

WJO 5<sup>th</sup> Anniversary Special Issues (5): Knee**Principles of postoperative anterior cruciate ligament rehabilitation**

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**Abstract**

It is known that anterior cruciate ligament (ACL) reconstruction needs to be combined with detailed postoperative rehabilitation in order for patients to return to their pre-injury activity levels, and that the rehabilitation process is as important as the reconstruction surgery. Literature studies focus on how early in the postoperative ACL rehabilitation period rehabilitation modalities can be initiated. Despite the sheer number of studies on this topic, postoperative ACL rehabilitation protocols have not been standardized yet. Could common, "ossified" knowledge or modalities really prove themselves in the literature? Could questions such as "is postoperative brace use really necessary?", "what are the benefits of early restoration of the range of motion (ROM)?", "to what extent is neuromuscular electrical stimulation (NMES) effective in the protection from muscular atrophy?", "how early can proprioception training and open chain exercises begin?", "should strengthening training start in the immediate postoperative period?" be answered for sure? My aim is to review postoperative brace use, early ROM restoration, NMES, proprioception, open/closed chain exercises and early strengthening, which are common modalities in the very comprehensive theme of postoperative ACL

rehabilitation, on the basis of several studies (Level of Evidence 1 and 2) and to present the commonly accepted ways they are presently used. Moreover, I have presented the objectives of postoperative ACL rehabilitation in tables and recent miscellaneous studies in the last chapter of the paper.

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**Key words:** Anterior cruciate ligament rehabilitation; Eccentric exercise; Proprioception; Strengthening; Postoperative; Anterior cruciate ligament

**Core tip:** In this topic highlight, I will review the answers given by some literature studies to questions in the literature about anterior cruciate ligament rehabilitation such as "could common ossified knowledge or modalities really prove themselves?", "is postoperative brace use really necessary?", "what are the benefits of early restoration of the range of motion?", "to what extent is neuromuscular electrical stimulation effective in protecting from muscular atrophy?", "how early can proprioception training and open chain exercises begin?", "should strengthening training start in the immediate postoperative period?"

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**INTRODUCTION**

Anterior cruciate ligament (ACL) reconstructions have to be combined with detailed postoperative rehabilitation in order for patients to return to their pre-injury activity levels. ACL reconstruction ensures structural ligament repair, whereas rehabilitation protects and maintains the lig-

**Table 1 Goals of 0-1 mo (acute phase)**

Education of patient
Pain control
Decrease effusion
Increase range of motion
Be able to do straight leg raise (1-2 d <sup>1</sup> )
Be able to lift the leg in all directions without assistance (1-7 d)
Flexibility (hamstrings, calves)
Strengthening (quadriceps, hamstrings, hip, calf, core, upper body, non-injured leg)
Patellar mobilization
Proprioceptive/balance training (start walking with crutches)
Start cardiovascular fitness (arm ergometer)
Achieve and maintain near or full ROM in knee flexion and extension (full extension 1-5 d <sup>1</sup> , full flexion 2-3 wk <sup>1</sup> )
Achieve and maintain weight bearing gait (2 crutches 0-1 wk <sup>1</sup> , 1 crutch 0-1 wk <sup>1</sup> , no crutches 0-2 wk <sup>1</sup> )
No apprehension when walking without a crutch
Home training program (2-3 h/d <sup>1</sup> , therabands, ROM exercises, etc.)
Start bicycling (90°-100° in active flexion <sup>1</sup> )
Start pool exercises (after suture removal, when wound is closed <sup>1</sup> )
Start to fight with fear of re-injury physically and psychologically
Return to work (3-4 wk <sup>1</sup> if office work)
MD visit 1/wk

<sup>1</sup>Author's approach.

ament repair and the physical and psychological state and performance capabilities of the athlete. The above paragraph is maybe the summary of the one point on which there is consensus about ACL reconstruction. Different rehabilitation protocols post-ACL reconstruction exist in our country and all over the world at sports medicine departments of universities and sports medicine clinics, as indicated on their websites. This lack of consensus led to uncertainties, which resulted in aggressive and non-aggressive approaches. Studies in the literature tried to determine the earliest optimal time to start rehabilitation and how long it should take, considering all parameters of the rehabilitation process. Although there are many studies on this topic, there is a lack of consensus in the literature even about commonly accepted modalities. Today, specialists decide on the type of exercises that need to be prescribed, and when in the ACL rehabilitation process to start them on the basis of their experience and interpretation of the condition. Different interpretations lead to more questions, which in turn lead to more original articles. New trial outcomes modify and develop current protocols. Thus, it would not suffice to say that the required exercises or modalities should be performed in a specific period of time. The ACL rehabilitation objectives that I summarize in Table 1, Table 2, Table 3 and Table 4 do not indicate a precise time; the times may overlap and modifications have to be made on the basis of the criteria associated with the time schedule.

