Vorderen Kreuzbandriss; operieren oder nicht ?

Gehe nach <https://www.ncbi.nlm.nih.gov/pubmed>

Gebe acl Anterior cruciate Ligament (vorderes Kreuzband) ein und klicke links auf review oder last 5 years

[J Knee Surg.](https://www.ncbi.nlm.nih.gov/pubmed/25438034) 2016 Jan;29(1):74-9. doi: 10.1055/s-0034-1396017. Epub 2014 Dec 1.

**Is Anterior Cruciate Reconstruction Superior to Conservative Treatment?**

[Dawson AG](https://www.ncbi.nlm.nih.gov/pubmed/?term=Dawson%20AG%5BAuthor%5D&cauthor=true&cauthor_uid=25438034)1, [Hutchison JD](https://www.ncbi.nlm.nih.gov/pubmed/?term=Hutchison%20JD%5BAuthor%5D&cauthor=true&cauthor_uid=25438034)2, [Sutherland AG](https://www.ncbi.nlm.nih.gov/pubmed/?term=Sutherland%20AG%5BAuthor%5D&cauthor=true&cauthor_uid=25438034)3.

[**Author information**](https://www.ncbi.nlm.nih.gov/pubmed/25438034)

**Abstract**

Not all patients who have a rupture of the anterior cruciate ligament (ACL) elect to have surgical reconstruction. The aim of this study was to assess the short-to-medium-term results of patients who chose conservative management in comparison to patients who had reconstructive surgery within the same time period. Sixty-three patients with an ACL injury were retrospectively studied. Forty patients were managed, according to patient choice, with ACL reconstruction and 23 conservatively. Four validated questionnaires were used to assess general and knee-specific function in a cohort with a median age of 32 years and a median follow-up period of 38 months. Patients were matched on demographic variables except for gender. There were no statistically significant differences in the outcome measures, and the majority of patients would proceed with the same treatment in the event the control leg became injured. Patients who elect to have conservative management of an ACL rupture can achieve similar function and satisfaction to those who elect to have reconstruction. Until a large randomized controlled trial is conducted, patients need to be made aware of the merits of both management strategies and the lack of evidence of superiority of one over the other.

 2016 Apr 3;4:CD011166. doi: 10.1002/14651858.CD011166.pub2.

**Surgical versus conservative interventions for treating anterior cruciate ligamentinjuries.**

[Monk AP](https://www.ncbi.nlm.nih.gov/pubmed/?term=Monk%20AP%5BAuthor%5D&cauthor=true&cauthor_uid=27039329)1, [Davies LJ](https://www.ncbi.nlm.nih.gov/pubmed/?term=Davies%20LJ%5BAuthor%5D&cauthor=true&cauthor_uid=27039329), [Hopewell S](https://www.ncbi.nlm.nih.gov/pubmed/?term=Hopewell%20S%5BAuthor%5D&cauthor=true&cauthor_uid=27039329), [Harris K](https://www.ncbi.nlm.nih.gov/pubmed/?term=Harris%20K%5BAuthor%5D&cauthor=true&cauthor_uid=27039329), [Beard DJ](https://www.ncbi.nlm.nih.gov/pubmed/?term=Beard%20DJ%5BAuthor%5D&cauthor=true&cauthor_uid=27039329), [Price AJ](https://www.ncbi.nlm.nih.gov/pubmed/?term=Price%20AJ%5BAuthor%5D&cauthor=true&cauthor_uid=27039329).

[**Author information**](https://www.ncbi.nlm.nih.gov/pubmed/27039329)

**Abstract**

**BACKGROUND:**

Rupture of the anterior cruciate ligament (ACL) is a common injury, mainly affecting young, physically active individuals. The injury is characterised by joint instability, leading to decreased activity, which can lead to poor knee-related quality of life. It is also associated with increased risk of secondary osteoarthritis of the knee. It is unclear whether stabilising the knee surgically via ACL reconstruction produces a better overall outcome than non-surgical (conservative) treatment.

**MAIN RESULTS:**

We identified one study in which 141 young, active adults with acute ACL injury were randomised to either ACL reconstruction followed by structured rehabilitation (results reported for 62 participants) or conservative treatment comprising structured rehabilitation alone (results reported for 59 participants). Built into the study design was a formal option for subsequent (delayed) ACL reconstruction in the conservative treatment group, if the participant requested surgery and met pre-specified criteria.This study was deemed at low risk of selection and reporting biases, at high risk of performance and detection biases because of the lack of blinding and at unclear risk of attrition bias because of an imbalance in the post-randomisation exclusions. According to GRADE methodology, the overall quality of the evidence was low across different outcomes.This study identified no difference in subjective knee score (measured using the average score on four of the five sub-scales of the KOOS score (range from 0 (extreme symptoms) to 100 (no symptoms)) between ACL reconstruction and conservative treatment at two years (difference in KOOS-4 change from baseline scores: MD -0.20, 95% confidence interval (CI) -6.78 to 6.38; N = 121 participants; low-quality evidence), or at five years (difference in KOOS-4 final scores: MD -2.0, 95% CI -8.27 to 4.27; N = 120 participants; low-quality evidence). The total number of participants incurring one or more complications in each group was not reported; serious events reported in the surgery group were predominantly surgery-related, while those in conservative treatment group were predominantly knee instability. There were also incomplete data for total participants with treatment failure, including subsequent surgery. In the surgical group at two years, there was low-quality evidence of far fewer ACL-related treatment failures, when defined as either graft rupture or subsequent ACL reconstruction. This result is dominated by the uptake by 39% (23/59) of the participants in the conservative treatment group of ACL reconstruction for knee instability at two years and by 51% (30/59) of the participants at five years. There was low-quality evidence of little difference between the two groups in participants who had undergone meniscal surgery at anytime up to five years. There was low-quality evidence of no clinically important between-group differences in SF-36 physical component scores at two years. There was low-quality evidence of a higher return to the same or greater level of sport activity at two years in the ACLreconstruction group, but the wide 95% CI also included the potential for a higher return in the conservative treatment group. Based on an illustrative return to sport activities of 382 per 1000 conservatively treated patients, this amounts to an extra 84 returns per 1000 ACL-reconstruction patients (95% CI 84 fewer to 348 more). There was very low-quality evidence of a higher incidence of radiographically-detected osteoarthritis in the surgery group (19/58 (35%) versus 10/55 (18%)).

**AUTHORS' CONCLUSIONS:**

For adults with acute ACL injuries, we found low-quality evidence that there was no difference between surgical management (ACL reconstruction followed by structured rehabilitation) and conservative treatment (structured rehabilitation only) in patient-reported outcomes of knee function at two and five years after injury. However, these findings need to be viewed in the context that many participants with anACL rupture remained symptomatic following rehabilitation and later opted for ACL reconstruction surgery. Further research, including the

**An evidence-based review of hip-focused neuromuscular exercise interventions to address dynamic lower extremity valgus**

[Kevin R Ford](https://www.ncbi.nlm.nih.gov/pubmed/?term=Ford%20KR%5BAuthor%5D&cauthor=true&cauthor_uid=26346471),1 [Anh-Dung Nguyen](https://www.ncbi.nlm.nih.gov/pubmed/?term=Nguyen%20AD%5BAuthor%5D&cauthor=true&cauthor_uid=26346471),2 [Steven L Dischiavi](https://www.ncbi.nlm.nih.gov/pubmed/?term=Dischiavi%20SL%5BAuthor%5D&cauthor=true&cauthor_uid=26346471),1 [Eric J Hegedus](https://www.ncbi.nlm.nih.gov/pubmed/?term=Hegedus%20EJ%5BAuthor%5D&cauthor=true&cauthor_uid=26346471),1 [Emma F Zuk](https://www.ncbi.nlm.nih.gov/pubmed/?term=Zuk%20EF%5BAuthor%5D&cauthor=true&cauthor_uid=26346471),2and [Jeffrey B Taylor](https://www.ncbi.nlm.nih.gov/pubmed/?term=Taylor%20JB%5BAuthor%5D&cauthor=true&cauthor_uid=26346471)1

**Introduction**

Hip-focused neuromuscular exercise interventions have gained considerable attention for addressing a myriad of lower extremity injuries. Most notably, anterior cruciate ligament (ACL) ruptures and patellofemoral pain (PFP) are two knee pathologies that may benefit from improved proximal strength and neuromuscular control strategies.[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b1-oajsm-6-291) Deficits in proximal hip strength or neuromuscular control may lead to dynamic lower extremity valgus.[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b2-oajsm-6-291) Dynamic lower extremity valgus is operationally defined as a combination of motions and rotations in the lower extremity, including hip adduction and internal rotation, knee abduction, tibial external rotation and anterior translation, and ankle eversion.[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b3-oajsm-6-291)During sport movements, dynamic lower extremity valgus often presents as a knocked-knee posture during deceleration during double leg and single leg tasks ([Figure 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f1-oajsm-6-291/)). Importantly, knee abduction moment, which directly contributes to dynamic lower extremity valgus, was a significant predictor for future ACL injury risk with 73% sensitivity and 78% specificity in a prospective study of young female athletes.[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b2-oajsm-6-291) Frontal plane knee motion was predictive, along with hip internal/external rotation moment, of second ACL injury risk in young athletes who returned to their previous sport following reconstructive surgery and rehabilitation.[4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b4-oajsm-6-291) Additionally, a recent investigation identified that high knee abduction moment was predictive of both PFP and ACL injury risk in young female athletes.[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b5-oajsm-6-291)



[Figure 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f1-oajsm-6-291/)

Dynamic lower extremity valgus.

Sex differences in the incidence of both PFP and non-contact ACL injury have led to a plethora of comparisons between males and females, indicating that the higher incidence of these two pathologies in females may be due to faulty lower extremity biomechanics and hip weakness. Biomechanically, it has been widely reported that females exhibit increased lower extremity valgus alignment and load compared with males during landing and pivoting movements,[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b6-oajsm-6-291)–[18](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b18-oajsm-6-291) which was confirmed in a recent systematic review that consistently identified that females land with increased knee abduction across a variety of landing conditions.[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b19-oajsm-6-291) Similar lower extremity valgus alignments are often demonstrated by females at the time of ACL injury.[20](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b20-oajsm-6-291)–[22](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b22-oajsm-6-291)

Additionally, males have longitudinal increases in hip strength during adolescent growth compared with no strength changes in females.[23](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b23-oajsm-6-291) The result of these sex differences following growth and development is that males have greater overall hip strength compared with females.[23](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b23-oajsm-6-291) This strength difference aligns with the divergent sex-specific patterns of ACL and patellofemoral joint injury rates. Competitive, collegiate male cross-country runners exhibit significantly greater hip extension and abduction strength measured isokinetically compared with female runners.[24](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b24-oajsm-6-291) Additionally, runners with lower hip abductor and hip extensor strength exhibit greater frontal plane and transverse plane hip motion.[25](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b25-oajsm-6-291) A systematic review that investigated hip strength in patients with PFP found strong evidence that hip abduction, external rotation, and extension strength were decreased compared with uninjured control subjects.[26](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b26-oajsm-6-291) Conflicting data exist on the specific movement patterns that may be present in patients with active PFP; however, the inability to eccentrically control hip adduction and internal rotation may lead to greater dynamic lower extremity valgus commonly seen during landing, squatting, and running.[27](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b27-oajsm-6-291),[28](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b28-oajsm-6-291)

Altered neuromuscular control strategies during landing may be a potential factor related to lower extremity and ACL injuries in women athletes.[29](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b29-oajsm-6-291),[30](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b30-oajsm-6-291) In a study of 315 young athletes, males had greater hip flexion at initial contact and greater hip extensor moment compared with females.[31](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b31-oajsm-6-291) There was also significant preference to underutilize the hip compared with the knee extensors in females, which indicates a sex-specific hip strategy during drop vertical jumps. Decker et al[32](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b32-oajsm-6-291)showed a decrease in negative joint work (decreased eccentric muscle contraction to absorb landing forces) at the hip in females compared with males during landing. Similarly, ACL reconstructed patients had greater hip moments during the stance phase of gait that may provide increased protection for the ACL.[33](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b33-oajsm-6-291) Patients with patellar tendinopathy also displayed increased hip joint moments during hopping compared with controls.[34](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b34-oajsm-6-291) Proximal mechanisms may play a significant role in neuromuscular control strategies for controlling and compensating for knee loading during a myriad of complex movements. Neuromuscular training positively alters hip kinematics and kinetics.[35](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b35-oajsm-6-291) Lephart et al[35](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b35-oajsm-6-291) found increased hip flexion at initial contact and increased peak internal hip extensor moment following a plyometric training protocol. These authors suggested that the modifications at the hip likely increase the hamstring forces that protect the ACL.[35](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b35-oajsm-6-291) Hip posture may play an important role in the mechanical efficiency of hamstrings in relation to quadriceps.[36](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b36-oajsm-6-291)

Clearly, the hip plays a central role in dynamic lower extremity valgus. The purpose of the clinically related narrative, aimed at sports medicine clinicians, was to identify and discuss hip-focused exercise interventions that aim to address dynamic lower extremity valgus. Specifically, hip muscle activation, strength, and biomechanical outcomes are presented. Furthermore, we discuss practical applications that may be utilized both clinically and in future randomized controlled trials.

**Functional anatomy**

Since strength, activation, and control of the hip play a critical role in dynamic valgus, understanding the functional anatomy of the hip is foundational in developing any successful intervention program. The gluteus medius is the primary abductor of the hip[37](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b37-oajsm-6-291)–[39](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b39-oajsm-6-291) and receives assistance in abduction from the gluteus minimus and the piriformis. The proximal attachment of gluteus medius is along the outer edge of the iliac crest and is fan-shaped, spanning the iliac crest from the anterior superior iliac spine to the posterior superior iliac spine. The muscle tapers into a strong tendon and attaches distally on the posterosuperior portion of the greater trochanter.[40](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b40-oajsm-6-291) The gluteus medius is specifically defined by three parts, anterior, middle, and posterior, that are approximately equal in volume. The anterior and middle fibers run almost vertical while the posterior fibers run horizontal and almost parallel to the neck of the femur.[41](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b41-oajsm-6-291) Using fine wire electromyography (EMG), the three segments of the gluteus medius have been found to function in a phasic pattern during submaximal functional activities such as walking, but were found to activate (both onset and duration) more simultaneously during maximal levels of activity such as the support phases of descending stairs.[42](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b42-oajsm-6-291),[43](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b43-oajsm-6-291)

The gluteus maximus is the largest muscle in the gluteal region and one of the largest muscles in the body.[37](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b37-oajsm-6-291) The proximal attachments of the gluteus maximus are along the posterior gluteal line of the ilium, dorsal surface of the sacrum and coccyx, and the sacrotuberous ligament. It slopes inferolaterally at a 45° angle across the ischial tuberosity and attaches distally into the superficial fibers of the iliotibial tract and the gluteal tuberosity of the femur.[37](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b37-oajsm-6-291),[44](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b44-oajsm-6-291) While the gluteus medius is the primary abductor of the hip, the gluteus maximus functions primarily as an extensor but also as an external rotator of the hip, allowing the gluteus maximus to control motions in the sagittal and transverse planes.[37](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b37-oajsm-6-291)

Proper functioning of the posterolateral hip musculature during single limb weight bearing is essential to providing proximal stability for lower extremity motion. Specifically, the roles of these muscles are to stabilize the pelvis in the frontal and transverse planes to maintain a level pelvis and control rotation at the hip.[37](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b37-oajsm-6-291)–[39](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b39-oajsm-6-291),[41](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b41-oajsm-6-291),[43](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b43-oajsm-6-291),[45](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b45-oajsm-6-291),[46](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b46-oajsm-6-291) In the frontal plane, the hip abductors must produce a large abduction torque to counteract the adduction torque produced from the product of body weight and its larger external moment arm acting at the hip.[47](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b47-oajsm-6-291) Failure to produce the abduction force is observed as a Trendelenburg posture, with the contralateral pelvis dropping.[47](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b47-oajsm-6-291) The important role of the hip abductors in stabilizing the pelvis during single limb function is further illustrated during the midstance phase of gait where activation and force production of the abductors have been observed to be the greatest.[48](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b48-oajsm-6-291),[49](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b49-oajsm-6-291) In the transverse plane, the abductors and external rotators work together to control hip and pelvis motion.[45](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b45-oajsm-6-291),[46](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b46-oajsm-6-291) Hence, weakness or inefficiency of the posterolateral hip musculature would decrease stability of the hip when loaded in a single limb weight-bearing stance, resulting in an inability to maintain a neutral alignment of the hip and knee. Therefore, much attention has been directed at correcting or improving hip strength or activation and its role in controlling dynamic lower extremity valgus.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/)

**Muscular activation with hip-focused exercises**

Hip muscle activation, particularly of the gluteus medius and gluteus maximus, have been examined across a variety of exercises commonly used during interventions. EMG is commonly used to quantify the motor-unit activity in a muscle or muscle group during intervention exercises and is reported as the percentage of a maximal voluntary isometric contraction (% MVIC). A greater level of muscle activity has been assumed to lead to muscle strengthening effects. It has been suggested that muscle activation during an exercise should reach a minimum of 40%–60% MVIC in order to achieve strength gains.[50](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b50-oajsm-6-291) This has led to a myriad of studies that have compared muscle activity during exercises. This section summarizes the observed gluteus maximus and gluteus medius muscle activation during non-weight-bearing, controlled weight-bearing, and functional exercises. The effects of common modifications to these exercises on hip muscle activation are also discussed.

**Non-weight-bearing exercises**

Non-weight-bearing hip exercises are often initiated to target a specific muscle group in isolation, or during the beginning stages of rehabilitation. Common exercises that have been suggested to target the gluteus medius include side-lying hip abduction, clam-shell exercises, and bridging exercises. Side-lying hip abduction ([Figure 2A](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f2-oajsm-6-291/)) is one of the most consistently reported exercises in the literature. Activation of the gluteus medius during this exercise have been reported to range from 23% to 81% MVIC.[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b51-oajsm-6-291)–[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b55-oajsm-6-291) The side-lying hip abduction exercise was observed to have 16%–43% greater gluteus medius activation in studies[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b51-oajsm-6-291),[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b53-oajsm-6-291)when compared with the clam-shell exercise, where the hip is abducted while keeping the feet together, with the hip and knees flexed ([Figure 2B](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f2-oajsm-6-291/)). This is supported biomechanically as the external hip adduction moment would be greater with the hip and knee extended compared with a flexed position. When comparing gluteus medius activation between side-lying hip abduction exercise and a unilateral supine bridge exercise ([Figure 2C](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f2-oajsm-6-291/)), the reports are somewhat conflicting. Two studies[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b53-oajsm-6-291),[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b54-oajsm-6-291) observed 8%–13% less gluteus medius activation during the unilateral supine bridge exercise, whereas one study[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b55-oajsm-6-291) observed an 8% greater gluteus medius activation during the side-lying hip abduction. The reasons for these conflicting findings are unknown.



[Figure 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f2-oajsm-6-291/)

Common non-weight-bearing exercises.

While the side-lying hip abduction exercise appears to effectively activate the gluteus medius, the side-bridge (plank) exercise has been shown to require greater activation of this muscle. The side-bridge exercise ([Figure 2D](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f2-oajsm-6-291/)) is performed in a side-lying position with the trunk supported by the upper extremity. The exercise is performed by lifting the hip off the ground while maintain a neutral alignment of the trunk, hips, and knees. The side-bridge has been observed to require 35%–40% greater activation than the side-lying hip abduction exercise.[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b53-oajsm-6-291),[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b55-oajsm-6-291) The greater activation during the side-bridge is likely due to the increased demand of the gluteus medius to abduct the hip by lifting the body’s mass and the need to stabilize the pelvis in the sagittal plane.

Common non-weight-bearing exercises to target the gluteus maximus are supine bridging exercises where hip extension is performed by lifting the body’s mass. Gluteus maximus activation have been observed to range between 17% and 25% MVIC during a bilateral supine exercise and between 35% and 54% MVIC during a unilateral supine bridging exercise.[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b53-oajsm-6-291)–[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b55-oajsm-6-291) The magnitudes of gluteus maximus activation during these bridging exercises are similar compared with the simplest non-weight-bearing exercise with individuals extending the hip against gravity. This is commonly done in a quadruped position and extending the hip while the knee is flexed. Direct comparison between the quadruped hip extension and unilateral bridging exercises reveals an approximately 5% difference in glu-teus maximus activation.[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b53-oajsm-6-291),[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b54-oajsm-6-291) However, the observed gluteus maximus activation during these exercises may be misleading and not result in strength gains, because there is evidence to suggest that simply contracting the gluteal muscles in a standing position activates the gluteus maximus 20% more than performing a unilateral bridging exercise.

**Controlled weight-bearing exercises**

As previously mentioned, the hip abductors must produce a large abduction torque to counteract the adduction torque produced from the product of the body weight and its larger external moment arm acting at the hip to stabilize the pelvis during single limb activities.[48](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b48-oajsm-6-291),[49](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b49-oajsm-6-291) Controlled weight-bearing exercises commonly used to target the gluteus medius include hip hikes (pelvic drops), single limb squats ([Figure 3A](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f3-oajsm-6-291/)), and lateral step-ups ([Figure 3B](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f3-oajsm-6-291/)). Activation of the gluteus medius during these exercises has been reported to range between 38% and 58% MVIC for hip hikes, 38% and 60% MVIC for lateral step-ups, and 48% and 82% MVIC for single limb squats.[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b51-oajsm-6-291)–[57](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b57-oajsm-6-291) Only one study was found that examined differences across all three exercises, and it reported a 22% and 24% greater activation of the gluteus medius during a single limb squat exercise compared with a lateral step-up and hip hike exercise, respectively.[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b53-oajsm-6-291) Collectively, these findings suggest that there is a negligible difference between the hip hike and lateral step-up exercises. However, it appears that there is a meaningful increase in the demand of the gluteus medius during a single limb squat.



[Figure 3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f3-oajsm-6-291/)

Common controlled weight-bearing exercises.

