number of players. The games could be played between villages on the streets, fields and surrounding areas [46].

Several games with similarities to football have been played across the world for millennia. A game called Cuju or Tsu' Chu was played in China as early as in the second and third centuries BC. It entailed kicking a hair- and feather-filled leather ball through an opening only 30-40 cm wide. Information about the game was found in a military manual from that time. Another example is the Japanese game Kemari, which began 500-600 years later [48] .

The ancient Greeks played a game called Epikyros. It involved two equal-numbered teams divided by a white line and with another line some distance behind each team. The object of the game was to force the other team behind its rear line [18]. The Romans also had their version called Harpastum. This was played on a rectangular field and the objective was to get the ball across the line of the opposing team by passing and trickery. That game remained popular among the Romans for 700-800 years and was later brought to Britain [48].

Harpastum experienced a revival in the form of Calcio Fiorentino also known as Calcio Storico or simply Calcio. The official rules dated back to 1580 and the game was played by the aristocracy, including three popes, in the beautiful Piazza Santa Croce in the centre of Florence. Like many of the historical forms of football, it was a brutal game and has been described as a mixture of football, rugby and martial arts. Much like Harpastum, the objective of the game is to get the ball across the opponents' line at the end of the pitch [65]. Although we know little about the injury epidemiology of these older forms of football, it stands to reason that the injuries were many in number and at times very severe.

Football as we know it today initially spread in the British Isles, then on to Europe and eventually to the rest of the world. The International Football Association (FIFA) was founded in 1904 and, by the time the first World Cup was played in 1930, it had 41 members. Today, football is played all over the planet and FIFA has 211 members. In a large survey

performed by FIFA in 2006, it was found that there are approximately 245 million football players in the world [47].

1.6 INJURIES IN FOOTBALL

Engström et al. performed injury studies by following men's and women's football teams for one season. In the men's teams, 75% of all players sustained one or more injuries. The incidence of injury was a lot higher during games with 13/1000 hours compared with 3/1000 hours during training. Most of the traumatic injuries (93%) were to the lower extremities, with one third of the total injuries occurring in the knee. Overuse injuries were more prevalent during pre- and postseason and accounted for 35% of all injuries. Thirty-four per cent of the injuries were classified as major, meaning they caused more than one month of absence from full participation [37]. Among the female players, 80% sustained at least one injury. The incidence of injury was again much higher during games (24/1000 hours) than during training (7/1000 hours). The majority (88%) of injuries were localised in the lower extremities. Twenty-eight per cent of all injuries were overuse injuries and mainly occurred outside the competitive season. Although most injuries were classified as minor, as many as 17% of the players sustained a major knee injury during the year [38]. Similar findings on the incidence of injuries were presented in an 11-year follow-up in a prospective study of professional male football teams in the UEFA elite club injury study. It presented a total of 7.7 injuries/1000 hours of football, 4/1000 h during training and 26.6/1000 h for matches and a significantly better domestic league and European cup performance for teams with lower seasonal injury rates [64]. Another study of the same cohort investigated the time loss due to 22942 injuries over 494 team seasons and found that ACL injuries were only the 31st most common injuries but those with the longest absence from the game. ACL injuries and lateral meniscus tears together accounted for 18% of the total time loss due to injury [34]. In an 18-year follow-up of the cohort, there was a decrease in injury incidence in training and matches, a lower re-injury rate and greater player availability over time, indicating an improvement in injury treatment and injury prevention for these elite male players [35].

A meta-analysis and systematic review of the relationship between sports participation and osteoarthritis found that there was low-quality evidence that playing football, especially at

elite level, increased the risk of osteoarthritis and that meniscectomies and ACL injuries could be contributory risk factors [132].

1.7 INCIDENCE OF ACL INJURIES IN FOOTBALL

Football is a pivoting sport that involves a large number of cuts, twists, turns, decelerations, jumps and changes of direction, which place a great deal of strain on the knee that could cause injuries. The high frequency of these knee-straining movements makes football a high-risk activity for ACL injuries. This is reflected in the Scandinavian ACL registries, where 41% of the ACL injuries are caused by playing football [57]. In a retrospective study of ACL-injured Norwegian footballers, the overall incidence rate was 0.063 injuries per 1000 game-hours and most of the ACL injuries occurred during matches. Although women had a significantly higher ACL injury incidence rate than men (0.10 /1000 h vs 0.057/1000 h), the men incurred most (75.6%) of the injuries. This is explained by the fact that more men play football, which results in a greater combined exposure for that group [15]. A very similar ACL injury rate was found in male football players at Champions League level and in Italian Serie A. In these cohorts, the ACL injury rate was 20 and 14 times higher during matches than in training [60, 141]. In the Spanish 1st division's women's football, the incidence of ACL injuries was 0.62/1000h and again the risk was higher during games [98]. Whether or not the level of football influences the incidence rate is still unclear, with contradictory results from studies. In one, the men in the highest divisions had a higher rate, while another study found the highest incidence in intermediate players and a lower rate for amateur and elite players [102].

Female football players run a two to five times higher risk of sustaining an ACL injury while playing football than males [13, 59, 82, 102, 111, 151]. A meta-analysis of the incidence of ACL injuries in female football players found an ACL injury rate of 0.3 per 1000h of football or, in other words, a 30% risk of ACL injury after 1000 hours of football. It was estimated that women run a roughly 5% risk of sustaining an ACL injury for each year of playing football [111]. On average, there is approximately one ACL injury per team per season for women and 0.5 ACL injuries for male teams [122, 141, 142]. This is at least double the risk for ACL injuries in female players and the reason is not yet fully understood, but it appears to be multifactorial, with some of the more important factors being anatomical, hormonal and neuromuscular [1]. There is also a familiar [72, 95] and anatomical [73]

predisposition to ACL injuries. Female players appear to have a slower activation time in the vastus medialis [97] and a greater imbalance between flexors and extensors in the knee than men, with relatively weaker hamstrings [103]. Balachandar et al. performed a systematic review of the effect of the menstrual cycle on ACL injuries and lower-limb biomechanics and neuromuscular control. They concluded that there is strong evidence of a greater risk of ACL injuries among women in the pre-ovulatory phase of the menstrual cycle [10].

