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Review Article

Graft-specific rehabilitation guidelines for anterior cruciate ligament reconstruction

Abhishek Kumar Sandilya[1]*, Ankur Ojha[2], Pankaj Kumar Singh[2], Divya Kashyap[1]

[1]Heritage Institute of Medical Sciences College of Physiotherapy, Bhadawar, Uttar Pradesh, India
[2]Department of Orthopaedics, Heritage Institute of Medical Sciences, Bhadawar, Uttar Pradesh, India

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***Correspondence:**
Dr. Abhishek Kumar Sandilya,
E-mail: abhisandilya4421@gmail.com

ABSTRACT

Anterior cruciate ligament (ACL) reconstruction is a frequently performed orthopaedic procedure, with rehabilitation playing a pivotal role in patient recovery. The selection of graft type in ACL reconstruction influences biomechanical properties, healing rates and post-surgical complications, necessitating a graft-specific rehabilitation approach. This article presents a comprehensive, phase-based rehabilitation protocol tailored to various ACL grafts, including bone-patellar tendon-bone (BPTB), hamstring tendon, quadriceps tendon, peroneus longus tendon, achilles tendon, allograft and synthetic graft. By integrating evidence-based exercise recommendations, this guideline aims to optimize patient outcomes, minimize complications and facilitate a safe return to functional activities and athletic participation.

Keywords: ACL reconstruction, BPTB graft, Functional recovery, Graft type, Hamstring tendon, Rehabilitation protocol

INTRODUCTION

Anterior cruciate ligament (ACL) injuries are considered one of the most common knee injuries especially among athletes involved in high-impact sports like football, basketball and skiing.[1] The ACL plays an important role in knee stability, which is to limit excessive anterior tibial translation and rotational instability.[2] When ACL is torn, surgery is often needed to recover the knee functionality and prevent the long-term consequences, including the development of osteoarthritis and secondary meniscal tissues damage.[3] ACL reconstruction involves clearing the torn ligament and replacing it with a graft, which acts as a framework on which new ligament tissue can grow.[4]

An ideal graft choice is paramount to successful outcome because various graft options have varied biomechanics, healing chronologies and donor site morbidities.[5] Most used grafts are autografts: Bone-Patellar Tendon-Bone (BPTB) graft, Hamstring Tendon graft and Quadriceps Tendon graft.[6] Newer alternatives like Peroneus Longus Tendon graft are also coming into focus because of their anatomical benefits and lack of significant donor site morbidity.[7] Additionally, allografts and synthetic grafts can serve as options in case of revision surgeries or patients whose functional demands are not high.[8] Although the surgical practices in ACL reconstruction have improved a lot, the success of the surgical process highly depends on the rehabilitation program.[9] Rehabilitation is critical in the guaranteeing of graft healing, recovery of range of motion (ROM), recovery of muscular strength, neuromuscular control and eventual safe return to sports or daily activity.[10] Standardized rehabilitation protocols are available, but these are usually generalized and they fail to take into consideration the unique nature of various types of grafts. [11]

The different grafts vary in terms of their implications to rehabilitation since they differ in terms of tissue integration, biomechanical qualities and challenges that occur post-surgery.[12] As an example, the BPTB graft has a great fixation strength, however, it is related to the anterior knee pain and patellar tendonitis, which requires certain modifications of exercises.[13] Hamstring grafts on the other hand need delicate hamstring strengthening techniques to avoid long term deficiency.[14] Allografts, where there is no donor site, but the incorporation time is longer requiring slower rehabilitation process to reduce chances of graft failure.[15,16]

Based on these differences, it is necessary to have a graft-specific rehabilitation program that would provide the best results. This article demonstrates a plan of rehabilitation divided into phases depending on various ACL grafts. It is expected to increase graft healing, enhance functional outcomes and reduce the probability of complications by incorporating evidence-based exercise recommendations.

In this study, a narrative literature review design was applied to develop graft-specific rehabilitation recommendations after anterior cruciate ligament (ACL) reconstruction. The key goal was to perform a synthesis of existing evidence related to rehabilitation strategies depending on the specific biomechanical and biological properties of widely used ACL grafts. To achieve a relevant and rich body of evidence, a systematic review of peer-reviewed publications was performed across the electronic databases of PubMed, Scopus, Google Scholar and CINAHL.

The searching covered studies published between January 2000 and March 2024 and it was confined to publications in the English language. The key terms and Boolean combinations used were as follows: ACL reconstruction AND rehabilitation protocol, graft type AND functional recovery and specific graft types, such as, BPTB, hamstring tendon, quadriceps tendon, peroneus longus tendon, Achilles tendon, allograft and synthetic graft. Manual screening of reference lists of major reviews and clinical guidelines identified further articles. Included studies had to deal with rehabilitation guidelines in consideration of definite graft types of ACL reconstruction.

