6-25-2023

Postoperative Considerations Based on Graft Type After Anterior Cruciate Ligament Reconstruction a Narrative Review

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Postoperative considerations based on graft type after anterior cruciate ligament reconstruction a narrative review

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Contributions: (I) Conception and design: A Leung, B DeSandis, R Zarzycki; (II) Administrative support: None; (III) Provision of study materials or patients: None; (IV) Collection and assembly of data: A Leung, B DeSandis, R Zarzycki; (V) Data analysis and interpretation: None; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

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Background and Objective: Graft selection for anterior cruciate ligament reconstruction (ACLR) affects rehabilitation throughout the course of postoperative care.

Methods: A search of PubMed and EBSCO was performed and abstracts independently reviewed by two authors. This search was also supplemented with additional evidence relevant to each phase of ACLR rehabilitation.

Key Content and Findings: Direct implications of graft type on clinical decisions vary throughout treatment phases, transitioning from potential differences in acute postoperative pain management immediately after surgery to facilitating sufficient and appropriate lower extremity loading in subsequent weeks. Regardless of graft type, surgical limb weakness persists throughout the course of rehabilitation; however, harvest site selection for autografts contributes to disproportionate weakness of the harvested muscle group and the potential for surgical-induced tendinopathy. In later phases of rehabilitation, as athletes are transitioning into return to sport (RTS), treatment decisions and protocols are less affected by graft type but expectations for meeting clinical milestones and the time required to do so does differ between graft types.

Conclusions: Targeted strengthening interventions to address muscle weakness following graft harvest in autografts should be continued throughout the rehabilitation process. Lingering deficits in quadriceps strength symmetry may also influence time to meet progression and RTS criteria following graft harvest from the extensor mechanism.

Keywords: Anterior cruciate ligament reconstruction (ACLR); graft type; rehabilitation

Received: 30 November 2022; Accepted: 09 June 2023; Published online: 25 June 2023.
doi: 10.21037/aoj-22-51
View this article at: https://dx.doi.org/10.21037/aoj-22-51

Introduction

Background

Anterior cruciate ligament (ACL) injuries are among the most common athletic knee injuries with rising incidence in youth athletes (1-3). Return to high level activity following ACL injury remains a major risk factor for subsequent ACL rupture, necessitating adequate understanding of contributing factors to successful rehabilitation and return to sport (RTS) (4). Current treatment in the United States nearly always includes surgical reconstruction, and in younger athletic populations autografts are generally

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Table 1 Search parameters and methods

Items	Specification
Date of search	4/3/2023
Databases and other sources searched	PubMed and EBSCO
Search terms used	PubMed: "anterior cruciate ligament reconstruction" AND "graft type"; EBSCO: graft type in ACL reconstruction
Timeframe	2000–2022
Inclusion criteria	Full text peer reviewed articles in English
Exclusion criteria	Articles pertaining to synthetic ligament augmentation, IT band autograft, anterolateral ligament reconstruction, skeletally immature athletes
Selection process	Titles and abstracts were independently reviewed by two authors (AL and RZ), consensus obtained by reviewing full texts

ACL, anterior cruciate ligament.

preferred as allografts are more likely to result in graft failure and carry risks of infection or delayed integration (1,5-12). Hamstring tendon (HT) and bone-patellar tendon-bone (BPTB) grafts are more commonly performed but recent evidence and trends may favor quadriceps tendon (QT) autograft as an alternative choice (1,5,13).

Rationale and knowledge gap

Graft type selection carries implications for decision making throughout rehabilitation following ACL reconstruction (ACLR) including appropriate protection and loading of tissues relevant to graft harvest, temporal milestones of graft integration, and expectations for achieving clinical benchmarks known to reduce injury risk (4,5,14,15). Notably, time to meet important clinical milestones after surgery differs between athletes who received different graft types, delaying progression and return to play in those with BPTB autografts (5). It is imperative that clinicians understand the relevance of graft type to rehabilitation following surgery in order to optimize outcomes. Existing published reviews have broadly addressed graft type implications within the perspective of rehabilitation but no reviews to date have identified specific implications of graft selection throughout the course of rehabilitation and RTS.

