REVIEW

Update on Rehabilitation Protocol Following ACL Reconstruction

Gavril Lucian Gheorghievici[1,2], Adriana Sarah Nica[1,3], Brindusa Mitoiu[1,3], Delia Clantau[1], Emil Haritinian[1,2], Cristian Ioan Stoica[1,2]

Abstract

Anterior cruciate ligament lessions represent one of the most frequently met injuries of the knee, determining pain and instability and having a decisive impact over the patients functional level and quality of life. Regardless whether or not the decision of surgical intervention is made, patients with ACL tear are at higher risk of developing osteoarthritis, long term disability and an increased risk of additional meniscus tear. Literature data, although it offers a sufficient amount of information on the subject, still presents debates on the advantages of one rehabilitation program over another. Achieving maximal range of motion as soon as possible is a main objective in ACL injuries, restrictions of mobility leading to prolonged rehabilitation periods. The are also discussions on the benefits of using open versus closed kinetic chain exercises, and also to what extend can the rehabititation program be accelerated in order to return the knee to the pre-injury state. The rehabilitation program must contain a multimodal approach composed of not only adapted kinetotherapy programs, but also associated modalities such as cryotherapy, neuromuscular stimulation, use of braces or hydrokinetotherapy in order to reduce pain and effusion and increase range of motion. The purpose of the present material is to analysis the existing data on the subject, and to evaluate the therapeutic benefit of the rehabilitation modalities used in ACL injuries.

Keywords: rehabilitation, ACL reconstruction, protocol

Rezumat

Leziunile de ligament încrucișat anterior reprezintă cele mai frecvent întâlnite consecințe ale unui traumatism la nivelul genuchiului, ce determină durere și instabilitate, având un impact decisiv asupra nivelului funcțional și calității vieții pacientului. Indiferent de decizia chirurgicală, pacienții cu ruptură de ligament încrucișat interior prezintă un risc crescut de evoluție către artroză, dizabilitate și șanse mai mari pentru o ruptură de menisc ulterioară. Datele din literatură, deși oferă informații suficiente pe acest palier, prezintă în continuare puncte de vedere diferite privind avantajele unui program de recuperare în favoarea altuia. Obținerea amplitudinii de mișcare maxime într-un timp cât mai rapid reprezintă un obiectiv principal, datorită faptului că limitarea prelungită de mobilitate conduce la creșterea perioadei de recuperare. Sunt puse de asemenea în discuție avantajele utilizării exercițiilor în lanț cinematic închis comparativ cu cele în lanț cinematic deschis, și, de asemenea, în ce măsură poate fi accelerat programul de recuperare pentru a aduce genuchiul operat în stadiul pre-traumatic. Programul de recuperare trebuie să cuprindă o abordare multimodală formată nu doar din kinetoterapie, ci și din modalități asociate cum sunt crioterapia, electrostimularea, hidrokinetoterapia și purtarea unei orteze, toate acestea având drept scop reducerea durerii și a inflamației, precum și cresterea amplitudinii de mișcare. Scopul prezentului material este acela de a analiza datele existente privind acest subiect, precum și de evaluare a beneficiului terapeutic individual oferit de către fiecare modalitate de tratament.

Cuvinte cheie: recuperare medicală, reconstrucția ligamentului încrucișat anterior, protocol

[1] „Carol Davila" University of Medicine and Pharmacy, Bucharest, Romania
[2] „Foisor" Orthopaedics Clinical Hospital, Bucharest, Romania
[3] National Institute of Rehabilitation, Physical Medicine and Balneology, Bucharest, Romania

Corresponding author:
Gavril Lucian Gheorghievici, „Carol Davila" University of Medicine and Pharmacy Bucharest, Romania.
E-mail: gavril.gheorghievici@gmail.com

BACKGROUND

Anterior cruciate ligament lessions represent one of the most frequently met injuries of the knee, with an increasing incidence depending on the statistics, most of them occuring in athletes or young adults[1-5]. The reconstruction of the anterior cruciate ligament can be obtained by using different surgical procedures and varies according to the graft material that is used. The outcomes after ACL reconstruction is depended on both surgical and rehabilitation factors[6,7]. The decision of reconstruction is dictated by the patient's symptomatology, as well as the the patients functional level, and the degree of participation in different activities. Regarless whether or not the decision of surgical intervention is made, patients with ACL tear are at a higher risk of developing osteoarthritis, long term disability and an increased risk of additional meniscus tear[8]. Injury of the ACL occurs mostly during dynamic activities, therfor any alteration in the biomechanics or muscular control of the knee increases the risk of an ACL injury[9].

