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Allograft Anterior Cruciate Ligament Reconstruction: Indications, Techniques, and Outcomes

he anterior cruciate ligament (ACL) plays an important role in the maintenance of knee stability. If left untreated, the natural history of an ACL-deficient knee can result in recurrent instability, inability to return to full athletic activity, meniscal tears, and articular cartilage damage.²⁷ Therefore, the goals of ACL reconstruction (ACL-R) are to re-establish the form and function of the native ACL, restore knee stability, allow return to the preinjury

activity level, and preserve the long-term health of the knee. Despite adherence to strict surgical principles, the inability to predict long-term articular cartilage degeneration after ACL-R has raised questions about the choices of surgical technique, fixation, graft type (various autografts versus allografts), and rehabilitation.¹⁰ Although ACL-R is a frequently researched topic in sports medicine, significant disagreement exists on the appropriate management of the torn ACL.²⁸ The following clinical commen-

• SYNOPSIS: The anterior cruciate ligament (ACL) is an important stabilizer of the knee against translational and rotational forces. The goal of anatomic reconstruction of the ACL-deficient knee is to re-create a stable knee that will allow for return to sport and prevent recurrent injury. Multiple graft options exist for ACL reconstruction, and each option has unique advantages and disadvantages. With appropriate patient selection, each graft can be utilized to optimize patient outcomes. Allograft options limit morbidity following ACL reconstruction, but care must be taken with tary discusses the factors affecting graft selection, with emphasis on indications and the technique of allograft ACL-R, as well as the rehabilitation and outcomes specific to this surgical approach.

PATIENT SELECTION

COMPREHENSIVE HISTORY AND physical exam are critical for selecting patients for ACL-R, as well as for choosing the optimal graft. This includes demonstration of ACL insuf-

surgical technique and postoperative rehabilitation to allow for graft incorporation. An understanding of the surgical technique and differences between graft options will allow the patient, surgeon, and physical therapist to maximize outcomes following ACL reconstruction.

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ficiency and assessment of the patient's activity level, expectations, associated injuries, and medical comorbidities. Surgical indications are based on 3 major criteria: the severity of perceived instability, associated knee injuries (meniscus or multiple ligaments), and chronicity of the ACL insufficiency.

Prior to surgical intervention on an acute ACL tear, the patient is treated with physical therapy, with the goals of achieving near full range of motion (ROM), symmetric quadriceps strength, and a decrease in joint effusion. Generally, most patients meet these criteria within 3 to 4 weeks. Contraindications to ACL-R include (1) partial tears with minimal reported instability and no joint laxity on examination, (2) older individuals with low physical demands and minimal instability, and (3) comorbidities that make surgical intervention unsafe for the patient.

PREOPERATIVE (DIAGNOSTIC) IMAGING

Radiographs

Diagnostic IMAGING BEGINS WITH plain radiographs. At our institution, we routinely obtain a 45° flexion, weight-bearing posteroanterior radiograph of both knees and lateral and Merchant views of the patella. These radiographs help identify associated fractures (avulsion, plateau, or subchondral

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impaction), gauge the amount of joint space narrowing in the 3 compartments, and assess patellar height (lateral view), tilt, and subluxation (Merchant view). A long-cassette anteroposterior view of the bilateral lower extremity is obtained to determine overall limb alignment. Importantly, radiographs are a prerequisite to assess the status of the growth plate in pediatric patients.

Magnetic Resonance Imaging

If a patient's history and physical exam suggest an ACL tear, then noncontrast magnetic resonance imaging of the knee is obtained (FIGURE 1). Discontinuity of the ACL in the coronal and sagittal planes is a reliable indication of an ACL tear. In addition, magnetic resonance imaging helps to identify associated injuries such as meniscal tears, chondral damage (including bone bruises), and concomitant ligament injuries (posterior cruciate ligament, medial and lateral collateral ligaments, and posterolateral corner). Allograft reconstructions may be beneficial for multiligament injuries, as they decrease operative time and minimize the associated morbidity of graft harvesting.

PREOPERATIVE REHABILITATION

UPTURE OF THE ACL RESULTS IN significant hemarthrosis, which may affect outcomes following ACL-R.