Protocols and interpretations may differ in ACL rehabilitation approaches, but what remains the same is the outcome that every sports medicine specialist tries to achieve. The overall objectives before a return to sports activities are control of pain and swelling, a full range of motion and flexibility, elimination of muscle atrophy, a

**Table 2 Goals of 1-4 mo (maintenance and acceleration phase)**

Decrease and disappearance of effusion
Full and pain-free knee range of motion
Continue flexibility exercises
Continue strengthening exercises (add isokinetic hamstring exercises)
Swimming
Bicycling (indoor)
Core training progression
Proprioceptive progression (focus on weak positions)
Maintain cardiovascular fitness
Determine and manage hamstring, quadriceps strength deficits
Prepare physically and psychologically for jogging
Deep water running
MD visit 2/mo

normal gait, a return to work for non-athletes, a return to pre-injury muscular strength and endurance levels, maintenance of cardiovascular fitness, restoration of proprioception, a return of self-confidence and overcoming kinesiophobia. When all these objectives are achieved the athlete can return to sports activities.

My aim is a review of the most common modalities in ACL rehabilitation, such as postoperative bracing, early range of motion (ROM), neuromuscular electrical stimulation (NMES), proprioception, open/closed chain exercises and early strengthening; I preferred not to approach the subject from the basic definitions and historical perspective, and present in the last chapter recent miscellaneous studies.

## POSTOPERATIVE BRACE USE

The objectives of postoperative brace use are restriction and development of the ROM of the knee, resistance of the knee to medial and lateral stressors, knee stability, and protection from knee injuries, however its role in ACL rehabilitation is controversial.

McDevitt *et al*<sup>11</sup> reported in 2002 that there was no definite evidence of improvements in outcomes or protection from re-injuries associated with the use of a brace in postoperative ACL reconstruction.

Swirtun *et al*<sup>12</sup> stated that use of a brace in non-operated ACL-injured patients reduced the feeling of instability, but increased complaints during day-to-day activities. They also underlined in their trial that the positive effects were not supported by objective outcomes.

Wright *et al*<sup>13</sup> indicated in a systematic review in 2007 that wearing of a knee brace had no additional treatment value after ACL reconstruction. This conclusion was supported in 2009 by Andersson *et al*<sup>14</sup>.

Birmingham *et al*<sup>15</sup> conducted a randomized controlled trial in 2008 to compare the outcomes of a rigid knee brace and a neoprene sleeve in 150 patients post-ACL reconstruction during exercise and all physical activities. The authors stated in the conclusion of their trial that the use of a rigid knee brace postoperatively was not superior to the use of a neoprene sleeve on the measured outcomes. Nevertheless, they stressed that the subjective

**Table 3 Goals of 4-6 mo (sports-specific phase)**

No effusion
Pain free jogging and running (no effusion)
Pain free landing (from double to single leg)
Pain free hopping (from double to single leg)
Functional strengthening (plyometrics, agility drills, etc.)
Sports specific proprioception training
Sport specific cardiovascular fitness
Training in the sports field
Adequate neuromuscular control
Continue fighting against fear of re-injury
Success in functional tests
MD visit 1/mo

confidence rating of patients that used the rigid knee brace was higher than in the neoprene sleeve group<sup>[5]</sup>.

Can the use of a brace attenuate pain, which is a significant problem in the postoperative period? Hiemstra *et al*<sup>[6]</sup> tried to answer this question in their randomized controlled trial from 2009. They carried out a comparative study of pain, use of analgesics, effusion and ROM parameters in 88 patients who were immobilized and non-immobilized post-ACL reconstruction. For immobilization, a soft, unhinged knee brace was used. They found no differences in pain or any of the secondary outcomes between immobilized and non-immobilized patients at any point during the first 14 d after ACL reconstruction<sup>[6]</sup>.

