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Research Article

The Evolution of Anterior Cruciate Ligament Reconstruction Rehabilitation Over the Past 20 Years

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Abstract

Background: The Anterior Cruciate Ligament (ACL) rupture is a common knee injury across various sports, consequently making its reconstruction (ACLr) a common surgical procedure in sports medicine. ACL reconstruction rehabilitation has evolved over the past 20 years.

Aim: To determine the difference in the rehabilitation phases, uses of open and closed kinetic chain exercise, and the testing done before return to play between the 1990s and 2017 onwards.

Methods: The study is done in two stages, (1) articles were retrieved by online database search with keywords for the time period between January 1992 to December 2017. (2) The retrieved articles' titles, abstracts and content were reviewed to assess the eligibility for the inclusion in this review.

Results: This review has found that over the years the graft choice has evolved from patellar tendon to hamstring tendon autograft. This is to reduce post-surgery complication and reduced ACL re-injury. However, both patellar tendon and hamstring tendon is widely used until today as that both grafts have their own benefits and drawbacks. While, for the rehabilitation phases post ACLr has been revised and improved with more enhanced method of testing before return to sport. The rehabilitation period has been extended to 9 months in the 2000s by adding one more additional phase which is prevention phase, while in 1990s an accelerated rehabilitation program would return the athlete to play in 4 months' time on average and the return to sport phase started sooner at 4th month. The open and closed kinetic chain exercises can begin as the athlete able tolerate the load, however the angle of the knee has to take into consideration while prescribing the exercises. Variation of the testing battery depending on the sports participated and type of level prior to return to sports are a key indicator of athlete's readiness post ACLr.

Conclusion: This study concludes that ACLr has evolved significantly in past 20 years together with the graft choice and fixation method. Enhanced graft fixation together with longer rehabilitation process and in-depth testing have resulted in the re-injury of the ACL reconstruction reducing over the years.

Keywords: *Anterior Cruciate Ligament (ACL); Anterior Cruciate Ligament Reconstruction (ACLr); Knee Joint*

Introduction

Knee injuries are the most common injuries among high performance athletes. The knee injury that probably draws the most attention is the anterior cruciate ligament (ACL) injury [35]. The ACL is one of the most frequently injured structures of the knee joint [7]. It is origi-

nated from lateral femoral condyle and inserted into the medial of tibial. The ACL is considered the main stabiliser of the knee, contributing to about 85% of knee stabilisation and enabling smooth and stable flexion and rotation of the knee [1]. It also prevents excessive tibial medial a rotation, as well valgus stresses. Together with the posterior cruciate ligament (PCL), the ACL guides the instantaneous center of rotation of the knee, therefore controlling its joint kinematics. While the anteromedial bundle is the primary restraint against anterior tibial translation, the posterolateral bundle tends to stabilize the knee near full extension, particularly during rotatory loads.

ACL injuries are common in individuals who participate in sports activities associated with pivoting, decelerating and jumping. ACL injuries can occur in two conditions: contact and non-contact. Most non-contact ACL injuries occur when the athletes suddenly change their direction of movement or position of the leg while landing from a jump. A cut-and-plant movement, where a sudden change in direction or speed with the foot firmly planted, is a typical mechanism that causes the ACL to tear [37]. Rapid deceleration moments, including those that also involve planting the affected leg to cut and change direction, have also been linked to ACL injuries, as well as landing from jumps, pivoting, twisting, and direct impact to the front of the tibia. However, ACL injury can also result from contact where an athlete is, for example, tackled by an opponent from the back or from a force against the side of the knee, especially the outer side.

ACL injuries occur more commonly in women than in men due to a variety of anatomical factors [23]. Females have larger hip angles compared to males and this indirectly causes the female knee to rotate internally more easily, commonly known as 'kissing knee'. This results in a higher risk of ACL injury. It should be noted that female hormones do increase ligament strength and flexibility. However, the fluctuation of hormones during menstrual cycle can cause the ligament to be weaker, and subsequently subject the ACL to a greater risk of getting injured.

The incidence of second ACL injuries, meaning to say re-injury, has decreased significantly over the years, primarily due to longer rehabilitation programs after ACL reconstruction [25]. However, Schilaty [26] also stated that 33% of re-injury occurs due to graft failure. This is because the grafts that were chosen for the reconstructions were not suitable and not strong enough for the athletes, in particular when allografts were utilized (which were taken from cadavers).