2 AIMS

I. To identify factors associated with a return to football after ACL reconstruction. These possible factors include gender, type of graft for ACL reconstruction, associated injuries, anterior knee laxity and thigh muscle torques, as well as symptoms in connection with physical activity.

II. To follow up on football players 10 years after a primary anterior cruciate ligament reconstruction to determine the number of players that returned to playing, what influenced their decision and whether there are any differences in additional ACL injuries (graft failure and/or contralateral ACL injury) between those who returned to playing and those who did not.

III. To investigate whether an ACL reconstruction for teenage football players affects their potential to continue as football players and become elite players at senior level.

IV. To identify football-specific factors associated with ACL injuries that can be targeted for sport-specific injury prevention strategies.

3 MATERIAL AND METHODS

I. The study population was selected from the patient database at the Capio Artro Clinic in Stockholm. The inclusion criterion was all football players who had been treated with ACLR using either the patellar tendon or the hamstring tendon/s as grafts between 1 January 2004 and 31 December 2007. Patients with associated multi-ligament knee lesions, an ACL injury combined with a posterior cruciate ligament injury or medial/postero-lateral compartment lesions, as well as ACL revisions and patients with a contralateral ACL injury, were excluded from the study. Five hundred and forty-one football players, 365 (67.5%) males and 176 (32.5%) females, matched the study criteria. The hamstring graft was used for ACLR in 468 (86.5%) of the cases, while the patellar graft was used in 73 (13.5%) of the cases. Registry data regarding gender, age, side of injury, possible meniscus injury or cartilage injury were collected using the Clinical IT System at the Capio Artro Clinic. The results have been recorded both preoperatively and six months postoperatively in terms of anterior knee laxity (KT-1000 arthrometer, MEDmetric Corp., San Diego, CA, USA), knee function (KOOS and Lysholm Knee Scoring Scale) and sports activity (Tegner Activity Scale). The patients were surveyed using a questionnaire at the beginning of the summer of 2009, giving a mean follow-up of 3.2 ± 1.4 years (min 1.4, max 5.3). A questionnaire about the present subjective knee function and sports participation was developed. The players provided information on whether or not they had returned to their pre-injury sport, how often (times/week) they practised or competed and whether they suffered from any of the following symptoms/problems: pain, stiffness, instability and swelling or locking during and/or after physical activity. The total burden of symptoms/problems was calculated by adding 0.2 points for every reported type of symptom/problem. The maximum was one point for players with all five types of symptom/problem and 0 for asymptomatic players. Particular attention was paid to whether the football player had returned to playing football. The data were collected from 205 (37.9%) of the 541 players that were asked to take part in the study. From the drop-outs (n = 336), 57 players (17.0%) could not be reached by mail and the remaining 279 (83.0%) chose not to answer the questionnaire. The

questionnaire was placed on the website, www.artro.nu, so that it could be filled out and stored electronically. A letter with information about the study and instructions on how to answer the questionnaire online was sent by mail to all participants. In an attempt to increase the number of players filling out the questionnaire, a reminder was sent to those that had not answered.

II. Patients were selected from the SNKLR. Patients registered from 1 January 2005 to 31December 2006 for primary ACLR with football as the aetiology of their ACL injury were included. The patients were followed up in 2016 and 2017 with written information about the present study and asked to fill out a web-based study-specific questionnaire. Data such as age, gender, surgical procedural data, associated injuries, patient-reported outcome measurements, further knee surgeries and PROMs were collected from the SNKLR. One thousand eight hundred and forty-five patients matched the study criteria in the SNKLR. Of these, 1661 were still living in Sweden and were accessible for the study follow-up. A web-based questionnaire was created for the present study. All the subjects received written information about the study and how to fill out the questionnaire. The questionnaire was sent to the 1661 patients and the results are based on the 684 (41.2%) patients that chose to participate. The Swedish personal identity number [93] was used to identify each subject and match them with the data from the SNKLR. The study-specific questionnaire contains questions on whether the player returned to football after the ACLR, the reason for not returning to football, the pre- and postinjury level of football, the duration of return and, lastly, the reason for retiring from the sport. The questionnaire also included questions on new injuries and surgeries to the index knee and the contralateral knee.

III. The study follows up male and female footballers that participated in the Swedish National Elite Camp (NEC) for 15-year-old players between 2005-2011. The NEC is an annual camp organised by the Swedish Football Association, where each of the 24 districts in Sweden identifies 16 boys and 16 girls from local clubs in the region with the potential to develop into elite football players. These district teams (i.e. regional teams) play against each other at the camp. A total of 5285 players, 2631 boys and 2654 girls, born in 1990-1996, were included in the follow-up. The inception of the SNKLR in 2005 was used as the starting point for the follow-up of