Single limb squat, step-up (lateral and forward, [Figure 3C](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f3-oajsm-6-291/)), and single limb dead lift ([Figure 3D](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f3-oajsm-6-291/)) exercises are controlled weight-bearing exercises that are commonly used to target the gluteus maximus. Activation of the gluteus maximus during these exercises has been reported to range between 41% and 71% MVIC for single limb squats, 29% and 64% MVIC for lateral step-ups, 23% and 74% MVIC for forward step-ups, and 59% MVIC for single limb dead lifts.[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b51-oajsm-6-291),[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b53-oajsm-6-291)–[57](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b57-oajsm-6-291)Differences in gluteus maximus activation between the forward and lateral step-up exercises are conflicting, with one study[56](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b56-oajsm-6-291) reporting an 18% increase and another study[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b53-oajsm-6-291) reporting a 9% decrease in gluteus maximus activation during the forward versus the lateral step-up exercise. There is also conflicting evidence when comparing single limb squat and the single limb dead lift exercises, with one study[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b51-oajsm-6-291) reporting no difference and another study[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b53-oajsm-6-291) reporting a 12% greater gluteus maximus activation during the squat exercise. There is consistent evidence suggesting that there is a 7%–16% increase in gluteus maximus during the single limb squat compared with the forward step-up exercise.[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b53-oajsm-6-291),[57](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b57-oajsm-6-291) Only one study[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b53-oajsm-6-291)was found that examined gluteus maximus activation across all four exercises, and it reported a high level of activation during all controlled weight-bearing exercises, with the greatest activation observed during the single limb squat.

**Functional exercises**

Increasing the complexity of exercises that continue to target the gluteal muscles in a more dynamic and functional movement pattern is a necessary component for an intervention program. Functional exercises commonly used to target the gluteus medius and gluteus maximus include lateral band walks ([Figure 4A](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f4-oajsm-6-291/)), side lunges ([Figure 4B](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f4-oajsm-6-291/)), forward lunges ([Figure 4C](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f4-oajsm-6-291/)), and rear lunges ([Figure 4D](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f4-oajsm-6-291/)). There are limited studies that have examined activation of the gluteal muscles during these exercises. Gluteus medius activation during these exercises have been reported to be 30%–61% MVIC for lateral band walks, 39% MVIC for side lunges, and 19%–42% MVIC for forward lunges. Gluteus maximus activation during these exercises have been reported to be 27%–28% MVIC for lateral band walks, 41% MVIC for side lunges, and 20%–44% MVIC for forward lunges.[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b51-oajsm-6-291),[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b54-oajsm-6-291),[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b55-oajsm-6-291) Only one study[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b51-oajsm-6-291)was found that compared the gluteal muscle activation across all three exercises. A comparison of gluteus medius activation between the functional exercises reported a 22%–25% greater activation of the gluteus medius during the lateral band walk compared with the lunge exercises while there was negligible difference between the lunge exercises. A comparison of gluteus maximus activation showed a negligible difference between the forward and side lunge exercises, but there was 14%–17% greater gluteus maximus activation compared with the lateral band walks. These findings are not unexpected, as the lunge exercises require greater hip dynamic flexion that would increase the demand on the gluteus maximus.



[Figure 4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f4-oajsm-6-291/)

Common functional exercises.

Plyometric (ballistic) exercises are often used in injury prevention settings or during the latter stages of rehabilitation. Plyometric exercise has been previously operationally defined as an “… activity that involves and capitalizes on the mechanisms of the stretch-shortening cycle to increase the efficiency of force production at a joint or increase performance”.[58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b58-oajsm-6-291) A number of papers provide detailed exercise descriptions and progressions.[58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b58-oajsm-6-291)–[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b61-oajsm-6-291) These exercises are important to assess readiness for return to play, but may also provide therapeutic benefit by preferentially recruiting the gluteus medius and maximus musculature. Gluteus medius muscle activity is highest during single-limb sagittal plane hurdle hops (100% MVIC), double-limb sagittal plane hurdle hops (61% MVIC), and split squat jumps (62% MVIC), with lesser activation during non-sagittal plane double-limb landings in the frontal (40% MVIC) and transverse (47% MVIC) planes.[62](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b62-oajsm-6-291) Similarly, the gluteus maximus is most highly activated during double-limb (63% MVIC) and single-limb (69.4% MVIC) sagittal plane landings, and less active in other planes (<40% MVIC).[62](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b62-oajsm-6-291) Of note, these results are during a land, and do not incorporate a subsequent jump which is common during plyometric activities. True plyometric activities, including a rapid change of direction, elicit significantly higher muscle activation (150%–190% MVIC) than isolated landings or controlled exercises.[63](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b63-oajsm-6-291) Continued work is needed to explore gluteal activation patterns during other commonly used functional exercises.

**Influence of exercise modification on gluteal activation**

During non-weight-bearing exercises, limb position, and joint angle can directly influence the activation of the gluteal muscles. Specifically, there is evidence to suggest that rotation at the hip during the side-lying hip abduction exercise can directly influence the magnitude of gluteus medius activation.[64](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b64-oajsm-6-291) It was reported that activation of the gluteus medius during the side-lying hip abduction exercise was 16% greater with the hip internally rotated than with the hip in neutral. In addition, gluteus maximus activation can be directly influenced by the position of the hip in the sagittal plane during non-weight-bearing hip extension exercises.[65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b65-oajsm-6-291)There is evidence to suggest that activation of the gluteus maximus is 12%–14% greater at 30–60 degrees of hip flexion compared with 90 degrees of hip flexion. Collectively, these data suggest that activation of the gluteal muscles is dependent on the length-tension curve where the gluteal muscles may have the greatest activation when they are close to their ideal length. These conclusions are based on hip muscle activation during isometric contractions. Additional work is needed to examine these relationships during isotonic exercises typically used in intervention programs.

The position of the trunk during controlled weight-bearing and functional exercises has been suggested to influence the demands on the hip muscles. Powers[66](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b66-oajsm-6-291) discusses this relationship where trunk position, either in the sagittal or frontal plane, that moves the body center of mass (and resultant ground reaction force vector) away from the hip joint will increase the demand placed on the hip muscles. This theory has been supported by empirical evidence that reports greater hip muscle activation during jumping and running tasks with the trunk in a more flexed position.[67](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b67-oajsm-6-291),[68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b68-oajsm-6-291) There are limited studies that have examined the role of the trunk during weight-bearing and/or functional exercises commonly used in intervention programs. Only one study could be found that examined the influence of sagittal plane trunk position on gluteus maximus activation during a forward lunge.[69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b69-oajsm-6-291) The authors reported that there was a 6% increase in gluteus maximus activation during a forward lunge with the trunk forward compared with the trunk in an erect position. Further research is needed to clarify the effects of modifications of exercises on hip muscle activation.

**Biomechanical and strength outcomes with hip-focused interventions**

A number of recent studies have examined the effects of hip-focused intervention programs on multi-planar hip strength and lower extremity biomechanical measures of dynamic lower extremity valgus ([Table 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/table/t1-oajsm-6-291/)).[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b70-oajsm-6-291)–[80](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b80-oajsm-6-291) These programs have been wide-ranging in their implementation, based largely on the population targeted or stage in the rehabilitation process. Hip-focused interventions have been used in healthy athletes for knee injury prevention strategies,[77](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b77-oajsm-6-291) and in those diagnosed with PFP.[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b70-oajsm-6-291),[72](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b72-oajsm-6-291),[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b74-oajsm-6-291),[75](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b75-oajsm-6-291) The duration and volume of hip-focused programs have also varied considerably, with all programs occurring two to three times per week, but ranging from 4 to 12 weeks in duration.[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b70-oajsm-6-291)–[76](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b76-oajsm-6-291)



[Table 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/table/t1-oajsm-6-291/)

Components, strength, and biomechanical outcomes of hip-focused intervention programs

Because of the heterogeneity in populations and stages of rehabilitation, the exercises used to target the hip have also been variable. Some programs have focused strictly on isolated non-weight-bearing hip exercises,[72](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b72-oajsm-6-291),[75](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b75-oajsm-6-291) while others have used a combination of non-weight-bearing and weight-bearing/functional exercises focused either in one (sagittal) or multiple (frontal and transverse) planes.[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b74-oajsm-6-291),[76](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b76-oajsm-6-291),[78](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b78-oajsm-6-291),[79](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b79-oajsm-6-291) Although all programs were varied, common exercises were used between research groups. Side-lying hip abduction, prone hip extension, clam-shells (resisted), and seated hip external rotation were common non-weight-bearing exercises used in hip focused interventions. Weight-bearing exercises, including single limb squats and deadlifts, lunges, forward and lateral step-ups, and resisted hip external rotation are also prevalent amongst hip-focused programs. Additionally, some programs have included trunk strengthening as part of their hip-focused intervention, using standard exercises such as planks or incorporating an unstable support surface (eg, BOSU balance trainer) to encourage trunk activation and stabilization,[71](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b71-oajsm-6-291),[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b74-oajsm-6-291),[77](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b77-oajsm-6-291) while other programs have focused on the latter stages of rehabilitation by including plyometric activities in addition to standard strengthening techniques.[71](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b71-oajsm-6-291),[77](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b77-oajsm-6-291)

Although the implementation methods of hip-focused intervention programs have been variable, these programs consistently produce improved measures of hip extension, abduction, and external rotation strength ([Table 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/table/t1-oajsm-6-291/)). Strength gains of 7%–42% in hip abduction,[22](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b22-oajsm-6-291),[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b70-oajsm-6-291)–[72](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b72-oajsm-6-291),[75](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b75-oajsm-6-291),[77](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b77-oajsm-6-291)–[80](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b80-oajsm-6-291) 6%–56% in hip external rotation,[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b70-oajsm-6-291),[72](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b72-oajsm-6-291),[75](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b75-oajsm-6-291),[78](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b78-oajsm-6-291)–[80](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b80-oajsm-6-291) and 8% in hip extension[71](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b71-oajsm-6-291) have been previously reported. However, these strength gains need to be interpreted cautiously. Although no previous studies have reported a significant reduction in hip strength, not all studies have reported statistically significant improvements in strength after hip-focused interventions[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b74-oajsm-6-291),[80](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b80-oajsm-6-291) which may be due to differences in the components, duration, and intensity of the programs, or the variability in the methodology of strength assessment, such as instrumentation (isokinetic versus handheld dynamometer), type of contraction (eccentric versus concentric versus isometric), and patient position (open versus closed chain). The largest gains in strength have typically been found in isometric strength, although we contend that eccentric strength may be of the most importance in controlling dynamic lower extremity valgus during jumping or cutting. Past research on the role of hip-focused interventions resulting in improved eccentric hip strength has been limited,[72](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b72-oajsm-6-291),[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b74-oajsm-6-291),[79](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b79-oajsm-6-291) and no studies have examined eccentric strength of the gluteus maximus or the combination of the three cardinal planes of hip motion.

More importantly, strength gains resulting from hip-focused interventions have translated to improved bio-mechanics at the hip and knee during athletic activities ([Table 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/table/t1-oajsm-6-291/)). Previous studies report greater peak hip flexion during a jump landing[71](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b71-oajsm-6-291)and less hip adduction and internal rotation, ipsilateral trunk inclination, and contralateral pelvis depression during a single leg squat,[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b74-oajsm-6-291) despite only modest gains in hip strength. At the knee, hip-focused interventions may result in lower levels of knee adduction moments during running,[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b70-oajsm-6-291) and lower knee-hip extensor moment ratios and peak knee abduction angles and moments during jump landings,[71](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b71-oajsm-6-291) although other studies have found no specific bio-mechanical changes at the knee.[76](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b76-oajsm-6-291) Examining previous programs that have documented biomechanical outcomes after training, hip-focused interventions that include closed chain activities and trunk stabilization appear to make the largest positive impact on distal biomechanics.[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b70-oajsm-6-291),[71](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b71-oajsm-6-291),[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b74-oajsm-6-291) Considering the demands on the gluteus maximus during closed chain and ballistic exercises in the frontal and transverse planes and the limited research on the biomechanical effects of these exercises, further research to optimize the effects of hip-focused intervention is warranted.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/)

**Practical application and conclusion**

Attention should be devoted to developing evidence to support progression of exercises with varying bases of support ([Figure 5A](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f5-oajsm-6-291/)), sports-related tasks with external load ([Figure 5B](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f5-oajsm-6-291/)), and resisted bands ([Figure 5C and D](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f5-oajsm-6-291/)). For instance, the resisted vertical bridge ([Figure 5D](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f5-oajsm-6-291/)) is a potential progression from the supine bilateral bridge with the ability to add changes in resistance in a vertical posture. The upright position transitions from the bridge to a closed kinetic chain posture as the femur loads into the acetabulum, which could be considered a more functional position in relation to human movement. The vertical bridge also allows the opportunity to engage the free upper extremities into other more “functional activities” that can promote perturbations to the trunk, ultimately engaging more core musculature than the isolated nature of the supine bridge.



[Figure 5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f5-oajsm-6-291/)

Late stage hip-focused exercises.

There may be a tendency to assume a linear relationship between improved strength, improved biomechanical variables in a sports-related task like jumping or landing, and improved biomechanical variables in the performance of the actual sport or activity. As this review has demonstrated, hip-focused exercises generally increase EMG activity, and increased EMG activity generally results in improved strength, which further results in improved task-related biomechanics. However, improved strength does not always result in changes to important biomechanical variables,[81](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b81-oajsm-6-291) and improved biomechanics in sports-related tasks does not necessarily equal improved biomechanical variables in performance of the sport itself.[80](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b80-oajsm-6-291) Controlling dynamic lower extremity valgus is complex ([Figure 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f1-oajsm-6-291/)) and likely involves a combination of strengthening and activation exercises and motor control of the hip, as well as use of feedback to facilitate integration into higher level activities.[82](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b82-oajsm-6-291)–[87](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b87-oajsm-6-291) Even with the addition of feedback, hip-targeted strengthening alone is not the answer. Dynamic lower extremity valgus and hip muscle inhibition is likely influenced by pain or inflammation,[88](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b88-oajsm-6-291) body structure,[89](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b89-oajsm-6-291),[90](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b90-oajsm-6-291) fatigue,[91](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b91-oajsm-6-291)–[94](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b94-oajsm-6-291) pubertal age and maturation,[9](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b9-oajsm-6-291),[31](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b31-oajsm-6-291),[95](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b95-oajsm-6-291) fear and other psychosocial variables,[96](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b96-oajsm-6-291)–[98](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b98-oajsm-6-291) and prior injury.[99](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/#b99-oajsm-6-291),[100](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/%22%20%5Cl%20%22b100-oajsm-6-291) With the evidence and these variables in mind, a focus on strengthening the hip to control dynamic valgus is a great start for many reasons, including that it helps clinicians move away from a local focus to a more regional focus for pathologies at the knee. The next step in the evolution of treating patients with knee pathology is a global focus considering fixed factors like sex and body structure, re-education strategies like modes of feedback, physiological factors like pain, inflammation, and fatigue, and psychosocial factors like fear and anxiety ([Figure 6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f6-oajsm-6-291/)). [Figure 6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f6-oajsm-6-291/) was constructed by the authors, based on the results of this evidenced-based review, to present a theoretical framework of the main steps to consider when initiating hip-focused neuromuscular exercises to modify dynamic lower extremity valgus, in addition to highlighting a few of the multivariate factors that should be considered when implementing hip-focused neuromuscular exercises in order to control dynamic lower extremity valgus. These factors likely play a critical role in the relative success of a program at each step along the continuum from initiating improved hip strength and activation to integrated neuro-muscular control during a variety of movements to the final optimization of safe biomechanics during high-level activities and sports.



[Figure 6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556293/figure/f6-oajsm-6-291/)

Theoretical framework for hip-focused neuromuscular exercises to modify dynamic lower extremity valgus.

This clinical narrative is limited to the current strength of literature that was discussed. The strength and quality of literature is varied, with few randomized controlled trials. Therefore, caution should be used when interpreting results from lower quality and less controlled studies. Additionally, it was out of the scope of the current review to exhaustively cover and address special patient populations and adaptations that should be considered with some of the exercises presented. In summary, the research indicates that hip-focused neuromuscular exercise may be an important component to consider when treating patients with ACL and PFP knee pathologies. Importantly, it also appears that targeting hip musculature activation and strength may aid in modifying dynamic lower extremity valgus, which may help to reduce the risk of future ACL injury and PFP. Research should continue to develop to identify and understand the mechanistic relationship between optimized biomechanics during sports and hip-focused neuromuscular exercise interventions.

**the clinical effectiveness of self-care interventions with an exercise component to manage knee conditions: A systematic review**

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**1. Introduction**

Self-care is a concept widely applied across healthcare and can be broadly defined as “what people do for themselves to establish and maintain physical and emotional health and prevent or deal with minor illness, injury, or chronic conditions”. This incorporates concepts such as exercise, hygiene, nutrition, medication, and environmental and socioeconomic factors [[1]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0005), [[2]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0010). Treatment techniques that have been incorporated into self-care programmes include: collaborative care plans between service users and healthcare professionals; setting goals that are reviewed and modified; helping individuals explore barriers to self-care; aiding people to monitor their symptoms and what action to take; providing advice and education; and coaching and peer support from other service users [[3]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0015),[[4]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0020). For musculoskeletal conditions, self-care programmes have been developed and evaluated for knee osteoarthritis, but their effectiveness is considered limited, due to methodological weaknesses in study designs [[5]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0025), [[6]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0030).

Despite this, current evidence suggests that individuals with knee conditions should be given access to information about their condition and advice on self-management, especially exercise [[6]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0030), [[7]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0035). This poses certain challenges to healthcare professionals that deliver exercise based interventions. Firstly, there is evidence within physiotherapy that information provision and exercise are the most widely used treatment modalities for knee rehabilitation [[8]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0040), but much of the self-care and exercise research has been carried out independent of each other. Therefore, the most successful approaches of combining self-care and exercise are not yet known; it is also not clear whether the same self-care techniques benefit all knee conditions. Secondly, exercise rehabilitation is an effective intervention across all knee conditions, ranging from ruptures of the anterior cruciate ligament to patellofemoral joint pain and post-operative care following knee surgery [[7]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0035). Techniques on exercise prescription and progression are however less well developed for individuals with a knee condition. Finally, when modern technology, such as the Internet, is used to deliver supported self-care programmes, it needs to be clarified how effective it is for individuals with knee conditions.

**3.8. Findings**

Nine studies measured outcome only up to the completion of the intervention, of these six were found to have a statistically significant improvement in outcome in the self-care intervention compared to the control group for WOMAC [[15]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0075), [[19]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0095),[[22]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0110), [[35]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0175), SF-36 [[19]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0095), AIMS/2 [[19]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0095), [[31]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0155) and self-reported physical disability and performance test [[28]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0140). Three studies found no statistically significant difference in primary outcomes compared to the control on completion of the intervention [[23]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0115),[[26]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0130), [[33]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0165) ([Table 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/table/t0005/)).

Four studies that included long-term follow-up beyond the completion of intervention demonstrated statistically significant improvement in the self-care intervention group compared to the controls [[20]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0100), [[27]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0135), [[34]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0170), [[36]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0180). In six studies with long-term follow-up there was no statistically significant difference between the self-care and control groups [[16]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0080), [[21]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0105), [[24]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0120), [[25]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0125), [[30]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0150), [[32]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0160). In one study there was no significant improvement for the primary outcome but there was for exercise health beliefs [[21]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0105). Two studies demonstrated better outcome for self-care at completion of their intervention [[15]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0075), [[31]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0155), but this benefit was not maintained at long-term follow-up [[16]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0080), [[30]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0150).

The data was explored to evaluate if a sub-group analysis could be carried out using pain as an outcome measure across the studies. This evaluation indicated that there was too much heterogeneity (clinical diversity) between the studies based on long and short term clinical effectiveness for types of self-care and exercise interventions, professional delivering and type of control group. Therefore no meta-analysis has been carried out on this data.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/)

**4. Discussion**

This systematic review evaluated the clinical effectiveness of self-care and exercise programmes for individuals with knee conditions. This has been done following the guidance set out in the PRISMA statement. Overall study quality was good, but based on the risk of bias tool there was an ‘unclear’ risk of bias that introduced some weakness in the evidence presented. As expected none of the studies scored well for blinding of participants due to the nature of the interventions.

When self-management and exercise outcome had been assessed at the post-intervention time point, the majority of studies demonstrated that individuals in the self-care and exercise group had a better outcome than controls [[15]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0075), [[18]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0090), [[19]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0095),[[22]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0110), [[28]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0140), [[31]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0155), [[35]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0175). This benefit was not maintained in studies that had a longer time span for follow-up (beyond the intervention), as only four demonstrated a long-term benefit to the patient for self-care and exercise programmes [[20]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0100), [[27]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0135),[[34]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0170), [[36]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0180). This is important because it is the long-term success of an intervention that is important to patients and policy makers. Therefore, based on the findings of this review, there is conflicting evidence regarding the long-term effect of self-care and exercise interventions. It is recommended that in the future all studies include a long-term follow-up beyond completion of the intervention. Some of the differences in outcome between studies may be related to study design and this is discussed in the following sections.

One reason for inconsistent long-term outcome between studies may be related to the type of control group used. Three of the studies with a positive long-term outcome used a control group that was very different from the self-care intervention group, i.e., medication control, electrotherapy, delayed start, and usual care. In these studies it also appeared that individuals in the control group had less contact with the individual delivering the programme. For example, in the study by Yip et al. [[17]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0085) patients in the control group received usual care, but this could have been little or no treatment and therefore no professional contact; unfortunately this was not defined in their publication. On the other hand, the studies that demonstrated no difference in outcome at the end of the intervention in the experimental group compared to the control group/s, often used treatment modalities within the different study arms that were common to the experimental and control arms. For example, in the study by Thomee et al. [[23]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0115), both groups used the same pool of exercises but the self-management intervention had two sessions on self-management. In two other studies there was a distinct self-management and exercise group but both studies contained a further group that was a mixture of both exercise and self-care [[26]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0130), [[33]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0165). This may have made it more difficult to demonstrate a statistically significant difference between the groups because the interventions they received were not sufficiently different to have a treatment effect. These potential confounding factors could have reduced the internal validity of the studies. It is essential in future studies to ensure the treatment content of the control group is sufficiently different to that of the experimental group.

A further factor that explains the varied clinical effectiveness of the self-care programmes is the high level of heterogeneity in the study population, research design, and intervention content. The high level of heterogeneity is the main reason that a meta-analysis had not been carried out. This review specifically included self-care interventions with an exercise component for all knee conditions to evaluate effectiveness of the interventions for enabling recovery and chronic condition prevention, as well as chronic condition management. Despite this, the majority of studies had been carried out using either an osteoarthritis or chronic knee pain population. In addition, within these populations there is a high degree of heterogeneity, especially for osteoarthritis, where it is recognised that there are different stages to the disease [[44]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0220). This means that an early osteoarthritis population is not automatically comparable to late stage osteoarthritis and heterogeneity within the population should be taken into consideration when designing the study. Adopting standardised criteria for the diagnosis of knee osteoarthritis such as that recommended by the American College of Rheumatologists [[45]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0225), [[46]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0230) has not routinely been used but may improve study quality and assessment of participant heterogeneity in the future.