Any sports related injury causes time loss to the athlete. Sporting time loss is frequently used to assess the severity of sports injuries and is most simply defined by the restricted participation in training or competition for at least 24 hours. ACL injury has been reported to have the highest time loss with a median of 6 to 9 months [3]. During the lost time an athlete may lose their source of income from the team they represent or from sponsors directly sponsoring them. In addition, the team/association responsible for the athlete will suffer opportunity and commercial losses due to non-competition of the athlete. Akoto [3] found that up to 14% of athlete reported time loss of more than 12 months after ACL injury.

It is clear that the time lost due to ACL injury incurs a heavy financial impact on the athlete, their team, and sponsors. Thus, undergoing surgery as early as possible and undergoing proper rehabilitation program will help to reduce recovery time, cut down on financial losses and help these athletes to return to sport and competition in optimal condition.

This paper conducts an article review of ACL rehabilitation phases, graft selection, open and closed kinetic chain exercises and testing before return-to-sport for high performance athletes that have undergone ACL reconstruction.

Purpose of the Study

The purpose of this study is to identify the difference of ACL reconstruction rehabilitation over the past 20 years.

Method

Search strategy

This review was conducted in two stages. In stage 1, articles were retrieved via online database searching, hand-searching reference lists and performing cited reference searches (See figure 1). The online databases on PubMed were searched, using terms such as "anterior cruciate ligament rehabilitation" and "anterior cruciate ligament reconstruction" to identify studies published from January 1992 to December 2017. Studies were included for assessment if they evaluated the effect of a particular rehabilitation program, or the specific exercises used within a rehabilitation program following ACL injury or reconstruction. Studies were excluded if they examined passive modalities, such as cryotherapy, continuous passive motion, braces, or electrophysical agents. Cardiorespiratory or general fitness responses to rehabilitation programs were also excluded because the primary goal following ACL rehabilitation is often the elimination of lower extremity functional deficits. The reference lists of articles retrieved for inclusion in the current review were searched to identify other relevant articles.

During stage 2, the titles, and abstracts of articles were reviewed to assess eligibility for inclusion in this review. Articles were regarded as relevant and warranting inclusion if they were studies examining ACL reconstruction rehabilitation protocols, specific exercises, graft choices, open and closed kinetic chain exercises, neuromuscular training, and return to sport criteria. If there was uncertainty about whether a study should be included based on the review of the tittle and abstract, the full article was retrieved.