Objective

The purpose of this review is to discuss relevant similarities and differences in post-operative ACLR rehabilitation based on graft type. We organized this perspective in sections based on time from surgery (i.e., early post-operative, mid-late postoperative, and transition/RTS). We present this article in accordance with the Narrative Review reporting checklist (available at https://aoj.amegroups.org/article/view/10.21037/aoj-22-51/rc).

Methods

A PubMed search was performed with keywords used as follows: "anterior cruciate ligament reconstruction" AND "graft type". EBSCO academic search ultimate search terms were as follows: graft type in ACL reconstruction, which yielded 304. Results of both searches were filtered for full text journal articles published 2000–2022 in English. Parameters of our search are outlined in *Table 1*. Our search yielded a total of 371 unique articles. Titles and abstracts were reviewed independently by two authors to determine appropriateness for inclusion followed by full text review as needed to reach consensus for inclusion. After review of abstracts and full text we included 31 articles from this process.

We also supplemented this search with separate searches to capture specific graft type considerations within each phase of rehabilitation based on our clinical knowledge of priorities and clinical criteria relevant to each phase and referenced additional literature. Our additional 75 references cited come from those searches, broader ACLR rehabilitation literature, and evidence pertinent to tendinopathy that we apply to rehabilitation of graft harvest site.

Discussion

Early post-operative phase

The primary concerns in the early post-operative phase of rehabilitation (defined here as 1–2 weeks following surgery) are managing pain, monitoring effusion, and restoring full range of motion (ROM). There is evidence of higher intensity and greater prevalence of pain early (i.e., immediately after surgery and 3 days post-ACLR) after surgery with BPTB *vs.* HT autograft (16). Despite differences in patient reports of pain, there was no significant difference in opioid usage over the same period of time, but patients who received HT autograft reported higher satisfaction with pain management compared to those who received BPTB autograft (16). The use of electrical stimulation for pain control following ACLR has not been widely studied; however, a recent systematic review supports a positive effect of strong non-painful electrical stimulation on reducing intensity of pain during and immediately after treatment in postoperative patients and following acute injury (17). Use of electrical stimulation as an adjunct to other interventions may be beneficial in managing post-operative pain.

Regardless of graft type, restoration of full knee extension should be achieved early, ideally within 4 weeks following surgery. Previous research has found a correlation between extension ROM at 4 weeks and at 12 weeks, which supports the importance of achieving full knee extension early after ACLR (18). Furthermore, clinical data have supported the feasibility of early ROM restoration with patients on average achieving full passive knee extension by 1 week and active knee extension by 2 weeks after surgery regardless of graft type (1).

The main difference in the early post-operative phase is higher intensity pain experienced after BPTB compared to HT. There are currently no published data on pain after QT reconstruction in the initial 2 weeks following surgery. Based on the limited literature examining acute pain immediately after ACLR by graft type, pain management following ACLR should include a multimodal approach that includes nerve blocks, oral medications, intra-articular injections, cryotherapy, and compression regardless of graft type (19).

Regardless of graft type, patients should also be monitored for signs of post-operative infection early after surgery. A meta-analysis found no significant difference between autografts and allografts but higher risk of infection after HT compared to BPTB autograft (20,21). Generally, the incidence of infection after ACLR is relatively low, but between autografts infection is less likely after BPTB compared to HT (relative risk =0.33) (20,21).

Mid-to-late postoperative phase

The main considerations for the mid-stage of postoperative rehabilitation (defined here as the restoration of a quiet knee starting 2–4 weeks following surgery and continuing until appropriate for progression into RTS phase no sooner than 3–4 months following surgery) are muscle strengthening to address asymmetries in knee extensor and flexor strength, restoring movement quality during foundational motor tasks and physical reconditioning, in addition to continuing to address remaining impairments from the early postoperative phase. Regardless of graft type, timely restoration of quadriceps strength is critical during this phase. Extensive research indicates that many patients do not sufficiently restore quadriceps strength after ACLR (22-25), with more than half of patients experiencing a deficit greater than 10% *vs.* the contralateral limb at the time of RTS (24-28). Associations between quadriceps dysfunction and poor biomechanics (24), reduced knee function (29,30), increased risk of knee osteoarthritis (31), and re-injury risk (4) are well established. Thus, targeted loading of the quadriceps and knee extensor mechanism immediately after surgery is crucial.