It is evident that there is a wide range of treatment approaches available to support self-care and it needs to be established which components are most beneficial and what is the most effective and efficient manner of delivery. This systematic review can provide some insight into this by analysing in detail the group of studies that had a positive long-term effect beyond completion of the intervention. All of these studies had a well-defined information provision component, but the exercise component was either part of the information and education [[20]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0100), [[34]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0170), or delivered as a practical exercise group [[17]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0085), [[27]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0135). Generally, there was insufficient detail on exercise prescription to be reproducible. One of these studies took self-management beyond information provision and also focused on other practical steps to develop self-management skills, such as goal setting and self-efficacy[[20]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/%22%20%5Cl%20%22bb0100). Recommendations based on this group of studies are that information provision is an essential component, but the best mode of delivery and content could not be specified. Likewise, exercise had been delivered in several ways across these studies, either through practical groups or as part of structured programmes that focus on the development of self-management skills. The optimal method is however yet to be established. Three of these studies did use the same theoretical framework [[17]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0085), [[20]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0100), [[34]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0170), i.e., social and cognitive theory [[47]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0235), to underpin their self-care approach, but there is no gold standard as to what self-management techniques this should include. In addition there is not an underlying framework that cohesively brings together the self-care and exercise components. What is reassuring is that these programmes were delivered with relatively few contacts with a healthcare professional (four to six contacts) and therefore had relatively low use of healthcare resources. This does demonstrate the potential for self-management and exercise programmes to be delivered independently to clinic visits.

A range of healthcare and exercise professionals were involved in delivering treatment across these studies. The studies with the best outcome were not delivered by one specific professional group, therefore which professional delivers the intervention does not appear to be a factor influencing clinical effectiveness. What seems essential is that adequate training is available to ensure that the individual has the skills to ensure delivery on both the self-management and exercise components. Of note, the studies that provided most detail on exercise prescription and progression were delivered by activity trainers and health educators. To improve programme quality, exercise prescription needs to be incorporated into future interventions and be embraced by other professional groups that frequently deliver exercise programmes within healthcare settings. Individuals with knee osteoarthritis, who acknowledge the importance of exercise in their management, have reported concerns over how this should be done long-term [[48]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0240).

Taking into consideration the heterogeneity in populations and different treatment components within the interventions, there is unlikely to be one type of self-management and exercise combination that suits all. There is therefore a need to establish which treatment components are likely to deliver maximum benefit to individual presentations, and future research needs to be directed at phenotyping or stratifying patients accordingly to provide these answers [[44]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0220). In addition further exploratory research is required to understand the patient's perspective on the most effective self-care components and if current methods of delivering exercise meets their needs. This fits in the MRC framework for researching complex interventions[[49]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/%22%20%5Cl%20%22bb0245).

The use of modern technology has not been reported by any of these studies, but using the Internet to deliver self-care programmes has been identified as an approach that warrants further research for healthcare delivery [[50]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0250). For example, online approaches could provide virtual contacts through tele-rehabilitation, better access to up to date information, virtual support groups, notifications and prompts, self-monitoring, and tracking. Several studies have recently been developed in this field, but did not match the inclusion criteria of this systematic review [[51]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0255), [[52]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0260). In addition, technology could facilitate new self-care approaches that incorporate factors that individuals with long-term conditions identify as important. This includes: better support that acknowledges the physical and emotional hard work of self-care, facilitates ongoing care, does not isolate healthcare to one time point, supports individualised strategies, promotes self-efficacy, does not trivialise the condition, provides encouragement and endorsement from clinicians and introduces help to younger populations [[48]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0240), [[53]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0265), [[54]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0270), [[55]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0275).

The patient rated outcome measure most frequently used across the studies was the WOMAC, because this is an osteoarthritis specific tool which measures patient rated changes in symptoms and function, which are generally considered to be the outcomes for arthritis research [[10]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0050). This outcome measure is not transferable to other knee pathology. Interestingly, only two studies included a measure of self-efficacy, this is surprising as this is what self-care interventions target and therefore ability to self-care would be expected to improve when symptoms may not [[56]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0280). These scales [[40]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0200), [[41]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0205) have not undergone full psychometric testing and tend to be condition specific so they do not translate across all knee conditions. Inclusion of a self-efficacy or empowerment outcome measure needs to be considered in future research to allow comparison across studies. As yet no gold standard for use across patient groups can be recommended [[56]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/#bb0280).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4642743/)

**5. Conclusion**

The studies included in this review demonstrated an ‘unclear’ risk of bias and conflicting evidence regarding the long-term effect of self-care and exercise interventions. Nine of the included studies failed to have a long-term follow-up, which threatens the external validity of their findings. The four studies that did demonstrate long-term clinical effectiveness all used an OA population and had a strong focus on information provision, goal setting, and developing self-management skills. The exercise component of these interventions was poorly developed and could be strengthened by improving the exercise content, prescription, and progression. The evidence on exercise prescription needs to have a higher priority alongside self-care interventions. Further research on how to combine and integrate the self-care and exercise components is required and using better designed studies on other knee conditions. This could be achieved using modern technology which to date has been underutilized in this field. Alongside this, there is a need to ensure that all healthcare professionals working in a rehabilitation environment have the skills to deliver on both the self-care and exercise treatment components. Greater integration of outcomes that measure patient ability to self-manage is required. Little evidence exists on the combined use of self-care and exercise interventions for prevention of chronic knee conditions, which needs to be addressed in the future.

**Controversies in Knee Rehabilitation: Anterior Cruciate Ligament Injury**

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**Introduction**

More than 250,000 anterior cruciate ligament (ACL) injuries occur yearly in the United States[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R1), with 125,000–175,000 undergoing ACL reconstruction (ACLR)[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/%22%20%5Cl%20%22R2),[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R3). While standard of practice in the United States is early reconstruction for active individuals with the promise of returning to pre-activity injury levels[4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R4),[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R5), evidence suggests athletes are counseled that reconstruction is not required to return to high level activity after a program of intensive neuromuscular training[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R6). Others advocate counseling for a delayed reconstruction approach[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R7), however no differences in outcomes exist between delayed and early ACL reconstruction[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R6). Furthermore, athletes in the United States are commonly counseled to undergo early ACLR[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R5) with the promise of restoring static joint stability, minimizing further damage to the mensicii and articular cartilage[8](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R8),[4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R4), and preserving knee joint health[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R5), however, not all athletes are able to return to sport or exhibit normal knee function following reconstruction[9](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R9). Several factors, such as impaired functional performance, knee instability and pain, reduced range of motion, quadriceps strength deficits, neuromuscular dysfunction, and biomechanical maladaptations, may account for highly variable degree of success.

In order to identify the minimum set of outcomes that identify success after ACL injury or ACLR, Lynch et al established consensus criteria from 1779 sports medicine professionals concerning successful outcomes after ACL injury and reconstruction[10](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R10). The consensus of successful outcomes were identified as no re-injury or recurrent giving way, no joint effusion, quadriceps strength symmetry, restored activity level and function, and returning to pre-injury sports[10](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R10) [Figure 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/figure/F1/). Using these criterions we will review the success rates of current management after ACL injury and provide recommendations for the counseling of athletes after ACL injury.

**Impairment Resolution**

Following ACL injury or reconstruction, athletes undergo an extensive period of vigorous rehabilitation targeting functional impairments. These targeted rehabilitation protocols strive for full symmetrical range of motion, adequate quadriceps strength, walking and running without frank aberrant movement, and a quiet knee: little to no joint effusion or pain[10](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R10). Despite targeted post-operative rehabilitation, athletes commonly experience quadriceps strength deficits[11](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R11),[12](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R12),[13](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R13), lower self-reported knee function[14](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R14), and movement asymmetry[15](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R15),[16](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R16) up to two years after reconstruction. The importance of quadriceps strength as a dynamic knee stabilizer has been established, as deficits have been linked to lower functional outcomes[12](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R12),[17](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/%22%20%5Cl%20%22R17). In a systematic review of quadriceps strength after ACLR, quadriceps strength deficits can exceed 20% 6 months after reconstruction, with deficits having the potential to persist for 2 years after reconstruction[13](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R13). Otzel et al reported a 6–9% quadriceps deficit 3 years after reconstruction, concluding that long-term deficits after surgery were the results of lower neural drive as quadriceps atrophy measured by thigh circumference was not significantly different between limbs[18](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R18). Grindem et al reported at two-year follow up 23% of non-operatively managed athletes had greater than 10% strength deficits compared to 1/3 of athletes who underwent reconstruction.[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R19) Another study comparing operatively and non-operatively managed patients 2–5 years after ACL injury found no differences in quadriceps strength between groups concluding reconstructive surgery is not a prerequisite for restoring muscle function[20](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R20). Regardless of operative or non-operative management, quadriceps strength deficits are ubiquitous after ACL injury, and can persist for the long term. The current evidence does not support ACLR as a means of improved quadriceps strength outcomes over non-operative management after ACL injury.

**Outcomes**

Individuals do not respond uniformly to an acute ACL injury and outcomes can vary. Most individuals decrease their activity level after ACL injury[21](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R21),[20](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/%22%20%5Cl%20%22R20),[22](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R22)–[25](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R25). While a large majority of individuals rate their knee function below normal ranges after an ACL injury, which is a common finding early after an injury[26](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R26)–[30](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R30), some individuals exhibit higher perceived knee function than others early after ACL injury[28](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R28)–[30](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R30). This highlights the variability in outcomes seen after ACL injury.

Knee outcome scores are lowest early after surgery and improve up to 6 years post surgery[29](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R29),[31](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/%22%20%5Cl%20%22R31),[32](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R32). Using the Cincinnati Knee Rating System, scores improved from 60.5/100 at 12 weeks post reconstruction to 85.9/100 at 1 year follow-up[32](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R32). By six months after surgery almost half of individuals score greater than 90% on the Knee Outcomes Survey- Activities of Daily Living Scale (KOS-ADLS) and Global Rating Scale of Perceived Function (GRS) and 78% have achieved these scores by 12 months[14](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R14). Using the GRS, scores improved from 63.1/100 taken at week 12 to 83.3/100 at week 52[32](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R32). Moksness and Risberg reported similar post-surgical GRS results of 86.0/100 at 1 year follow-up[29](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R29). Poor self-report on outcome measures after ACLR are associated with chondral injury, previous surgery, return to sport, and poor radiological grade in ipsilateral medial compartment[33](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R33). ACLR revision and extension deficits at 3 months are also predictors of poor long term outcomes[34](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R34),[35](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/%22%20%5Cl%20%22R35)

Patient reported outcomes from multiple large surgical registries are available concerning patients after ACLR. A study from the MOON consortium of 446 patients reported International Knee Documentation Committee Subjective Knee Form 2000 (IKDC) for patients 2 and 6 years after reconstruction[36](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R36). The median IKDC score was 45 at baseline, rose to 75 at 2 year follow up, and reached 77 at 6 years after reconstruction[36](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R36). Grindem et al compared IKDC scores between athletes managed non-operatively or with reconstruction at baseline and 2 years[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R19). The non-operative group improved from a score of 73 at baseline to 89 2 years after injury[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R19). The reconstructed group improved from 69 at baseline to 89 2 years after surgery[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R19). There were no significant differences between groups at baseline or at 2 year follow-up[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R19). Using the Knee Injury and Osteoarthritis Outcome Score (KOOS), Frobell et al compared patient reported outcomes at 5 years after ACL injury and found no significant differences in change score from baseline to 5 years in those managed with early reconstruction versus those managed non-operatively or with delayed reconstruction[37](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R37). Outcomes after ACL injury, whether managed non-operatively or with ACLR, have similar patient reported outcomes scores at up to 5 years after injury.

**Long-Term Joint Health**

Preventing further intra-articular injury and preserving joint surfaces for long-term knee health is a purposed reason to surgically stabilize an unstable knee[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R5). Patients who had increased knee laxity after an ACL injury are more likely to have late meniscal surgery[33](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R33) and time from ACL injury is associated with the number of chondral injuries and severity of chondral lesions[38](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R38). Injury to menisci or articular cartilage places the knee at increased risk for the development of osteoarthritis[39](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R39). Barenius et al found a 3 fold increase in knee osteoarthritis prevalence in surgically reconstructed knees 14 years after surgery[39](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R39). They concluded that while ACLR did not prevent secondary osteoarthritis, initial meniscal resection was a risk factor for osteoarthritis with no differences in osteoarthritis prevalence seen between graft types[39](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R39). A recent systematic review compared operatively and non-operatively treated patients at a mean of 14 years after ACL injury[40](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R40) and found no significant differences between groups in radiographic osteoarthritis[40](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R40). The operative group had less subsequent surgery and meniscal tears, as well as increased Tegner change scores however there were no differences in Lysholm or IKDC scores between groups[40](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R40). The current evidence does not support the use of ACLR to reduce secondary knee osteoarthritis after ACL injury.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/)

**Return to Pre-Injury Sports**

Returning to sports is often cited as the goals of athletes and health care professionals after ACL injury or ACLR. When asked, 90% of NFL head team physicians believed that 90–100% of NFL players returned to play after ACLR[41](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R41). Shah et al found that regardless of position 63% of NFL athletes seen at their facility returned to play[42](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R42). A recent systematic review reported 81% of athletes return to any sports at all, but only 65% return to their pre-injury level and an even smaller percentage, 55%, return to competitive sports[43](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R43) [Figure 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/figure/F2/). This review found that younger athletes, men, and elite athletes were more likely to return to sports[43](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R43). Similar reports within this range are common when examining amateur athletes by sport. McCullough et al. report that 63% of high school and 69% of college football players return to sport[44](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R44). Shelbourne found that 97% of high school basketball players return to play, 93% of high school women and 80% of high school male soccer players returned[45](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R45). Brophy et al. found a slightly different trend in soccer players; 72% returned to play, where 61% returned to the same level of competition but when broken down by sex more men (75%) returned than women (67%)[46](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/%22%20%5Cl%20%22R46). These studies highlight the fact that while there may be a link between sport and return to sport, due to a lack of high quality research, current literature was unable to come to any conclusion[47](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R47).



[Figure 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/figure/F2/)

Meta-analysis pooled return to sport rates[43](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R43)

Reduced return to sport rates can be attributed to many factors, including age, sex, pre-injury activity level, fear and psychological readiness. Age and sex are two variables which have been identified in multiple studies[43](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R43),[46](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/%22%20%5Cl%20%22R46), with men and younger athletes being more likely to return to sport. Age, may be a proxy measure for changing priorities (i.e. family), commitments (i.e. employment), and/or opportunities to play at the same level (i.e. no longer have the competitive structure of high school, college, or club sports)[43](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R43). Further, it has been hypothesized that “For those athletes whose life and social networks are inherently structure around participating in sport, a stronger sense of athletic identity may be a positive motivator for return to sport”[43](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R43). While this hypothesis remains to be tested, this could explain the higher rates of return to sport in younger and elite/professional level athletes. Dunn et al found that higher level of activity at prior to injury and a lower BMI were predictive of higher activity levels at two years following ACLR[48](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R48). Ardern et al found that elite athletes were more likely to return to sport that lower level athletes[43](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R43). Professional and elite level athletes may have access to more resources, particularly related to rehabilitation services, but motivation to return to that high level of play and athletic identity may also drive such return to sport[43](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R43). Interestingly, Shah et al. found that in NFL players return to play was predicted by draft round. Athletes drafted in the first four rounds of the NFL draft were 12.2 times more likely to return to sport than those athletes drafted later or as free agents[42](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R42). This could represent the perceived talent of the player as well as the investment of the organization in that player[42](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R42).

**Re-Injury**

Second injury, whether it is an insult to the ipsilateral graft or the contralateral ACL, is a growing problem after ACLR as rates appear to be higher than once thought. Risk factors for second injury include younger athletes[49](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R49) who return to high level sporting activities early[50](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R50),[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R51), with women having a higher risk of contralateral injury[52](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R52),[53](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R53), and men having a higher risk of ipsilateral injury[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R54),[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R55). While second injury rates in the general population 5 years after reconstruction are reported to be 6%[56](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R56), rates in young athletes are considerably higher.[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R51) Paterno et al followed 78 athletes after ACLR and 47 controls over a 24 month period. They found an overall second injury rate of 29.5% which was an incidence rate nearly 4 times that of the controls (8%)[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/%22%20%5Cl%20%22R51). Over 50% of these injuries occurred within the first 72 athletic exposures, while in the control group only 25% were injured within the same time frame[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R51). The MOON cohort reported a 20% second injury rate in women and a 5.5% rate in men of 100 soccer players returning to sport after ACLR[46](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R46). Shelbourne et al[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R55) and Leys et al[57](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R57) both reported 17% second injury rates in younger athletes. Besides missing more athletic time, increasing healthcare costs, and increased psychological distress, re-injury and subsequent revision surgery has significantly worse outcomes compared to those after initial reconstruction[34](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R34). [FIGURE 3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/figure/F3/)



[Figure 3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/figure/F3/)

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/)

**Discussion**

ACLR continues to be the gold standard treatment of ACL injuries in the young athletic population. A survey of American Academy of Orthopedic Surgeons reported 98% of surgeons would recommend surgery if a patient wishes to return to sport, with 79% believing ACL deficient patients are unable to return to all recreational sporting activities without reconstruction[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R5). Revisiting the successful outcomes criterion after ACL injury, a successful outcome is considered no re-injury or recurrent giving way, no joint effusion, quadriceps strength symmetry, restored activity level and function, and returning to pre-injury sports[10](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R10). After reviewing the current literature looking at these criterions, counseling athletes to undergo early reconstruction after ACL injury may not be in the athlete’s best interests. Undergoing reconstruction does not guarantee athletes return to their pre-injury sport, and return to the pre-injury competitive level of sport is unlikely. The risk of a second injury is high in young athletes returning to sport, especially in the near-term. Risk of secondary injury increases for the contralateral limb in females, or the ipsilateral limb in males. The risk for developing osteoarthritis is high in the long-term regardless of surgical intervention, and even higher if a revision procedure is required[58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R58). A Cochrane Review found that there was insufficient evidence to recommend ACLR compared to nonoperative treatment, and recent randomized control trials have found no difference between those who had ACLR and those treated nonoperatively with regards to knee function, health status, and return to pre-injury activity level/sport after two and five years in young, active individuals[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R19),[37](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R37),[59](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R59). With no differences in outcomes between early reconstruction, delayed reconstruction, and no surgery at all, counseling should start by considering non-operative management. Eitzen et al[60](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/#R60) found a 5 week progressive exercise program after ACL injury led to significantly improved knee function before deciding to undergo reconstruction or remain non-operatively managed [Figure 4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/figure/F4/). The authors reported good compliance with few adverse events during training. Non-operative management is a viable evidence based option after ACL injury, allowing some athletes to return to sport despite being ACL deficient, with equivalent functional outcomes to those after ACLR. Given there is no evidence in outcomes to undergo early ACLR, non-operative management should be a first line of treatment choice in athletes after ACL injury. [Figure 5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379426/figure/F5/)

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**Key Points**

* Undergoing ACL reconstruction does not guarantee athletes will return to their pre-injury sport, and return to the pre-injury competitive level of sport is unlikely.
* The risk of a second ACL injury is high in young athletes returning to sport, especially in the near-term.
* The risk for developing osteoarthritis after ACL injury is high in the long-term regardless of surgical intervention, and even higher if a revision procedure is required.
* Despite common misconceptions, non-operatively managed athletes can return to sport without the need for reconstruction
* Without differences in outcomes between early reconstruction, delayed reconstruction, and nonoperative management, counseling should start by considering non-operative management.

[Knee.](https://www.ncbi.nlm.nih.gov/pubmed/24238648) 2014 Mar;21(2):462-70. doi: 10.1016/j.knee.2013.10.009. Epub 2013 Oct 23.

**Is reconstruction the best management strategy for anterior cruciate ligamentrupture? A systematic review and meta-analysis comparing anterior cruciate ligament reconstruction versus non-operative treatment.**

[Smith TO](https://www.ncbi.nlm.nih.gov/pubmed/?term=Smith%20TO%5BAuthor%5D&cauthor=true&cauthor_uid=24238648)1, [Postle K](https://www.ncbi.nlm.nih.gov/pubmed/?term=Postle%20K%5BAuthor%5D&cauthor=true&cauthor_uid=24238648)2, [Penny F](https://www.ncbi.nlm.nih.gov/pubmed/?term=Penny%20F%5BAuthor%5D&cauthor=true&cauthor_uid=24238648)3, [McNamara I](https://www.ncbi.nlm.nih.gov/pubmed/?term=McNamara%20I%5BAuthor%5D&cauthor=true&cauthor_uid=24238648)4, [Mann CJ](https://www.ncbi.nlm.nih.gov/pubmed/?term=Mann%20CJ%5BAuthor%5D&cauthor=true&cauthor_uid=24238648)5.

[**Author information**](https://www.ncbi.nlm.nih.gov/pubmed/24238648)

**Abstract**

**AIMS:**

The purpose of this study was to determine the optimal clinical and cost-effective strategy for managing people following ACL rupture.

**METHODS:**

A systematic review of the published (AMED, CINAHL, MEDLINE, EMBASE, PubMed, psycINFO and the Cochrane Library) and unpublished literature (OpenGrey, the WHO International Clinical Trials Registry Platform, Current Controlled Trials and the UK National Research Register Archive) was conducted on April 2013. All randomised and non-randomised controlled trials evaluating clinical or health economic outcomes of isolated ligament reconstruction versus non-surgical management following ACL rupture were included. Methodological quality was assessed using the PEDro appraisal tool. When appropriate, meta-analysis was conducted to pool data.

**RESULTS:**

From a total of 943 citations, sixteen studies met the eligibility criteria. These included 1397 participants, 825 who received ACL reconstruction versus 592 who were managed non-surgically. The methodological quality of the literature was poor. The findings indicated that whilst reconstructed ACL offers significantly greater objective tibiofemoral stability (p<0.001), there appears limited evidence to suggest a superiority between reconstruction versus non-surgical management in functional outcomes. There was a small difference between the management strategies in respect to the development of osteoarthritis during the initial 20 years following index management strategy (Odds Ratio 1.56; p=0.05).

**CONCLUSIONS:**

The current literature is insufficient to base clinical decision-making with respect to treatment opinions for people following ACL rupture. Whilst based on a poor evidence, the current evidence would indicate that people following ACL rupture should receive non-operative interventions before surgical intervention is considered.

[Phys Sportsmed.](https://www.ncbi.nlm.nih.gov/pubmed/24231595) 2013 Nov;41(4):33-40. doi: 10.3810/psm.2013.11.2034.

**Operative and nonoperative treatment options for ACL tears in the adult patient: a conceptual review.**

[Bogunovic L](https://www.ncbi.nlm.nih.gov/pubmed/?term=Bogunovic%20L%5BAuthor%5D&cauthor=true&cauthor_uid=24231595)1, [Matava MJ](https://www.ncbi.nlm.nih.gov/pubmed/?term=Matava%20MJ%5BAuthor%5D&cauthor=true&cauthor_uid=24231595).