TABLE 1	Comparison of the Advantages and Disadvantages of Graft Options	
Graft Type	Advantages	Disadvantages
Allograft, bone-tendon	Bone-to-bone healing	• Cost
	Decreased surgical time	Infectious disease transmission
	Predictable graft size	Risk of bridging physis
	Availability	Higher failure rate
		Delayed incorporation
Allograft, soft tissue	Decreased surgical time	• Cost
	Predictable graft size	Infectious disease transmission
	Availability	Higher failure rate
	 Less risk with bridging physis 	Delayed incorporation
Autograft, bone-tendon	Faster incorporation and healing	Prolonged surgical time
	Better outcomes in young, active patients	Donor site morbidity (anterior knee pain)
		Risk of bridging physis
		Risk of fracture
Autograft, soft tissue	Faster incorporation and healing	Prolonged surgical time
	Better outcomes in young, active patients	Donor site morbidity (knee flexion
	Less risk with bridging physis	weakness)
		Unpredictable graft size
		Compromise of medial structures

Large effusions can result in quadriceps inhibition. In patients with an ACL-deficient knee, the role of the quadriceps as a dynamic stabilizer of the knee should not be underestimated. The return of quadriceps function and a reduction in effusion are among the primary goals of preoperative rehabilitation. Inadequate quadriceps strength has been shown to produce altered gait patterns following ACL-R²⁶ and an increase in the transfer of forces across the reconstructed ACL.

One of the early pitfalls of arthroscopically assisted ACL-R was the development of postoperative stiffness. This complication was largely attributed to poor preoperative ROM and early surgical intervention during the inflammatory phase of healing.18,44,45 More recent studies have shown early surgical intervention to be safe,3,9,20 with the best indicator of postoperative ROM loss being the patient's preoperative ROM.30 Patients should be carefully evaluated for preoperative ROM deficits and aggressively treated to prevent postoperative complications. The patient is ready for surgery once the inflammatory period

has resolved. This period may last 2 to 3 weeks and corresponds to a decrease in effusion and a resultant increase in ROM. Flexion must be adequate enough to allow for knee hyperflexion during ACL reconstruction. Depending on concomitant pathology, surgery may be performed early (eg, displaced bucket-handle meniscus tears) or may be delayed (eg, medial collateral ligament disruption).

GRAFT SELECTION

Principles of Graft Selection

Several factors, including stable fixation, biological graft-bone integration, adequate graft strength, and, most importantly, anatomic positioning. Accordingly, graft selection is a very important part of preoperative planning and depends on several factors: the patient's preference, age, activity level, and physical requirements; expected outcomes; the time line for return to play; associated ligamentous injuries; medical comorbidities; previous surgery; tissue availability; and surgeon preference and experience.

Whereas significant debate still exists regarding the best graft choice, what is widely accepted is that the ideal graft should reflect the anatomy and biomechanics of the native ACL, minimize harvest site morbidity, be amenable to stable fixation, and result in rapid remodeling and incorporation into the reconstructed knee. As such, graft selection is a tradeoff between the benefits and potential morbidity of each graft (**TABLE 1**).

Graft Types

Graft sources for ACL-R fall into 3 major categories: synthetic/artificial ligaments, autografts, and allografts. Synthetic grafts such as scaffolds (carbon fiber) and stents (Kennedy ligament augmentation device), and prostheses such as polytetrafluoroethylene Gore-Tex (W.L. Gore & Associates, Inc, Elkton, MD), polyethylene terephthalate (Leeds-Keio artificial ligament), and Dacron (Invista, Wichita, KS), have demonstrated poor clinical results secondary to loosening, fatigue failure, and a strong host immune response.29,43,58 Commonly used autografts include the central third of the patellar tendon, hamstring tendons (semitendinosus and gracilis), and the quadriceps tendon. Several allograft options are available as well. These can be divided into grafts providing bone-to-bone healing and grafts consisting solely of soft tissue. The patellar-tendon allograft is the only option for proximal and distal osseous integration. Achilles tendon and quadriceps tendon allografts contain a single osseous attachment. Soft tissue allografts include the hamstring, tibialis anterior, tibialis posterior, and peroneus longus tendons, as well as the tensor fascia lata.

Allograft Advantages/Disadvantages All graft types offer distinct advantages and disadvantages to the patient and the surgeon. The benefits of allograft use include absence of donor site morbidity, shortened operating time, availability for complex cases (multiligament knee and revision ACL-R), greater availability and more predictable graft sizes, and comparable strength and stiffness to autograft

TABLE 2

A SUMMARY OF THE RELATIVE Indications for Allograft Anterior Cruciate Ligament Reconstruction

Most Common Indications for Allograft ACL-R

- · Patients older than 40 y
- Multiple ligament knee injuries
- · Prior harvest from donor sites
- · Patient preference
- Revision ACL-R*

Abbreviation: ACL-R, anterior cruciate ligament reconstruction.