Active loading for all graft types should consist of both open-kinetic chain (OKC) and closed-kinetic chain (CKC) exercises. Despite persistent resistance to the use of OKC exercises early during ACLR due to fear of excessive strain on the healing ACL graft, multiple studies have shown strain on the ACL is low with OKC exercise (32,33), with significantly more strain occurring during midstance and late swing phases of gait (34-36). Therefore, exercises such as long arc quads (LAQ) are safe to begin 90° to 0° with light ankle cuff weight resistance in the early postoperative phase, with progression to a resisted knee extension machine during mid-stage rehabilitation or earlier depending on response and tolerance of the patient. In a recent clinical review by Brinlee *et al.*, the authors advocate for using knee soreness and effusion as a guide for exercise progression, not perceived strain on the ACL graft (1). Thus, routine assessment of knee effusion using the sweep test and monitoring pain via soreness rules should be used to determine whether a patient is appropriate for progression in strengthening program regardless of graft type.

Graft type should be considered with targeted loading of the extensor mechanism. With both QT and BPTB grafts, it is reasonable to anticipate harvest site tendinopathy after reconstruction and rehabilitation should include considerations for surgically-induced tendinopathy (1). Typical tendinopathy treatment consists of tendon loading exercise programs and modalities such as noxious electrical stimulation to address pain (37). Therefore, similar quadricep and patellar tendon loading is logical following QT and BPTB grafting. In order to promote tissue remodeling, the harvest site must be loaded with active quadriceps contraction. To properly isolate the rectus femoris and QT during quadriceps strengthening and tendon loading exercises, the patient should be placed into positions where the hip is extended (38). Conversely, the patellar tendon is loaded whenever knee flexion angle changes and the quadricep is contracted, so patients with BPTB grafts have less specific considerations regarding exercise set up and hip/knee positioning. However, due to increased patellofemoral forces and possible irritation during progressive resisted exercises, therapists should treat increases in anterior knee pain with noxious electrical stimulation and patellar taping as needed, follow the tendinopathy pain monitoring model (39), and consider the alteration of knee flexion angles to the most comfortable between 45–60° for maximal volitional contractions and neuromuscular electrical stimulation (NMES) treatment to decrease strain on patellofemoral joint (1).

In order to ensure exercises are targeting the harvest site, therapists should ask patients where they are feeling the muscle effort and/or pain to ensure it is localized to the harvest site. They should also use the Numeric Pain Rating Scale (NPRS) and pain-monitoring model to ensure loads are safe but sufficient enough to allow for tendon remodeling (39). Pain ratings within the "safe zone" (0–2/10 NPRS) indicate the exercise is safe but probably not applying enough load through the tendon to allow for remodeling. Pain ratings in the "acceptable zone" (2–5/10 NPRS) suggest there is enough load being applied to the harvest site for remodeling without risk of overstressing the tissue or putting the patient at risk for patellar fracture. If pain ratings exceed the 5/10 NPRS "high risk" zone, the exercise should be terminated to reduce risk of tissue overload and patellar fracture.

With HT autografts, the semitendinosus (ST) and/or gracilis tendon (GT) are most commonly used. Graft harvest requires a smaller incision and leaves the extensor mechanism intact. However, hamstring harvest leads to greater knee flexion strength deficits, approaching 50% at 4 weeks, after ACLR with HT (40-42). This strength deficit generally coincides with the transition from the early postoperative to mid-stage of rehabilitation. Current recommendations specific to HT graft delay targeted hamstring specific strengthening for 6–8 weeks after ACLR (33,43,44). Hamstring strengthening can be initiated with isometric knee flexion at week 6, progressing to dynamic knee flexion at week 8. Once pain-free with dynamic knee flexion, load can be introduced from 0–90° at 8–12 weeks. Hamstring restrictions are then lifted beyond 12 weeks postoperative.