Mayr *et al*<sup>[7]</sup> randomized 73 patients to compare the clinical outcomes of postoperative ACL rehabilitation using a water-filled soft brace to those using a hard brace. Braces were applied for 6 wk after the surgery. The soft brace group had significantly higher postoperative International knee documentation committee (IKDC) subjective ratings, Tegner activity scores and Lysholm knee scores and significantly less effusion. The hard brace group had significantly more extension deficits and no significant difference was reported between the groups on knee ROM, knee laxity and thigh atrophy parameters. The authors stated that the water-filled soft brace was easy-to-use and safe and might be an efficacious alternative to the hard brace<sup>[7]</sup>.

In a recent study, Stanley *et al*<sup>[8]</sup> reported that the use of a knee extension constraint brace reduced the peak posterior ground reaction force when walking, but this effect was not observed when descending stairs and jogging. They concluded that the knee extension brace modified the lower extremity movement pattern which made re-injuries less possible and this is why it could be used for postoperative ACL rehabilitation<sup>[8]</sup>.

Kruse *et al*<sup>[9]</sup> investigated the outcome of 11 studies in their systematic review and concluded that the postoperative use of a brace did not provide any additional benefits. Lobb *et al*<sup>[10]</sup> found in their systematic review strong evidence of no added benefit of the use of a brace for 6 wk postoperatively compared with standard treatment in the short term. Meuffels *et al*<sup>[11]</sup> reported in their study, which referred to the recommendations of the Dutch Orthopaedic Association, that a brace can be used in

**Table 4 Month 4-6 (return to sports phase)**

Flawless running
Good psychology
Maintain good results of functional tests
Adequate sports specific aerobic/anaerobic measures
Quadriceps and hamstring strength at least 85% of the normal leg
No swelling
No laxity
No fear

patients with instability symptoms who do not qualify or who do not want to qualify for operative treatment.

In our clinical approach, we do not use postoperative braces in many of our patients. We prefer using braces for only 1-2 wk in patients who find it difficult to regain their confidence or are temperamentally conservative and anxious. In our clinical experience, the most common complaints associated with postoperative brace use are too much restriction during motion and the desire to be able to move independently sooner. The question “is the use of a brace required?” is mainly answered with “No, it is not” by the literature. Nevertheless, as indicated in the introduction, optimistic specialists based on their clinical experience and referring to trials that find the use of braces beneficial continue using them in the postoperative period. I think that force vectors of the knee joints during movement need to be investigated and compared in future research studies in order to clarify this point.

## EARLY RESTORATION OF ROM

Many investigators underline that the priority goal of postoperative ACL rehabilitation should be restoration of the full ROM<sup>[12-15]</sup>.

Rubinstein *et al*<sup>[12]</sup> reported that full knee extension in the immediate postoperative period in 194 patients that underwent autogenous bone-patellar-tendon ACL reconstruction did not damage the graft or joint stability. Protection of the graft is important for both the patient and the orthopedist who performed the surgical procedure. Orthopedists refer their patients to those sports medicine clinics they are convinced will perform a rehabilitation modality that will not adversely affect the graft recovery process. It is obvious that patient compliance with the rehabilitation protocol will improve when patients trust the orthopedist who performed the surgical procedure, and orthopedists trust physicians responsible for the rehabilitation program.

An early start to quadriceps exercises in the postoperative period has been reported to improve early ROM development<sup>[13]</sup>. Another study found that restoration of symmetrical ROM in the early period of ACL rehabilitation was quite valuable for long-term ROM maintenance of the patients<sup>[14]</sup>. Early restoration of strength and ROM will accelerate early mobilization of the patient and more effective participation of the patient in the following rehabilitation phases. This in turn will allow for different training activities to be performed on the knee joints and long-

term ROM maintenance will be ensured. Previous studies have shown that patients who maintain normal ROM according to IKDC criteria have better outcomes after ACL reconstruction<sup>[16,17]</sup>. In their study of the long-term outcomes of postoperative ACL reconstruction, Shelbourne and Gray reported that the most important reason for low subjectivity scores of the patients was the absence of normal knee extension and normal knee flexion<sup>[17]</sup>.