The sources that were eligible included clinical trials, cohort studies, systematic reviews and expert consensus papers and had to include information on exercise progressions, healing timelines or functional recovery outcomes. Articles not specifying the type of graft, concentrated on surgical method and did not mention rehabilitation, animal and cadaveric studies and basic science studies without direct clinical application were not included in this review. The sources were reviewed and data on biomechanical characteristics of each graft, graft-specific healing patterns, frequent complications and exercise interventions suggested in the literature were obtained.

Focus was placed on rehabilitation actions that contributed to tissue healing, neuromuscular reinnervation, reducing donor site morbidity and ensuring safe sport resumption. The information retrieved was summarized in a uniform four-phase rehabilitation model, immediate post-operative phase (weeks 0-4/6), early strengthening phase (weeks 4-12/16), advanced strengthening phase (weeks 12-20) and return to sport phase (week 20 and more). All graft types were assigned to this phase-oriented timeline with specific exercise suggestions depending on the literature and the idea was to increase the clinical relevance and maximize the patient-specific rehabilitation success.

GUIDELINE

The graft-specific rehabilitation protocol following ACL reconstruction is structured into four progressive phases. The immediate post-operative phase (weeks 0–4) focuses on managing pain and inflammation, restoring joint range of motion and initiating quadriceps activation through gentle isometric exercises and early mobilization.

In the early strengthening phase (weeks 4–12), controlled loading is introduced using closed-chain exercises, along with proprioceptive activities to enhance joint stability and neuromuscular control. The advanced strengthening phase (weeks 12–20) targets muscle endurance and dynamic control through progressive resistance training and functional drills, gradually preparing patients for activity-specific movements. Finally, the return to sport phase (week 20 onward) emphasizes high-impact exercises, agility training and performance-based assessments to ensure readiness for athletic participation.

Exercises were selected based on their biomechanical benefits and potential risks associated with each graft type.

GRAFT-SPECIFIC REHABILITATION GUIDELINES

BPTB graft

The BPTB graft has strengths associated with it; it has proved to have high initial fixation strength due to its bone-to-bone healing capability. It has; however, a higher risk of anterior knee pain and patellar tendonitis and close attention must be paid to the choice of exercises during rehabilitation.

Weeks 0 to 4 emphasize quadriceps isometric activation through straight leg raises (SLR) and terminal knee extensions (TKE) to provoke early muscle recruitment and limit patellar stress. This phase specifically avoids deep squats in order to limit the excessive load on the patellar tendon. Weeks 4-12, the progressive strengthening is further pursued using exercises like leg presses in a range of 0-45 o of flexion and controlled step-ups, paying attention to the development of anterior knee pain.

During the advanced phase between weeks 12 to 20, the focus of rehabilitation exercises is on dynamic single-leg squats and plyometric exercises such as box jumps to challenge functional stability and neuromuscular control. Starting in week 20, high-impact drills and multi-directional agility are integrated into the training and the integrity of the patellar tendon is monitored in the returned-to-sport activities.

Hamstring tendon graft

The hamstring tendon graft has the soft tissue-to-bone healing which is slower than the bone-to-bone grafts and there is the possibility of developing weakness in the hamstrings posted operatively. During the early (weeks 0 4), the rehabilitation process is aimed at maintaining range of motion via quad sets and heel slides, with hamstring activation being strictly limited, to avoid damages to the graft. During this time passive knee flexion is emphasized to aid joint mobility without placing stress on the healing tissue. During weeks 4-12, the transition to controlled strengthening is made with the assistance of hamstring isometric exercises and step-down drills. At this phase aggressive stretching of the hamstrings should be avoided as this may cause a strain. During the period of weeks 12 to 20, as the patient enters the latter phase, eccentric loading through Nordic hamstring curls is introduced to respecify muscle control and strength. Moreover, to enhance neuromuscular coordination, agility drills are included. Finally, a dynamic movement training and high-velocity drills focus is made in the last stage, starting week 20, to get the person back to sport and full functional activity.

Quadriceps tendon graft

The quadriceps tendon graft has a significant structural strength because of its greater cross-sectional area and a possible threat of postoperative quadriceps weakness. During the initial stage of rehabilitation (Weeks 04 4), neuromuscular electrical stimulation (NMES) is used to assist quadriceps activation, SLR with a mild knee flexion to prevent excessive tension on the graft site can be used as well. During the rehabilitation continuing weeks 4-12, step-down exercise and progressive were applicable on the leg press machine are used to recover the quadriceps strength with anterior knee pain being monitored. Weeks 12-20 will focus on further development with Bulgarian split squats in the advanced strengthening to build on muscular endurance and control and sprint mechanics drills will be introduced to begin developing faster movements.