The recommendations made in the previous paragraph are based on multiple factors including a resultant grade 4 muscle-tendon lesion following HT harvest and proximal migration of the ST muscle-tendon junction, which has varying incidence following ACLR with HT but requires an estimated 18 months to regenerate when such a lesion does occur (45-49). Recently, Buckthorpe *et al.* suggested a lack of quality evidence to support this delay and advocated for integration of early hamstring specific exercise at low intensity (50). However, it is important to note their suggestion is based on anecdotal experience, with no published studies demonstrating safety and improvements in hamstring recovery with earlier initiation of hamstring specific exercise. The above recommendation included low intensity isometric and concentric hamstring exercises in positions that shorten hamstring length during the early stage of rehabilitation in order to minimize knee flexor strength deficits and allow for easier hamstring strength recovery during the mid- and later phases of rehabilitation (50). Example exercises include neuromuscular activation exercises and low-intensity controlled movements such as co-contractions, controlled prone limb lowering, and controlled knee flexion recovery in gait (pool priority). Once patients transition into the mid-stage of rehabilitation at about 4 weeks, they recommend gradual progression of resistance (described as low-to-moderate loads), which may be supplemented by blood flow restriction (BFR) (51). A complementary variety of knee and hip focused exercises should be used, focusing first on isometric or concentric actions. Increased hamstring loading via either isolated or functional exercise are appropriate and safe to include beyond 6–8-week postoperative timepoint to mitigate hamstring strength deficits. Emphasis must be placed on optimal technique during functional exercise to ensure positive motor control adaptations.

There is no difference between graft type in regards to neuromuscular re-education exercise and aerobic training during this stage of rehabilitation. Balance and proprioceptive exercises on variable surfaces can be initiated in addition to perturbation progressions. Patients can then be progressed to higher level balance activities that include multi-tasking and incorporate sport-specific equipment as appropriate. Aerobic training on the bike, elliptical and Stairmaster can safely be initiated at 4 weeks, increasing duration and intensity as tolerated.

As patients enter the later phase of rehabilitation, protocols do not differ significantly between graft types as the goals of this phase are to improve tolerance to loading and muscle performance, improve aerobic conditioning, and increase variability of training, focusing on optimizing neuromuscular control, movement performance and sport-specific training. Therapists should continue to be considerate of tendinopathy symptoms for all graft types as they progress patients, modifying load and treating with modalities as needed. Utilization of progressive resistive exercise for quadriceps strengthening should be continued in order to achieve quadricep strength of at least ≥80–90% of the uninvolved side. Use of BFR and NMES should be continued if strength is still deficient, discontinuing once the patient is able to tolerate >70% 1-RM load and once ≥80% quadricep strength is achieved, respectively.

It has been established that hamstring muscle lesions and persistent strength deficits increase risk of hamstring strain injury (HSI) (52-54). HSIs typically occur when the hamstrings act eccentrically to decelerate the knee at the end of swing phase during running and sprinting (55). Hamstring grafting results in a grade 4 muscle lesion to the hamstrings, with resultant deficits in eccentric hamstring strength after ACLR with HT having been reported as ranging from 16% to 20% (56-58). This strength deficit can be due to altered muscle morphology of the graft site, but also alterations in neuromuscular activation and muscle inhibition during eccentric contractions (58-60). Studies have shown that 6–10 weeks of knee-based eccentric hamstring strengthening can improve knee flexor eccentric strength by 13–19% and may, in turn, reduce risk of sustaining a future HSI (61-63). Therefore, eccentric training following ACLR is particularly important following HT autograft in order to overcome persistent weakness, improve eccentric strength and avoid future HSI.

For eccentric training, time under tension is important. Thus, a tempo such as 1:1:5 (concentric: isometric: eccentric) should be assigned to eccentric exercises. Since the hamstrings act both to extend the hip and flex the knee, exercises that train patients to absorb force at the hip (into hip flexion) and at the knee (into knee extension) should be utilized during training (49). Examples of hip dominant eccentric exercises include bridging exercises, Romanian deadlifts (RDLs), eccentric hip extension at cable column, and rear-foot elevated split squats. Knee dominant eccentric exercises include Nordic hamstring curls, Swiss ball single leg roll outs, seated or prone hamstring curl machine eccentrics. Eccentric exercises accomplish a greater overload to the muscle than concentric exercise and often results in increased incidence of delayed onset muscle soreness (DOMS) (50). Thus, set and rep ranges should start lower (i.e., 2×5), progressively increasing volume week by week as tolerated working toward 3 sets of 8–12 reps (63). Eccentric training should be performed before light training or off days and can include progressive introduction of speed to increase load as patients are able to withstand longer forward falls (63).