The reason for early ROM restoration brings to the fore the question of whether rehabilitation should be accelerated or non-accelerated. There is no consensus on this subject in the literature. Beynnon *et al*<sup>[18]</sup> reported that in postoperative ACL rehabilitation, accelerated programs were not significantly different from non-accelerated programs on knee laxity, clinical assessment, proprioception, functional performance and thigh muscle strength parameters. Shelbourne followed the recommendations regarding immediate full extension and maintenance and stated that, after ACL reconstruction graft remodeling, continued loss of ROM could be associated with long-term osteoarthritis modifications in radiography<sup>[15]</sup>.

In a recent study, Christensen *et al*<sup>[19]</sup> found no differences between early aggressive and nonaggressive rehabilitation after ACL reconstruction on the primary outcomes of knee laxity and subjective IKDC score. In addition, they observed no differences in secondary outcomes between groups for differences in ROM and peak isometric force values. Kruse *et al*<sup>[9]</sup> stressed in the conclusion of their systematic review that further investigations were needed to clarify the effect of accelerated, aggressive rehabilitation on quick return to sports.

In the light of the above studies we can say that the importance of early ROM recovery in postoperative ACL rehabilitation is obvious. However it is still uncertain when to start ROM exercises in the early postoperative period. Early ROM of extension and flexion is known to reduce the risk of arthrofibrosis<sup>[20]</sup>. We target a full ROM in the first 2-3 wk in our patients. This can be accepted as the accelerated approach in the literature. In our experience, ROM recovery in the first 2-3 wk should be encouraged unless there is a problem with compliance of the patient with the treatment.

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## NEUROMUSCULAR ELECTRICAL STIMULATION

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In the early phase, normal gait should be restored by controlling and synchronizing the quadriceps with the antagonist hamstring. Improvement of gait varies from person to person. Sensitivity to pain, anxiety and other factors can prolong this period. In this phase, in nearly all cases atrophy of the quadriceps caused by a knee effusion that inhibits the quadriceps muscle is observed. Many studies have proven that electrical stimulation (ES) protects from muscle atrophy<sup>[21-23]</sup>.

Sisk *et al*<sup>[24]</sup> examined the effect of prolonged daily ES on quadriceps strength in casted 22 patients during the 6 wk following anterior cruciate reconstruction. They

found no difference in quadriceps strength between the two groups during the 7<sup>th</sup>, 8<sup>th</sup>, and 9<sup>th</sup> week postoperatively. The length of time (how much time per day and how many weeks) for the use of ES in the ACL rehabilitation process is not known yet.

Wigerstad-Lossing *et al*<sup>[21]</sup> in a 1988 study found that the effect of ES plus voluntary muscle contraction increased the isometric muscle strength more than control group. In the conclusion of their study they stated that ES combined with voluntary muscle contraction was significantly protecting from atrophy of the muscles. In a study in 1988 Delitto *et al*<sup>[22]</sup> compared the isometric torque values of an ES co-contraction group and voluntary isometric co-contraction group in postoperative ACL reconstruction. They found that isometric torque was significantly increased in the extensors and flexors in the ES group.

In a study in 1991, Snyder-Mackler *et al*<sup>[23]</sup> evaluated 10 patients who were randomized to ES with voluntary contraction *vs* only voluntary contraction. They found a significantly positive difference in the ES group on the values for cadence, walking velocity, stance time of the involved limb, and flexion-excursion of the knee during stance *vs* the voluntary exercise group. They emphasized that the ES group had stronger quadriceps muscles and more normal gait patterns than those in the voluntary exercise group<sup>[23]</sup>.

In a study in 1995 Snyder-Mackler *et al*<sup>[25]</sup> investigated 110 patients in 4 groups, a high-intensity NMES group, a high-level volitional exercise group, a low-intensity NMES group, and a combined high- and low-intensity NMES group. They found that high intensity ES either alone or in combination with low intensity ES increased recovery of the opposite limb quadriceps strength.

Although most of the above-mentioned studies stressed the benefit of ES, Wright *et al*<sup>[26]</sup> reported in a systematic review in 2008 that the quality of these studies varied; many did not address randomization or were not blinded and their results were not evaluated by independent observers. In the light of these findings, they underlined that NMES helped the development of the quadriceps, but one could not conclude that NMES was certainly required for successful ACL rehabilitation<sup>[26]</sup>.

