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DETERMINANTS OF RETURN TO SPORT IN ELITE ATHLETES AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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DETERMINANTS OF RETURN TO SPORT IN ELITE ATHLETES AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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Doctoral Thesis in Medicine submitted to the Faculty of Medicine of the University of Porto

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LIST OF PUBLICATIONS

In accordance with the Doctoral studies regulation of Portuguese Universities, this Thesis comprises the following publications:

- Pinheiro VH, Borque KA, Laughlin MS, Jones M, Balendra G, Kent MR, Ajgaonkar R, Williams A. **Determinants of Performance in Professional Soccer Players at 2 and 5 Years After ACL Reconstruction**. Am J Sports Med. 2023 Dec; 51(14):3649-3657. doi: 10.1177/03635465231207832. Epub 2023 Nov 13. PMID: 37960868. (Quartile 1, SJR);
- Pinheiro VH, Laughlin M, Borque KA, Ngo D, Kent MR, Jones M, Neves N, Fonseca F, Williams A. **Career Length After Surgically Treated ACL Plus Collateral Ligament Injury in Elite Athletes**. Am J Sports Med. 2024 Aug;52(10):2472-2481. doi: 10.1177/03635465241262440. Epub 2024 Aug 3. PMID: 39097768. (Quartile 1, SJR);
- Pinheiro VH, Jones M, Borque KA, Balendra G, White NP, Ball SV, Williams A. **Rates and Levels of Elite Sport Participation at 5 Years After Revision ACL Reconstruction**. Am J Sports Med. 2022 Dec;50(14):3762-3769. doi: 10.1177/03635465221127297. Epub 2022 Nov 3. PMID: 36326297. (Quartile 1, SJR).

Other publications complementary to the Dissertation:

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- Borque KA, Jones M, Laughlin MS, Balendra G, Willinger L, Pinheiro VH, Williams A. **Effect of Lateral Extra-articular Tenodesis on the Rate of Revision Anterior Cruciate Ligament Reconstruction in Elite Athletes**. Am J Sports Med. 2022 Nov;50(13):3487-3492. doi: 10.1177/03635465221128828. Epub 2022 Oct 18. PMID: 36255290. (Quartile 1, SJR);
- Borque KA, Jones M, Balendra G, Willinger L, Pinheiro VH, Anand BS, Williams A. **High return to play rate following treatment of multiple-ligament knee injuries in 136 elite athletes**. Knee Surg Sports Traumatol Arthrosc. 2022 Oct;30(10):3393-3401. doi: 10.1007/s00167-022-06926-3. Epub 2022 Mar 13. PMID: 35279739. (Quartile 1, SJR);
- Jones M, Pinheiro VH, Balendra G, Borque K, Williams A. **No difference in return to play rates between different elite sports after primary autograft ACL reconstruction**. Knee Surg Sports Traumatol Arthrosc. 2023 Dec;31(12):5924-5931. doi: 10.1007/s00167-023-07654-y. Epub 2023 Nov 10. PMID: 37947828. (Quartile 1, SJR);
- Borque KA, Laughlin MS, Hugo Pinheiro V, Ngo D, Kent M, Balendra G, Jones M, Williams A. **The Effect of Primary ACL Reconstruction on Career Longevity in English Premier League and Championship Soccer Players Compared With Uninjured Controls: A Matched Cohort Analysis**. Am J Sports Med. 2024 Apr;52(5):1183-1188. doi: 10.1177/03635465241235949. Epub 2024 Mar 15. PMID: 38488398. (Quartile 1, SJR).

ABREVIATIONS

AMB	Anteromedial bundle
ACL	Anterior Cruciate Ligament
ACL-R	Anterior Cruciate Ligament Reconstruction
AFL	Australian Football League
ALC	Anterolateral Complex
CPL	Canto Posterolateral
GPS	Global Positioning Systems
HS	Semitendinosus and Gracilis
LCA	Ligamento Cruzado Anterior
LCM	Ligamento Colateral Medial
LET	Lateral Extra-Articular Tenodesis
MARS	Multicenter ACL Revision Study
MCL	Medial Collateral Ligament
MLKI	Multi-ligamentous
MLS	Major League Soccer
NFL	National Football League
NHL	National Hockey League
PER	Player Efficiency Rating
PLC	Posterolateral Corner
PROs	Patient-Reported Outcomes
PT	Patellar Tendon
RCT	Randomized Controlled Trials
RTP	Return to Play
RTS	Return to Sport
R-LCA	Reconstrução do Ligamento Cruzado Anterior

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TABLE OF CONTENTS

ABSTRACT

Anterior cruciate ligament (ACL) injuries are among the most common sports-related injuries, and their incidence is increasing at all levels of competition. Elite athletes undergo anterior cruciate ligament reconstruction (ACL-R) with the goal of returning to their preinjury level of performance and continuing to play at the highest level possible. However, despite advances in ACL-R techniques and physiotherapy that have led to a significant improvement in simple return to play (RTP) rates in elite sports, little is known about subsequent performance levels, and career longevity outcomes, as well as the factors that influence them.

The aim of this doctoral thesis is to identify the determinants of return to sport (RTS) rates, levels of performance, and career longevity after ACL-R in elite athletes, providing a better understanding of the impact of patient, surgical and post-operative factors on RTS. As truly "isolated" ACL-R surgery is becoming less common with the recognition of important associated peripheral structure lesions, especially so in elite athletes, and the fact that graft re-rupture rates remain high in this population, and there is a lack of data on the above mentioned outcomes after primary and revision ACL-R, three studies were carried out.

In the first study a consecutive cohort of 200 professional soccer players undergoing primary ACL-R between 2005 and 2019 were analysed. The effect of patient, surgical, and post-operative factors on performance (combination of league level and playing time) rates were evaluated with univariate and multivariate logistic regression models. The presence of ≥50% thickness chondral pathology, ACL-R without lateral extra-articular tenodesis, and age over 25 years at the time of surgery were all significant risk factors of worse performance rates after ACL-R. Significant decreases in performance rates were also noted at 2 and 5 years post-operatively.

The second study consisted of an analysis of consecutive cohort of 98 elite athletes undergoing combined ACL+medial collateral ligament (MCL) and ACL+posterolateral corner (PLC) surgery between February 2001 and October 2019. A subgroup of elite male soccer players from this population was compared to a previously identified cohort (population analysed in first study) having had isolated primary ACL-R without other ligament surgery. Among these elite athletes, the average career length after surgical treatment of combined ACL+MCL and ACL+PLC injuries was 4.5 years. Professional soccer players with combined ACL+PLC surgery returned at a lower rate and required a longer RTP time when compared to the ones with isolated ACL or combined ACL+MCL injuries. However, those that did RTP had the same career longevity and competition level.

In the third study a retrospective review of a consecutive series of 48 elite athletes undergoing revision ACL-R between 2009 and 2019 was carried out. RTP rates and competition level decreased over time after revision ACL-R. The presence of ≥50% thickness chondral pathology was associated with lower RTP rates and competition level at RTP time, while medial meniscus pathology was associated with lower competition level at RTP.

By providing a better understanding of the patient, surgical and post-operative factors that affect RTS rates after ACL-R, this thesis allows realistic expectations about outcomes to be set, and to predict and potentially improve RTS outcomes in elite athletes undergoing ACL-R. This knowledge is also valuable for general population as studying elite athletes helps define important prognostic factors and identify best treatment choices. Studies of the general population often fail to do so.

RESUMO

As lesões do ligamento cruzado anterior (LCA) estão entre as lesões desportivas mais comuns, e a sua incidência tem vindo a aumentar em todos os níveis de competição. Os atletas de elite são submetidos a reconstrução do LCA (R-LCA) com o objetivo de voltar ao nível de desempenho prévio à lesão, continuando a competir ao mais elevado nível possível. No entanto, apesar dos avanços nas técnicas de R-LCA e fisioterapia terem levado a uma melhoria significativa nas taxas de retorno à competição em desporto de elite, pouco se sabe sobre os níveis de desempenho subsequentes e a longevidade da carreira, bem como os fatores que os influenciam.

O objetivo principal desta tese de Doutoramento é identificar os determinantes do retorno ao desporto (RTS), níveis de desempenho e longevidade da carreira após R-LCA em atletas de elite, proporcionando uma melhor compreensão do impacto dos fatores do paciente, cirúrgicos e pós-operatórios no RTS. À medida que a cirurgia de R-LCA verdadeiramente "isolada" se torna menos comum, com o reconhecimento de importantes lesões de estruturas periféricas associadas, especialmente em atletas de elite, e o facto de as taxas de re-rotura do enxerto permanecem elevadas nesta população, associado à escassez de dados sobre os resultados supramencionados após R-LCA primária e de revisão, foram realizados três estudos.

No primeiro estudo, analisámos uma coorte consecutiva de 200 jogadores de futebol profissionais submetidos a R-LCA primária entre 2005 e 2019. O efeito dos fatores do paciente, cirúrgicos e pós-operatórios nas taxas de desempenho (combinação de nível de liga e tempo de jogo) foi avaliado com modelos de regressão logística uni e multivariada. A presença de patologia condral com atingimento ≥50% da espessura, R-LCA sem tenodese extra-articular lateral e idade acima de 25 anos no momento da cirurgia foram todos fatores de risco significativos para piores taxas de desempenho após R-LCA. Reduções significativas nas taxas de desempenho também foram observadas aos 2 e 5 anos após a cirurgia.

O segundo estudo consistiu na análise de uma coorte consecutiva de 98 atletas de elite que realizaram cirurgias combinadas de LCA + ligamento colateral medial (LCM) e LCA + canto posterolateral (CPL) entre fevereiro de 2001 e outubro de 2019. Um subgrupo de jogadores de futebol masculino de elite dessa população foi comparado a uma coorte previamente identificada (população analisada no primeiro estudo) que realizou R-LCA primária isolada sem outras cirurgias ligamentares. Entre esses atletas de elite, a duração média da carreira após o tratamento cirúrgico de lesões combinadas de LCA+LCM e LCA+CPL foi de 4.5 anos. Jogadores de futebol profissionais com cirurgia combinada de LCA+CPL apresentaram taxas inferiores de retorno à competição e necessitaram de mais tempo para o seu retorno em comparação com aqueles com lesão do LCA isolada ou lesões combinadas de LCA+LCM. No entanto, os que retornaram ao jogo tiveram a mesma longevidade de carreira e nível de competição.

No terceiro estudo, foi realizada uma revisão retrospetiva de uma série consecutiva de 48 atletas de elite

que realizaram revisão de R-LCA entre 2009 e 2019. As taxas de retorno à competição e o nível de competição diminuíram ao longo do tempo após a revisão de R-LCA. A presença de patologia condral com atingimento ≥50% da espessura foi associada a menores taxas de retorno à competição e nível de competição no momento do retorno, enquanto a presença de patologia do menisco medial foi associada a um nível de competição mais baixo aquando do retorno à competição.

Ao proporcionar uma melhor compreensão dos fatores do paciente, cirúrgicos e pós-operatórios que afetam as taxas de RTS após R-LCA, esta tese permite estabelecer expectativas realistas sobre os resultados, prever e, potencialmente melhorar os resultados de RTS em atletas de elite submetidos a R-LCA. Esse conhecimento será também valioso para a população em geral, uma vez que estudar atletas de elite ajuda a definir fatores de prognóstico importantes e a identificar as melhores opções de tratamento. Os estudos da população em geral muitas vezes não o conseguem fazer.

CHAPTER I

INTRODUCTION AND AIMS OF THE THESIS

1. INTRODUCTION

1.1 ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION IN ELITE ATHLETES

ACL injuries are among the most common sports-related injuries, and their incidence is increasing at all levels of competition [1-5]. ACL-R is commonly performed in an effort to restore knee stability and function [6] . Although it is possible for athletes to return to high-level sport with ACL deficient knees,[7] most require, and benefit from, reconstructive surgery to RTS predictably and safely [8]. Athletes undergoing ACL-R have high expectations: in one study 88% expect a return to their preinjury level of sport [9]. However, only 60% of non-elite[10] and 83% of elite athletes [11] achieve this goal. A combination of physical, psychological, and social factors [8,12-15] may give elite athletes a greater chance of returning to sport after ACL-R than non-elite athletes.

There is no consensus on elite athlete definition, due to the complexity of intra- and inter-sport differences [16]. Several factors are relevant for elite status categorisation, such as age, gender, professionalism, competition/league level, national/international ranking, nationality, sport and success/achievements [15,17]. Therefore, in the present thesis, elite athletes are defined as those who are paid to perform their sport, or participate at national/international level in an amateur sport [10,11,18]. This population presents a great challenge to the treating clinician, as returning to "near peak" performance may not be sufficient to restore them to their preinjury performance [19]. Elite athletes test judgement and surgery, and even minor failures can lead to significant interference with athletic performance [15]. Other challenges include management of confidentiality with the club and media, as well as managing expectations on return to preinjury performance of athletes, agents, coaches, clubs, parents, and public [15,19]. In addition, the potential for lawsuits is increasing, partly due to large financial gains [15,20]. Despite being a great challenge, elite athletes enhance the quality of a surgeon's practise. For instance, they allow learning of conditions that are rarely present in general population. However, they also get knee conditions common in the general population but that are greatly exacerbated and exaggerated. Also, the intensity training and playing on this special group differentiates treatment outcomes unlike in the general population. Studies of elite athletes allow differentiation of what works and what does not work. This leads to improvements in care that can also be offered to patients in general [8,15].

Although advances in ACL-R techniques and physiotherapy have led to a significant improvement in simple RTP rates in elite sports,[11,16,21] little is known about subsequent performance levels, and career longevity outcomes. There is simply not enough data to determine which athletes will return to high levels of play *versus* those who may RTP but never to their preinjury levels, as well as their ability to continue playing. A better understanding of which patient, surgical, and postoperative factors affect these outcomes would be extremely valuable to surgeons, athletes, and their coaching and medical teams. It would allow realistic expectations about outcomes to be set, and to predict and potentially improve, RTS outcomes in elite athletes undergoing ACL-R. All of this knowledge drives better care of the general population.

1.2 RETURN TO SPORT AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

The resumption of sports participation after ACL injury represents a RTS continuum from return to participation (return to training or participation in sport at a lower level but not yet ready to return to full sporting activity at the previous level), to RTS/RTP (return to the previous level of sport but not preinjury performance), and finally to return to preinjury performance [22,23]. Both concepts RTP or RTS are appropriate, although RTP is most suited to the team sport athlete [22]. In this thesis, RTP was treated as a dichotomous outcome and defined as playing at least one match or competing in at least one event following ACL-R at professional level or at national/international level in an amateur sport. Time to RTP was defined as the time between the ACL-R and first match or event appearance.

RTP rates and times in elite sport have been studied in many different sports, and range from 55.8% to 98.4%,[11,16,24-28] and 6-13 months,[16,24,26,29] respectively, with some variations between sports [16]. Prior studies reporting RTP in elite sports are predominantly limited to single sport cohorts, and due to the different methodologies used, comparative data on sport-specific outcomes after ACL-R are not well-established. There are few multi-sport studies which therefore provide limited comparisons between sports [16,30]. Better understanding of potential sport-specific differences in outcomes after ACL-R could help optimize rehabilitation and personalise RTP programs for each specific sport.

In elite sport, being able to perform at, or above, preinjury level is the ultimate goal after ACL injury, and should be considered the next stage of progress after RTP [22,23]. Data concerning the return to preinjury performance after ACL-R is inconsistent. While some studies report unchanged,[27,28,31,32] or improved post-surgery performance,[33-35] the majority show a reduction in performance statistics [24,26,29,36-42]. Given the limited number of studies available for each sport, the lack of standardized methods to measure performance, and the conflicting results between some studies, any attempt to summarise data on performance after ACL-R is challenging.

Whilst RTP at preinjury level is a significant achievement after ACL-R, the return to preinjury performance may only be considered to have been achieved in practical terms after playing consistently over a period of time. The concept of studying sport career length after ACL-R is relatively new and under-researched, with most of the available data coming from studies carried out in the last decade [16,27,33,38-40,43-45]. Career longevity after isolated ACL-R has been reported ranging from approximately 2 years in National Football League (NFL) to 7 years in elite skiing, respectively [16,21,33,43]. At elite level, the decision to retire is multifactorial [46,47]. Factors other than ongoing knee problems, such as contract status, injuries to other body parts, and even family wishes, make it difficult to assess the individual impact of a single factor, such as undergoing ACL-R on career longevity. In order to control for the dynamic nature of elite sports and the progression of time, few studies have used a matched control group against which to compare the career longevity of the study groups [33,37,39]. Further studies with larger control groups are needed to determine the effect of the ACL injury itself, as well as additional surgical factors on the longevity of their careers.

1.3 OUTCOME MEASURES

While isolated ACL-R has yielded favourable outcomes in the general population,[48] discerning clinical success in elite athletes is more challenging. It is evident that this patient group necessitates more rigorous outcome measures than those employed in standard postoperative questionnaires designed for the general population [49,50]. As the baseline function in the elite sport population is higher than the general population, patient-reported outcomes (PROs) may not fully reflect treatment effectiveness in a higher functioning individual. This ceiling effect hinders differentiation of elite athletes from the general population [51-53]. Thus, to address the former population, several studies have used sport specific outcomes to evaluate treatment efficacy [11,21,54]. Sport specific performance can be defined as any measure that determines performance within the athlete's sport, beyond simply a RTS [21]. Examples of performance statistics after ACL-R include career longevity,[31,33,39,43] games played per season,[27,28,38] league level,[41] rankings,[33] goals scored,[28,38] "assists",[28,38] home runs scored by baseball players,[42] player efficiency rating (PER) in basketball,[31] solo tackles in American football,[43] participation time,[28,38,40] and medals [33,34]. Despite data available in professional sports which facilitates comparison of pre-and post-injury performance, the literature on sport-specific outcomes after ACL-R is scarce, lacking consistency and validation [21,54-56]. Most research on playing performance after ACL-R relied solely on media-based injury data which, despite allowing the athlete's performance to be tracked, can under report the true incidence of injuries. These studies also lack important surgical and post-operative information. Hence, the available literature should be interpreted with an understanding of their inherent limitations and biases [57,58]. Moreover, there are confounding factors such as fear of further injury/surgery, motivation, athlete's position or team performance, as well as coach's decision, among other factors that may affect these results. Thus, the most important outcome measures for elite athletes after ACL-R are the ability to RTP, the level of performance: specifically at preinjury level, as well as career progression, and career longevity [15,21,49].