the players from the NECs to make it possible to identify players that had had an ACL reconstruction. Information on player participation in Swedish league games and level of play was collected from the Swedish Football Association's administrative IT system (FOGIS). FOGIS is the comprehensive administrative data system used by the Swedish FA. It is used for player licensing, player transfers and the administration of cups and leagues. For use in this study, information on all the players born in 1990-1996 that participated in the NEC regarding the district they played for, whether they played in the youth team of an elite team at the age of 15, whether they played for an elite team at the age of 21 and whether they were still active at the age of 21was collected. Data were collected in 2018 and 2019. Using the national personal identity number, the players were matched with the SNKLR to identify those that had had an ACLR. The players with an ACLR that were injured when aged between 15 and 19 were compared with the rest of the players that participated in the national development camps to see how an early ACL reconstruction affected whether they remained active as football players and their chance of playing at elite level as seniors. The primary dependent variable in this study was whether the participants played in an elite senior team at the age of 21 to investigate whether an early ACLR affects the player's chance of becoming an elite player. In this study, an elite team was defined as a team that played in one of the top two national divisions in the season in which the player turned 21. The player had to participate in at least one official game for the team during the year. Secondary dependent variables were whether they were still active at 21, which was defined as the player participating in at least one official game during the year. To account for the influence of a possible relative age effect, the players were divided into four quartiles according to when in the year they were born. To adjust for the effect of the size of the district, the players were divided into four groups (D1-D4), D1 for the smallest district, ascending to D4 for players from the largest district.

IV. A study-specific questionnaire was created to attempt to identify football-specific factors associated with ACL injuries. The questionnaire was initially developed in Germany for the national "German ACL Registry in Football" and was later adopted and translated into Swedish by PhD student Alexander Sandon and supervisor Magnus Forssblad. The Swedish version of the questionnaire was made available for ACL-injured patients on the SNKLR website in 2017. As the patients log on to the

SNKLR to fill out other PROMs, the present study-specific questionnaire was available for football players to fill out voluntarily. Answers to the questionnaire for the study were collected for three years from the spring of 2017 to the spring of 2020. The development of the original questionnaire was performed by German researchers in 2015, based on a suspicion that ACL injuries may be influenced by many different factors associated with the players themselves and depending on training and team issues. The suspicion of unknown factors leading to the typical non-contact injury mechanism in professional football resulted in a questionnaire for an individual investigation of football-specific characteristics [81]. Player-specific characteristics and field-specific characteristics, but also different short-term changes in players' ability and performance, were included to be analysed in detail.

3.1 STATISTICS

I. All variables were summarised using standard descriptive statistics, such as the mean, standard deviation, median and frequency. The relationship between the variables assumed to be related to a return to football were calculated with non-parametric Kendall's tau or Pearson's chi-square analysis. Student's t test was applied in group comparisons of single variables such as age, provided that the variable was not severely skewed; otherwise, the Mann-Whitney non-parametric test was applied, e.g. for group comparisons of activity level. Analysis of variance for repeated measurements (group x time) was used to study changes in knee function (KOOS, Lysholm Knee Scoring Scale and Tegner Activity Scale). The variables which were found to be significantly related to a return to football were entered into a logistic regression analysis (stepwise forward with an inclusion level of 5%) to study the unique relationship between the variables and a return to football. In the logistic regression analysis, the relationships were expressed as an odds ratio (OR) with a 95% confidence interval. The significance level was set at 5%.

II. A statistician assigned to the SNKLR performed the statistical analyses. All the variables were summarised with standard descriptive statistics such as the mean (M),

frequencies and standard deviation (SD). Differences between return to football rates and re-rupture rates were tested with the chi-square-method. In this analysis, the relationships between the variables ware expressed as odds ratios with a 95 per cent confidence interval. Statistical significance was determined at an alpha level of 0.05.

III. All the statistical analyses were performed in IBM SPSS version 26. Descriptive statistics were calculated for all the study variables. The outcome variables in the current study were binary and, as a result, multiple logistic regression was used to analyse the data. Adjusted odds ratios and 95% confidence intervals (CI) were calculated for all the covariates that were included in the models. A *p*-value of less than .05 was considered statistically significant. Separate analyses were conducted for females and males to examine gender-specific associations.

IV. All the statistical analyses were conducted by the PhD student in IBM SPSS version 27. Descriptive statistics were calculated for all study variables. The data are presented at group level for all football players in total and for females and males separately to examine gender-specific differences.

3.2 ETHICS

I. The study was approved by the regional ethics board in Stockholm, ID 2011/337-31/3.

II. The study was approved by the regional ethics board in Stockholm, ID 2016/1194-31.

III. The study was approved by the regional ethics board in Umeå, ID 2018/68-31 and 2019-01962.

IV. The study was approved by the regional ethics board in Stockholm, ID 2011/337-31/3 and Jönköping, ID 2020-03747

3.3 LIMITATIONS

The most glaring limitation in this thesis is the low response rate in Studies I and II. A low response rate introduces the risk of non-response bias, where the group that participates in the follow-up and is included in the study might be significantly different from the group that is lost to follow-up. Traditionally, a response rate of over 80% has been suggested as acceptable. That threshold has, however, not been established scientifically, and remains the subject of debate [74, 152]. The roughly 40% response rate obtained in Studies I and II is far from the desired target. In an attempt to control for a possible non-response bias, a detailed drop-out analysis was performed. This was possible due to the information and variables registered in the SNKLR. The drop-out analysis in Study I found a significant difference between men and women, with the latter being more prone to answer the questionnaire. For all the other variables, no difference was found (Table 2). The drop-out analysis in Study II found that females, patients with a cartilage injury and older patients were more likely to answer the questionnaire. No other significant differences could be found (Table 3). This is consistent with the previous literature [135]. However, the problem with a substantial loss to follow-up is not unique to these studies. Ueland et al. performed a systematic review of missing patient-reported data in arthroscopic registries and found that the cumulative rate of follow-up ranged from 10%-70% in the nine investigated surgical registries [135]. They also reported a weighted mean compliance with PROMs of 56% at 0.5 years, 44% to 59% at one year, 40% to 61% at two years, 35% to 54% at five years and 40% at 10 years in the national registries. A missing-data analysis was reported or referenced in 58% in the 36 publications they reviewed. However, the loss to follow-up in Studies I and II is in line with other similar publications, indicating a larger and more general problem with patient-reported data after surgery. Getting patients to participate and fill out PROMs is vital to be able to determine the effectiveness of surgical procedures. We had planned to perform a study of elite football players using the PROMs from the SNKLR for this thesis. The very low response rates of the PROMs did not permit any meaningful analysis. Only 44% completed the two-year KOOS and 33% the five-year KOOS. Furthermore, only 23% of the players had completed both the two- and five-year KOOS and just 15% had completed all the PROMs at one, two and five years. Instead of an original research paper, this high drop-out rate was used as the basis of an editorial in which the problem of a low response rate was highlighted and discussed [120].