In a study in 2011, Hasegawa *et al*<sup>[27]</sup> administered NMES from postoperative day 2 following ACL reconstruction until the 4<sup>th</sup> month. They reported that early NMES helped the recovery of knee extension strength measured at 3 mo postoperatively. Moreover, there was a significant increase in the vastus lateralis and calf thickness at 4 wk postoperatively in the NMES group *vs* the control group<sup>[27]</sup>.

In an interesting recent study, NMES was found to modify gene expression in mice post-ACL surgery and delay atrophy of the muscles. NMES was reported to decrease atrogene and myostatin accumulation in the quadriceps muscle and protect from early atrophy on postoperative day 3 but did not affect atrophy on the 7<sup>th</sup> and 15<sup>th</sup> day<sup>[28]</sup>. Future human gene studies may be the key in answering the question of how long NMES and

other modalities should be applied postoperative.

Most of the above-mentioned studies report that NMES contributes to atrophy prevention in postoperative ACL rehabilitation<sup>[21-23,25,27]</sup>, whereas some publications report no such effects<sup>[24,26]</sup>. When using NMES as part of our treatment we ask the patient to do voluntary muscle contraction each time. Even if we assume that NMES is not efficacious, we think that it could contribute to atrophy prevention when combined with voluntary muscle contraction.

## PROPRIOCEPTION

Balance and proprioception training have a positive effect on joint position sense, muscle strength, experienced knee function, outcome of functional capacity, and return to full activity<sup>[29-32]</sup>. Hewett *et al*<sup>[33]</sup> stated that balance exercises on the balance board could start early in the postoperative period. Proprioceptive exercises actually begin when the patient steps on the ground early in the postoperative period. Early start of locomotion at a level tolerated by the patient will ensure early restoration of proprioception and facilitate progress in proprioceptive exercising.

Friden *et al*<sup>[34]</sup> reported in a review published in 2001 that despite the existence of many proprioception tests there were no standardized reference tests. They also underlined that the link between the conscious and non-conscious proprioceptive system and their specific roles was unknown. Additionally, they stated that information regarding how proprioceptive training restored sensorial defects was limited. Nevertheless, they reported that during rehabilitation each patient must create muscle strength, alertness, and stiffness in harmony with the disturbed mechanics of the knee, which were present both after nonoperative treatment of the ACL and after a reconstruction of the ACL<sup>[34]</sup>.

In a systematic review published in 2003, Thacker *et al*<sup>[35]</sup> stated that neuromuscular and proprioceptive training was an important factor in protection from knee injuries. At the same time, they wrote that the studies reviewed were inadequate due to methodological mistakes, and more studies were needed to shed light on this topic in the future<sup>[35]</sup>.

A study in 2005 investigated the effect of early proprioceptive coordination training on neuromuscular performance values post-ACL surgery. The authors stated they found a highly statistically significant correlation between the single leg stance, one leg hop, Lysholm, and Tegner tests at 6 wk, and 4, 6, 9 and 12 mo in the postoperative period<sup>[36]</sup>.

In a randomized controlled study, Cooper *et al*<sup>[37]</sup> compared the effects of proprioceptive and balance exercises and the strengthening program in the early period post-ACL reconstruction. The investigators reported that the strengthening exercise group had better Cincinnati and patient specific functional scale scores than the proprioceptive group, and early postoperative strengthening training could be more beneficial than proprioceptive

training<sup>[37]</sup>. It is difficult to clearly draw the line between muscle strengthening training and proprioceptive training. Each strength training has proprioceptive properties and most proprioceptive exercises have strength-associated properties.

Angoules *et al*<sup>[38]</sup> compared knee proprioception post-ACL reconstruction with hamstring *vs* patellar tendon autografts. They reported that there was no statistically significant difference in the joint position sense and threshold to detection of passive motion values between graft groups during any time period, and the knee proprioception returned to normal in postoperative month 6<sup>[38]</sup>.

In a systematic review in 2011, Howells *et al*<sup>[39]</sup> tried to answer the question whether postural control could be restored postoperative ACL reconstruction. The authors stated that the results were not conclusive due to the limited number of studies on this topic and different methodologies applied in them. They stressed that deficits in dynamic tasks may be more relevant to people intending to return to sport following surgery due to the inherently dynamic nature of sport and should perhaps be the focus of future research<sup>[39]</sup>.