HT autograft also results in selective ST muscle atrophy (10–28%) (46,64-66) and can sometimes be associated with gracilis muscle atrophy (~30%) (65,66). This leads to decreased knee flexion strength but may also lead to deficits in transverse plane knee control as the medial hamstrings assist with tibial internal rotator and medial stability. As a result, patients may compensate through external rotation of the lower extremity during hamstring strengthening exercises such as hamstring curls or bridging to substitute with the biceps femoris. Therapists should be aware of these compensations and cue patients to maintain neutral alignment. Exercises can also be modified to increase activation of the medial hamstrings by changing lower extremity/foot position to more internal rotation (67).

Transition and RTS

There is no evidence supporting different protocols or RTS testing criteria based on graft type. Criterion-based guidelines have been widely used in rehabilitation decisions for progression, with emphasis on the importance of quadriceps strength symmetry for initiation of plyometrics and running (1,5,68). Objective measures of quadriceps strength should be performed to inform appropriateness of progression through these phases, and persistent asymmetry in quadriceps strength would delay progression.

Expectations for quadriceps and hamstring function early in this phase differ somewhat between autograft types (5,69-71). Existing literature suggests that at around 3–4 months after surgery patients tend to have less strength in the harvest site muscle group, with HT showing lower hamstring strength and BPTB showing lower quadriceps strength 4 months after ACLR (69,70). Quadriceps function following QT autograft has not been as widely studied to date, but studies have found greater quadriceps asymmetry in both QT and BPTB compared to HT at multiple time points after ACLR including 6 months post-reconstruction and beyond (72-75). Because of these differences in function, continuation of adequately dosed strengthening during this transitional phase is appropriate and may be more targeted toward the hamstrings or quadriceps depending on graft type and informed by objective strength measures. Greater emphasis on quadriceps strengthening via open chain knee extension and functional quadriceps strengthening exercises may be necessary following graft harvest of the extensor mechanism (QT or BPTB) as compared to following HT graft. Functional quadriceps training (i.e., closed chain exercises) should be designed to increase quadriceps activation. This can be accomplished by moving the individual's center of mass farther away from the knee joint's center of rotation. Similarly, following HT graft, hamstring specific exercises including those listed in the previous section are likely necessary during this phase. Regardless of graft type, objective strength measures should inform intervention selection throughout rehabilitation.

Despite evidence of differences in quadriceps strength and other objective measures relevant to RTS early in the transitional phases, there is no remarkable difference between autograft types on hop testing or strength testing at RTS (76). In a recent study by Smith *et al.* athletes who received BPTB autograft met progression criteria on average 6 weeks later (at 28.5 weeks) and RTS criteria 12 weeks later (at 44.7 weeks) than HT, but at 1 year follow up between group differences in quadriceps strength symmetry were no longer present (5).

Differences on functional testing and other criteria for progression between graft type recipients are less well documented. Cristiani *et al.* reported differences in single leg hop symmetry at 4 months with HT performing better than BPTB, but no significant differences were noted at any other time point (6-, 8-,12-, and 24-month) (69). A recent cross-sectional study found differences in posteromedial reach on the lower quarter Y-balance test between autografts, with HT performing better than BPTB, but there were no remarkable differences in performance on functional tests including the Landing Error Scoring System and single leg hop testing (77).

Previously held beliefs that allowed for RTS 6 months after surgery have been widely called into question (1,5,27,78-80). Multiple studies have found the majority of patients are unable to pass RTS criteria at this time point, though RTS criteria used by different groups has been variable (27,78,79). Evidence also suggests that delaying RTS, especially in cutting and pivoting sport, to 9 months after surgery reduces secondary injury rate (80), which suggests the longer duration of rehabilitation to achieve recommended RTS criteria may have a protective effect on athletes after BPTB autograft by delaying exposure to sport activity (5).

There is wide variability in practice patterns of surgeons and physical therapists when it comes to objective test performance and RTS criteria (68,81-83). However, limb symmetry >90% on single leg hop tests and isokinetic hamstring and quadriceps testing, and high reports of knee function and psychological readiness on patient reported outcomes are associated with greater RTS and reduced rate of reinjury based on several studies and clinical practice guidelines (1,4,14,15,78,84). Recent recommendations also include RTS no sooner than 9 months post-reconstruction for all autografts and no sooner than 1 year for allografts, dependent on passing defined RTS criteria (1).