In the present thesis performance after ACL-R was measured in three ways: league level, playing time, and a combination of both. We attempted to identify metrics for athletes of all sports and genders, however we found that performance metrics were only reliably available for the male, elite soccer players. Thus, for the female athletes and male athletes from sports other than elite soccer, the national league in which the athletes' participated or participation in international competitions were used to determine their competition level.

Several publications, mainly in non-elite population, have focused on psychological readiness and functional testing,[59-61] to determine when an athlete should RTP. However, as these studies focused on the post-operative phase, the variables identified should be considered as decision criteria for returning to sports, rather than predictors. Therefore, these measures were not included in the scope of this thesis.

1.4 RETURN TO SPORT AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION IN SOCCER PLAYERS

Elite soccer players undergo ACL-R with the goal of returning to their preinjury level of performance and continuing to play at the highest level possible. Despite being well known for having high RTP rates following ACL-R compared to other sports,[11] ranging from 59.4% to 98.4%,[4,25,27,29,38-40,62-65] data concerning the return to preinjury performance is scarce and contradictory. While one study reported that playing performance was unchanged,[27] the majority of studies showed a reduction in performance statistics [29,38-41,62]. In a media based study, Erickson *et al*.[27] found minutes played per game and games played per season after ACL-R were not significantly different than preinjury in a matched-cohort analysis of 52 Major League Soccer (MLS) players. Conversely, Barth *et al*.[38] stated that only by the third season post-surgery did professional soccer players play similar minutes per game than preinjury and the same trend was reported in other studies with similar methodologies [38-41,62].

Considering the return to preinjury level of performance and continuing to play being the main concerns of both soccer players and their team, surprisingly little is known about the patient, surgical and post-operative factors that have impact on these outcomes. In a non-elite population study, Muller *et al*.[66] found five independent variables that predict the return to preinjury level of sports participation: age, being a competitive athlete ("participants in strenuous sports activities 4 to 7 times per week"), time from injury to surgery, tibiofemoral chondral status, and having had any form of chondral surgery done. They concluded that younger patients, those who participated in competitive sports, those who underwent surgery earlier, and those who did not have a chondral injury or require chondral surgery returned to sports more often. In elite soccer, the evidence on patient, surgical, and post-operative factors influencing RTP rates after ACL-R is even more scarce,[36,40,63] and the subsequent impact on performance throughout a footballer's career has not yet been adequately explored. Howard *et al*.,[63] in a study of 78 collegiate female soccer athletes reported higher RTP rates in those undergoing ACL-R earlier in the college career as well as those who had a scholarship. In a media-based study of European soccer, Mazza *et al*.[40] reported that players older than 30 years presented a statistically significantly shorter RTP time than players aged 25 to 30 years, whereas in a study from a similar population, but also including an analysis of the intra-operative information, Farinelli *et al*.[36] did not find any surgical factors that significantly increased RTP time. However, the authors recognised that the small sample size (23 players) led to limited and underpowered statistical analysis (type II errors). Therefore, given the paucity of available data, further studies are needed, with larger populations, to assess the impact of patient, surgical and postoperative factors on the RTS rates after ACL-R in elite soccer players not only at the point of RTP but also throughout their career.

1.5 RETURN TO SPORT AFTER SURGICALLY TREATED ANTERIOR CRUCIATE LIGAMENT PLUS COLLATERAL LIGAMENT INJURY

The previous discussion was related to the "isolated" ACL injury scenario. The relevance of this has been increasingly questioned, particularly in elite sports,[67] due to recent evidence of high rates of concomitant medial or lateral soft tissue envelope disruption in association with ACL injuries [37,68-72]. It is therefore clear that the ideal ACL-R is not just about the ACL graft positioning, fixation, and graft type.

The anterolateral complex (ALC) has been extensively studied, as well as the role it plays (i.e. control of anterolateral rotatory laxity) in the ACL injured knee [73-78]. Although the indications, and the ideal surgical technique, are still debated,[78] there is growing evidence that anterolateral procedures can help protect ACL graft while healing, and provide secondary restraint to anterolateral rotatory stress, thereby decreasing re-rupture rates both in non-elite [79] and elite population [80]. Elite athletes place greater stresses on the reconstructed ligament after surgery than the average patient and therefore have higher re-rupture rates [45,81]. At the highest level of sport, ACL re-rupture, even with subsequent revision, has potentially career-ending consequences [18]. Thus, from 2014 onwards, after multiple cadaveric studies had demonstrated the critical role of lateral extra-articular tenodesis (LET) in offloading ACL grafts and restoring rotational stability without an increase in lateral compartment nor patellofemoral forces,[82-85] the present thesis supervisor (A.W.) began routinely performing a LET at the time of primary ACL-R in elite athletes.

Equally, unaddressed laxity of MCL or PLC complexes, which when intact restrain coronal and axial torques [86-88] leads to anteromedial and posterolateral rotatory laxity respectively and this increases the risk of ACL graft failure [89-96]. Therefore, surgical treatment of PLC and MCL laxity excess in ACL-R is justified in some cases. However, there is only one previous study of multi-ligamentous (MLKI) injury, reporting RTP rates of 70.8% after combined ACL+MCL surgery in elite athletes,[97] and did not evaluate career longevity or competition level following RTP.

After isolated ACL-R, career longevity has been reported ranging from approximately 2 and 7 years in NFL and elite skiing, respectively,[16,21,33,43] and approximately 1 to 4 years in professional soccer [27,38,39]. In MLS, Arundale *et al*.[39] found that players who RTP after ACL-R had significantly shorter careers (length approximately halved) compared to age-matched controls. In European professional soccer evidence suggests players inability to maintain their preinjury competition levels 3 years after ACL-R [4,25,36,40,41]. While less common than isolated ACL tears, concomitant MCL or PLC injury requiring surgical treatment at the time of ACL-R reflects an initially larger injury to the knee, followed by a bigger surgical insult. This may have major consequences on elite athletes' recovery times, performance levels and career longevity. Khair *et al*.[98] found that additional medial or lateral ligament reconstruction did not significantly affect the number of seasons played in NFL, reporting approximately 2.7 and 2.2 seasons after isolated ACL-R and combined ligament surgery respectively but their series consisted of only 6 cases and there was no breakdown of the injury patterns treated, nor surgical

details of collateral ligament surgery employed. To date, no study has compared how the presence, and surgical treatment of concomitant MCL or PLC injuries at the time of ACL-R affect elite soccer players' competition levels and career longevity compared with isolated ACL-R.

1.6 RETURN TO SPORT AFTER REVISION ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

Despite increasing knowledge and development of ACL surgery, graft re-rupture remains a relatively common and complex problem to manage. The cause of failure can be difficult to determine and is often multifactorial [18,99]. In this context, the surgeon is challenged not only by the technical aspects of restoring stability to the knee,[18] but also by managing patients expectations, which, despite being lower than in primary ACL-R setting, are still high [100].

For elite athletes ACL graft re-rupture is relatively high, and occurs in up to 19.3% of cases,[4,11,16,26,43,101-103] although a recent report had a graft re-rupture rate of 2% [104]. This is of great importance as needing revision surgery is career-threatening,[18,105-109] in terms of both of RTP and the ability to return to the same level of sport. RTP at preinjury level in athletes following revision ACL-R is lower compared to primary ACL-R, ranging from 13% to 69%,[110] and from 77% to 88%,[11] respectively. However, it is important to note that in Glogovac's systematic review,[110] the studies included, were predominantly conducted in recreational sports or in mixed populations,[105,106,108,109,111-116] with only limited information on RTP rates and level of competition after revision ACL-R in elite sports. In fact, there are only two previously published studies reporting RTP rates following revision ACL-R in elite athletes with series of more than five cases, showing RTP rates of 79% (19 of 24 cases)[107] and 87.5% (35 of 40 cases) [18]. Neither evaluated career longevities nor competition levels.

Among the general population, clinical outcomes after revision ACL-R are inferior to primary surgery in terms of PROs, further graft re-rupture, and re-operations, and also show a greater risk of developing tibiofemoral osteoarthritis [117-120]. It is likely that recurrent injury and instability cause more trauma to the joint, but little is known about patient or surgical factors associated with poorer outcomes. The Multicenter ACL Revision Study (MARS) was developed to identify both modifiable and non-modifiable factors which could have an impact on revision ACL-R [121]. At 2 years follow-up, the strongest predictors of poorer outcome were the presence of trochlear groove chondral damage and history of a previous lateral meniscectomy [122]. At 6 years follow-up, meniscal and chondral pathology at the time of revision ACL-R had continued significant detrimental effects on PROs [123].

In elite sports there is no data to evaluate the impact of patient, surgical and postoperative factors at the time of revision surgery on RTP rates, competition level and career longevity.

2. AIMS OF THE THESIS

The main aim of this thesis is to identify the determinants of RTS after ACL-R in elite athletes, providing a better understanding of the impact of patient, surgical and post-operative factors on time to RTP, RTP rates, performance, career longevity and graft re-rupture rates. It is hoped that this will help predict, and potentially improve, outcomes in this population after ACL-R, but also that the knowledge gained will benefit the general population.

As truly "isolated" ACL-R surgery is becoming less common with the recognition of important associated peripheral structure lesions, especially so in elite athletes, and the fact that graft re-rupture rates remain high in this population, and there is a lack of data on the above mentioned outcomes after primary and revision ACL-R, the following specific objectives were then defined:

Objective I

To identify patient, surgical, and post-operative factors that contribute to playing performance in professional soccer players post ACL-R, as well as to report their playing performance post ACL-R compared to their preinjury performance.

Objective II

To evaluate career length after surgical treatment of combined ACL+MCL and ACL+PLC injuries in elite athletes, as well as, in a subgroup analysis of male professional soccer players, to compare career length and competition level after combined ACL+MCL or ACL+PLC surgeries with a cohort who underwent isolated ACL-R.

Objective III

To report RTP rates, competition level and career longevity in elite athletes after revision ACL-R, as well as to assess the association of this with meniscus and chondral pathologies at the time of revision surgery.

Studies Overview

To answer the proposed objectives, three studies were conducted.

Regarding **Objective I**, a consecutive cohort of 200 professional soccer players undergoing primary ACL-R were analysed between 2005 and 2019. The effect of patient, surgical and post-operative factors on performance rates (combination of league level and playing time) was evaluated with univariate and multivariate logistic regression models. The presence of ≥50% thickness chondral pathology, ACL-R without LET and age over 25 years at the time of surgery were all significant risk factors of worse performance rates after ACL-R. Significant decreases in performance rates were also noted at 2 and 5 years post-operatively.

These results are presented in Chapter II.

To answer **Objective II**, a consecutive cohort of 98 elite athletes undergoing combined ACL+MCL and ACL+PLC surgery was analysed between February 2001 and October 2019. A subgroup of male elite soccer players from this population was compared to a previously identified cohort (population analysed in **Objective I**) having had isolated primary ACL-R without other ligament surgery. Among these elite athletes, the average career length after surgical treatment of combined ACL+MCL and ACL+PLC injuries was 4.5 years. Professional soccer players with combined ACL+PLC surgery returned at a lower rate and required a longer RTP time when compared to the ones with isolated ACL or combined ACL+MCL injuries. However, those that do RTP had the same career longevity and competition level.

These results are presented in Chapter III.

To answer **Objective III**, a retrospective review of a consecutive series of 48 elite athletes undergoing revision ACL-R between 2009 and 2019 was carried out. RTP rates and competition level decreased over time after revision ACL-R. The presence of ≥50% thickness chondral pathology was associated with lower RTP rates and competition level at RTP time, while medial meniscus pathology was associated with lower competition level at RTP.

These results are presented in Chapter IV.

CHAPTER II

Determinants of Performance in Professional Soccer Players at 2 and 5 Years After Anterior Cruciate Ligament Reconstruction

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Determinants of Performance in Professional Soccer Players at 2 and 5 Years After ACL Reconstruction

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Investigation performed at Fortius Clinic, London, United Kingdom

Background: A number of studies have investigated return to play after anterior cruciate ligament reconstruction (ACLR) in professional soccer players, but it is unclear which factors are associated with a return to the preinjury performance and ability to play over time.

Purpose: To identify factors that contribute to a professional soccer player's return to preinjury performance after ACLR, as well as to report their playing performance at 2 and 5 years after ACLR compared with their preinjury performance.

Study Design: Case-control study; Level of evidence, 3.

Methods: A consecutive cohort of professional soccer players undergoing primary ACLR were analyzed between 2005 and 2019. A minimum 2-year follow-up was required. The effect of patient, surgical, and postoperative factors on performance rates, defined as a combination of league level and playing time, was evaluated with univariate and multivariate logistic regression models.

Results: A total of 200 male professional soccer players were included. When combining league level and playing time, 30% of athletes returned to their preinjury performance at 2 years and 22% at 5 years. However, 53% of athletes returned to their preinjury performance for at least 1 season by year 5. At 2 years, a chondral lesion of grade 3 or 4 decreased the odds of return to preinjury performance (odds ratio [OR], 0.37; $P = .010$). Athletes receiving an ACLR with the addition of a lateral extra-articular tenodesis procedure were 2.42 times more likely to return to preinjury performance at 2 years than athletes with ACLR alone ($P = .004$). By 5 years after ACLR, athletes aged $\geq$25 years at the time of reconstruction were 3 times less likely to be performing at their preinjury performance (OR, 0.32; $P < .001$), and those with a grade $\geq$3 chondral lesion were $>$2 times less likely to be performing at their preinjury performance (OR, 0.43; $P = .033$).

Conclusion: The presence of $>$50% thickness chondral pathology, ACLR without lateral extra-articular tenodesis, and age $>$25 years at the time of surgery were all significant risk factors of worse performance rates after ACLR. Significant decreases in performance rates were noted at 2 and 5 years postoperatively.

Keywords: performance; anterior cruciate ligament reconstruction; soccer; professional players; return to play

In elite sports, being able to perform at or above one's preinjury level is the ultimate goal after anterior cruciate ligament (ACL) injury and should be considered as the next stage of progress after return to play (RTP).[2,27] Professional soccer players are known to have higher RTP rates after ACL reconstruction (ACLR) compared with athletes in other sports,[22] ranging from 59.4% to 98.4%.[#] However, the data concerning the return to preinjury performance in professional soccer players after ACLR is scarce and contradictory. Although 1 study reported that the playing performance was unchanged,[11] the majority of studies showed a reduction in performance statistics.[3,5,13,26,31,38]

At the elite level, most research on playing performance after ACLR has relied solely on media-based injury data, which, despite allowing the athlete's performance to be tracked, can underreport the true incidence of injuries. These studies also lack important surgical and postoperative information. Hence, the available literature should be interpreted with an understanding of the inherent limitations and biases.[17,20] Thus, even though there is already evidence on patient, surgical, and postoperative factors influencing RTP rates in professional soccer players after ACLR,[4,7,12,16,26,32] a better understanding of how these factors affect playing performance would be extremely valuable for players, physicians, and the players' medical teams. It would allow realistic expectations about

[#]References 3-6, 11, 13, 16, 21, 26, 31, 39, 41.

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outcomes to be set, and the prediction, and potentially improvement, of performance outcomes in professional soccer players undergoing ACLR.

The purpose of the present study was to identify patient, surgical, and postoperative factors that contribute to playing performance in professional soccer players at 2 and 5 years after ACLR. The secondary objective was to report their playing performance at 2 and 5 years after ACLR compared with their preinjury performance. It was hypothesized that chondral pathology and older age would be associated with lower performance rates, while adding a lateral extra-articular tenodesis (LET) would improve it. It was also hypothesized that short- and midterm playing performance rates would be lower compared with preinjury performance.

METHODS

A retrospective review of a consecutive series of primary ACLR by the senior author (A.W.) from 2005 and 2019 was performed. Approval to undertake the study was given by the institution involved, in line with UK Health Research Authority guidance.[15]

All male professional soccer players who underwent primary ACLR with a minimum of 2 years of follow-up were included. Typically, professional athletes performed in one of the top 6 leagues in the English football system or the equivalent in another country. Exclusion criteria included athletes who had a ligament other than the ACL operated on at the same time, as well as revision ACLR. Study data including age, sex, mechanism of injury, history of ipsilateral or contralateral knee injuries, surgical technique, meniscal pathology and treatment, grade of chondral lesions if present, return to professional soccer timeline, and the date and details of any additional surgeries before RTP were collected from clinical and operative notes.

Graft type and femoral tunnel technique choice were as previously described.[4,7] Since 2014, a modified Lemaire LET was also undertaken.[40] There were no other systematic changes to the surgical technique during the study period. Meniscal lesions were treated, when possible, with repair, but some needed partial meniscectomy. Chondral lesions were treated according to size and depth and often left alone. For data collection purposes, cartilage lesions were divided into 2 groups: International Cartilage Regeneration & Joint Preservation Society (ICRS) grade <3, which included no lesion, and ICRS grade ≥ 3. In those requiring treatment, chondroplasty was performed for partial-thickness lesions, while microfractures were performed for full-thickness lesions.

Immediate weightbearing as tolerated was allowed postoperatively, and initial rehabilitation focused on regaining full extension. Flexion and weightbearing were restricted if the patient had also undergone microfracture or repair of a radial or posterior root tear of a meniscus. After satisfactory review by the senior surgeon (A.W.) at a minimum of 6 months postoperatively, the progression to RTP was supervised by the team's medical staff.

As well as clinical data, soccer performance data were collected from publicly available databases for 1 year before ACLR until 5 years after ACLR. Data collection included player position, league, total minutes played, age at senior debut, date of first game after ACLR, and, if applicable, retirement date. The 1-year data before ACLR were used to determine each player's baseline. Performance after ACLR was measured in 3 ways, all compared with each player's baseline: (1) league level, (2) playing time, and (3) a combination of league level and playing time.

League level was classified in a system similar to the English football pyramid. The top leagues were denoted as level 1. For leagues in Europe, football associations that obtain automatic bids into the Union of European Football Associations (UEFA) Champions League had their top league denoted as level 1. Lower leagues for the country were then classified as levels 2 through 6 as appropriate. For non-European counties, the Fédération Internationale de Football Association (FIFA) world ranking system was used as a surrogate. The top league in each country was assigned a league level of 1 to 5, depending on the strength of the FIFA ranking system. The league an athlete was playing in at the time of ACL injury was considered baseline. League level was then classified as the same, higher, lower, or nonprofessional for each year from 2 to 5 years. Baseline playing time was determined 1 year before ACLR to account for ACL injuries incurred during the season. Playing time was then classified as the same (within 20%), more, or less playing time for each season as compared with baseline performance.