According to some authors, ACL lessions have a four to six times higher incidence in female compare to male athletes[10]. Additionally it is estimated that a large percent of the patients with an ACL reconstruction will suffer a reintervention or additional meniscus tear[11]. The role of the rehabilitation is decisive. Numerous authors have suggested the association of different rehabilitation techniques in order to outline the necessity of a structured rehabilitation protocol[12-14]. Various protocols express the idea of early motion, due to the fact that prolonged immobilization can generate a number of complications after surgery and lenghten the rehabilitation period. The type of exercises must be adapted in order to offer the protection required by the graft. Although most of the attention is dedicated to strentghtening the quadriceps muscle, the rehabilitation program should take into consideration all the muscle involved, particularly the hamstring muscles[15,16]. The clinical evaluation has be focused also on the patient related factors, that might influence the postoperative evolution and the time needed for rehabilitation. In order for those objective to be obtained, a preoperative rehabilitation program must be initiated in order to further assess the patients clinical particularities and to better estimate the further outcomes of the postsurgical period[17]. The rehabilitation program must contain a multimodal approach composed of not only adapted kinetotherapy programs, but also associated modalities such as cryotherapy, neuromuscular stimulation, use of braces or aquatic therapy in order to reduce pain and effusion and increase range of motion. The purpose of the present material is to analysis the existing data on the subject, and to evaluate the therapeutic benefit of the rehabilitation modalities used for ACL injuries.

MATERIAL AND METHOD

We performed a sistematic review using the online available database (Pubmed, Cochraine, EMBASE, Medline) in order to asses the use of protocols for this field of pathology. The search strategy included the words ,,ACL", ,,rehabilitation", ,,protocol", ,,knee", ,,open chained", ,,closed chained", ,,aquatic therapy", ,,cryotherapy" and the study selection criteria included full text peer-reviewed articles published between 2000-2018.

RESULTS AND DISCUSSIONS

Although literature data offers sufficient information on the subject, we could not observ a developed consensus or a uniformed designed protocol regarding rehabilitation of ACL injuries. Numerous randomized controlled studies were found, but in some cases the methodological design of the studies was mixed, presenting bias information or incomplete data on the experimental design[18-20].

The first issue that generates debate in the literature regards the use open vs. closed kinetic chain exercises following ACL reconstruction, both techniques presenting advantages and disadvantages. The general tendency is to prefer the CKCE due to the fact that they are predominantly focused on increasing muscle strengh on the quadriceps, and improving coordination. Therefor CKCE are considered to be safer because they do not increase the tensile strain on the ACL and so, reduce the risk of tibial displacement, while using open chain kinetic exercises for ACL rehabilitation might increase the anterior shear of the knee[21,22]. Tagesson et al. (2008) express significant results for open chain kinetic exercises only in terms of muscle strengh on the quadriceps compared to CKCE, while functional outcome is similar in both cases[23].

Uçar et al. (2014) observes diminished pain scores for both exercises and an increase in Lysholm knee score for both OKCE and CKCE, but in a higher percentage for close kinetic chain exercises. The most frequent postoperative signs are swelling and edema, and if managed poorly can lead to muscle weakness of even athophy of the quadriceps muscle, and represents

one of the main arguments for prefering closed kinetic chain exercises compared to OKCE[24].

Other opinions on open vs closed kinetic chain exercises refer to the fact that closed kinetic chain exercises work mostly on the vasti muscles, while open kinetic chain exercises have a demanding effect on the rectus femoralis, and therfor allow more specific muscle strengthening due to an isolated muscle activity. On the other side, prolonged exercise will generate fatigue, which will put a destabilising risk for the ACL due to an isolated muscle strenghtening[25,26]. Closed kinetic chain exercises however, being mostly focused on the agonist muscles can not offer specific muscle strengthening, but can provide safer conditions for the ACL in case of fatigue.

