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Rehabilitation Following Anterior Cruciate Ligament Injury

Current Recommendations for Sports Participation

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Contents

Abstract

Knee ligament injuries often result in a premature end to a career in sports. The treatment after rupture of the anterior cruciate ligament (ACL) may be operative or conservative. In both cases, the goal is to reach the best functional level for the patient without risking new injuries or degenerative changes in the knee. Return to high level of athletic activity has been an indicator of treatment success. Rehabilitation is an important part of the treatment. Knowledge of healing processes and biomechanics in the knee joint after injury and reconstruction, together with physiological aspects on training effects is important for the construction of rehabilitation programmes. Current rehabilitation programmes use immediate training of range of motion. Weight bearing is encouraged within the first week after an ACL reconstruction. Commonly, the patients are allowed to return to light sporting activities such as running at 2–3 months after surgery and to contact sports, including cutting and jumping, after 6 months. In many cases, the decisions are empirically based and the rehabilitation programmes are adjusted to the time selected for returning to sports. In this article, some criteria that should be fulfilled in order to allow the patient to return to sports are presented. Surgery together with completed rehabilitation and sport-specific exercises should result in functional stability of the knee joint. In addition, adequate muscle strength and performance should be used as a critical criterion. Other factors, such as associated injuries and social and psychological hindrances may also influence the return to sports and

must be taken into consideration, both during the rehabilitation and at the evaluation of the treatment.

The yearly incidence of anterior cruciate ligament (ACL) injuries has been reported to be 3 per 10 000 inhabitants in Denmark, with a greater frequency among athletes.[1] In Sweden, ACL injuries comprise 43% of all soccer-related knee injuries.[2] Elite players experience a greater risk for injury.[2,3] The injury risk has also been reported to be higher among women,[2-5] and female soccer players are younger than their male counterparts when they get injured.[2,3] An ACL injury leads to static and functional instability that causes changes in motion patterns[6-8] and an increased risk of osteoarthrosis.[9] In many cases, an ACL injury results in a premature end to a career in sports[2,3,10-13] and Roos et al.[2] observed that only 30% of soccer players were active in soccer 3 years after an ACL injury.

Management after ACL injury may involve an operation to replace the torn ligament with a graft in an attempt to reduce excess anterior tibial movement in the sagittal plane. The main goal of reconstruction is to restore knee function without any pain or degenerative changes correlated to the operation. Although the ACL reconstruction may not result in a normal knee, it may give the patient the chance to return to sporting activities, usually at a lower level than before.[14] Not all patients with an ACL tear need to undergo surgery. The most common selection criteria are the patient's age, associated ligament and meniscal injuries, functional and sporting demands on the knee and the patient's ability and willingness to participate in postoperative rehabilitation.

1. Rationale for Treatment After Anterior Cruciate Ligament (ACL) Injury or the Way for Safe Return to Sports

The rationale for rehabilitation after an ACL injury is to gain a good functional stability, reach the best possible functional level and to decrease the risk for re-injury. The training programmes are focused both on the injured leg, but also on the non-injured leg, hip and trunk muscles that are needed in order to stabilise the entire body. The functional stability of the knee joint is dependent on the interplay of passive structures and the dynamic system. The ACL provides an average of 86% of the total resisting force to anteriorly directed forces on the tibia.[15] After an ACL rupture, the sagittal translation increases and various rehabilitation exercises may produce harmful forces for the secondary restraints or the graft that undergoes remodelling and maturation.[16-19] Functional knee stability is also dependant on the dynamic system of muscle strength, coordination and overall proprioceptive ability. Muscle strength[13,20-26] and proprioceptive deficits (see review by Friden et al.[27]) have been found after ACL injury. There is evidence that supports the importance of the dynamic system: (i) large differences in sagittal translation between the injured or reconstructed knee and non-injured knee do not correlate with subjective scores of knee function;[22,28-32] (ii) some patients, despite increased side-to-side sagittal translation difference, can control the knee and do not utilise the whole available static translation space during activity;[8,33-35] and (iii) some patients can continue to participate in sports despite a torn ACL.[28,36,37]

Neuromuscular training is aimed towards improving the nervous system's ability to generate a fast and optimal muscle contraction, enhance coordination and balance and to relearn movement patterns and skills.[38] The importance of neuromuscular training has been demonstrated in prospective controlled studies where the incidence of ACL injuries were significantly lower in athletes who participated in proprioceptive training.[5,39] Fitzgerald et al.[36] found beneficial results with specific perturbation training and Zätterström et al.[40] found enhanced postural control after physiotherapy. Risberg et al.[38] developed a neuromuscular rehabilitation programme based on knowledge of graft healing, function of ligament mechanoreceptors and neuromuscular control, but results on its implementation have not been presented.