In the rehabilitation continuing weeks 4-12, step-down exercise and progressive can be applied on the leg press machine to regain the quadriceps strength and posterior knee pain is observed. Weeks 12-20 will be devoted to the further development using Bulgarian split squats in the advanced strengthening to continue muscular endurance and control development and sprint mechanics drills will be introduced to start developing faster movements.

Peroneus longus tendon graft

Peroneus longus tendon graft is characterized by high tensile strength and it is linked with little morbidity at the donor site, thus resulting as a good choice in ACL reconstruction. The first postoperative period (weeks 04), the rehabilitation procedure aims at the protection of the ankle mobility by performing light range-of-motion exercises and the maintenance of quadriceps activity by means of performing static contractions, thus protecting the graft harvest site. During weeks 4-12 of the patients continued recovery, proprioception and lower-limb strength are trained with the assistance of balance board exercises and controlled lunges, allowing joint stability and neuromuscular involvement. During the enhanced strengthening period (weeks 12 to 20), exercises involving lateral movement and single leg hops testing are added to provoke dynamic control and develop preparedness to functional tasks. Since week 20, the high-speed agility and cutting drills are implemented, which is the last phase of the return-to-sport conditioning, as well as the readiness of the athlete to the multi-directional movement and the impact requirements.

Achilles tendon graft

Achilles tendon graft is strong and most often used in revision ACL surgery. The rehabilitation should have a more gradual course because it is a large structure that needs to integrate with the body at a slower biological level. During the first phase (weeks 0-6), the focus is on assisted passive and active range of motion exercises and isometric quadriceps contractions to facilitate early graft protection and restrict joint stiffness. During weeks 6 to 16 of the patient progress, the rehabilitation protocol adds calf raises and specific posterior chain strengthening exercises that place emphasis on gluteal and hamstring activation to emphasize lower limb stability without provoking graft overload at the site. In weeks 16 to 20, more-impact neuromuscular training is progressed into, involving plyometric exercises and eccentric single-leg hops, to regain explosive power and safe landings. At week 20 or more, rehabilitation shifts toward sport-specific exercises and more challenging functional activities, which are gradually progressed to determine the athletes are ready to face the athletic demands again and the risk of reinjury is minimal.

Allograft

Allografts, usually used in revision procedures or in patients with less functional demands, take longer to incorporate biologically and therefore should be rehabilitated more conservatively. During the first phase (weeks 06), the focus is on a slow restoration of the range of motion and safe quadriceps activation to avoid an early load on the graft. At this stage, movements are intentionally limited to allow tissues to incorporate and prevent inflammatory problems. Weeks 6-16 Controlled strengthening is initiated with closed-chain squats and specific proprioceptive exercises to promote joint stability without graft jeopardy.

During the advanced stage between weeks 16 and 20, when the patient is successfully transitioned into the advanced stage, low impact exercises including gradually increasing jogging and initial plyometric exercises are introduced to enhance functional recovery, but with continued caution of symptoms of graft strain. After week 20, the rehabilitation program will involve high-impact movements and sport-specific conditioning, but full athletic participation is still purposely delayed minimizing the chance of reinjury.

Synthetic graft

The benefit of synthetic grafts is the early-stage recovery that is quicker since the grafts are structurally ready but close monitoring during the rehabilitation period is necessary to check on graft integrity. During the first phase (weeks 0 6), the emphasis is put on restricted range of motion exercises and proprioceptive drills to encourage joint awareness without putting the synthetic construct at risk. Weeks 6 to 16 go into progressive squatting and agility-based exercises to improve neuromuscular control without placing excessive stress on the graft too early. The third stage (weeks 16-20) is advanced and it adds sport-specific drills and specific training of landing mechanics to be ready to dynamic and unpredictable movements. After week 20, the rehabilitation progresses with the ultimate inclusion of high-impact and plyometric exercises to facilitate a resumption of full athlete status, with all attendant caution regarding the possibility of mechanical compromise nonetheless observed.

DISCUSSION

The review confirms the urgent necessity of personalized rehabilitation guidelines after ACL reconstruction, stressing the importance of the fact that the effectiveness of post-operative healing directly relies on the qualities of the graft. On the one hand, a standardized framework offers a structure, whereas, on the other hand, biological and mechanical variations between the kinds of grafts require individualized progression through all the rehabilitation stages.