The differences between the two remain to be discussed, especially because many of the daily activities can not be defined as open or closed chained, activities such as walking or stair climbing involving a combination of the two[27,28].

Achieving maximal range of motion as soon as possible is a main objective in ACL injuries, restrictions of mobility leading to prolonged rehabilitation periods. There are also separated opinions on the development of the rehabilitation program, some authors suggesting a prolonged immobilization in order to protect the graft and knee, while weight bearing should be avoided in order to prevent instability, other points of view implying early mobilisation and an accelerated rehabilitation that should start from the first day postoperative in order to rapidly obtain full extension[29,30].

Continuous passive motion following ACL reconstruction has been put into debate, whether it offer short or long term effects to the rehabilitation program. Most protocols propose the initialising of CPM early following surgery and continue upon four weeks postoperative, in order to protect the integrity of the repair and also to prevent de consequences of prolonged immobilization[31-33]. According to some authors initiating CPM immediatly after surgery reduces blood and oedema from the joint and the periarticular tissue, and so reduces the risk of post surgical joint stiffness. However, in a review that included 7 randomized controlled studies and 465505 cases, 2 studies found no statistically significant differences regarding joint laxity compared to the control group, while only 1 study found a significantly greater active and passive knee flexion in CPM patients. There were no significant differences between groups regarding pain, but 2 studies evidenced significant analgesy in the immediate postsurgery period for the CPM group. There were no statistically significant differences concerning swelling, joint position , blood drainage and complication between the two groups[34].

Another matter of debate involves the aspect of restoring the operated knee to the pre-injury state, this leading to the idea of regaining bilateral knee symmetry. In order to obtain this, the evaluation of the patient and the rehabilitation program should begin pre-operatively and continue until complete knee symmetry is obtained post-surgery[35]. However, this results in the necessity of a close follow-up of the patient in order to evaluate long term effects of the surgical procedure. Pre interventional rehabilitation will initially start with reduction of pain, inflammation and swelling of the involved limb, and continue with obtaining complete passive range of motion which is a key element to the entire rehabilitation protocol[36]. Once ROM and inflammation are reduced, the rehabilitation program can continue with neuromuscular retraining. Also, an emphasis should be made on patient and family education regarding the purpose of the rehabilitation program, in order to gain a better adherence to the proposed objectives, and also to understand the postsurgical precautions regarding the state of the graft. Adherence to the rehabilitation programs is also important in gaining full functional level and reducing the reinjury rates[37,38]. Postoperative, ROM exercises should begin early in the first phase after surgery in order to facilitate flexion, which should be met at 120 degres after a maximum of 4 weeks, followed by a full symmetrical flexion by the end of the 12 week[39].

Another discussion involves weight-bearing, its progression being dictated depending on the surgical procedure and graft selection. Early weight bearing has been accepted to be beneficial in reducing patellofemoral pain, and it also avoids the appearence of later complications such as arthrofibrosis. By most authors, weight bearing in the first stage should be partial, with the use of crutches and subsequently progress according to the patients level of tolerance, allowing the joint to acclimate with increased loads[40].

Plyometric exercises have been recommanted as part of rehabilitation protocol, with some reservations being present because of the high load on the lower extremity that could predjudice knee articular cartilage. No differences were observed between low and high intensity plyometric exercises by some authors, (Chmielewski et al. 2016), both type of exercises inducing favorable effects on knee function and psychosocial factor[41]. Stationary bike could begin after 4 weeks with gradual

progression according to endurance. This will allow the patient to increase the muscle activity without putting the ligament graft to higher strain values[39].

Accelerated rehabilitation versus normal rehabilitation programs have been evaluated in randomized trials, but without any significant results in shortening the rehabilitation period below 6 month. There is very little scientific data on returning to sport activities earlier than 4 month, additional research being necessary in order express whether shorter rehabilitation periods are safer for the graft, articular cartilage and general outcome[42].