*It is the author's preference to use an autograft in revision cases if that graft has not been harvested in previous surgery and if the patient meets criteria for autograft use (ie, age, activity level).

tissue at the time of reconstruction.^{4,35,38,52} Significant disadvantages of allograft tissue are potentially higher failure rates, increased time to incorporation, variability in mechanical strength due to secondary sterilization techniques, risk of disease transmission, immunogenic reaction, lack of long-term outcome data (especially for young patients under the age of 25), and higher cost.^{31,46,58} The senior author's (C.D.H.) preferred technique is anatomic single-bundle ACL-R using a bone-patellar tendon-bone autograft.

INDICATIONS FOR ALLOGRAFT ACL RECONSTRUCTION

N THE SENIOR AUTHOR'S (C.D.H.) PRACtice, the graft choice for each ACL-R is tailored to suit the individual patient. We routinely utilize multiple graft choices, with approximately 80% of them being autografts (70% bone-patellar tendon-bone and 30% hamstring) and 20% allografts (100% bone-patellar tendonbone). Generally, allograft tissue is reserved for patients older than 40 years. In this population, the autograft benefits of more rapid incorporation and healing do not appear to warrant the increased morbidity from harvesting a graft from the patient. Allograft tissue is only used in special circumstances for patients who are 12 to 30 years old, and autografts are also strongly recommended for patients who are 30 to 40 years old. The ideal candidate for an allograft at our center is a

mildly to moderately active patient older than 40 years who experiences symptomatic instability during activities of daily living and whose clinical presentation is consistent with ACL rupture. Other indications for use of allograft tissue are reconstruction of multiligament knee injuries, revision ACL-R, cases where autograft tissue is inadequate, and patient preference (TABLE 2).^{1,41,42}

TECHNIQUE FOR MEDIAL PORTAL ACL-R

W FE PROVIDE A BRIEF DESCRIPTION of our technique for anatomic ACL-R using the medial portal for femoral tunnel drilling. We aim for anatomic placement of the femoral and tibial tunnels. Femoral tunnel placement is done via the medial portal, allowing placement independent of the tibial tunnel (the transtibial technique). This technique may be utilized in all cases of primary (single-bundle, double-bundle, or augmentation) or revision ACL-R, and is not dependent on the choice of graft, instrumentation, or final fixation.

Portals and Incisions

During the procedure, we utilize 3 portals (**FIGURE 2**): anterolateral (viewing), anteromedial (working), and superolateral (outflow). The medial portal is made under direct arthroscopic visualization using a spinal needle. This is done not only to avoid damaging the medial meniscus



FIGURE 2. Incisions for allograft anterior cruciate ligament reconstruction. Anterolateral viewing portal, anteromedial working portal, and superolateral outflow portal. A medial tibial incision is used for tibial tunnel placement and graft passage.



FIGURE 4. Posterior tibialis allograft prior to (A) and following (B) graft preparation.



FIGURE 3. Bone-patellar tendon-bone allograft prior to (A) and following (B) graft preparation.

but also to allow adequate clearance from the medial femoral condyle. When using allograft tissue, a 3-cm vertical incision is made on the anteromedial aspect of the tibia for drilling the tibial tunnel later in the procedure. The location of this incision is estimated by provisional placement of the tibial tunnel ACL guide midway between the anterior and posterior borders of the tibia.

Allograft Preparation

Bone-Patellar Tendon-Bone Our preference is for the bone-patellar tendon-bone allograft (**FIGURE 3**). The central 10 mm of the patellar tendon is utilized, with bone plugs measuring 20 mm in length both proximally and distally. The plugs



FIGURE 5. Arthroscopic image of anterior cruciate ligament rupture.

are designed to be trapezoidal in shape, and the leading plug is tapered to facilitate graft passage. Two 1.5-mm holes are drilled in the tibial bone plug and a number 5 Ethibond (braided, nonabsorbable; Ethicon, Inc, Somerville, NJ) is threaded through the holes. These will be used to secure final plug fixation over a post. The femoral bone plug is secured using the EndoButton CL (Smith & Nephew Inc, Memphis, TN) device to provide suspensory fixation (**FIGURE 4**).