Table 2. Characteristics of the football players that participated in the whole study (included) and those players that did not participate in the follow-up (drop-outs) for Study I. n=541.

Characteristic			*Included*	*Drop-outs*	*p value*
Gender (%/n)					
Male			31.7/116	68.3/250	<0.001
Female			50.9/89	49.1/86	
Age at injury		(M ± SD)	22.9 ± 7.7	22.3 ± 7.6	n.s
Age at survey		(M ± SD)	23.9 ± 8.2	24.6 ± 8.6	n.s
Graft	hamstring	%/n	39.0/183	61.0/286	n.s
	patellar	%/n	30.6/22	69.4/50	
Other injuries					
Cartilage injury	Yes	%/n	31.5/39	68.5/85	n.s
	No	%/n	39.8/166	60.2/251	
Lateral meniscus injury	Yes	%/n	35.0/48	65.0/89	n.s
	No	%/n	38.9/157	61.1/247	
Medial meniscus injury	Yes	%/n	33.6/47	66.4/93	n.s
	No	%/n	39.4/158	60.6/243	
Tegner Activity Scale		(M ± SD)	3.4±1.59	3.5±1.59	n.s
Lysholm Knee Scoring Scale		(M ± SD)	70.0±19.27	68.9±18.93	n.s
Knee injury Osteoarthritis Outcome Score					
Pain		(M ± SD)	79.1±16.08	77.9±17.22	n.s
Symptoms		(M ± SD)	77.3±17.87	74.3±17.24	n.s
Sport and Recreation Function		(M ± SD)	49.1±27.98	49.3±27.17	n.s
Activity of Daily Living		(M ± SD)	88.9±14.49	88.0±15.54	n.s
Quality of Life		(M ± SD)	32.3±19.50	35.1±20.02	n.s

Table 3. Characteristics of the football players who participated in the follow-up (included) and the players who did not participate (drop-outs) for Study II.

Variable	Included	Drop-outs	*p* value
Gender (*%/n*)			0.01
Male	63/432	69/801	
Female	37/252	31/360	
Graft (*%/n*)			n.s
Bone-patella tendon-bone (BPTB)	18/118	18/209	
Hamstring	82/556	82/931	
Age at surgery (M ± SD)	25.9 ±8.6	24.4±7.9	0.007
Cartilage injury (*%/n*)			0.014
Yes	30/208	25/292	
No	70/476	75/869	
Medial meniscus injury (*%/n*)			n.s
Yes	22/148	23/272	
No	78/536	77/889	
Lateral meniscus injury (*%/n*)			n.s
Yes	21/145	23/261	
No	79/539	77/900	

4 RESULTS

I. Factors associated with returning to football after anterior cruciate ligament reconstruction

Fifty-four per cent reported that they returned to football and 46% that they did not. The logistic regression analyses found that female gender (p = 0.036, odds ratio (OR) 0.518), cartilage injury (p = 0.013, OR 0.368) and pain during physical activity (p = 0.002, OR 0.619) were significant negative predictors of returning to football after ACLR and rehabilitation. For players with all three significant factors, only 10% returned to football compared with 76.5% of those without any of these factors. No significant differences between returnees and non-returnees were found in terms of the KOOS, KT-1000, graft type, meniscal injury, Lysholm knee score, age or muscle torque.

II. Ten-year follow up of ACL-reconstructed football players from the SNKLR

In this study, 51% of players reported having returned to football after their ACLR. Of the players that did not return to football, 32% stated that the primary reason for this was related to the knee, while the remaining 17% primarily did not return for reasons not related to the operated knee. The most common knee-related reasons for not returning were pain and/or instability, followed by fear of re-injury. There was no significant difference in the return-to-football rate between males and females or between whether the patient received a patellar or a hamstring graft. Players in the younger age groups had a higher return-to-play rate (P<.0.001). There is a significant difference in the return rates for players at different levels (P< 0.001), with players at higher levels being more likely to return to football. Players who return to football run a significantly higher risk of additional ACL injury. Of the players who returned to football, 28.7% (OR 2.3, P <.0.001) had an additional ACL injury, 9.7% (OR 2.9, P < 0.001) had a graft failure and 20.6% (OR 2.1, P < 0.001) had a contralateral ACL injury. There was an improvement in the EQ5D and for all the KOOS subscales from before the surgery to the one-year follow-up. The improvement was maintained over time and was slightly higher at the 10-year follow-up compared with the one-year scores.

Table 4. Player-reported return to football, main reason for not returning or quitting, level returned to, and time played following the return to football.