There is also low quality evidence on the benefits of surgical treatment of ACL followed by rehabilitation program compared to structured rehabilitation program only. In a study that tried to compare these differences, Monk et al. (2016), followed 141 patients with ACL injury that were divided into two groups – ACL reconstruction followed by particularised rehabilitation program and a second group composed of patients with conservative treatment reprezented by rehabilitation programs only. The authors express no significant changes of the KOOS score for both groups at baseline or at five years follow-up. There were however low quality evidence on diferences between SF36 questionary components at follow up and also incomplete data on subsequent surgical treatment in the studied group[43].

Return to more demanding activities and sports is still controversial. According to some authors[44], one out of four patients with an ACL intervention will suffer a second tear within the next 10 years, while Paterno et al.[45] suggest the reaccurance of an injury within two years after returning to sport activities. According to Brosnan et al., progression to exercises such as vertical and horizontal jumping from double to single and progressive running should begin 4 month after the ACL reconstruction. In case of revisions for ACL reconstruction, the rehabilitation protocol remanins mainly the same until 12 weeks, progression to functional and sport activities beginning after 5 to 6 month[39,40].

Cryotherapy is generally used after ACL reconstruction for the reduction of pain, inflammation and oedema. The action mechanisms include local vasoconstriction which prevents fluid extravasation and inhibition of afferent nerve conduction that reduces muscle spasm and pain levels and also lowers local metabolism activity preventing cell death. There have been many techniques proposed in order to achive those effects with points of view offering benefits on one techique over another[46,47]. More recent techniques refer to cryotherapy combined with dynamic intermitent compression which has been proposed as an alternative to permanent static compression, that could provide better tissue oxygenation, and better facilitate soft tissue exchanges, on the same time decreasing the risk of skin necrosis associated with static cryotherapy[48]. Despite the widespread use of cryotherapy, there are still differences of opinion in the literature concerning the effectiveness of its various application methods and the quantification of variables such as frequency, duration and best time for use. The cryotherapy application time ranges between 10 and 20 minutes, from two to four times a day. In the systemic review concerning the application of ice, few studies evaluated the effectiveness of ice after injuries to the soft tissues and there was no evidence of the best method and duration of the treatment[46,49].

A meta-analisis on the effectiveness of cryotherapy in ACL reconstruction included seven randomized controlled trials and 553 participants, in which pain levels were significant reduced in two studies in favor of cryotherapy group, while the rest of the studies repoarted dicrete improvements. Only one study expressed a significant reduction of drainage in favour of cryotherapy group, while minimal improvements were observed for range of motion. Due to the experimental design of the mentioned studies and the risk of bias which was observed, further studies need to be conducted in order create a better a unified protocol and also to determine which parameter is better for increasing the effective use of cryotherapy[50].

Aquatic therapy has been suggested as part of rehabilitation protocol for ACL reconstructions, yet only few studies have been developed in this direction. Hydrokinetotherapy could facilitate movement and improve circulation due to the hydrostatic effect based on Archimedes law. Some studies observed that patients with hydrokinetotherapy in the rehabilitation program were able to walk a greater distance in 6 min compared to patients with conventional rehabilitation protocol at 1 month follow-up. This can be attributed to the fact that with water immersion, the gravitational forces can be partially or totally compensated, allowing only specific forces to act on the reconstructed knee. Water ambulation, such as using an underwater treadmill can be introduced in the rehabilitation program in order to gradually apply an increased load to the joint and contribute to the development of a normal gait pattern. Also, it has been suggested that hydrokinetotherapy programs associated with conventional programs could faciliate loading of the joint to a greater degree, and co-

uld improve the rehabiltiation process in patients who do not tolerate land exercises because of diminished pain tolerance, age, or low activity level[51-53].

Neuromuscular electrical stimulation has been proven to be effective in increasing muscle strengh of the quadriceps muscle in the early phases of the rehabilitation process. Association of NMES with repeated sit-to-stand-to-sit exercises has been observed to be beneficial in increasing muscle strength of the knee extensors, which conducted to lower pain perception and a better symmetry in lower extremity loading[54]. Also, it has been reported by some authors, a greater chance of achieving clinical criteria for advancing to agility training at 16 weeks, for patients that associated NMES to the usual rehabilitation program[55].