The current knowledge of knee proprioception and neuromuscular control has recently been reviewed.[27,41-44] A description of effects of muscle

action and some aspects of graft healing on knee stability follows.

1.1 Effects of Muscle Action

Quadriceps muscle strength correlates with good outcome after knee surgery.[22,28,30,37,45] Quadriceps contraction extends the knee joint and causes anterior tibial translation between 0° and 75° of flexion.[46-49] Little attention has been paid to the gastrocnemius muscle, although some authors have demonstrated its functional importance for knee stability.[8,34,50] Contraction of the gastrocnemius results in an anterior tibial translation by pulling the femur backward through posterior shear forces exerted on the femur. In addition, the gastrocnemius flexes the knee joint and increases joint compression[51] (figure 1). Both quadriceps and gastrocnemius contraction results in increased ACL strain.[46,48,52]

The role of the hamstring muscles are to flex the knee joint, increase joint compression and to pull the tibia backwards through a posterior shear force at flexion angles greater than 20°. Hamstring contraction decreases ACL strain.[48,53] Although the hamstrings are supposed to be important muscles for knee stability, no correlation could be found between hamstring strength and functional tests.[20] It has also been questioned if hamstrings really can limit anterior shear forces during activity and reduce ACL load at the important flexion angles between 20° and 40°.[34,35,54]

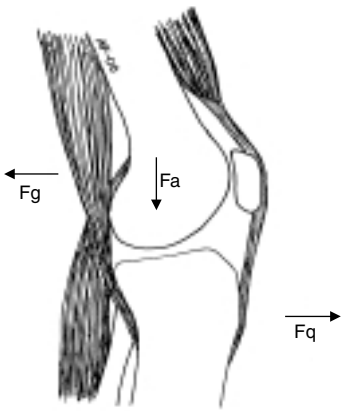

Fig. 1. Effects of axial load (Fa) and muscle action (quadriceps [Fq] and gastrocnemius [Fg]) on the knee joint. In the upright position standing on the leg, axial load results in anterior translation of the tibia due to the posterior tilt of the tibial plateau. Contraction of quadriceps and gastrocnemius muscle helps to stabilise the tibia in that position.

Closed kinetic chain (CKC) exercises have become increasingly popular and strongly recommended for rehabilitation after an ACL injury because they are believed to be safer than other exercises;[24,55-60] however, no valid evidence exists to support this conclusion.[13,61-63] During CKC exercises, lower leg muscles work together, but this cocontraction may not necessarily reduce the anteriorly directed forces on the tibia.[48] CKC exercises imply weight bearing that results in joint compression with increased conformity between the joint surfaces, increased friction and decreased translational movements.[64] Li et al.[65] demonstrated *in vitro* a decrease of the total anterior-posterior tibial motion during weight bearing, but also an anterior position of the tibia. Due to the posterior tilt of the tibia plateau, the gravitational forces during weight bearing results in a posterior shear force on the femur causing an anterior positioning of the tibia[66,67] (figure 1). In line with the *in vitro* results by Li et al.,[65] we have found that the total tibial translation movement during weight-bearing exercises (squat and raising from a chair) was halved and the tibia was anteriorly positioned throughout the range of motion (ROM) compared with non-weight-bearing exercises[8] (and unpublished results). Hence, weight-bearing results in small total tibial translational movements[64,65] and anterior positioning of the tibia.[8,34,65-68] In clinical studies comparing rehabilitation regimes, no[13,62] or only minor[55] differences in tibial translation were found after rehabilitation with CKC alone compared with a group training with combined CKC and open kinetic chain (OKC) exercises.

In addition, CKC exercises may not be sufficient for strengthening the quadriceps muscle.[13] Remaining weakness of the quadriceps muscle is common after ACL injury and reconstruction[13,20-26] and modifications of the rehabilitation programmes with more emphasis on quadriceps strength training have been proposed.[13,20,25] The importance of good quadriceps strength has been demonstrated by Mikkelsen et al.,[13] who found significant stronger quadriceps in patients who trained with a combina-

tion of OKC and CKC. In addition, more of these patients returned to their pre-injury level and this 2 months earlier compared to patients who did not include OKC exercises in their rehabilitation programme.