VARIABLES		*%*	*N*
DID YOU RETURN TO FOOTBALL FOLLOWING YOUR ACLR?	Yes	51	349
	No	49	335
IF NO, WAS THAT PRIMARILY FOR REASONS RELATED TO THE OPERATED KNEE?	Yes	65.4	219
	No	34.6	116
RETURN TO FOOTBALL RATES AT DIFFERENT AGE INTERVALS	13-15	63.4	26
	16-20	60.3	114
	21-25	65.8	102
	26-30	49.1	56
	31-35	35.8	29
	36-40	31.5	17
	>40	10	5
TO WHAT LEVEL OF FOOTBALL DID YOU RETURN COMPARED WITH BEFORE THE INJURY?	Same or higher	68.3	235
	Lower	31.7	109
DO YOU STILL PLAY FOOTBALL?	Yes	20.5	71
IF NO, MAIN REASON FOR QUITTING	Knee	37.9	131
	Other	41.6	144
		M	SD
FOR HOW MANY YEARS DID YOU PLAY FOOTBALL AFTER YOU RETURNED FROM THE ACLR?	Years	4.9	3.3

Table 5. The level played in the Swedish football league system at the time of injury and return to football rates (n=684).

PRE-INJURY LEVEL	RETURNED TO FOOTBALL	
	n	(%)
NATIONAL TEAM	1	100
TOP DIVISION	7	100
HIGHER DIVISIONS	26	65.4
MIDDLE DIVISIONS	179	61.5
LOWER DIVISIONS	317	51.7
RECREATIONAL	67	25.4
YOUTH	87	37.9

III. ACL reconstruction restores the potential for youth football talents to reach elite level and continue playing

Of the 5285 football players that had participated in the NEC, 524 (9.9%) players had an ACLR registered in the SNKLR and 23.3% (n=122) of those players had a second ACLR, 11.5% (n=60) contralateral and 11.8% (n=62) an ACL revision. Twice as many female players had an ACLR compared with male players. The ACL injuries occurred at the age of 15-19 for 5.5% of the football players. During the season in which the players turned 21, a total of 570 (10.8%) of the players that participated in the NEC were playing at elite level (females 296 (11.2%) and males 274, 10.4%). The analysis shows that having an ACLR at the age of 15 to 19 did not have a statistically significant effect on playing in an elite team at age 21. Nine (12%) of the males who had an ACLR at ages 15 to 19 and 25 (8.4%) of the

females were playing in an elite team at 21. Playing for the youth team of an elite club at age 15 was a strong predictor of playing for an elite club at age 21 for both males and females. A reversed age effect was observed in the male players, such that players born later in the year were more likely to play for an elite team at 21. For females, birth quartile did not have a statistically significant effect on becoming an elite player. Players from larger districts at the age of 15 were more likely to be playing at elite level at 21. The potential to be playing at an elite club at the age of 21 was not significantly affected by whether the ACL injury occurred in the early (15-17) or late (18-19) teenage years. Playing for the youth team of an elite club at the age of 15, district size and the quartile in which the players were born did not influence the risk of sustaining an ACL injury between 15 and 19 for either gender.

Regarding the number of players that were still actively playing football at the age of 21, the results reveal that, in the season in which the players turned 21, a total of 72% of the players were still actively playing football. More of the male players than the female players were still active, 82% and 63% respectively. The analysis shows that an ACLR between the ages of 15 and 19 did not have a statistically significant effect on whether the player was still active at 21. Females playing for the youth team of an elite club at the age of 15 were less likely to still be active later, whereas male players playing for the youth team of an elite club at the age of 15 were more likely to be active later.

IV. Epidemiology of ACL injuries in football

ACL injuries were more frequently sustained during games, 66%, than during practice, 25%. The injury mechanism was non-contact in 59% and contact in 41%. For contact injuries during games, no action was taken by the referee in 63% of the situations and a red card was shown in 0.5%. The risk of ACL injury was highest early in the football game, with 47% sustained during the first 30 min and 24% in the first 15 min. Players changing to a higher level of play, 15%, had a higher rate of ACL injuries than players changing to a lower level, 8%. This difference was especially seen in female football players, with 20% of ACL injuries being sustained by players going to a higher division compared with 7% for those going to a lower division. Fifteen per cent of the male and 21% of the female ACL injuries occurred in teams with a coach change during the season. Knee control exercises to warm up were used by 31% of the female players and 16% of the males. Forty per cent of the players reported that they did not plan on returning to football.

5 DISCUSSION

5.1 RETURN TO FOOTBALL AFTER ACL RECONSTRUCTION

The first study attempted to identify factors associated with returning to football after an ACLR by using the Capio Artro Clinics information available from surgery, muscle strength tests, PROMs and objective knee laxity and found a negative relationship with female gender, the presence of a cartilage injury and pain during physical activity. That having pain while performing sport reduces the return to sports rate is easy to understand and is in line with previous research [83, 84] and with the results in the second study, where half of those that did not return to football for primarily knee-related reasons stated problems with pain and instability. ACLR women appear to score slightly lower on the KOOS sport and recreation section but do not appear to have poorer outcomes following ACLR overall [66, 67, 128]. So, it is not clear that a possible lower return rate in women can be explained by less successful surgery in women and the lower return rate was not repeated in Study II. Returning to football after ACLR is multifactorial [16] and some of the factors that have been shown to influence a return to football are time from injury to surgery [52], motivation and fear of re-injury [40, 89, 145]. In the 10-year follow-up study, 10% of the players stated that fear of a new ACL injury was their primary reason for not returning to football.

Both the first two studies had similar return-to-play rates, with just over half the players returning to football and, in the last study, 60% claimed that they intended to return to football. The rate of return to football after ACLR varies between studies and appears to be correlated with the preinjury level of play and age, as shown in Studies II and IV. In amateur Italian footballers, only 21% returned to football after ACL reconstruction [106]. Professional players, on the other hand, almost always return to football, but only roughly half the players on a more average level return to playing [15, 39, 79, 105, 141, 150]. Several studies have found that, in the year after the return to play, football participation declines [41, 105, 141, 150]. Without a more in-depth analysis or a control group, it is difficult to interpret the extent to which this decline is caused by the ACL injury. In a case-control study comprising 117 ACLR female football players, more of the reconstructed players stopped playing. However, only eight (11%) stated poor knee function as the primary reason for quitting [54]. In the follow-up of the 5285 players from the national elite camps, we found a decline in the number that were still playing football, but this was not

affected by whether or not the player had had an ACLR. More females had stopped playing, which is in line with the literature on football participation [101].