Other modalities proposed as part of the rehabilitation program refer to trigger point dry needling of the quadriceps vastus medialis for treatment of trigger point miofascial syndrome that can be associated after ACL reconstructions. The technique is proposed in the last phase of the rehabilitation program. Velázquez-Saornil et al. (2016) in a randomized, single-blinded, clinical trial which included 44 subacute patients with surgical reconstruction after ACL rupture observed statistically significant difference for both the group that received rehabilitation program and the group that received rehabilitation program associated with dry needling of the vastus medialis (eta2 coefficient from 0.962 to 0.980, $p < 0.01$), for VAS and WOMAC scores, with higher scores for the dry needling group, although pain intensity was higher in the first day of treatment for the dry needling group[56].

The association of bracing as part of the rehabilitation program has been reviewed in multiple articles. The use of braces is particularly designed to limit the range of motion and also to prevent the knee from excessive varus and valgus stress. In a review by Wright et al. the authors evaluated the advantages of postoperative bracing, but all of the studies included contained biased data, including improper description of the randomization. Only one study observed an improvement regarding extension following locking the brace in full extension, at first week post surgery. On the same time the review did not evidence a possible agravating effect when prescribing a brace, and also it was not observed an increase in pain or risk of injury[57,58].

CONCLUSIONS

Literature data is abundent in terms of randomized controlled studies and meta-analysis regarding the benefit of using one rehabilitation protocol compared to another. There is a need for a structured rehabilitation program that should begin preoperative and continue with a rigurous follow-up period starting from the first day post surgery and continue until 12 month after. There is also a need for clinical outcome measures to be developed in an uniform way that should takes into consideration the physical, behavioral, and cognitive elements in an interdisciplinary context. The association of aquatic therapy offers an improvement to the rehabilitation process, while additional techniques such NMES, cryotherapy and bracing are proving to be effective, yet more riguours data in needed to establish a consensus on ACL rehabilitation program.

Abbreviations

ACL	Anterior Cruciate Ligament
VAS	Visual Analogue Scale
CKCE	Closed Kinetic Chain Exercises
OKCE	Open Kinetic Chain Exercises
WOMAC	Western Ontario and McMaster Universities Osteoarthritis Index
ROM	Range of Motion
CPM	Continuous passive motion
NMES	Neuromuscular electrical stimulation
KOOS	Knee Injury and Osteoarthritis Outcome Score

Compliance with ethics requirements:

The authors declare no conflict of interest regarding this article.

The authors declare that all the procedures and experiments of this study respect the ethical standards in the Helsinki Declaration of 1975, as revised in 2008(5), as well as the national law. Informed consent was obtained from all the patients included in the study.

References

1. Mall NA, Chalmers PN, Moric M, Tanaka MJ, Cole BJ, Bach BR Jr, Paletta GA Jr Incidence and trends of anterior cruciate ligament reconstruction in the United States. Am J Sports Med. 2014 Oct;42(10):2363-70.
2. Griffin LY, Albohm MJ, Arendt EA, et al. Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. Am J Sports Med. 2006;34(9):1512–1532.
3. Lyman S, Koulouvaris P, Sherman S, Do H, Mandl LA, Marx RG. Epidemiology of anterior cruciate ligament reconstruction: trends, readmissions, and subsequent knee surgery. J Bone Joint Surg Am. 2009;91(10):2321–2328.