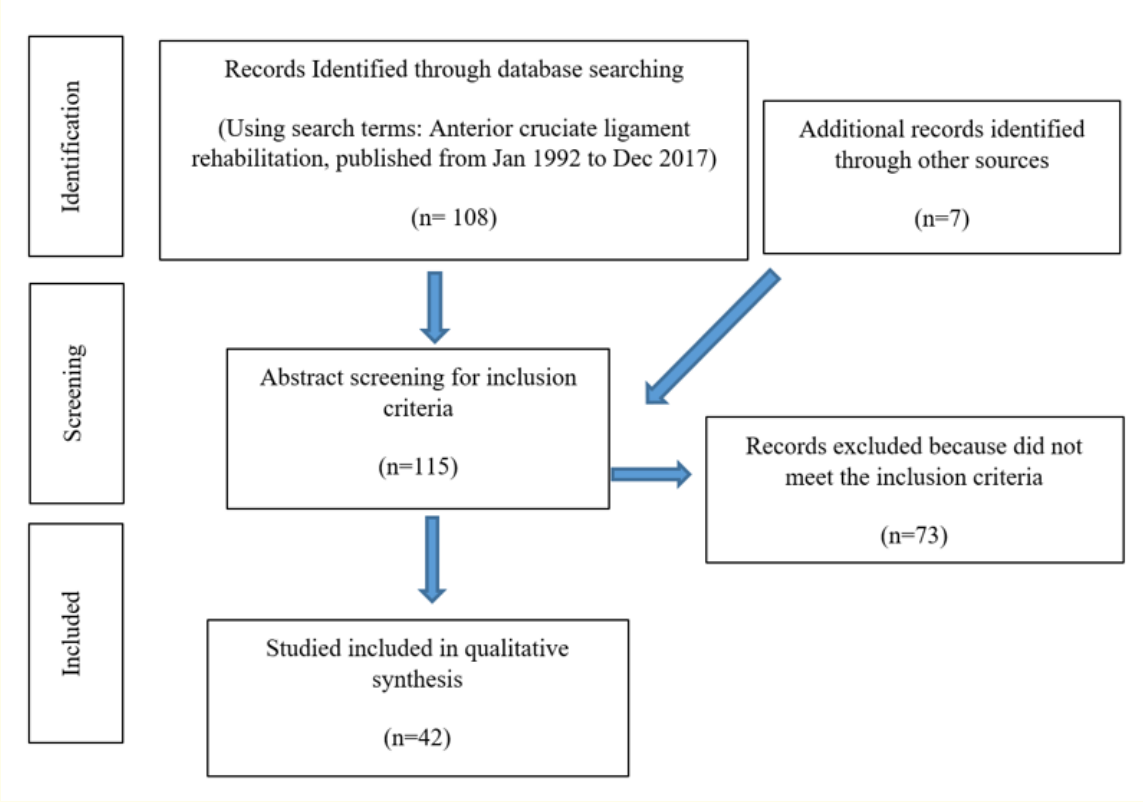

Figure 1: *Prisma flow chart*

Result

A PubMed search for key term from 1992 to 2017 revealed 108 publications. Out of these 108 papers, 66 were excluded because they failed to meet the inclusion criteria. The remaining 35 papers were included in this review. Furthermore, an additional 7 papers that met the inclusion criteria were identified from other sources. Thus, a total of 42 studies were included in the review.

In contrast to rehabilitation program for patients with ACL deficiency, rehabilitation programs for patients following ACL reconstruction must consider the strains caused by the new graft during various exercises as well as the graft healing response. ACL strain values related to rehabilitation exercises will therefore be included in this review. In addition, studies from the literature search covered the following areas of ACL rehabilitation: 'Rehabilitation protocols', 'ACL reconstruction graft selection', 'open kinetic chain (OKC) and closed kinetic chain (CKC) exercises', 'testing and measurement before return to sports' and 'neuromuscular training'.

Among the 42 papers initially selected:

- 16 papers were related to rehabilitation phases after ACL reconstruction.
- 3 examined open kinetic chain versus closed kinetic chain exercises.
- 6 examined different type of graft choices and compare between autograft and allograft selection.
- 2 papers focused on testing before return to sports: and,
- 8 examined re-injury after ACL reconstruction.

Additional 2 papers were related to unexpected disturbance program after ACL reconstruction and 5 were prospective cohort studies after ACL reconstruction.

Discussion

ACL reconstruction and re-injury rate

The ACL tear has been cited as the most common injury in most of the orthopaedic literature [23]. Erickson [10] also stated that ACL injuries gradually increased in number from 1996 to 2012, having analysed 57 players with 62 ACL ruptures, with the additional ruptures resulted from re-injury or injuring the contralateral leg. The same trend was also identified by Walden [36], where 149 players with 157 ACL injuries were investigated, including re-ruptures on the ipsilateral and contralateral legs. As an aside, it was noted that the number of total ruptures is higher than partial ACL ruptures.

Sander [23] reported that the peak rate of ACL injury occurs among males aged 19 to 25 years and females aged 14 to 18 years. This is due to the high level of engagement in sports at those particular ages where ACL injuries represent a major burden in high school athletes as they often require surgical repair followed by extensive long-term rehabilitation [15]. Furthermore, the incidence of ACL injury was significantly higher in younger females than males although the male-to-female ratio was reduced when adjusting for age [35]. In general, it was demonstrated that ACL injury incidence risk was five times higher during match play compared with training [35].

Most ACL injuries require surgical attention, and it was reported that ACL reconstruction increased by 37% from year 1994 to 2006 [4]. Similar pattern of increment was also observed by another group of researchers where it was reported that between 2005 and 2010, about 75% of subjects underwent ACL reconstruction within the first year of injury [23]. This rising rate of ACL reconstruction could be explained by changes in treatment pattern as surgeons develop better techniques and more predictable outcomes. There may also be an increasing desire among patients to return to high levels of activity after ACL injury [23].