1.2 Healing of the ACL Graft

There is no current information about what strain magnitudes are deleterious to a healing graft or within what limits strain may improve graft healing.[61] Controlled load can facilitate ligament healing[69] but excessive load can stretch or disrupt the graft. However, some information is provided in a recent review by Beynnon et al.[70] mostly based on measurement on ACL strain and reviewing results from clinical studies.

Initially following ACL reconstruction, the graft undergoes necrosis and revascularisation.[16-19] Biomechanical studies in animals have shown the load to failure and stiffness of the new ligament to be less than 25% of normal, 7–12 months postoperatively.[16,18] There is some histological evidence for longitudinally-oriented fibres of the ACL graft 6–12 months after reconstruction in animals[16] and in humans[19] but low scores for fibre pattern orientation at 3–6 months.[16,19] There have been suggestions that some part of the graft remains vital and Rougraff and Shelbourne[71] found that 3–8 weeks after surgery only 30% of a human graft biopsy showed necrosis. Beynnon et al.[72] demonstrated in a case report that the load to failure and stiffness of a bone-patellar tendon-bone graft was 90% of the normal 8 months postoperatively, but knee laxity was 185% of the contralateral knee and the grafts' energy absorbed to failure was nearly half compared with normal. These results, together with the strain behaviour demonstrated in their report, show that despite some mechanical and histological properties being similar, the graft biomechanics differ substantially from normal. In addition, it has been shown that anterior tibial translation increases with time after ACL reconstruction in some patients.[22,73,74] An increase in anterior tibial translation relative to the femur is correlated to weakened structural properties of the graft.[18]

2. Current Rehabilitation Programmes

The rehabilitation process for knee ligament-injured patients has changed dramatically in the past several years. Previously, conservative rehabilitation with limitation of ROM, delayed weight bearing with full weight bearing at 8–10 weeks and returning to sports after 9–12 months has been the norm. The trend today is accelerated protocols with immediate training of ROM and weight bearing and returning to sports within 4–6 months. In most studies, the rehabilitation programmes are presented without motivation or references reported in articles. Some studies just mention that the rehabilitation programme is constructed in order to give the graft normal mechanical stress and facilitate healing[75,76] or discuss the fixation technique that should allow for an aggressive rehabilitation.[77] Detailed rehabilitation programmes are described by some authors.[13,20,22,62,78-81]

In order to review some trends in rehabilitation and returning to light activities (jogging) and contact sports, a systematic search in Medline was done for articles published between 1998 and February 2003. Thirty-nine articles were found that presented results after ACL reconstruction. Some aspects on ROM, weight bearing, time and criteria for returning to sports follows in the text and are presented in table I.

2.1 Range of Motion

Most of the articles used immediate training of ROM.[12-14,75,76,83-87,89,94,95,100-102] Limitation in ROM was only described in three studies; in two of these, the iliotibial band autograft was used and the surgery was performed before 1996[91,92] and in one study, the purpose was to evaluate early ROM versus immobilisation.[24] Prevention and treatment of knee ROM defects after ACL reconstruction have been highlighted before.[79,103] Early postoperative knee motion eliminates the deleterious effects of immobilisation on graft stiffness and ultimate knee strength. In addition, Henriksson et al.[24] found no differences in knee stability, subjective knee function and activity level 2 years after ACL surgery followed by early ROM training compared with immobilisation.

Table I. Time and criteria used for the decision to allow a patient to return to light activities and contact sports. The studies are ordered accordingly to the time of return to contact sports