Soft Tissue In certain cases, a soft tissue allograft is used. This graft is generally doubled over to increase its diameter. It is important to pay careful attention to the necessary diameter of the graft because dimensions may not be consistent throughout the entire length of the graft. The goal is to prepare an appropriately sized graft with consistent dimensions and adequate length for ACL-R. We use an EndoButton CL device, over which the graft is doubled. A suture is tied within the proximal portion of the graft, and a second nonabsorbable suture is secured within the distal portion of the graft to be tied around a post for tibial fixation (**FIGURE 4**).

Arthroscopic ACL-R

The fat pad is left intact to prevent postoperative scarring, patellar entrapment, and pain. Assessment of any associated intra-articular pathology is performed before preparation of the femoral and tibial insertion sites. On the femoral side, using the location of the torn ACL remnant as a guide (FIGURE 5), we mark the center of the anatomic ACL insertion site with a 30° Steadman awl (FIGURES 6A and **6B**). On the tibial side, a significant portion of the ACL stump is preserved to enhance proprioceptive and vascular properties.²⁵ We do not routinely perform a notchplasty unless it is needed for better visualization (1-2 mm) or to alleviate graft impingement.

Femoral Tunnel Placement The native ACL footprint, although variable in each individual, is generally 4 to 6 mm anterior to the posterior femoral cortex with the knee at 90° of flexion. Appropriate tunnel position is further confirmed via intraoperative fluoroscopy by taking a lateral image of the knee (90° of flexion and overlapping condyles) with the awl still in position (FIGURE 6C). With the knee hyperflexed, a guide pin is placed in the anatomic footprint (FIGURE 7A) and an acorn reamer is carefully advanced over the guide wire to avoid damaging the cartilage of the medial femoral condyle (FIGURE 7B). Finally, a 3.2-mm EndoButton drill is used to breach the lateral femoral cortex.

Tibial Tunnel Placement Anatomic tibial tunnel position is also accomplished using a combination of visual arthroscopic landmarks (**FIGURE 8**) and fluoroscopic imaging (**FIGURE 9**). An ACL elbow-tip guide is set at 50° to 55° and placed at the intersection between the posterior edge of the



FIGURE 6. The anatomic femoral insertion is identified during arthroscopy (A and B). The planned tunnel placement is confirmed with fluoroscopy (C).

anterior horn of the lateral meniscus and the midline of the tibial spines. Verification of the Kirschner wire placement is done with arthroscopy and fluoroscopy. After correct placement of the guide pin, a cannulated compaction reamer is used over the Kirschner wire.

Graft Passage Using passing sutures, the graft is advanced up the tibial tunnel and the tendinous portion of the bone-patellar tendon-bone allograft is maintained in



FIGURE 7. Femoral tunnel placement. With the knee hyperflexed, a guide pin is placed in the anatomic footprint of the anterior cruciate ligament on the medial wall of the lateral femoral condyle (A). Arthroscopic view of guide wire placement in anatomic footprint (B).

the posterior aspect of both tunnels (**FIG-URE 10**). After clearing the lateral femoral cortex with the EndoButton, the device is toggled to engage the cortex and prevent passage back into the tunnel. Tension is applied to the tibial sutures, and the knee is cycled to minimize graft creep. Graft isometry and impingement are checked.

Graft Fixation

Multiple options exist for graft fixation. These options include tying over a post, suspensory fixation, and interference screws, and are dependent to some extent on the type of graft chosen (ie, bone block or soft tissue alone). Our choice for tibial fixation is tying over a post (4.5-mm AO fully threaded cortical screw over a washer, bicortical purchase). After the far cortex is engaged but before final seating, the tibial sutures are individually tied around the post. The screw-and-washer construct is then fully tightened and the Lachman and pivot shift tests are performed for fi-



FIGURE 8. The tibial guide is placed in the anatomic footprint for passage of the tibial guide pin.

nal verification of graft tension. We prefer suspensory and suture/post fixation with bone plugs to allow for maximal healing between the graft and host bone (**FIGURE 11**).

There are many benefits to performing fixation in this manner. The tunnels in the above technique are dilated to exactly fit the graft, providing circumferential interaction between the graft and apposed bone within the tunnel. There is no fixation device within the tunnel to interfere with graft healing or the interaction of the graft with potentially beneficial growth factors. Lastly, should revision surgery be required, the retained hardware will not limit surgical options.