However, a second ACL injury is unfortunately typically more devastating than the initial one. Schilaty [25] stated that the risk of a second rupture after an initial ACL reconstruction was reported at approximately 6.0%. The acute-onset ACL tears in the population were second tears, with graft failure comprising 33.3% and contralateral tears comprising 66.7% of the total 66 second ACL ruptures observed.

Graft type strongly influences the occurrence of second ACL injuries. Schilaty [26] indicated that allograft failure was nearly 3 to 4 times more likely than the failure in comparative autografts. In addition, hamstring autograft failure was twice as likely as that of a patellar tendon autograft. Walden [36] in his study also stated that there was a major change in graft choice as current trends favour hamstring autograft compared with patellar tendon autograft, which may result in an increased risk of recurrent ACL injury. Even though hamstring grafts demonstrate a higher rate of re-injury rate, they are still widely used as the hamstring tendon exhibits less complication rates in terms of extension loss, anterior knee pain, patellar fracture, weakening of the quadriceps muscle, patellar tendon rupture and/or patellar tendinitis [6].

Reconstruction and graft choices

ACL reconstruction and graft selection have been a topic of research over the past 30 years [5]. The most frequently used grafts are the patellar tendon graft (bone-patellar tendon-bone (BTB)) and semitendinosus-gracilis hamstring graft (HS). The graft choice is surgeon dependent and patient specific as there is no exact indication criteria for the different reconstruction graft types. The ideal graft to be used in ACL reconstruction should exhibit structural and biomechanical properties similar to those of the native ligament, permit secure fixation and rapid biological incorporation, and limit donor site morbidity. Nonetheless, while patellar tendon autograft might allow patients to return to higher levels of activity and maintain rotational stability in comparison with hamstring autografts [2], some authors argued that the use of BTB autograft is more favourable because it resembles the torn ACL as fixation allows bone-to-bone healing [24]. This thick tendon has good biomechanical properties and potentially lowers the risk of re-rupture of the graft. Previous studies also showed there was decreased pivot and rotational instability with patellar tendon autograft.

However, patellar tendon autograft was associated with more post-operative complications and harvesting side-morbidity. A previous study done by Kautzner [16] reported that patellar tendon autograft may aggravate the anterior knee pain shortly after surgery. In addition, Xie [40] found that patella tendon graft may increase the risk of patellar fracture, kneeling and/or persistent patellar tendon weakness. There is potentially a bony defect created on the patella and the tibial tubercle during bone-to-bone patella tendon harvest, resulting in an increased sensitivity to pain when the anterior knee presses directly on the surface during kneeling and walking. It is also reported that the pain in the early post-operative period may alter the patient compliance with the rehabilitation protocol. Those patients whose ACL was reconstructed using patellar tendon autograft may develop potential risk for meniscal or chondral lesion, contralateral ACL tears, loss of range of motion and exhibit a higher risk of osteoarthritis (OA) [21].

In contrast, Poehling-Monaghan [21] found that is no difference in patellar tendon autograft and hamstring autograft with regards to graft failure at a minimum of two years of follow-up. These authors showed that in the 1990s the bone-to-bone patellar tendon autograft was widely used. They harvested the middle third of the patellar tendon and this usage became the "gold standard" for ACL grafts. In the following years they discovered that the patellar tendon graft posed problems such as risk of patellar fracture, patellar tendinitis, residual flexion contracture and anterior knee pain. The use of a hamstring tendon graft was thought to be the solution to all these problems.

Nonetheless, both alternatives, patellar tendon as well as hamstring tendon grafts, are popular until today with no real modification except a different fixation technique [5]. In line with this, both the patellar tendon and hamstring tendon autografts provide satisfactory short and long-term results in terms of range of motion, subjective stability and functional scores [13]. Thus, this review concludes that the choice of graft is surgeon- and patient-specific, and that both types of graft have their own benefits and drawbacks. Notwithstanding this, the rehabilitation protocol according to the type of graft plays an important role.

Rehabilitation phases 1990s vs 2000s

The best surgically reconstructed ACL requires a standardized and individual rehabilitation protocol, developed in accordance with and tailored to the needs of the patient. Otherwise, it can lead to inappropriate and/or ineffective rehabilitation. In addition, progression from one phase to the next is based on readiness by achieving functional criteria rather than the time elapsed since surgery [39]. Myer [19] stated that the rehabilitation following ACL reconstruction is commonly divided into early and late rehabilitation phases. The functional criteria guidelines for the early rehabilitation phase are range of motion and progression to full weight bearing and exercise selection. For the later stage of rehabilitation, the exercise prescriptions are typically broader and may progress without specific milestones to introduce high-risk and high-joint landing activities (jumping).