In a recent study, athletes who underwent postoperative ACL reconstruction proved able to start balance training on the Biodex platform 4 wk earlier than with the use of the conventional approach. The authors concluded that the combination of classical rehabilitative techniques with balance training, Speed Court training, and training on the alpine ski simulator made it possible to begin special alpine ski training on the snow 2 mo earlier than with the use of conventional methods<sup>[40]</sup>.

There is no clearly defined starting time for proprioceptive training. Regain of confidence, absence of pain and willingness to exercise are factors contributing to the start of balance training.

## OPEN/CLOSED CHAIN EXERCISES AND EARLY STRENGTHENING

Closed chain exercises can be introduced in early rehabilitation due to their benefits, *e.g.*, reduction of shear and acceleration forces on the joints, development of dynamic early joint stability and stimulation of proprioceptors. The question is which open chain exercises can be used safely at which stage in the rehabilitation process. According to Fitzgerald, closed chain exercises are considered safer and more functional compared to open chain exercises<sup>[41]</sup>. Notwithstanding, Seto *et al*<sup>[42]</sup> stated that the open and closed chain exercises could co-exist in enabling rehabilitation and strengthening objectives. In their prospective randomized trial, Bynum *et al*<sup>[43]</sup> reported that closed kinetic chain (CKC) exercises were recommended to provide improved arthrokinematics in comparison with open kinetic chain (OKC) exercises for rehabilitation of ACL injury. Kvist *et al*<sup>[44]</sup> stated that CKC exercises produced a smaller magnitude of anterior tibial translation (ATT) than OKC activities.

Some studies<sup>[45,46]</sup> have reported that the kinematic ef-

fects, resulting from hamstring co-activation and increase in the joint compression force during CKC exercises, are not sufficient to reduce ATT significantly. There are also reports of larger ATTs and similar ACL strain during CKC compared with OKC exercises<sup>[45,47]</sup>. In the early phase of rehabilitation, closed-chain exercise therapy is likely to give fewer patello-femoral complaints and less laxity than open-chain exercises<sup>[4,26,31]</sup>. Heijne *et al*<sup>[48]</sup> aimed to evaluate physical outcome after ACL reconstruction with early *vs* late initiation of OKC exercises for the quadriceps in patients operated on either patellar tendon or hamstring grafts. They reported an exercise program with early OKC exercises (postoperative week 4) would lead to more laxity with hamstring grafts than late OKC exercises (postoperative week 12)<sup>[48]</sup>.

Glass *et al*<sup>[49]</sup> published a systematic review about the effects of open *vs* closed kinetic chain exercises on patients with ACL-deficient or -reconstructed knees in 2010. In their conclusion, they wrote that CKC and OKC exercises seem to have similar outcomes on knee laxity, knee pain, and function and therefore could both be used during the rehabilitation of a patient with ACL deficiency or post-ACL reconstruction<sup>[49]</sup>. They stated that one article found positive significant effects with inclusion of OKC exercises in the rehabilitation program<sup>[50]</sup> and another found significant benefits with a combination of OKC and CKC exercises<sup>[51]</sup>. CKC exercises alone were not found by any studies to be superior to OKC exercises. Mikkelsen *et al*<sup>[51]</sup> found that using CKC and OKC exercises together led to greater quadriceps torque return and a quicker return to sport than CKC alone. Tagesson *et al*<sup>[50]</sup> reported that OKC exercises for quadriceps led to better gains in quadriceps strength than when using CKC exercises. In their systematic review, Glass *et al*<sup>[49]</sup> concluded that OKC exercises should be initiated after the 6<sup>th</sup> week of the postoperative period. Meuffels *et al*<sup>[11]</sup> stated that only the use of closed-chain exercises was recommended in early rehabilitation.

A recent study measured the amount of ATT of ACL-deficient knees during selective OKC and CKC exercises. The authors found no significant differences between the ATTs of the ACL-deficient and intact knees at all flexion angles during forward lunge and unloaded open kinetic knee extension. Nevertheless, they recommended that weight-bearing CKC exercise should be preferred over OKC knee extension exercises in ACL-deficient knees<sup>[52]</sup>.