[**Author information**](https://www.ncbi.nlm.nih.gov/pubmed/24231595)

**Abstract**

Injury to the anterior cruciate ligament (ACL) is common among athletic individuals. Both nonoperative and operative treatment options exist. The optimal treatment of an adult with an ACL tear depends on several patient-specific factors, including age, occupation, and desired activity level. In less active patients with sedentary jobs, nonoperative management, consisting of physical therapy, bracing, and activity modification can yield successful results. In active patients who want to resume participation in jumping, cutting, or pivoting sports, patients who have physically demanding occupations, or patients who fail a trial of nonoperative management, ACL reconstruction is recommended. Reconstruction utilizing autograft tissue is preferred over allograft, especially in the younger athlete, but allograft tissue is a reasonable option in the older (aged > 40 years) and less active adult, as well. Successful results have been achieved with both patellar tendon and hamstring grafts. The optimal treatment in adult patients with ACL tears should be based on careful consideration of the patient's goals for return to activity, knee-specific comorbidities, such as coexistent meniscal pathology or osteoarthritis, and his or her willingness to follow a detailed rehabilitation regimen. Our article provides an overview of current nonoperative and operative treatment options for adults with ACL tears, considers the outcomes of both nonoperative and operative strategies, and provides general recommendations as to the ideal management for a given patient.

[Phys Ther Sport.](https://www.ncbi.nlm.nih.gov/pubmed/23068905) 2012 Nov;13(4):270-8. doi: 10.1016/j.ptsp.2012.05.001. Epub 2012 Jun 7.

**A review of systematic reviews on anterior cruciate ligament reconstruction rehabilitation.**

[Lobb R](https://www.ncbi.nlm.nih.gov/pubmed/?term=Lobb%20R%5BAuthor%5D&cauthor=true&cauthor_uid=23068905)1, [Tumilty S](https://www.ncbi.nlm.nih.gov/pubmed/?term=Tumilty%20S%5BAuthor%5D&cauthor=true&cauthor_uid=23068905), [Claydon LS](https://www.ncbi.nlm.nih.gov/pubmed/?term=Claydon%20LS%5BAuthor%5D&cauthor=true&cauthor_uid=23068905).

[**Author information**](https://www.ncbi.nlm.nih.gov/pubmed/23068905)

**Abstract**

The aim of this systematic review of systematic reviews was to critically appraise systematic reviews on Anterior Cruciate Ligament (ACL) reconstruction rehabilitation to determine which interventions are supported by the highest quality evidence. Electronic searches were undertaken, of MEDLINE, AMED, EMBASE, EBM reviews, PEDro, Scopus, and Web of Science to identify systematic reviews of ACL rehabilitation. Two reviewers independently selected the studies, extracted data, and applied quality criteria. Study quality was assessed using PRISMA and a best evidence synthesis was performed. Five systematic reviews were included assessing eight rehabilitation components. There was strong evidence (consistent evidence from multiple high quality randomised controlled trials (RCTs)) of no added benefit of bracing (0-6 weeks post-surgery) compared to standard treatment in the short term. Moderate evidence (consistent evidence from multiple low quality RCTs and/or one high quality RCT) supported no added benefit of continuous passive motion to standard treatment for increasing range of motion. There was moderate evidence of equal effectiveness of closed versus open kinetic chain exercise and home versus clinic based rehabilitation, on a range of short term outcomes. There was inconsistent or limited evidence for some interventions. Recommendations for clinical practice are made at specific time points for specific outcomes.

**Rehabilitation After Anterior Cruciate Ligament Reconstruction**

A Systematic Review

[L.M. Kruse](https://www.ncbi.nlm.nih.gov/pubmed/?term=Kruse%20L%5BAuthor%5D&cauthor=true&cauthor_uid=23032584), MD,1 [B. Gray](https://www.ncbi.nlm.nih.gov/pubmed/?term=Gray%20B%5BAuthor%5D&cauthor=true&cauthor_uid=23032584), MD,1 and [R.W. Wright](https://www.ncbi.nlm.nih.gov/pubmed/?term=Wright%20R%5BAuthor%5D&cauthor=true&cauthor_uid=23032584), MD1

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/)

**Abstract**

**Background:**

Rigorous rehabilitation after anterior cruciate ligament (ACL) reconstruction is necessary for a successful surgical outcome. A large number of clinical trials continue to assess aspects of this rehabilitation process. Prior systematic reviews evaluated fifty-four Level-I and II clinical trials published through 2005.

**Methods:**

Eighty-five articles from 2006 to 2010 were identified utilizing multiple search engines. Twenty-nine Level-I or II studies met inclusion criteria and were evaluated with use of the CONSORT (Consolidated Standards of Reporting Trials) criteria. Topics included in this review are postoperative bracing, accelerated strengthening, home-based rehabilitation, proprioception and neuromuscular training, and six miscellaneous topics investigated in single trials.

**Results:**

Bracing following ACL reconstruction remains neither necessary nor beneficial and adds to the cost of the procedure. Early return to sports needs further research. Home-based rehabilitation can be successful. Although neuromuscular interventions are not likely to be harmful to patients, they are also not likely to yield large improvements in outcomes or help patients return to sports faster. Thus, they should not be performed to the exclusion of strengthening and range-of-motion exercises. Vibration training may lead to faster and more complete proprioceptive recovery but further evidence is needed.

**Conclusions:**

Several new modalities for rehabilitation after ACL reconstruction may be helpful but should not be performed to the exclusion of range-of-motion, strengthening, and functional exercises. Accelerated rehabilitation does not appear to be harmful but further investigation of rehabilitation timing is warranted.

**Level of Evidence:**

Therapeutic Level II. See Instructions for Authors for a complete description of levels of evidence.

Successful anterior cruciate ligament (ACL) reconstruction requires physical rehabilitation to help patients return to an active lifestyle. Prior systematic reviews by Wright et al. in 2008 included fifty-four studies with Level-I or II evidence published through 2005 ([Table I](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/table/tbl1/))[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib1),[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib2). Since 2005, numerous studies have evaluated the safety of accelerated and brace-free rehabilitation protocols that attempt to return athletes to sports more quickly[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib3)-[11](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib11). Several studies investigated the use of bracing for additional benefits such as pain control[12](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib12)-[14](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib14). Additionally, longer-term data from previously published trials are becoming available[15](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib15)-[17](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib17). The present systematic review methodically evaluates studies on rehabilitation following ACL reconstruction that have Level-I or II evidence and have been published since the previous systematic reviews. It provides recommendations on the inclusion of these new protocols into an ACL rehabilitation program.



**Home-Based Rehabilitation**

Four studies included in the previous systematic reviews had evaluated home-based compared with outpatient physical therapy for rehabilitation after ACL reconstruction[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib1),[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/%22%20%5Cl%20%22bib2). Despite flaws in reporting and study design that resulted in biases, the studies indicated that a motivated patient could obtain reasonable results with minimally supervised home-based rehabilitation. Two additional studies have subsequently evaluated home-based rehabilitation ([Table IV](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/table/tbl4/)).

Grant and Mohtadi provided longer-term data[16](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib16) on a previously included trial comparing home-based rehabilitation that had minimal therapist involvement (four sessions) with physical therapist-guided rehabilitation (seventeen sessions)[23](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/%22%20%5Cl%20%22bib23). Eighty-eight (68%) of the original 129 patients returned for follow-up between twenty-six and fifty-nine months (loss to follow-up, 32%). A blinded examiner evaluated range of motion, laxity measured with the KT1000, isokinetic hamstring and quadriceps tests, and the ACL-QOL. No significant difference was noted in any parameter except the ACL-QOL (80.0 in the home therapy group compared with 69.9 in the physical therapist group, p = 0.02). One physical therapist treated all patients in the home therapy group, but each physical therapy group chose its own outside therapist, resulting in a performance bias. On the basis of these findings, home-based rehabilitation may be effective.

**Neuromuscular Training**

Nine randomized trials evaluated neuromuscular training as part of rehabilitation after ACL reconstruction ([Table V](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/table/tbl5/))[17](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/%22%20%5Cl%20%22bib17),[25](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib25)-[32](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/#bib32). The training included proprioceptive and balance training, perturbation training, and vibratory stimulation.



[TABLE V](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/table/tbl5/)

Summary of Studies on Neuromuscular Training\*

**Discussion**

Numerous aspects of rehabilitation following ACL reconstruction have been investigated with Level-I and II clinical trials. As with most systematic reviews, inclusion of published studies often involves a publication bias in favor of positive findings. This is less relevant when studying rehabilitation, as both positive and negative findings are deemed important.

Although many of the included studies have a selection bias, it is still possible to draw some valuable conclusions. Multiple types of bracing were evaluated, including knee immobilization, rehabilitation bracing, and functional bracing. Overall, no brace or length of brace wear demonstrated an advantage over another type of brace, another duration of bracing, or no bracing at all. Bracing does not provide any benefit and is not necessary. Accelerated rehabilitation has shown no deleterious effects, and it is likely safe for patients to begin immediate postoperative weight-bearing, move the knee from 0° to 90° of flexion, and perform closed-chain strengthening exercises. Eccentric quadriceps muscle strengthening and isokinetic hamstring muscle strengthening were safely incorporated three weeks after surgery; they may be safe sooner, but further research is needed. Home-based rehabilitation can be effective.

Neuromuscular exercises are not likely to be harmful to patients; however, their impact was small, making them unlikely to yield large improvements in outcomes or help patients return to sports faster. Neuromuscular exercises should not be performed to the exclusion of strengthening and range-of-motion exercises. Neither supplemental vitamin C nor vitamin E appears to be beneficial. Postoperative hyaluronic acid injections may improve some measurable parameters, but their cost must be kept in mind. Single-leg cycling to maintain cardiac fitness may be beneficial. Continuous passive motion is still not recommended.

The studies presented in this paper focused on improving rehabilitation following ACL reconstruction, with a goal of safely allowing expeditious return of mobility, strength, and ultimately sport participation. However, few studies actually measured the ability to return to sports and its timing following the interventions. The availability of such data could strengthen the conclusions of studies and should be considered in future research. Despite the large number of randomized trials, further investigations of the timing of rehabilitation and supplemental rehabilitation exercises are needed to continue to improve the care and function of patients following ACL reconstruction.

**What Do We Really Know About Rehabilitation After ACL Reconstruction?**

Commentary on an article by L.M. Kruse, MD, et al.: “Rehabilitation After Anterior Cruciate Ligament Reconstruction. A Systematic Review”

[Robert J. Johnson](https://www.ncbi.nlm.nih.gov/pubmed/?term=Johnson%20RJ%5BAuthor%5D&cauthor=true&cauthor_uid=23032598), MD1,\* and [Bruce D. Beynnon](https://www.ncbi.nlm.nih.gov/pubmed/?term=Beynnon%20BD%5BAuthor%5D&cauthor=true&cauthor_uid=23032598), PhD1,\*

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See the article "[Rehabilitation After Anterior Cruciate Ligament Reconstruction](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448301/)" in volume 94 on page 1737.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3448302/)

**Commentary**

The authors of this investigation appropriately used a systematic review to identify articles concerning anterior cruciate ligament (ACL) rehabilitation that had a Level of Evidence of I or II. The search methodology, level of evidence, and inclusion criteria were clearly defined. They assembled the articles that met their entry criteria into five groups: postoperative bracing (six studies), accelerated strengthening (six studies), home-based rehabilitation (two studies), neuromuscular training (nine studies), and miscellaneous (six studies). The disparity in methodology used in these twenty-nine articles did not allow the authors to use the more powerful methodology of a meta-analysis. The conclusions that they presented at the end of each of their sections were generally adequately supported by the studies they investigated.

Although the studies evaluated in this systematic review were of a high level of evidence, many problems were encountered by the reviewers in their attempt to evaluate the articles. Because the authors of the individual studies had not chosen similar study designs, outcome measures, and definitions of rehabilitation techniques (i.e., accelerated compared with standard rehabilitation procedures), the results of these investigations are difficult to compare or to use for meta-analysis. Weaknesses in the individual papers included failure to verify and measure compliance with rehabilitation protocols in the majority of cases, flawed randomization methods, lack of power analysis, and failure to address the safety and efficacy of the protocols used. The reviewers pointed out these deficiencies very appropriately.

Unfortunately, the methodology used in some of the studies did not allow the reader to ascertain which protocol resulted in a superior outcome. Little difference between the treatments was found during short-term follow-up in most cases, including studies concerning bracing, accelerated strengthening, home-based rehabilitation, neuromuscular training, continuous active motion, and two-month running retraining programs. In several cases, even when statistically significant differences were observed, the clinical relevance of these findings was at least questionable. On the other hand, hyaluronic acid injection at eight weeks postoperatively was associated with superior outcomes, but cost and insurance approval issues led the reviewers to conclude that its use was impractical.

Clinically relevant benefits were observed in two studies. An instructional video concerning anxiety, pain, and functional outcomes may be helpful in managing expectations of pain and self-efficacy following surgery. A one-legged cycling program using the uninjured leg may be beneficial during rehabilitation to maintain cardiovascular fitness; however, measurement and selection bias may have been present in the relevant study.

We do wish to raise one concern regarding the authors’ statement in the Discussion that “accelerated rehabilitation has shown no deleterious effects, and it is likely safe for patients to begin immediate postoperative weight-bearing, move the knee from 0° to 90° of flexion, and perform closed-chain strengthening exercises.” The investigations reviewed by the authors were limited in scope and could not possibly substantiate the above statement for all types of graft materials (autografts and allografts), all feasible modified rehabilitation protocols, all fixation techniques, and the effects of damage to articular cartilage or the menisci that is associated with many ACL injuries. Care must be taken when generalizing the findings currently available in the literature to untested hypotheses concerning rehabilitation following ACL injury and reconstruction.

**Variables Associated With Return to Sport Following Anterior Cruciate Ligament Reconstruction: A Systematic Review**

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**Abstract**

**Background**

As one of the purposes of anterior cruciate ligament reconstruction (ACLR) is to return athletes to their pre-injury activity level, it is critical to understand variables influencing return to sport. Associations between return to sport and variables representing knee impairment, function and psychological status have not been well studied in athletes following ACLR.

**Purpose**

The purpose of this review is to summarize the literature reporting on variables proposed to be associated with return to sport following anterior cruciate ligament reconstruction.

**Study Design**

Systematic Review

**Methods**

Medline, Embase, CINAHL and Cochrane databases were searched for articles published before November 2012. Articles included in this review met these criteria: 1) included patients with primary ACLR, 2) reported at least one knee impairment, function or psychological measure, 3) reported a return to sport measure and 4) analyzed the relationship between the measure and return to sport.

**Results**

Weak evidence existed in sixteen articles suggesting variables associated with return to sport included higher quadriceps strength, less effusion, less pain, greater tibial rotation, higher Marx Activity score, higher athletic confidence, higher pre-operative knee self-efficacy, lower kinesiophobia and higher pre-operative self-motivation.

**Conclusion**

Weak evidence supports an association between knee impairment, functional, and psychological variables and return to sport. Current return to sport guidelines should be updated to reflect all variables associated with return to sport. Utilizing evidence-based return to sport guidelines following ACLR may ensure athletes are physically and psychologically capable of sports participation, which may reduce re-injury rates and the need for subsequent surgery.

**Keywords:**anterior cruciate ligament reconstruction, return to sport, psychological, rehabilitation

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/)

**BACKGROUND**

Anterior cruciate ligament (ACL) tears are the most commonly reported knee injury in athletes, with nearly 300,000 anterior cruciate ligament reconstructions (ACLR) performed yearly in the United States.[[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R1)] Previous reports indicate that 98% of orthopaedic surgeons recommend surgery if patients wish to return to sport,[[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R2)] but not all patients return to sport following ACLR. Clinical guidelines suggest that patients should be expected to return to sport by nine months post-surgery, but many patients have not achieved this activity level up to 18 months after receiving clearance to return to sport.[[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R3)] Declines in sports participation compared to pre-injury levels are noted as far as five and seven years post-surgery,[[4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R4)–[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R7)] though reasons for activity level changes may be unrelated to knee function.

Improved understanding of variables influencing patients' ability to return to sports is needed. Return to sport recommendations following ACLR are varied and often based on clinical experience or reviews reporting the criteria utilized in randomized control trials (RCTs).[[8](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R8)–[11](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R11)] Most return to sport criteria following ACLR includes assessments of knee impairment and function, such as knee range of motion (ROM), quadriceps strength and functional test performance. Achieving knee ROM equivalent to the uninvolved limb is frequently emphasized[[12](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R12)–[17](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R17)] as ROM asymmetry between limbs has been linked to worse subjective outcomes 10 years post-surgery, though the ability of these patients to return to sport is unknown.[[18](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R18)] Quadriceps and hamstring strength are the most commonly utilized objective criteria when determining patient readiness to return to sport,[[13](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R13), [14](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R14), [16](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R16),[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R19)–[26](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R26)] and published reports note persistent quadriceps weakness years after surgery.[[27](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R27), [28](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R28)] Typical criteria include a quadriceps limb symmetry index (LSI) equivalent to >80–90% of the opposite side.[[13](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R13), [14](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R14), [16](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R16), [19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R19)–[26](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R26)] Although quadriceps weakness may alter knee kinematics during running and cutting,[[29](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R29)] the actual relationships between quadriceps strength and functional test performance such as hop testing is unclear.[[30](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R30)–[34](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R34)] Single leg hop LSI ≥90% is also often cited,[[15](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R15), [23](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R23), [25](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R25), [35](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R35)–[38](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R38)] but the relationship between functional test performance and athletic performance is not well established.[[39](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R39)] Despite post-surgical emphasis on strengthening and functional performance, abnormal lower limb kinematics are evident during hopping and jumping two to four years following ACLR.[[40](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R40), [41](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R41)] The ability of these frequently utilized clinical criteria to predict athletes' ability to return to sport is unknown.

**Variables Associated with Return to Sport**

**Variables Representing Knee Impairment and Function**

The evidence reporting the association between knee impairment and function and return to sport is limited. Based on four level 4 studies and one level 2 study, weak evidence[[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R54)] supports associations between return to sport and higher post-operative quadriceps torque,[[59](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R59), [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69), [70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R70)] less knee effusion[[60](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R60), [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] and a higher Marx Activity Score[[62](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R62)]. Based on two level 2 studies and one level 4 study, weak evidence[[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R54)] supports associations between return to sport and greater post-operative tibial rotation,[[67](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R67)] less pain[[60](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R60), [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] and fewer episodes of instability.[[69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] Based on one level 2 study and four level 4 studies, weak evidence[[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R54)] indicates no association between return to sport and pre-operative quadriceps torque,[[64](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R64)] pre-operative anterior knee joint laxity,[[64](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R64)] post-operative anterior knee joint laxity,[[60](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R60), [68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R68), [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] pre-operative knee extension ROM,[[64](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R64)] post-operative knee extension or flexion ROM,[[69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] or pre-injury activity level.[[64](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R64)] There is conflicting evidence for associations between return to sport and the IKDC subjective form score,[[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R6), [62](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R62),[69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] IKDC Grade,[[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R6), [58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R58), [62](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R62)] post-operative hamstring torque,[[59](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R59), [61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R61)] Lysholm Knee score[[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R6), [61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R61), [62](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R62)] and post-operative LSI for single hop or crossover hop for distance.[[58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R58), [61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R61), [68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R68)] Available raw data and between-group statistics for each study is presented in [Table 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/table/T4/).



[TABLE 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/table/T4/)

VARIABLES ASSOCIATED WITH RETURN TO SPORT

**Psychological Variables**

Studies utilized several standardized measures to assess psychological variables, including the Tampa Scale of Kinesiophobia (fear of movement or re-injury),[[48](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R48), [65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R65), [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] Anterior Cruciate Ligament-Return to Sport after Injury Scale (athletic confidence, emotions and risk appraisal),[[66](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R66), [68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R68)] Psychovitality questionnaire (self-motivation to return to sport),[[62](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R62), [63](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R63)] Knee Self-Efficacy Scale (evaluates beliefs about the ability to perform tasks),[[49](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R49)] Shortened Profile of Mood States (negative affect),[[65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R65)] Pain Catastrophizing Scale (evaluates people's thoughts and feelings about pain)[[65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R65)] and Emotional Responses of Athletes to Injury Questionnaire.[[68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R68)]

Based on three level 2 and two level 4 studies, weak evidence[[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R54)] supports associations between return to sport and kinesiophobia[[48](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R48), [65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R65), [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] and athletic confidence.[[66](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R66), [68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R68)] Based on one level 2 and one level 4 study, weak evidence[[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R54)] supports associations between return to sport and pre-operative knee self-efficacy[[49](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R49)] and pre-operative self-motivation.[[62](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R62), [63](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R63)] Weak evidence[[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R54)] exists indicating that emotional response to injury/surgery,[[68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R68)] negative affect and pain catastrophizing[[65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R65)] are not associated with return to sport. Available raw data and between-group statistics are presented in [Table 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/table/T4/).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/)

**DISCUSSION**

Surgery is commonly recommended for athletes with ACL tears wishing to return to their previous level of sports activity.[[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R2)] However, many of these athletes never return to their pre-injury level of play.[[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R3), [5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R5)] This review summarizes the literature on knee impairment, function and psychological variables associated with return to sport following ACLR. In this review, we broadly defined return to sport to include all possible definitions (any sport, the same sport and the same level in pre-injury sport) and at any post-surgical timeframe. A limited number of articles met our inclusion criteria. Many potentially relevant articles only included self-report of function as the primary outcome and were excluded. Although functional improvement is important, return to sport is often the main reason patients elect surgery.[[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R2)] Based on our review, weak evidence[[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R54)] exists suggesting that higher post-operative quadriceps strength,[[59](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R59), [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69), [70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R70)] less knee effusion,[[60](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R60), [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] lower pain,[[60](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R60), [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] fewer episodes of instability,[[69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] greater tibial rotation ROM,[[67](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R67)] lower kinesiophobia,[[48](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R48), [65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R65), [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)] higher athletic confidence,[[66](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R66), [68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R68)] higher pre-operative knee self-efficacy[[49](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R49)] and higher pre-operative self-motivation[[62](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R62), [63](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R63)] are associated with return to sport. Although post-surgical anterior knee joint laxity has been linked with patient satisfaction[[71](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R71)] and general knee function[[72](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R72)] following ACLR, there was insufficient evidence that anterior knee laxity influences return to sport.[[60](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R60), [68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R68), [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R69)]

Return to sport criteria following ACLR includes various assessments of knee impairment and function. Recently, Barber-Westin and Noyes[[10](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/%22%20%5Cl%20%22R10)] reported the most commonly cited post-surgical return to play criteria included achieving specific LSI for quadriceps strength and hop testing, full knee ROM and no knee effusion. They also advocated for the inclusion of a drop-jump test, single-leg squat test to 90 degrees, assessment of knee laxity and examination of sports-specific drill performance. Thomeé et al.[[9](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R9)] recommended strength and hop test performance criteria utilizing both absolute values and between-limb comparisons prior to return to sport, and proposed criteria be adjusted according to type of sport patients are returning to (e.g. cutting/pivoting, recreational/competitive, contact/noncontact). Our review supports including assessment of LSI for quadriceps strength and measurement of knee effusion. However, we found conflicting evidence to support the use of hop testing, and insufficient evidence to support using anterior knee joint laxity assessment or knee flexion and extension ROM in return to sports criteria following ACLR. Although functional testing, which traditionally evaluates differences between the surgical and non-surgical limb, is considered important to assess athletes' neuromuscular control and has been linked to better self-reported knee function,[[73](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R73)] only three studies examined the association between hop testing and return to sport.[[58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R58), [61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R61), [68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R68)] Although two studies found no association between LSI on the single hop for distance[[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R61), [68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R68)] or crossover hop for distance[[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R61), [68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R68)] and return to sport, Ardern et al.[[58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/#R58)] noted that a LSI ≥ 85% on both hop tests significantly increased the likelihood of return to pre-injury level of sports participation. Baltaci et al.[[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/%22%20%5Cl%20%22R61)] also studied the triple hop for distance and found no association with return to sport. Additional studies investigating the relationship between hop testing and return to sport are needed for more definitive conclusions.