4. Beck NA, Lawrence JTR, Nordin JD, DeFor TA, Tompkins M. ACL Tears in school-aged children and adolescents over 20 years. Pediatrics 2017;139:e20161877.
5. Sanders TL, Maradit Kremers H, Bryan AJ, et al. Incidence of anterior cruciate ligament tears and reconstruction: a 21-year population-based study. Am J Sports Med. 2016;44(6):1502–1507.
6. Davis JC, Bryan S. Patient Reported Outcome Measures (PROMs) have arrived in sports and exercise medicine: why do they matter? Br J Sports Med 2015;49:1545-1546.
7. Bekkers JEJ, de Windt TS, Raijmakers NJH, Dhert WJ, Saris DB. Validation of the Knee Injury and Osteoarthritis Outcome Score (KOOS) for the treatment of focal cartilage lesions. Osteoarthritis Cartilage 2009;17:1434-1439.
8. Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. Am J Sports Med. 2007 Oct;35(10):1756-69. Epub 2007 Aug 29.
9. Domnick, C., Raschke, M. J., & Herbort, M. (2016). Biomechanics of the anterior cruciate ligament: Physiology, rupture and reconstruction techniques. World Journal of Orthopedics, 7(2), 82–93.
10. Sutton KM, Bullock JM. Anterior cruciate ligament rupture: differences between males and females. J Am Acad Orthop Surg. 2013 Jan;21(1):41-50.
11. Ekås GR,Ardern C, Grindem H, Engebretsen L New meniscal tears after ACL injury: what is the risk? A systematic review protocol. Br J Sports Med. 2018 Mar;52(6):386.
12. Dragicevic-Cvjetkovic, D., Jandric, S., Bijeljac, S., Palija, S., Manojlovic, S., & Talic, G. (2014). The Effects of Rehabilitation Protocol on Functional Recovery After Anterior Cruciate Ligament Reconstruction. Medical Archives, 68(5), 350–352.
13. Micheo W, Hernandez L, Seda C. Evaluation, management, rehabilitation and prevention ACL injury: current concepts. PMR. 2010;2(10):935–944.
14. Kruse LM, Gray B, Wright RW. Rehabilitation After Anterior Cruciate Ligament reconstruction: A Systematic Review. J Bone Joint Surg Am. 2012;94(19):1737–1748.
15. Palmieri-Smith, R., & Lepley, L. (2015). Quadriceps Strength Asymmetry Following ACL Reconstruction Alters Knee Joint Biomechanics and Functional Performance at Time of Return to Activity. The American Journal of Sports Medicine, 43(7), 1662–1669.
16. Keays SL, Bullock-Saxton J, Newcombe P, Keays AC. The relationship between knee strength and functional stability before and after anterior cruciate ligament reconstruction. J Orthop Res. 2003;21:231–237.
17. Grindem, H., Granan, L., Risberg, M., Engebretsen, L., Snyder-Mackler, L., & Eitzen, I. (2015). How does a combined pre-operative and post-operative rehabilitation program influence the outcome of ACL reconstruction 2 years after surgery? A comparison between patients in the Delaware-Oslo ACL Cohort and the Norwegian Knee Ligament Registry. British Journal of Sports Medicine, 49(6), 385–389.
18. Wright, R. W., Preston, E., Fleming, B. C., Amendola, A., Andrish, J. T., Bergfeld, J. A., Williams, G. N. (2008). ACL Reconstruction Rehabilitation: A Systematic Review Part I. The Journal of Knee Surgery, 21(3), 217–224.
19. Thomson LC, Handoll HHG, Cunningham A, Shaw PC. Physiotherapist-led programmes and interventions for rehabilitation of anterior cruciate ligament, medial collateral ligament and meniscal injuries of the knee in adults. The Cochrane Database of Systematic Reviews. 2002;(1)
20. Grant JA, Updating Recommendations for Rehabilitation after ACL Reconstruction: a Review. Clin J Sport Med. 2013 Nov; 23(6):501-2.
21. Glass R, Waddell J, Hoogenboom B. The Effects of Open versus Closed Kinetic Chain Exercises on Patients with ACL Deficient or Reconstructed Knees: A Systematic Review. North American Journal of Sports Physical Therapy : NAJSPT. 2010;5(2):74-84.