Statistical Analysis

Stata software (Version 17; StataCorp LLC) was used for all statistical analyses. Baseline patient characteristics were summarized and presented as mean ± standard

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TABLE 1
Athlete Characteristics[a]

	Value
Age, y	
At senior debut	18.6 ± 1.4
At ACLR	24.1 ± 4.2
Playing position	
Forward	58 (29)
Midfielder	61 (31)
Defender	69 (35)
Goalkeeper	12 (6)
League level	
1	59 (30)
2	61 (31)
3-6	80 (40)
Mechanism of injury	
Contact	49 (25)
Jump landing	17 (9)
Noncontact	125 (63)
Unknown	9 (5)
Return to professional sports	194 (97)
Months to RTP	10.7 ± 3.9
Additional injuries	
Lateral meniscal pathology	134 (67)
Medial meniscal pathology	63 (32)
ICRS grade ≥3 lesions	31 (16)
Graft rerupture	
No	182 (91)
Before RTP	3 (2)
After RTP	15 (8)

[a]Values are presented as mean ± SD or n (%). ACLR, anterior cruciate ligament reconstruction; ICRS, International Cartilage Regeneration & Joint Preservation Society; RTP, return to play.

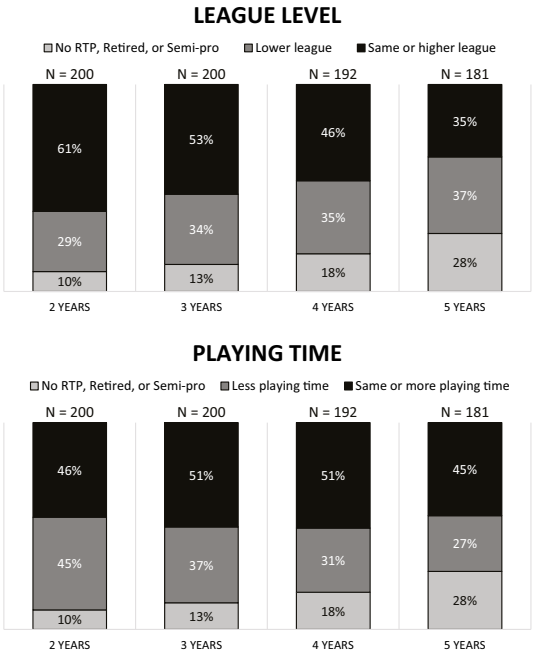

Figure 1. League level and playing time after primary anterior cruciate ligament reconstruction. RTP, return to play.

deviation or count and percentile, as appropriate. The effects of pre-, intra-, and postoperative factors on league level and playing time were evaluated at both 2 and 5 years after ACLR with Fisher exact tests. Ordered logistic regression was used to predict soccer player performance at 2 and 5 years after primary ACLR with the following performance levels:

- Same or higher league and same or more playing time (level 5)
- Same or higher league and less playing time (level 4)
- Lower-level league and same or more playing time (level 3)
- Lower-level league and less playing time (level 2)
- No RTP, retired, or semiprofessional (level 1)

The ordered logistic regression model included all univariate pre-, intra-, and postoperative factors with $P < .10$ as possible predictors.

RESULTS

A total of 208 male professional soccer players underwent ACLR during the study period. Soccer performance statistics were not able to be located for 3 athletes, and 4 players did not have a full senior season before ACL injury; therefore, baseline data were not available and thus these players were excluded. Additionally, 1 player was excluded despite reaching level 1 after ACL because he injured his ACL while playing in a nonprofessional league. The final cohort included 200 athletes with a mean age at ACLR of 24.1 ± 4.2 years (Table 1). At the time of ACL injury, 60% of the athletes were playing in the top 2 league levels, with 40% playing in levels 3 to 6. Overall, 194 of 200 (97%) athletes returned to professional soccer at a mean of 10.7 ± 3.9 months.

At 2 years after ACLR, 61% of athletes were playing in the same or higher league level, 29% were playing in a lower league, and 10% were retired, were playing semiprofessionally, or did not return to professional soccer (Figure 1). By 5 years, the number of athletes playing at the same or higher league decreased to 35%, while the number playing at a lower league (37%) and the number who were retired, playing semiprofessionally, or did not RTP (28%) increased. At 2 years after ACLR, 46% of athletes played the same or more minutes than baseline, while at 3, 4, and 5 years after ACLR, athletes played the same or more in 51%, 51%, and 45% of cases, respectively.

Athletes who were <25 years of age at ACLR had a greater chance of playing in the same or higher league level at both 2 years ($P = .042$) and 5 years ($P = .001$) postoperatively (Table 2). Additionally, the presence of a grade ≥3 chondral lesion significantly decreased the chance of playing at the same or higher-level league postoperatively at 2 and 5 years ($P = .026$ and $P = .030$, respectively).

TABLE 2
Effect of Pre-, Intra-, and Postoperative Factors on League Level After ACLR[a]

	2 y (N = 200)				5 y (n = 181)			
	Same or Higher League (n = 122)	Lower League (n = 59)	No RTP, Retired, or Semiprofessional (n = 19)	*P* Value	Same or Higher League (n = 64)	Lower League (n = 67)	No RTP, Retired, or Semiprofessional (n = 50)	*P* Value
Age, y				.042				.001
<25	79 (63)	40 (32)	7 (6)		48 (43)	43 (38)	21 (19)	
≥25	43 (58)	19 (26)	12 (16)		16 (23)	24 (35)	29 (42)	
Chondral lesion				.026				.030
No lesion or ICRS grade <3	106 (63)	51 (30)	12 (7)		61 (39)	55 (35)	40 (26)	
ICRS grade ≥3	16 (52)	8 (26)	7 (23)		3 (12)	12 (48)	10 (40)	
Recurrent effusion				.709				.469
Not reported	85 (60)	42 (30)	15 (11)		47 (37)	43 (34)	36 (29)	
Reported	37 (64)	17 (29)	4 (7)		17 (31)	24 (44)	14 (25)	
LET				.050				.243
ACLR + LET	41 (75)	10 (18)	4 (7)		19 (46)	13 (32)	9 (22)	
ACLR alone	81 (56)	49 (34)	15 (10)		45 (32)	54 (39)	41 (29)	

[a]Values are presented as n (%). ACLR, anterior cruciate ligament reconstruction; ICRS, International Cartilage Regeneration & Joint Preservation Society; LET, lateral extra-articular tenodesis; RTP, return to play.

TABLE 3
Effect of Pre-, Intra-, and Postoperative Factors on Playing Time After ACLR[a]

	2 y (N = 200)				5 y (n = 181)			
	Same or More Minutes (n = 91)	Fewer Minutes (n = 90)	No RTP, Retired, or Semiprofessional (n = 19)	*P* Value	Same or More Minutes (n = 82)	Fewer Minutes (n = 49)	No RTP, Retired, or Semiprofessional (n = 50)	*P* Value
Age, y				.043				.001
<25	61 (48)	58 (46)	7 (6)		64 (57)	27 (24)	21 (19)	
≥25	30 (41)	32 (43)	12 (16)		18 (26)	22 (32)	29 (42)	
Chondral lesion				.018				.231
No lesion or ICRS grade <3	81 (48)	76 (45)	12 (7)		71 (46)	45 (29)	40 (26)	
ICRS grade ≥3	10 (32)	14 (45)	7 (23)		11 (44)	4 (16)	10 (40)	
Recurrent effusion				.566				.077
Not reported	66 (47)	61 (43)	15 (11)		62 (49)	28 (22)	36 (29)	
Reported	25 (43)	29 (50)	4 (7)		20 (36)	21 (38)	14 (25)	
LET				.280				.287
ACLR + LET	30 (55)	21 (38)	4 (7)		23 (56)	9 (22)	9 (22)	
ACLR alone	61 (42)	69 (48)	15 (10)		59 (42)	40 (29)	41 (29)	

[a]Values are presented as n (%). ACLR, anterior cruciate ligament reconstruction; ICRS, International Cartilage Regeneration & Joint Preservation Society; LET, lateral extra-articular tenodesis; RTP, return to play.

An ACLR with LET had a positive effect on league level at 2 years ($P = .050$), but by 5 years the effect was not significant. Graft type, meniscal pathology and treatment, recurrent effusion, tunnel position, or additional meniscal surgery before RTP were not significant predictors of league level at either 2 or 5 years.

The same factors were evaluated for association with playing time after ACLR (Table 3). A higher number of athletes <25 years of age maintained the same or higher number of minutes after ACLR at 2 years ($P = .043$) and 5 years ($P = .001$), while the presence of a grade ≥3 chondral lesion decreased the chance of playing time at 2 years ($P = .018$) but not at 5 years ($P = .231$). No other factors were significantly associated with playing time after ACLR.

When combining league level and playing time, 30% of athletes returned to their preinjury performance at year 2 and 22% at year 5 (Figure 2). Nevertheless, 53% of athletes returned to their preinjury league and playing time for at least 1 season between years 2 and 5. An additional 18% of athletes played at the same or higher level but received less playing time.

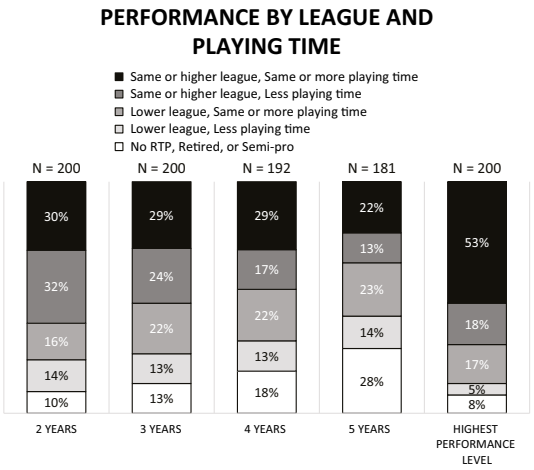

Figure 2. Player performance from 2 to 5 years after primary anterior cruciate ligament reconstruction. RTP, return to play.

Of the 18 athletes who reruptured their ACL, 3 did so before RTP and 15 after RTP. After revision, all 18 athletes returned to their professional level. Thirteen of the 18 (72%) returned to the same or higher league level during the study period, with 61% playing the same or more minutes and 39% playing less. One athlete retired 2 years after revision, while 3 other athletes played a season or 2 in a nonprofessional league before returning to their previous league level.

Multivariate ordered logistic regression models were used to evaluate the factors associated with player performance at 2 and 5 years after primary ACLR. The factors included in the model were age, chondral lesion, ACLR with a LET, meniscal treatment, and recurrent effusion reported. At 2 years (Table 4), a chondral lesion of grade 3 or 4 decreased the odds of return at preinjury performance (odds ratio [OR], 0.37; $P = .010$). Athletes receiving an ACLR with the addition of a LET procedure were 2.42 times more likely to return to their preinjury performance at 2 years than athletes with ACLR alone ($P = .004$). Age, meniscal treatment, and recurrent effusion did not significantly influence performance at 2 years.

By 5 years after ACLR (Table 5), athletes aged ≥25 years at the time of reconstruction were 3 times less likely to be performing at their preinjury performance (OR, 0.32; $P < .001$) and those with a grade ≥3 chondral lesion were >2 times less likely to be performing at their preinjury performance (OR, 0.43; $P = .033$). By 5 years, an ACLR with LET was no longer a significant indicator of performance. In addition, meniscal treatment and recurrent effusion did not significantly influence performance at 5 years.

TABLE 4
Ordered Logistic Regression Predicting Performance at 2 Years After Primary ACLR[a]

	OR	95% CI	*P*
Age ≥25 y	0.80	0.47-1.39	.445
ICRS grade ≥3 lesions	0.37	0.18-0.79	.010
ACLR alone	1 (reference)	1.32-4.46	.004
ACLR + LET	2.42		
Meniscal treatment			
Intact/stable	1 (reference)		
Repair	1.04	0.57-1.93	.884
Meniscectomy	1.06	0.51-2.22	.865
Recurrent effusion reported	0.77	0.44-1.37	.374

[a]ACLR, anterior cruciate ligament reconstruction; ICRS, International Cartilage Regeneration & Joint Preservation Society; LET, lateral extra-articular tenodesis; OR, odds ratio.

TABLE 5
Ordered Logistic Regression Predicting Performance at 5 Years After Primary ACLR[a]

	OR	95% CI	*P*
Age ≥25 y	0.32	0.18-0.58	<.001
ICRS grade ≥3 lesions	0.43	0.19-0.93	.033
ACLR alone	1 (reference)	0.87-3.20	.126
ACLR + LET	1.66		
Meniscal treatment			
Intact/stable	1 (reference)		
Repair	1.02	0.54-1.92	.938
Meniscectomy	0.91	0.42-1.97	.806
Recurrent effusion reported	1.08	0.61-1.91	.792

[a]ACLR, anterior cruciate ligament reconstruction; ICRS, International Cartilage Regeneration & Joint Preservation Society; LET, lateral extra-articular tenodesis; OR, odds ratio.

DISCUSSION

The most important finding of this study was the identification of 3 variables that significantly affected return to preinjury performance. The presence of ICRS grade ≥3 chondral lesions, ACLR without LET, and age >25 years at the time of surgery were all significant risk factors of worse performance rates after ACLR. When combining league level and playing time, 30% of athletes returned to their preinjury performance at 2 years and 22% at 5 years after ACLR.

Factors Affecting Performance After ACLR

Professional soccer players undergo ACLR with the goal of returning to their preinjury performance and continuing to play at the highest level possible. However, little is known regarding their success in achieving this goal or the factors that influence performance and longevity after ACLR. Younger soccer players (<25 years of age at the time of ACLR) were significantly more likely to still be playing at their preinjury performance at 5 years after surgery. Although the same trend was observed at 2 years, there was no statistical significance. Similar findings were reported by Mazza et al[26] in European soccer, and also

between athletes in National Hockey League (NHL),[37] elite skiing[14] and Australian Football League (AFL).[23] Our results may reflect the fact that younger players are more willing and able to follow the rehabilitation after ACLR, to reach their performance peak, or to become established, while more veteran players found it more difficult to consolidate their RTP and restore their preinjury performance. It could also just be that the performance of players >25 years of age naturally declines more regardless of whether they have an ACL injury, and knowing that their best performances are behind them, they more easily accept retirement.[34] A similar observation has recently been reported that RTP rates are also significantly higher in the players <25 years.[4]

The current study shows that athletes receiving an ACLR with the addition of a LET procedure were 2.42 times more likely to return to their preinjury performance at 2 years than athletes with ACLR alone. In the context of elite sports, there are no studies with which to compare these results. At 2 years of follow-up, in a pivoting nonelite sports population, Porter et al[33] found better patient-reported outcome measures (PROMs) in patients who had a LET. Recently, Borque et al[7] found that the addition of LET reduced the risk of undergoing revision by 2.8 times in elite athletes undergoing primary ACLR, suggesting the status as an elite athlete should be included as a potential indication for a LET, as they are at increased risk for ACL graft failure. In a previous study,[4] there was also no delay in RTP in cases with additional LET. The benefits of LET when treating elite athletes with an ACL injury are clear, given the deleterious career consequences of ACL rerupture[32] combined with the increased risk of osteoarthritis from any persisting anterolateral instability after ACLR. Our study reinforces the status as professional soccer players as a potential indication for LET, as it better predicts performance rates at 2 years after ACLR. However, it is hard to explain why this is. Perhaps it is related to the avoidance of graft rerupture, entailing revision surgery from which RTP and return to preinjury performance would take longer. More players remain at their preinjury performance at 5 years, but this was not statistically significant. At the elite level, it usually takes >1 year to return to preinjury performance,[25] and up to 2 years to achieve baseline joint biological health and function after ACLR,[30] so our results may reflect the positive effect of LET in providing better joint kinematics and stability. Those without LET may have abnormal joint motion and minor subluxations that, although not producing clinical instability, will need better neuromuscular control before RTP, and this will take longer to achieve. This would account for the advantage of having a LET as shown at 2 but not 5 years. Of course, the failure to demonstrate statistical significance at 5 years could simply be a type 2 statistical error because of the lack of sufficient cases.

The presence of chondral lesions of >50% thickness at the time of surgery significantly impacted performance, with only 4% of athletes playing at the same or higher performance level at 5 years after surgery, and these athletes were >2 times less likely to be performing at their preinjury performance. In AFL players, the presence of concomitant knee injuries was reported not to be associated with differing odds of returning to preinjury performance.[23] However, in that study the nature of concomitant injuries was not reported, so it is not possible to make comparisons with our results.

The presence of chondral lesions in elite athletes does not seem to alter RTP rates.[4,24] However, we found conflicting results in the published literature in non-elite populations. Two studies reported that play rates after surgery were unchanged,[8,18] while other studies reported that a chondral lesion was a negative predictor for returning to play after either primary[29,36] or revision ACLR.[1] Our results reflect the increasingly negative effect of these injuries over time in professional soccer players. Interestingly, of the 58 athletes who did not return to their preinjury performance for at least 1 season between years 2 and 5 after ACLR, 15 (26%) had chondral lesions of ICRS grade ≥3 at the time of surgery. Thus, only 50% of athletes with chondral lesions of ICRS grade ≥3 returned to their preinjury performance, for at least 1 season, during the study period, which is indicative of its harmful consequences at this competitive level.

There was no association between meniscal status and return to preinjury performance, which may indicate that meniscal injuries may take more time to have an effect on cartilage and therefore have a later effect on function. This possibility has been reported in NHL players, in whom the presence of a meniscal injury was associated with a decreased length of career.[37] Little is published about factors altering performance and longevity rates in elite athletes.[23] Similar to our results, but only reported at the point of RTP, femoral tunnel technique, graft type,[4,9,10,16] and recurrent effusion[4] did not significantly affect performance rates among elite athletes.

Performance After ACLR

Being able to return to preinjury performance after ACLR is of utmost importance for any athlete.[27] Excellent RTP rates have been previously reported after ACLR among professional soccer players** (up to 96%[4]), as published from the same center as the authors of the present study and also in elite athletes from other sports,[22,25,28] but little is known about their short- and midterm performance rate outcomes. In a UEFA Champions League study, Waldén et al[39] found that even though 130 of 134 (97.0%) players returned to play at the preinjury league level, 81 of 93 (87.1%) players were still playing at 3 years after ACLR, but only 60 (64.5%) at the same league level. Krutsch et al[21] and Szymski et al,[38] in German professional soccer, and Mazza et al,[26] in the top 8 European soccer leagues, also described a similar restricted ability of players to maintain the preinjury league level of professional soccer 3 years after ACL rupture: 59% in the first study and 50% in the last 2 studies. At 5 years after the season in which the rupture occurred, Niederer et al[31] reported that 69.9% of professional soccer players were still playing,

**References 3-6, 11, 13, 16, 21, 26, 31, 39, 41.

but only 24.8% at the same level. The present study also shows a similar pattern of decreasing playing rates and competition level over time. It determined that >90% of soccer players RTP at the same or higher level after ACLR, while at 3 and 5 years, only 53% and 35%, respectively, were playing at the same or higher competition level. This is very important information for the treating clinician, athletes, medical teams, and coaches to know.