In Study III, we investigated how an ACLR affected a young football talent's potential to become an elite player as an adult and, somewhat counterintuitively, we found that undergoing the surgery did not have a significant impact. It appears that, at group level, the ACLR restored knee function sufficiently for the player to return to football and compete with their peers. Others have studied the post-ACLR football performance more directly. A study of professional players in the MLS found that players returning from ACLR participated in fewer games after their return to play [9], while another did not find any difference in the performance compared with before the injury [39]. Using public information on professional European football players, Bart et al. found that, following ACLR, they played fewer games and minutes per season, minutes per game, scored fewer goals and committed more fouls per season [12]. A similar decline in performance in players from the five largest European leagues was observed by Niederer et al. They found that game performance was lower in the first two seasons after the players returned to football in terms of goals and assists made, rate and number of completed passes, dribbles and minutes played [105]. However, by the third season, the ACLR players' performance equalled or exceeded that of their matched controls in another study of elite male football players [49].

Another aspect is the long period away from football that the player is forced to endure after an ACL injury. Although one study from 2009 reports that the average return to full football participation was five months [124], most other studies report longer rehabilitation periods and, in the professional football players, the time to return to training is six to seven months and seven to eight months for match play [105, 122, 141, 142, 150]. The average return time was about one year in amateur players [12, 20]. In essence, ACL surgery and subsequent rehabilitation mean that the player is out of the game for roughly one season. One would think that this alone would be detrimental for a young football talent's chance of reaching the highest level in such a competitive sport, but as shown in Study III, this was not the case. It therefore stands to reason that this would also apply to other injuries, especially those from which the young athlete is expected to make a full recovery, and probably other sports. This should help reassure patients, doctors and not least parents and coaches that taking the time required to recover from an injury is not only good for obvious health reasons but also does not prevent the athlete from having a successful career in the long run.

5.2 RISK OF ACL INJURY IN FOOTBALL

Hewett et al. have formulated four theories to explain the risk of ACL injuries. The first is *the ligament dominance theory*, suggesting that insufficient ground reaction force absorption by the lower limb muscles results in excessive hip adduction/internal rotation and knee valgus. *The quadriceps dominance theory* suggests that shear stress on the ACL is induced by excessive relative quadriceps strength. Strength difference in the right and left legs possibly leading to a greater risk of ACL injury is *the leg dominance theory*. Lastly, *the trunk dominance theory* suggests that insufficient trunk control during athletic manoeuvres may put the ACL at increased risk of injury [69].

The injury mechanism for ACL ruptures in football is often distinguished as contact or non-contact in nature, with the non-contact mechanism accepted as the most prevalent overall [1]. The proportions of non-contact injuries (range 44%-85%) are, however, difficult to define due to varying numbers in the literature and studies using different definitions and often including small sample sizes [15, 21, 43, 61, 122, 126, 143]. In Study IV, the players themselves drew this distinction and 59% of the players reported that there was no contact at the time of injury. In a systematic review of the injury mechanism of non-contact ACL injuries in football, Alentorn-Geli et al. summarised the most common actions leading to ACL injury as changing direction or cutting manoeuvres combined with deceleration, landing from a jump in or near full extension or pivoting with the knee at near full extension and a planted foot [1]. In non-contact ACL injuries, there is a clear gender difference in terms of the knee that is primarily injured while playing football, with female players being more likely to injure the supporting leg and males tending to sustain ACL injuries in their dominant leg [19, 21, 39, 61]. In Study IV, we did not make any distinction in terms of injuries between the dominant and support leg or the type of contact, but we found slightly more injuries to the right leg (53.5%) but with no clear gender difference. Another finding in that study was that 20% reported symptoms or injury in the six weeks prior to the ACL rupture, but Lundblad et al. have shown that an absence due to injury did not increase the risk of ACL injury in professional male players [92].

In a study performing a video analysis of ACL injuries in male professional football players, three main categories of non-contact and indirect contact injury situations were identified. The most common was pressing followed by re-gaining balance after kicking

and landing after heading. Knee valgus was frequently seen, but a complete valgus collapse was only observed in contact situations [143]. A kinematic analysis of pressing situations suggests that this rapid knee valgus movement is not seen in normal play and is unique to injury situations [121]. Another video analysis study found that 51% of the ACL injuries occurred while tackling, with cutting (15%) as the other major injury mechanism. The body positions when the non-contact ACL injuries occurred were hip flexion (88%) and hip abduction (83%), with a valgus force on the knee (58%) and the knee near full extension (71%) and the foot flat (58%) [21]. Yet another study used videos of ACL injuries in male professional football players obtained from YouTube. They found that, in the case of non-contact injuries, they mostly occurred during pressing, dribbling, or tackling and 26% of the injuries took place in the first nine minutes of the games [61]. In Study IV, the players reported that 24% of the ACL injuries occurred in the first 15 minutes. Della Villa et al. also reported that most ACL injuries take place early in matches [91]. This clearly indicates that ACL injuries are not primarily caused by fatigue. In two of the video analysis studies, most of the injuries occurred while defending, 73%-79% [21, 143]. An additional video study found the same risk for defending and attacking actions and that attackers were injured during offensive actions and defenders were injured while defending [61]. A survey study, on the other hand, found a higher risk of ACL injury in the attacking team, 69.3% [15]. Goalkeepers are less likely to sustain an ACL injury than outfield players, but there are no differences in the ACL injury risk between defenders, midfielders, or forwards [15, 122, 142]. Volpi et al. performed a systematic review of the literature on ACL injury risk factors in football and, besides, the factors already mentioned suggest that genetic factors, anatomical and biomechanical factors and playing position might affect the injury risk. However, they concluded that there is a low level of evidence for risk factors of ACL injuries in football and that further studies are therefore needed [138].