Study	Return to light activities		Return to contact sports		Tests for muscle strength and performance
	time (mo)	criteria	time (mo)	criteria	
Sauter et al.[82]	1.5–2	NA	3	Full knee function	NA
Marcacci et al.[83]	2	NA	3–4	NA	Isok, jump test
Muellner et al.[26]	NA	NA	3–6	Good joint function and muscle reaction	Isok
Marcacci et al.[75]	2	NA	4	NA	Isok, jump test
Howell and Deutsch[77]	2–2.5	NA	4	NA	Thigh girth, jump test
Webster et al.[84]	1.3–1.5	<30% strength deficit	4–6	Full ROM, no effusion, good knee stability, complete running programme	Jump test
Gobbi et al.[85]	1.3–1.5	<30% strength deficit	4–6	Full ROM, no effusion, good knee stability, complete running programme	Isok, jump test, vertical jump
Noyes et al.[79]	2–3	≤3mm AP displacement, ≤30% strength deficit	5	≤3mm AP displacement, <15% strength deficit, no symptoms, completion sport-specific drills	NA
Scranton et al.[81]	3	NA	5	Warranted limb and ligament stability	Isok, jump test
Pinczewski et al.[60]	1.5	NA	6	Knee stability confirmed in clinical examination	Thigh girth, jump test
Aune et al.[86]	2.5	NA	6	Full ROM, no effusion, good knee stability and strength	Isok, jump test, stairs hopple test
Muneta et al.[87]	3	<35% strength deficit	6	Each patient carefully assessed	Isok
Eriksson et al.[88]	3	NA	6	NA	Thigh girth, jump test, triple jump test
Peterson et al.[89]	3	NA	6	NA	NA
Barett et al.[76]	3	NA	6	NA	Thigh girth
Ejerhed et al.[14]	3	NA	6	Full functional stability	Isok, jump test
Järvelä et al.[90]	3–4	NA	6	NA	Isok, jump test
Möller et al.[78]	3–4	NA	6	<10% strength and performance deficit, satisfy clinical evaluation	Isok, jump test
Jorgensen et al.[91]	NA	NA	6	NA	Jump test
Bak et al.[92]	NA	NA	6	NA	Jump test
Panni et al.[59]	NA	NA	6–8	NA	Jump test
Deehan et al.[93]	3–6	NA	6–9	Formal clinical evaluation	Thigh girth, jump test
Jansson et al.[58]	NA	NA	6–12	NA	Isok, jump test
Hamada et al.[94]	4	NA	8–9	NA	Isok, jump test
Hamada et al.[95]	4	NA	8–9	NA	Isok, jump test
Webb et al.[96]	1.5	NA	9	NA	Jump test

Continued next page

Table I. Contd

Study	Return to light activities		Return to contact sports		Tests for muscle strength and performance
	time (mo)	criteria	time (mo)	criteria	
Keays et al.[20]	3	If necessary muscle control achieved	9	<10% strength and performance deficit	Isok, jump test, triple hop, shuttle run, side-step, carioca
Jomha et al.[97]	NA	NA	9	NA	Jump test
Zysk et al.[12]	3–6	NA	9–12	NA	Jump test
Marumo et al.[98]	5–6	NA	12	Rehabilitation criteria met	NA
Rupp et al.[73]	6	NA	12	NA	Jump test
Henriksson et al.[24]	4	<25% strength deficit	NA	NA	Isok
Mikkelsen et al.[13]	3–4	NA	NA	NA	Isok
Hehl et al.[99]	NA	NA	NA	NA	Jump test

AP = anterior-posterior; **isok** = isokinetic testing; **jump test** = one-leg jump test; **NA** = data not available; **ROM** = range of motion.

Braces limit ROM and in some cases prevent anterior-posterior translation. No benefits have been found when using a knee brace during the first 6 weeks postoperatively.[21,26,78,80,102]

2.2 Weight Bearing

In the reviewed articles, weight bearing during level walking was allowed immediately after surgery in 21 of 34 articles, depending on pain, joint effusion and degree of extension loss.[11,14,26,58,60,75,77,78,82-89,93,96,100-102] As described earlier, weight bearing results in anterior translation of the tibia.[8,34,65-68] The effect of early weight bearing on knee laxity has not been thoroughly investigated. Tyler et al.[104] compared immediate weight bearing with weight bearing starting 2 weeks postoperatively and found no significant difference in knee laxity between the groups at 7 months follow-up, although approximately 40% of all patients had 3mm or more in difference in sagittal translation between legs.

2.3 When to Return to Light and Contact Sports Activities

The decision when to permit a patient to return to unrestricted activities and sports is in most cases empirical. Unnecessarily delaying the return to unrestricted activities is undesirable to the worker or athlete, but so is a premature return that can injure the graft. In a retrospective study, Glasgow et al.[105] found no difference in sagittal translation or graft failure in a group returning to sports activities before 6 months compared with the group returning after 6 months from surgery. Shelbourne and Nitz[56] were first to describe accelerated rehabilitation with return to sports activities between 4–6 months. Later they observed that some of their patients participated in sporting activities against their advice 3 months after surgery.[106] Measurements of sagittal translation before and after sports participation revealed increased translation in only 2% of the patients. On the other hand, as many as 30% of the patients had 3mm or more difference in sagittal translation between the healthy and the ACL-reconstructed knee. Marcacci et al.[83] found similar results when their patients returned to sports 3–4 months after surgery, with 45% of the patients hav-

ing 3mm or more difference in sagittal translation 2 years after surgery.