Although RTP at the preinjury level is a significant achievement after ACLR, the return to preinjury performance may only be considered to have been achieved in practical terms after playing consistently over a period of time. Using publicly available detailed performance statistics, Erickson et al[11] found minutes played per game and games played per season after ACLR were not significantly different than preinjury in a matched-cohort analysis of 52 Major League Soccer players. Conversely, Barth et al[5] stated that only by the third season after surgery did professional soccer players play similar minutes per game as preinjury, and the same trend was reported in other studies with similar methodologies.[3,5,26,31,38] In terms of player performance after RTP, when combining league level and playing time, our results showed that only 30% and 22% of athletes returned to their preinjury performance at 2 years and 5 years, respectively, after ACLR. When considering the highest performance level obtained by an athlete between years 2 and 5, 53% of athletes returned to their preinjury performance level for at least 1 year, with an additional 18% at the same or higher league level but receiving less playing time. This may reflect that, while professional soccer players may be ready to RTP, they have likely not returned to their preinjury performance, reinforcing the necessity to analyze not only RTP rates, but also performance metrics at and after RTP. Of the 58 (29%) athletes who did not reach this goal, 7% (4/58) had reruptured their ACL graft and 29% (17/58) had injured their contralateral ACL.

In the current study, 13% (26/200) and 18% (36/195) of athletes ended their professional careers 3 and 4 years after ACLR, respectively, which is in line with previous reports showing that 11.8% to 20% of professional soccer players have ended their career 3 years after injury.[13,21,31,38,39] At the elite level, reasons for early retirement may be multifactorial, such as decreased performance, fear of further injury/surgery, loss of motivation for continuing playing at a lower competition level, and, for older players, the simple matter of their realization that it is time to retire. Retirement does not necessarily reflect the presence of knee problems.[35]

There are several limitations to the present study. It is retrospective, and as a result, the preoperative assessment, surgical plan, and various surgical factors such as timing of surgery, graft choice, need for LET, chondral and meniscal pathology treatment, and further surgery were decided based on the senior surgeon's clinical judgment, and not based on a randomization process. No validated PROMs were collected, and while this can also be considered a limitation, it has recently been argued that a clinical outcome such as RTP is more appropriate than a PROM that has not been validated for use in the condition or outcome being studied in athletes.[19] For this study, it was thought that performance rates, and the factors affecting them, are of more importance to the players, their medical teams, and treating surgeons. Tegner scores were not included as they are a gross indicator of performance compared with league level, minutes, and matches played and cannot identify if a player with a Tegner score of 9 returns to a lower-level club. The high availability of performance data for elite athletes (200/208 cases) and full follow-up data for those cases who have reached 5 years after surgery (181/200) add to the value of this information. Focusing on these coarse measures of outcome allowed inclusion of a larger number of athletes, decreasing the chance of selection bias and recall bias. At this level of competition there are unpredictable factors, such as additional injuries, that may influence a player's performance and may have affected our results. The career span of the majority of professional athletes is relatively short, but the lack of a matched group does not allow a comparison of longevity and performance rates between our cohort and healthy players, and therefore we do not know whether the changes in performance we report actually just demonstrate the normal performance changes of a professional soccer player. Because the study population is elite soccer players, the findings in this study may not be directly extrapolated to the general population. However, lessons learned from such a study are valuable for the nonprofessional population as the intensity of knee loading in athletes differentiates treatment outcomes more clearly than in the general population.

Failure to return to their preinjury performance does not necessarily mean that athletes are not playing well, as a common reason for returning at a lower level is a team's relegation to a lower league. Also, league level may be a reflection of not only the individual player's performance ability, but also the team's success.

Even though some of the factors investigated in this study were associated with return to preinjury performance, there may be other factors that are equally important but not included here. For example, nonselection in the team, psychological condition, and contract status may influence performance rates.

Despite the mentioned limitations, the present study reports the largest cohort of professional soccer players in analyzing performance after ACLR. It provides valuable information for surgeons, athletes, and their coaching and medical teams. By providing a better understanding of the patient, surgical, and postoperative factors that affect performance, this study enables surgeons to set realistic expectations for elite athletes before surgery regarding their short- to medium-term performance. Importantly, this study did not solely rely on publicly available data, the inherent biases of which have recently been highlighted,[17,20] but rather was founded on the senior surgeon's practice data.

CONCLUSION

The presence of a chondral lesion of >50% thickness, ACLR without LET, and age >25 years at the time of

surgery were all significant risk factors of worse performance rates after ACLR. Even though professional soccer players achieved high initial RTP rates after ACLR, with the vast majority returning to preoperative levels of competition, significant decreases in performance rates were noted in the short and medium term.

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CHAPTER III

Career Length After Surgically Treated Anterior Cruciate Ligament Plus Collateral Ligament Injury in Elite Athletes

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Career Length After Surgically Treated ACL Plus Collateral Ligament Injury in Elite Athletes

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Investigation performed at Fortius Clinic, London, UK

Background: Limited data are available regarding career length and competition level after combined anterior cruciate ligament (ACL) and medial- or lateral-sided surgeries in elite athletes.

Purpose: To evaluate career length after surgical treatment of combined ACL plus medial collateral ligament (MCL) and ACL plus posterolateral corner (PLC) injuries in elite athletes and, in a subgroup analysis of male professional soccer players, to compare career length and competition level after combined ACL + MCL or ACL + PLC surgeries with a cohort who underwent isolated ACL reconstruction (ACLR).

Study Design: Cohort study; Level of evidence, 3.

Methods: A consecutive cohort of elite athletes undergoing combined ACL + MCL and ACL + PLC surgery was analyzed between February 2001 and October 2019. A subgroup of male elite soccer players from this population was compared with a previously identified cohort having had isolated primary ACLR without other ligament surgery. A minimum 2-year follow-up was required. Outcome measures were career length and competition level.

Results: A total of 98 elite athletes met the inclusion criteria, comprising 50 ACL + PLC and 48 ACL + MCL surgeries. The mean career length after surgical treatment of combined ACL + MCL and ACL + PLC injuries was 4.5 years. Return-to-play (RTP) time was significantly longer for ACL + PLC injuries (12.8 months; $P = .019$) than for ACL + MCL injuries (10.9 months). In the subgroup analysis of soccer players, a significantly lower number of players with combined ACL + PLC surgery were able to RTP (88%; $P = .003$) compared with 100% for ACL + MCL surgery and 97% for isolated ACLR, as well as requiring an almost 3 months longer RTP timeline (12.9 months; $P = .002$) when compared with the isolated ACL (10.2 months) and combined ACL + MCL (10.0 months) groups. However, career length and competition level were not significantly different between groups.

Conclusion: Among elite athletes, the mean career length after surgical treatment of combined ACL + MCL and ACL + PLC injuries was 4.5 years. Professional soccer players with combined ACL + PLC surgery returned at a lower rate and required a longer RTP time when compared with the players with isolated ACL or combined ACL + MCL injuries. However, those who did RTP had the same career longevity and competition level.

Keywords: elite athletes; combined anterior cruciate ligament injury/surgery; medial collateral ligament; posterolateral corner; competition level; career length; soccer

In elite sport, there is a high incidence of concomitant medial or lateral soft tissue envelope disruption in combination with anterior cruciate ligament (ACL) injuries.[7,17,37,41,65,72] Unaddressed laxity of medial collateral ligament (MCL) or posterolateral corner (PLC) complexes, which when intact restrain coronal and axial torques,[46,56,73] leads to anteromedial and posterolateral rotatory laxity, respectively, and this increases the risk of ACL graft failure.[8,35,38,47,55,61,62,68] Therefore, surgical treatment of PLC and MCL laxity excess in ACL reconstruction (ACLR) is justified in some cases. However, there is limited evidence of the effect of PLC and MCL surgery in addition to ACLR on return-to-play (RTP) times and levels or on subsequent career length in elite atheletes.[5,15]

After isolated ACLR, career longevity has been reported to be approximately 2 years in the National Football League (NFL) and 7 years in elite skiing.[32,49,51,57] In Major League Soccer, Arundale et al[4] found that players who RTP after ACLR had significantly shorter careers (length approximately halved) than age-matched controls. In European professional soccer, there is evidence of the inability of players to maintain their preinjury competition levels 3 years after ACLR.[24,45,52,69,70] Although less common than isolated ACL tears, concomitant MCL or PLC

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injury requiring surgical treatment, at the time of ACLR, reflects a larger injury to the knee initially, followed by a bigger surgical insult, and may have major consequences on elite athletes' recovery times, performance levels, and career longevity. To date, no study has compared how the presence and surgical treatment of concomitant MCL or PLC injuries at the time of ACLR affect professional soccer players' competition levels and career longevity compared with isolated ACLR. Knowledge of this would allow players, physicians, and the players' medical teams to set realistic expectations about outcomes, and would allow future treatment developments to be evaluated against contemporary practice.

The primary aim of the present study was to evaluate career length after surgical treatment of combined ACL + MCL or ACL + PLC injuries in elite athletes. The secondary aim was to compare these findings, as well as player competition level after surgery, in a subgroup analysis of male professional soccer players having undergone combined surgical treatment of ACL + MCL or ACL + PLC injuries with those who underwent isolated ACLR. It was hypothesized that there would be no significant difference in career length between elite athletes with combined ACL + MCL and ACL + PLC surgeries. It was also hypothesized that elite soccer players with combined ACL + MCL or ACL + PLC injuries would have shorter careers and lower competition levels compared with players after isolated ACLR.

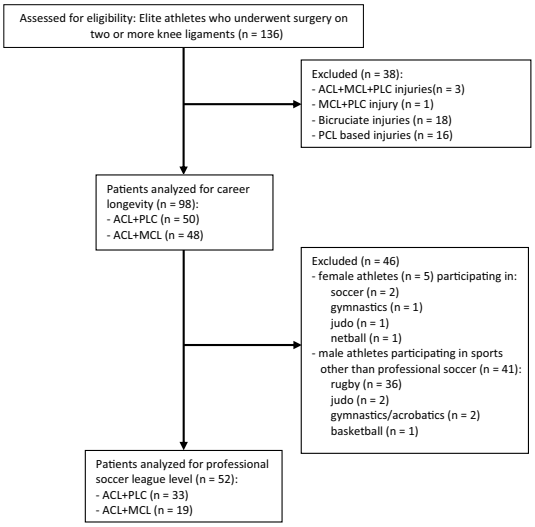

Figure 1. CONSORT (Consolidated Standards of Reporting Trials) diagram showing the inclusion and exclusion of patients for the career longevity and professional soccer league–level analyses. ACL, anterior cruciate ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament; PLC, posterolateral corner.

METHODS

Approval to undertake the study was given by Fortius Clinic in accordance with UK Health Research Authority guidance.[33] A consecutive cohort of elite athletes undergoing combined ligament surgery was previously identified to evaluate injury characteristics and RTP rates and levels but not career longevity.[15] In the present study, a subset of the cohort, which included 98 elite athletes with ACL plus collateral ligament injuries, was utilized to evaluate career length after surgical treatment. Of these, 52 male elite soccer players were analyzed for competition level. Athletes who underwent surgery between February 2001 and October 2019 were eligible for inclusion, while athletes with combined ACL + MCL + PLC, MCL + PLC, bicruciate, or posterior cruciate ligament injuries were excluded (Figure 1).

An elite athlete was defined as one who is paid to participate in one's sport or one who participates in national- or international-level competitions in amateur sports. RTP was defined as playing $\geq$1 match or competing in $\geq$1 event after ACLR at the professional level or at the national/international level in an amateur sport. Time to RTP was defined as the time between the surgery and first match appearance. All athletes were $\geq$17 years of age at the time of surgery. Clinical data were collected from medical and surgical reports, while career length was collected from publicly available data sets. Participation in elite sport was tracked annually, and if applicable, a retirement date was documented. If an athlete was still competing at the end of the 2020-2021 season, career length was censored at the end of this season. Data were censored if the subject did not meet the study endpoint at the end of the study. For this study, if an athlete had not retired by the end of the 2020-2021 season, data collection was stopped.

The second objective was to evaluate competition level after combined ACL plus collateral ligament surgery.

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Data collection required performance metrics to be available for each player from 1 year before injury to 5 years after surgery. We attempted to identify metrics for athletes of all sports and sexes; however, we found that performance metrics were only reliably available for the male professional soccer players in this cohort. Thus, all female and male athletes from sports other than professional soccer were excluded from the competition-level analysis. Male professional soccer athletes with combined surgical treatment of both components of ACL plus collateral ligament injury were compared with a previously identified cohort of male professional soccer players who had undergone isolated primary ACLR without other ligament surgery.[6] All athletes had a minimum of 4 years of follow-up and typically performed in one of the top 6 leagues in the English football system or the equivalent in another country. The league level in which the player was injured was considered baseline, and a player was followed for 5 years or until retirement. For years 2 and 5, league level was classified as the same, higher, lower, or nonprofessional. An athlete was considered nonprofessional if he or she competed in a level 7 league or lower.

Surgery was performed as soon as full extension and 100° of flexion in a "quiet" knee were achieved. If this was not achieved within 3 weeks of the injury, surgery to address the collateral ligament injury was undertaken, and a staged ACLR was performed later, once full range of motion was achieved. The staged procedures were undertaken as the knees concerned had too much inflammation to address all ligamentous lesions at once. In all cases, the PLC was addressed acutely, as early surgery allowing anatomic repair plus reconstruction to protect the repair is associated with better outcomes.[48] Further delay would mean the loss of opportunity to undertake anatomic repair. The small number of staged procedures prevented any statistical analysis to compare staged versus 1-stage surgery. Surgical repair and reconstruction for collateral ligament complex injuries combined with ACLR is performed by the senior author (A.W.) on patients who meet the following criteria: minimum of grade 2 varus or valgus laxity (ie, >5 mm of joint opening excess compared with the contralateral knee) at 30°, or any degree of compartment opening in full extension, and/or increased rotational laxity on the "dial test," and for the MCL, a Stener lesion or occasions in which the avulsed MCL was folded into the joint cavity.

Surgery consisted of a combination of anatomic repair plus reconstruction to protect the repair and allow early unrestricted motion.[13,14,23] Surgery for MCL injuries involved repair of the torn native tissue to restore natural anatomy, and this repair was protected by a reconstruction using the Ligament Augmentation and Reconstruction System ligament. A short isometric construct reconstruction was used in all cases.[13,14] For PLC injuries, a modified Larson technique[23] was used with a single femoral tunnel and single fibular tunnel. Before reconstruction, repair of the torn native tissues was undertaken. The reconstruction was to protect the PLC repairs and undertaken with hamstring tendon autograft with femoral fixation using an Endobutton CL (Smith & Nephew) (usually 60 mm) and an interference screw to create separate anterior and posterior bands of graft. Both were passed deep to the iliotibial band. The posterior band was taken medial to the biceps and then from posterior to anterior through the fibular head tunnel. Then the anterior band was taken from anterior to posterior through the fibular tunnel. With the knee at 30° and neutral rotation, the graft was fixed in the fibula with an interference screw. ACL injuries were treated with a single-bundle reconstruction utilizing patellar tendon or semitendinosus and gracilis hamstrings (HS) tendon autograft. The femoral tunnel was drilled via the anteromedial portal and sited in the anteromedial bundle position of the femoral "footprint,"[21] except between March 2010 and March 2013, when an "anatomic" (central femoral footprint position)[58] placement was used. In all cases, the tibial tunnel was placed to pass through the center of the tibial ACL footprint. Meniscal lesions were treated, when possible, with repair, but some needed partial meniscectomy.[16] Chondral lesions were treated according to size and depth and often left alone. For data collection purposes, cartilage lesions were divided into 2 groups: International Cartilage Regeneration & Joint Preservation Society grades <3, which included normal, and grades ≥3. In those requiring treatment, chondroplasty was performed for partial-thickness lesions, while microfracture or chondral lesion fixation with bioabsorbable pins (Smart Nails; CONMED) was performed for full-thickness lesions. Postoperative rehabilitation protocols emphasized early range of motion and focused on regaining full extension as soon as possible. Flexion was only restricted (to 90° for 4 weeks) when necessary to limit movement after repair of a radial or posterior root lateral meniscal tear. Patients with combined ACL plus collateral ligament surgeries were placed in a hinged knee brace when mobilizing for 6 weeks, with no restrictions on motion. They were kept touch weightbearing for 2 weeks, followed by 2 weeks of partial weightbearing. Immediate full weightbearing was allowed after isolated ACLR. After satisfactory review by the senior surgeon (A.W.) around 6 months postoperatively, the progression to RTP was supervised by the team's medical staff and the senior surgeon. RTP was permitted when there was no effusion and the player was confident, was aerobically fit, and had <10% side-to-side differences on functional and strength testing.

Statistical Analysis

Injury and surgical factors for the athletes who had undergone surgical treatment of combined ACL plus collateral ligament injury are summarized and presented as mean ± standard deviation or count and percentile, as appropriate. Student *t* tests were used to evaluate continuous variables, and the Fisher exact test for categorical data. Cox proportional hazards modeling was utilized to determine if there were career length differences between the ACL + MCL or ACL + PLC groups while controlling for age at surgery. The time of study entry was the date of surgery for all athletes, and career length was the number of playing years after surgery or until the end of the 2021 season.