**Summary Box: What are the new findings?**

* Variables that may be associated with good functional outcome and patient satisfaction following anterior cruciate ligament reconstruction have been examined, but few studies have examined whether these variables are also associated with return to sport.
* There is weak evidence for some of the existing return to sport criteria following anterior cruciate ligament reconstruction.
* Weak evidence exists supporting an association between psychological variables and return to sport, suggesting that psychological variables should be considered for inclusion in return to sport criteria.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975129/)

**Neuromuscular Training to Target Deficits Associated With Second Anterior Cruciate Ligament Injury**

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See other articles in PMC that [cite](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/citedby/) the published article.

Anterior cruciate ligament (ACL) rupture is one of the most physically, financially, and emotionally devastating sport-related knee injuries.[24](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R24),[34](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R34),[49](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R49),[141](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R141) Return to activity is highly desired and expected for many athletes following ACL reconstruction (ACLR) and postsurgical rehabilitation, but reported success rates range from 43% to 93%.[4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R4),[17](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R17),[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R19),[76](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R76),[88](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R88),[138](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R138) Unfortunately, for those who do resume their previous level of activity, the risk of a second ACL injury may range from 6% to as high as 30% [65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R65),[79](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R79),[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126),[133](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R133),[136](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R136),[160](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R160) and can be associated with several factors, including surgical technique,[16](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R16),[65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R65),[79](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R79),[84](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R84) age,[65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R65),[84](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R84),[136](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R136),[150](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R150) activity level,[16](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R16),[133](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R133) sex,[125](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R125),[136](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R136) time since surgery,[75](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R75),[133](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R133),[150](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R150) and biomechanical adaptations during dynamic tasks.[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126) Although several of these factors are nonmodifiable, the biomechanical components of second–ACL injury risk may be effectively addressed with targeted neuromuscular training prior to unrestricted sports participation.

Aberrant neuromuscular and biomechanical patterns are commonly seen up to 2 years after ACLR[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R54),[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R55),[108](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R108),[123](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R123),[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126),[130](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R130) and may help explain the high rate of second ACL injury. Deficits in the neuromuscular control of both lower extremities following ACLR have been directly implicated in the risk for second ACL injury[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126) and may not only be a result of the initial knee injury and subsequent surgery,[23](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R23),[131](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R131),[132](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R132) but may also characterize the athlete’s preinjury movement patterns.[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61),[161](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R161),[162](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R162) Therefore, identification and subsequent targeted treatment of aberrant post-ACLR movement patterns are critical not only to maximize functional recovery but also to reduce the risk for a second ACL injury. Though neuromuscular training programs can effectively reduce primary–ACL injury prevalence by between 43.8% and 73.4%,[145](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R145) the efficacy of similar programs for reduction of second–ACL injury risk has not been examined. To date, there is no validated rehabilitation program that addresses not only the residual neuromuscular impairments following ACL injury and reconstruction, but also the known risk factors for second ACL injury. The purpose of this paper is to build on the theoretical framework for second–ACL injury prevention set forth previously[58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R58)and to (1) summarize the neuromuscular deficits that precede primary injury and persist following injury, ACLR, and return to activity; (2) provide the evidence for risk factors related to second ACL injury and their link to previous neuromuscular impairments; (3) detail a method to assess neuromuscular impairments following ACLR; and (4) propose a method of intervention to address common neuromuscular deficits in this population.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/)

**ACL INJURY RISK FACTORS**

**Neuromuscular Deficits Prior to Primary ACL Injury**

Primary-injury risk factors provide an important window into the underlying neuromuscular deficits that may persist in athletes following injury and ACLR. Active stabilization of the knee joint during vigorous sporting tasks depends largely on the coordinated coactivation and force generation of the adjacent musculature,[82](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R82),[86](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R86),[143](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R143) and variance in these dynamic joint-loading strategies between sexes is theorized to explain the differences in their relative risk for ACL rupture.[50](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R50),[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R51),[60](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R60),[63](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R63),[96](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R96),[121](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R121) Female athletes, who are several times more likely to sustain a primary ACL tear compared to their equally active male counterparts,[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R2),[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R5)have long been the cohort of scientific interest to evaluate the mechanisms of ACL injury risk. In healthy adult volunteers, women demonstrated reduced dynamic knee joint stiffness during both non–weight-bearing[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R51) and weight-bearing tasks.[50](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R50),[121](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R121) Specifically, reduced stiffness values in women were identified despite higher levels of lower extremity muscle activity when compared to men,[51](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R51),[121](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R121)highlighting the likely role of sex-specific differences in neuromuscular strategies in primary–ACL injury risk.

Deficits in thigh muscle strength may also be a key variable in the primary–ACL injury risk model of young female athletes.[96](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R96),[100](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R100),[101](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R101) In a prospective, matched-control study of 132 healthy athletes, only the female athletes who went on to sustain an ACL injury demonstrated lower hamstrings strength when compared to uninjured male controls.[96](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R96) A low hamstrings-to-quadriceps strength ratio is 1 of 5 clinically based measures that combine to accurately predict high knee abduction moment (KAM) status in healthy adolescent female athletes.[101](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R101) Importantly, a high KAM during 3-D analysis of a drop-vertical jump task was the most accurate predictor of future ACL injury in a cohort of 205 adolescent female athletes.[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61) The clinical prediction model for high KAM, which includes a low hamstrings-quadriceps strength ratio,[101](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R101) has since been validated against 3-D motion analysis techniques.[100](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R100)

Sex-specific differences in kinematics and kinetics during sport-related tasks provide additional insight into the mechanisms of risk for primary ACL injury.[21](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R21),[46](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R46),[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61),[67](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R67),[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R70),[92](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R92),[161](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R161) Uninjured females demonstrate altered peak hip and knee flexion angles,[21](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R21),[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61),[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R70) increased frontal plane motion of the hip and knee,[46](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R46),[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61),[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R70) and larger ground reaction forces[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61),[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R70) during athletic tasks compared to their male counterparts. Differences in temporal components of dynamic movement between high-level male and female athletes may partially explain the relative sex disparity in primary–injury risk.[67](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R67) Peak hip adduction, dynamic knee valgus, and ankle eversion occurred earlier in women than in men during a drop-jump landing task.[67](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R67) In the same cohort of 10 male and female Division I college athletes, the females demonstrated knee valgus angular velocities that were nearly twice as high as those of the males.[67](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R67)

To date, only 1 prospective study has measured and identified biomechanical variables predictive of primary–ACL injury status.[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61) In this study,[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R61) 205 uninjured adolescent female soccer, basketball, and volleyball players underwent preseason biomechanical assessment of a drop-vertical jump task to determine potential factors predictive of future ACL rupture. At the termination of the team’s injury-surveillance period more than 1 year later, 9 athletes had sustained an ACL injury. Peak knee abduction angles and external joint moments, as well as initial contact values, significantly predicted ACL injury status. Independently, the magnitude of the external KAM predicted ACL injury status with 73% specificity and 78% sensitivity.[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61) In the same prospective sample, smaller peak knee flexion angles and larger vertical ground reaction forces and external hip flexion moments were also identified in those who went on to sustain an ACL injury, further highlighting the multidimensional risk profile for primary ACL injury.[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61)

Risk for primary ACL injury is not solely related to neuromuscular deficits of the lower extremities,[161](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R161),[162](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R162) as impairments in the proprioception and neuromuscular control of the trunk may also increase primary–ACL injury risk, particularly in female athletes.[161](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R161) A cohort of 277 healthy college athletes were prospectively examined to determine whether excessive trunk motion, errors in repositioning accuracy, and history of injury could predict knee injury status over a 3-year period.[161](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R161),[162](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R162) Sex-specific knee injury prediction models were identified both by assessment of the neuromuscular response of the trunk during a seated active trunk-repositioning task and a kneeling sudden force-release task.[161](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R161) Error in the active repositioning of the trunk predicted knee ligament or meniscal injury status with 86% sensitivity and 61% specificity only in female athletes.[161](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R161),[162](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R162) Deficits in neuromuscular control, as quantified by lateral, extension, and flexion displacements of the trunk during the kneeling sudden force-release task, provided the most accurate prediction model for ACL injury in female athletes, whereas history of low back pain was the strongest predictor of future knee ligament injury in male athletes.[161](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R161) So, while the magnitude of external frontal plane loading at the knee is a critical modulator of peak ACL strain at the time of failure,[77](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R77),[159](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R159)there is strong evidence that poor neuromuscular control of trunk position may also increase the risk for ACL injury.[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61),[64](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R64),[135](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R135),[162](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R162)

**Neuromuscular Deficits Following ACL Injury**

Abnormal neuromuscular patterns and significant physical impairments characterize the acute postinjury phase. Joint effusion, limited range of motion, and reduced quadriceps strength are all common impairments following ACL injury. Episodes of giving way (knee joint subluxations) are not uncommon in many of these acutely injured athletes[36](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R36),[132](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R132) and may be related to reduced dynamic knee joint control,[131](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R131),[132](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R132) decreased thigh muscle force,[48](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R48) and abnormal joint loading.[47](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R47) Though some athletes are capable of return to sport in the short term following specific neuromuscular retraining,[44](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R44),[45](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R45) the majority of athletes continue to experience recurrent instability and significant functional limitations,[36](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R36),[132](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R132) and are often advised to undergo ligament reconstruction.[87](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R87) Left untreated prior to surgery, these acute postinjury impairments can have significant negative implications for postoperative outcomes.[37](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R37),[57](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R57),[80](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R80)

Rehabilitation programs administered early following ACL injury have the potential for significant positive effects on immediate[39](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R39),[45](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R45) and midterm nonsurgical outcomes in this population.[38](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R38),[90](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R90) In a study by Eitzen et al,[38](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R38)performance on functional tests following 10 physical therapy sessions, in addition to age, activity level, and episodes of giving way, explained a significant proportion of the variance in the prediction of those athletes who later underwent ACLR. In a different study,[90](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R90) it was demonstrated that with prolonged nonsurgical rehabilitation (approximately 6 months), athletes initially classified as noncopers on the basis of poor function and knee instability during a screening examination were just as likely to return to their previous level of sports activity as those athletes who had initially been classified as potential copers. While it is apparent that the neuromuscular systems of athletes following ACL injury are adaptable to rehabilitation, the optimal rehabilitation program to restore high-level function in these athletes without surgery is unknown.

**Common Neuromuscular Deficits After ACLR**

**Muscle Weakness**

Muscle weakness,[33](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R33),[78](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R78),[120](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R120),[134](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R134) impaired dynamic joint motion,[30](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R30),[31](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R31),[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R54),[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R55),[78](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R78),[130](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R130) abnormal neuromuscular control,[116](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R116),[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126),[148](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R148),[154](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R154) and difficulty returning to sports[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R3),[4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R4) are all common deficiencies in the months and years following ACLR, and often persist in spite of formal rehabilitation.[31](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R31),[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R55),[56](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R56),[130](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R130) Strength symmetry with the uninjured contralateral limb, in particular, is proposed as one of several important indicators of return-to-sport readiness and, eventually, for discharge to unrestricted sports activity following ACLR.[56](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R56),[107](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R107),[146](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R146),[151](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R151) Quadriceps strength is strongly related to measurements of knee function and neuromuscular control in athletes following ACL injury and those who have undergone ACLR.[25](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R25),[37](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R37),[68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R68),[69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R69),[78](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R78),[91](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R91),[134](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R134),[137](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R137) While hamstrings strength alone may not show a significant effect on knee function following ACL injury and reconstruction,[18](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R18),[69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R69) hamstrings activation may be an important component in neuromuscular control of the reconstructed knee.[18](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R18) Deficits in the hamstrings-quadriceps torque production ratio also appear to be a key variable in the primary–ACL injury risk model,[96](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R96),[100](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R100) but the relationship to second–ACL injury risk has not yet been assessed. Prior to the resumption of high-level, high-risk sports activity, many groups advise that symmetry in quadriceps and hamstrings strength, compared to the contralateral limb, be at least 85%.[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R1),[56](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R56),[107](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R107),[146](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R146) The relationships between muscle weakness, neuromuscular control deficits, and risk for reinjury are still under investigation, but an understanding of the interplay may be critical to the development of effective, patient-specific rehabilitation programs and reduction of second-injury risk.

**Impaired Neuromuscular Control**

Recovery of normal strength symmetry after ACLR unfortunately does not ubiquitously translate to appropriate neuromuscular control.[31](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R31),[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R55) This concept is also evident in healthy athletic females who demonstrate high-risk biomechanical features despite adequate leg-to-leg strength symmetry.[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61) Good neuromuscular control is achieved by the intricate balance of adequate strength and mobility, kinesthetic awareness, efficient joint mechanics, and a sufficiently adaptive motor control system. Even after athletes have undergone ACLR and been cleared to return to activity, deficits in neuromuscular control are evident.[31](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R31),[108](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R108),[123](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R123),[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126) In tasks as basic as walking, athletes who fail functional return-to-sport criteria demonstrate more kinematic and kinetic asymmetries of the knee and hip compared with those who pass these criteria.[31](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R31)During sport-related jumping tasks, alterations in force-attenuation and force-generation strategies, as well as multidimensional kinematic and kinetic asymmetries of the hips and knees, have been identified up to 4 years after ACLR.[20](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R20),[26](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R26),[89](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R89),[123](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R123),[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126)

Importantly, deficits in the neuromuscular control of both lower extremities following ACLR are highly predictive of the risk for second ACL injury.[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126)Paterno and colleagues[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126) prospectively examined 56 athletes following ACLR who were medically cleared for sports participation to document the movement characteristics predictive of second ACL injuries. One year following baseline testing, 13 athletes had sustained a second ACL injury, from which 4 predictive biomechanical factors for second-injury risk were identified: (1) a net internal rotator moment of the uninvolved hip upon landing, (2) increased frontal plane knee motion during landing, (3) sagittal plane knee moment asymmetries at initial contact, and (4) deficits in postural stability.[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126) This model was shown to predict injury risk with excellent specificity (88%) and sensitivity (92%),[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R126) and was the first study of its kind to link deficient movement patterns to second–ACL injury risk in athletic individuals.

**Deficits in High-Level, Sports-Related Function**

Recent prospective, longitudinal data sets highlight the varied return-to-sport success rate of highly active individuals.[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R3),[88](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R88),[138](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R138) Within the first year following surgery, two thirds of athletes post-ACLR who had been cleared for participation had not returned to their competitive sport.[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R3) A recent systematic review found that only 44% of athletes successfully returned to sport after an average of 41.5 months following ACLR.[4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R4) The low return-to-activity rates may be explained, in part, by the persistence of physical impairments even after formal rehabilitation. When significant quadriceps weakness persists, athletes who have undergone ACLR demonstrate poorer functional-hop performance scores than their stronger counterparts.[134](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R134) Less than 50% of high school–level and collegiate-level athletes indicated that they were able to perform at their pre–ACL injury level.[88](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R88)Therefore, focused neuromuscular re-education and sports-related training should represent a significant component of postsurgical rehabilitation programs.[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R1),[58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R58),[107](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R107)

**Linking Presurgical and Postsurgical Neuromuscular Impairments With Second–ACL Injury Risk**

Several modifiable and nonmodifiable factors have been reported to increase an athlete’s risk for a second ACL injury. Nonmodifiable factors, including surgical technique, sex, and age of the patient, can significantly impact second-injury risk.[15](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R15),[65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R65),[83](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R83),[125](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R125),[136](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R136),[149](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R149) Specifically, graft inclination angles less than 17°[65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R65) and use of allografts (odds ratio = 5.56)[16](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R16) significantly increase an individual’s risk for graft rupture, whereas the use of patellar tendon grafts may significantly increase the risk for contralateral ACL rupture (odds ratio = 2.6).[79](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R79) Graft size also appears to influence second-injury risk; within 4 years of ACLR, the odds ratio for graft rupture in athletic individuals with a smaller graft size was 2.2, and revision was performed significantly more often in those athletes with a graft diameter of 7 mm or less.[84](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R84) Age[65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R65),[84](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R84),[136](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R136),[150](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R150) and sex[125](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R125),[136](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R136) also play a significant role in second-injury risk. Young, active female athletes, in particular, have a significantly increased risk for a second[17](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R17) and contralateral injury when compared to young, athletic males.[125](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R125),[136](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R136) The incidence rate of a second ACL injury in young female athletes is 16 times greater when compared to primary–ACL injury incidence in the same population, and 4 times greater than second-injury rates in young male athletes.[125](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R125) Interestingly, after ACLR, the risk for contralateral ACL rupture may be at least twice that of graft rupture, regardless of sex, and may be indicative of residual and magnified asymmetries in neuromuscular control.[125](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R125),[160](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R160)

One of the most significant modifiable predictors of a second ACL injury is the athlete’s activity level.[16](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R16),[133](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R133) Return to higher levels of activity that require cutting, pivoting, and jumping may substantially increase the risk of a second ACL injury between 5-fold[16](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R16) and 10-fold.[133](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R133) Though time since surgery may not dictate functional performance following ACLR,[105](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R105) an earlier time since surgery appears to be significantly related to higher second-injury risk.[75](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R75),[133](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R133),[150](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R150) As the first several months following ACLR are also characterized by compensatory movement patterns and asymmetries,[31](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R31),[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R54),[55](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R55),[112](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R112),[130](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R130) attention must be given to the role of modifiable neuromuscular deficits in second–ACL injury risk.[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126) In a study by Paterno et al,[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126) multiplanar neuromuscular impairments found in both the ACL-reconstructed and uninjured limbs combined to predict second ACL rupture with 92% sensitivity and 88% specificity. Interestingly, knee abduction motion appears to be a key factor in both primary–[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61) and second–ACL injury[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126) risk models. Although the efficacy of neuromuscular training in reducing second–ACL injury risk has not been empirically tested, reduction of primary-injury incidence using similar methods has proven effective.[110](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R110),[145](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R145)

**PROPOSED ASSESSMENT OF IMPAIRMENTS POST-ACLR**

Current evidence-based standards for postoperative rehabilitation include exercises and neuromuscular training to restore full and pain-free range of motion, maximize strength, and achieve preinjury function.[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R1),[107](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R107) Targeted rehabilitation programs are likely most effective when tailored to patient-specific neuromuscular deficits, but methods of assessing these deficits can vary widely.[8](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R8) The proposed late-phase rehabilitation program described herein incorporates progressively more challenging tasks; therefore, objective criteria should be used to enter patients safely into this program. To perform the proposed clinical testing battery, it is advised that all patients demonstrate full and pain-free knee range of motion equal to that of the contralateral limb,[139](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R139) minimal joint effusion,[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R1) at least 70% strength symmetry,[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R1) and the ability to hop in place without pain or apprehension.

Time since surgery alone does not adequately identify readiness for return to sport,[105](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R105) nor should it determine the course of progression through each phase of rehabilitation.[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R1),[107](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R107) Use of a battery of clinical tests and measures, including objective measures of strength, dynamic knee function, and self-reported measures of knee function, is advocated at multiple points throughout the late phase of rehabilitation to document progress toward functional goals and to determine return-to-sport readiness.[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R7),[8](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R8),[58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R58),[81](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R81),[105](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R105),[146](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R146),[151](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R151) Quadriceps strength deficits in athletes following ACLR are related to restricted knee motion during gait,[78](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R78) lower limb-symmetry values on single-leg hop tests,[134](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R134) and poorer self-reported function.[134](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R134) Midterm knee function as measured by single-leg hop tests 6 months after surgery demonstrated excellent accuracy for prediction of athletes who will have normal knee function 1 year following ACLR.[80](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R80) In a longitudinal outcomes study of 79 athletes following ACLR, those who reported knee function within normal ranges on the International Knee Documentation Committee 2000 Subjective Knee Evaluation Form 1 year after surgery had significantly higher limb-symmetry values on the crossover test and timed 6-meter hop test when tested 6 months after surgery.[80](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R80) Thus, serial clinical testing can be an excellent source of information for treating clinicians as they progress their athletes through the phases of rehabilitation and back into their sports activity.

**PROPOSED INTERVENTION TO PREVENT SECOND ACL INJURY**

Persistent deficits in neuromuscular control postsurgery are a key component of increased second-injury risk following ACLR.[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126) Applying the theories of motor learning,[43](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R43) previous findings from our laboratory,[98](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R98),[102](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R102),[103](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R103),[109](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R109) and the work of others,[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R6),[9](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R9),[52](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R52),[115](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R115),[116](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R116) a late-phase, targeted neuromuscular rehabilitation program is presented that aims to address all modifiable components of the second–ACL injury risk profile, as well as common residual preinjury and postinjury movement deficits.[58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R58),[95](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R95),[106](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R106) The use of programs that enhance control of 3-D body positions[9](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R9),[52](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R52),[98](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R98),[102](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R102),[103](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R103),[109](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R109),[113](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R113)-[116](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R116) is substantiated by literature that has evaluated ACL injury risk, mechanisms, and joint loading considering multiplanar factors.[61](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R61),[110](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R110),[145](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R145),[152](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R152),[161](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R161)

Programs that have been shown to successfully reduce primary-injury risk and incidence of ACL injuries have incorporated 3-D movement retraining of progressively greater speed and difficulty, while emphasizing proper jump-landing[59](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R59),[71](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R71),[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R74),[85](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R85),[119](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R119),[127](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R127),[145](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R145),[152](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R152) and balancing techniques.[71](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R71),[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R74),[111](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R111),[119](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R119),[127](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R127),[142](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R142) The exercises outlined in this manuscript were selected for 3 specific reasons: (1) they activate the muscles hypothesized to be deficient at the time of return to sport, (2) they utilize surfaces and movements that elicit muscle coactivation capable of modifying mechanics theorized to be related to injury risk, and (3) they elicit movements that may replicate conditions experienced during sport ([**TABLE 2**](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/table/T2/)). These exercises, in varying combinations, have been evaluated for their efficacy in reducing factors related to primary–ACL injury risk and have been summarized in detail previously.[95](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R95),[124](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R124) Because leg-to-leg asymmetries greatly increase the risk of second ACL injury,[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126) and asymmetries in athletes following ACLR appear to be the product of bilateral limb adaptations,[42](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R42),[54](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R54),[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126),[130](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R130) this rehabilitation protocol incorporates bilateral training to address neuromuscular deficits that may exist in both limbs.