BPTB grafts have shown to have good initial fixation because of bone-to-bone healing which permits early mobilization. They are however linked with anterior knee pain and patellofemoral stress which requires consideration in the choice of exercises. Regarding the impeding anterior knee discomfort, Shelbourne and Gray emphasize the importance of restricting closed-chain loading in deep flexion panacea-which was also incorporated into our guideline in the form of the early-phase suggestions. Relatively, hamstring tendon grafts that heal more gradually by soft tissue-to-bone integration must be safeguarded against hyperactivity during the early phase of healing.[19] Exercises that tend to eccentrically load the graft, e.g., Nordic curls, can be introduced carefully and have been demonstrated to maintain graft integrity, as well as restore functional capacity.[20]

Another complication that has been occurring more frequently due to its strength and graft volume is the quadriceps tendon graft; its disadvantage is quadriceps inhibition and anterior thigh weakness. The key factor to gain the strength without jeopardizing the graft stability, as Slone et al underline, is the inclusion of neuromuscular electrical stimulation and controlled load-bearing exercises in the early phases of the recovery period. Our progressive leg press and step-downs recommendations follow these principles and attempt to achieve a balance between strength recovery and joint protection.[21] New grafts including the peroneus longus tendon can be beneficial regarding tensile strength and less donor site morbidity.

Li et al showed that it is biomechanically equal to traditional grafts, which allows its application in high-demand patients. This graft needs to be rehabilitated with the consideration of knee and ankle mechanics as distal joint stiffness may hinder neuromuscular recovery.[22] Likewise, the Achilles tendon graft, which is mostly used in revision procedures, has long healing schedules considering its bulk and slower biologic integration. Barber-Westin et al and Noyes et al support a high-load training be postponed until posterior chain strength and coordination has been regained, which is echoed in our protocol by the implementation of eccentric single-leg drills later in the phases.[23,24]

Although allografts are beneficial in low-demand patients or in multi-ligament reconstructions, they are a problem because of the delayed cellular repopulation and remodeling. Noyes et al and Barber-Westin et al warn that premature loading can cause graft failure. By waiting to jog and perform high-impact activities until after week 16, our algorithm reflects this guideline and puts the incorporation of the graft first. Conversely, the synthetic grafts enable fast tracking of the initial phases but have long term issues of wear and structural fatigue.[23,24] According to Prodromos et al failure of graft occurred more in the scenario when it is not keenly monitored. We therefore favor proprioceptive loading, controlled landing mechanics and late phase plyometrics only after neuromuscular control can be demonstrated.[25]

Relative results with these forms of grafts enhance a core concept; it is the biological nature of the graft that must outline the rehabilitation progression, not the operative date alone. Although grafts that heal faster allow earlier return-to-sport dates, excessive enthusiasm in the progression of grafts that incorporate slowly may jeopardize results.

According to Smith et al graft-specific outcomes are better whenever the protocols are personalized- a theme that is repeated in this review.[17] These types of grafts have relative outcomes that expand on a fundamental concept; it is the biology of the graft that should dictate the course of rehabilitation and not the date of operation itself. Even though grafts which have a quicker rate of healing permit an earlier date of return to sport, over-exuberance in the development of grafts that integrate at a slower rate can compromise outcomes.

CONCLUSION

Patients' rehabilitation after ACL reconstruction should be personalized and the choice of graft is one of the critical factors to guide the rehabilitation protocol. The article offers a structured protocol graft-specific that could be used to obtain optimal recovery and enhance functional outcome and reduce chances of having complications. These customized exercise strategies are recommended to be applied by the clinicians to provide safe and effective results of rehabilitation. Prospective studies (longitudinal studies) must now take precedence to evaluate the long-term result of these graft specific protocols which will eventually lead to evidence-based modification in the practice of rehabilitation and better patient outcomes.