The second objective to evaluate competition level followed a similar analysis plan with the male professional

TABLE 1
Injury and Surgical Factors[a]

	All Patients (n = 98)	ACL + PLC (n = 50)	ACL + MCL (n = 48)	*P*
Age, y	24.3 ± 4.6	23.6 ± 4.4	25.0 ± 4.7	.113
Female sex	5 (5)	3 (6)	2 (4)	.964
Sport				.022
Soccer	54 (55)	34 (68)	20 (42)	
Rugby	36 (37)	12 (24)	24 (50)	
Others	8 (8)	4 (8)	4 (8)	
ACL graft type				.570
Patellar tendon	67 (68)	34 (68)	33 (69)	
Hamstring tendon	30 (31)	16 (32)	14 (29)	
Quadriceps tendon	1 (1)	0 (0)	1 (2)	
Meniscal pathology				.023
Medial only[b]	5 (5)	2 (4)	3 (6)	
Lateral only[c]	35 (36)	13 (26)	22 (46)	
Both medial and lateral[d]	16 (16)	6 (12)	10 (21)	
Normal	42 (43)	29 (58)	13 (27)	
ICRS grade ≥3[e]	4 (4)	1 (2)	3 (6)	.305
RTP, %	87 (89)	44 (88)	43 (90)	.804
RTP timeline, mo	12.0 ± 4.5	12.8 ± 4.3	10.9 ± 3.5	.019
Rerupture	4 (4)	2 (4)	2 (4)	.967
Career after surgery, y	4.5 ± 2.9	4.8 ± 3.2	4.2 ± 2.7	.372

[a]Data are presented as n (%) or mean ± SD. ACL, anterior cruciate ligament; ICRS, International Cartilage Regeneration & Joint Preservation Society; MCL, medial collateral ligament; PLC, posterolateral corner; RTP, return to play.
[b]Included 5 repairs.
[c]Included 24 repairs, 11 partial meniscectomies.
[d]Included 15 repairs, 1 partial meniscectomy.
[e]Included 1 lateral femoral condyle microfracture, 1 medial femoral condyle chondral lesion fixation with bioabsorbable pins (Smart Nails; CONMED).

soccer player cohorts (ACLR alone, ACL + PLC, and ACL + MCL). Injury and surgical factors were summarized, and analysis of variance was used to determine differences between cohorts for continuous variables and the Fisher exact test for categorical variables. League level at 2 and 5 years after surgery was analyzed with the chi-square test, while career length was analyzed with a Cox proportional hazards model controlling for age at surgery. All analyses were performed using Stata software (Version 17; StataCorp), and statistical significance was set at $P < .05$.

RESULTS

A total of 98 elite athletes underwent ACLR plus collateral ligament surgery during the study, with 50 ACL + PLC and 48 ACL + MCL surgeries (Table 1). The cohort was 95% male, a majority played soccer (55%), and 37% played rugby and 8% participated in other elite sports such as gymnastics, judo, basketball, and netball. Significantly more soccer players incurred an ACL + PLC injury, while more rugby athletes incurred an ACL + MCL injury (P = .022). Meniscal pathology was different between groups; a significantly higher number of ACL + PLC injured knees had a normal meniscus (29/50 [58%]; P = .023), while ACL + MCL injured knees had more lateral meniscal pathology (22/48 [46%]; P = .023). Of the 4 athletes who had staged surgery, 3 (75%) returned to play and 1 retired after 18 months because of a rerupture. There was no significant difference between surgical groups for ACL graft type, the presence of a grade 3 or higher chondral lesion, RTP rate, or graft rerupture (all $P > .05$). However, the timeline for RTP was significantly longer for ACL + PLC surgery (12.8 months) as compared with ACL + MCL injuries (10.9 months; P = .019).

On average, career length after surgery of an athlete in the ACL + PLC group was 4.8 years, and an ACL + MCL group athlete played for 4.2 years. After controlling for age at surgery with Cox proportional hazards modeling, career length was not significantly different between injury groups (Figure 2). At 2 years, 76% of athletes in both injury groups were still playing, and by 5 years the rate had decreased to 61%.

To evaluate competition level after surgery, 3 male professional soccer player cohorts with a total of 252 athletes (Table 2) were studied and included ACLR alone (n = 200), ACL + PLC (n = 33), and ACL + MCL (n = 19). Athlete age at surgery was not significantly different between injury groups (mean, 24.0 years; P = .820), and 73% of all athletes received a patellar tendon ACL graft (P = .063 compared with 27% receiving hamstring tendon graft). A significantly higher number of athletes in the ACL + PLC injury group had a normal meniscus (58%) as compared with the ACR-alone (24%) and ACL + MCL (26%) groups (P = .009). The RTP rate in professional soccer players was significantly lower in the ACL + PLC group (88%) relative to

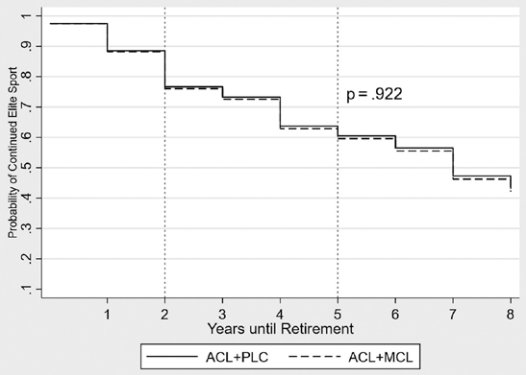

Figure 2. Career length was not significantly different after ACL + PLC and ACL + MCL injuries after controlling for age at surgery. ACL, anterior cruciate ligament; MCL, medial collateral ligament; PLC, posterolateral corner.

the ACLR-alone (97%) and ACL + MCL (100%) groups (P = .003). In addition to the lower RTP rate, the time to RTP was also significantly longer in the ACL + PLC group (12.9 months) when compared with the ACLR-alone (10.2 months) and ACL + MCL (10.0 months) groups (P = .002).

League level at 2 years after surgery was the same or higher for 61% of the ACLR-alone, 53% of the ACL + PLC, and 83% of the ACL + MCL cohorts (P = .121). The higher but nonsignificant trend continued at 5 years, with 59% of the ACL + MCL group playing at the same or higher league level as compared with 35% of the ACLR-alone and 42% of the ACL + PLC groups (P = .128) (Figure 3). At both 2 and 5 years, there were no significant differences between injury groups in the number of athletes playing in a lower league, or the number who did not RTP or retire or were playing semiprofessionally (all $P > .05$).

Career length after surgery averaged 5.9 years for ACLR alone, followed by 5.7 years for ACL + MCL and 5.4 years for ACL + PLC injuries (P = .650). When controlling for age at surgery with Cox proportional hazards modeling, career length was not significantly different between injury groups (Figure 4). At 2 years, 11% of the ACLR-alone group and 15% of the ACL + PLC and 16% and ACL + MCL groups had retired. By 5 years, 28% of the ACLR-alone, 37% of the ACL + PLC, and 39% of the ACL + MCL injury groups had retired.

DISCUSSION

The main finding of this study was that in a population of elite athletes, consisting mostly of professional soccer (55%) and rugby (37%) players, there was no difference in career longevity between ACL + MCL and ACL + PLC surgery. Moreover, in a subgroup analysis of professional male soccer players, those with combined ACL + PLC surgery returned at a lower rate and required a longer RTP

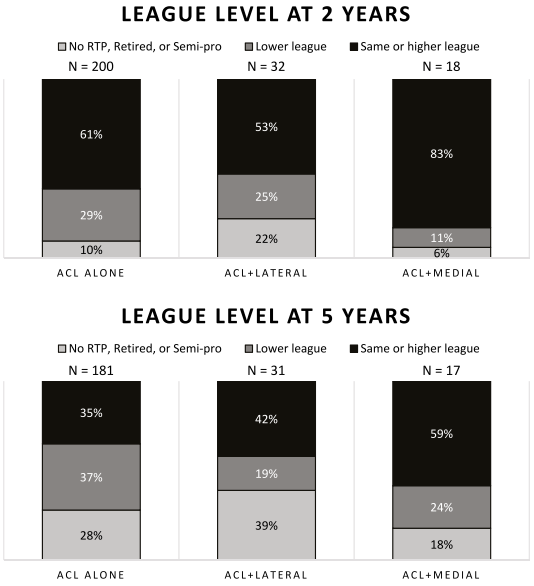

Figure 3. League level at 2 and 5 years after anterior cruciate ligament (ACL) reconstruction in professional soccer players. RTP, return to play.

time when compared to those undergoing isolated ACLR or combined ACL + MCL surgery. However, career length and competition level were not significantly different between injury groups, which suggests that once athletes undergoing ACL + PLC surgery RTP, they do equally well as those in different surgical groups.

Career Length of Elite Athletes After Surgical Treatment of Combined ACL + MCL or ACL + PLC Injuries

There is very little published in the field, particularly in relation to level of play and career longevity. Two previous studies of multiligament knee injuries reported RTP rates of 70.8% and 89.6% after combined ACL + MCL surgery[5,15] and of 88% after combined ACL + PLC surgery in elite athletes.[15] Compromise of the relevant secondary restraints such as menisci, but also collateral ligament complexes, has been highlighted as an important factor in ACL graft failure.[54] Better understanding of PLC anatomy and its functional interaction with ACL[20,25,46,47,67] has led to good outcomes after combined ACL + PLC surgery in recreational or nonathletes.[12,50,71] There is no literature on the effects of this surgery on career longevity in elite athletes. Although a combined ACL + MCL injury is more common, treating it can be challenging given the wide range of options and the lack of high-quality outcome data available in the literature.[30,64,74] Recent work has highlighted the importance of a functional MCL complex in the context of an ACL injury, to help control

TABLE 2
Injury and Surgical Factors of Male Professional Soccer Athletes[a]

	All Soccer Athletes (n = 252)	ACLR Alone (n = 200)	ACL + PLC (n = 33)	ACL + MCL (n = 19)	*P*
Age, y	24.0 ± 4.3	24.1 ± 4.2	23.9 ± 4.9	23.4 ± 5.0	.820
ACL graft type					.063
Patellar tendon	183 (73)	140 (70)	25 (76)	18 (95)	
Hamstring tendon	69 (27)	60 (30)	8 (24)	1 (5)	
Meniscal pathology					.009
Medial only	24 (10)	21 (11)	2 (6)	1 (5)	
Lateral only	108 (43)	92 (46)	8 (24)	8 (42)	
Both medial and lateral	49 (19)	40 (20)	4 (12)	5 (26)	
Normal	71 (28)	47 (24)	19 (58)	5 (26)	
ICRS grade ≥3	32 (13)	31 (16)	0 (0)	1 (5)	.071
RTP, %	242 (96)	194 (97)	29 (88)	19 (100)	.003
RTP timeline, mo	10.5 ± 3.9	10.2 ± 3.9	12.9 ± 4.2	10.0 ± 2.4	.002
Rerupture	19 (8)	18 (9)	0 (0)	1 (5)	.342
Career after surgery, y	5.8 ± 2.8	5.9 ± 2.7	5.4 ± 3.4	5.7 ± 2.3	.650

[a]Data are presented as n (%) or mean ± SD. ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; ICRS, International Cartilage Regeneration & Joint Preservation Society; MCL, medial collateral ligament; PLC, posterolateral corner; RTP, return to play.

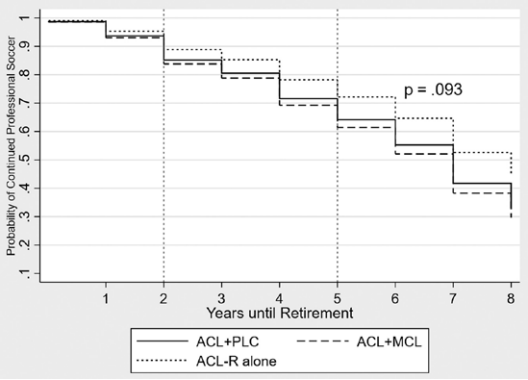

Figure 4. Cox proportional hazards model demonstrating the probability of a continued professional soccer career. The model controls for age at surgery, and there were no significant differences for career length between surgery groups.

anteromedial rotatory laxity.[8,55,73] Also, unaddressed MCL laxity increases ACL graft failure.[1,66,68] This is likely to increase the incidence of MCL surgery in combination with ACLR in the future. Current evidence[30,64,74] suggests that in ACL + MCL injury a trial of nonoperative treatment for the MCL seems appropriate in most cases of nonelite athletes, followed by delayed ACLR and, if symptoms/laxity demands, a delayed MCL retensioning plus reconstruction. Early surgery for the MCL component of the injury is appropriate in special circumstances, including Stener-type lesions, those with the avulsed part of the MCL folded into the joint, and competitive athletes with a grade ≥2 MCL injury who require expedited rehabilitation. Traditionally, even in elite athletes, bracing and rehabilitation were undertaken for 6 to 8 weeks before delayed ACLR. In the senior author's experience, this was problematic, as at the time of ACLR disuse osteoporosis and loss of some motion were common. There is limited literature regarding the effect of combined ACL + MCL injuries on athletes, particularly elite ones. In a mixed cohort of competitive and recreational athletes, Canata et al[18] reported 27 of 36 (75%) athletes returned to play after MCL surgery and ACLR in the setting of ACL deficiency combined with chronic grade ≥2 MCL laxity. In a randomized controlled trial of a cohort with similar activity levels and combined ACL + MCL grade 2 injuries, with a medial meniscus elevated from the tibia due to failure of the meniscotibial part of the MCL complex, Funchal et al[27] reported higher Tegner and Lysholm scores at 2 years of follow-up in the 58 cases treated operatively versus the 54 cases treated nonoperatively. In the present study, the mean career lengths after ACL + MCL and ACL + PLC surgery in elite athletes were 4.2 and 4.8 years, respectively. After controlling for age, career length was not significantly different between injury groups. Knowledge of career longevity after ACLR combined with collateral ligament surgery is of great concern for elite athletes given that their income depends on performing their sport, and also for their teams, with regard to the teams' performances and financial interests.[31,42,53]

Career Length and Competition Level of Professional Soccer Players After Surgical Treatment of Combined ACL + MCL, ACL + PLC, or Isolated ACL Injuries

The current study demonstrates that when compared with the isolated ACLR (194/200 [97%]) and combined ACL + MCL (19/19 [100%]) groups, a significantly lower number of soccer players with combined ACL + PLC (29/33 [88%]; *P* = .003) were able to RTP, as well as requiring

almost 3 months longer to RTP (12.9 months; $P = .002$). The fact that in the present study the ACL + MCL surgery results were comparable with those of ACLR alone may be explained by an exceptional healing potential of MCL,[2,59] enabling athletes with combined ACL + MCL surgeries to RTP faster and in a higher proportion compared with those with combined ACL + PLC surgeries, in which healing potential of structures with smaller cross-sectional area is less. In a nonelite athlete population, Cartwright-Terry et al[19] reported that combined ACL + PLC surgery had statistically and clinically worse Knee injury and Osteoarthritis Outcome Score Sports subscale results at all time evaluation points up to 5 years after surgery, when compared with isolated ACLR. It should be noted that in the ACL + PLC cohort, only patients who underwent split biceps tenodesis were included, and only when the lateral collateral ligament was intact. A study from the Swedish National Knee Ligament Registry[68] reported inferior 2-year Knee injury and Osteoarthritis Outcome Score results in patients with combined ACL + MCL or ACL + lateral collateral ligament surgery compared with isolated ACL tears. Even though isolated ACLR and surgical treatment of combined ACL + MCL or ACL + PLC have led to good outcomes in the general population,[12,29,64,74] clinical success in professional athletes is harder to discern, and the reality is that this patient group requires more demanding outcome measures than standard postoperative questionnaires aimed at the general population.[10,43] In addition, although RTP at the preinjury competition level is a significant achievement after ACLR, true clinical success may only be considered to have been achieved after a prolonged period of sustained play. Career longevity after isolated ACLR has been reported to range from approximately 2 years in the NFL to 7 years in elite skiing[32,49,51,57] and approximately 1 to 4 years in professional soccer.[4,9,22] In the present study, results are more favorable, with a mean career longevity of 5.9 years after isolated ACLR, 5.7 years after ACL + MCL surgery, and 5.4 years after ACL + PLC surgery. These differences in career longevity between groups were not significant, perhaps because of the lower numbers in the combined ACL + MLC or ACL + PLC cohorts. Khair et al[39] found that additional medial or lateral ligament reconstruction did not significantly affect the number of seasons played in the NFL, reporting approximately 2.7 and 2.2 seasons after isolated ACLR and combined ligament surgery, respectively. However, the latter consisted of only 6 cases, and there was no breakdown of the injury patterns treated or surgical details of collateral ligament reconstruction. In a study of the National Hockey League,[65] the mean career length after ACL injury was 2.8 seasons compared with 4.4 seasons in the matched uninjured control group ($P = .004$). It was found that 32 of 47 (68%) players had concomitant MCL injury, of which 12 (37.5%) were grade 3 on valgus stress testing. It was not stated whether the MCL was treated surgically. There was no statistically significant relationship between MCL injury severity and career length.

Although little is known about mid- and long-term performance outcomes after ACLR in soccer players, there are no available data published on this after combined ACL + MCL or ACL + PLC surgery. In professional soccer, excellent RTP rates have been previously reported after ACLR[#]; however, there has been evidence of restriction in players' ability to maintain their preinjury competition level 3 years after ACLR.[24,45,52,69,70] At 5 years after rupture season, Niederer et al[60] reported that 69.9% of professional soccer players were still playing but only 24.8% at the same level. The present study also shows a similar pattern of decreasing playing rates and competition level over time in all groups. At the 5-year follow-up, 35%, 42%, and 59% of players in the isolated ACLR, combined ACL + PLC surgery, and ACL + MCL surgery groups, respectively, were still playing at the preinjury competition level. At the professional level, reasons for early retirement may be multifactorial, such as decreased performance, fear of further injury/surgery, loss of motivation for continuing playing at a lower competition level, nonselection on the team, contract status, and, for older players, the simple matter of their realization that it is time to retire. Retirement does not necessarily reflect the presence of knee problems.[63] In the current study, soccer players' career length and competition level were not significantly different between injury groups once RTP had been achieved. The surgical strategy assessed in this study aimed to minimize proprioceptive and ligament function deficit, through early anatomic repairs of the damaged collateral ligament complex tissues, as well as protecting the restored anatomy during its healing phase with a biomechanically sound reconstruction.[3,13,23] These strong constructs allow safe and early restoration of range of motion, thereby decreasing stiffness. This approach allows a career longevity after combined ACL + MCL or ACL + PLC surgeries that resembles that with an isolated ACLR surgery, although fewer athletes who undergo ACL + PLC do RTP and take longer to do so.

In the present study, a significant number of athletes in the combined ACL + PLC group had a normal meniscus (29/50 [58%]; $P = .023$), while those in ACL + MCL group had more lateral meniscal pathology (22/48 [46%]; $P = .023$) at the time of surgery. Also, in the soccer player subanalysis, a significantly higher number of athletes in the ACL + PLC surgery group had a normal meniscus (19/33 [58%]; $P = .009$) as compared with the ACLR-alone (47/200 [24%]) and ACL + MCL surgery (5/19 [26%]) groups. Differences in patterns of associated intra-articular pathology between isolated ACLR and combined ACL + MCL or ACL + PLC surgeries may be related to the type of sport played, to different mechanisms of injury, and the amount of violence at injury.[17,28,40,41] It is important to recognize that the additional injuries can skew the data and results, and are therefore a major risk of bias.