POSTOPERATIVE REHABILITATION AND RETURN TO PLAY

ROM and Strengthening

EHABILITATION FOLLOWING ACL-R should follow a logical progression that allows for progressive strength-



via fluoroscopy on anteroposterior (A) and lateral (B) views.

ening and protection of the reconstructed ACL. Following ACL-R, the overall goals of rehabilitation are to minimize inflammation, to restore knee motion and quadriceps strength, to enhance proprioception, neuromuscular control, and dynamic joint stability, and to ensure a return to sport-specific activities.

During the initial postoperative period, guarded ROM exercises help to initiate the processes of healing and strengthening. For the first week after surgery, the patients are asked to bear weight with crutches and a knee brace locked in full extension. Basic home exercises include quadriceps sets, straight leg raises, calf pumps, and heel slides. The goal during this phase is to protect the graft while regaining quadriceps strength and full passive and active knee extension symmetrical to the uninvolved side. At the first postoperative visit (1



FIGURE 10. Arthroscopic view of graft passage before (A) and after (B) the bone plug has been advanced into the femoral tunnel. Fluoroscopic imaging to confirm EndoButton placement (C).

week), we initiate heel-to-toe gait training with the brace unlocked and enroll the patient in formal physical therapy. Important milestones for ROM are full passive extension within 1 week and full active extension within 2 weeks. Goals for knee flexion are 90° by 2 weeks and full symmetrical flexion by 8 weeks after reconstruction. The patient is allowed to wean himself or herself from crutches after 6 weeks.



FIGURE 11. Postoperative radiographs following allograft anterior cruciate ligament reconstruction.

As rehabilitation progresses, sportspecific activities are initiated. There should be a logical, supervised progression from protected, simple exercises to complex, sport-specific drills aimed at regaining neuromuscular control and returning the patient to full participation. Some protocols follow a time line for transition through specific phases, assuming that graft incorporation will occur over time and that protecting the

graft will allow for incorporation and progression of activities once adequate time has passed. Other protocols follow objective measurements of muscle strength in the involved and uninvolved sides. Once the patient has regained adequate strength and proprioception to minimize the forces transmitted across the graft and adequate healing/maturation has taken place, the patient is allowed to return to sport.

A combination of the previous approaches is used to best rehabilitate patients; however, good measures of patient rehabilitation and adequate assessment prior to return to sport are lacking in the literature.6 Suggested objective measures to determine a patient's readiness to return to sport include muscle strength testing, thigh circumference, ROM, laxity testing, validated questionnaires, and hop testing.6,57 Specifically, the importance of testing the involved extremity in isolation (eg, unilateral hop tests) is increasing because unilateral deficits may not be apparent during bipedal tasks.^{11,36} Developing and adhering to these protocols is even more important for individuals with an allograft. Compared to autografts, allografts are at greater risk of rupture, and they undergo delayed incorporation and healing. Additionally, with allografts, patients experience less morbidity associated with graft harvesting, particularly in the early phases of rehabilitation, which further increases the risks of being overly aggressive during rehabilitation. Progression through the rehabilitation process is individualized, based on an evaluation of objective measures during each phase of rehabilitation. Guidelines can be helpful to allow for adequate graft incorporation and healing (APPENDIX).

Return to Play

The expected return to full activity is typically 9 to 12 months after surgery (**APPENDIX**). However, accelerated rehabilitation programs that allow early return to sport have been described.¹⁴ These programs have drawn the attention of athletes and coaches who have new expectations and pressures for surgeons to meet those expectations. These protocols should be utilized with caution. Biologic healing and incorporation of ACL grafts require time.¹² Rehabilitation protocols have not been shown to change the time to graft healing and maturation. Mounting data have shown that the reconstructed ACL is at greatest risk of failure during the initial 9 months following reconstruction, especially in patients undergoing allograft reconstruction.⁵⁶

More systematic protocols examining objective measures for return to sport are being developed. The specific measures proposed include the visual analog scale for pain, thigh circumference, ROM, the International Knee Documentation Committee Subjective Knee Form, hop tests, and isokinetic testing.57 Other potential measures include an assessment comparing the involved and contralateral sides, fatigue resistance, and measures of neuromuscular control. By developing these measures, we may be able to better assess the protective capabilities of dynamic knee stabilizers prior to return to play. These tests are even more important for patients with an allograftreconstructed knee, where healing and cellular repopulation are delayed.¹² As stated earlier, the risks associated with an accelerated program in this population are compounded by the fact that these patients clinically appear ready to progress more rapidly than patients who have the morbidity associated with autograft harvesting.