Fridén *et al*<sup>[53]</sup> stated that there were no clinical trials that evaluated outcomes of OKC exercises in a restricted ROM for pain, function, muscle strength, and anterior knee laxity at 1 year after surgery. The goal in their randomized controlled clinical trial was to determine if an early start of OKC exercises for quadriceps strength in a restricted ROM would promote a clinical improvement without causing increased anterior knee laxity in patients after ACL reconstruction. They concluded that an early start of OKC exercises for quadriceps strengthening in a restricted ROM did not differ from a late start in terms of anterior knee laxity.

In a study in 2005, Shaw *et al*<sup>[13]</sup> started isometric quadriceps exercises and straight leg raises in a group immediately postoperative and compared the result with the non-exercise control group. In postoperative week 2, both groups were enrolled in the same rehabilitation system. They concluded that there was no significant difference in the 6<sup>th</sup> month postoperatively regarding knee laxity, hop tests, Cincinnati score and isokinetic quadriceps force measurements<sup>[13]</sup>.

Gerber *et al*<sup>[54-56]</sup> compared the effects of progressive eccentric exercises started in 3<sup>rd</sup> and 12<sup>th</sup> week after ACL reconstruction. In their first study, eccentric exercises were performed in knees with full ROM at 20°-60° knee flexion. They reported no statistically significant difference between both groups on pain, effusion and anterior laxity parameters in the 14<sup>th</sup> week postoperatively<sup>[55]</sup>. In another study in 2009, they extended the follow-up period to 1 year and detected a statistically significant increase in the cross-sectional areas and volumes of the quadriceps and gluteus maximus muscles and in the quadriceps muscle strength in the group that started eccentric exercises early *vs* late<sup>[56]</sup>.

Sekir *et al*<sup>[57]</sup> compared the outcomes of isokinetic hamstring strengthening exercises initiated in 3<sup>rd</sup> and 9<sup>th</sup> wk post-ACL reconstruction with patellar tendon autograft. The group that started early hamstring strengthening had a better quality of life, activities of daily living in the 1<sup>st</sup> month, and isokinetic hamstring strength performed at 60°/s angular velocity. Sekir *et al*<sup>[57]</sup> reported that early hamstring strengthening was not harmful at any point in time during the ACL rehabilitation process.

In a systematic review in 2012, Kruse *et al*<sup>[9]</sup> reported that immediate postoperative weight-bearing, knee ROM from 0° to 90° of flexion, and strengthening with closed-chain exercises were likely safe, and starting eccentric quadriceps strengthening and isokinetic hamstring strengthening at week 3 after ACL surgery might improve or accelerate strength gains.

In the literature, CKC exercises were proved to benefit the patient in the early postoperative period and new studies focus on the safest point in time to start OKC exercises in early ACL rehabilitation. This remains uncertain. We want to underline that in our clinical approach we are cautious when it comes to the initiation of early postoperative OKC exercises.

## RECENT MISCELLANEOUS STUDIES

In this part, I have reviewed the outcomes of some recent interesting studies.

In a study published in 2013 patients that underwent ACL surgery were divided into 2 groups, smokers and non-smokers. The stability and functional scores of the smokers were found to be worse (less satisfactory) than those of the non-smokers. The Achilles tendon-bone allograft of the smokers group rendered the worst result *vs* the other autografts, and the bone-patellar tendon-bone autograft was reported to be more appropriate for ACL reconstruction in smokers<sup>[58]</sup>.

A 15-year prospective, randomized, controlled trial published in 2013 compared the failure rate, knee injury osteoarthritis outcome score (KOOS) (pain, symptoms, Sport/Rec, quality of life, daily living function), Tegner activity scale, anterior knee pain-score, Lysholm score, Rolimeter laxity, extension deficit, single hop and crossover hop for distance outcomes of an iliotibial band autograft and bone-patellar-bone autograft. The authors concluded that the use of an iliotibial band graft could be a safe alternative<sup>[59]</sup>.

In a recent study, Månsson *et al*<sup>[60]</sup> aimed to identify preoperative factors that had a positive affect on postoperative health-related quality of life. The study concluded that preoperative pivot shift, knee function, ROM and Tegner activity levels were significant factors for postoperative health-related quality of life<sup>[60]</sup>.