There are several limitations to the present study. First, being retrospective, the preoperative assessment, surgical plan, surgical factors such as timing of surgery, graft choice, comorbid intra-articular pathology treatment, and further surgery were decided based on the senior surgeon's clinical judgment and not on a randomization process. No power analysis was made because of the inherent limita-

[#]References 4, 6, 9, 11, 22, 24, 26, 34, 45, 52, 60, 70, 75.

tions in constructing exclusive elite athletes' samples. The consequently smaller sample sizes in the combined ACL + MCL or ACL + PLC surgeries (48 and 50 cases, respectively) are therefore a major limitation of our study, by increasing the risk of type 2 errors. Nonetheless, these series are the largest ever published in this population. No validated patient-reported outcome measures were collected, and while this can also be considered a limitation, it has recently been argued that patient-reported outcome measures designed to capture data from the normal population have limited value in assessing high-level athletes in whom clinical outcomes such as RTP times and rates, levels of play, and career longevity are more appropriate and important to players, their medical teams, and treating surgeons.[43] Focusing on these coarse measures of outcome allowed inclusion of a larger number of athletes, thereby decreasing the chance of selection bias and recall bias. The national league in which the athlete's club participates or the athlete's participation in international competitions is a crude reflection of the athlete's level, not least because it does not reflect the performance on the pitch. In addition, a player who is injured when the team is at a higher level and then returns to play when the team has been relegated to a lower league appears to be playing at a lower level, with the reverse scenario, of course, also being true.

Despite the mentioned limitations, to our knowledge, this is the first study to assess career longevity after combined ACL + MCL or ACL + PLC surgery in elite athletes and compare it with that of soccer players who underwent isolated ACLR. It provides valuable information for surgeons, athletes, and their coaching and medical teams, enabling them to set realistic expectations for elite athletes before surgery regarding their career longevity and the competitive level maintained throughout it. Lessons learned from such a study are also valuable for the nonprofessional sports population. Also, this study did not solely rely on publicly available data, whose inherent biases have recently been highlighted,[36,44] but rather was founded on the senior surgeon's practice data.

CONCLUSION

Elite athletes achieved the same career length after combined ACL + MCL or ACL + PLC surgery as those undergoing isolated ACLR. Although professional soccer players with combined ACL + PLC injuries returned at a lower rate and required longer time to RTP than those with isolated ACLR or combined ACL + MCL surgeries, those who make it back had the same career longevity and level of competition.

ACKNOWLEDGMENT

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CHAPTER IV

Rates and Levels of Elite Sport Participation At 5 Years after Revision Anterior Cruciate Ligament Reconstruction

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Rates and Levels of Elite Sport Participation at 5 Years After Revision ACL Reconstruction

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Background: There is a paucity of data regarding return to play (RTP), level of competition, and longevity of play after revision of anterior cruciate ligament (ACL) reconstruction (ACLR) in elite athletes.

Purpose: To report RTP rates and competition levels in elite athletes at the point of RTP, as well as at 2 and 5 years after revision ACLR, and the effect of meniscal and chondral pathology at revision surgery on these outcomes.

Study Design: Case series; Level of evidence, 4.

Methods: A retrospective review of a consecutive series of all revision ACLRs undertaken by the senior author between 2009 and 2019, with a minimum 2-year follow-up, was carried out. Outcome measures were RTP rates and competition level.

Results: A total of 49 knees in 48 elite athletes met the inclusion criteria. After revision ACLR, 43 (87.8%) elite athletes achieved RTP, of whom 75.5% were at the same level. At 2 years after surgery, 39 (79.6%) were still playing, 25 (51%) at the same level; at 5 years after surgery, 20 (44.4%) were still playing, 9 (20%) at the same level. Elite athletes with $<$50% thickness or no articular cartilage lesions were more likely to RTP (94.6% vs 66.7%; P = .026), as well as return to the same competition level (83.8% vs 50%; P = .047), compared with those with $\geq$50% thickness chondral lesions. Those without medial meniscal pathology were more likely to RTP at the same level after revision surgery (94.4% vs 64.5%; P = .036). The median time elite athletes continued to play after revision ACLR was 73 months (95% CI, 43.4-102.6); 23 months at the same level (95% CI, 13.6-32.4). The probability of still playing at 5 years after surgery was 55.9%, with a 22.5% chance of maintaining preinjury competition level.

Conclusion: In elite athletes, RTP rates and competition level decreased over time after revision ACLR. The presence of $>$50% thickness chondral pathology was associated with lower RTP rates and competition level at RTP time, while medial meniscal pathology was associated with lower competition level at RTP.

Keywords: revision ACL reconstruction; elite athletes; return to play; competition level

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Elite athletes are known to have high return to play (RTP) rates after anterior cruciate ligament (ACL) reconstruction (ACLR), but unfortunately, rerupture of the ACL occurs in 2% to 19.3% of cases.¶ Revision ACLR is correctly considered career threatening,[1,6,22,26,32,33] in terms of both RTP and the ability to return to the same level of sport. Although there is evidence in the literature on return to sports after revision ACLR, this is predominantly in recreational athletes or mixed populations,# with only limited information regarding RTP rates and level of competition after revision ACLR in elite athletes.

Meniscal and chondral pathologies at the time of revision ACLR have been shown to be associated with poorer outcomes after revision ACLR, but again this is focused on the nonelite sports population.[1,20,30,31] Better understanding of

¶References 2, 5, 10, 11, 13, 18, 19, 23, 29.
#References 1, 6, 8, 12, 15, 22, 28, 30, 31, 33.

how these factors affect RTP rates and competition level outcomes in elite athletes would be extremely valuable for athletes, physicians, and the athlete's medical team, as it would allow realistic expectations about outcomes to be set and allow future treatment developments to be evaluated against contemporary practice.

The purpose of the present study is to report RTP rates and competition level in elite athletes at the point of RTP and at 2 and 5 years after revision ACLR. The secondary objectives are to assess the association between meniscal and chondral pathologies at the time of revision surgery on RTP and competition level. It was hypothesized that RTP rates and competition level would be lower than that seen historically after primary ACLR. It was also hypothesized that meniscal and chondral pathology would be associated with lower RTP rates and competition level.

METHODS

A retrospective review of a consecutive series of all revision ACLRs undertaken by the senior author (A.W.) between 2009 and 2019 was carried out. Patients were included if they were elite athletes aged ≥17 years who underwent revision ACLR a minimum of 2 years previously. Cases of combined-ligament injury and cases that required high tibial osteotomy, either concurrently or previously, were excluded.

Elite athletes were defined as those who are paid to perform their sport or those who participate at the national/international level in an amateur sport. RTP was defined as playing ≥1 match or competing in ≥1 event after revision ACLR at the professional level or at the national/international level in an amateur sport.

A flowchart of the inclusion criteria is depicted in Figure 1. Approval to undertake the study was given by the institution involved, in line with UK Health Research Authority guidance. Patient consent was not required.

In all cases, preoperative assessment, surgical plan according to tunnel size and position, graft choice and fixation, and ACL graft offloading were carried out based on a decision-making algorithm by White et al[32] for single-stage revision ACLR. A lateral extra-articular tenodesis was performed in all cases from 2014 onward and in those considered to have adverse factors for graft survival before this.[32] Meniscal lesions were treated, when possible, with repair, but some needed partial meniscectomy. Repairs were carried out using a combination of all-inside and inside-out techniques, according to the specific tear pattern.[4] All-inside devices were exclusively used in the posterior third of the meniscus. Chondral lesions were treated according to size and depth and often left alone. For data collection purposes, cartilage lesions were divided into 2 groups: International Cartilage Regeneration & Joint Preservation Society (ICRS) grades <3, which included normal, and ICRS grades ≥3. In those requiring treatment, chondroplasty was performed for partial-thickness lesions, while microfractures were performed for full-thickness lesions.

Apart from the restrictions below, all elite athletes followed the same postoperative rehabilitation protocol.

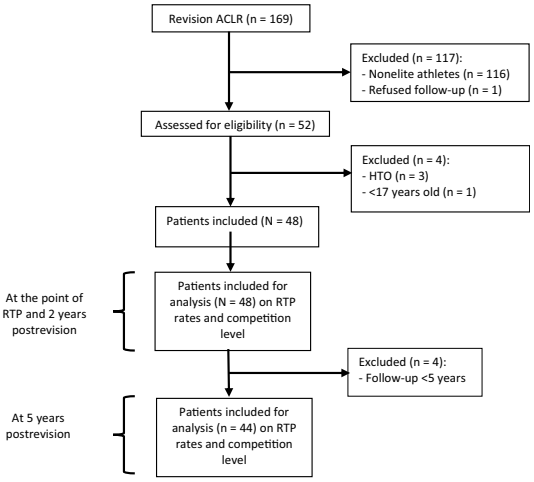

Figure 1. Flowchart of the included patients. ACLR, anterior cruciate ligament reconstruction; HTO, high tibial osteotomy; RTP, return to play.

They were allowed to bear weight and to flex the knee as tolerated, with an emphasis on immediate restoration of full extension. Flexion and weightbearing were restricted if the patient had also undergone chondral microfracture or repair of a radial or posterior root tear of a meniscus. After satisfactory clinical evaluation at 6 months postoperatively, the progression of rehabilitation and fitness to RTP was supervised by the teams' medical staff.

Information regarding medical history, clinical examination, operative details, complications, further procedures, and clinical follow-up was collected from medical records and medical teams. Elite athletes were contacted directly to ascertain if they had undergone any further surgeries, if they had sustained graft failure, and to complete a Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaire. Sources for RTP rates, time, duration, and competition level included elite athletes' interviews, medical records, athletes' medical teams, team websites, press releases, personal websites, and match or event appearance records. Multiple sources were used when possible to cross-reference and ensure accuracy of reporting.

Primary outcome measures were RTP rate and competition level before and after revision ACLR. RTP time was calculated as the time from surgery to the first competitive match or event after revision ACLR. The national league in which the athlete participated or participation in international competitions was used to determine the competition level. This was divided into 3 categories: 1, play in a lower league club or no longer competing internationally; 2, play in a same-level league club or still competing at the international level; and 3, play in a higher-level league club.

The secondary outcomes were defined as the presence or absence of meniscal and chondral pathologies and determined based on surgical details from medical records.

TABLE 1
Preoperative Clinical and Demographic Characteristics[a]

Characteristic	Value
Number of knees	49
Age at surgery, mean ± SD, y	23.9 ± 4.3
Female/male	6 (12.5)/42 (87.5)
Left/right	20 (40.8)/29 (59.2)
Previous revision ACLR	3 (6.3)
Sport	
Soccer	26 (54.2)
Rugby	17 (35.4)
Other[b]	5 (10.4)
Mechanism of reinjury	
Contact	7 (14.3)
Noncontact—rotation	27 (55.1)
Noncontact—jump/land	5 (10.2)
Noncontact—other	6 (12.2)
Unknown	4 (8.2)
Mode of failure	
Traumatic	20 (40.8)
Technical	9 (18.4)
Biological	7 (14.3)
Combined	13 (26.5)
Failed primary graft type	
Patellar tendon	16 (32.7)
Hamstrings	27 (55.1)
Allograft	4 (8.2)
Fascia lata	1 (2.0)
Synthetic	1 (2.0)

[a]Values are presented as number (%) unless otherwise indicated. ACLR, anterior cruciate ligament reconstruction.
[b]Other: netball (1); karate (1); field hockey (1); surfing (1); skiing (1).

TABLE 2
Operative Details and Findings[a]

Characteristic	Value, n (%)
Injury to revision surgery time[b]	
≤14 days	21 (44.7)
15-28 days	11 (23.4)
>28 days	15 (31.9)
Tunnels	
Reused	
Femur	32 (65.3)
Tibia	38 (77.6)
Adjusted	
Femur	8 (16.3)
Tibia	5 (10.2)
Completely new	
Femur	9 (18.4)
Tibia	6 (12.2)
Revision graft type	
Patellar tendon	29 (59.2)
Hamstrings—ipsilateral	16 (32.7)
Hamstrings—contralateral	3 (6.1)
Synthetic	1 (2.0)
Lateral extra-articular tenodesis	
Macintosh	43 (87.8)
Lemaire	1 (2.0)
Medial meniscal pathology[c]	31 (63.3)
Lateral meniscal pathology[d]	32 (65.3)
Chondral pathology[e]	
ICRS ≥3	12 (24.5)
ICRS <3	37 (75.5)

[a]ICRS, International Cartilage Regeneration & Joint Preservation Society.
[b]Exact injury date unknown in 3 cases.
[c]Included 20 repairs, 7 partial meniscectomies, and 6 previous treatments.
[d]Included 13 repairs, 18 partial meniscectomies, and 6 previous treatments.
[e]Included 6 chondroplasties, 1 microfracture, and 25 nonoperative treatments.

Statistical Analysis

Data were processed using SPSS Version 28.0 (IBM Corp). Categorical variables are shown in numbers (percentages), and continuous variables are expressed as mean ± SD. Fisher exact and χ^2 tests were used to determine whether RTP rates and competition level differed with age (<24 compared with ≥24 years), sport (soccer vs rugby), having a medial or lateral meniscal lesion (tear or previous resection), and the presence and extent of chondral damage (ICRS <3 compared with ≥3) at revision ACL surgery. Kaplan-Meier curves were generated to illustrate RTP rates and maintenance of preinjury competition-level survival at 2 and 5 years after surgery, as well as the study athletes' median career longevity time and the median time of maintaining their preinjury competition level after revision ACLR. Statistical significance was set at $P < .05$.

RESULTS

A total of 49 knees in 48 elite athletes met the criteria to be included in the study, with a mean patient age of 23.9 ± 4.3 years at the time of surgery. Of these, 26 (54.2%) were soccer players and 17 (35.4%) were rugby players. At 2 years, 48 patients were included in the analysis, and 44 were included at 5 years after revision surgery. Full patient characteristics are shown in Table 1.

Operative Details and Findings

A single-stage revision ACLR was performed in all cases. Both tunnels were deemed to be in a satisfactory position in 31 (63.3%) of cases and therefore reused. An autologous patellar tendon was the most common graft used for the revision procedure (29 cases [59.2%]). The only synthetic graft was used specifically at 1 patient's request and against advice. Five patients, all operated on before 2014 when the use of a lateral extra-articular tenodesis became standard procedure in this elite athlete group, did not have a lateral extra-articular tenodesis as they did not have any adverse factors for graft survival (Table 2).

Clinical Outcome and Further Surgery

Clinical assessment of laxity was taken at the last documented clinical follow-up (mean 1 year after surgery and

TABLE 3
Elite Athletes Who Were Competing According to Age, Sport, and Presence or Absence of Meniscal and Chondral Pathology[a]

	RTP		2 Years		5 Years	
Characteristic	No. (%)	*P* Value	No. (%)	*P* Value	No. (%)	*P* Value
Age						
<24 years	22 (95.7)	.194	22 (95.7)	**.012**	14 (70)	**.002**
≥24 years	21 (80.8)		17 (65.4)		6 (24)	
Sport						
Soccer	26 (96.3)	**.025**	25 (92.6)	**.017**	13 (52)	.251
Rugby	12 (70.6)		10 (58.8)		5 (33.3)	
Medial meniscus						
Pathology present	25 (80.6)	.073	22 (71)	.070	11 (39.3)	.371
No pathology	18 (100)		17 (94.4)		9 (52.9)	
Lateral meniscus						
Pathology present	28 (87.5)	≥.999	25 (78.1)	≥.999	10 (34.5)	.070
No pathology	15 (88.2)		14 (82.4)		10 (62.5)	
Chondral pathology						
ICRS <3	35 (94.6)	**.026**	32 (86.5)	0.050	18 (52.9)	.079
ICRS ≥3	8 (66.7)		7 (58.3)		2 (18.2)	

[a]ICRS, International Cartilage Regeneration & Joint Preservation Society; RTP, return to play. The bold values demonstrate a significant difference in RTP between the 2 groups.

earliest 3 months after surgery). All patients had negative pivot-shift and Lachman tests, but there was a grade 1 anterior drawer test in 14 (28.6%) knees. KOOS scores were obtained in 34 (69.4%) cases, at a mean follow-up of 3.9 ± 1.8 years: KOOS Pain (87.7 ± 13.0), KOOS Symptoms (74.9 ± 17.4), KOOS Activities of Daily Living (94.0 ± 8.8), KOOS Sport and Recreation (76.8 ± 22.8), and KOOS Quality of Life (69.4 ± 36.3).

There was confirmed graft failure in 2 patients (4.1%). Both occurred in rugby players, who remained functionally stable (both had a lateral extra-articular tenodesis), and have not been rerevised. Thirteen athletes (27.1%) underwent subsequent surgical procedures with some athletes having multiple interventions. The interventions included 7 arthroscopic medial meniscectomies, all of which had medial meniscal repair at the time of revision surgery; 3 cases of arthroscopic chondroplasty and 1 case of arthroscopic microfracture; 5 cases of arthroscopic treatment of fixed-flexion deformity, of which 2 did not return to play; and 1 prominent staple removed. There were 4 superficial wound complications requiring debridement, but no deep infections.

RTP Rates After Revision ACLR

After revision ACLR, 43 (87.8%) elite athletes achieved RTP at a mean of 11 ± 3.1 months, and 39 (79.6%) were still playing at 2 years after revision surgery. A total of 40 athletes were playing more than 5 years after surgery, and a further 4 had retired before reaching this time point. Of these 44 athletes (45 knees), 20 (44.4%) were still playing at 5 years after surgery (Figure 2). Soccer players had a significantly higher playing rate at the point of RTP (96.3% vs 70.6%; $P = .025$), as well as at 2 years after surgery (92.6% vs 58.8%; $P = .017$), when compared with rugby players (Figure 3 and Table 3). Younger patients (aged <24 years) were more likely to still play at 2 (95.7% vs 65.4%; $P = .012$) and 5 (70% vs 24%; $P = .002$) years after surgery (Table 3).

Elite athletes with no articular cartilage damage or lesions of <50% thickness (ICRS grade <3) were more likely to RTP after revision surgery (94.6% vs 66.7%; $P = .026$) than those with worse chondral lesions. Playing rates at 2 and 5 years after surgery were not significantly affected by the presence of chondral or meniscal pathology (Table 3).