Long-term outcomes

Given the high prevalence of secondary ACL injury, either via graft rupture or contralateral ACL rupture, one of the primary measures of long-term outcomes after ACLR is secondary injury. There are a multitude of factors beyond graft type that contribute to secondary injury, but some evidence suggests graft selection influences reinjury rates as well (4,85,86). Multiple studies have found higher rates of graft failure in HT compared to BPTB (6,77,85,87,88) and relative to QT (89). Specifically, a recent meta-analysis that found higher rates of graft rupture in HT compared to BPTB; however, the rates of failure were low in each group which brings into question whether these findings are clinically meaningful (90). Prevalence of contralateral rupture does not significantly differ between autograft types (85). Evidence has also consistently shown higher failure rates in allografts compared to autografts (1,6-12,85).

Other considerations for long term outcomes include development of osteoarthritis, continued pain, and return to prior activity level. Patients may be more likely to develop tibiofemoral osteoarthritis following BPTB compared to HT autograft, but the evidence is mixed (91-93). There is also some evidence that anterior knee pain and pain with kneeling is more common at long-term follow-up after BPTB autograft (94-98).

Given the potential increased risk for graft rupture of allograft more than HT autograft, injury prevention programs beyond RTS may be beneficial for athletes to implement. Patients and athletes should also be educated on the relevance of osteoarthritis and persistent anterior knee pain following BPTB autograft and would benefit from comprehensive home exercise programs with these outcomes in mind at time of discharge from rehabilitation.

There are no studies specifically investigating the relevance of sex to ACLR rehabilitation based on graft type. Female athletes are more likely to sustain ACL rupture than males, and existing literature outlines differences in long term outcomes and quadriceps function based on sex (99-106). Regardless of graft type, female athletes may require additional training or education on secondary injury prevention and continued quadriceps strengthening in order to return to previous activity levels.

Strengths and limitations

Strengths of this review include the authors combined extensive clinical experience treating patients after ACLR and familiarity with the existing literature. There is extensive evidence on ACLR rehabilitation, but a limited number of specific clinical trials comparing graft type course of care and outcomes. The majority of existing literature that specifically compares graft type focuses on long term outcomes such as revision and/or graft rupture rate. A systematic review was not performed to grade the quality of our references or assess for risk of bias.

Conclusions

The most notable effect of graft type on course of rehabilitation after ACLR is decreased strength of the harvest site muscle group, which affects time expectations for meeting clinical milestones to progress through rehabilitation phases. Following BPTB and possibly QT graft it is reasonable to expect greater asymmetries in quadriceps strength throughout recovery, which then requires more time to meet objective clinical criteria to progress through stages of rehabilitation. This delay may also be protective against secondary injury. Following HT autograft, it is reasonable to expect greater asymmetries in hamstring strength, though these deficits do not seem to affect timepoints for progression. The other main considerations for graft type include higher acute post-operative pain after BPTB, increased risk of graft failure after allograft more than HT autograft, and higher incidence of osteoarthritis after BPTB autograft. RTS decisions should be informed by clinical criteria regardless of graft type, but recipients of allograft reconstructions should delay RTS to a minimum 12 months after surgery compared to a minimum of 9 months from surgery for those after autografts. Finally, graft type should influence patient education for long term outcomes and preventative exercise for patients to continue beyond RTS and discharge from skilled care.

Acknowledgments

Funding: None.

Footnote

Provenance and Peer Review: This article was commissioned by the Guest Editor (Nicholas N. DePhillipo) for the series “Implications of Graft Choice in ACL Reconstruction” published in *Annals of Joint*. The article has undergone external peer review.

Reporting Checklist: The authors have completed the Narrative Review reporting checklist. Available at https://aoj.amegroups.org/article/view/10.21037/aoj-22-51/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://aoj.amegroups.org/article/view/10.21037/aoj-22-51/coif). The series “Implications of Graft Choice in ACL Reconstruction” was commissioned by the editorial office without any funding or sponsorship. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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doi: 10.21037/aoj-22-51

Cite this article as: Leung A, DeSandis B, O'Brien L, Hammoud S, Zarzycki R. Postoperative considerations based on graft type after anterior cruciate ligament reconstruction a narrative review. Ann Joint 2023;8:26.