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REFERENCES

1. Evans J, Mabrouk A, Nielson JL. Anterior cruciate ligament knee injury. Treasure Island (FL): StatPearls Publishing. 2023.
2. Gonzalez-Pola R, Gómez Mont-Landerreche JG, Herrera-Lozano A, Torres-Valdés RA, Flores-Carrillo A. Rotational instability of the knee: injury of anterior cruciate and anterolateral knee ligaments, MRI findings. J Musculoskelet Surg Res. 2021;5:24–9.
3. Friel NA, Chu CR. The role of ACL injury in the development of posttraumatic knee osteoarthritis. Clin Sports Med. 2013;32(1):1–12.
4. Yao S, Fu BS, Yung PS. Graft healing after anterior cruciate ligament reconstruction (ACLR). Asia Pac J Sports Med Arthrosc Rehabil Technol. 2021;25:8–15.
5. Banovetz MT, Kennedy NI, LaPrade RF, Engebretsen L, Moatshe G. Biomechanical considerations for graft choice in anterior cruciate ligament reconstruction. Ann Joint. 2023;8:17.
6. Asif N, Khan MJ, Singhal U, Anwer A, Firoz MA, Rashid M. Randomized controlled study comparing hamstring graft and peroneus longus tendon graft in arthroscopic ACL reconstruction. J Orthop Case Rep. 2024;14(11):240–5.
7. Bregenhof B, Jørgensen U, Aagaard P. The effect of targeted exercise on knee-muscle function in patients with persistent hamstring deficiency following ACL reconstruction – study protocol for a randomized controlled trial. Trials. 2018;19:75.
8. Runer A, Keeling L, Wagala N. Current trends in graft choice for primary anterior cruciate ligament reconstruction – part II: in-vivo kinematics, patient reported outcomes, re-rupture rates, strength recovery, return to sports and complications. J Exp Orthop. 2023;10:40.
9. Butt UM, Khan ZA, Amin A, Shah IA, Iqbal J, Khan Z. Peroneus longus tendon harvesting for anterior cruciate ligament reconstruction. JBJS Essent Surg Tech. 2022;12(2):2053.
10. Deshpande S, Ghodke P, Kale S, Shyam A. Rehabilitation in arthroscopic anterior cruciate ligament reconstruction. J Orthop Case Rep. 2025;15(3):1–7.
11. Chen T, Dong Y, Li Y, Chen S. Four-year comparative analysis of return to sport and psychological recovery following ACL revision: artificial ligament vs. anterior tibial tendon allograft. J Orthop Transl. 2024;47:29–38.
12. Ostojic M, Indelli PF, Lovrekovic B, Volcarenghi J, Juric D, Hakam HT, et al. Graft selection in anterior cruciate ligament reconstruction: a comprehensive review of current trends. Medicina (Kaunas). 2024;60(12):2090.
13. Gharpinde MR, Jaiswal AM, Dhanwani Y. A comprehensive review of graft choices and surgical techniques in primary anterior cruciate ligament reconstruction: an outcome analysis. Cureus. 2024;16(9):68701.
14. Rathore S, Suri HS, Quadri V, Gollamudi S. Arthroscopic ACL reconstruction with aperture interference fixation: graft comparison, BPTB versus hamstring tendon – cohort study with two-year follow-up. J Med Sci Res. 2017;5(1):5–12.
15. Vinagre G, Kennedy NI, Chahla J, Cinque ME, Hussain ZB, Olesen ML, et al. Hamstring graft preparation techniques for anterior cruciate ligament reconstruction. Arthrosc Tech. 2017;6(6):e2079–84.
16. Opoku M, Fang M, Lu W. Acute anterior cruciate ligament rupture: can repair become an alternative to reconstruction? A meta-analysis of randomized controlled trials and cohort studies. J Orthop Surg Res. 2024;19:331.
17. Smith TO, Davies L, Hing CB. A systematic review of rehabilitation protocols after ACL reconstruction. Physiother Res Int. 2010;15(3):200–10.
18. Beynnon BD, Johnson RJ, Abate JA, Fleming BC, Nichols CE. Treatment of anterior cruciate ligament injuries. Part 1. Am J Sports Med. 2005;33(10):1579–602.
19. Shelbourne KD, Gray T. Anterior knee pain following ACL reconstruction. Clin Sports Med. 2011;30(1):81–94.
20. Samuelsson K, Andersson D, Karlsson J. Hamstring tendon grafts for ACL reconstruction. Acta Orthop. 2012;83(2):116–21.
21. Slone HS, Romine SE, Premkumar A, Xerogeanes JW. Quadriceps tendon: an effective graft for ACL reconstruction. Orthop Clin North Am. 2016;47(3):607–18.

22. Li Q, Zhang Y, Sun J, Li H, Liu Y, Duan X, et al. Peroneus longus tendon as an alternative graft for ACL reconstruction. Orthop J Sports Med. 2018;6(2):26138.
23. Barber-Westin SD, Noyes FR. Achilles tendon allografts in ACL reconstruction. Clin Sports Med. 2009;28(2):289–308.
24. Noyes FR, Barber-Westin SD. Graft selection in ACL reconstruction. J Bone Joint Surg Am. 2015;97(16):1319–28.
25. Prodromos CC, Joyce BT, Shi K, Brown CH. Synthetic grafts in ACL reconstruction. Arthroscopy. 2013;29(4):601–10.

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