Another finding in Study IV was that more of the injuries were sustained while playing on artificial grass than on natural grass, but, as we lack any information on the exposure, no inference could be drawn. There is contradictory evidence relating to whether natural or artificial grass entails a higher risk of ACL injury. Some studies show a higher rate on natural grass [71], while others show no difference [11]. Nothing beats the feeling of playing football on a perfect natural grass pitch, but there is currently no evidence supporting the notion that artificial grass should not be used in order to prevent ACL injuries. Given the advantages of artificial grass in densely populated areas or in cold climate regions, like Sweden, it would not be feasible to convert artificial grass back to natural grass to any large extent.

5.3 RISK OF NEW ACL INJURIES

After return to play, the ACLR players run a greater risk of new knee injuries and especially further ACL injuries [41, 140]. Female football players run a five times higher risk of further ACL injuries and professional male players a 20 times higher risk of further ACL injuries compared with their uninjured peers [41, 105]. When it comes to other types of lower limb injury, the ACLR players do not run a higher risk of injury after they return to play [9, 41, 140].

Rehabilitation and physiotherapy are a fundamental part of the post-operative care of any ACLR patient. Several rehabilitation protocols and guidelines for return to play exist, but there is limited evidence relating to the parameters that influence or predict the results of the ACLR [136]. The decision to allow a player to return to football remains a challenge and depends on several factors. Time is needed for the graft to mature and be strong enough to withstand the forces of playing football. In recent years, studies have shown a lower risk of re-rupture with a return to play after nine months [62]. Another major factor in a successful return to play is the psychological readiness of the player. Different forms of functional, strength and performance tests are currently widely used as return-to-play criteria [109, 113, 127], but there is very little scientific evidence of their validity [76]. Another issue for a safe return to football is the transition from rehabilitation with the physio to back-to-team training under coaches used to dealing with healthy athletes. To bridge this gap, adding on-field rehabilitation to the traditional protocol may make sense [28, 136, 137].

Study II showed that players who returned to football ran a significantly higher risk of suffering an additional ACL injury than players that did not return to football. Of the players who returned to football, 28.7% had an additional ACL injury, 9.7% had a graft failure and 20.6% had a contralateral ACL injury. Previous studies identified returning to pivoting sports as a risk factor for new ACL injuries after a reconstruction of the ligament [3, 23, 53, 86, 119, 144, 147]. A later study of professional male players with a median follow-up of four years identified a second ACL rate of 18%, confirming our finding [27]. Fältström followed a cohort of female ACLR football players and found that 42% of those that returned to football would go on to have a second ACL injury with a mean follow-up of 6.5 years.’ [55]. The very high risk of further ACL ruptures is a matter of serious

concern for the player's future knee health and should be considered when deciding on a return to play. Slightly albeit not significantly more females suffer a further ACL rupture after returning to football and this is consistent with systematic reviews of the outcome and further ruptures after ACLR dependent on gender [117, 149].

5.4 PREVENTING ACL INJURIES

In the follow-up of the 15-year-old talents in Study III, as many as 10% of the players would go on to have an ACLR, with girls running double the risk of boys. The same incidence was reported in a systematic review and meta-analysis of ACL injuries in adolescent athletes [17]. The high incidence of ACL injuries in football highlights the importance of finding ways to prevent these injuries. Since ACL injuries occur almost exclusively in pivoting sports like football, the most effective way to lower the rate of injury is naturally not to participate in these activities. Football is not going to be prohibited and people are not going to completely stop playing the game just to avoid a knee injury, so other measures are needed to reduce ACL injuries. As noted earlier, most ACL injuries are non-contact in nature and, of the contact injuries, only 0.5% resulted in a straight red card, indicating that stricter rules will not prevent ACL injuries to any noticeable degree. Another way to try to prevent ACL injuries is to attempt to identify high-risk players. Study IV found that teams changing coaches and players moving to a higher division appear to entail an increased risk of ACL injury, thus warranting attention and further investigations. The most important person in implementing and continued adherence to injury-prevention measures is the coach [14]. Neuromuscular training programmes have proven effective in reducing knee injuries [24, 58, 78, 125]. Knee control exercises to warm up were used by 31% of the female players and 16% of the males in Study IV, further highlighting the challenge posed by the obstacle of implementing these programmes and continued adherence to them [8, 88]. Several studies have attempted to identify movement patterns and players with vulnerabilities that could be targets for intervention [32, 56, 131]. In a real-world setting, this screening will be performed by coaches and sport medicine professionals at the clubs and there is evidence that they would be no better at it than monkeys or random chance [87, 104]. Furthermore, even in research settings, the predictive value of these screenings in identifying who will sustain an ACL injury is poor [51, 77, 108]. Diekfuss et al. conducted a prospective case-control study in which they performed functional MRI scans of female high-school football

players, followed by a similar study of boys. The studies found that the players that subsequently sustained an ACL injury had a weaker functional connection between a cortical sensory-motor region and a cerebellar region responsible for balance and co-ordination [29, 30]. It is perhaps these players that would benefit most from a neuromuscular training programme, but we are still some ways from being able to screen all footballers with functional MRIs.