22. Jewiss D, Ostman C, Smart N. Open versus Closed Kinetic Chain Exercises following an Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-Analysis. Journal of Sports Medicine. 2017;2017:4721548.
23. Tagesson S, Oberg B, Good L, Kvist J. A comprehensive rehabilitation program with quadriceps strengthening in closed versus open kinetic chain exercise in patients with anterior cruciate ligament deficiency: a randomized clinical trial evaluating dynamic tibial translation and muscle function. Am J Sports Med. 2008 Feb;36(2):298-307. Epub 2007 Oct 16.
24. Uçar, M., Koca, I., Eroglu, M., Eroglu, S., Sarp, U., Arik, H. O., & Yetisgin, A. (2014). Evaluation of Open and Closed Kinetic Chain Exercises in Rehabilitation Following Anterior Cruciate Ligament Reconstruction. Journal of Physical Therapy Science, 26(12), 1875–1878.
25. Perry MC, Morrissey MC, Morrissey D, et al. Knee extensors kinetic chain training in anterior cruciate ligament deficiency. Knee Surg Sports Traumatol Arthrosc. 2005;13(8):638–648
26. Morrissey MC, Hudson ZL, Drechsler WI, et al. Effects of open versus closed kinetic chain training on knee laxity in the early period after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2000;8(6):343–348
27. Mikkelsen C, Werner S, Erikson E. Closed kinetic chain alone compared to combined open and closed kinetic chain exercises for quadriceps strengthening after anterior cruciate ligament reconstruction with respect to return to sports: A prospective matched follow-up study. Knee Surg Sports Traumatol Arthrosc. 2000;8(6):337–342
28. Heijne A, Werner S. Early versus late start of open kinetic chain quadriceps exercises after ACL reconstruction with patellar tendon or hamstring grafts: a prospective randomized outcome study. Knee Surg Sports Traumatol Arthrosc. 2007;15:402–414
29. Beynnon BD, Uh BS, Johnson RJ, Abate JA, Nichols CE, Fleming BC, Poole AR, Roos H. Rehabilitation after anterior cruciate ligament reconstruction: a prospective, randomized, double-blind comparison of programs administered over 2 different time intervals. Am J Sports Med. 2005;33(3):347–359.
30. Liu-Ambrose T, Taunton JE, MacIntyre D, McConkey P, Khan KM. The effects of proprioceptive or strength training on the neuromuscular function of the ACL reconstructed knee: a randomized clinical trial. Scand J Med Sci Sports. 2003;13(2):115–123.
31. Jansen D: Shoulder & Knee CPM guideline for Patrick M. Connor, MD. A personal communication, October 2005.
32. An, Keun Ok. (2017). Exercise Rehabilitation after Anterior Cruciate Ligament Reconstruction. Exercise Medicine. 1. 1. 10.26644/em.2017.001.
33. Millett P, Wickiewicz TL, Warren R: Motion Loss after Ligament Injuries to the Knee. Am J Sport Med 29(5), 2001
34. Smith T O, Davies L. The efficacy of continuous passive motion after anterior cruciate ligament reconstruction: a systematic review. Physical Therapy in Sport 2007; 8(3): 141-152.
35. Biggs, A., Jenkins, W. L., Urch, S. E., & Shelbourne, K. D. (2009). Rehabilitation for Patients Following ACL Reconstruction: A Knee Symmetry Model. North American Journal of Sports Physical Therapy : NAJSPT, 4(1), 2–12.
36. Keays SL, Bullock-Saxton JE, Keays AC, et al. A 6-year follow-up of the effect of graft site on strength, stability, range of motion, functional and joint degeneration after anterior cruciate ligament reconstruction. Am J Sports Med. 2007;35:729–739
37. Sugimoto D, Myer GD, Bush HM, et al. Compliance with neuromuscular training and anterior cruciate ligament injury risk reduction in female athletes: a meta-analysis. J Athl Train. 2012;47(6):714–723.
38. van Reijen M, Vriend I, van Mechelen W, et al. Compliance with