**DISCUSSION**

**Symmetry**

Due to the known influence of side-to-side limb asymmetry on second–ACL injury risk,[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R126) and that several batteries of tests to determine return-to-sport readiness continue to emphasize limb symmetry,[146](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R146) rehabilitation protocols should be tailored to address deficits identified in both limbs. This is especially important as we begin to better understand the implications of asymmetry as well as deficits in athletes following ACL injury compared to those in healthy controls, not only for shortterm functional performance but also for reinjury rates and future function. Athletes recovering from ACLR should not be considered fully rehabilitated purely in the absence of asymmetry. Consideration of the sport-specific and position-specific demands of each athlete, combined with residual bilateral neuromuscular deficits, will allow clinicians to tailor return-to-sport recommendations to fit individual needs. Our proposed methods to treat neuromuscular deficits following ACLR are based on the assumption that the restoration of limb symmetry and normal movement patterns will not only maximize functional performance but also mitigate future injury risk. While there is strong evidence for the effectiveness of neuromuscular training in modifying risky neuromuscular patterns in healthy athletes[93](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R93),[97](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R97),[98](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R98),[102](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R102),[103](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R103),[109](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R109) and athletes who are ACL deficient,[32](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R32),[39](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R39),[45](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R45) far less is known about the ability of athletes who have undergone ACLR to improve aberrant movement strategies via similar programs. Specifically, the effectiveness of this proposed strategy in achieving functional symmetry, maximizing sport performance, and minimizing abnormal movement strategies must be prospectively examined in athletes following ACLR.

**Return to Sport**

Clinicians must consider the specific needs of each athlete to tailor the late-phase rehabilitation and preparatory return-to-activity program. The goal of this paper was to provide evidence-based guidelines for the late-phase postoperative care of these athletes in preparation for a safe return to sports activity. Specific return-to-sport training was not the focus of this paper but may be an important component of return-to-activity preparation[27](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R27),[88](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R88) and should be implemented based on the needs of each athlete and the demands of the sport, as previously published for sports like soccer, basketball, and downhill skiing.[11](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R11),[72](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R72),[153](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R153) To date, the effectiveness of the exercise components described has not been empirically tested on athletes following ACLR; however, recent reports indicate that the addition of on-field rehabilitation helps to address lingering deficits in the return-to-sport phase.[11](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R11),[27](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R27),[72](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R72),[153](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R153) Future studies should focus on randomized controlled trials of specific, targeted neuromuscular interventions.

**CONCLUSION**

The goal of this review was to describe the neuromuscular characteristics associated with second-injury risk factors and to provide sports health practitioners with evidence-based information regarding late-phase ACLR rehabilitation. Achievement of optimal function and sports performance after ACLR is likely dependent on a number of both modifiable and nonmodifiable factors.[35](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R35),[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/%22%20%5Cl%20%22R126),[160](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R160)Neuromuscular control deficiencies are, at this time, the only known modifiable factors predictive of second–ACL injury risk.[126](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R126) Targeted interventions aimed at these movement impairments may significantly reduce reinjury risk in athletes who have undergone ACLR.[58](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#R58) The long-term benefits of an effective rehabilitation program may also be realized, both by the full restoration of functional performance and by the improved ability of these individuals to maintain lifetime activity participation without disabling knee symptoms. The evidence outlined in this review provides a platform on which evidence-based treatment approaches can be developed. Future research studies should focus on randomized controlled trials of specific, targeted neuromuscular interventions.

​

**SYNOPSIS**

Successful return to previous level of activity following anterior cruciate ligament (ACL) reconstruction is not guaranteed, and the prevalence of second ACL injury may be as high as 30%. In particular, younger athletes who return to sports activities within the first several months after ACL reconstruction may be at significantly greater risk of a second ACL rupture compared to older, less active individuals. Significant neuromuscular deficits and functional limitations are commonly identified in athletes following ACL reconstruction, and these abnormal movement and neuromuscular control profiles may be both residual of deficits existing prior to the initial injury and exacerbated by the injury and subsequent ACL reconstruction surgery. Following ACL reconstruction, neuromuscular deficits are present in both the surgical and nonsurgical limbs, and accurately predict second–ACL injury risk in adolescent athletes. While second ACL injury in highly active individuals may be predicated on a number of modifiable and nonmodifiable factors, clinicians have the greatest potential to address the modifiable postsurgical risk factors through targeted neuromuscular interventions. This manuscript will (1) summarize the neuromuscular deficits commonly identified at medical discharge to return to sport, (2) provide the evidence underlying second–ACL injury risk factors, (3) propose a method to assess the modifiable deficits related to second–ACL injury risk, and (4) outline a method of intervention to prevent second ACL injury. The program described in this clinical commentary was developed with consideration for the modifiable factors related to second-injury risk, the principles of motor learning, and careful selection of the exercises that may most effectively modify aberrant neuromuscular patterns. Future validation of this evidence-based, late-phase rehabilitation program may be a critical factor in maximizing return-to-activity success and reduction of second-injury risk in highly active individuals.

**Appendix A**

**Single-Leg Anterior Progression**

[](https://www.ncbi.nlm.nih.gov/core/lw/2.0/html/tileshop_pmc/tileshop_pmc_inline.html?title=Click%20on%20image%20to%20zoom&p=PMC3&id=4163697_nihms-627240-f0002.jpg" \t "tileshopwindow)

The clinician instructs the athlete to descend into a deep–knee flexion hold upon each take-off and landing, avoiding excessive non–sagittal plane motion of the lower extremities and trunk. Phase 1 focuses on symmetry during take-off and landing, and the clinician should encourage jumping farther once the athlete has mastered the basic technique. Progression to phase 2 should occur only after the athlete can demonstrate proper technique during phase 1. Single-leg jumping for distance with proper take-off and landing is the focus of phase 3, prior to repeated anterior jumps in phase 4 (phases 1-4: 3 × 10 repetitions bilaterally).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/)

**APPENDIX B**

**Single-Leg Lateral Progression**

[](https://www.ncbi.nlm.nih.gov/core/lw/2.0/html/tileshop_pmc/tileshop_pmc_inline.html?title=Click%20on%20image%20to%20zoom&p=PMC3&id=4163697_nihms-627240-f0003.jpg" \t "tileshopwindow)

The clinician instructs the athlete to begin and end each hop hold with deep knee flexion, avoiding excessive non–sagittal plane motion of the lower extremities and trunk during take-off and landing. In the later phases, the athlete should also be instructed to minimize the amount of rebound (or reverberation) of the BOSU under the foot. Phase 4 should incorporate lateral and medial jumping (phases 1-4: 3 × 10 repetitions bilaterally).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/)

**APPENDIX C**

**Lunge Progression**

[](https://www.ncbi.nlm.nih.gov/core/lw/2.0/html/tileshop_pmc/tileshop_pmc_inline.html?title=Click%20on%20image%20to%20zoom&p=PMC3&id=4163697_nihms-627240-f0004.jpg" \t "tileshopwindow)

The clinician instructs the athlete to maintain most of the weight on the lead leg as they lunge forward into a deep knee flexion, avoiding hyperextension of the trunk. A slight forward lean is acceptable, as this will assist the patient to drive off the lead leg. The athlete’s knee should never advance beyond the ankle during the exercise. The clinician should also cue the athlete to avoid pausing between the lunge and upright portions of the task (phase 1: 3 × 10 repetitions bilaterally; phases 2-4: 10 m × 2 sets).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/)

**APPENDIX D**

**Tuck Jump Progression**

[](https://www.ncbi.nlm.nih.gov/core/lw/2.0/html/tileshop_pmc/tileshop_pmc_inline.html?title=Click%20on%20image%20to%20zoom&p=PMC3&id=4163697_nihms-627240-f0005.jpg" \t "tileshopwindow)

The clinician instructs the athlete on the proper countermovement preparation (slight crouch downward, extending arms behind body) prior to the vertical jump. The vertical jump begins as the athlete vigorously swings the arms forward as they jump straight up, pulling their knees up as high as possible. The goal is to achieve a parallel position of both thighs in relation to the floor, and to use a toe-to-midfoot rocker landing upon descent into a deep–knee flexion hold. As the athlete progresses from 2 consecutive jumps (phase 2) with proper technique to multiple consecutive jumps (phase 3), the clinician instructs the athlete to avoid excessive non–sagittal plane motion of the lower extremities and trunk, and to try to take off and land in the same footprint in which the task started. Tuck jumps performed over an object should be completed only if the athlete completes repeated phase 3 jumps with proper technique (phases 1-2: 2 × 10 repetitions; phases 3-4: 2 × 10 seconds).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/)

**APPENDIX E**

**Lateral Jump Progression**

[](https://www.ncbi.nlm.nih.gov/core/lw/2.0/html/tileshop_pmc/tileshop_pmc_inline.html?title=Click%20on%20image%20to%20zoom&p=PMC3&id=4163697_nihms-627240-f0006.jpg" \t "tileshopwindow)

The goal of this exercise is to focus on minimizing the frontal plane motion of the trunk and lower extremities during lateral jumping. The height of the jump is not the focus; rather, increasing speed with good technique is the criterion by which the athlete will be progressed to the next phase. A deep–knee flexion position is emphasized upon each take-off and landing, regardless of phase. The clinician should encourage the athlete to jump “close to the line” in preparation for quicker lateral movements. This exercise is progressed from double leg (phases 1 and 2) to single leg (phases 3 and 4) once the athlete can demonstrate symmetrical timing and proper alignment with single- (phase 1) and then repeated double-leg landing (phase 2) (phases 1-2: 2 × 10 repetitions; phase 3: 2 × 10 repetitions bilaterally; phase 4: 2 × 10 seconds bilaterally).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/)

**APPENDIX F**

**Lateral Trunk Progression**

[](https://www.ncbi.nlm.nih.gov/core/lw/2.0/html/tileshop_pmc/tileshop_pmc_inline.html?title=Click%20on%20image%20to%20zoom&p=PMC3&id=4163697_nihms-627240-f0007.jpg" \t "tileshopwindow)

The clinician provides stabilization at the pelvis and lower extremities throughout the phases. The clinician instructs the athlete to bend laterally at the waist during the crunch movement and avoid non–frontal plane motion of the trunk. The athlete should also maintain the arms in a crossed position over the chest, except when involved in a partner toss-and-catch activity. Progression should be implemented when the athlete can complete the current phase with proper form and full trunk motion (phases 1-4: 3 × 10 repetitions bilaterally).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/)

**APPENDIX G**

**Prone Trunk Stability**

[](https://www.ncbi.nlm.nih.gov/core/lw/2.0/html/tileshop_pmc/tileshop_pmc_inline.html?title=Click%20on%20image%20to%20zoom&p=PMC3&id=4163697_nihms-627240-f0008.jpg" \t "tileshopwindow)

The clinician instructs the athlete to minimize the amount of rebound (or reverberation) of the BOSU under the trunk, especially during partner perturbations. As the athlete progresses to the prone bridge position (phases 3 and 4), the 2 to 3 contact points away from the center of mass further destabilize the athlete as they alternate extremity limb positions. The goal is to avoid excessive trunk rotation and flexion or hyperextension as they lift their limbs (phases 1-4: 3 × 10 repetitions bilaterally).

**Kneeling Trunk Stability**



The clinician instructs the athlete to maintain slight hip flexion throughout the different phases. Excessive trunk flexion and upper extremity strategy (flailing of arms) should be avoided, especially when the clinician is providing perturbations to the support surface (phase 4). The clinician should avoid administering a subsequent destabilizing perturbation prior to the athlete restoring their equilibrium (phases 1, 3, and 4: 3 × 20 seconds; phase 2: 3 × 20 seconds bilaterally).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/)

**APPENDIX I**

**Posterior Chain Progression**

[](https://www.ncbi.nlm.nih.gov/core/lw/2.0/html/tileshop_pmc/tileshop_pmc_inline.html?title=Click%20on%20image%20to%20zoom&p=PMC3&id=4163697_nihms-627240-f0010.jpg" \t "tileshopwindow)

The clinician instructs the athlete to avoid lumbar hyperextension during the bridging-task phases. Manual and verbal cues may be necessary to acclimate the athlete to a neutral pelvic position during this exercise, avoiding contralateral hip drop. As the athlete advances through stages, the goal is to perform full, uncompensated motion. Phase 3 is designed to narrow the base of support and the number of contact points to increase the diffculty of the task. In phase 4, the athlete should be instructed to minimize motion of the ball under their feet while achieving controlled hip flexion and extension (phases 1-4: 3 × 10 repetitions).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/)

**APPENDIX J**

**Romanian Dead Lift Progression**

[](https://www.ncbi.nlm.nih.gov/core/lw/2.0/html/tileshop_pmc/tileshop_pmc_inline.html?title=Click%20on%20image%20to%20zoom&p=PMC3&id=4163697_nihms-627240-f0011.jpg" \t "tileshopwindow)

The key component to this exercise progression is the ability of the athlete to minimize trunk deviation in the frontal and transverse planes while avoiding excessive cocontraction of the muscles of the lower extremities. The clinician instructs the athlete to keep the muscles of the standing leg relaxed, with the knee slightly flexed and toes and foot relaxed. Hip hinging with an erect spine should be emphasized throughout the phases (phases 1-4: 3 × 10 repetitions bilaterally).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/)

**APPENDIX K**

**Lunge Jump Progression**

[](https://www.ncbi.nlm.nih.gov/core/lw/2.0/html/tileshop_pmc/tileshop_pmc_inline.html?title=Click%20on%20image%20to%20zoom&p=PMC3&id=4163697_nihms-627240-f0012.jpg" \t "tileshopwindow)

This is a plyometric advancement of the lunge progression in [**APPENDIX C**](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/#APP3), and the same emphasis should be placed on the mechanics of the lead leg and trail leg, as well as the trunk. The clinician instructs the athlete to maintain more weight toward the lead limb to generate adequate power for the jump and maintain balance. The clinician instructs the athlete to descend into a deep–knee flexion hold upon each jump take-off and landing, avoiding excessive non–sagittal plane motion of the lower extremities and trunk (phases 1 and 3: 3 × 10 repetitions bilaterally; phases 2 and 4: 3 × 20 seconds).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4163697/)

**Current status of ACL reconstruction in Germany.**

[Shafizadeh S](https://www.ncbi.nlm.nih.gov/pubmed/?term=Shafizadeh%20S%5BAuthor%5D&cauthor=true&cauthor_uid=26897352)1, [Jaecker V](https://www.ncbi.nlm.nih.gov/pubmed/?term=Jaecker%20V%5BAuthor%5D&cauthor=true&cauthor_uid=26897352)2, [Otchwemah R](https://www.ncbi.nlm.nih.gov/pubmed/?term=Otchwemah%20R%5BAuthor%5D&cauthor=true&cauthor_uid=26897352)2, [Banerjee M](https://www.ncbi.nlm.nih.gov/pubmed/?term=Banerjee%20M%5BAuthor%5D&cauthor=true&cauthor_uid=26897352)2, [Naendrup JH](https://www.ncbi.nlm.nih.gov/pubmed/?term=Naendrup%20JH%5BAuthor%5D&cauthor=true&cauthor_uid=26897352)3.

**INTRODUCTION:**

Reconstruction of the anterior cruciate ligament (ACL) is characterized by a variety of possibilities concerning its implementation. Different choices for grafts, fixation methods and tunnel positioning, as well as diverse technical tools are available and have clinical significance. Besides specific pre- and post-operative procedures, different indications for surgery and further surgeon-/clinic-related factors add variability to the treatment. In response to the lack of descriptive statistics about the implementation of these factors and the increasing numbers of ACL reconstructions this study has been conducted to display the current state of the treatment for ACL tears throughout Germany.

**MATERIALS AND METHODS:**

709 clinics with surgical and orthopedic departments were provided an online-questionnaire that surveyed their statistical records (e.g. annually implemented operations, number of surgeons, duration of operations), implemented techniques (e.g. choice of grafts, construction of drilling tunnel, tibial/femoral fixation) and personal assessment (e.g. frequency/cause of graft failure, frequency/handling of infection). The response rate was 22 % (n = 155). Based on the statistical records a specialized group within the respondents was identified, enabling a cross-comparison between high- and low-volume surgeons.

**RESULTS:**

On average, the German orthopedic surgeons in the clinics surveyed annually performs 35 ACLreconstructions, with each operation lasting an average of 67 min. After subdividing the data with references to annually performed surgeries into high- and low-volume-surgeons, differences and common features between the subgroups become apparent. Differences between high- and low-volume-surgeons, respectively, show shorter duration of both ACL reconstructions (55 vs. 71 min) and revision ACL reconstructions (75 vs. 90 min), higher membership rates in professional associations (83 vs. 38 % have at least one membership), more frequent implementation of stability examinations (47 vs. 21 %) and different frequencies of femoral drilling techniques (using the anterolateral portal in 71 vs. 54 %). With reference to evaluating operation dates, choosing grafts and assessing reasons for graft failure both groups share commonalities, as well as regarding the predominant use of monofixation for femoral fixation (88 % of the participants-mainly with endobutton in 38 % and transfixation pin in 27 %) and for tibial fixation (81 % of the participants-mainly with bioabsorbable screw in 60 %).

**CONCLUSIONS:**

The treatment of ACL tears in the group of German clinics studied is characterized by a variety of surgical possibilities. This condition might reflect the entirety of clinics reconstructing ACL in Germany. For the first time, a descriptive statistical survey was implemented to display this variety and to provide insight into the current status quo. Within the entirety of surgeons implementing ACL reconstruction a specialized subgroup with a particular expertise seems to exist.

[J Pediatr Orthop.](https://www.ncbi.nlm.nih.gov/pubmed/26165552) 2015 Jul 9. [Epub ahead of print]

**A 10-year Retrospective Review of Functional Outcomes of Adolescent Anterior Cruciate Ligament Reconstruction.**

[Reid D](https://www.ncbi.nlm.nih.gov/pubmed/?term=Reid%20D%5BAuthor%5D&cauthor=true&cauthor_uid=26165552)1, [Leigh W](https://www.ncbi.nlm.nih.gov/pubmed/?term=Leigh%20W%5BAuthor%5D&cauthor=true&cauthor_uid=26165552), [Wilkins S](https://www.ncbi.nlm.nih.gov/pubmed/?term=Wilkins%20S%5BAuthor%5D&cauthor=true&cauthor_uid=26165552), [Willis R](https://www.ncbi.nlm.nih.gov/pubmed/?term=Willis%20R%5BAuthor%5D&cauthor=true&cauthor_uid=26165552), [Twaddle B](https://www.ncbi.nlm.nih.gov/pubmed/?term=Twaddle%20B%5BAuthor%5D&cauthor=true&cauthor_uid=26165552), [Walsh S](https://www.ncbi.nlm.nih.gov/pubmed/?term=Walsh%20S%5BAuthor%5D&cauthor=true&cauthor_uid=26165552).

[**Author information**](https://www.ncbi.nlm.nih.gov/pubmed/26165552)

**Abstract**

**BACKGROUND:**

Rupture of the anterior cruciate ligament (ACL) is an increasingly prevalent sporting injury in adolescents. Surgical reconstruction of the ACL in adolescents has been controversial and there has been little reported on functional outcomes after surgery.The aim of this study was to undertake a retrospective notes review and questionnaire survey of a group of adolescents who had their ACL surgically reconstructed over the previous 10 years, assessing delay to surgery, levels of meniscal damage, reoperation rates, and functional outcomes.

**METHODS:**

A retrospective chart review was performed on 100 adolescent patients who underwent arthroscopicACL reconstruction using a transphyseal technique. These patients were also contacted and completed the Knee Osteoarthritis Outcome Score (KOOS).

**RESULTS:**

One hundred patients had their records reviewed. The average age at follow-up was 20.5 (SD, 2.4) years. There were 49 females and 51 males. Meniscal tears were present in 76% of patients at the time of surgery. The rate of medial meniscal tears increased with delay to surgical intervention beyond 3 months. Reoperation rate for these patients was 24%.Eighty patients completed the KOOS questionnaire. Patients were a mean of 4 (SD, 2.2) years postsurgery. The main findings indicate that in the 5 key KOOS domains patients scored a mean of 60 (SD, 13) for symptoms, 65 (SD, 10) for pain, 70 (SD, 6.4) for activities of daily living, 54 (SD, 17.6) for sport and recreation, and 47.2 (SD, 20.1) for quality of life.

**CONCLUSIONS:**

This study demonstrates that young people with ACL injuries have a very high associated incidence of meniscal pathology at the time of surgery. There is a high reoperation rate for meniscal surgery and graft failure. Four years post-ACL reconstruction many have not yet returned to a fully functional state.Further research to understand why functional outcomes are modest is required.

**Baseline Predictors of Health-Related Quality of Life After Anterior Cruciate Ligament Reconstruction**

A Longitudinal Analysis of a Multicenter Cohort at Two and Six Years

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/)

**Abstract**

**Background:**

Limited information exists regarding predictors of general quality of life following anterior cruciate ligament (ACL) reconstruction with up to six-year follow-up. We hypothesized that certain variables evaluated at the time of ACL reconstruction will predict the general quality of life as measured by the Short Form-36 (SF-36).

**Methods:**

All unilateral ACL reconstructions from 2002 to 2004 in patients currently enrolled in a prospective multicenter cohort were evaluated. Patients preoperatively completed the SF-36 validated outcome instrument. Surgeons documented intra-articular pathological conditions and treatment, as well as the ACL reconstruction surgical technique. At baseline and at a minimum of two and six years postoperatively, patients completed the SF-36. Longitudinal analysis was performed for the two-year and six-year end points.