Bracing and ACL-R

Perceived benefits of bracing following ACL-R are decreased swelling, improved ROM, protection of the graft, improved proprioception, and improved walking kinematics to regain a normal gait pattern.⁸ Knee immobilizers, functional braces, and hyperextension bracing have all been described as options in the immediate postoperative period.³⁴ The benefit of bracing in the early postoperative period has been demonstrated primarily for swelling and ROM, because bracing

does appear to help achieve full knee extension. $^{\scriptscriptstyle 33,34}$

The use of functional bracing following ACL-R has not had a clear role in the late phases of rehabilitation. Routine bracing to achieve satisfactory objective outcome measures of stability, strength, single-leg hop performance, and ROM has been under scrutiny, as the literature has not demonstrated that braces are effective at achieving those goals.^{32,59} However, functional bracing appears to help prevent reinjury in skiers.⁵³

Effect of Allograft Tissue on Rehabilitation

The use of allograft tissue allows for rehabilitation without the postoperative morbidity of autograft harvesting. Allografts are associated with less anterior knee pain and hamstring weakness than patellar tendon and hamstring autografts, respectively.23,54 As a result, patients with allograft ACL-R may be better prepared for early physical therapy, which may allow for easier progression of and adherence to exercises than for those who have undergone autograft ACL-R. Even so, allograft ACL-R should follow a delayed rehabilitation protocol to allow for allograft incorporation and healing, as discussed earlier.12

It has been demonstrated that the strength of nonirradiated allograft tissue is comparable to that of autograft tissue. However, allograft remodeling (ligamentization) and incorporation are slower and presumably more susceptible to early failure.^{7,17} This hypothesis was tested via a model that compared patellar-tendon autografts to allografts in goats that underwent ACL-R. The authors showed that after 6 months, the autograft-reconstructed knees had less anterior/posterior displacement, twice the force to ACL failure, a greater cross-sectional area, and a greater number of small-diameter collagen fibrils.²¹ In our practice, we delay the return-to-play time line for patients who undergo allograft ACL-R (6 to 9 months for autograft ACL-R and 9 to 12 months for allograft reconstruction). In this study, compared to autograft tissue, allograft tissue demonstrated more similar cellular repopulation and reorganization of collagen fibrils to the native ACL, albeit at a delayed rate.²¹ Greater laxity at 6 months in the allograft group, as measured by anterior translation, was noted as well, leading the authors to suggest prolonged protection in patients undergoing allograft ACL-R.²¹

GRAFT PROCESSING

To MINIMIZE THE RISK OF DISEASE transmission from the allograft, careful processing of the tissue is paramount. Contamination can occur from pathogens originating within the donor's blood/organs or during tissue processing/packaging. This process begins with a careful screening of all donors for risk factors of communicable disease. To minimize the risk of harvesting a contaminated graft, standards for the timing and methods of procurement have been set by the American Association of Tissue Banks.

Terminal sterilization is the last step before the graft can be stored and eventually utilized for ACL-R. Historically, ethylene oxide and gamma irradiation have been effective in terminal sterilization; however, ethylene oxide has been shown to result in chronic synovitis and has largely been abandoned in favor of gamma irradiation.22 Relatively low doses (1.5-2.0 mrad) can effectively kill bacteria, fungi, and spores. To deactivate HIV, doses of 2.5 mrad are required.16,49 A biomechanical trade-off exists at doses above 2.0 mrad: studies have demonstrated a reduction in the biomechanical properties of the graft.13,15 Newer methods of sterilization have been developed and patented by various companies. These methods include patented washes that use a combination of detergents, antibiotics, alcohol, and peroxide to safely disinfect the tissue and minimize the risk of disease transmission while limiting the detrimental effect on the biomechanical properties of the graft. As these newer methods are refined, future studies will

be needed to define their effects on the biomechanical properties of the graft.

OUTCOMES

Allografts

INCLUDE LLOGRAFT OPTIONS grafts with bone-to-bone healing (patellar tendon, quadriceps tendon, Achilles tendon) and those with soft tissue alone (hamstring, anterior tibialis, posterior tibialis, and peroneus longus tendons). In the long term, allograft tissue has been shown to undergo ligamentization and resemble the native ACL both grossly and microscopically.21,37 Clinically, the reported failure rates of allograft tissue vary. When looking at tibialis anterior allografts, the literature is inconsistent, with good outcomes and low failure rates (5.5%) reported in some studies⁵⁰ and early graft slippage and failure rates as high as 23% in young patients in other studies.47,48 Interestingly, the age-dependent variation in outcomes has not been established in bone-patellar tendon-bone allografts. Barber et al5 showed no difference in outcomes between patients older than 40 years and patients younger than 40 years when bone-patellar tendon-bone allografts were used. One theory is that the variation in healing between younger and older patients may be negated by the process of bone-to-bone healing in bonepatellar tendon-bone allografts.