Competition Level After Revision ACLR

A total of 37 (75.5%) elite athletes achieved RTP at the preinjury competition level after revision ACLR; 25 (51%) and 9 (20%) were still competing at the same level at 2 and 5 years after surgery, respectively (Figure 2). Competition level was not significantly affected by age or sport (Table 4). Elite athletes without medial meniscal pathology were more likely to RTP at the same level (94.4% vs 64.5%; $P = .036$), as well as those who had <50% thickness articular cartilage lesions (ICRS grade <3) (83.8% vs 50%; $P = .047$). Competition level at 2 and 5 years was not significantly affected by the presence of chondral or meniscal pathology (Table 4).

Career Longevity and Maintenance of Preinjury Competition Level After Revision ACLR

Kaplan-Meier survival analysis was conducted to estimate the elite athletes' career longevity (Figure 4) and the maintenance of preinjury competition level time (Figure 5) after revision ACLR. The median time elite athletes continued to play after revision ACLR was 73 months (95% CI, 43.4-102.6). The probability of still playing was 79.6% at

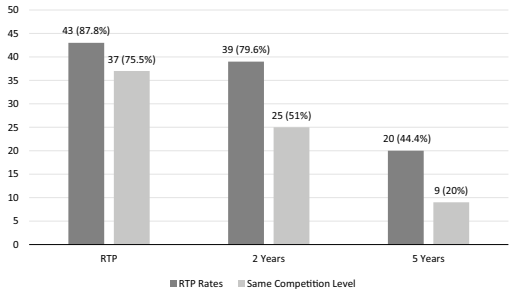

Figure 2. Overall return to play (RTP) rates and competition level at the point of RTP, 2 years and 5 years after revision anterior cruciate ligament reconstruction.

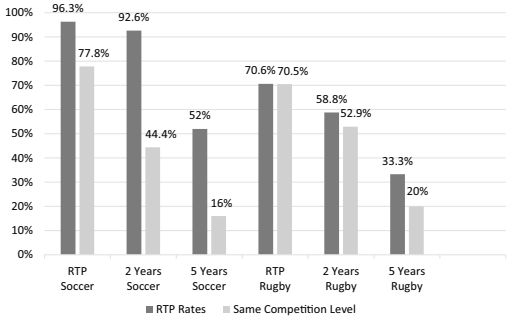

Figure 3. Soccer and rugby return to play (RTP) rates and competition level at the point of RTP, 2 years and 5 years after revision anterior cruciate ligament reconstruction.

TABLE 4
Elite Athletes Who Were Competing at the Preinjury Level According to Age, Sport, and the Presence or Absence of Meniscal and Chondral Pathology[a]

	RTP		2 Years		5 Years	
Characteristic	No. (%)	*P* Value	No. (%)	*P* Value	No. (%)	*P* Value
Age						
<24 years	19 (82.6)	.277	15 (65.2)	.062	5 (25)	.482
≥24 years	18 (69.2)		10 (38.5)		4 (16)	
Sport						
Soccer	21 (77.8)	.724	12 (44.4)	.583	4 (16)	≥.999
Rugby	12 (70.6)		9 (52.9)		3 (20)	
Medial meniscus						
Pathology present	20 (64.5)	**.036**	13 (41.9)	.095	4 (14.3)	.265
No pathology	17 (94.4)		12 (66.7)		5 (29.4)	
Lateral meniscus						
Pathology present	26 (81.3)	.296	17 (53.1)	.686	7 (24.1)	.456
No pathology	11 (64.7)		8 (47.1)		2 (12.5)	
Chondral pathology						
ICRS <3	31 (83.8)	**.047**	21 (56.8)	0.158	9 (26.5)	.087
ICRS ≥3	6 (50)		4 (33.3)		0	

[a]ICRS, International Cartilage Regeneration & Joint Preservation Society; RTP, return to play. The bold values demonstrate a significant difference in RTP between the 2 groups.

2 years and 55.9% at 5 years after surgery (Figure 4). The mean age at retirement was 28.9 ± 4.4 years.

Elite athletes were able to maintain the preinjury competition level for a median time of 23 months (95% CI, 13.6-32.4). The probability of maintaining it was estimated to be 49% at 2 years and 22.5% at 5 years after surgery (Figure 5).

DISCUSSION

Elite athletes undergo revision ACLR with the goal of returning to play at the preinjury competition level and continuing to do so. The main finding of this study is that 87.8% of elite athletes were able to RTP at a mean of 11 ± 3.1 months after revision ACLR, and 75.5% were at the same preinjury competition level. However, only 44.4% were still playing at 5 years after surgery, and only 20% were at the preinjury level. To our knowledge, this is the first report of RTP rates, levels of play, and longevity in elite athletes after revision ACLR.

RTP Rates and Competition Level

In a population of mostly professional soccer players (54.2%) and rugby players (35.4%), the 87.8% RTP rate compares favorably with the published 79% and 87.5% RTP rates after revision ACLR[26,32] and even with the 83% pooled RTP rate from a meta-analysis of RTP after primary ACLR in elite athletes.[13] This is much higher than the RTP rates found in recreational athletes, but in 19% of those cases, the knee was not the primary reason for their decision not to RTP.[21] However, our RTP rate is

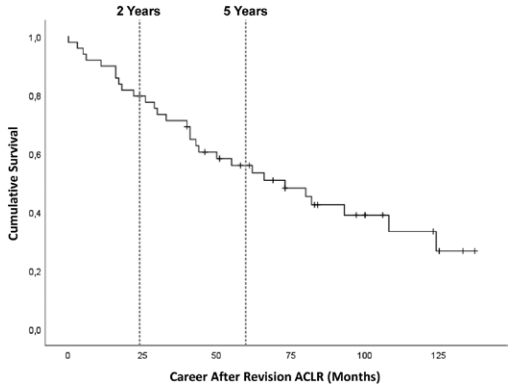

Figure 4. Kaplan-Meier survival curve: career longevity. ACLR, anterior cruciate ligament reconstruction.

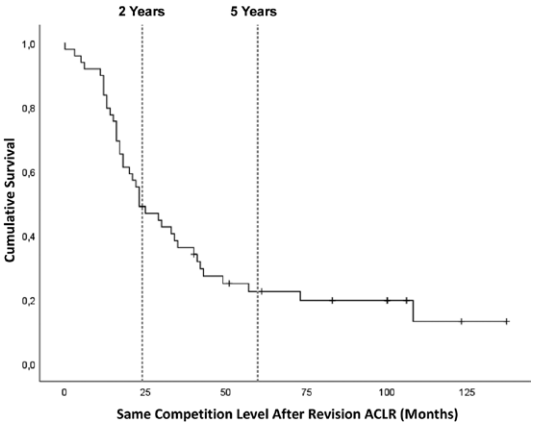

Figure 5. Kaplan-Meier survival curve: maintenance of preinjury competition level. ACLR, anterior cruciate ligament reconstruction.

lower than the RTP of 96.1% reported by Balendra et al[2] after primary ACLR in professional soccer players. The current study shows that soccer players had a significantly higher playing rate at the point of RTP (96.7% vs 70.6%; P = .025) as well as at 2 years after surgery (92.6% vs 58.8%; P = .017) when compared with rugby players. In the context of revision ACLR, there are no comparative studies between different elite sports. Mai et al[19] reported that out of 344 professional athletes, 298 (86.6%) reported RTP after primary ACLR and that National Hockey League athletes had a significantly higher RTP rate compared with those of all other sports (95.8% vs 83.4%; P = .04). In the current study, we cannot explain the significant difference shown in the RTP rates. There are likely to be a number of reasons. The possible factors include the fact that financial reward for playing professional rugby is much lower and the attritional damage from accumulated injury greater when compared with soccer. Similar to the findings of Okoroha et al,[26] in the National Football League (NFL), we found that age did not affect RTP rate after revision ACLR. However, and predictably, younger patients (<24 years) were more likely to still play at 2 (95.7% vs 65.4%; P = .012) and 5 (70% vs 24%; P = .002) years after surgery.

Like most studies that report on RTP rates, we have used a dichotomous definition of RTP, which is the appearance in a single competition match or event, but this cannot accurately reflect the athlete's performance level on returning from injury. The national league in which the athlete's club participates or the athlete's participation in international competitions is a crude reflection of the athlete's level, not least because it does not reflect one's performance during a match or competition. In addition, a player who is injured when the team is at the highest level and then returns from injury when the team has been relegated to a lower league appears to be playing at a lower level, with the reverse scenario, of course, also being true.

Two previous studies have evaluated the competition level at the point of RTP in small groups of elite athletes after revision ACLR.[26,33] In a mixed-population study, Zaffagnini et al[33] reported 8 of 12 (67%) athletes returned at the elite level at a mean 6.7 ± 1.5 months. Okoroha et al[26] reported 19 of 24 (79%) NFL players returned to play at the same level at a mean of 12.6 months. Similarly, in the current study, we found, at a mean of 11 ± 3.1 months, that 37 of 48 (75.5%) elite athletes returned to play at the same level. It also compares favorably with numbers reported in the primary ACLR context, in which the elite athletes' mean rates of return to preinjury level ranged 59.4% to 90.1%.[2,7,18,19,25,27] These relatively high rates may be due to the fact that elite athletes, when compared with the normal population, are more motivated and benefit from specialized medical teams. They may also be more confident about RTP, having already previously returned to play after a primary ACLR.

In the context of revision ACLR, little is published about RTP rates and competition level after initial RTP in elite athletes. Anand et al[1] reported 4 of 7 professional athletes were competing at their previous injury level at a mean 4.9 years of follow-up, while White et al[32] reported 15 of 40 (37.5%) at a mean 4.4 years after surgery. The present study goes further and shows that 39 (79.6%) elite athletes were still playing at 2 years after revision ACLR, 25 (51%) at the same level, while only 20 (44.4%) were still playing at 5 years, with 9 (20%) at the same level. In the context of primary ACLR in soccer players, Waldén et al[29] reported that 81 of 93 (87.1%) players were still playing at a 3-year follow-up, with 60 (64.5%) at the same level. Niederer et al,[25] in a media-based study, reported that in the post-RTP season, 93% of professional soccer players were still playing, 60.9% at the same level, and at the 5-year post-rupture season, 69.9% were still playing, with 24.8% at the same level. This latter study shows a similar pattern of decreasing playing rates and competition level after revision ACLR as reported in the present study, which is

important information for the treating clinician, medical teams, and coaches as well as the athletes themselves.

Career Longevity and Maintenance of Preinjury Competition Level

The present study shows the median time elite athletes continued to play after revision ACLR to be 73 months (95% CI, 43.4-102.6), and 23 months at the same level (95% CI, 13.6-32.4). Little is published about career longevity and the time elite athletes maintain their preinjury performance level after revision ACLR. Okoroha et al[26] found that after revision ACLR, 19 of 24 NFL athletes had a mean career time of 2.3 seasons. In the Canadian Football League, Longstaffe et al[18] reported that, after primary ACLR, 30 (69.8%) athletes were able to play 2.8 seasons further.

In elite sport, the goal of the athlete is not just to RTP but to return at least to the previous competition level. We report not just the RTP and competition level rates but also the probability of playing, and at the preinjury level, at 2 and 5 years after surgery. In the primary ACLR setting, Forsythe et al[7] state that only by the third season postinjury did professional soccer players have a similar performance to noninjured players. Similarly, Barth et al[3] reported that soccer players start fewer games and score fewer goals per game at 3 seasons after injury. In the current study, the probability of maintaining the same competition level was estimated to be 49% at 2 years. Of 14 elite athletes who were playing at a lower level at 2 years after revision ACLR, only 2 were representing the same club as before the injury. The reason for the transfer is not known, and although it could be due to a decline in performance after revision ACLR, it could also be due to many other reasons, including the financial deal on offer. The present study also showed that the probability of still playing at 5 years after surgery was 55.9%, with a 22.5% chance of maintaining preinjury competition level. The mean age at retirement was 28.9 ± 4.4 years. White et al[32] reported that of 35 (87.5%) elite athletes who returned to play, 5 (14.3%) had since retired at a mean of 3.1 years after surgery, at a mean age of 30 years. There are no other studies published in the setting of revision ACLR with which to compare the results of the present study in terms of retirement age. Read et al[27] wrote that the rate of retirement in NFL players who returned to play after primary ACLR was higher and that they retired earlier than their matched controls. In a revision ACLR setting, reasons for early retirement may be multifactorial, such as decreased performance, fear of further injury/surgery, loss of motivation for continuing at a lower competition level, and, for older players, the simple matter of their realization that it is time to retire. Retirement does not necessarily reflect knee problems.

Association Between Operative Findings and RTP Rates/Competition Level

Meniscal and chondral pathology at the time of revision ACLR have been shown to be associated with poorer outcomes.[20,30,31] Consistent with previous studies,[9,16,32] the present study found that, at the time of revision, 63.3% elite athletes had medial and 65.3% had lateral meniscal pathology, and 62% had chondral pathology. Two previous studies found that RTP rate at the same or higher level was significantly higher in patients with less severe chondral changes, but it was not significantly affected by the presence of meniscal pathology after revision ACLR.[1,30] There is no previous study reporting the effect of chondral/meniscal pathology on RTP rates/competition level after revision ACLR in an elite athlete population. In the present study, an association between no or less severe chondral pathology and RTP (94.6% vs 66.7%; $P = .026$) was shown, as well competing at the same level (83.8% vs 50%; $P = .047$). Those without medial meniscal pathology were also more likely to RTP at the same level (94.4% vs 64.5%; $P = .036$). There was no association between lateral meniscal status at the time of revision and RTP/competition level. This is, perhaps, a little surprising given the more problematic experience with lateral versus medial meniscal tears in elite athletes.[4,17,24] At 2 and 5 years after surgery, there was no association between meniscus/chondral status and RTP rates/competition level. Presumably, a knee capable of coping with the loading needed to RTP continues to be able to cope.

There are several limitations to the present study. It is retrospective, and as result, the preoperative assessment, surgical plan, the various surgical factors such as timing of surgery, graft choice, the need for lateral tenodesis, chondral and meniscus pathology treatment, and further surgery were decided based on clinical judgment and not on a randomization process. However, in all cases, the decision-making algorithm for single-stage revision ACLR was applied, which has already been reported to have good outcomes in elite and nonelite athletes.[32] The present study adds 3 years of experience with this algorithm in an elite athlete population, with added focus on RTP rates and competition level at medium- and long-term outcomes.

The sample size was 48 cases, composed of elite athletes from different sports, and no comparison of RTP rates/competition level between athletes of different sports could be made due to small numbers in each group. However, all cases are part of a consecutive series, reflecting the senior author's practice in elite sports, and the information gained can be used when counseling elite athletes undergoing revision ACLR.

Although KOOS scores were obtained in 34 (69.4%) cases, no other validated outcome score was collected, which is consistent with previous studies on elite athletes.[2,14,18,29,32]

The national league in which the athlete's club participates or the athlete's participation in international competitions is a crude reflection of the athlete's performance, and we are unable to comment on the individual player's performance. While this is a limitation, it was thought nevertheless that RTP rates and competition level, as well as the effect of the intra-articular pathology on these outcomes, are of the utmost importance to the players, their medical teams, and treating surgeons. Focusing on these coarse measures of outcome allowed 100% follow-up at the point of RTP, at 2 years, and 92% at 5 years, decreasing the chance of selection bias and recall bias.

Despite the mentioned limitations, reporting on this large cohort of elite athletes provides valuable information for surgeons, athletes, and their coaching and medical teams. This study enables surgeons to set realistic expectations for elite athletes before surgery regarding their

medium- to long-term RTP rates, competition level, and career longevity outcomes, as well as the effect of intra-articular pathology on these outcomes, and it will provide a comparison for future studies.

CONCLUSION

Elite athletes achieved high initial RTP rates after revision ACLR, with the majority returning to preoperative levels of competition. Significant decreases in RTP level were noted at 2 and 5 years postoperatively. Medial meniscal pathology and chondral lesions with ICRS grade $\geq$3 were negative predictive factors for initial RTP but had no effect at 2 and 5 years.

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CHAPTER V

Discussion, Conclusions and Future Developments

1. DISCUSSION

1.1 FACTORS AFFECTING RETURN TO SPORTS AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

In elite athletes, RTS after ACL-R is ultimately characterised by the achievement of preinjury performance levels, rather than simply returning to play [22,23]. However, little is known regarding the success of athletes in reaching this goal, or the factors that influence it.

The main aim of this thesis is to contribute to a better understanding of the impact of patient, surgical, and post-operative factors on RTS outcomes, including time to RTP, RTP rates, levels of performance, career longevity, and graft re-rupture rates after ACL-R in elite athletes. Identifying and evaluating these RTS determinants will help to predict and potentially to improve, outcomes in this population after ACL-R, as well as, in the general population.

In elite soccer, the published evidence on patient, surgical, and post-operative factors influencing RTP rates after ACL-R is scarce,[36,40,63] and the subsequent impact on performance throughout a footballer's career, and career longevity, has not yet been adequately explored. A retrospective assessment of a consecutive cohort of 200 professional soccer players undergoing primary ACL-R was performed. The presence of ≥50% thickness chondral pathology, ACL-R without LET, and age over 25 years at the time of surgery were all significant risk factors of worse performance rates after ACL-R. Also, in a complementary study to this thesis, on a similar population and with data from the same surgeon's practise, Balendra *et al*.[124] found that key factors affecting both rate and time to RTP were age and the need for subsequent surgery prior to RTP.

Younger soccer players (<25 years at the time of ACL-R), were significantly more likely to RTP, as well as to still be playing at their preinjury performance at 5 years post-surgery. Our findings may reflect the fact that younger players are more willing and able to follow the rehabilitation after ACL-R, in order to RTP and reach their performance peak, and to become established and successful, while more veteran players found it more difficult to RTP, and to restore their preinjury performance. It could also just be that the performance of players over 25 years naturally declines more regardless of whether they have an ACL injury, and knowing that their best performances are behind them they are less motivated, and more easily accept retirement [47]. Similar findings were reported by Mazza *et al*.[40] in European soccer, and also between athletes in National Hockey League (NHL),[37] elite skiing [33] and Australian Football League (AFL)[125]. On the other hand, as younger age is known to be a predictor for ACL re-injury,[126] medical teams may endeavour to decrease this risk by taking longer for rehabilitation, and this may have contributed to the longer RTP times,[124] which is in contrast to the older group, where the more established, and more valued players were back at the earliest opportunity.