A systematic review published in 2013 investigated the psychological predictors of postoperative ACL reconstruction. Self-confidence, optimism, and self-motivation factors were reported to have a predictive value for outcomes. They stated that postoperative emergence of knee symptoms and compliance with rehabilitation were adversely affected by preoperative stress and positively affected by social support<sup>[61]</sup>.

In a randomized, controlled trial published in 2013, Frobell *et al*<sup>[62]</sup> followed-up 121 patients for 5 years who were part of the same rehabilitation program after ACL reconstruction. The trial concluded that early or late ACL reconstruction did not differ significantly in absolute KOOS4 score, all 5 KOOS subscale scores, SF-36, Tegner activity scale, meniscal surgery, and radiographic osteoarthritis parameters<sup>[62]</sup>.

A retrospective comparative study published in 2013 investigated the return to sport rates after ACL reconstruction; 46% of 135 patients returned to their pre-injury levels while 56% did not (non-returners). Half of the reasons why non-returners did not return to sport were related to fear of reinjury<sup>[63]</sup>.

Fridén *et al*<sup>[64]</sup> reported that the impact of fear on self-report of function and performance following ACL reconstruction was less clear. The findings of this study lend further support to the theoretical application of the fear-avoidance model in knee rehabilitation, and identified fear of movement/reinjury as a potential target for ACL reconstruction rehabilitation guidelines.

Nyland *et al*<sup>[65]</sup> drew attention to the importance of kinesiophobia. They believed that increased self-efficacy and confidence and decreased kinesiophobia suggested a greater patient willingness to use the involved lower extremity. Ardern *et al*<sup>[66]</sup> stated that the single limb hop for distance and the crossover hop test scores served as indicators of an athlete's likelihood to return to sport.

On the other hand, in their systematic review, Narducci *et al*<sup>[67]</sup> underlined that although functional performance testing was valuable for the assessment of ACL injured patients, they did not identify any clinical test or battery of tests that predicted the athletes' ability to return to play sports.

In a cohort study in 2012, Logerstedt *et al*<sup>[68]</sup> stated

that the outcomes of the single-legged hop tests conducted in the 6<sup>th</sup> mo after ACL reconstruction were valuable in predicting outcomes in the 1<sup>st</sup> postoperative year, whereas preoperative single-legged hop tests did not have a predictive value for the postoperative outcome. Moreover, they indicated the presence of minimal side to side differences in the crossover hop tests conducted in the 6<sup>th</sup> mo postoperatively could improve knee functions in the 1<sup>st</sup> year postoperative period if patients continued with the training program<sup>[68]</sup>.

Two separate studies reported that the coordinated coactivation of the hamstrings and quadriceps might play a role in mitigating primary injury risk by reducing ligament strain<sup>[69]</sup> and promoting normal landing mechanics<sup>[70]</sup>. In a cross-sectional study in 2012, Begalle *et al*<sup>[71]</sup> reported that the most balanced quadriceps-hamstring coactivation ratios were identified in the single-limb dead-lift, lateral-hop, transverse-hop, and lateral band-walk exercises which could be safely used in post-injury rehabilitation programs. They stressed that balanced agonist and antagonist coactivation might also protect the reconstructed knee against second ACL injury risk *via* similar protective mechanisms<sup>[71]</sup>.

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## CONCLUSION

The basic approach in ACL rehabilitation is to ensure a return to sports activities at the 6<sup>th</sup> mo postoperatively. However, many studies have been and will be conducted with the purpose of shortening this period for all rehabilitation modalities. The objective is to find the optimal strengthening and maximal safe loading times and type of loading for all rehabilitation modalities without creating ACL re-injury. Although there are many studies in the literature on ACL rehabilitation that have not been mentioned in this review, they did not result in the setting of definite and clear criteria and standards, and the reason could be that these have touched upon the mere surface of the topic. As new studies are underway with the advancement of technology we hope to find out how modalities used in ACL rehabilitation affect genetic and biochemical pathways. Today postoperative ACL rehabilitation guidelines are time-focused. This approach makes implementation of the program easier, but does not cover all cases. Rehabilitation varies and should vary from person to person, so it would not be wrong to assume that future ACL rehabilitation guidelines will focus on rehabilitation techniques instead of time. I believe that, with the emergence of criteria-based guidelines, standardization will come.

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