Comparison to Autografts Historically, outcome research has reported comparable results between allograft and autograft ACL-R. Initial outcome studies found similar stability between groups, with less morbidity for the allograft group.^{2,19} Some outcomes, such as postoperative ROM, appeared to favor allograft reconstruction.¹⁹ These studies were generally smaller cohorts, and the results were not always reproducible.

Recently, several meta-analyses have reviewed the recent literature and compared the outcomes of allograft reconstruction to those of autograft reconstruction, with mixed results. Carey et

al¹⁰ reviewed laxity data in addition to subjective outcomes after a minimum follow-up of 2 years. This study evaluated 191 autograft and 266 allograft reconstructions and found no significant difference between groups. In this review, patients treated with bone plug and soft tissue reconstructions were included in both groups. Rerupture of the reconstructed ACL was not specifically examined but was included with all other reasons for failure of the reconstruction, with the data favoring the use of autografts. A significant rerupture rate was identified in the allograft group in a meta-analysis by Krych et al²⁴ that compared bone-patellar tendon-bone allografts to autografts. In that study, 256 autograft reconstructions and 278 allograft reconstructions were evaluated after a minimum follow-up of 2 years. Return to sport was allowed between 6 and 12 months after reconstruction. Results on the Lachman and pivot shift tests and rates of return to the preinjury level of activity were similar between groups.

In one of the largest meta-analyses, Prodromos et al⁴⁰ compared the stability of allograft and autograft reconstructions after a minimum of 2 years of follow-up. The authors found that the use of autografts resulted in significantly better knee stability compared to allografts. They then compared soft tissue allografts to soft tissue autografts and bone-tendon allografts to bone-patellar tendon-bone autografts. The finding of improved stability with autograft reconstruction was still present when soft tissue grafts were used. A similar but less pronounced trend was present in the bone-tendon reconstructions. In summary, short-term data have demonstrated subtle differences in stability and graft rerupture rates between allograft and autograft ACL-R.

Longer follow-up has helped to demonstrate differences in graft choices between populations. Spindler et al⁵¹ reported on a cohort of 446 patients, 84% of whom were still being followed after 6 years. Their findings suggest greater im-

provements in validated knee scores and return-to-sport function in patients who underwent autograft reconstruction. In addition, a recent study on a cohort of military cadets demonstrated the ACL rerupture rate to be as much as 3 times higher after allograft reconstruction than after autograft reconstruction.³⁹ As a result, there has been a trend toward favoring autograft reconstruction in higher-demand, younger athletes.

COMPLICATIONS

OMPLICATIONS SPECIFIC TO THE MEdial portal technique for ACL-R can occur secondary to incorrect placement of the medial portal and resultant damage to the medial femoral condyle. This is usually the result of inadequate clearance from the medial femoral condyle for safe passage of the guide pins and drill bits. Other complications generally associated with arthroscopic ACL-R using either autograft or allograft tissue include iatrogenic injury to the menisci, articular cartilage, and tibial spines, postoperative infection, arthrofibrosis, deep vein thrombosis, or failure of graft healing despite a properly executed reconstruction.

Complications related specifically to allograft tissue primarily relate to the risk of disease transmission and the immune response to allograft tissue by the host. The potential for infection is low, with few reported cases in the literature of either viral (HIV and hepatitis) or bacterial transmission.55 The HIV transmission rate is approximately 1 in 1.5 million. The risk of disease transmission can be reduced by polymerase chain reaction testing for viral transmission and close adherence to the recommendations for screening, harvesting, and storage outlined by the American Association of Tissue Banks. Complications associated with autograft harvesting, which can be avoided by utilizing allograft tissue, include fracture of the donor site that can result from quadriceps and bone-patellar tendon-bone harvesting.