sport injury prevention interventions in randomised controlled trials: a systematic review. Sports Med. 2016;46:1125–1139.
39. Brotzman S., Wilk K, Clinical Orthopaedic Rehabilitation, 2nd edition, Elsevier 2003, ISBN 0-323-01186-1
40. Giangarra C, Manske R., Clinical Orthopaedic Rehabilitation. A team approach, 4th edition, Elsevier, 2017, ISBN: 9780323393706
41. Chmielewski TL, George SZ, Tillman SM, Moser MW, Lentz TA, Indelicato PA, Trumble TN, Shuster JJ, Cicuttini FM, Leeuwenburgh C Low- Versus High-Intensity Plyometric Exercise During Rehabilitation After Anterior Cruciate Ligament Reconstruction. Am J Sports Med. 2016 Mar;44(3):609-17. doi: 10.1177/0363546515620583. Epub 2016 Jan 21.
42. Wright, R. W., Preston, E., Fleming, B. C., Amendola, A., Andrish, J. T., Bergfeld, J. A., … Williams, G. N. (2008). ACL Reconstruction Rehabilitation: A Systematic Review Part II. The Journal of Knee Surgery, 21(3), 225–234.
43. Monk AP, Davies LJ, Hopewell S, Harris K, Beard DJ, Price AJ. Surgical versus conservative interventions for treating anterior cruciate ligament injuries. Cochrane Database of Systematic Reviews 2016, Issue 4. Art. No.: CD011166.
44. Pinczewski LA, Lyman J, Salmaon LJ, Russell VJ, Roe J, Linklater J. A 10-year study comparison of anterior cruciate ligament reconstruction with hamstring tendon and patellar tendon autograft: a controlled, prospective trial. Am J Sports Med. 2007;35:564–574.
45. Paterno MV, Rauth MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of second ACL injuries 2 years after primary ACL reconstruction and return to sport. Am J Sports Med. 2014;42(7):1567–1573.
46. Dambros, C., Martimbianco, A. L. C., Polachini, L. O., Lahoz, G. L., Chamlian, T. R., & Cohen, M. (2012). Effectiveness of cryotherapy after anterior cruciate ligament reconstruction. Acta Ortopedica Brasileira, 20(5), 285–290.
47. Bleakley CM, O'Connor S, Tully MA, Rocke LG, Macauley DC, McDonough SM. The PRICE study (Protection Rest Ice Compression Elevation): design of a randomized controlled trial comparing standard versus cryokinetic ice applications in the management of acute ankle sprain [ISRCTN13903946] BMC Musculoskelet Disord. 2007;8:125.
48. Murgier J, Cassard X, Cryotherapy with dynamic intermittent compression for analgesia after anterior cruciate ligament reconstruction. Preliminary study. . Orthop Traumatol Surg Res. 2014 May;100(3):309-12. doi: 10.1016/j.otsr.2013.12.019. Epub 2014 Mar 25.
49. Warren TA, McCarty EC, Richardson AL, Michener T, Spindler KP. Intra-articular knee temperature changes: ice versus cryotherapy device. Am J Sports Med. 2004;32(2):441–5.
50. Raynor M C, Pietrobon R, Guller U, Higgins L D. Cryotherapy after ACL reconstruction: a meta-analysis. Journal of Knee Surgery 2005; 18(2): 123-129.
51. Cavanaugh, J. T., & Powers, M. (2017). ACL Rehabilitation Progression: Where Are We Now? Current Reviews in Musculoskeletal Medicine, 10(3), 289–296.
52. Tovin BJ, Wolf SL, Greenfield BH, Crouse J, Woodfin BA. Comparison of the effects of exercise in water and on land on the rehabilitation of patients with intra-articular anterior cruciate ligament reconstructions. Phys Ther. 1994;74:710-719.
53. Wright, R. W., Haas, A. K., Anderson, J., Calabrese, G., Cavanaugh, J., Hewett, T. E., Wolf, B. R. (2015). Anterior Cruciate Ligament Reconstruction Rehabilitation: MOON Guidelines. Sports Health, 7(3), 239–243.
54. Labanca L, Rocchi JE, Laudani L, Guitaldi R, Virgulti A, Mariani PP,Macaluso A. Neuromuscular Electrical Stimulation Superimposed on Movement Early after ACL Surgery. Med Sci Sports Exerc. 2018 Mar;50(3):407-416
55. Fitzgerald GK, Piva SR, Irrgang JJ. A modified neuromuscular electrical stimulation protocol for quadriceps strength training following anterior cruciate ligament reconstruction. J Orthop Sports Phys Ther. 2003 Sep;33(9):492-501.
56. Velázquez-Saornil J, Ruíz-Ruíz B, Rodríguez-Sanz D, Romero-Morales C, López-López D, Calvo-Lobo C. Efficacy of quadriceps vastus medialis dry needling in a rehabilitation protocol after surgical reconstruction of complete anterior cruciate ligament rupture.
57. Wright RW, Fetzer GB. Bracing after ACL reconstruction: a systematic review. Clin Orthop Relat Res. 2007;455:162–8.
58. Melegati G, Tornese D, Bandi M, Volpi P, Schonhuber H, Denti M. The role of the rehabilitation brace in restoring knee extension after anterior cruciate ligament reconstruction: a prospective controlled study. Knee Surg Sports Traumatol Arthrosc. 2003;11(5):322–6.