**Results:**

Of the initial 1512 subjects, at least one follow-up questionnaire was obtained from 1411 subjects (93%). The cohort was 44% female, and the median patient age at enrollment was twenty-three years. The mean scores were 41.9 points for the Physical Component Summary (PCS) and 51.7 points for the Mental Component Summary (MCS) at baseline, 53.6 points for the PCS and 52.0 points for the MCS at two years, and 54.0 points for the PCS and 52.4 points for the MCS at six years. Significant predictors of a higher PCS score were a higher baseline PCS score, younger age, lower baseline body mass index, having >50% of the lateral meniscus excised, or having no treatment done on a lateral meniscal tear. In contrast, significant predictors of a lower PCS score were a shorter follow-up time since surgery, revision ACL reconstruction, smoking at baseline, fewer years of education, and chondromalacia of the lateral tibial plateau. The mean utility gained at six years after ACL reconstruction was 5.3 quality-adjusted life years (QALYs).

**Conclusions:**

Large improvements in the PCS (with an effect size of 1.2) were noted at two years and were maintained at six years after ACL reconstruction. Lower education and smoking were significant predictors of lower PCS and MCS scores. ACL reconstruction resulted in a relatively high gain of QALYs.

**Level of Evidence:**

Prognostic Level I. See Instructions for Authors for a complete description of levels of evidence.

There is sparse literature regarding the prognosis and predictors of anterior cruciate ligament (ACL) reconstruction outcomes at six years as measured by validated patient-based outcome instruments and assessed by multivariable analysis. Knowing prognostic information would be valuable in physician counseling of patients considering ACL reconstruction.

Large sample sizes with adequate follow-up are necessary for such analysis. A previously published randomized controlled trial had an enrollment of 225 patients[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/#bib1), which limits risk factor analysis. A previous cohort study utilizing multivariable analysis was limited by 69% follow-up and the lack of baseline measurements of the outcomes[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/#bib2), which are important to adjust for, as they are often the strongest predictor of follow-up scores.

The Short Form-36 (SF-36) is a widely used measure of general quality of life. It allows for comparison across different disease categories; therefore, normative-based scoring converts the scores such that they have direct interpretation related to the general United States population, with a mean score (and standard deviation) of 50 ± 10 points. Hence, a 1-point change in a score is one-tenth of a standard deviation or an effect size of 0.10[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/#bib3). The Short Form-6 dimension (SF-6D), a preference-based utility measure, can be calculated from the SF-36, allowing the calculation of quality-adjusted life years (QALYs)[4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/%22%20%5Cl%20%22bib4). Previous studies utilizing the SF-36 in athletic populations have compared domain scores, ranging from 0 to 100 points, to normative values, which do not as easily lend themselves to interpretation, but have not reported normative-based scores[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/#bib5),[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/#bib6). The eight subscales of the SF-36 can be collapsed into two components, the Physical Component Summary (PCS) score and the Mental Component Summary (MCS) score. The use of the PCS and MCS has been advocated for large studies, particularly when there is a focus on the general effect on health[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/#bib7).

The aim of the current study was to determine the prognosis and predictors of health-related quality of life as measured by the SF-36 at two and six years after surgery as well as the utility gained following ACL reconstruction as measured by the SF-6D. These results should aid evidence-based decision-making as related to a patient’s prognosis following ACL reconstruction, should provide a high level of evidence for surgeon decision-making, and should have the potential to identify future modifiable risk factors that could be altered to improve outcomes of ACL reconstruction. Furthermore, the improvements in health-related quality of life and utility according to the SF-6D should provide justification for expenditures related to patients with ACL injuries.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/)

**Results**

**Study Population**

From January 1, 2002, to December 31, 2004, 1512 subjects met the inclusion criteria of having a unilateral ACL reconstruction and are included in our analyses; see the flow diagram for exclusion criteria ([Fig. 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/figure/fig1/)). Of the initial 1512 subjects, at least one repeat questionnaire was obtained from 1411 subjects (93%). Two-year follow-up was obtained for 1308 subjects (87%), and six-year follow-up was obtained for 1307 subjects (86%). The median age of the cohort was twenty-three years (interquartile range [IQR], seventeen to thirty-five years), and the cohort was 44% female.

**Study End Points**

The mean subscale scores as well as the PCS and MCS scores at baseline and two and six years are presented in [Figure 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/figure/fig2/). The mean scores were 41.9 points for the PCS and 51.7 points for the MCS at baseline, 53.6 points for the PCS and 52.0 points for the MCS at two years, and 54.0 points for the PCS and 52.4 points for the MCS at six years. The mean utility gained at six years was 5.3 QALYs.



[Fig. 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/figure/fig2/)

Normative-based scoring of the SF-36 profile. t0 = baseline, t2 = two-year follow-up, and t6 = six-year follow-up.

Multivariable analysis was used to determine which baseline variables measured at the time of index ACL surgery were significant predictors of health-related quality of life at two and six years after surgery. We summarized the results of the ten models by including two plots, one for the physical domain models and the PCS ([Fig. 3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/figure/fig3/)) and one for the mental domain models and the MCS ([Fig. 4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/figure/fig4/)). The plots show the independent variables on the vertical axis, and the relative portion of the variation in the outcome accounted for by the given variable on the horizontal axis. This importance is measured by Wald chi-square statistics minus the degrees of freedom. The subscale measured at the time of surgery tended to be the most important variable in predicting the corresponding subscale measured at subsequent times. The different domain scores showed consistency in the ranking of the importance of the independent variables. Hence, results are presented for the two summary scores and not for all subscale scores.

The following variables were significant predictors of higher scores: a higher baseline PCS (IQR odds ratio [the change in log odds from the twenty-fifth to the seventy-fifth percentile for continuous predictors], 1.57 [95% confidence interval {95% CI}, 1.26 to 1.96]; p < 0.0001); younger age (IQR odds ratio, 2.04 [95% CI, 1.28 to 3.23]; p = 0.002); lower baseline BMI (IQR odds ratio, 1.35 [95% CI, 1.18 to 1.53]; p < 0.0001); lateral meniscal treatment (p = 0.009), specifically, having >50% of the lateral meniscus excised (IQR odds ratio, 2.45 [95% CI, 1.49 to 4.01]); or having no treatment done for a lateral meniscal tear (IQR odds ratio, 1.27 [95% CI, 1.01 to 1.59]).

The following variables were significant predictors of lower scores: shorter follow-up time since surgery (IQR odds ratio, 0.64 [95% CI, 0.50 to 0.82]; p < 0.0001), revision ACL reconstruction (IQR odds ratio, 0.51 [95% CI, 0.39 to 0.68]; p < 0.0001), fewer years of education (IQR odds ratio, 0.70 [95% CI, 0.59 to 0.84]; p = 0.0001), current smoker (IQR odds ratio, 0.52 [95% CI, 0.37 to 0.73]; p = 0.0004), and chondromalacia of the lateral tibial plateau (IQR odds ratio, 0.53 [95% CI, 0.31 to 0.92]; p = 0.03).

A nomogram, which can be used to estimate the mean response for individual patients and to show the relationship among the different predictor variables and how this affects the predicted PCS score, is shown in the [Appendix](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/#app1).

**Discussion**

This study produced several interesting findings that merit further discussion. First, this study showed that the SF-36 is responsive to ACL reconstruction. Next, although no significant changes were observed in the MCS in this relatively young and healthy cohort, large improvements were noted in the PCS at two years and were maintained at six years (effect size of 1.2 at two and six years), demonstrating the durability of the improvement after ACL reconstruction. Specific factors were identified as significant predictors of PCS scores and MCS scores. Our data demonstrated gained QALYs after ACL reconstruction and this gain was clinically important. Lastly, our data exposed some perplexing relationships between concomitant meniscal surgery and SF-36 outcomes after ACL reconstruction.

Our study demonstrated that ACL reconstruction resulted in large improvements in the PCS, with a mean improvement of 12 points at both the two-year and six-year follow-ups. It was encouraging to see maintenance of improved physical scores up to six years after surgery, which demonstrates intermediate-term durability. Baseline activity level as measured with use of the Marx scale was a significant predictor of MCS scores but not PCS scores in the current study. To our knowledge, comparative literature has been limited. Eitzen et al. found lower bodily pain subscores at two years in subjects with concomitant ACL reconstruction and meniscal injuries requiring treatment, but subjects who had meniscal injuries requiring repair were excluded from that study[20](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/#bib20). Månsson et al. examined baseline predictors of health-related quality of life using the SF-36 at three to six years following ACL reconstruction and found that the pre-injury activity level was a predictor of two of the SF-36 subscales[21](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/#bib21). Specifically, a higher baseline Tegner activity level was associated with higher general health scores and lower role emotional scores, whereas we did not find activity level to predict outcome. This discrepancy may be due to the different activity scales (Marx compared with Tegner) used in the two studies.

In contrast to the physical score changes after ACL reconstruction, the MCS and the general health subscale were both well above the population norm of 50 points at baseline and did not change dramatically over time ([Fig. 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/figure/fig2/)). The subjects also reported baseline mental health and vitality subscale scores above the population norm of 50 points ([Fig. 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/figure/fig2/)). This reflects the relatively young and healthy patient cohort studied. Consistent

The outcomes relative to meniscal treatment in the setting of ACL reconstruction are perplexing. However, in the current cohort of more than 1400 ACL reconstruction cases, meniscal treatment is not easily dismissed. Our data demonstrated that having >50% of the lateral meniscus excised was associated with higher outcome scores. This may be the most difficult finding to explain. With an ACL tear, the knee pivots and the anterolateral aspect of the distal part of the femur contacts the posterior aspect of the lateral tibial plateau. In some cases, this can be quite traumatic and can result in subclinical impaction fractures noted as bone bruising on magnetic resonance imaging. Lateral meniscal tears are commonly seen at the time of acute ACL injury, and this is thought to be due to the meniscus being trapped or crushed during these pivoting events. In the MOON cohort, lateral meniscal tears were not found in 49% of ACL reconstruction cases. One could theorize that the meniscus is not normal (despite the absence of a tear), or is covertly damaged, in those cases in which resection did not occur, resulting in lower outcomes. The relationship between meniscectomy and meniscal repair after ACL reconstruction is compelling enough that it warrants further investigation. Our data would suggest that current meniscal tear treatments and algorithms need to be closely examined and to be investigated further. We do not advocate resection of a normal-appearing meniscus. These intermediate-term data also cannot speak to possible long-term outcomes relative to meniscus-preserving compared with meniscus-removing surgery in the setting of ACL reconstruction. Leaving some lateral meniscal tears untreated was associated with improved PCS scores, consistent with previous studies[9](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/#bib9),[32](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/%22%20%5Cl%20%22bib32).

This study had several limitations. The SF-36 is a general health measure and may not be as responsive to ACL reconstruction as joint and condition-specific measures. These knee and disease-specific data were collected but were beyond the scope of the current study, in which impact on general health was the focus. It is possible that other potential influential variables were not included in our analysis efforts despite our attempt to use an exhaustive list of potential variables. To our knowledge, there has been limited information in the orthopaedic literature regarding QALYs, and thus the relative importance of the QALYs gained after ACL reconstruction is difficult to relate in the context of other procedures. Lastly, the findings related to meniscal treatment are perplexing. It is possible that these findings do not reflect reality. However, intensive scrutiny and the use of a very large cohort size suggest that there is merit to further investigating the role of meniscal treatment on outcome in the setting of ACL reconstruction.

In summary, ACL reconstruction results in a large improvement in the SF-36 PCS at two years and is durable to a minimum of six years. The QALYs gained after ACL reconstruction are substantial relative to other successful operations where this has been explored, suggesting that ACL reconstruction utilization is appropriate. Lastly, interesting relationships appear to exist between the treatment of meniscal pathological conditions during concomitant ACL reconstruction and the ultimate outcome assessed using SF-36 measures, which may be explained by patient characteristic confounders.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372989/)

**Evaluation of functional rehabilitation physiotherapy protocol in the postoperative patients with anterior cruciate ligament reconstruction through clinical prognosis: an observational prospective study**

**Background**

The incidence of anterior cruciate ligament injury among the American population associated to sports practice is 3 per 10,000 inhabitants, and approximately one hundred thousand surgeries for the reconstruction of such ligament are performed in the United States on a yearly basis [[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR1)–[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR3)].

Normal operation of the lower limbs is essential both for the activities of daily life and for sports. The interest in the knee joint, particularly the anterior cruciate ligament (ACL) reconstruction has increased more and more, since the disease and its treatment is a challenge for many health care professionals connected to this tematic [[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR1)–[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR5)].

In relation to the cruciate ligament injury most authors agree that it results in biomechanical abnormalities, abnormal function and knee kinematics. On the other hand, several studies have shown conflicting results in physical therapy and rehabilitation programs. The work developed is based on professional experiences or focuses on specific aspects of rehabilitation. For this reason, we did not find statistical or a follow-up long-term data to prove the conclusions reached with physical therapy rehabilitation programs realized [[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR1)–[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR5)].

Physical therapy plays an important role in the recovery of these patients, as several studies have been developed to support clinical guidelines that must be followed and thus enable effective and updated treatment, which can solve the deficiencies, normalize the static stability and knee dynamic and rehabilitate in the shortest time possible, but in a highly secure manner. The first treatments, entitled conventional, emphasized the protection of the graft restricting movement and increasing the turnaround time activities. The increased incidence of joint stiffness in these postoperative led to further studies and changes in protocols [[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR3)–[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR6)].

Later studies developed the accelerated protocols showing that the knee mobilization and its early strength did not compromise the graft healing, knee stability and even decreased the patients recovery time [[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR7), [8](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR8)]. Currently other studies have been conducted emphasizing that, in addition to earliness of movements, there is a need for full functional recovery and is directed to the patients individual needs [[8](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR8)–[11](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR11)].

Although several lines of research related to physical therapy, it is known that the main difference between treatment protocols has been the temporal duration. On the other hand, we did not find in the literature consensus on the effectiveness of treatments or better type of protocol to be followed [[11](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR11), [12](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/#CR12)]. The aim of the study was to evaluate the application of a functional protocol physical therapy rehabilitation in patients with ACL reconstruction based on functional clinical prognosis.

[Table 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/table/Tab2/)

Distribution of patients undergoing functional guideline after surgical reconstruction of the anterior cruciate ligament, according to the classification obtained from Lysholm and IKDC questionnaires

The first classifications indicates the presence of symptoms (measured especially by the Lysholm score) and function impairment (measured mainly by the IKDC). A considerable increase on test scores was observed on the 30th, 90th and 180th days of treatment among participants of the study, which indicates a positive evolution on decreasing the presence of symptoms and increasing the gain of function. It was also observed that only a small percentage Lysholm (5.1 %) and IKDC (1.7 %) of the patients had not reach the highest score at the tests in the end of the 180 days of treatment, in other hand (24.9 %) reached the maximum score of the IKDC form, which implies in full function recovery.

Figures [1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/figure/Fig1/) and [​and22](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/figure/Fig2/) shows that there was a significant statistically increase on Lysholm and IKDC questionnaires gross values during the treatment (p < 0.001), which indicates progressive gain of function.



[Fig. 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/figure/Fig1/)

Evolution of Lysholm scores of patients undergoing physiotherapy functional post-surgery protocol reconstruction of the anterior cruciate ligament, Santo André, Brazil



[Fig. 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/figure/Fig2/)

Evolution of IKDC scores of patients undergoing physiotherapy functional post-surgery protocol reconstruction of the anterior cruciate ligament, Santo André, Brazil

Figure [1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/figure/Fig1/) shows the progress of patients according to the Lysholm scale. The median between 1st, 30th, 90th and 180th days (median 27, 51, 95 and 100 respectively), and Fig. [2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/figure/Fig2/) shows the scale according to the IKDC, 27.6 median for the 1st day, 43.7 for the 30th day, the 90th day to 74.7 and 98.9 for the 180th day. The evolution of the knee functionality was statistically significant at both Lysholm scale (p ≤ 0.001) and IKDC (p ≤ 0.001) from the first to the last day established by the guideline.

The Lysholm scale shows a stronger growth on the first 30 days (70.6 %), while the IKDC scale stronger growth is showed from 30th to 90th days (41.5 %).

Although both smaller scales shows evolution from 90th to 180th, the observed evolution on Lysholm scale was minor than that the evolution found in IKDC scale (5 and 24.4 %, respectively).

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5034679/)

**Discussion**

The principal findings of this study were:

1. The majority of patients undergoing this guideline treatment protocol evolved from bad to excellent in the Lysholm scale (94.9 %)
2. From 177 patients studied (95.5 %) started with a score <41 and at the end of the study (98.45 %) reached the top 81 in the IKDC score scale
3. A considerable increase on test scores was observed for this guideline, which indicates a positive evolution on decreasing the presence of symptoms in the first 30 days showed by Lysholm scale (70.6 %) and increasing the gain of function among 30–90 days in the IKDC scale (41.6 %).

According to the found results there was a significant statistically increase on gross values for Lysholm and IKDC, which suggests a progressive gain of functionality.

**Conclusion**

Given the values obtained with the IKDC and Lysholm in treating patients with reconstruction of the anterior cruciate ligament (ACL), there is a satisfactory functional outcome of these patients suggesting that this protocol may be a physical therapy treatment alternative to be used.

**Cruciate Ligament Reconstruction and Risk of Knee Osteoarthritis: The Association between Cruciate Ligament Injury and Post-Traumatic Osteoarthritis. A Population Based Nationwide Study in Sweden, 1987–2009**

[Richard Nordenvall](https://www.ncbi.nlm.nih.gov/pubmed/?term=Nordenvall%20R%5BAuthor%5D&cauthor=true&cauthor_uid=25148530),1,2,\* [Shahram Bahmanyar](https://www.ncbi.nlm.nih.gov/pubmed/?term=Bahmanyar%20S%5BAuthor%5D&cauthor=true&cauthor_uid=25148530),3,4,5 [Johanna Adami](https://www.ncbi.nlm.nih.gov/pubmed/?term=Adami%20J%5BAuthor%5D&cauthor=true&cauthor_uid=25148530),3 [Ville M. Mattila](https://www.ncbi.nlm.nih.gov/pubmed/?term=Mattila%20VM%5BAuthor%5D&cauthor=true&cauthor_uid=25148530),1,2,6and [Li Felländer-Tsai](https://www.ncbi.nlm.nih.gov/pubmed/?term=Fell%26%23x000e4%3Bnder-Tsai%20L%5BAuthor%5D&cauthor=true&cauthor_uid=25148530)1,2

Gwendolen Reilly, Editor

**Introduction**

Musculoskeletal injuries are common worldwide [[1]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Woolf1). A predominant location is the knee joint, where the cruciate ligaments play a vital role in both stabilization and kinematics [[2]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Andriacchi1).

Injuries to the cruciate ligaments (CL) are common and generally affect the anterior cruciate ligament (ACL) [[3]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Nordenvall1). These injuries occur primarily in activity with knee-pivoting movements such as soccer, basketball and alpine skiing. The mean age at time of diagnosis is 32 years [[3]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Nordenvall1). The incidence of diagnosed CL injury in Sweden is 78 per 100,000 inhabitants and approximately 36% undergo reconstructive surgery [[3]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Nordenvall1). Although men have an increased risk for CL injury in the general population (RR = 1.44) compared with women [[3]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Nordenvall1), the risk among women participating in certain sports is between 2–9 times higher than the risk among men participating in the same activities [[3]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Nordenvall1)–[[9]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Stevenson1).

The most important complication after ACL injury is knee osteoarthritis (OA). In the general population OA in the knee has a reported prevalence of 5% in patients over 26 years and 12% in patients over 60 years [[10]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Lawrence1)–[[12]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Dillon1). Known risk factors for OA are age, obesity and knee trauma [[13]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Niu1). CL injury increases the risk for OA and the prevalence of knee OA after CL injury varies in different studies. Results from a meta-analysis and two systematic reviews show a prevalence of OA after CL injury ranging between 0–48% [[14]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Claes1)–[[16]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Chalmers1). Apart from well-established risk-factors in the CL-sufficient knee the presence of associated injuries such as meniscus and cartilage injuries increase the risk for developing OA after CL-injury. A concomitant meniscal tear occurs in 25–65% of the cases [[17]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Louboutin1).

Optimal treatment of a CL injury is under continuous debate and new inventions range from a multitude of surgical methods, fixation devices and rehabilitation protocols [[18]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Maffulli1), [[19]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Spindler1). A number of different techniques and grafts have been suggested [[20]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Bach1)–[[22]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-vanEck1). The purpose of CL reconstruction (CL-R) is to counteract knee instability and to restore kinematics, aiming to facilitate return to a desired activity level (often including pivoting sports) regardless of the risk to develop OA. Although treatment of CL injury varies in different countries reconstructive surgery of the CL is considered as the first line of treatment for specific groups of patients such as elite athletes, while conservative treatment with structured rehabilitation is considered to have a corresponding outcome in the general population [[23]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Casteleyn1), [[24]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Swirtun1). Some studies have reported that CL-R decreases the risk of post traumatic OA. However the results are conflicting [[14]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Claes1), [[25]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Friel1), [[26]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Neuman1) and the studies have limitations such as small sample sizes or short follow-up time.

This nationwide cohort study with long follow-up time used data from the National Swedish Patient Register to estimate the risk of OA in the knee after CL injury for patients treated surgically compared to patients treated non-surgically.

**Discussion**

To the best of our knowledge this is the first population based nationwide study describing the association between CL injury and the development of knee OA in a large cohort. We observed that surgically reconstructed ACL injured patients were more frequently diagnosed with knee OA in specialized healthcare during follow-up than non-reconstructed patients. This suggests that decreasing the long-term risk for post traumatic OA after CL injury is not an argument for CL reconstruction. The results also demonstrated that the risk to develop OA did not differ between males and females. Concomitant meniscal injury was associated with increased risk for OA irrespective of timing of surgery.

The strengths of this study include the large nationwide patient database with excellent coverage [[29]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Ludvigsson1), equal access to health care in Sweden and relatively long follow-up allowing for analysis of the development of OA in both patients treated conservatively and surgically. Moreover, since we had the opportunity to control for major confounding factors included in the registry and this is a cohort with prospectively collected outcome data the possibility of bias is limited. However, possible selection bias cannot be completely ruled out since more extensive knee trauma increases the risk for osteoarthritis and might as well be associated with a higher risk to be selected for surgery. The risk for reverse causality is small since the main symptom for osteoarthritis is pain and according to Swedish protocols pain has never been an indication for CL reconstruction. The result of stratified analysis showed that the risk for osteoarthritis increased with increasing time after surgery which also strengthens this argumentation.