SUMMARY

WHEN DECIDING BETWEEN ALlograft and autograft ACL-R, it is important to consider the advantages and disadvantages of each technique and which graft option will best address the patient's needs. These considerations will extend into the postoperative period. Extra caution is necessary when allograft tissue has been used for ACL-R, because patients tend to clinically improve faster than their graft can incorporate itself. As a result, they may desire a return to activities that the graft is not yet prepared to handle. •

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APPENDIX

REHABILITATION FOLLOWING ALLOGRAFT ACL RECONSTRUCTION

Phase 1: 0 to 6 Weeks

<u>Goals</u>

- Protect graft fixation
- · Minimize effects of immobilization
- · Control inflammation
- Full extension range of motion
- Educate patient on rehabilitation

Brace:

- 0 to 1 week, locked in full extension for ambulation and sleeping
- 1 to 6 weeks, unlocked for ambulation, remove for sleeping Weight-bearing status:
- 0 to 6 weeks, weight bearing as tolerated with 2 crutches
- Therapeutic exercises:
- Heel slides
- Quadriceps sets, hamstring sets
- Patellar mobilization
- Non-weight-bearing gastrocnemius/soleus, hamstring stretches
- Straight leg raise (all planes) with brace locked in full extension until quadriceps strength is sufficient to prevent extension lag
- Quadriceps isometrics at 60° and 90° of knee flexion

Phase 2: 6 to 8 Weeks

Criteria for Advancement to Phase 2

- 1. Good quadriceps set, straight leg raise without knee extension lag
- 2. Approximately 90° of knee flexion
- 3. Full extension
- 4. No signs of active inflammation
- <u>Goals</u>
- · Initiate weight-bearing (closed kinetic chain) exercises
- Restore normal gait
- · Protect graft fixation

Brace/weight-bearing status:

- Discontinue use of brace and crutches as allowed by physician when the patient has full extension and can perform a straight leg raise without extension lag
- Patient must exhibit nonantalgic gait pattern. Consider using single crutch or cane until gait is normalized
- Therapeutic exercises:
- Wall slides, 0° to 45°, progressing to minisquats
- 4-way hip
- Stationary bike (begin with high seat and low tension to promote range of motion. Progress to single leg)
- Weight-bearing terminal knee extension with resistive tubing or weight machine
- Toe raises
- Balance exercises (eg, single-leg balance)
- Hamstring curls
- · Aquatic therapy with emphasis on normalization of gait

Continue hamstring stretches. Progress to weight-bearing gastrocnemius/soleus stretches

Phase 3: 2 to 6 Months

Begins at approximately 8 weeks and extends through approximately 6 months

<u>Goals</u>

- Full range of motion
- Improve strength, endurance, and proprioception of the lower extremity to prepare for functional activities
- Avoid overstressing the graft
- Protect the patellofemoral joint
- Therapeutic exercises:
- · Continue and progress previous flexibility and strengthening activities
- Seated knee extensions, 90° to 45°, and progress to eccentrics
- Advance weight-bearing activities (leg press, single-leg minisquats 0° to 45° of flexion, step-ups beginning at 5 cm and progressing to 20 cm, etc)
- Progress proprioceptive activities (slide board, use of ball, etc)
- · Progress aquatic program to include pool running, swimming

Phase 4: 6 to 9 Months

Begins at approximately 6 months and extends through approximately 9 months

Criteria for Advancement to Phase 4

- 1. Full, pain-free range of motion
- 2. No evidence of patellofemoral joint irritation
- 3. Strength and proprioception of approximately 70% of the uninvolved side
- 4. Physician clearance to initiate advanced weight-bearing exercises and functional progression

<u>Goals</u>

- · Continue and progress previous flexibility and strengthening activities
- Functional progression, including:
 - Walk/job progression
 - Forward/backward running at half, three-quarters, and full speed

Phase 5: After 9 Months

Criteria for Advancement to Phase 5

- 1. No patellofemoral or soft tissue complaint
- 2. Necessary joint range of motion, strength, endurance, and proprioception to safely return to work or athletics
- 3. Physician clearance to resume partial or full activity

<u>Goals</u>

- Initiate cutting and jumping activities
- Completion of appropriate functional progression
- Maintenance of strength, endurance, and proprioception
- Patient education with regard to any possible limitations

APPENDIX

Therapeutic exercises:

· Functional progression, including but not limited to the following:

- Walk/job progression
- Forward/backward running at half, three-quarters, and full speed
- Cutting
- Plyometric activities appropriate to patient's goals

- Sport-specific drills
- Safe, gradual return to sport after successful completion of functional progression
- Maintenance program for strength and endurance Brace:
- Functional brace may be recommended by the physician for use during sports for the first 1 to 2 years after surgery