In this review, we seek to compare the ACL reconstruction rehabilitation phases between the periods of 1992 - 2000 and 2001 - 2017.

The ultimate goal of the rehabilitation process is to limit the extent of the injury, reduce functional loss, enable return-to-sport and prevent any re-injury. This review found that there were three rehabilitation phases in the 1990s whereas in the 2000s there were five rehabilitation phases. Listed below is the comparison of the rehabilitation phases in 1990s and 2000s.

Phase 0 (Pre-operative phase)

The preoperative rehabilitation phase is for patients who have delayed ACL reconstructions. Before patients undergo the surgical procedure, they have to achieve specific physical goals. These goals were almost the same in the 1990s as in the 2000s. As for the entire rehabilitation program, the goals include restoring full range of motion of the injured knee, especially achieving the full knee extension, decreasing the swelling and restoring of normal gait. Another target is good quadriceps strength that allows the athlete to return-to-sport sooner after surgery [29]. Nazir Ahmad [20] found that gradual strengthening of the hamstring and quadriceps muscles may improve the stability of the knee joint. In addition, reduced knee pain and swelling, and a more stable knee with improved range of movement, become criteria for a patient to be mentally and physically prepared to undergo ACL reconstruction. Shelbourne [28] suggested to have a minimum of 3 weeks of pre-rehabilitation before undergoing surgery. This statement was supported by Malempati [17] whose study recommended three physiotherapy sessions followed by an exercise programme at home. Grant [11] also postulated that providing pre-operative and post-operative informational videos related to patients could improve the patient's psychological well-being before ACL reconstruction.

1990s	2000s
1. Full Range of motion	1. Minimal pain, swelling and inflammation
2. Minimal swelling	2. Full range of motion
3. Normal gait	3. Decreased expect post-surgical pain
4. Good strength	4. Educate patient to use crutches
5. Review post - operative rehabilitation program	
6. Mental preparation for surgery	

Phase 1 (Wound healing)

In this phase, the goal is to reduce or minimize the surgical complication. The most important goals in phase 1 are controlling pain, limiting activities to prevent knee effusion or swelling and controlling inflammation. To reduce the post-surgical pain, patients are required

to consume medication, do post-surgical compression wraps and elevation. In addition, cryotherapy will significantly help to reduce pain [34].

1990s (1 - 2 weeks)	2000s (1 - 4 weeks)
1. Limit activities to prevent knee effusion	1. Controlling the pain, swelling and inflammation
2. Decrease swelling	2. Recovery of Range of motion
3. Complete wound healing	3. Neuromuscular control
4. Full symmetrical hyperextension	4. Maintain full knee extension and immediate weight bearing.
5. Flexion to 110°	5. Initiate isometric closed chain exercises (0°-60°) and open chain knee extension, unresisted (90°- 40°).
6. Normal gait	6. Normal gait

After the pain is reduced, recovery of passive and active range of motion starts immediately. Multi-directional mobilization of the patella should be included to reduce any inhibition of knee range of motion. Certain open and closed kinetic chain, as well as isometric exercises could begin without any risk to the ACL graft [34]. In addition, full weight bearing exercises should be included to improve the quadriceps function, prevents patellofemoral pain and maintain the knee stability [34].

Phase 2

The aim of the second phase of ACL reconstruction rehabilitation is to improve proprioception, achieve complete passive knee extension and gradually increase the strength of the hamstring and quadriceps muscle [20]. The application of cryotherapy will be continued to reduce the pain, swelling and inflammation. The table above explains that in the 1990s, the rehabilitation protocol emphasizes extension, in contrast to the immobilization in flexion and restrictions [27]. While with 2000s the rehabilitation program focusses on both gradual increase of flexion and extension.