Marcacci et al.[75] further reported that out of 50 athletes competing at high level in various sports who underwent ACL reconstruction, 40% returned to pre-injury sports activity after 4 months, 40% returned between 4–6 months and the remaining 20% between 6–8 months. In particular, nine soccer players returned to play an official game 4 months after surgery. Five years after surgery, 92% of the patients rated the knee as normal or nearly normal. On the other hand, a subjective feeling of a normal knee does not correlate to knee laxity.[30]

In the reviewed studies, patients were usually allowed to return to light activities such as running at 2–3 months after surgery and to contact sports after 6 months (table I). Often, subjective criteria such as 'full functional stability' or criteria not clearly described are used in order to decide when the patient can return to sports. In some studies, more strict criteria of muscle strength (isokinetic muscle testing) and performance (one-leg jump for distance test) were set[20,24,78,79,84-87] (table I). The reliability of these tests is good (test–retest intraclass correlation coefficient 0.94–0.95).[29]

Evaluation of muscle strength and performance 6 months after surgery is important because traditionally patients return to contact sports at this time. Most reviewed studies report 19–44% quadriceps muscle strength deficit 6 months after surgery.[13,20-24,26,30,78] Hamstring muscles are reported to have less than a 10% deficit[20,23,24,26,78] with the exception of two studies that reported a 17–21% deficit.[13,22] At 1-year follow-up, the quadriceps deficit was lower, approximately 13–24%[22,24-26,30,58] and hamstring muscle strength was nearly normalised.[22,24-26] One-leg jump test for distance is included in the International Knee Documentation Committee (IKDC) scoring and is often used in order to assess knee function. Deficits between 8 and 18% have been found 6 months after surgery.[20,78,85,86] These results show that there are significant deficits in muscle function at the time for returning to sports.

In the previously mentioned studies, only few specified exact limits of muscle strength and performance for allowing the patient to return to sports[20,78,79] (table I). In normal athletes, similar isokinetic muscle strength was found between the right and left leg. However, when the comparison was made between the strongest and weakest leg, the strength deficit rose to 4–16%.[107] Therefore, the greatest acceptable deficiency in isokinetic muscle strength should be about 15% before allowing the patient to return to sports. No such differences between the strongest and weakest leg were found at the one-leg jump test.[107] According to IKDC, less than a 10% deficit at the one-leg jump test implies to normal knee function. Of course, these limits must be considered together with other criteria for returning to sports such as asymptomatic knee (no pain or effusion, full ROM), associated injuries and psychological factors[22,29,108,109] (figure 2). Knee stability is an important criterion for returning to sports, although sagittal translation measured when the patient is resting (for example with KT-1000), does not correlate with outcome[22,28,30-32] or participation restriction.[29] Laxity measurements during activity should be more important, especially with the knowledge that some patients can control the knee and do not use the entire available translation area during activity.[8,33-35]

3. Recommendations for Return to Sports

One of the main indication for ACL reconstruction is to allow patients to return to sports.[96] In addition, the rate of return to a high level of athletic activity has been a critical indicator of the success of ACL reconstruction.[93] However, the question has been raised whether the only effect of ACL reconstruction in some individuals is "to give the patient enough security to reach the goal of going back to strenuous sports, and then ruining the knee".[110]

In order to let the patient to return to sports, rehabilitation must have been completed according to the guidelines presented in section 2.3 and in figure 2. The criteria that should be fulfilled for a safe return to sports after ACL reconstruction are generally unknown. In principle, the time for rehabilitation is determined by those criteria. Therefore, the time for return is a secondary goal, the first must be to fulfil the necessary criteria, which in turn will result in a certain rehabilitation time. It seems that many contemporary authors decide on the time first and then try to adjust rehabilitation to the selected time. This must be an inadequate approach. Some