Soccer players receiving an ACL-R with the addition of a LET procedure were 2.42 times more likely to return to preinjury performance at 2-years than athletes with ACL-R alone. In the context of elite sports, there are no studies with which to compare these results, as they are previously unreported and so unique. At 2 years

follow-up, in a pivoting non-elite sports population, Porter *et al*.[127] found better PROs in patients who had a LET. In another complementary study to this thesis, again from the same surgeon's unit, Borque *et al*.[128] found that in 455 elite athletes undergoing primary ACL-R those with additional LET had a significant reduction of risk of revision surgery from 9.5% to 3.4% (p=.045). Similarly, in an identical population of 342 athletes, Hopper *et al*.[80] demonstrated that those who underwent isolated ACL-R had a >2-fold higher graft failure rate than when ACL-R was combined with an anterolateral procedure. It is also important to note that the addition of a LET did not increase the number of subsequent surgeries,[128] or RTP time [124]. Thus, the benefits of LET when treating elite athletes with an ACL injury are clear, given the deleterious career consequences of ACL re-rupture,[18] combined with the increased risk of injury to other structures and osteoarthritis from any persisting anterolateral instability after ACL-R even without graft re-rupture. Our results support the status of elite athletes as a potential indication for LET, as it leads to a 2.8-times reduced risk of ACL graft failure in this population, as well as better predicting performance rates at 2 years after ACL-R in soccer players. At elite level it usually takes more than 1 year to return to preinjury performance,[16] and up to 2 years to achieve baseline joint biological health and function following ACL-R,[129] so our results may reflect the positive effect of LET in providing better joint kinematics and stability, as well as decreasing re-rupture rates. Those without LET may have abnormal joint motion and minor subluxations which, whilst not producing clinical instability or graft re-rupture, will need better neuromuscular control prior to RTP and to achieve preinjury performance, which will take longer to achieve. This would account for the advantage of having a LET found at 2 but not 5 years. Of course, the failure to demonstrate statistical significance at 5 years could simply be a type II statistical error due to lack of sufficient cases.

The presence of ≥50% thickness chondral pathology at the time of surgery didn´t seem to alter return to play rates in elite athletes [124,130]. However, we found that it had significant impact on performance, with only 4% of athletes playing at the same or higher performance level at 5 years post-surgery; and these athletes were more than 2 times less likely to be performing at preinjury performance. Our results reflect the increasingly negative impact of these injuries over time in professional soccer players. In AFL players, the presence of concomitant knee injuries was reported not to be associated with differing odds of returning to preinjury performance [125]. However, in that publication the nature of concomitant injuries was not reported, so it is not possible to make comparisons with our results.

There was no association between meniscal status and return to preinjury performance, which may indicate that meniscal injuries may take more time to have an effect on articular cartilage and therefore have later impact on function. This possibility has been reported in NHL players, in whom the presence of meniscal injury was associated with a decreased length of career [37]. We also found that having a medial meniscal repair in addition to the ACL-R significantly prolonged the RTP time, compared to those who underwent meniscectomy (12.5 *vs* 9.6 months p=.022) [124]. This may well be related to higher failure rates of medial meniscal repair and need for subsequent partial medial meniscectomy [131,132].

Little is published about factors altering performance and longevity rates in elite athletes [125]. Similar to our results, but only reported at the point of RTP, both femoral tunnel technique and graft type, [32,63,133] did not significantly affect performance rates among elite athletes. However, we found that the graft re-rupture rate varied according to the graft selected, femoral tunnel placement, and usage of a LET [124]. This ranged from 18.5% utilizing a single-bundle doubled semitendinosus and gracilis (HS) autograft placed in an "anatomic" (central femoral footprint) position without LET to 2.0.% when a patellar tendon (PT) autograft was placed in the anteromedial bundle (AMB) position on the femur with concomitant LET. Despite those differences and the fact that it was not possible to demonstrate a statistically significant difference between the surgical techniques, it should not be assumed that there is no difference at all, as type II errors, i.e. falsely concluding that there is no difference, are thought to occur in more than 20% of studies that fail to show statistical significance [134]. In fact, in a larger population of 455 elite athletes undergoing primary ACL-R, Borque *et al*.[128] found that those with additional LET had a significant reduction of risk of revision surgery from 9.5% to 3.4% (p=.045).

In a sub-group analysis of players from the top two leagues in English soccer that complements this thesis, Borque *et al*.[135] demonstrated that players who underwent ACL-R had a 1.6-year shorter career on average (6 *vs* 7.6 years; p<.001) than a player without an ACL-R after controlling for age, league, position, and game appearances/minutes. Very little data have been published on the effects of ACL-R on professional soccer players' careers. In the MLS, Arundale *et al*.[39] reported a mean career length after ACL-R of 1.2 years compared with the 6 years in the present study. The differences found in career longevity can be explained by the way they were measured. In the present thesis it was defined from the date of surgery to the last professional game played. In Arundale *et al*.[39] it was calculated as career length from the first game played after surgery until the last game played. Considering professional soccer players usually return from ACL-R between 6 and 13 months post-surgery,[11,124] this explains approximately one year of the discrepancy. Another contributing factor is the level of soccer played as the higher level players play for much longer than lower level players, and so the lower level of play in the MLS compared to English leagues is likely to be a significant contributing factor. There is well-known large earnings' discrepancy between players in European leagues compared to MLS and this too may account for the shorter MLS careers.

Measuring and comparing the RTS outcomes across different sports, and leagues, is challenging as there is no standardised measurement method. While no difference was found in RTP rates between different sports, rugby players returned to playing significantly faster than soccer players (9.6 *vs* 10.6 months, p=.027) [130]. However, this is slower than the less than 6 months RTP time shown in a study of 12 rugby players by Fabbriciani *et al*.,[136] which may be related to the use of a different, unspecified definition of RTP.

While less common than isolated ACL tears, concomitant MCL or PLC injury requiring surgical treatment at the time of ACL-R reflects an initially larger injury to the knee, followed by a bigger surgical insult, and this may have major consequences on elite athletes' RTS rates. Two previous studies of multi-ligamentous (MLKI)

series, one of which is complementary to this thesis,[137] reported RTP rates of 70.8% and 89.6% after combined ACL+MCL surgery,[97,137] and of 88% after combined ACL+PLC surgery in elite athletes [137]. There is very little published in the field, particularly in relation to level of play and career longevity. This was the focus of the second study described in the present thesis, in which a consecutive cohort of 98 elite athletes undergoing combined ACL+MCL and ACL+PLC surgery was assessed. Then, a subgroup of male elite soccer players from this population was compared to the previously identified cohort analysed in the first study having had isolated primary ACL-R without other ligament surgery. We found no difference in career longevity between ACL+MCL and ACL+PLC surgery (4.2 *vs* 4.8 years, p=.372). Moreover, when compared to isolated ACL-R (194/200 = 97% RTP) and combined ACL+MCL (19/19 = 100% RTP) groups which had very high rates of RTP, a significantly lower number of soccer players with combined ACL+PLC were able to RTP (29/33 = 88%, p=.003), as well as requiring almost 3 months longer to achieve it (12.9 months, p=.002). The fact that ACL+MCL surgery results were comparable to ACL-R alone may be explained by an exceptional healing potential of MCL,[138,139] enabling athletes with combined ACL+MCL surgeries to RTP faster and in a higher proportion compared to those with combined ACL+PLC surgeries in which healing potential of structures with smaller cross-sectional area is less. In addition, the time to RTP was little less than for an isolated ACL-R (10.0 months *vs* 10.2 months), thereby indicating little additional impact of concomitant MCL surgery in elite athletes. We also found that soccer players' career length and competition level were not significantly different between injury groups once RTP had been achieved. The surgical strategy assessed in this study aims to minimize proprioceptive and ligament function deficit, through early anatomic repairs of the damaged collateral ligament complexes' tissues, plus protecting the restored anatomy during its healing phase with a biomechanically sound reconstruction [140-142]. These strong constructs allow safe and early restoration of range of motion, thereby decreasing stiffness. This approach allows a career longevity after combined ACL+MCL or ACL+PLC surgeries that resemble those with an isolated ACL-R surgery, although less ACL+PLC surgery cases RTP, and take longer to do so as described above.

Whilst inferior clinical outcomes have been reported in the general population following revision ACL-R compared with primary surgery,[117-120] there is no data to assess the impact of patient, surgical, and postoperative factors in revision surgery cases on RTS rates in elite athletes. We therefore conducted a third study, a retrospective review of a consecutive series of 48 elite athletes who underwent ACL-R revision. We found that soccer players had a significantly higher playing rate at the point of RTP (96.7% *vs* 70.6%, p=.025) as well as at 2 years post-surgery (92.6% *vs* 58.8%, p=.017) when compared with rugby players. In the context of primary ACL-R we demonstrated a similar trend, but without reaching a statistically significant difference (95.7% *vs* 92%, p=.272) [130]. There are no comparative studies between different elite sports after revision ACL-R with which to compare these results. Possible reasons that may explain the significant difference shown in the RTP rates include the fact that financial reward for playing professional rugby is much lower, as well as the attritional damage from accumulated injury is greater when compared to soccer. Similar to the findings of Okoroha *et al*.,[107] in the NFL, we found that age did not affect RTP rate after revision ACL-R. However, and predictably, younger patients were

more likely to still play at 2 (95.7% *vs* 65.4%, p=.012) and 5 (70% *vs* 24%, p=.002) years post-surgery.

In the general population, meniscus and chondral pathology at the time of revision ACL-R have shown to be associated with poorer PROs and lower rates of return to preinjury level of sport [109,114,123,143]. There is no previous study reporting the impact of chondral/meniscal pathology on RTP rates/competition level after revision ACL-R in an elite athlete population. It was found that athletes with chondral lesions affecting <50% of cartilage thickness were more likely to RTP (94.6% *vs* 66.7%, p=.026), as well as competing at the same level (83.8% *vs* 50%, p=.047). Those without medial meniscus pathology were also more likely to RTP at the same level (94.4% *vs* 64.5%, p=.036). There was no association between lateral meniscal status at the time of revision, and RTP/competition level. This is, perhaps, a little surprising given the more problematic experience with lateral *versus* medial meniscal tears on elite athletes [131,144,145]. At 2 and 5 years post-surgery there was no association between meniscus / chondral status and RTP rates/competition level. Presumably a knee capable of coping with the loading needed to RTP continues to be able to cope.

1.2 RETURN TO SPORTS AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

Although media reports may have skewed the public perception of recovery from ACL injury by highlighting cases of elite athletes who return to preinjury performance after surgery, data presented in the present thesis suggests that this is not always the case. It was found that 90% of soccer players RTP at the same or higher level after ACL-R, while at 3 and 5 years, only 53% and 35% respectively were playing at the same or higher competition level. After combined ACL plus medial or lateral ligament complexes' surgeries a similar a decrease in play rates was found. At 5-year follow-up, 42% and 59% of soccer players in the ACL+PLC and ACL+MCL surgery groups, respectively, were still playing at the preinjury competition level. Furthermore, as expected, the difficulty of maintaining the preinjury competitive level is even more pronounced after revision ACL-R in elite athletes, with only 51% and 20% to achieve this at 2, and, 5 years post-surgery, respectively. At elite level, reasons for early retirement may be multifactorial, such as decreased performance, fear of further injury/surgery, loss of motivation for continuing playing at a lower, or even the same, competition level, non-selection in the team, contract status and, for older players, the simple matter of their realization that it is time to retire. Retirement does not necessarily reflect the presence of knee problems [146]. While little is known about mid and long-term performance outcomes after ACL-R in elite athletes, there is no available data at all on this after combined surgically treated ACL plus collateral ligament injury or revision ACL-R. In professional soccer, there has been evidence of restriction in players' ability to maintain preinjury competition level 3 years after ACL-R [4,25,36,40,41]. At 5 years post-rupture season, Niederer *et al*.[62] reported 69.9% of professional soccer players were still playing, but only 24.8% at the same level. In the present thesis a similar pattern of decreasing playing rates and competition level over time in all groups is demonstrated. This is very important information for the treating clinician, athletes, medical teams and coaches to know.

While RTP at preinjury level is a significant achievement, after ACL-R the return to preinjury performance may only be considered to have been achieved in practical terms after playing consistently over a period of time. In terms of player performance after RTP, when combining league level and playing time, the results in the present thesis show that only 30% and 22% of soccer players returned to their preinjury performance at 2 years and 5 years, respectively, after ACL-R. When considering the highest performance level obtained by players between years 2 and 5, 53% of them returned to their preinjury performance level for at least one year with an additional 18% at the same or higher league level but having less playing time. Using publicly available detailed performance statistics, Barth *et al*.[38] stated that only by the third season post-surgery did professional soccer players play similar minutes per game than preinjury and the same trend was reported in other studies with similar methodologies [38-41,62]. This may reflect that, while professional soccer players may be ready to RTP, they have likely not returned to their preinjury performance, reinforcing the necessity to analyse not only RTP rates, but also performance metrics at and after RTP.

2. LIMITATIONS

This thesis has several limitations. Firstly, being based on retrospective studies, the preoperative assessment, surgical plan, surgical factors such as timing of surgery, graft choice, comorbid intra-articular pathology treatment and further surgery were decided based on the senior surgeon's clinical judgement, and not based on a randomization process. Whilst we strongly agree that evidence-based medicine is generally preferable to experience-based medicine,[147] a lot of elite sports knee practice, as is presented in this thesis, can never be subject to a prospective randomised controlled trial. Athletes need to believe that there is only one answer for their problem, and they would certainly not wish to be "randomised" to different treatments [15]. No power analysis was made because of the inherent limitations in constructing exclusive elite athletes' samples, increasing the risk of type II errors. No validated PROs were collected, and while this can also be considered a limitation, it has recently been argued that PROs designed to capture data from the normal population have limited value in assessing high-level athletes [50]. For this thesis it was felt that RTS rates, levels of play, and longevity of careers, and the factors affecting them, are of much more importance to the athletes, their medical teams and treating surgeons than PROs. Focusing on these coarse outcome measures allowed for inclusion of a larger number of athletes, as well as to follow up rates close to 100%, because an extensive media RTS data collection in elite sports makes it easier to follow them before and after injury. This also makes elite athletes good study subjects, and reduces the likelihood of selection and recall bias. In addition, due to the level of intensity of training and play they really test decision making, treatment choices, operative technique, and rehabilitation regimes and so, unlike many studies on the general population, differentiate between treatment options making a useful contribution to understanding what works, and what doesn't - unlike many studies of the general population which show "non-inferiority".

We attempted to identify metrics for athletes of all sports and genders, however we found that performance metrics were only reliably available for the male, elite soccer players. In cases of female and male athletes from sports other than elite soccer, the national league in which the athlete's club participates or the athlete´s participation in international competitions represent a crude reflection of the athlete's level, not least because it does not reflect their performance on the pitch. Failure to return to their preinjury competition level does not necessarily mean that athletes are not playing well, as a common reason for returning at a lower level is a team's relegation to a lower league. Another limitation is the use of media data for performance tracking. Multiple sources were used, when possible, to cross-reference and ensure accuracy of reporting. Nevertheless, whilst inaccuracies are possible, the use of this methodology has already been validated for elite soccer [58]. Finally, even though some of the factors investigated in this thesis were associated with RTS after ACL-R, there may be other factors that are equally important but not included here. For example, non-selection in the team, psychological condition and contract status may influence RTS rates.

3. CONCLUSIONS AND FUTURE DEVELOPMENTS

This thesis reports the largest cohort of elite athletes analysing RTS rates after ACL-R. It provides valuable information for surgeons, athletes, and their coaching, and medical teams some of which is unique.

The first study shows that the presence of ≥50% thickness chondral pathology, ACL-R without LET and age over 25 years at the time of surgery are all significant risk factors of worse performance rates after ACL-R. While professional soccer players achieve high initial RTP rates after ACL-R, with the vast majority returning to pre-operative levels of competition, significant decreases in performance rates are noted at short and medium term.

The second study demonstrates that elite athletes achieve the same career length after combined ACL+MCL or ACL+PLC surgery as compared to those undergoing isolated ACL-R. Whilst professional soccer players with combined ACL+PLC injuries return at a lower rate and require longer time to RTP when compared to those with isolated ACL-R or combined ACL+MCL surgeries, those that make it back have the same career longevity.

The third study shows that medial meniscal pathology and chondral lesions ICRS ≥3 at the time of revision ACL-R surgery are negative predictive factors for initial RTP but had no effect at 2 and 5 years. While elite athletes achieve high initial RTP rates after revision ACL-R, with the vast majority returning to pre-operative levels of competition, significant decreases in RTP level were noted at 2 and 5 years post-operatively.

By providing a better understanding of the patient, surgical and post-operative factors that affect RTS rates after ACL-R, this thesis allows realistic expectations about outcomes to be set, and to predict and potentially improve RTS outcomes in elite athletes undergoing ACL-R. This knowledge is also valuable for general population. Importantly, it does not solely rely on publicly available data, but rather was founded on the thesis supervisor's (A.W.) practice data.

This thesis emphasises the multifactorial nature of RTS outcomes after ACL-R. However, the interaction between the different factors and their combined effect on RTS outcomes needs to be further investigated, as well as the reasons why some elite athletes do not RTS or retire.

Future studies with larger sample sizes and multicenter designs are needed to validate our findings and explore additional factors influencing RTS.

Given the low number of female athletes in the study population we could not determine whether outcomes differed between male and female elite athletes who underwent ACL-R. Although female athletes have a higher risk of ACL rupture when participating in the same sports as male athletes, there is a little of research on RTS rates in them, and this should be a focus of future research.

While many elite sports use metrics to quantify performance, the use of tracking devices such as Global Positioning Systems (GPS) and accelerometers, which can quantify many aspects of load and performance, will become increasingly valuable in evaluation of sport-specific targets of RTS. This could help to improve or even replace some of the sport-specific performance measures currently in use that show a lack of consistency, enabling a more reliable assessment of RTS outcomes after ACL-R.

This thesis emphasises the concept that the ideal ACL-R is not just about the ACL graft position, fixation, and graft type. It shows that there will be an increase in adjunctive procedures for ACL-R in the near future, such as cartilage and meniscus repair, and the addition of LET and MCL repair and reconstruction. It becomes clear that "isolated ACL-R", even in general population, will be reserved for a very small group of patients. Thus, the surgeons must learn to identify and treat many pathologies associated with ACL injury, switching from a standard approach to a more individualized approach for each single patient.

CHAPTER VI

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DETERMINANTS OF RETURN TO SPORT IN ELITE ATHLETES AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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