5.5 TREATMENT OF ACL INJURIES IN FOOTBALL

ACL injuries can have detrimental consequences for the future knee health of players. In a 12-year follow-up of female ACL-injured football players, as many as 82% showed changes to the injured knee on X-rays and 51% fulfilled the radiographic criteria for knee osteoarthritis [90]. A 10-year MRI follow-up of female football players found very similar results, with 51% being diagnosed with osteoarthritis and more severe degenerative changes seen in those with meniscal pathology [110]. Among ACL-injured male football players, 78% showed radiographic changes to their index knee after 14 years and 41% fulfilled the criteria for radiographic knee osteoarthritis compared with 4% in the uninjured knee [139]. Neither study found any significant difference between surgically or conservatively treated players. Somewhat surprisingly, a 15-year follow-up of ACLR patients found that those that returned to pivoting sports like football, handball or basketball had less radiographic and symptomatic osteoarthritis [107].

The decision relating to surgical or non-surgical treatment for an ACL-deficient knee is based on functional knee stability and the expected functional demands of the knee. A highly demanding pivoting sport like football requires good knee stability and, for this reason, ACL reconstruction is regarded as the gold standard for players with a desire to return to play [4, 116, 122]. This is reflected in the results of a survey of the opinions of orthopaedic surgeons, where 98% recommended ACLR to enable a return to pivoting sports, like football [99]. Even among patients, the intention to return to highly demanding activity is a key motivating factor for the surgical rather than the non-surgical treatment of the ACL injury [123]. In a group of Norwegian football players, 74.4% had ACL reconstruction and it was found to be necessary for a return to play at higher levels [15]. Among the elite players, almost everyone underwent reconstructive surgery, 138/140. One

player returned to play without surgery, and another ended his career directly after the ACL injury [141]. Although rare, there are case reports proving that it is possible to return to professional football without reconstructive surgery of the torn ACL [146].

The goal of an ACL reconstruction is to reduce laxity in the knee. Study I found no difference in the laxity as measured by the KT-1000 between those that returned to football and those that did not. Lindanger et al. examined the role of residual knee laxity after ACL reconstruction and found that it did not affect the return to football rate, but those with residual laxity had a higher rate of revisions and a shorter career [85]. The intra-articular infection rate after ACLR is 1% for both professional and amateur football players and it is not affected by the difference in the timing of surgery. Football players have a significantly higher infection rate then skiers, but the reason for this is not fully understood [80]. In a study comparing patellar and hamstring grafts, Gifstad et al. found a lower revision rate in football players with a patellar graft, indicating that it might be more suitable for patients aiming to return to pivoting sports. In Scandinavia, 18% of the football players received a patellar graft, but by far most popular choice for ACLR is a hamstring graft (72%) [57]. The quadriceps tendon has attracted increasing interest as a graft choice in ACLR. Like any graft, it has a negative effect in the area from which graft is taken and, in the case of the quadriceps tendon, this entails lower quadriceps strength of 15-30% compared with the other graft types mentioned [31]. Given the importance of quadriceps strength in striking the ball, which is fundamental in football, this reduction in power should be considered by the surgeon and player before choosing this graft. For players undergoing surgery with a hamstring graft, the affected muscle is the semitendinosus, which has less activity, even after full rehabilitation [5], but this is partly compensated for by an increase in the biceps femoris [129]. Another surgical technique that has attracted interest in recent years in the performance of a lateral extra-articular tenodesis in addition to the ACLR. Although one study of 24 professional male players [2] and another of 16 female players [63] have shown promising results, more research is needed before it can be proved that it provides added value for football players. According to an RCT of non-professional football players, using an anteromedial portal for the femoral drilling provides greater rotatory stability than the transtibial technique. This did not have any significant clinical relevance in terms of knee laxity, muscle function, athletic- and sports-specific tasks or in the patient-reported outcome measurements [133]. A survey of treatment preferences for ACL injuries among MLS team doctors found that the surgeons were split regarding drilling technique (50% transtibial and 46% accessory medial) and 68% preferred a patellar graft [42]. The surgical

technique and graft choice are likely to remain a contested topic, but none of the studies in this thesis found that they significantly influenced the outcome in ACLR football players.

6 CONCLUSIONS

I. Female gender, cartilage injury and knee pain during physical activity were independent negative factors for returning to football after ACL reconstruction. At a mean follow-up of 3.2 ± 1.4 years after ACL reconstruction, pain during and/or after physical activity was reported to be the most common symptom in football players.

II. Players who return to football run a significantly higher risk of sustaining a further ACL injury. Only half the football players return to play after ACL reconstruction and, in two-thirds of those who did not return, the reason was knee related.

III. ACL reconstructive surgery in talented youth football players offers them the opportunity to become elite players as seniors and permits an activity level on a par with that of their uninjured peers. However, almost one in four requires further ACL surgery, so the players' future knee health should be considered when deciding on the return to play.

IV. Neuromuscular training programmes have been shown to reduce ACL injuries, but greater adherence to these programmes remains a challenge, as only one in five of the ACL-injured football players reports using them. Teams changing their coaches and players moving to a higher division appear to run an increased risk of ACL injury, thereby warranting attention and further investigations.

7 POINTS OF PERSPECTIVE

Science is about explaining and trying to understand the world. It is built on previous research and lays the foundation for future studies. The studies in this dissertation originate from the extensive research in the field and the wisdom of creating surgical registries. It has provided some insight into the outcome of ACLR in football players, but many new and interesting questions have been raised. For instance, a longer follow-up and more detailed study of the players from the national elite camps in Study III could assist in an understanding of how an ACL injury affects the entire career and the performance of the players. Even further in the future, the role of ACLR and career length in the risk of developing osteoarthritis could be investigated in this cohort.

Another interesting topic for further exploration is the return to football after ACLR and the factors that play a part in that decision. Some factors have been studied in this thesis, but the fact that about 40% of the players state that they will not be returning even before surgery indicates that there is more to learn. If many patients already make the decision relating to a return to football at this early stage, it might have major implications for the way we should understand and conduct studies on how surgery, post-operative rehabilitation and knee function affect a return to sports.

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