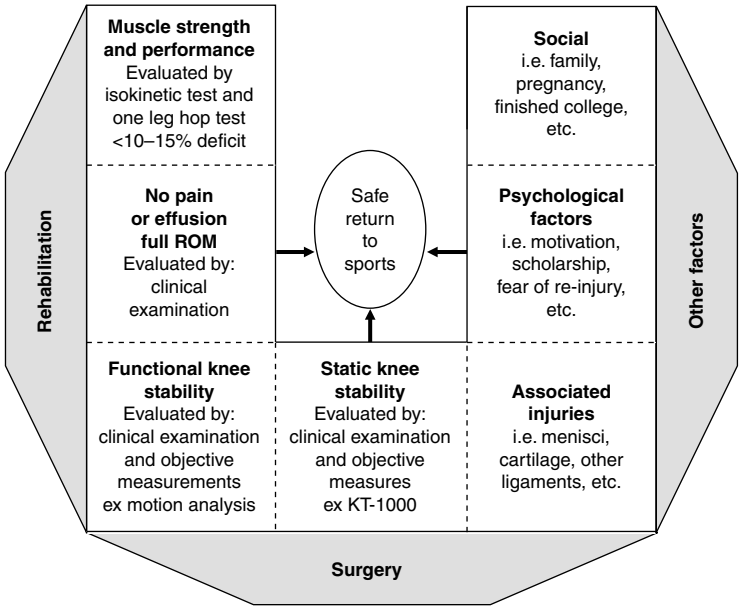

Fig. 2. Factors and criteria that influence a safe return to sports. **ROM** = range of motion.

criteria that should be fulfilled before letting the patients return to sports are presented in figure 2. The following sections discuss questions that are raised about the return to sports after ACL reconstruction.

3.1 Should the Athlete Return to the Sports Activity with the Risk for Re-Injury?

In the reviewed articles, graft failure rate (only verified failures) was a mean 2% (range 0–18%).[11,13,14,24,58,60,73,75-78,81,82,85,86,88-97,99,100,102] Shelbourne and Davis[106] reported that the patients stated that the re-injury mechanism was very similar to that which caused the first injury. In addition, they reported that as many as 4.4% of the patients injured their contralateral, previously non-injured ACL. Although the risk for graft failure is quite low, especially compared with the overall risk for ACL injury, it must be taken into consideration. In addition, there is an increased risk for osteoarthrosis after ACL injury and reconstruction[9] and high impact sports accelerate the progression.[111]

3.2 What is the Effect of an ACL Reconstruction?

In most cases, ACL reconstruction results in a stable knee with decreased sagittal translation. Little is still known about functional stability and motion patterns after intervention. In the reviewed articles, approximately 20% (range 6–75%) of the study participants had 3mm or more difference in sagittal translation between the operated and the non-injured knee, 2 years after surgery.[12,24,60,76,77,79,81-84,88,91-96,99] Sagittal translation alone is a poor predictor for knee-related disability.[22,28-32] No study reports translation during activity as an indicator of functional stability.

3.3 How Does the Status of Other Knee Structures Influence a Return to Sports Activity?

This point has not been highlighted in this review. Associated knee injuries have been shown to be a negative predictor for returning to sports.[29,108] On the other hand, Järvelä et al.[90] reported no difference in returning to sports between patients with isolated ACL injuries compared with combined injuries.

3.4 Which Patients Return to Sports Activities?

Do they return because their knee feels normal or is it their ambition and sometimes money (in professional athletes) that makes them return to sports? If so, a return to sports is not necessarily an accurate indicator of knee function or successful treatment. Why do some patients not return to sports despite a good objective knee function? Many athletes may see the ACL injury as a good reason to stop with competitive sports and give more of their time to social and family life. Others may feel a psychological hindrance such as a fear of re-injury.[3] In the reviewed studies, only some reported the reasons why the patient did not return to their pre-injury activity level.[13,92-94,96] Only 36% (range 13–70%) of the patients who reduced their activity level, did so because of knee problems. In two studies,[13,94] 77% and 21% of the patients, respectively, reported that they reduced their activity level due to social reasons and Mikkelsen et al.[13] found that 7% of the patients reported fear of re-injury as an important reason. In an unpublished study, we found a significant correlation between fear for re-injury and a 'failure' to return to pre-injury activity levels, recorded by the Tampa Scale of Kinesiofobia.[112]

4. Conclusion

The trend in rehabilitation after ACL injury and reconstruction is heading towards accelerated programmes with an early return to sports. In addition, returning to sports is often considered the result of a successful treatment. However, both the question of whether the return to sport can be safe and the reason why the patient does not return to sports must be taken into consideration. The goal of reconstruction is to improve stability but even after ACL reconstruction, sagittal translation may be increased. Furthermore, this is not correlated to knee function or a return to sports. Many patients can participate in sports despite a large difference in sagittal translation or a torn ACL, emphasising the importance of functional stability and good muscle function. Based on current knowledge and patient compliance, some criteria should be fulfilled before allowing the patient to return to sports. These are a completed rehabilitation with adequate muscle strength and performance and as a result, knee functional stability. Surgery should result in a stable knee evaluated by static measures of sagittal translation. Other factors, such as associated injuries and social and psychological hindrances may influence the return to sports.

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