1990s (2 - 5 weeks Strength and agility)	2000s (4 - 6 weeks Strength and Neuromuscular control)
1. Maintain full hyperextension.	1. Gradually increase flexion and extension
2. Flexion to 135°	2. Protect graft.
3. Quadriceps muscle strength at 65% of opposite normal leg	3. Prevent postsurgical complication like arthrofibrosis
4. Resume normal gait pattern	4. Increase quadriceps and hamstring strength with Isokinetic exercises without endangering the graft.
5. Increase knee bends, step-ups, calf raise, leg press, stairmaster, bicycle	5. Gait training on treadmill => cycling

In the 1990s, if after 5 weeks following the operation the patient's isokinetic quadriceps strength ratio is 65% or greater compared to the contralateral leg, light functional and agility training can begin. This includes lateral shuffles, cariocas, running side-to-side and rope jumping. The agility exercises help to improve the fast speed strength and to restore quickness and proprioception early after reconstruc-

tion [7]. However, in the rehabilitation protocols of the 2000s, the primary focus is on normalizing gait without compromising against loss of extension. Sometimes, the altered gait may be unconscious in nature, thus the use of a feedback mirror can help the patient to re-alter the gait pattern.

The healing of graft will need to be taken into consideration as during this phase the revascularization started. Isometric exercises can be shifted to isotonic and slowly allow increased stress to the knee following greater graft strength. Balance and proprioception exercises can be prescribed, with weight shifting bilaterally and progressions to unilateral exercises if tolerated. By this time, healing of the donor site of the hamstring (either ipsilateral or contralateral) has completed and hence gentle hamstring, calf flexibility and strengthening exercises can be encouraged. The strengthening of the hamstring muscle in this phase may provide a primary restraint to anterior tibial translation. The neuromuscular control can be enhanced by adding perturbation forces to proprioception exercises by taping the body or sides of the wobble board [22].

Phase 3

There are clear differences between time periods in this Phase 3 of post-surgical rehabilitation program. In the 1990s, the athletes were allowed to start sports specific activity and return-to-sport after 4 months. Under such circumstances, patients were believed to return to sports specific activity with 65% of quadriceps strength Shelbourne [29] and were allowed to progress to competitive sports as strength and confidence continued to improve, which usually took a further 3 to 4 months [29]. In addition, while some patients returned to sporting activity as early as 2 months, typically most athletes returned to full activity between 4 to 6 months after ACL reconstruction [9]. However, in the 2000s, the rehabilitation phases continue with progression of strength, endurance, and neuromuscular control. During this time period, the return to sports and agility work were introduced at later stage to ensure the strength of the reconstructed leg was restored and proper graft healing.

1990s (5 weeks - 4 months Return-to-sport)	2000s (6 weeks - 3 months Running, Agility and Landing)
1. Obtain full symmetrical ROM	1. Full ROM
2. Continue to increase quadriceps muscle strength to more than 90% of contralateral knee.	2. Improve strength of quadriceps (whole leg muscles)
3. Agility drills	3. Improve endurance
4. Start sports specific activities and return to competition with increasing confidence	4. Improve proprioception
	5. Initiate agility exercises
	6. Initiate plyometric and light jogging

Phase 4

In phase 4, maximizing endurance and strength of the knee stabilizers, optimizing neuromuscular control with plyometric exercises, agility training and sport-specific exercises are the essential goals of this phase [33].

2000s (3 - 6 months Return-to-sport)
1. Progressive strength
2. Progressive power
3. Progress proprioception
4. Prepare for return to controlled individual functional sports
5. Symmetric performance basic and sport specific agility drills
6. Quadriceps and hamstring at least 85%

Sports-specific agility training with variation in running, turning and cutting manoeuvres, acceleration and deceleration was included to improve arthrokinetic reflexes so that new trauma during competition can be prevented. In this phase, the rehabilitation exercises will progress from double leg impact control to single leg impact exercises. For instance, improvement in single limb balance can begin by maintaining a single limb stance on a flat level surface while moving the contralateral leg through classic movement patterns. These balance exercises can be progressed by having the athlete perform balance techniques in increasing degrees of knee flexion. This serves to limit the exposure to excessive anterior tibial shear loads that may overload the graft tissue during the performance of these dynamic tasks. This is then followed by developing proper technique and appropriate neuromuscular control through start and stop movements and changes of direction drills including cutting and pivoting actions.