The main limitation of this study is potential misclassification of CL-injury, OA and acute meniscus injury since the registry does not include information about criteria or diagnostic methods. CL injury is diagnosed by physical examination, magnetic resonance imaging (MRI), or arthroscopy. Since 2000 there has been a dramatic increase in MRI accessibility and in 2009, around, 50,000 MRI examinations of the knee were undertaken in Sweden, giving an incidence of about 5,5 per 1000 inhabitants [[30]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Dahlberg1). OA, on the other hand, has traditionally been diagnosed mainly by clinical examination and X-ray. In this study knee OA was classified as patients being diagnosed with OA in specialized healthcare. This population is most likely patients with more severe OA then patients being diagnosed with OA in primary healthcare and not included in the study. Detection bias could be a limitation if reconstructed patients have a greater propensity to contact or be referred to specialist healthcare. However this is unlikely since patients treated non-surgically have the same risk to be diagnosed with OA in specialized during the first years of follow-up. Based on the register data, it is not possible to define if the knee diagnosed with OA is the same knee that had previous CL injury, although it has been shown that this is usually the case. For example van der Hart et al. showed that there is an almost 50% higher prevalence of OA in the injured knee [[31]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-vanderHart1). Another limitation is that patients diagnosed or treated in outpatient setting before 2001 are not included in the study. This explains why the descriptive results presented in this study are not coherent with the results presented earlier [[3]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Nordenvall1). This could potentially cause some bias as the inpatient cases might be severe cases. However, restricting the results to those diagnosed after 2001 did not change the results notably. Another limitation is that patients with CL injuries, who never seek medical care for their injury, are not included in this study. However since CL injuries lead to a rapid hemarthrosis of the knee precluding continuation of activity [[32]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Noyes1), most patients are likely to visit a health-care provider where a correct diagnosis can be established. It is a limitation that bilateral injuries and the type of CL injury cannot be identified, making it impossible to differ between ACL injury and PCL injury. Data from the Swedish Cruciate Ligament Register show that 2% of the patients underwent bilateral reconstruction [[33]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-XX1). Isolated posterior cruciate ligament injuries are uncommon and account for an estimated 3% of all acute knee injuries [[34]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Kim1). Thus, the vast majority of our patients represent patients with ACL injuries and the results can be extrapolated to all ACL injuries. Like most chronic diseases, OA is complex and multifactorial. It cannot be excluded that there might be differences between the patients treated with CL-R and those treated non-operatively that we did not have information on, e.g. level of physical activity.

The increasing number of older people and the changes in lifestyle throughout the world mean that the burden of musculoskeletal injuries and diseases will increase dramatically [[1]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Woolf1). Our study reports a prevalence of OA of 10% in patients between 15–60 years 10 years after they were diagnosed with a CL injury. This is less than reported in earlier studies which is most likely explained by the fact that the definition of OA in this study was based on hospital data and concomitant registered diagnosis of OA in specialist care. Patients only diagnosed with OA in primary were not identified in this study.

In this study 41% of the patients had a diagnosed meniscal injury which is to be compared with 25–65% described in earlier studies [[17]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Louboutin1). Meniscal injury cannot however be assessed as a dichotomy, it is a continuous variable ranging from traumatic lesions to degenerative injuries. Further, meniscal injuries are not always symptomatic [[35]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Englund1). Since we were interested in the acute traumatic injuries, we attempted to exclude degenerative meniscal injuries as well as meniscal injuries in patients older than 35 years. Our results showed that concomitant meniscal injury was the strongest risk factor to develop OA which is coherent with earlier results[[14]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/%22%20%5Cl%20%22pone.0104681-Claes1). Results from cohort studies have shown an association been early CL reconstruction and fewer meniscal surgeries. Reducing the risk of meniscus tear would mean that CL-R might protect a CL injured knee from post-traumatic OA. Although some cohort studies support this hypothesis there are conflicting results reporting no difference or even an increased risk for OA [[14]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Claes1), [[25]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Friel1), [[36]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Meuffels1). A randomized clinical trial by Frobell et al did not show a difference in risk for radiographic OA up to 5 years in patients treated surgically compared to those treated non-surgically [[27]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-The1), [[37]](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141753/#pone.0104681-Frobell1). Our results suggest that there is an increased long term risk for OA after CL-R. Taking into account the more recent published results together with ours we conclude that decreasing the long-term risk for post-traumatic OA after CL injury is not an argument for CL-reconstruction.

[chrane Database Syst Rev.](https://www.ncbi.nlm.nih.gov/pubmed/27039329) 2016 Apr 3;4:CD011166. doi: 10.1002/14651858.CD011166.pub2.

**Surgical versus conservative interventions for treating anterior cruciate ligamentinjuries.**

[Monk AP](https://www.ncbi.nlm.nih.gov/pubmed/?term=Monk%20AP%5BAuthor%5D&cauthor=true&cauthor_uid=27039329)1, [Davies LJ](https://www.ncbi.nlm.nih.gov/pubmed/?term=Davies%20LJ%5BAuthor%5D&cauthor=true&cauthor_uid=27039329), [Hopewell S](https://www.ncbi.nlm.nih.gov/pubmed/?term=Hopewell%20S%5BAuthor%5D&cauthor=true&cauthor_uid=27039329), [Harris K](https://www.ncbi.nlm.nih.gov/pubmed/?term=Harris%20K%5BAuthor%5D&cauthor=true&cauthor_uid=27039329), [Beard DJ](https://www.ncbi.nlm.nih.gov/pubmed/?term=Beard%20DJ%5BAuthor%5D&cauthor=true&cauthor_uid=27039329), [Price AJ](https://www.ncbi.nlm.nih.gov/pubmed/?term=Price%20AJ%5BAuthor%5D&cauthor=true&cauthor_uid=27039329).

[**Author information**](https://www.ncbi.nlm.nih.gov/pubmed/27039329)

**Abstract**

**BACKGROUND:**

Rupture of the anterior cruciate ligament (ACL) is a common injury, mainly affecting young, physically active individuals. The injury is characterised by joint instability, leading to decreased activity, which can lead to poor knee-related quality of life. It is also associated with increased risk of secondary osteoarthritis of the knee. It is unclear whether stabilising the knee surgically via ACL reconstruction produces a better overall outcome than non-surgical (conservative) treatment.

**OBJECTIVES:**

To assess the effects of surgical versus conservative interventions for treating ACL injuries.

**MAIN RESULTS:**

We identified one study in which 141 young, active adults with acute ACL injury were randomised to either ACL reconstruction followed by structured rehabilitation (results reported for 62 participants) or conservative treatment comprising structured rehabilitation alone (results reported for 59 participants). Built into the study design was a formal option for subsequent (delayed) ACL reconstruction in the conservative treatment group, if the participant requested surgery and met pre-specified criteria.This study was deemed at low risk of selection and reporting biases, at high risk of performance and detection biases because of the lack of blinding and at unclear risk of attrition bias because of an imbalance in the post-randomisation exclusions. According to GRADE methodology, the overall quality of the evidence was low across different outcomes.This study identified no difference in subjective knee score (measured using the average score on four of the five sub-scales of the KOOS score (range from 0 (extreme symptoms) to 100 (no symptoms)) between ACL reconstruction and conservative treatment at two years (difference in KOOS-4 change from baseline scores: MD -0.20, 95% confidence interval (CI) -6.78 to 6.38; N = 121 participants; low-quality evidence), or at five years (difference in KOOS-4 final scores: MD -2.0, 95% CI -8.27 to 4.27; N = 120 participants; low-quality evidence). The total number of participants incurring one or more complications in each group was not reported; serious events reported in the surgery group were predominantly surgery-related, while those in conservative treatment group were predominantly knee instability. There were also incomplete data for total participants with treatment failure, including subsequent surgery. In the surgical group at two years, there was low-quality evidence of far fewer ACL-related treatment failures, when defined as either graft rupture or subsequent ACL reconstruction. This result is dominated by the uptake by 39% (23/59) of the participants in the conservative treatment group of ACL reconstruction for knee instability at two years and by 51% (30/59) of the participants at five years. There was low-quality evidence of little difference between the two groups in participants who had undergone meniscal surgery at anytime up to five years. There was low-quality evidence of no clinically important between-group differences in SF-36 physical component scores at two years. There was low-quality evidence of a higher return to the same or greater level of sport activity at two years in the ACLreconstruction group, but the wide 95% CI also included the potential for a higher return in the conservative treatment group. Based on an illustrative return to sport activities of 382 per 1000 conservatively treated patients, this amounts to an extra 84 returns per 1000 ACL-reconstruction patients (95% CI 84 fewer to 348 more). There was very low-quality evidence of a higher incidence of radiographically-detected osteoarthritis in the surgery group (19/58 (35%) versus 10/55 (18%)).

**AUTHORS' CONCLUSIONS:**

For adults with acute ACL injuries, we found low-quality evidence that there was no difference between surgical management (ACL reconstruction followed by structured rehabilitation) and conservative treatment (structured rehabilitation only) in patient-reported outcomes of knee function at two and five years after injury. However, these findings need to be viewed in the context that many participants with anACL rupture remained symptomatic following rehabilitation and later opted for ACL reconstruction surgery. Further research, including the two identified ongoing trials, will help to address the limitations in the current evidence, which is from one small trial in a young, active, adult population.

[Am J Sports Med.](https://www.ncbi.nlm.nih.gov/pubmed/25384503) 2015 Jan;43(1):138-45. doi: 10.1177/0363546514555673. Epub 2014 Nov 10.

**Long-term clinical and radiographic results after delayed anterior cruciate ligamentreconstruction in adolescents.**

[Månsson O](https://www.ncbi.nlm.nih.gov/pubmed/?term=M%C3%A5nsson%20O%5BAuthor%5D&cauthor=true&cauthor_uid=25384503)1, [Sernert N](https://www.ncbi.nlm.nih.gov/pubmed/?term=Sernert%20N%5BAuthor%5D&cauthor=true&cauthor_uid=25384503)2, [Rostgard-Christensen L](https://www.ncbi.nlm.nih.gov/pubmed/?term=Rostgard-Christensen%20L%5BAuthor%5D&cauthor=true&cauthor_uid=25384503)3, [Kartus J](https://www.ncbi.nlm.nih.gov/pubmed/?term=Kartus%20J%5BAuthor%5D&cauthor=true&cauthor_uid=25384503)4.

[**Author information**](https://www.ncbi.nlm.nih.gov/pubmed/25384503)

**Abstract**

**BACKGROUND:**

The risk of further intra-articular damage associated with nonoperative or delayed anterior cruciate ligament (ACL) reconstruction must be considered against the risk of growth disturbance with early reconstruction and transphyseal drilling. Long-term follow-ups after the surgical treatment of ACL injuries in adolescents are rare.

**PURPOSE:**

To evaluate results 10 to 20 years after ACL reconstruction in terms of the radiographic presence of osteoarthritis, clinical assessments, and health-related quality of life in patients who were adolescents at the time of surgery.

**STUDY DESIGN:**

Case series; Level of evidence, 4.

**METHODS:**

Thirty-two adolescents (mean age, 15.2 years [range, 12-16 years]; 11 boys, 21 girls), with a symptomatic unilateral ACL rupture, underwent reconstruction using bone-patellar tendon-bone (n=10) or hamstring tendon (n=22) autografts at an almost skeletally mature age according to Tanner stage 4. Twenty-nine patients (91%) underwent clinical, radiographic, and health-related quality of life assessments after 10 to 20 years (mean, 175 months).

**RESULTS:**

The mean time between the injury and index surgery was 11.6 months. The reconstructed knee had significantly more osteoarthritic changes compared with the noninvolved contralateral knee (P=.001). Preoperatively, the median Tegner activity level was 4 (range, 2-8), and the median Lysholm knee score was 75 (range, 50-90) points. At follow-up, the respective median values were 4 (range, 1-7) and 84 (range, 34-100) points (P=not significant [preoperatively vs follow-up]). The median finding for the single-legged hop test was 84% (range, 0%-105%) preoperatively and 93% (range, 53%-126%) at follow-up (P=.01). At follow-up, muscle strength measurements displayed more than 90% of the noninvolved leg in both extension and flexion. The manual Lachman test result was significantly improved at follow-up compared with preoperatively (P<.001). The 36-item Short Form Health Survey (SF-36) revealed scores comparable with those of healthy controls. The mean EuroQol (EQ-5D) score was 0.86±0.12. The Knee injury and Osteoarthritis Outcome Score (KOOS) values were lower in all dimensions compared with age-matched healthy controls.

**CONCLUSION:**

In the long term, patients who were adolescents at the time of ACL reconstruction revealed significantly more radiographically visible osteoarthritic changes in their operated knee than in their noninvolved contralateral knee. Clinical outcomes and health-related quality of life are comparable with those of healthy controls.

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PMCID: PMC3236993

**Reconstruction versus conservative treatment after rupture of the anterior cruciate ligament: cost effectiveness analysis**

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/)

**Background**

Rupture of the anterior cruciate ligament (ACL) changes the kinematics of the knee [[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B1)] and often results in instability with accompanying functional disability and pain [[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B2)-[22](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B22)]. Although there are more than 2000 scientific articles in the literature [[23](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B23)] illuminating several aspects of ACL rupture, there is no consensus on the optimal treatment. Whereas some authors reported adequate outcomes after operative treatment using various techniques [[8](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B8),[13](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B13),[24](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B24)-[44](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B44)], others documented sufficient clinical results after conservative treatment with various protocols of immobilization and physiotherapy [[4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B4),[45](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B45)-[64](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B64)]. Although several instruments and scoring systems [[65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B65)-[69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B69)] have been developed to facilitate standardized reporting and comparison of differently treated patients, decision towards one or the other, namely, conservative or surgical treatment seems currently challenging [[14](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B14)] due to lack of randomized controlled trials with information on long-term results [[70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B70)].

Most surgeons advocate ACL reconstruction for patients with ACL rupture associated with subjective instability whereas some orthopedic surgeons routinely favor conservative treatment of ACL ruptures. Thus there is still controversy on this common injury with an estimated incidence of approximately 1500/100,000 person-years in Switzerland, 1200/100,000 person-years in New Zealand [[71](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B71)], and 3000/100,000 person-years in the United States [[23](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B23)]. The occurrence of ACL ruptures depends on sex, age, and sports activities of those affected [[72](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B72)]. The Swiss National Insurance System for Injuries (UVG), which covers half the Swiss population, provides around 200-250 million US dollars equivalent yearly for patients with ACL injuries, including 40% of direct treatment costs.

A critical evaluation of benefits and expenditures of the two treatment options so as to provide valuable information for treating physicians and healthcare policymakers is in progress. Technical arguments appear unable to determine superiority of one or the other strategy and complementary research using economic and public health approaches including assessment of quality of life, direct cost, and cost effectiveness is necessary. Although cost effectiveness would significantly affect the decision toward one or other strategy, such studies for this common injury are rare [[73](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B73),[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/%22%20%5Cl%20%22B74)]. A cost effectiveness analysis would allow rational allocation of limited resources and resolve an uncertainty that might potentially have been created by setting the focus on purely medical factors rather than economics aspects.

Gottlob et al [[75](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B75)] reported that in young adults in the United States, surgical treatment of ACL ruptures was more cost-effective than conservative treatment. However, due to lack of studies comparing the two treatment options in the same study groups at that time (1999) as well as more recent advances particularly in the surgical treatment of ACL ruptures, the results must be interpreted with caution and might not represent the current status. Although several authors aimed to compare surgical with conservative treatment [[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B2)-[22](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B22)], these reports are difficult to use for cost effectiveness analysis due to lack of necessary information and use of outdated surgical techniques. The purpose of the present cost-utility analysis was to identify the more cost effective treatment option for ACL ruptures in patients at an average age 30-35 years from the viewpoint of third party payers in the Swiss setting by the use of evidence created by studies comparing directly both treatment options in the same study population.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/)

**Reviewing process of currently available literature to filter studies with direct comparison of conservative and surgical treatment and sufficient information on activity levels**.

**Results**

**Extraction of effectiveness data and compilation to utility**

The available literature was sufficient to allow construction of a population of 384 patients (229 treated surgically and 155 conservatively) with a mean follow-up after surgical and conservative treatment of 89 months and 90 months, respectively. Using the transformation key based on the experts survey[[76](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/%22%20%5Cl%20%22B76)], level of activities could be assigned to patient groups of extracted articles (Table [​(Table1).1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/table/T1/)). The proportion of patients with high levels of activity (IV and V) was higher after surgical (70.7%) than conservative treatment (49.7%) (Table [​(Table11](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/table/T1/)).

**The cost-effectiveness acceptability frontier shows the probabilistic sensitivity analysis-based on the probability of surgically and conservatively treated ACL patients of being cost-effective**. For different willingness to pay thresholds, a different **...**



[Figure 3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/figure/F3/)

**The cost-effectiveness scatter plot uses the cost-effectiveness plane to plot the cost and effectiveness pair for each recalculation of the model with 10,000 runs for each strategy**.

In the worst-case scenario, not accounting for sequelae such as late meniscal lesions or development of osteoarthritis, the incremental cost effectiveness would be 68,715 USD/QALY for surgical treatment.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/)

**Discussion**

The decision whether to treat conservatively or reconstruct surgically a torn ACL has been debated throughout the history of knee surgery. The high prevalence and associated public health burden of torn ACL has led to continuous arguments in favor of one or the other strategy, which produced, however, no clear solution. Although thousands of studies have been published in regard to ACL [[23](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B23)], a critical evaluation of benefits and expenditures of both treatment options to provide valuable information for treating physicians and healthcare policymakers has not been performed [[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B74)]. Here, we analyzed the cost effectiveness of the two procedures in the Swiss setting and found surgical reconstruction to be cost effective assuming the patient has from symptoms such as the knee giving way, pain, or instability.

The results of our analysis must, however, be interpreted with caution. First, the information of clinical outcome or effectiveness for each treatment approach was based on compiled data from reported studies. Efforts were made to review systematically the currently available literature (Figure [​(Figure1)1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/figure/F1/)) so as to find the most suitable sources of information. Although the retracted studies [[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B5),[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B7),[13](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B13),[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B19)] were potentially heterogeneous and were not randomized controlled trials, they did compare the two treatment strategies in the same experimental setting and provide sufficient outcome data for abstraction to utility values.

Second, the decision tree is a model only. On the other hand, sensitivity analysis showed a very robust model. The most sensitive determinant changing the incremental cost effectiveness for surgical therapy > 10 fold to 68,715 USD/QALY was removal of sequelae of torn ACL. This however is an unrealistic scenario [[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B7),[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/%22%20%5Cl%20%22B19)]. Changes in the kinematics of gait produced by a deficient ACL have been described to result in subsequent osteoarthritis relatively unrelated to whether a reconstruction has been performed [[77](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B77),[78](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/%22%20%5Cl%20%22B78)]. Meniscal lesions are commonly concomitant to ACL ruptures and also play a contributive role in development of osteoarthritis [[79](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B79),[80](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/%22%20%5Cl%20%22B80)]. ACL-deficient, conservatively treated patients do need more often surgical treatment for meniscal lesions [[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B5),[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/%22%20%5Cl%20%22B7),[13](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B13),[19](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B19)]. The results of studies that might describe no difference in sequelae for either treatment strategy should be interpreted with caution to a common limitation being a selection bias of patients with less severe injuries to the conservative arm of the study. Further, the severity of osteoarthritis should be considered in studying long-term results of both treatment options; while the overall rate of osteoarthritis might not significantly be related to the treatment procedure, more severe degeneration has been reported in patients undergoing conservative treatment [[81](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B81)]. It is however unquestionable that some patients will benefit more from ACL reconstruction than others. How and when to select patients for surgery remain strongly disputed issues. Stratification regarding the need for surgery has not been possible in the current analysis because there are no uniform guidelines or consensus.

Third, the cost of the conservative arm seems underestimated. Although hospital infrastructure, administration, and organization costs were mainly covered by surgically treated patients with in-hospital stays, these are also significantly used by ambulatory patients such as those whose ACL is conservatively treated.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/)

**Conclusion**

ACL reconstruction is cost effective. Our calculated incremental cost effectiveness of 4890 USD/QALY is in good agreement with the hitherto only available analysis performed by Gottlob et al (5857 USD/QALY) [[74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/#B74)]. However, although the results of this study might contribute to informed decision making for health policymakers, the individual situation of the patient must be respected when suggesting one or the other strategy.

[Go to:](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3236993/)

[Knee Surg Sports Traumatol Arthrosc.](https://www.ncbi.nlm.nih.gov/pubmed/21773828) 2012 Jan;20(1):48-61. doi: 10.1007/s00167-011-1614-x. Epub 2011 Jul 20.

**Anterior cruciate ligament tears: conservative or surgical treatment? A critical review of the literature.**

[Delincé P](https://www.ncbi.nlm.nih.gov/pubmed/?term=Delinc%C3%A9%20P%5BAuthor%5D&cauthor=true&cauthor_uid=21773828)1, [Ghafil D](https://www.ncbi.nlm.nih.gov/pubmed/?term=Ghafil%20D%5BAuthor%5D&cauthor=true&cauthor_uid=21773828).

[**Author information**](https://www.ncbi.nlm.nih.gov/pubmed/21773828)

**Abstract**

**PURPOSE:**

Is it rational to recommend surgical reconstruction of the torn anterior cruciate ligament to every patient? Is conservative management still a valid option?

**METHOD:**

Through a literature review, we looked for the arguments from each side and checked their validity.

**RESULTS:**

Unfortunately results of most studies cannot be compared because of the following reasons not exhaustively cited: studied populations differed with respect to age, sex, professional and sports activity level, lesions associated with ACL rupture, patient recruitment methods, time from injury to treatment and different therapeutic modalities. Furthermore, various methods were used to evaluate the clinical and radiological results and there was no consensus of their interpretation. Some authors assumed that the incidence of further meniscus lesions could probably be reduced if the torn ACL was surgically reconstructed. But, we have no evidence to believe that this would be due to the surgical repair rather than to a decrease of involvement in strenuous activities. At present it is not demonstrated that ACL-plasty can prevent osteoarthritis. Numerous factors could explain evolution to arthrosis whatever the treatment for the ACL-ruptured knee. Studies comparing surgical and conservative treatments confirm that ACL reconstruction is not the pre-requisite for returning to sporting activities. More recent and scientifically well-designed studies demonstrate that conservative treatmentcould give satisfactory results for many patients. They suggest some methods to help them choose the besttreatment.

**CONCLUSION:**

At present there are no evidence-based arguments to recommend a systematic surgical reconstruction to any patient who tore his ACL. Knee stability can be improved not only by surgery but also by neuromuscular rehabilitation. Whatever the treatment, fully normal knee kinematics are not restored. While the patients wish to go back to their sport and want everything possible done to prolong their ability to perform these activities, they should be informed that the risk of further knee lesions and osteoarthritis remains high, whatever the treatment, surgical or conservative.