Plyometric activity begins after 12 weeks. Plyometric exercises use the muscles' stretch shortening cycle to allow maximum production of concentric contraction following a rapid eccentric loading of the muscles [18]. As the patient progresses through this phase, they begin to perform entry-level double-limb plyometric jumps with a progression to low intensity single-limb plyometrics. This training will gradually allow the addition of ground reaction force attenuation during more functional activities. In an ACL reconstruction rehabilitation protocol developed by the North Sydney Orthopaedic Research Group, it was noted that several sports specific injury prevention programs should be developed, incorporated and performed for at least 6 weeks to maximise effectiveness. These included plyometric and agility drills, single and double leg hops/jumps and change of direction exercises. In addition, some sports specific drills could be tailored for the particular sport, for example agility exercises such as side stepping through cones or poles for football.

Phase 5

2000s (> 6 months Prevent re-injury)	
1.	Safe to return-to-sport as the strength, endurance and proprioception maintained

The ACL reconstruction rehabilitation continues with phase 5. It is stated in the ACL Rehabilitation Protocol published by the North Sydney Orthopaedic Research Group, that, from a biological perspective, normal graft strength and stiffness in ACL reconstructed patients occur after 8 months, and overall remodelling continues beyond 12 months. Nonetheless, in general, the athletes are safe to return to sporting activity after 6 months. However, in some cases they won't be fully fit to return to competition. Thus, the strength, endurance and neuromuscular training will need to be continued with a variety of exercises. The athlete should complete "on-field" sports specific rehabilitation and return to team training. An athlete must develop the confidence and comfort to return to sports, and he/she must understand the importance of an injury prevention program. Repetition of training and skill work, and adherence to prevention programs will improve both performance and confidence.

The primary variations of ACL reconstruction rehabilitation in 1990s and 2000s are present in the return to sport phase. In the 1990s, the athletes or patients were allowed to return to sport as soon as they felt confident and could pass certain testing criteria. In the 1990s the athletes were allowed to return to sports as early as four months post-op and six months to take part in competition (including contact sports). The criteria for return were an isokinetic quadriceps strength ratio greater than 80% of the contralateral side at each speed and successful completion of functional progression. The athlete was encouraged or advised to wear knee brace up to one year following ACL reconstruction.

In the 2000s, similar testing was incorporated before an athlete's return to sport. The test includes whether full ROM is achieved; the hop tests and strength of the hamstring and quadriceps are at least 85% compared to the contralateral side; the difference in hamstring or quadriceps strength ratio is less than 15% compared to the contralateral side; and when the patient can tolerate sports-specific activities with no increase in pain and swelling. The hop and isokinetic tests can, in any case, only be performed if the knee is stable in active situa-

tions. However, the athlete should be advised while interpreting these test results their complete relevance for the return to sports, since these tests were not performed under fatigue condition. A gradual return to contact sports was recommended after ACL reconstruction, such as football (6 months) and basketball (up to 9 months) [38].

Unexpected disturbance program

The unexpected disturbance program (UDP) has recently been introduced as a new rehabilitation technique, in a study which was conducted among Malaysian national athletes from various sports at the National Sports Institute of Malaysia. This rehabilitation training program resulted in a positive outcome in terms of injury prevention, readiness for actual contact sports and competition level and was shown to be effective when applied during the final phase of the rehabilitation. Unexpected disturbance refers to the random perturbation that is applied during the execution of training exercises. This training regime utilizes exercises in response to so-called involuntary short mild latency disturbance [31]. Using exercises and movements with short-latency period (time spans of less than 200ms), coupled with unexpected environments and/or stimuli, the UDP was created to provide specific challenges to the sensorimotor function of the injured well-trained athletes, such that it would better mimic the nature of real-life competitive sporting situations. During the UDP training the athlete is forced to react to unexpected disturbance applied either manually or visually while executing specific exercises. This program helps to increase the effect of neuromuscular stimulus/function. Specifically, strength and the rate of force development improved. Besides, the authors Teichmann [31] also found out that UDP training helps to increase the functional performance and recovery process. The researchers postulated that this intervention would help to reduce the athletes' fears of movements and thereby reduce the athletes' fear of re-injury. The level of kinesiophobia has not yet been quantitatively tested. However, using a psychological questionnaire it was found that the athletes' self-confidence has improved [30].

One-joint versus multiple-joint movements - Open and closed kinetic chain

OKC exercises refer to exercises in which the proximal part of the joint is fixed while the movements of the distal part of the joint occur. In contrast, CKC exercises are exercises where the distal part of the joint is fixed while movement in only one joint occurs. One example of OKC exercise is the leg extension whereas for CKC exercise is the squat. Both OKC and CKC exercises had been used since the 1990's. However, in the 1990's, OKC was used only after 6 weeks of immobilization because it was commonly believed that the OKC exercises caused increased strain on the ACL as well as increased joint laxity and anterior tibial translation. Yack [41] stated that a distally fixed foot in the case of CKC exercises is safer than a non-distally fixed foot in OKC exercises. In 2000's, however, OKC and CKC exercises were used as soon as possible depending on the patient's adaptation and condition. Recently, Jewiss [14] showed that there is no significant difference between OKC and CKC exercises for pain scores, knee extensor strength, laxity, and knee flexion. Therefore, the authors concluded that both OCK and CKC exercises can begin as soon as tolerable. The latest clinical recommendations for CKC on strengthening ROM during closed chain activity are from 0° to 90°; however, earlier in the phase it may be best to limit ROM to shallower depths such as 45° to 60° to limit patellofemoral stress. OKC exercises with knee angles greater than 40° of flexion can be performed for quadriceps muscle strength training without increasing the strain on the ACL. Furthermore, this prevents additional stresses on the patellofemoral joint from six (6) weeks post-operation, with full ROM OKC exercises starting after 12 weeks post-op. OKC exercises seem to be favourable for increasing quadriceps muscle strength, primarily carefully controlled OKC exercises within the 40° - 90° of flexion starting at week 6 post-operatively could be recommended, based on the previously reported literature [17].

Testing before return-to-sport

The fixation method of the graft and other reconstruction techniques increases the rate of surgical success with ACL reconstruction. The advanced surgical technique causes a beneficial outcome which may allow an athlete to return to his or her previous level of sport. However, an athlete's return to play is often limited by graft stability, patient confidence, post-surgical duration, and subjective medical team opinion.

Rehabilitation and ultimate return-to-sport, using objective tests that quantitatively measure functional ability, increase confidence in the athlete's re-integration to sports at the same competitive level as prior to the injury. The variety of testing is related to the rehabilitation phase and the sport or discipline of the athlete. Prior study shows that before return-to-sport training, the athlete should demonstrate sufficient strength to improve potential success. Sufficient strength can be defined as 80% of the quadriceps strength as compared to the contralateral leg [29]. In the early 1990s, the functional testing was more focused on strength, power and speed whereas in 2000s, additional testing related to the specific sport is conducted before an athlete's return-to-sport.

In the 2000's, as a first step the athlete's health status is taken into consideration. This is followed by the examination of the risks associated with returns to sport (based on the type and level of sport). Besides range of motion, strength, power, and speed, the therapists also need to ascertain whether the return is to a pivoting or non-pivoting sport, contact or non-contact sport, the same pre-injury sports and competitive level, the same sport but on lower level, or a different sport, and that if the athlete merely perceives that the return to sport is successful. A battery of tests will be followed by a clarification of the athlete's readiness to return to play. In the test battery, the strength and hop performance will be measured, amongst others, and will ultimately justify the capability to return to sport [32].

Conclusion

The rate of ACL re-injury has reduced through the years due to the advanced surgery techniques used by the surgeon, the graft choice for ACL reconstruction and longer rehabilitation phases. In recent years, both patellar and hamstring tendon grafts have been widely used by the surgeons with different fixation techniques. These grafts provide satisfactory results when combined with good rehabilitation programs. In recent years, the hamstring tendon graft has become more popular due to the reduced side effects. The rehabilitation is now longer than in the 1990s where the accelerated ACL rehabilitation protocol was applied. Current studies support the notion that the longer rehabilitation phase helps to prevent the risk of re-injury. Furthermore, incorporating perturbation techniques (UDP) in the final phase of rehabilitation improves the athlete's awareness of real competition scenarios and may help to alleviate kinesiophobia. To achieve strong results during the rehabilitation phase, open and closed kinetic chain exercises can both be started as soon as tolerable. Various test batteries, based on the type and/or level of sport, prior to return to sport are key indicators of athlete's readiness and progress through rehabilitation.

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